

Lecture Material on Hydrology.

Subject - Water Resource

Date

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Engg

Prepared by

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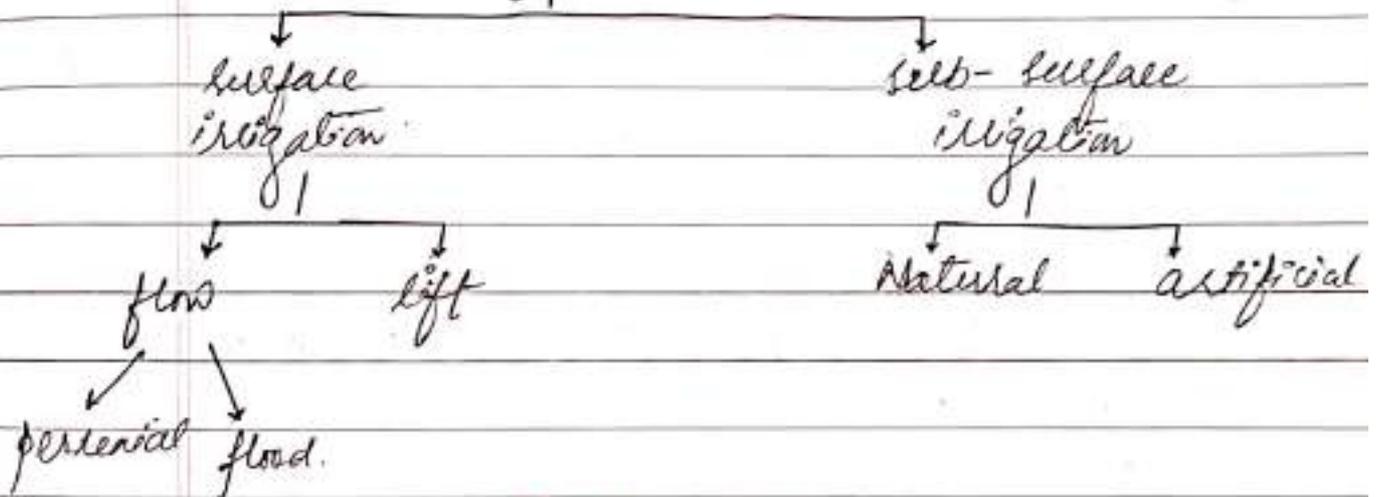
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Irrigation :- It is a science of artificial ~~irrigat~~ applicat^on of water to the land in accordance with the crop requirement throughout the crop period.

Irrigation



Methods of Irrigation :-

1. free flooding.
2. border flooding.
3. check-in
4. basin
5. furrow.
6. sprinkler
7. Drip

Soil Moisture

- gravitational
- capillary
- hygroscopic

1) gravitational :- It drains out freely due to gravity

2) capillary: It is held in soil by surface tension.

3) hygroscopic: water absorbed by pores of dry soil.

- soil moisture tension: - It is the force per unit area that must be exerted in order to extract water from the soil.

- soil moisture stress: - It is the sum of soil moisture tension plus osmotic pressure.

- Osmotic pressure: - force exerted which water moves across a membrane.

- Soil moisture constants:

1) saturation capacity: - It is the total water content of the soil when all the pores of the soil are filled with water. It is also known as max. water holding capacity of the soil.

At the saturation capacity, θ_{sat} is the soil moisture constant in ratio.

2)

field capacity: - It is the maximum amount of moisture which can be held by a soil against gravity. It is the upper limit of capillary water.

At field capacity soil moisture constant θ_{fc} is $\frac{1}{3}$ of moisture.

3)

permanent wilting point: - It is the minimum content of water the plants are held so tightly that the plant's roots cannot extract enough moisture at sufficiently rapid rate of water transpiration to supplement the water in the wilting of plants.

At permanent wilting point soil moisture θ_{pwp} is 7-32 atm.

4.

Available moisture: - It is the difference b/w field capacity and permanent wilting point.

5

readily available moisture: - It is water easily extracted by plant roots. Approximately - 75% of available moisture.

1) Moisture Equivalent :- It is the ratio of moisture retained in an air-dry state after being subjected repeatedly to a constant force of 1m times gravity for a period of 30 mins

• It is an approximate measure of the pore capacity

Depth of water retained in soil zone = V_a to V_b

V_a - dry density of soil

V_b - density of water.

V_c - pore capacity

depth of readily available water

$$= \frac{(V_a - V_c) - (V_b - V_c) \cdot P_{wp}}{V_a}$$

Water Requirement of crop :-

1) Crop period :- It is the total time that it takes from sowing and till harvesting

2) Base period :- It is the time from first sowing to sowing a crop and last

watering before harvesting

3) Growth period :-

10) Duty :- It is the area of land in hectares which can be irrigated by giving any crop if 1 cumec of water is supplied continuously to the land for the entire base period of the crop unit - hectare

11) Delta :- It is the total depth of water applied over an irrigated land for different rotations throughout the base period.

Unit - cm

$$D = \frac{8.64VB}{\Delta}$$

B in days

Δ - in meters

D in ha hectares/cumec

• Command Area :- It is the area which can be irrigated by a canal system

• Gross Command Area :- It is the total

area which can irrigated by a canal system so that quantum of quantity of water is available

• **Culturable command Area :-** It is a portion of gross command area which can be cultivated

• **Intensity of Irrigation :-** It is the %age of the culturable command area that is prepared to be irrigated annually

• **Crop Ratio :-** It is the ratio of the area of the land irrigated during the 1st main crop season

• **Kor depth :-** It is the depth of water applied during kor watering

• **Kor watering :-** It is the first watering after the plants have grown a few cms high

• **Kor period :-** The kor watering continues upto a limited period which is known as kor period

• **Outlet pattern :-** It is the duty of water

at the head of field channels (water courses)

• **Capacity pattern :-** It is the ratio of the mean supply discharge of a canal canal full & certain division to its maximum discharge capacity

• **Wine pattern :-** It is the ratio of d.m.c of crop the canal has actually run during a water period to the total no. of days of the watering period.

• **Live storage :-** It is the water stored in the reservoir b/w the full reservoir level and the lowest supply level

• **Dead storage :-** It is the water stored b/w the lowest supply level and the bed deposit level bed level

• **Gross storage :-** It is the storage capacity b/w full reservoir level and the river bed level. = live storage + dead storage

Regulation efficiencies :-

1. **Water Conveyance efficiency :-** $\eta_c = \frac{Q_2}{Q_1} \times 100$

1. w_f - quantity of water delivered to the field
 w_r - quantity of water available in the canal from the river.

2. Water application efficiency:-

$$\eta_a = \frac{w_f}{w_r} \times 100$$

$w_f \rightarrow$ It is the quantity of water reaches in the root zone

3. Water use efficiency

$$\eta_u = \frac{w_p}{w_f} \times 100$$

w_p - quantity of water used beneficially

4. Water storage efficiency:-

$$\eta_s = \frac{w_s}{w_a} \times 100$$

$w_a \rightarrow$ Available moisture content

5. Water distribution efficiency:-
 $\eta_d = \left[1 - \frac{d_a}{d_s} \right] \times 100$

4. It is the avg. numerical distance in the depth of water stored from 0 to depth 'd' stored in the root zone during irrigation

6. Consumptive Use efficiency:-

$$\eta_{cu} = \frac{w_{cu}}{w_d} \times 100$$

w_d - net amount of water depleted from the root zone

w_{cu} - net actual consumptive use of water (comp. Transpiration)

7. Irrigation requirements :-

1. Consumptive Irrigation Requirement :-
 $I_c = \int d_t \times dt$

I_c - eff. Rainfall in cm.

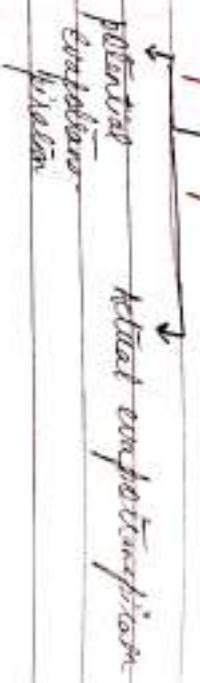
2. Net Irrigation Requirement = $CI R + IR - PR$
 \uparrow Net R

LE - Leaching Requirement
 PR - Pre Irrigation Requirement
 Net R - Netting water Requirement

3. Field Irrigation Requirement = $\frac{NIR}{\eta_a}$

4. gaseous diffusion equivalent = $\frac{E_{TR}}{q_e}$

Evapotranspiration :-



methods to measure evapotranspiration

1) Direct measure of Evapⁿ

- soil moisture studies
- lysimeter ~~meter~~ method
- gravimetric method
- lysimeter and gageon studies

2) indirect measure (use of empirical formulae)

• Hargreaves - climate eqn :-

$$E_a = \frac{K_p}{40} [1.8T + 32]$$

K - crop factor

p → monthly monthly %age of annual day length in hrs

T → mean monthly temp in °C

E_a - most monthly evaporation use from

• Hargreaves' class - A pan evaporation method

$$E_a = K \cdot E_p$$

E_p - pan evaporation
 K - pan coefficient

• Penman's equation :-

$$E_T = \frac{A H_n + E_p Y}{A + Y}$$

cm/s

Y → psychrometric constant $Y = 0.09 \text{ mm of H}_2\text{O}$

E_a → cm/day

A → slope of saturation vapour pressure vs temp curve
 H_n → net incoming solar radiation mm/day

Ques 3 answer

capacity of well = $4\pi r^2 h$

depth = 20 hrs each day

time interval = 30 days

depth of impregnation = 10m

Volume of water's capacity & time

$$= 4200000$$

$$= 1600000$$

area = volume / depth

$$= \frac{1600000}{0.07}$$

$$= 2.29 \times 10^7 \text{ m}^2$$

Que 4: rate = 180 litres

area = 2.5 hectares

distance = 8 km

actual delivery = 180 litres

loss = 2000 m³

Area = 180 x 10³

actual delivery = 180 x 10³ x 8 x 60 x 60

loss = 2000 m³

so after loss delivery = 2880000

(net water in field) = 2880000

∴ $\frac{2880000}{100} \times 100$

∴ 72.0%

Que 5: 80 days

A = 100.000

∴ $\Delta = 0.592 \text{ cm}$

B = 1648

∴ $\Delta = 5000 \text{ micrometers}$

capacity = $\frac{\text{depth}}{\text{area}} \cdot \frac{\text{area}}{\text{depth}}$

$\frac{100,000}{100,000} = 100,000$

$\frac{100,000}{500} = 200,000$

designed for more than 200,000.

available content = 0.05

field capacity = 0.15

root zone depth = 1.10

(ca) consumption due to evaporation

$18 \cdot 1.5$

evaporation efficiency = 65%

$t = 8 \text{ days}$

depth of water in root zone = $\frac{\text{root zone depth} \cdot \text{field capacity}}{\text{evaporation efficiency}}$

$= \frac{1.5 \times 1.1 \times (0.15 - 0.05)}{0.65} = 0.15 \times 1.1$

$= 16.5 \text{ mm}$

1 day evaporation

so for 8 days = $16.5 \times 8 = 132 \text{ mm}$

so net depth of water should be irrigated

$= 132 + 16.5 = 148.5 \text{ mm}$

supply & amount of water needed to grow.

$$0.65 \times 185000$$

$$d = \frac{175}{0.65} = 269.23 \text{ mm}$$

Area = 21105

monthly irrigation = 40%

for water depth = 11 cm

$$d = \frac{864 \times 11}{100} = 95.04 \text{ cm}$$

149.14 m² of area required for 100% depth.

discharge = area \times depth

$$= 1.33 \times 100 \text{ cm} = 133.98 \text{ cumec}$$

$$= \frac{864 \times 11}{100} = 1728 \text{ m}^3 \text{ per acre}$$

discharge = 21105

$$\frac{1728}{21105} = 8.19\%$$

Ques 12: Cu = 2.0 cm/day

max depth of available water in soil zone = 60 cm

amount of available water = 50% of max available

.. 30 cm water required for soil zone = 30 cm

so frequency of irrigation = $\frac{30}{60} = \frac{1}{2}$ 15 days

Ques 15: area = 457 ha

b = 90 day

d = 105 cm

rainfall = 18 cm

so required d = 105 - 15 = 90 cm

$$d = \frac{864 \times 90}{100} = 777.6 \text{ ha per acre}$$

Q16: area = 180 ha

m = 180 cm

irrigation = 50% available moisture in soil zone.

pump = 10 ha a day

$$\eta_a = 75\%$$

moisture retention in %

moisture holding capacity = 0.18 m³/ha

water left after depletion = 50 / 9 = 5.5

• 0.07 m³/ha

for 1 ha moisture holding cap = 0.01 m³

no frequency of watering = 9000

5 cm/day

area = 36 ha = 18 days = 18 x 0.5 m³

18 x 0.5 m³

Q = $\frac{V \times 10^6}{\text{area} \times d}$

$\frac{18 \times 0.5 \times 10^6}{36 \times 10^4}$

195000 / 360000 = 0.54

• 0.05

0.75 x 0.05

a = 0.0375

Q19

for crop y.

for 0.1 m moisture holding cap = 0.09 m³

frequency of watering = $\frac{72000}{9}$

8000/day

• 18 days

40117 t/c • $\frac{2 \times 72 \times 10^3}{15 \times 10^4 \times 3600 \times 0.075}$

→ 40 x 10³

1%

400000000 a = 0.7%

Q19

wheat - B = 120 days

D = 5 cm/d

Required = 1000 mm

9.60%

Q = 0.01 m³/ha

Required D = 45 cm

B = 80 days x 120 = 2504 ha/ha

45

area 0.8 ha = $\frac{2504 \times 60}{100}$

150240

13422 ha

Q20

wheat = $\frac{30 \times 2000}{100} = 600$

100

gram = $\frac{50 \times 2000}{100} = 1000$

gram B = 18 days a = 1400
wheat, B = 80 days a = 1100

Water = $\frac{864 \times 18}{12} = 1296 \text{ ha/cm}$
 duty = $\frac{164 \times 18}{15} = 1985.8 \text{ ha/cm}$

~~1035.8 ha/cm~~

plan = $\frac{864 \times 18}{12} = 1296 \text{ ha/cm}$
 duty

plan (Q) = 0.46
 shear (Q) = 0.916

Water = 1.427

CANAL DESIGN :-

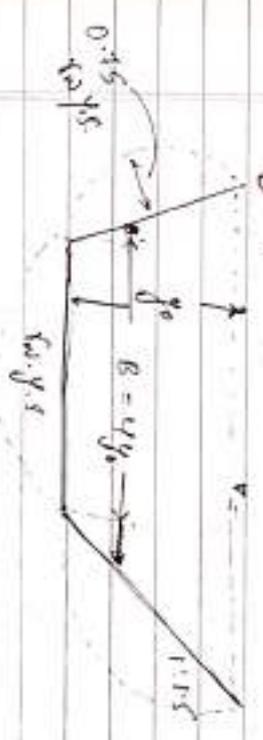
canals are the artificial channels constructed to carry water from a river or a reservoir or the irrigation field

- 1) Based on nature or source
 - > permanent canal -> perennial
 - > irrigation canal -> non-perennial

2) Based on discharge :-

- > Reservoir -> main canal -> branch canal
- > major distributary -> minor distributary
- > gate channel

Design of Unlined canal :-



1. Mean diam at the bottom of canal
 $T_0 \rightarrow \text{F.O.R.s (K-hgt. mean diam. rps)}$
2. Mean diam at the top of canal
 $= 0.75 T_0$
 $T_{0.75}$ to hat flow is not permanent movement.
3. Critical mean diam at bottom $C_c = 0.056 \sqrt{T_0 (1.49 - 1)}$
4. T_c at entry of canal = $T_c \sqrt{\frac{1 - 0.51 T_c}{0.51 T_c}}$

d - dia of sediments θ - stirrup angle
 s - sp. grav of sediments
 on gradual c. - $T_{0.75}$ range of repose

Coilc and Co Ltd

Design of the canal:-

lining of canal:- the earthen surface of channel is lined with a stable strong surface like concrete, asphalt, boulders etc. in order to minimize the seepage losses.

Advantages:-

- Reduces seepage
- Prevention of water logging.
- Increases canal capacity.
- Reduces maintenance charges

Types of lining:-

- 1) Hard surface lining
 - cement concrete lining
 - stone masonry lining
 - cc tiles
 - asphaltic concrete
 - boulder lining
- 2) Soft type lining
 - compacted earth lining

• save costs lining.

Economic justification:-

• Avg annual benefit:-

Sm - sum of water saved by preventing seepage.
This is amount of water is sold to farmers @ Rs/acre

K₁ - maintenance cost of unlined canal or P fraction of this amount is saved after lining.

∴ total benefit benefit = $mK_1 + P K_1$

benefit due benefit to seepage due to $\frac{mK_1 + P K_1}{100}$

• Avg. expense

c - total initial investment required
y - canal life in years.
r - rate of simple interest

$$\text{Avg. annual cost} = \frac{c(1+r)^n}{100} + \frac{c r}{100}$$

Let y be life.

So total avg annual expense

$$= \int_0^y (C_1 + C_2) y \, dy$$

So benefit would be 2 expenses less canal is justified economically.

Design of Regime Channel :-

(Khosla)

Regime or stable channel :- A channel is said to be in a state of regime if in the long run there is no need to dig and scouring of silt and debris.

Khosla's theory :-

In 1895, Khosla gave his 'regime' system.

- 1) Discharge should be constant
- 2) silt - grade and silt content be constant
- 3) For channel scouring should be completely

$$V_0 = C_1 y C_2$$

$$C_1 \rightarrow 0.55$$

$$C_2 \rightarrow 0.6V$$

$$V_0 = 0.33m \cdot y \cdot 0.6V$$

m - critical velocity ratio
fine materials 0.7 - 1.0
coarse 1 - 1.2

Design Procedure :-

1) Kutter's formula.

$$V = \left[\frac{1}{n} + \frac{(0.3 + 0.00155)}{s} \right] \left[\frac{1}{1 + \frac{(0.3 + 0.00155)}{s}} \right] \times \frac{R^{2/3}}{1.49}$$

n - roughness coeff, Manning's coeff.

2) Manning's formula :-

$$V = 1.49 R^{2/3} S^{1/2}$$

3) Lacey's Theory :-

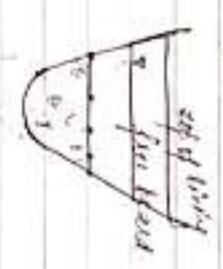
1) silt - Regard :- constant discharge, constant flow, silt grade, all grades are same

$$q = \frac{Q}{L} \rightarrow \text{width is } m$$

Difference b/w Kennedy's and Lacey's

Kennedy's Lacey's

- 1) Channel's top width is constant but side slopes are variable
 - 2) slope for bed slope is constant
 - 3) it is a best practice procedure
 - 4) it is appropriate for any channel
- (1) Design of these canals (triangular section)



area = $\frac{1}{2} \times \text{top width} \times y$

area = $\frac{1}{2} \times (y \cot \theta + y) \times y$

Perimeter = $y \left[\frac{y \cot \theta}{y} + 1 + \frac{y}{y} \right]$

$R = \frac{A}{P} = \frac{y \left[\frac{y \cot \theta}{y} + 1 + \frac{y}{y} \right]}{y \left[\frac{y \cot \theta}{y} + 1 + \frac{y}{y} \right]}$

10) Canal design:-

designer's out, Canal with out the slope and the plan out - but slope and depth water

11) Canal design:-

It is the process that with water, slope and depth water

1) velocity of flow = $\left[\frac{Q}{A} \right]^{1/2}$

$f = \text{Manning's coefficient} = 1.49 \left[\frac{1.49}{1000} \right]$

2) Hydraulic mean depth, $R = \frac{A}{P} \left[\frac{V^2}{f^2} \right]$

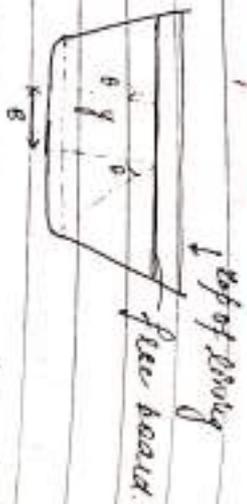
3) area = $\frac{Q}{V}$

4) $P = 4.75 \sqrt{Q}$

5) bed slope $S = \frac{f^2 V^2}{R^2 Q}$

6) cross slope $m = 1.35 \left(\frac{Q^{0.2}}{f} \right)^{1/3}$

1) Trapezoidal section



$$\text{Area} = y [g + ye + ye + ye]$$

$$\text{Perimeter} = e + y + y + g + y$$

Rise

OWN HEADWORKS:-

In order to divert water from the river into the canal it is necessary to construct certain works or structures across the river. These are termed as canal headworks.

Types of Headworks:-

- 1) Weir Headwork
- 2) Diversion Headwork

#

Weir Headwork: It consists of a dam structure across the river to create a reservoir in which water is stored.

during the period of excess flow in the river.

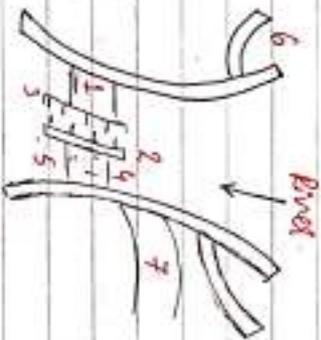
Diversion Headwork: It raises the water level in the river and directs the required quantity into the canal.

→ Classification of Diversion Headwork:-

- 1) Temporary (1 year or less)
- 2) permanent (weir or barrage)

→ Temporary :- It is constructed all-in-all every year after the floods subside :- most of the diversion headworks are permanent.

→ Components of Diversion Headwork:-



- 1- weir
- 2- divide wall
- 3- fish ladder
- 4- approach channel
- 5- sluiceway
- 6- gate
- 7- head regulator canal

* Weir are provided on the steep bank
 water level ponding is achieved by the
 raised crest. 3 types of weirs
 - narrow - narrow - concrete.

• weir:- It is an obstruction constructed
 across a river to raise the
 water level and divert the water
 into the canal. ↓

• Abutment wall:- It is a long masonry wall
 constructed at right-angle to the
 crest of the weir to separate
 the weir gate from the rest of the
 weir.

• fish ladder: It is provided to enable
 the fish ascend the headwater of
 the river.

• Sluice gate:- It is also known as scum
 sluice. It is the opening provided in
 the weir wall with their crest
 at low level. It helps in lowering
 the stir near head regulator.

• Canal head regulator: It is a sluice
 constructed at the head of the canal
 taking off from the upstream of weir
 or a barrage.

• Barrage:- It is similar to the weir with
 the only difference that the crest is
 kept at a low level and the ponding
 of water is achieved mainly by gates.
 They are also known as River Regulator.

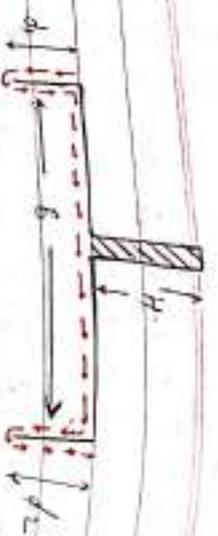
Failure of weir on permeable foundation

• Due to seepage flow:-
 a) By piping - remedy is provide piles at the
 upstream and downstream ends
 b) provide sufficient length of the impervious
 floor

b) By uplift pressure:- water penetrating through
 the foundation exerts an upward
 pressure on the impervious floor
 remedy: provide sufficient thickness of the
 impervious floor (strip)

• Due to surface flow:-
 a) due to scouring at the upstream end
 the depth of weir
 b) by siltation due to the hydraulic jump

Regr's Deep Seepage:-



$$L = B + \Delta x_1 + \Delta x_2$$

↓ pipe accelerating length

$$\text{Head loss} = \frac{H}{L} \cdot H \cdot (B + \Delta x_1 + \Delta x_2)$$

Types of Hydraulic Distribution:

• Supply against piping :-

$$L = \frac{H}{c}$$

c → pipe's coefficient

$$\frac{1}{c} \frac{H}{L} \text{ for supply against piping}$$

• Supply against uplift pressure :-



h → altitude of

uplift pressure

t → thickness of

the floor at the

circular section

uplift pressure = $\frac{H}{L} \cdot H \cdot L$
 distributed pressure exerted by soil
 weight = $t \cdot G \cdot L$

for stable condition $H \cdot L = t \cdot G \cdot L$

$$H = t \cdot G$$

$$H - t = t \cdot G - t$$

$$H - t = t(G - 1)$$

$$t = \frac{H - t}{G - 1} = \frac{L}{G - 1}$$

$$G - 1$$

t increases by 33% (100)

$$t = \frac{H - t}{G - 1}$$

Krober's theory :-

Principle :- Heavy water does not creep along the bottom certain & upward but move along a set of streamlines which always envelope in a vertical plane for a homogeneous soil some exposure by Laplace eqn :-

$$\frac{d^2 y}{dx^2} + \frac{d^2 y}{dy^2} = \frac{\rho \cdot H}{\rho \cdot H}$$

$$G_E = \frac{H}{d} \frac{1}{\sqrt{A}}$$

$$A_1 = \frac{d}{2} \sqrt{A}$$

$$A_2 = \frac{d}{2} \sqrt{1+A^2}$$

p. 221's other that
h. 15m height
1.5 m total earth top.

Exit gradient :- The distribution of any point is proportional to the gradient of pressure. Will at that point and gradient is same as exit gradient.

Critical exit gradient :- when upward distribution (force on the grain) is just equal to the submerged weight of the grain at the exit the gradient is known as critical exit gradient.

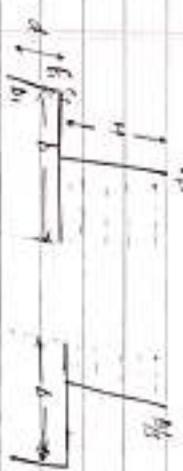
$$T_e = \frac{1}{2} \frac{L_e}{L} \frac{L_e}{L} T_e$$

This factor of safety is applied on to keep the structure safe against piping.
Wass. $\frac{1}{2} \frac{L_e}{L} (T_e - 1)$

$$T_e = \frac{G_E - 1}{1.75}$$

Determination of pressure and exit gradient below a weir or
1) **Flowlet method of independent variable**

A complex profile is broken up into a no. of simple profiles each with same exit ratio mathematically.
2) **Equivalent horizontal flow of equivalent thickness (with a flow pipe of the same h.p. p. d. exit)**



$$\phi_{b_1} = m \cdot \phi_c$$

$$\phi_{b_1} = m \cdot \phi_c$$

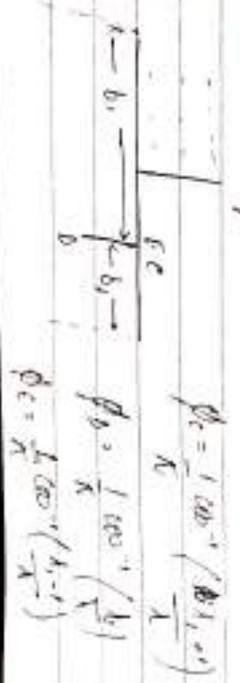
$$A_1 = \frac{L}{2}$$

$$\phi_c = \frac{1}{\pi} \cos^{-1} \left(\frac{A-2}{A} \right)$$

$$\phi_b = \frac{1}{\pi} \cos^{-1} \left(\frac{A-1}{A} \right)$$

$$A = \frac{1.414 \sqrt{1+A^2}}{2}$$

b) **Strong horizontal flow of equivalent permeability with a flow pipe at same intermediate point**



$$\phi_c = \frac{1}{\pi} \cos^{-1} \left(\frac{b}{1+b} \right)$$

$$\phi_b = \frac{1}{\pi} \cos^{-1} \left(\frac{b}{1+b} \right)$$

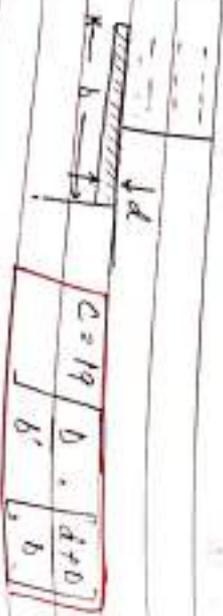
$$\phi_c = \frac{1}{\pi} \cos^{-1} \left(\frac{b}{1+b} \right)$$

$$h_1 = b/d$$

$$h_1 = h_2/d$$

$$h_1 = \frac{\sqrt{1+h_2^2} - \sqrt{1+h_1^2}}{2}$$

c) Stronger horizontal floor displacement holds the bed but without any vertical offsets



- c - correction applied for mutual displacement of pipe
- d - depth of pile
- b - depth of pile
- b - water head first length
- b - distance of pipe lines

Answer

$$Q_{avg} = 1.55 \left(\frac{2^2}{7} \right)^{1/2}$$

$$= 0.69$$

Qy

$$d = 0.9 \text{ mm}$$

$$Q = 3$$

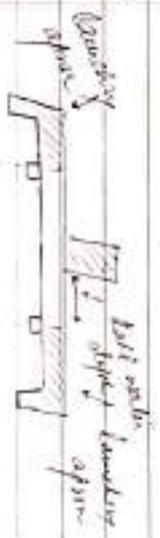
$$f = 1.76 \sqrt{d}$$

$$= 1.11$$

$$1.55 \frac{f}{515} = \frac{1.11 \times 3}{2590 \times 0.815}$$

$$= 1/3370L$$

Q.5



$$f = 1$$

$$Q = 6.5$$

Full water depth

$$m = 1.55 \left(\frac{2^2}{7} \right)^{1/2} = 0.7 \text{ m}$$

Double rowing depth = 1.4 m

to length of lamelling system

= 5m (1m)

Die 11×0.015

$2.15m$

$V = 0.55 m^3 s^{-1}$

$= 0.75 m^3$

Water logging :-

It is a phenomenon in which productivity of the land gets affected due to the high water table leading to rotting of root zone of the plants and thereby plant ill-effects.

Nitrogenation :- It is a process under which the nitrates are consumed by the plants (produced by bacteria)

nitrogen \rightarrow O_2 cutting \rightarrow bacteria die \rightarrow no food for plants \rightarrow increased productivity

Other problems created by water logging

- Several cultivations should not be easily carried out in wet soil
- Water logging also leads to salinity.

Salinity :- It is defined as the presence of salts in the soil and the depletion of the upward flow of the water

* Salinity has serious effect on the roots

Alkaline soil :- It is soil characterized by a high pH level. A base exchange reaction set up particularly if the soil is clayey and the soil becomes impermeable, ill-aerated, and highly unproductive.

Causes of Water logging :-

- Over and extensive irrigation
- Heavy soils
- Impermeable substratum
- Seepage of water through the cracks
- Seepage of water from the adjoining lands
- Submergence due to floods

to length of lamellar span
= 5m (4-5)

Q10 $\rho = 0.015$
of 1.5m
of 0.1-1.1

$v = 0.55 \text{ m}^3 \text{ g}^{-1} \text{ h}^{-1}$
 $\cdot 0.1 \text{ m}^3 \text{ m}^{-3}$

Water logging :-

It is a phenomenon in which productivity of the land gets affected due to the high water table leading to rotting of root zone of the plants and, mostly, them ill-effects.

Nitrogen fixation :- It is a process under which the nitrogen is converted by the plants (produced by bacteria)

nitrogen \rightarrow O_2 cutting \rightarrow bacteria die \rightarrow no food for plants \rightarrow die and producing

- Other problems created by water logging
- Normal cultivation should not be easily carried out in wet soil
- water logging also leads to salinity.

* Salinity :- It is a phenomenon of salt in the soil zone & the crop that is the upward force from the water taking has osmotic effect on the roots

Alkaline soil :- If soil alkaline contains for a longer period, a base exchange of nutrient gets up partially. If the soil is clayey that the soil becomes impermeable, ill-aerated, and highly unproductive.

Causes of water logging :-

- over and extensive irrigation
- heavy rains
- Supplemental obstructions
- leakage of water through the canals
- leakage of water from the adjoining lands
- subsidence due to plants

* A spillway is a waterway provided to dispose surplus flood water from a reservoir when it has been filled to its max capacity.

SPILLWAYS:-

It is a structure constructed at a dam site for disposing surplus flood water from reservoir to downstream. It should fulfill the following requirements:-

- 1) It should be able to pass excess of water past without having too much backwater above the high flood level.
- 2) It should provide the structural stability to the dam against all kinds of flood.
- 3) The section of the spillway should be economical.
- 4) The operation of the spillway should be efficient.

Location of spillway:-

It can be located either within the body of the dam or one end of a reservoir away from it.

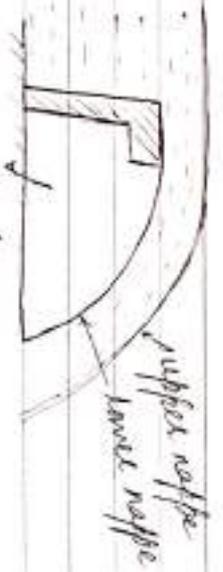
Controlled And Uncontrolled spillway

The flow of water over a spillway may be

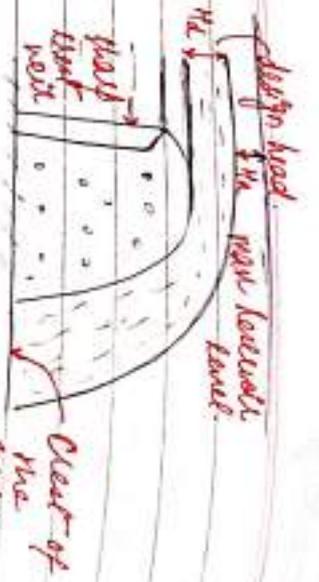
controlled by installing gates. It is called **controlled spillway**. If there are no gates, it is called **uncontrolled spillway**.

Classification of spillway:-

- 1) Based on discharge or outfall:-
 - **weir type or overflow spillway:-**
 - Simplest form type of spillway may be constructed in small scale.
 - water falls freely from the crest under the action of gravity.



• **Open spillway or overflow spillway**



The structural design and detailing requirement of spill way are same as that of a gravity dam. If it some time known as overflow basin of the dam.

average flow over the spillway

$$Q = C L H^{3/2}$$

$C \rightarrow$ coeff of discharge (for high spillway)

$L \rightarrow$ discharge in meter

$H \rightarrow$ height of the spillway
 $H_e \rightarrow$ actual head over the crest including velocity head.

for high spillways $H_e = H_e$ (velocity head neglected)

$$H_e = \frac{V_e^2}{2g}$$

V_e - velocity of approach

$$L_e = L + 2L_p + K_a H_e$$

$L \rightarrow$ Net clear length of the spillway crest

$L_p \rightarrow$ pier contraction coeff.

$K_a \rightarrow$ abutment contraction coeff.

$N \rightarrow$ No of piers

$K_a \rightarrow 0.1 \rightarrow$ for rounded abutment with bases head wall at 90° to the direction of flow

$\rightarrow 0.2 \rightarrow$ for square abutments with head wall at 90° to direction of flow

$K_p \rightarrow 0 \rightarrow$ pier pier for pointed nose pier

$0.01 \rightarrow$ for rounded nose pier

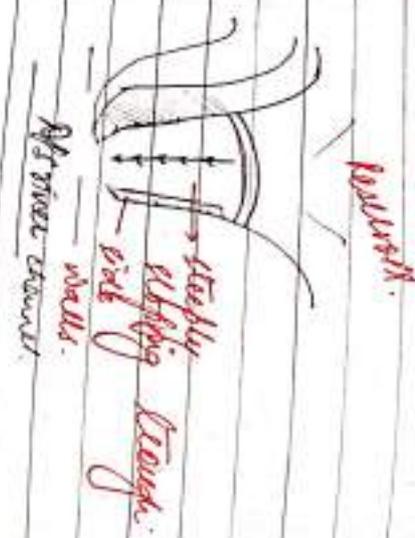
$0.02 \rightarrow$ for square nose pier with rounded corners

$0.1 \rightarrow$ for simple square pier

• Strength spillway :-

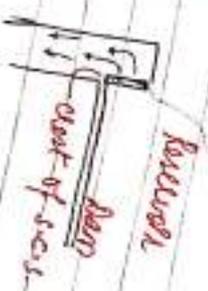
Spillways are the one which passes the surplus discharge through a stepped shape open channel called a spillway. It is often along a dam abutment or through a saddle

→ It is spillway where discharge is conveyed from reservoir to a downstream level through an open channel.



• Side channel spillway :-

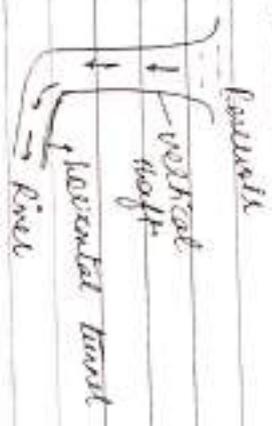
→ It is a spillway in which the base is approximately parallel to the position of the spillway discharge. In this spillway the flow of water is often spilling over the crest of the spillway by 90° such that it flows parallel to the weir crest.



→ It is provided in narrow valleys where there are no side channel flanks of sufficient width to accommodate a through spillway.

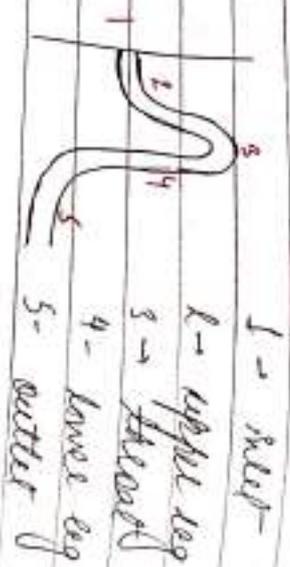
• Graft spillway :-

It is a spillway in which the water enters from the reservoir into a vertical graft with converging sides. As a horizontal tunnel from where the water is discharged into a trough or river channel.



• Bottom spillway :-

It is a closed conduit system formed in the slope of "U" form so that the water of the head of the water passage may be at normal reservoir storage level.



ENERGY DISSIPATORS:-

- The water flowing over the spillway (when floods are anticipated) acquires a lot of K.E. by the time it reaches the near the toe of the spillway due to the conversion of potential energy into K.E.

To dissipate this huge K.E. of water or else large scale destruction will take place on the downstream side of the spillway. Some arrangements are known as energy dissipaters.

V.F. of this flow can be dissipated in two ways:-

→ By converting super critical flow into subcritical flow by hydraulic jump.

0 → By directing the flow of water into bins and then making it fall away from the toe of spill structure.

Hydraulic Jump:-

It is a sudden and turbulent passage of water from supercritical to sub-critical flow.

- In hydraulic jump the flow is accompanied by the formation of extremely turbulent eddies and there is considerable dissipation of energy.

It is observed according to the value of Froude's Number (F_1)

→ for $F_1 < 1$: the flow is critical. No jump formation.

→ for $F_1 = 1$ to 1.7 : nodular jump formation. Energy dissipation is quite low (approx 15%).

→ for $F_1 = 1.7$ to 2.5 : weak jump. Uniform velocity of flow throughout (approx - 20% energy dissipation).

→ for $F_1 > 0.5$ to 0.5 ; oscillating jump
 energy dissipation 40-45%

→ for $0.5 < F_1 < 0.9$; well balanced jump
 - energy dissipation 45/5%

→ for $F_1 > 0.9$; strong jump
 Energy dissipation - 85%

Fruder's No $F_1 = \frac{V_1}{\sqrt{gH_1}}$

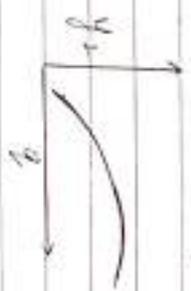
Hydraulic jump $y_2 = -y_1 + \sqrt{\frac{y_1^3 + 0.25^2}{g y_1}}$

q → discharge intensity
 $q \Rightarrow$ Area jump depth
 y_1 → pre-jump depth



* 4 slope plates the discharge out

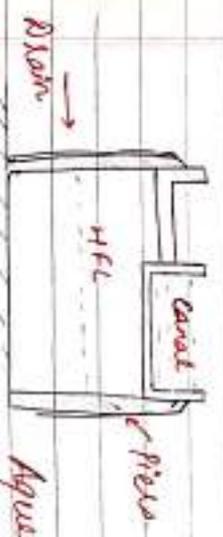
directly over the pre-jump depth y_2
 is known as jump height curve



CROSS DRAINAGE WORK :-

It is a structure constructed for carrying a canal over a natural drain or river intercepting the canal to not to disperse the discharge water without intercepting the continuous canal surface

• when the cross drainage work carry the canal over drainage



Aqueduct :-

It is a hydraulic structure with carries a canal through a duct across

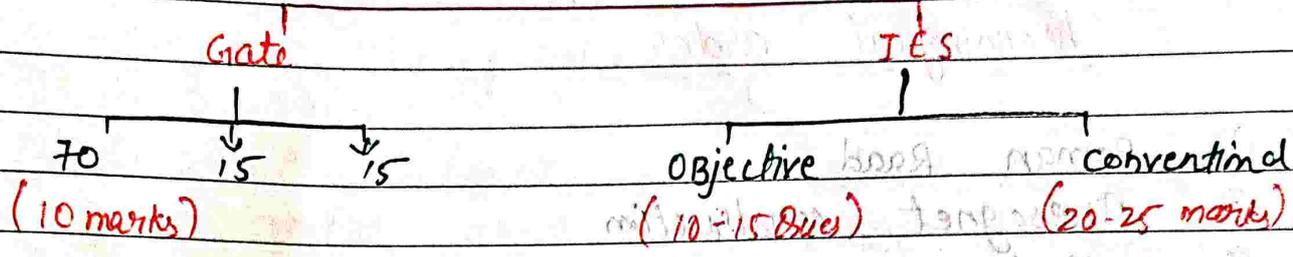
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Date _____

NAME MRITYUNJAY SAMU

Subject: Transportation Engⁿ

Highway ENGINEERING



SYLLABUS

- ① INTRODUCTION
- ② GEOMETRIC DESIGN
- ③ TRAFFIC
- ④ HIGHWAY MATERIAL
- ⑤ DESIGN OF PAVEMENT

Chromological order

INTRODUCTION

Coastive + Airward

- ① Roman Road
- ② Mesopotam construction
- ③ meta
- ④ Telford
- ⑤ Macadam
- ⑥ WBM
- ⑦ BM (Bituminous Macadam)

Note: Water Board Macadam is not used as a surface course because

- ① Formation of dust in summer season.
- ② Formation of mud in winter season.

Measure recommendation of Jucker committee (1927)

- ① Road development should be considered as a national imp. interest.

② An extra tax should be levied on petrol & High speed diesel to create Road Road development fund - that is central Road fund (CRF) established in 1929.

NOTE:

CRF fund has been given statutory status while CRF acts 2000 through gaged of India. currently 82 per liter in an extra tax levied on petrol & High speed Diesel.

* SDI per liter exempted for construction and maintenance of National Highway.

* A semi-official technical body should be established that is INDIAN ROAD SCIENTISTS (IRS) in 1939

* RR (Research & Development organization should be established that is CRII (Central Road Research Institute) established in 1950 (CRRDI)

Motor Vehicle Act 1939 ⇒ Revised in 1988 ⇒ used for violation of traffic law

Highway Research Board (1973)

NHAI (National Highway Authority of India) 1988

NATIONAL HIGHWAY ACT 1956 (INTERVIEW)

① Central government is responsible for construction of national Highway.

* Central govt is empowered to omit any national Highway from the list of NH. or it can declare any state Highway as National Highway.

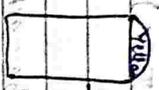
NOTE: Geometric Design Parameters for NH & SH are same.

Yellow colour = National Highway

NH - The national Highways network of India is a network of highways that managed and maintained by agencies of the Govt of India

* The top portion of Nishikhe is Yellow & they adjacent Road is NH.

& It is in green. adjacent road is SH



* National Highway Development Program (NHDP) (1998)

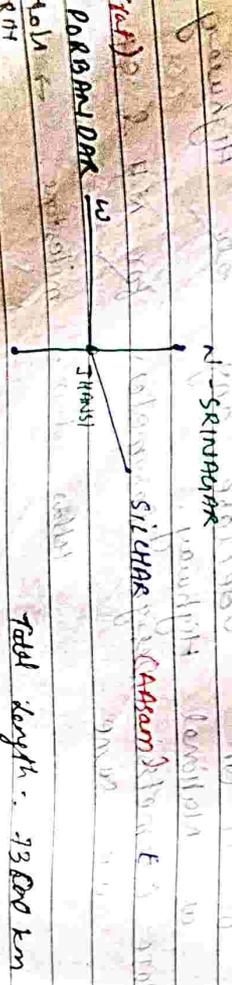
Minister of Surface Road - K.H. Muniyappa

① Golden Quadrilateral: (5846 km)



Total length = 5846 km

② North South & East West Corridor: (7300 km)



Total length = 7300 km

* Total length of NH is around 2% of total length of Road, but it carries 40% of total traffic.

List of National Highway (NH)

① NH-1 ⇒ Delhi to Amritsar via Ambala

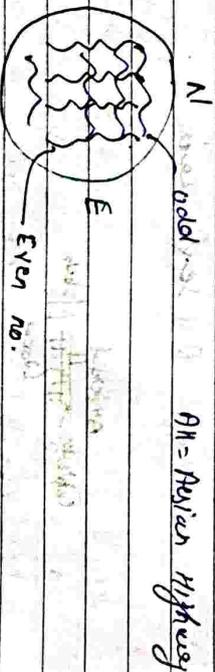
② NH-3 ⇒ Bombay to Agra

③ NH-7 ⇒ Varanasi to Kanyakumari (largest NH) (2500 to 2600 km)

④ NH-47A ⇒ shortest length 5.9 km

⑤ NH-15 ⇒ RT covers more than 50% area of Rajasthan.

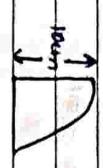
⑥ NH-223 ⇒ Alone NH in Andaman Nicobar.



NH-200 - Kavaratti Bheemur Changa Rajgadh Thangasuda inc. 6

① Types of kerb:

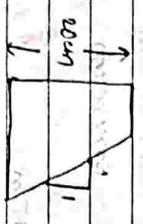
① Low or mountable type kerb:



② Semi-barrier type kerb



③ Barrier type kerb



EX) WIDTH OF FORMATION / ROADWAY

* For single lane road width of formation

= width of pavement or carriageway + total width of shoulder.

② For two lane width of formation =

total width of pavement + shoulder + median (width)

Types or Class of Road TERRAIN

SH/NH

a) Single lane 12m 6.25m

b) Double lane 12m 8.8m

width of shoulder = 2.5m

NOTE:- width of roadway for single lane bridge is 4.25m & for two lane bridge it is 7.5m

* width of bridges is measured from outer side of parapet wall (outer to outer).

> 6m - Bridge

< 6m Culvert

According to IRC minimum width of median is 5m for rural highways & it can be reduced to 3m if road is restricted.

Purpose of median:-

① To separate the traffic

② To reduce the clearing effect due to headlights during night time.

Types of Urban Road Design Speed

- ① arterial $40 < V < 80$ or > 100
- ② sub-arterial $60 - 80$ or 100
- ③ collector $40 - 60$ or 80
- ④ local 30

Ruling means Design

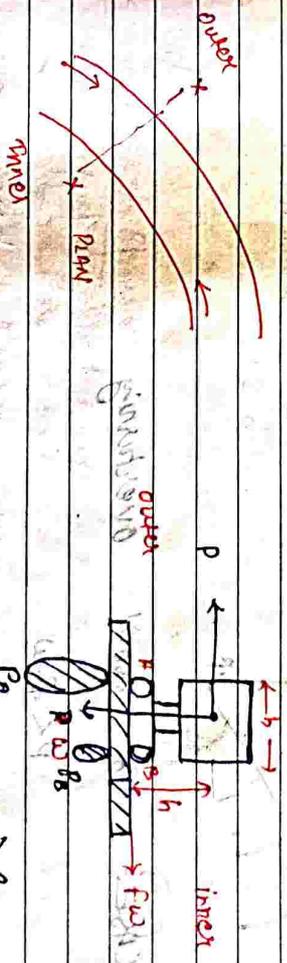
- ① Terrain \rightarrow Cross-slope $0 - 10\%$
- ② Rolling $10 - 25\%$
- ③ mountainous $25 - 60\%$
- ④ steep $> 60\%$



Horizontal Curve

Effect of centrifugal force when there is no super elevation.

* When a vehicle travels on a horizontal curve it is subjected to centrifugal force which acts outwards in outward direction.



On the verge of overturning $P_g = 0$

Effect of centrifugal force, when $e = \text{super elevation} = 0$

① Overturning

$$P \times h = w \times \frac{b}{2}$$

$$P = \text{Impact factor or centrifugal} = \frac{b}{2h}$$

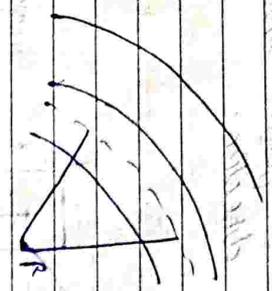
$$P = \frac{wv^2}{gR}$$

$$\frac{P}{w} = \frac{v^2}{gR}$$

② Skidding

$$\frac{P}{w} = F$$

$$P = Fw$$



R is measured from centre line of road

Case: To avoid overturning

$$P < Fw$$

$$\frac{P}{w} < F$$

③ - To avoid both

$$\frac{P}{w} < \min \text{ of } \frac{b}{2h} \text{ \& \& } f$$

④ Vehicle skids prior to overturning

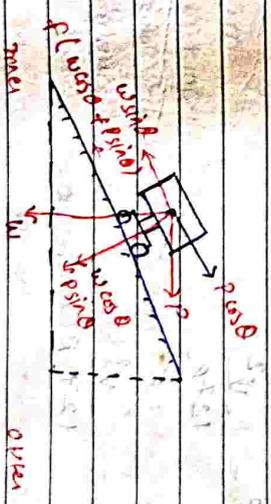
$$F < \frac{b}{2h}$$

⑤ Vehicle overturns prior to skidding

$$\frac{b}{2h} < F$$

* Super-elevation :-

Superelevation: Raising of outer edge with counteract the tendency of centrifugal force to overturn. Or in known as "CANT" OR "BANKING".



$$P \cos \theta = w \sin \theta + F (w \cos \theta + P \sin \theta)$$

$$P (\cos \theta - F \sin \theta) = w (\sin \theta + F \cos \theta)$$

$$\frac{P}{w} = \frac{v^2}{gR} = \frac{\sin \theta + F \cos \theta}{\cos \theta - F \sin \theta}$$

③ $e = \frac{V^2}{127R} = 0.197$

* Attainment of Super-elevation

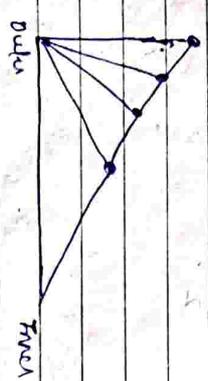
① Step: Elimination of crown of camber.

Method :- 1

Outer half is rotated about axis.



② m:2 : Diagonal Shear method



Negative Super-elevation is introduced

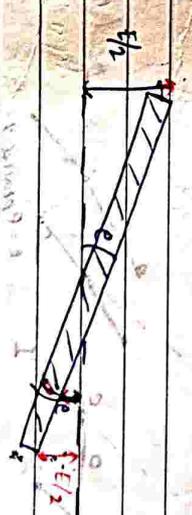


Pavement is rotated about inner face.

Step-2 :-

Rotation of Pavement

a) About center



Result :-

① Vertical alignment remains same

② Earth work balanced

Demerit :-

① Drainage Problem

$2V.O.O = \frac{52}{101 \times 5.51} = 211.0$

$f.e.i.o = \frac{34}{101 \times 5.51} = 119$

Name - Mrityunjay Sahi.

Sub - Graduate Engg.

NOTES

BHAVESH ANAND DHAIRYA

BRIDGE ENGINEERING

SR.NO.	CULVERT	BRIDGE
1	These components of a culvert are comparatively simpler and include concrete boxes or cells, pipes, a top deck or slab, and supporting parts.	These basic components of a bridge(Parts of a bridge) are superstructure, substructure, and deck [transfers surface load to other components].
2	The culvert is generally a tunnel-like structure that allows water to pass under a roadway or railway.	The bridge is a passage of transportation over a large body of water or physical obstruction.
3	These Culverts are usually embedded in the soil, which bears the major portion of the culvert load.	Abutments and Piers are the supporting structures of a bridge.
4	Culverts are totally enclosed structures that may be semi-circular, rectangular, elliptical or pear-shaped.	A bridge is usually straight and linear assage.
5	The culvert is an enveloping structure that consists of two sides, a roof, and a floor.	The bridge contains no floor.
6	The length of culverts is typically not more than 6 meters.	A bridge spans from 6 meters to more than 120 meters.
7	Noi required a deep foundation in the culvert.	Construction of a deep and strong foundation is very important in building a bridge. A foundation along the entire breadth supports the bridge.

8	These Culverts are built at less than 20 feet high over the obstruction.	These Bridges are constructed at a height of more than 20 feet.
9	Culverts may be pre-constructed or built on the site.	Bridges are usually constructed in the site or pre-constructed in smaller parts.
10	The Culverts are simpler in structure and design, so it can be constructed with less time and labor.	The Construction of bridges generally requires a lot of time and manpower.
11	The construction of a culvert may be done with a low budget.	This structure and design of a bridge are elaborate and complex, hence its construction requires a substantial budget.
12	A culvert may be constructed to accommodate roadways both over and under the deck.	This only way of transportation is over the deck of the bridge.
13	Some culverts, like box culverts, have sharp corners that are unsuitable for high-velocity vehicles.	Bridges may withstand heavy and speeding vehicles.
14	A culvert is constructed when water needs to be conveyed through tunnels or channels under a roadway.	A bridge is built over a body of water that is large and has variable flow.
15	Culverts prevent waterlogging, flood, and erosion, and allows water to flow its natural course under a roadway or railway.	Bridges provide an easier route of transportation that saves time and reduces distance.

BRIDGE INTRODUCTION

General:

A *bridge* is an arrangement made to cross an obstacle in the form of a low ground or a stream or a river or over a gap without closing the way beneath. The bridges are required for the passage of railways, roadways, footpaths and even for the carriage of fluids.

CULVERTS

Definition:

A *culvert* is defined as a small bridge constructed over a stream which remains dry for most part of the year. A culvert is thus a cross drainage work having a total length not exceeding 6 m between the faces of abutments or extreme ventway boundaries when measured at right angles to the axis of ventway.

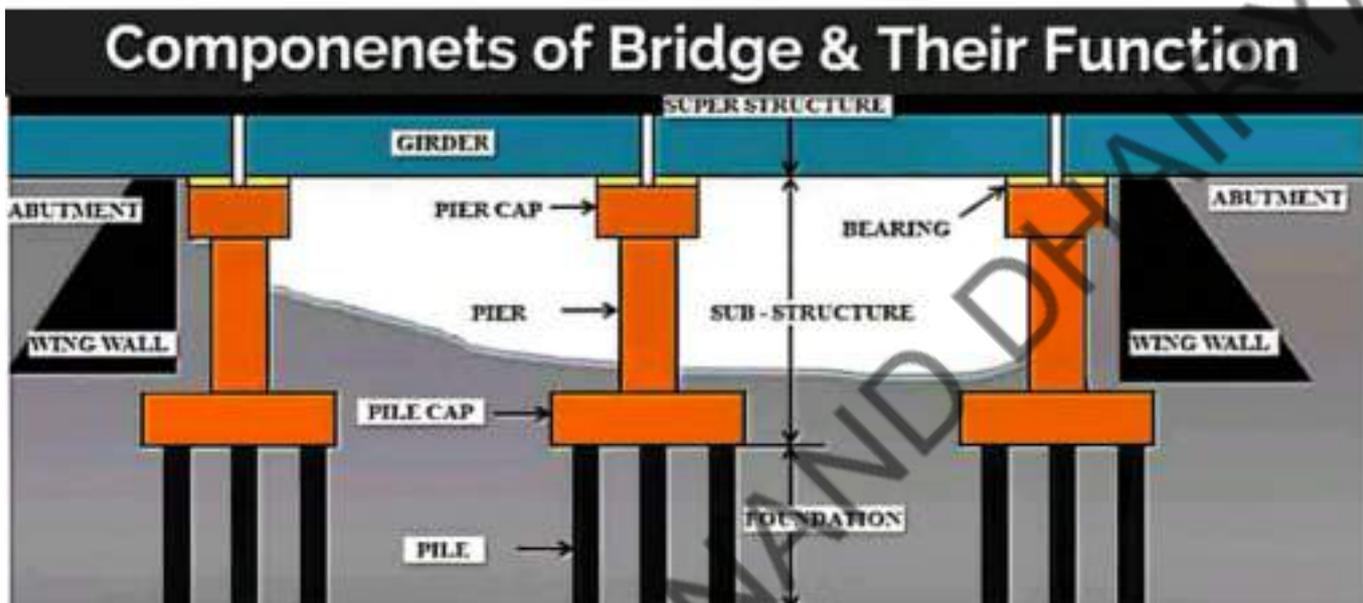
The culverts are provided as the cross drainage structures in the following two cases:

- (1) for draining small pockets or catchments with no definite stream channels and also where the height of the bank is small, and
- (2) for small streams with rigid boundaries or semi-rigid boundaries.

Bridge Components and Their Function:

The main components of a bridge are

1. Substructure
2. Superstructure
3. Adjoining structure



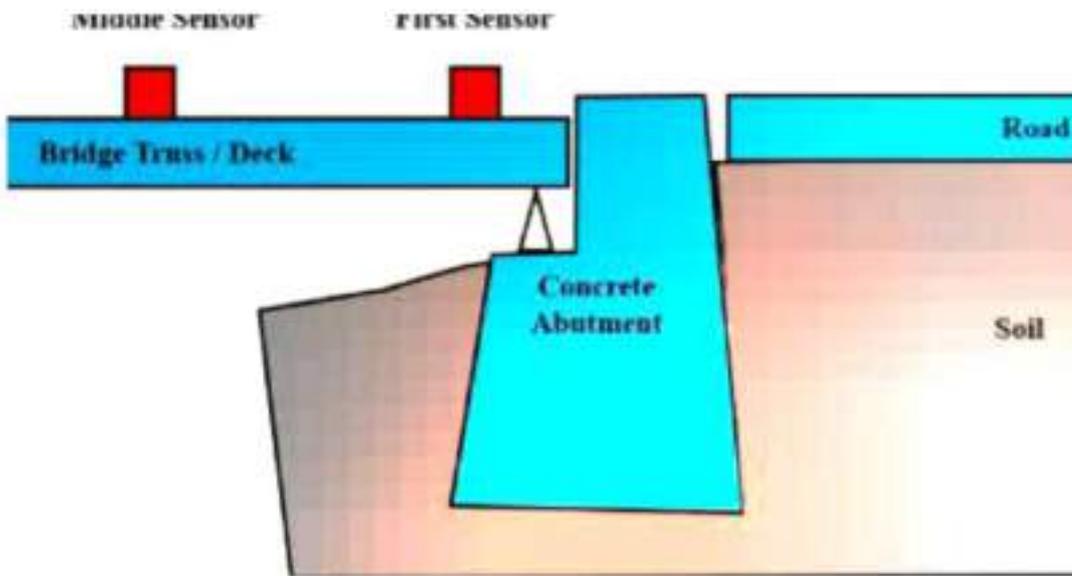
i) Substructure:

The components of the bridge below the level of bearings is known as Substructure. It consists of the following.

The function of the substructure is to support the superstructure components and transmit their loads safely to the subsoil,

ii) Abutments:

It is a structure mostly used for bridge and dam as substructure at the ends of a bridge span or dam and on that superstructure is rest. Bridge with a single span has two abutments that offer vertical and lateral support. It also plays the role of retaining walls to resist lateral movement of the earthen fill of the bridge approach.



The abutment can also be defined by the structure supporting one side of an [arch](#), or masonry used to resist the lateral forces.

iii) Piers:

Piers provide intermediate support between two bridge spans. Bridge piers mainly support the bridge superstructure element and transfer the load to the foundation.

Pier must be strong to handle the horizontal as well as lateral. Piers are known as compression members of the bridge.

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iv) Wing walls:

It is one of the earth retaining structures in the bridge. They are located adjacent to the abutments and act as retaining walls. Wing wall retains soil for abutment, roadway and approach embankment, which can be at a right angle to the abutment or splayed at different angles.



(2) Superstructure: (Bridge Components)

The components of the bridge above the bearing are known as superstructure.

It consists of the following.

i) Beams, girders:

Both have a similar function to support the roadway and prevent bending. Girder is also one type of beam support. Where loads are heavy girders are used instead of beam support.

Beam has a rectangle cross-section, whereas girders have composed of I-shaped cross-sections with two load-bearing flanges and web for stabilization.

ii) Bearing:

A bearing is provided between bridge girder and pier cap. The main function of bearing to allow free movement or vibration of the top superstructure and reduce effect stress to reach the bridge foundation.



iii) Arch, Cables:

Arched and Cable both have specified used. Arched are used for arch bridge construction and cable are used for suspension, cable-stayed bridge, etc. For different types of bridge construction arches and cable play a vital role.

iv) Parapet wall, handrail:

The parapet is one of safety component of any bridge which prevent the vehicle from falling off where there is a drop. It is also useful for restricting views, to prevent rubbish from passing below, and to act as noise barriers.

v) Flooring:

Its top surface of bridge roadway on vehicle travel. It is made of concrete or bituminous road.

3) Adjoining structures:

It consists of the followings:

i) Approaches:

It is a structured constructed at the starting or ending of any bridge. Its main function is to provide smooth and easy entry or exit from bridge.

It is a structured constructed at the starting or ending of any bridge. Its main function is to provide smooth and easy entry or exit from bridge.

ii) Guard stones:

They are used to restrict traffic on the particular lane or sometimes as road railing but are generally positioned to protect a specific object, such as a corner of a street or the side of a gate.

Difference between Bridge and Culvert

SR.NO.	CULVERT	BRIDGE
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7	Not required a deep foundation in the culvert.	Construction of a deep and strong foundation is very important in building a bridge. A foundation along the entire breadth supports the bridge.

Identification of bridges:

To have the uniform policy of numbering the cross-drainage works along a highway, the Indian Roads Congress have prepared the code IRC: 7-1971 for identifying or numbering the culverts and bridges. According to the provisions of this system, the culverts and bridges on a road are numbered in serial order, the number being expressed as a fraction. The numerator of the number indicates the kilometre in which the structure is situated and the denominator indicates the kilometre-wise serial number of the structure.

For instance, the fourth cross-drainage structure in ninth kilometre (i.e. between kilometre stones 8 and 9) will be designated as 9/4. The number of the structure is inscribed near the top of the left hand side parapet wall as seen by the road users in the end elevation when approaching the structure from each direction. For structures having railings without parapet walls, separate pillars are constructed to inscribe the structure number. If any new culverts are to be introduced between any two existing ones, say between 4th and 5th culverts in km 30 (i.e. between kilometre stones 29 and 30), then the new culverts will be designated

as $\frac{30}{4-1}$, $\frac{30}{4-2}$, etc.

The above practice of identification of bridges developed by the specifications and standards committee of the Indian Roads Congress has proved of great help to the staff employed for the maintenance and inspection of bridges.

Selection of bridge site:

Following are the factors to be carefully considered while selecting the ideal site for a proposed bridge:

- (1) Connection with roads
- (2) Firm embankments
- (3) Foundations
- (4) Materials and labour
- (5) Right-angle crossing
- (6) Straight stretch of river
- (7) Velocity of flow
- (8) Width of river.

Each of the above factor will now be briefly described.

(1) Connection with roads: The bridges are constructed to connect the roads on either side of a river. The bridge site should therefore form a proper link between the roads on either side of a river. The bed of approaches connecting ends of bridge with the roads should be dry and hard. The approaches at the bridge site should be such that they do not involve heavy expenditure. The approaches

should avoid the cutting across the built-up area or religious structures because the acquisition of the land and structures will be expensive, time-consuming and sometimes may cause social problems.

(2) Firm embankments: The embankments on the upstream side and downstream side of bridge site should be firm, high, permanent, solid, straight and well-defined. Such embankments are not disturbed at the time of heavy floods and they do not allow the course of river to alter.

(3) Foundations: The nature of soil at the bed of river at bridge site should be such that good foundations are available at reasonable depths for the substructures of bridge. The site subject to minimum scour should preferably be chosen.

(4) Materials and labour: The site of the proposed bridge should be so located that the materials and labour required for the construction of bridge are easily available. The transport charges for materials and labour at the bridge site should be minimum.

(5) Right-angle crossing: At bridge site, the direction of flow of water should be nearly perpendicular to the centre-line of bridge. Such a crossing is known as the *right-angle crossing* or *square crossing* or *normal crossing* and it is desirable to have such a crossing as far as possible because of the following facts:

- (i) It grants a smooth flow of water.
- (ii) It permits the construction of segmental wing walls and return walls with minimum sharp angled structures and thereby, the formation of eddies and cross currents are avoided.
- (iii) It provides the shortest length of the bridge span as well as the length of the pier and abutments.

The *skew* or *slanting bridges* are not desirable and they are usually avoided for the following reasons:

- (i) It is difficult to construct the skew bridges, especially the skew arch bridges.
- (ii) The depth of bridge foundations is likely to be more as the foundations are to be subjected to the scour.
- (iii) The design of skew bridges is complicated.
- (iv) The maintenance of skew bridges is difficult.
- (v) The passage of water under the skew bridges is not smooth and whirls or currents are produced.
- (vi) The piers of the skew bridge have to resist excessive water pressures.

(6) Straight stretch of river: The river should have a straight stretch over a reasonable long distance on the upstream side and downstream side of the bridge site. Such a straight stretch of river ensures smooth and uniform flow of water and it allows smooth navigation. The curved stretch of river is not desirable as it creates problems during construction and maintenance of the bridge.

(7) Velocity of flow: It is very important to check that the velocity of flow at bridge site is proper. If velocity of flow is less than a particular value, the *silting* will occur and on the other hand, if it is more than a particular value, the *scouring* will occur. As a matter of fact, the velocity of flow at bridge site should be between the range of non-silting and non-scouring velocities. The permissible velocity depends on the nature of bed of river. Table 1-1 shows the permissible velocities for different types of beds of river.

TABLE 1-1
PERMISSIBLE VELOCITIES AT BRIDGE SITE

No.	Nature of bed of river	Permissible velocity in cm per second	
1.	Very fine sand	60	to 90
2.	Fine sand and loose clay	Upto	50
3.	Coarse sand	50	to 100
4.	Fine gravel, sandy or stiff clay	100	to 150
5.	Clay with sand		150
6.	Clay		200
7.	Soil with rock and coarse gravel	150	to 250
8.	Rock and boulders	250	to 500

(8) Width of river: It is quite evident that the width of river indicates length of bridge. It is desirable to have minimum width of river at the bridge site. The smaller the width of river, the cheaper will be the bridge.

The conditions stated above are for an ideal site of a bridge. But in practice, it is difficult to obtain a site which will fulfil all these conditions. Hence, every case has to be studied independently and out of a number of alternatives, that site is to be recommended which satisfies most of the conditions for an ideal site. In this connection, the best guide would be the study of particulars of the existing bridges on the same river especially with respect to the foundation details, clearances, physical features, etc.

The characteristics of an ideal site for a bridge across a river are:

- a. straight reach of the river.
- b. Steady river flow without cross currents:
- c. A narrow channel with firm banks
- d. Suitable high banks above high flood level on each side.
- e. Rock or other hard in erodible strata close to the river bed level.
- f. Economical approaches danger of floods, the approaches should be free from obstacles such as hills, frequent drainage crossings, scared places, graveyards or built up areas or troublesome land acquisition
- g. Absence of sharp curves in the approaches;
- h. Absence of expensive river training works;
- i. Avoidance of excessive underwater construction.

Alignment:

After the site of bridge is decided, the next step is to set out or align the centre-line of bridge. Following aspects of the bridge alignment should be carefully studied:

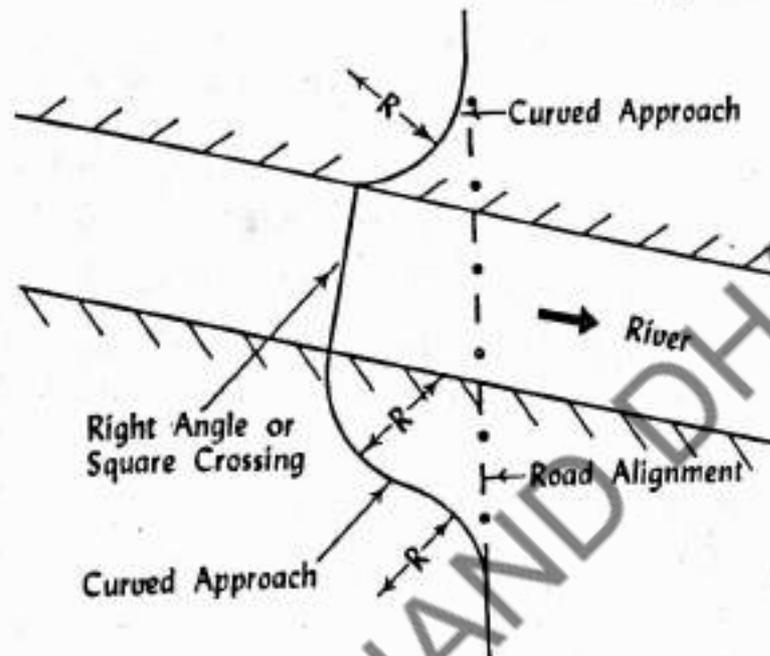
- (1) Alignment on curve
- (2) Control of highest flood level
- (3) Effects of silting and scouring
- (4) Layout of approaches
- (5) River training works
- (6) Skew bridges.

(1) Alignment on curve: In hilly areas, it is not possible to avoid the alignment of bridge on a curve. In such cases, it is necessary to adopt R.C.C. or steel girders for the superstructure and it should be seen that the axis of each pier is nearly parallel to the centre-line of river.

(2) Control of highest flood level: The highest flood level or H.F.L. of river plays a great role in fixing the height of bridge. It is possible to control H.F.L. either by diversing the extra flood water or by constructing a storage reservoir on upstream side of the river. It is found that with controlled H.F.L., the design of bridge with adverse alignment can be accurately made.

(3) Effects of silting and scouring: The necessary precautions should be taken along the bridge alignment to bring down the effects of silting and scouring to the minimum possible extent.

(4) **Layout of approaches:** If the existing road alignment is such that it results in an inclined alignment, the curved approaches may be adopted, as shown in fig. 1-5, to form right-angle or square crossing. The layout of approaches is made with suitable curve radii so as to cause the least inconvenience to the traffic using such approaches.



Layout of approaches

FIG. 1-5

(5) **River training works:** If necessary, the river training works should be carried out to form what are known as the nodal points i.e. points of minimum displacement in a system of stationary waves, along the bridge alignment. A nodal point is defined as the location where the river regime does not normally shift. The natural nodal points are established by the river flow over the years. The channels of the river shifting its course at the nodal points will be minimum and thus, the stability of the structure is insured. For this purpose, it is desirable to carry out experiments on the models to decide exactly the location of artificial river training works along the river.

(6) **Skew bridges:** As far as possible, the skew bridges should be avoided. However, if it is not possible to adopt the right-angle crossing, great care should be taken in the design and execution of skew bridges. The analysis and design of a skew bridge, especially when the skew angle is more than 15° , are more complicated and rigorous than those of a right-angled bridge. The conditions which force the adoption of skew bridges are excessive cost of land, acquisition for approaches, existing road alignment, length of bridge, nature of flow, importance of bridge, etc.

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Following *four* precautions should invariably be taken in the design of skew bridges:

- (i) It is preferred to arrange the piers parallel to the axis of river.
- (ii) The entry and exit of water below the skew bridge should be smooth.
- (iii) The skew alignment should not be curved as it is difficult to construct and maintain the curved bridge. The additional force due to the centrifugal action will come into play in case of the curved bridge.
- (iv) The skew should be restricted to 30° .

Maximum flood discharge:

Wherever possible, the maximum flood discharge at bridge site is found out from at least *two* different methods and the higher of the *two* values is adopted as the discharge for designing the bridge. If the value by *two* different methods differ by more than 50% the maximum design discharge is limited to 1.5 times the lower estimate. This is due to the fact that from point of view of economy, it is not desirable to design the bridge for flood of extraordinary high intensity which will rarely occur due to reasons such as failure of dam or tank on the upstream side of bridge site.

It is considered reasonable to design bridges for floods occurring once in 100 years and to design culverts for floods occurring once in 20 years. The design aspects should however ensure that the likely damages due to rarer floods are brought down to the minimum possible extent.

Following are the *two* methods of calculating the maximum flood discharge:

- (1) Direct method
- (2) Indirect method.

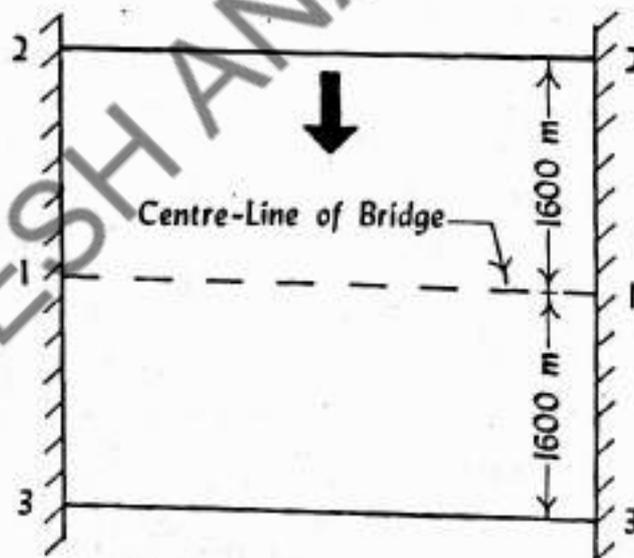
The salient features of each of the above method will now be briefly described.

(1) **Direct method:** In direct method, the area of cross-section upto the highest flood level or H.F.L. and the velocity of flow are determined. The multiplication of area and velocity gives the maximum flood discharge.

Measurement of area: Following procedure is adopted to measure the area of cross-section upto the H.F.L. at bridge site:

(i) The information regarding the height of the highest flood level is carefully gathered and it is confirmed, wherever possible, by flood marks. If there is railway track near the bridge site, the signs of the highest flood discharge would usually be available in the form of markings on railway cross-drainage works. However, in case of new road formation in undeveloped or sparsely inhabited areas, the engineer during investigation has to decide the height of the highest flood discharge by contacting the elderly inhabitants of the area and by observing the river banks, deposits of debris on tree trunks, etc.

(ii) Usually, *three* widths of river are selected, as shown in fig. 1-7. In addition to one at bridge site, one extra is selected on upstream side as well as on downstream side. The distance between the bridge site and the position of extra width is about 1600 m.



Measurement of area

FIG. 1-7

(iii) Along the widths so marked, the levels of bed of river are taken. These levels are plotted to a scale and cross-sections, as shown in fig. 1-8, are obtained. The hydrographic surveying is used for measuring the soundings which are the vertical downward distances from the surface of water to the river bed. The soundings are located by observations either entirely from boat or entirely from the shore or from boat as well as from shore.

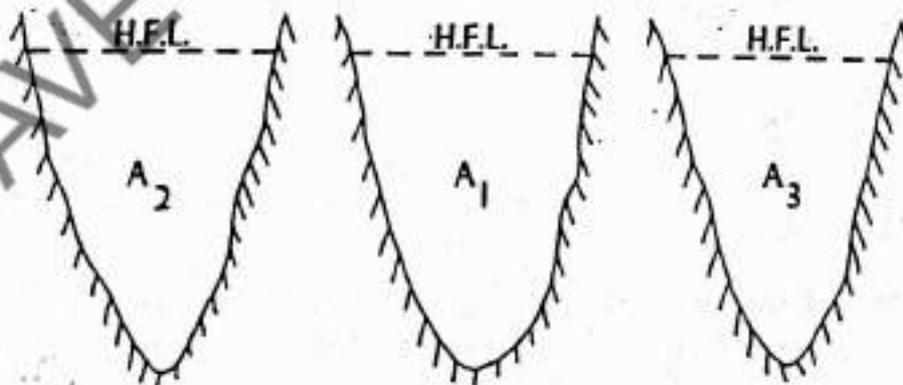
The depth of water is measured from a boat with the help of sounding poles, lead lines or sounding machines.

The sounding poles are made from well-seasoned timber with diameter of about 50 mm to 80 mm and length of about 5 m to 8 m. They are suitable for shallow and quiet waters.

The lead lines, also known as sounding lines, are in the form of lengths of hemp, cotton or brass chain. It is provided with a sounding lead at the end. The sounding lead is made of lead and it is conical in shape. Its weight varies from 40 N to 120 N depending upon the depth of water and the strength of the current of water. The line is graduated and it should be kept dry when not in use. But the line should be soaked in water for about an hour before it is used for taking soundings so that it attains its tested length. The lead lines are usually used for depth over about 6 m.

The sounding machines in the form of battery-operated and electronic echo sounders are now available. They directly measure the depth of water. The principle of echo-sounding lies in recording the interval of time between the emission of sound impulse directed to the bottom of the sea or river and the reception of the wave or echo reflected from the bottom. The echo-sounding machines are reliable, quick and convenient to use even when the weather is unfavourable. However, their calibrations should be checked frequently against trial measurements to avoid errors.

(iv) The height of the H.F.L. is marked on the cross-sections as shown in fig. 1-8.



Plotting of cross-sections

FIG. 1-8

(v) The areas of cross-sections upto H.F.L. are then worked out. If A_1 , A_2 and A_3 represent the areas of cross-sections 1-1, 2-2 and 3-3 respectively, the average area of cross-section is obtained as follows:

$$\text{Average area of cross-section} = \frac{A_1 + A_2 + A_3}{3}$$

Measurement of velocity of flow: The velocity of flow is measured by one of the following methods:

- (a) by application of Chezy's formula, or
- (b) by direct observation.

(a) By application of Chezy's formula:

According to Chezy's formula,

$$v = C \sqrt{m i}$$

where v = Velocity of flow in m per second

C = Chezy's constant

m = Hydraulic mean depth

i = Slope of hydraulic grade line.

The above formula was given by French engineer Chezy in 1775. Following points should be noted:

(i) For finding out the value of m , let m_1 , m_2 and m_3 be the respective hydraulic mean depths and P_1 , P_2 and P_3 be the respective wetted perimeters of cross-sections 1-1, 2-2 and 3-3, as shown in fig. 1-7 and fig. 1-8.

$$\text{Then, } m = \frac{m_1 + m_2 + m_3}{3}$$

$$\text{where } m_1 = \frac{A_1}{P_1}$$

$$m_2 = \frac{A_2}{P_2}$$

$$m_3 = \frac{A_3}{P_3}$$

(ii) The slope of hydraulic grade line or hydraulic gradient, as it is called, is obtained as follows:

$$i = \frac{D}{3200}$$

where D = Difference in levels between upstream and downstream sections 2-2 and 3-3. Refer fig. 1-7.

(iii) Chezy's constant is very complex and its value can be obtained either by Kutter's formula or Bazin's formula.

Kutter's formula:

$$C = \frac{23 + \frac{0.00155}{i} + \frac{1}{N}}{1 + \frac{N}{\sqrt{m}} \left(23 + \frac{0.00155}{i} \right)}$$

where N is called the *rugosity factor* or *roughness coefficient* and its value varies from 0.02 to 0.03, depending on the condition of bed and sides of river.

This formula was given by Kutter in 1869.

Bazin's formula:

$$C = \frac{157.6}{1.81 + \frac{k}{\sqrt{m}}}$$

where k is Bazin's constant and its value varies from 1.54 to 3.17, depending on the condition of bed and sides of river.

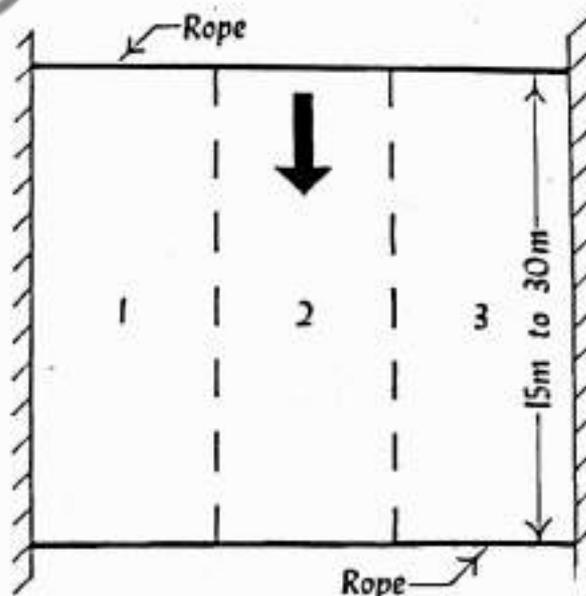
The formula was given by Bazin in 1897.

(b) By direct observation:

Following procedure is adopted to obtain the velocity of flow by the direct observation:

(i) The two lines, as shown in fig. 1-9, are marked across the river with the help of ropes. The distance between these two lines depends on the width of river. But it is usually kept as 15 m to 30 m.

(ii) The width of river between these two lines is suitably divided, usually in *three* sections, as shown in fig. 1-9.

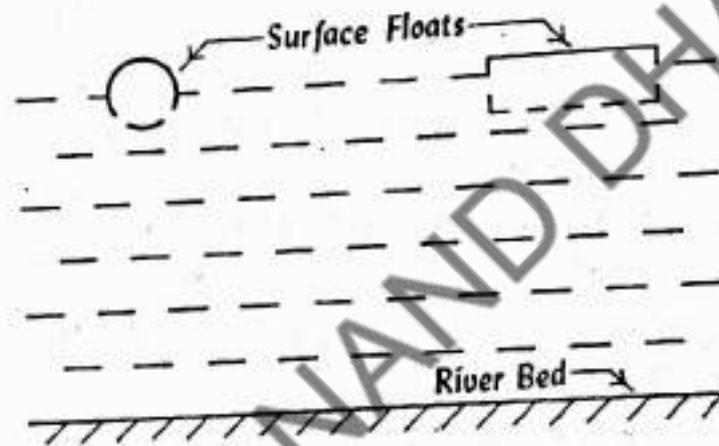


Measurement of velocity of flow by direct observation

FIG. 1-9

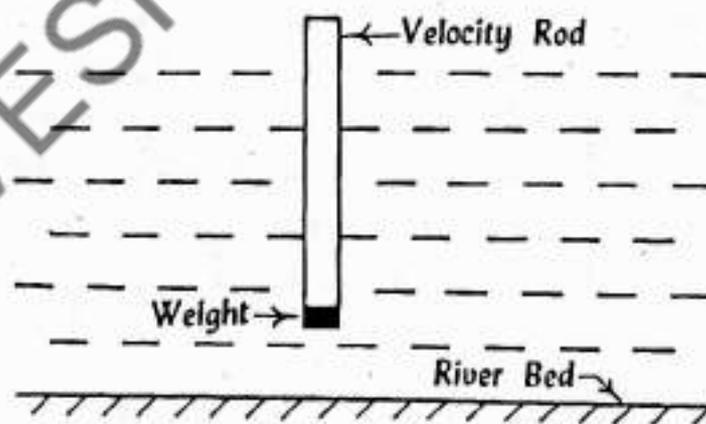
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(iii) The time taken by a surface float or a velocity rod to travel from one line to the other is noted. The surface float is shown in fig. 1-10 and it is to be adopted for small rivers. The velocity rod is shown in fig. 1-11 and it is to be adopted for large rivers. The surface floats are made of light materials such as cork or drift wood and they are generally of diameter varying from 80 mm to 160 mm. The velocity rods are made of hollow metal tube or wood and they are generally of diameter varying from 30 mm to 50 mm. The velocity rods are provided with weight at their bottom so that they can float vertically with their top just above the water surface. They are made of adjustable lengths to suit the different depths of water.



Surface float

FIG. 1-10



Velocity rod

FIG. 1-11

(iv) Let t_1 , t_2 and t_3 be the time in seconds taken by surface float or velocity rod to travel from one line to the other.

Then,

$$\text{Average time} = \frac{t_1 + t_2 + t_3}{3} \text{ seconds.}$$

(v) Velocity of flow in cm per second is then obtained as follows:

$$\text{Velocity} = \frac{\text{distance travelled in cm}}{\text{time in seconds}}$$

Following points should be noted:

(1) When surface floats are used, they give surface velocity and hence, to obtain mean velocity, the following correction is to be applied:

$$\text{Mean velocity} = e \times \text{surface velocity}$$

where $e = 0.8$, if surface velocity is less than 90 cm/sec.
 $= 0.9$, if surface velocity exceeds 90 cm/sec.

(2) The velocity rods give directly the mean velocity and hence, no correction is necessary, when they are used.

(3) The special instruments, known as the *velocity meters* may be used to obtain directly the velocity of flow. The meter is lowered from a boat and by applying formula for the meter, the mean velocity of flow can be worked out.

(2) Indirect method: Following are the two indirect ways of estimating the maximum flood discharge:

- (i) Rational method
- (ii) Use of empirical formulae.

(i) *Rational method:* The upstream area from the bridge site which contributes to the water of river is known as its *catchment area*. A careful study of the catchment area is made and the following *three* factors are combined in the form of an equation:

- (1) Catchment area
- (2) Maximum intensity of rainfall
- (3) Runoff coefficient.

(1) *Catchment area:* The ridge line is marked on the topo sheet and with the help of a planimeter, the catchment area of the river on the upstream side of the proposed bridge site is worked out. If the catchment area is large, it should be divided into small sections with reference to the rainfall and topography. Then, the discharge or runoff from each section should be worked out separately and added together to get the total discharge.

(2) Maximum intensity of rainfall: The rainfall is measured by the standard instruments which are known as the rain gauges. They may be non-automatic or automatic. The Simon's non-automatic rain gauge is commonly used in India. The rain gauge stations should be evenly distributed over the area so as to obtain the representative figure of rainfall for the entire area. For hilly areas, they are situated nearer and for plain country, one station is provided for an area of about 130 km². The rain gauge stations should not be obstructed by roofs of buildings, large trees, etc.

The readings for record of daily rainfall are taken at an interval of 24 hours. The monthly rainfall and yearly rainfall can then be worked out from the data of daily rainfall. From the records of rainfall, the maximum intensity of rainfall of catchment area of the proposed bridge site is obtained.

(3) Runoff coefficient: The rainfall on an area is expressed as so many centimetres over the entire area for a certain fixed interval of time. But all the water coming down from the rainfall is not available for further use. Some quantity of it is lost in evaporation or percolation or transpiration. The *evaporation* is the loss of water from land and water surfaces back to the atmosphere due to action of heat of the sun. The *percolation* indicates the loss of water penetrated into the soil. The *transpiration* is the loss of water caused by the leaves of the growing vegetation. The net quantity of water which remains on surface after all the losses is termed as the surface runoff.

The term runoff coefficient is used to indicate the ratio of surface runoff from an area to the total rainfall on that area in a fixed interval of time. The value of runoff coefficient varies from 0.20 to 0.70 and it should be carefully decided as it depends on a combination of so many factors and its prediction becomes far from exact science. The factors which contribute to the flood flow are as follows:

- (1) Area of catchment: The smaller the catchment area, the smaller will be the coefficient of runoff and vice versa.
- (2) Characteristics of catchment: It is very essential to study in detail the characteristics of catchment area as they considerably affect the value of runoff coefficient. The matters to be studied are size, slope, vegetation, porosity, climate, etc.

- (3) Condition of ground at the time of rainfall: If ground is dry at the time of rainfall, it will absorb more water and coefficient of runoff will be small. For ground wet at the time of rainfall, reverse will be the case.
- (4) Intensity of rainfall: If it rains heavily in short duration of time, the soil does not get opportunity to absorb all the water. It thus increases the surface flow and consequently, the coefficient of runoff is also increased.
- (5) Interval between successive showers: The smaller the interval between successive rainfall showers, the greater will be the coefficient of runoff and vice versa.
- (6) Season of rainfall: The rainfall during hot season gives less surface flow than that during cold season.
- (7) Yearly rainfall: The greater the annual rainfall, the greater is the runoff coefficient and vice versa.

Let A = Area of catchment in hectares
 I = Maximum intensity of rainfall in cm per hour for duration of time of concentration
 P = Coefficient of surface runoff
 Q = Maximum flood discharge in m^3 per second.

Then, the general equation becomes as follows:

$$Q = K A I P$$

where K = Constant which permits the expression of three factors in convenient units.

In this case, with units as mentioned above,

$$Q = 10000 A \times \frac{1}{100} \times \frac{1}{3600} \times I \times P$$

$$= \frac{AIP}{36}$$

Hence, K is equal to $\frac{1}{36}$.

Problem 1-1.

From the following data, calculate lineal waterway required for a bridge to be constructed across the river:

Catchment area	: 600 hectares
Maximum intensity of rainfall	: 1 cm per hour
Runoff coefficient	: 60 per cent
Permissible velocity	: 120 cm per second
Average depth of flow	: 180 cm.

Chapter 4

FIXED-SPAN SUPERSTRUCTURES

General:

The superstructure of a bridge can broadly be classified into two categories, namely, fixed-span superstructure and movable-span superstructure.

In case of fixed-span superstructures, the superstructure remains in a fixed position and most of the bridges are of this category. In case of movable-span superstructures, the superstructure is lifted or moved with the help of some suitable arrangement.

In this chapter, the bridges with the fixed-span superstructures will be discussed and the bridges with the movable-span superstructures will be discussed in the next chapter.

Following are the various types of bridges with the fixed-span superstructures:

- I. Simple bridges
- II. Continuous bridges
- III. Cantilever bridges
- IV. Arch bridges
- V. Bow-string girder type bridges
- VI. Rigid frame bridges
- VII. Suspension bridges
- VIII. Cable-stayed bridges.

I. Simple bridges:

In case of simple bridges, the span is simply supported and they are sometimes referred to as the *independent-span bridges*. Depending upon the position of superstructure, the simple bridges are divided into the following three categories:

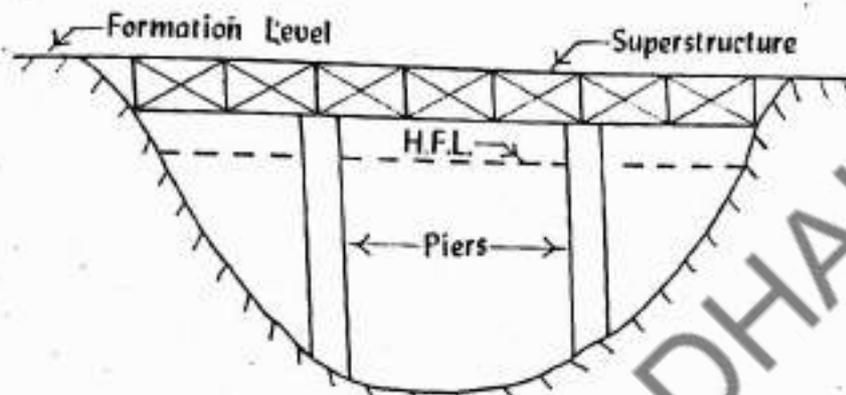
- (1) Deck bridges
- (2) Through bridges
- (3) Semi-through bridges.

(1) **Deck bridges:** For any bridge, the following two levels are to be carefully decided:

(i) **Formation level:** The ground level of approaches is to be taken into consideration for fixing the formation level of road or railway line.

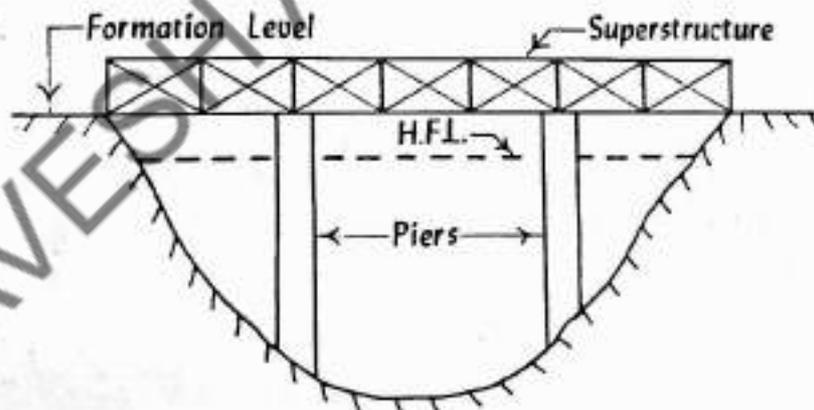
(ii) **Highest flood level or H.F.L.:** While making the calculations for maximum flood discharge, the H.F.L. for the river or stream is determined.

If it is possible to accommodate the superstructure of bridge between these two levels with suitable allowance for clearance, as shown in fig. 4-1, the bridge is known as the *deck bridge*.



Deck bridge
FIG. 4-1

(2) **Through bridges:** Sometimes the difference between the formation level and H.F.L. is not sufficient to accommodate the superstructure of bridge. In such cases, the superstructure projects above the formation level, as shown in fig. 4-2. Such a bridge is known as the *through bridge*.

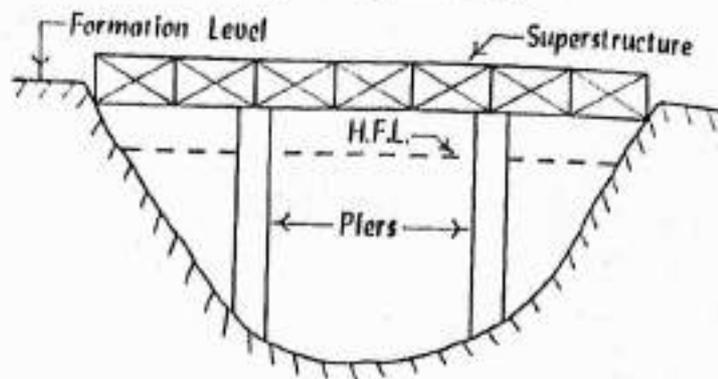


Through bridge
FIG. 4-2

(3) **Semi-through bridges:** When the superstructure of bridge projects partly above the formation level and partly below the formation level, as shown in fig. 4-3, it is known as the *semi-through bridge* and it is thus an intermediate type between the deck bridge and through bridge.

Out of three types of simple bridges, the deck type proves to be economical. Following are the advantages of a deck bridge:

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Semi-through bridge

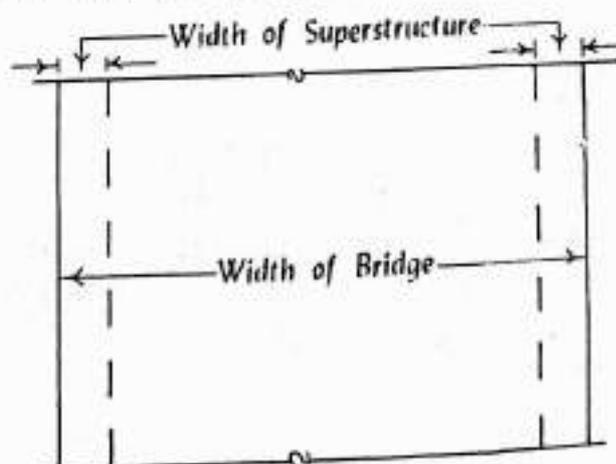
FIG. 4-3

(i) *Effect of horizontal forces:* The effect of various horizontal forces such as tractive effort and wind load will be comparatively less on a deck type bridge than that on a through type bridge. The deck bridge gets this advantage as its superstructure is situated below the formation level of road or railway line.

(ii) *Erection:* For steel bridges, it proves to be easier to erect the superstructure of a deck bridge than that of a through bridge.

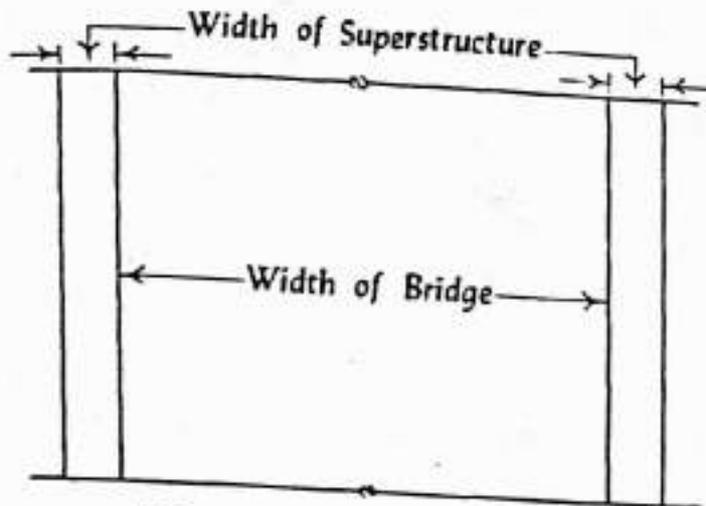
(iii) *Natural scenery:* A deck bridge grants better view of the surrounding scenery and hence, it is preferred to the through bridge for carrying the highway traffic.

(iv) *Width of bridge:* The total width of a deck bridge will be equal to its actual width, as shown in fig. 4-4. The total width of a through bridge will be equal to the actual width of bridge plus width of superstructure on either side, as shown in fig. 4-5. Thus, the total width of a through bridge will be more than that of a deck bridge. Hence, for the same width of bridge, the weight of superstructure in case of through bridge will be more than that of a deck bridge.



Plan of deck bridge

FIG. 4-4



Plan of through bridge

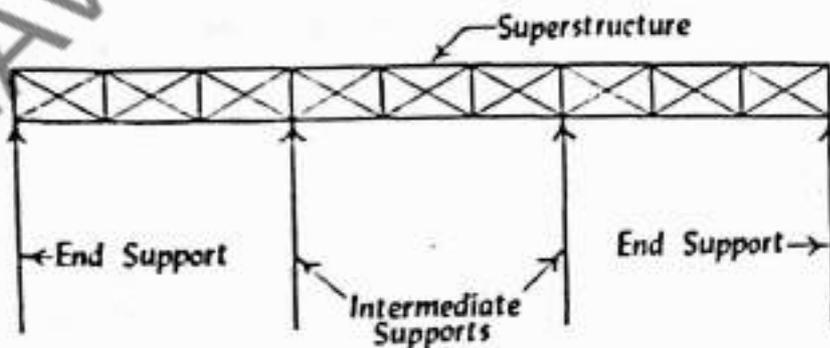
FIG. 4-5

II. Continuous bridges:

When the bridge is designed to continue unbroken over intermediate supports, it is said to be continuous bridge. Fig. 4-6 shows a continuous bridge.

When the design of a bridge is made on a continuous span, it is found that the bending moment anywhere in the span is considerably less than that in case of a simply supported span. Such reduction of bending moment ultimately results in the economic section for the bridge. But to take maximum advantage of a continuous span, it is essential that the following two conditions are satisfied:

- (1) Facilities for erection
- (2) Hard soil.



Continuous bridge

FIG. 4-6

(1) **Facilities for erection:** For steel bridges, the girder for continuous span will be of a fairly heavy weight. Hence, it is necessary to have suitable facilities at bridge site to erect such girders.

(2) **Hard soil:** A continuous bridge is an indeterminate structure. Hence, a slight sinking of any support considerably alters the designed values of bending moment and shear force at various sections along the span of bridge. It is, therefore, necessary to check that the foundations of supports rest on hard and firm soil. At places where there are chances for foundation to sink or settle, the continuous bridges are not adopted.

Following are the *advantages* of R.C.C. continuous girder bridges over simply supported girder bridges:

- (1) As the bearings are placed on the centre-lines of piers, the reactions at piers are transmitted centrally.
- (2) It is found that the continuous girder bridge suffers less vibration and deflection.
- (3) The continuous girder bridge requires only one bearing at each pier as against two bearings for simply supported girder bridge.
- (4) The depth of decking at midspan is reduced and it may prove to be useful for overbridges where the headroom is of prime consideration.
- (5) The expansion joints required will be less.
- (6) There is reduction in cost as less quantities of concrete and steel are required.

Following are the *disadvantages* of R.C.C. continuous girder bridges over simply supported girder bridges:

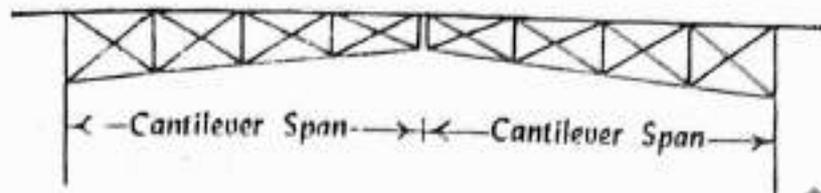
- (1) The design is more complicated as it is a statically indeterminate structure.
- (2) The detailing and placing of reinforcements are to be carried out with extreme care.
- (3) The placing of concrete and removal of formwork are to be executed carefully in proper sequence.

III. Cantilever bridges:

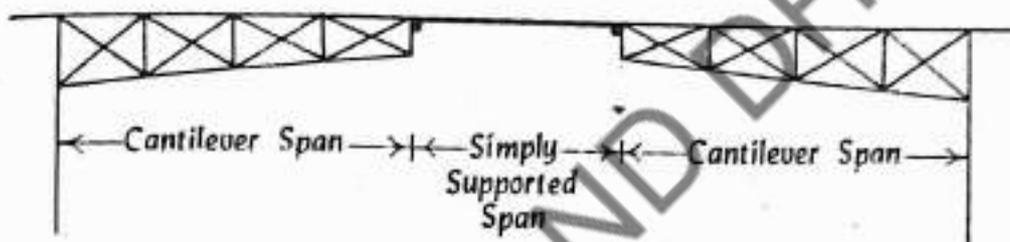
A cantilever bridge is formed of the cantilevers projecting from the supporting piers. The ends of a cantilever bridge are treated as fixed. A cantilever bridge combines the advantages of a simply supported span and a continuous span. For long spans and deep valleys and at places where it will not be practicable to use centering, the cantilever bridges are more suitable.

The construction of a cantilever bridge may either be of simple type or of balanced type. Fig. 4-7 shows a cantilever bridge with simple construction. The ends of

cantilever just meet at the centre of span. Fig. 4-8 shows a cantilever bridge with balanced type of construction. In this case, the hinges are provided at the points of contraflexure of a continuous span and an intermediate simply supported span is suspended between these two hinges.

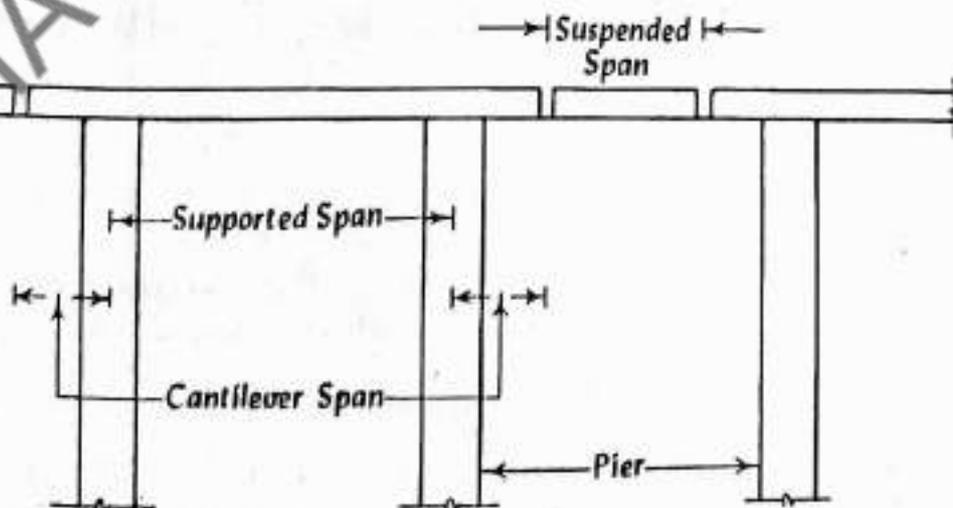


Cantilever bridge with simple construction
FIG. 4-7



Cantilever bridge with balanced type construction
FIG. 4-8

A modified form of this type can be constructed in R.C.C. with two cantilevers on either side of the pier and providing a suspended span as shown in fig. 4-9. The size and shape of the counter-weighted cantilevers are determined after trying several possible combinations. The usual length of cantilever span is about one-fifth to one-third of the main supported span.



Bridge with counter-weighted cantilevers
FIG. 4-9

However, this type of construction demands extreme care and skill in its design and elaborate detailing of reinforcements. But it affords the various *advantages* over simply supported construction such as fewer expansion bearings, reduction in quantity of steel and concrete, piers of moderate dimensions, lower initial and maintenance costs, etc.

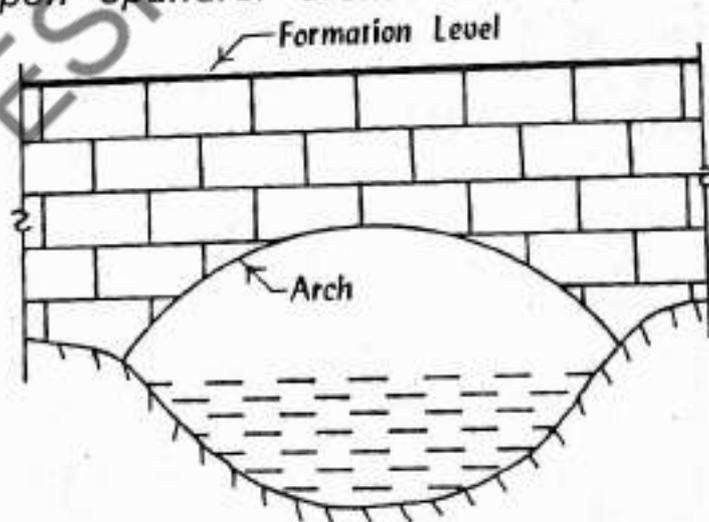
IV. Arch bridges:

In case of arch bridges, the road or railway track is carried on arches. The rise of the arch is kept as large as possible so as to reduce the horizontal thrust and to economise on the design of the piers, abutments and foundations. It is usually kept not less than one-third span, but in no case less than one-fifth span. It is also desirable to choose a simple shape for the arch. It will facilitate its setting out and construction.

Classification of arches: The bridge arches are classified as follows:

- (1) according to condition of spandrel,
- (2) according to number of hinges,
- (3) according to shape, and
- (4) according to width.

(1) *According to condition of spandrel:* Depending upon the condition of space above the arch and below the formation level, the arches are classified as *filled spandrel arch* and *open spandrel arch*.



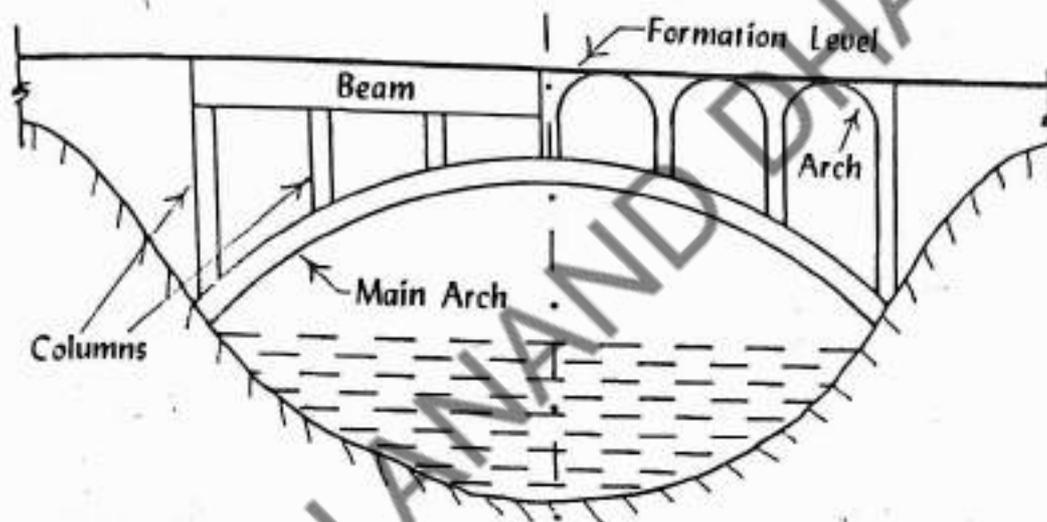
Filled spandrel arch

FIG. 4-10

Fig. 4-10 shows a filled spandrel arch. The side walls are taken up to the bottom of formation level and the interior portion is filled up either by earth or any other suitable filling material up to the road formation level. A filled spandrel

arch is suitable when ratio of rise to span is small. If rise to span ratio is above a certain limit, a filled spandrel arch proves to be uneconomical as it will require excessively heavy side walls and considerable amount of filling.

Fig. 4-11 shows an open spandrel arch. The flooring of bridge is supported either by beams and columns or by arches and columns. The main arch supports the columns. The space between the columns is kept open. This type of arch is aesthetically good and it provides a beautiful structure specially in a narrow valley or gorge.



Open spandrel arch

FIG. 4-11

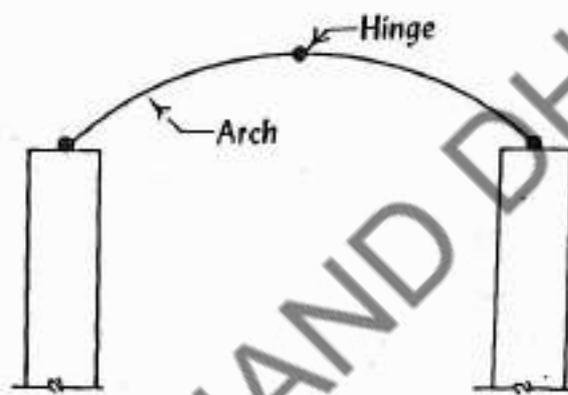
An open spandrel arch is suitable when ratio of rise to span is high and it proves to be economical because of the following reasons:

- (1) There is considerable reduction in the dead load of the structure as the filling material is not required. It will thus reduce the costs of arch and foundation.
- (2) The main arch may be made of rib type and two or more independent narrow ribs may be provided to support the bridge. Further, these ribs may be made deeper and they may be suitably reinforced. All such measures will result in the reduction of bending moments and tensile stresses.

(2) *According to number of hinges:* Depending upon the number of hinges provided, the arches are classified as *three-hinged arch*, *two-hinged arch*, *one-hinged arch* and *hingeless or fixed arch*.

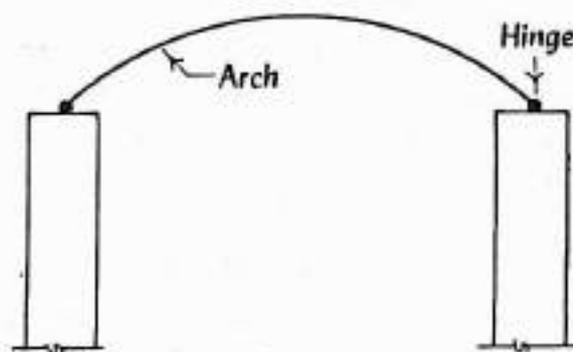
Fig. 4-12 shows a three-hinged arch. It contains hinges at crown and springing points. A three-hinged arch is structurally stable and is adopted when it is difficult to obtain hard soil within a reasonable depth or where the foundations are likely to yield.

The *disadvantage* of this type of bridge is that the thickness at the quarter points is more than that at spring. Hence, the masking is required for aesthetic purposes. The three-hinged arches are sometimes provided only while using the steel arches.



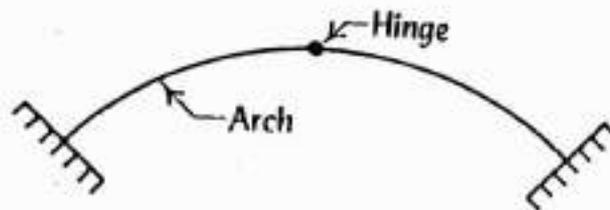
Three-hinged arch
FIG. 4-12

Fig. 4-13 shows a two-hinged arch. It contains hinges at the supports i.e. pier or abutment. The two-hinged arches are simple for analysis as there is no bending moment at the support and only reactions are transmitted to the supports. They are easily adaptable for the construction of concrete and steel arches. The bow-string girder arch in R.C.C. is also treated like a two-hinged arch for the purpose of design.



Two-hinged arch
FIG. 4-13

Fig. 4-14 shows a one-hinged arch. It contains only one hinge at the crown.



One-hinged arch
FIG. 4-14

Fig. 4-15 shows a fixed arch. It does not contain any hinge. It is adopted where hard unyielding soil is available for the supports of an arch. It is the most commonly employed arch especially in masonry and it provides a very good aesthetic appearance. It is, however, difficult for analysis. But it is economical and can be adopted for long spans also.



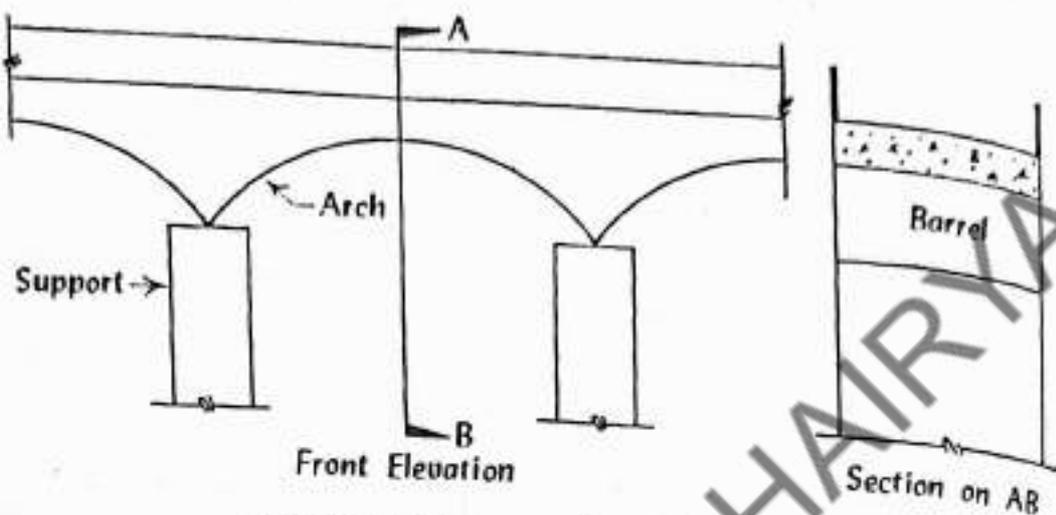
Fixed arch
FIG. 4-15

(3) *According to shape:* The bridge arches can also be classified according to the shape of arch. The commonly adopted shapes of bridge arches are semi-circular, segmental, pointed, semi-elliptical and multi-centered. At places where sufficient height is available, the pointed or semi-circular shapes can be adopted.

For medium span lengths, the segmental or parabolic profiles will be more appropriate. For long spans, the multi-centered shapes are found to be convenient.

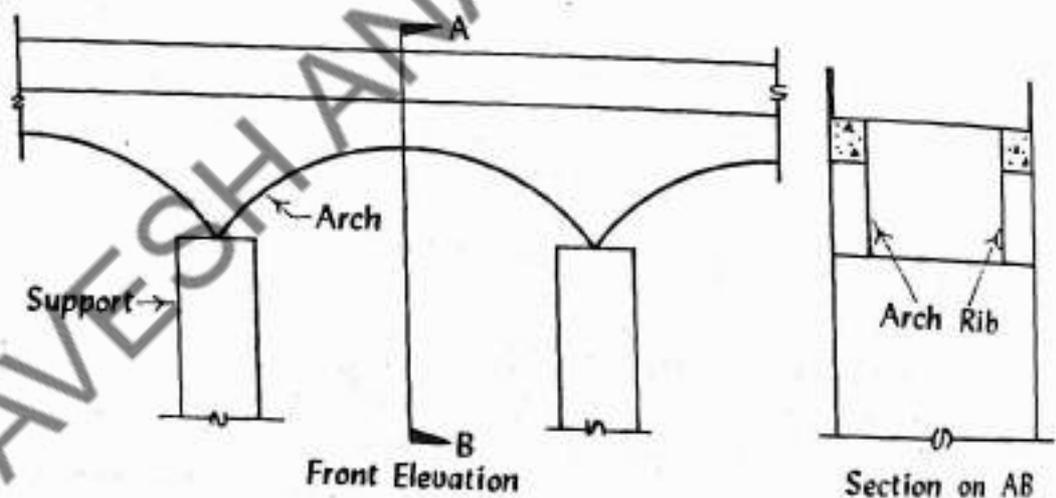
(4) *According to width:* Depending upon the width of arch in the transverse direction of bridge, the arches are classified as *barrel type* or *rib type*.

Fig. 4-16 shows a barrel type arch bridge. The widths of arch and bridge are the same and it results in the formation of a barrel.



Barrel type arch bridge
FIG. 4-16

Fig. 4-17 shows a rib type arch. The ribs which are in the form of curved beams are provided to support the flooring of bridge.



Rib type arch bridge
FIG. 4-17

Advantages: Following are the advantages of the arch bridges:

- (1) *Aesthetic effect:* If suitable shape is given to the arch, it fits easily with the natural surroundings. The arches can thus be used to develop desired architectural effect.
- (2) *Design:* The arch section is to be designed only for normal thrust and radial shear. The effect of bending moment is practically eliminated by the action of horizontal thrust at the supports.

(3) *Gorges*: The arch bridges are found to be most suitable for deep gorges with the embankments of hard rock.

(4) *Maintenance*: The arch bridges are comparatively easy to maintain.

(5) *Span*: With suitable material of construction, the arch section can be designed for quite a reasonably long span.

(6) *Vibrations*: Due to heavy mass of the structure, the vibrations due to impact forces are practically eliminated and consequently, the noise, which is very common in case of steel bridges, is almost absent in the arch bridges.

Disadvantages: Following are the *disadvantages* of the arch bridges:

(1) *Inclined reactions*: The reactions are inclined in case of the arch bridges. It becomes, therefore, necessary to provide heavier sections for the abutments and piers to resist the inclined reactions.

(2) *Indeterminate structure*: An arch is an indeterminate structure with only exception of that of a three-hinged arch. Hence, the designed stresses are considerably altered, even if there is a slight settlement of any support.

(3) *Rise*: It is evident that the rise of arch will have to be accommodated between the formation level of road or railway line and the springing level of arch. If the level of approaches is very low, it becomes uneconomical to provide an arch bridge.

V. Bow-string girder type bridges:

The bow-string girder type bridge derives its name from its shape. The arch rib and tie respectively resemble bow and string. The flooring of bridge rests on ties and the load is transmitted to the arch rib through suspenders. Suitable bracing may also be provided in case of steel bow-string girders.

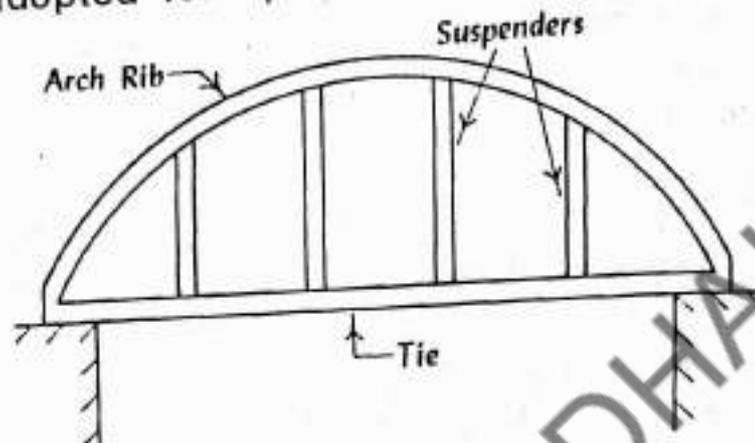
The bow-string girder type bridge removes the following two disadvantages of the arch bridges:

(1) The horizontal thrust is resisted by ties. Hence, the reactions at supports are vertical and not inclined as in case of the arch bridges. As a result of vertical reactions, the supports require lighter sections.

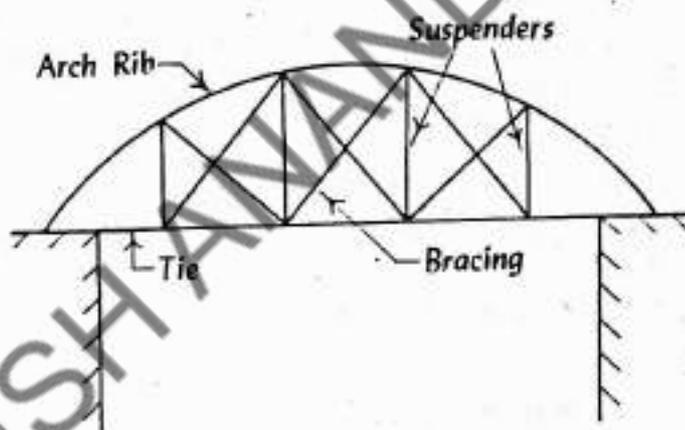
(2) The bow-string girders project above the formation level of road or railway line. Hence, the question of accommodating the rise between the level of approaches and the springing level of arch does not arise.

The bow-string girder type bridges are therefore very suitable for multiple spans and at places where the available clearance is restricted.

Fig. 4-18 shows an R.C.C. bow-string girder bridge and it can be adopted for spans of 30 m to 45 m.



R.C.C. bow-string girder bridge
FIG. 4-18



Steel bow-string girder bridge
FIG. 4-19

Fig. 4-19 shows a steel bow-string girder bridge and it can be adopted for spans of 120 m to 240 m.

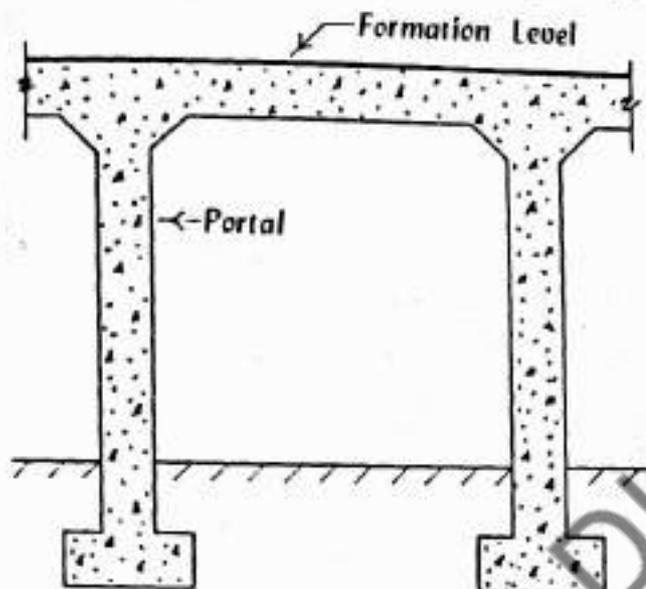
VI. Rigid frame bridges:

In case of rigid frame bridges, the monolithic portal frames are designed for the superstructure and substructure.

Following are the favourable conditions for a rigid frame bridge:

- (1) It is not possible to provide an arch bridge.
- (2) The bearing capacity of soil is low.
- (3) There is restriction of headroom over the full span.
- (4) The roadway is wide.
- (5) The span is small.

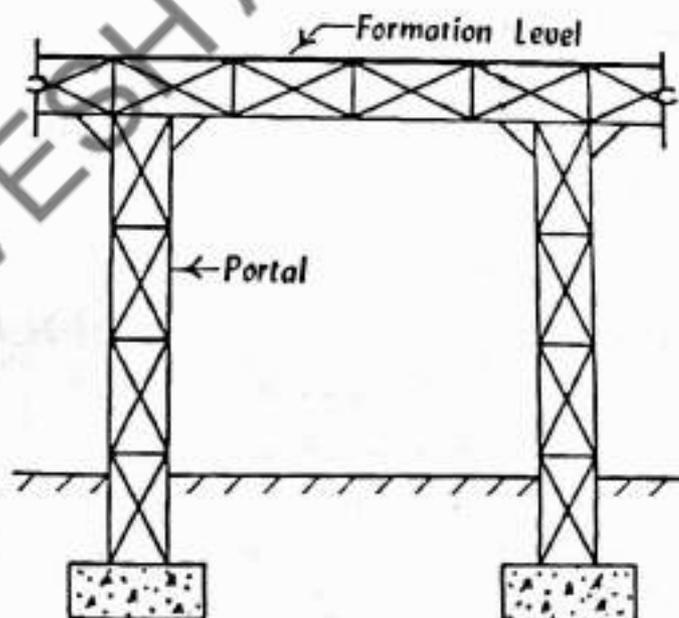
Fig. 4-20 shows an R.C.C. portal frame. Suitable reinforcement may be provided as required. The bridge may consist of single portal or continuous portals. The R.C.C. portal frames are suitable for spans upto 15 m or so.



R.C.C. portal frame

FIG. 4-20

Fig. 4-21 shows a steel frame. It may suitably be braced as required. The bridge may consist of single portal or continuous portals. It is possible to construct steel portals in short time and they are suitable at places where the cost of construction for the abutments is high.



Steel portal frame

FIG. 4-21

In addition to the advantages offered by the continuous bridges, the rigid frame bridges grant the following additional advantages:

- (1) As the connections are rigid, it gives more stability to the supports as compared to independent piers of the same dimensions.
- (2) The bearings at supports are not required.
- (3) The view for the traffic below the bridge is the least obstructed in view of the slender dimensions of the supporting piers.

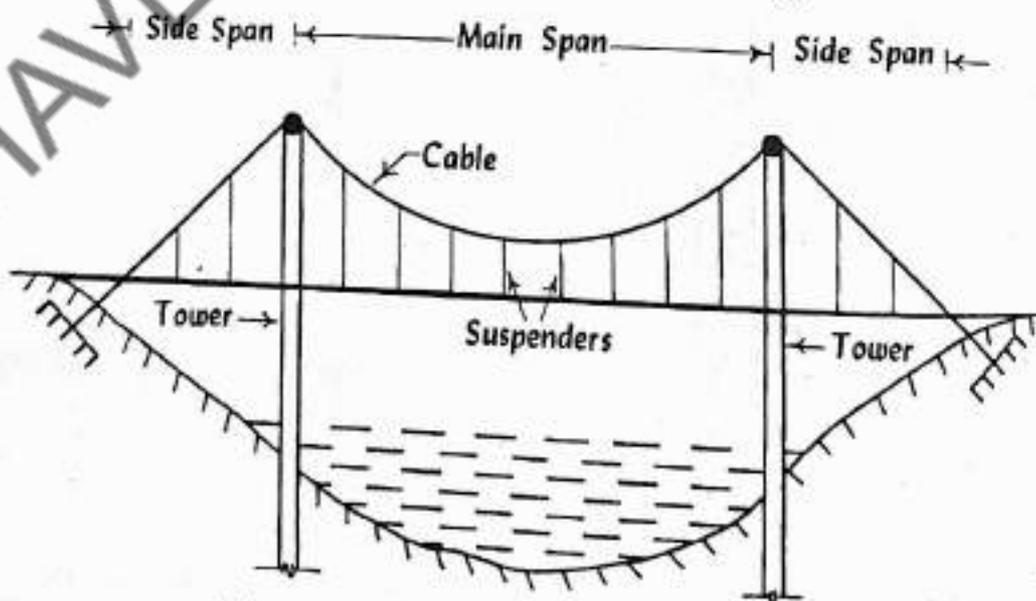
VII. Suspension bridges:

Suspension bridges are ideal solution for bridging gaps in hilly areas because of their simple construction technology and capability of spanning large gaps.

The suspension bridge consists of a hanging cable which is anchored at the two ends. The cable takes the shape of a catenary between two points of suspension. The flooring of bridge is supported by the cable by virtue of tension developed in its cross-section. The vertical members, known as the *suspenders*, are provided to transfer the load from bridge floor to the suspension cable.

The cables are usually of chains or steel wire ropes. The suspenders are usually of twisted wire ropes and they are connected with the cable by loops. Depending upon the site conditions, the side span to main span ratio varies from 0.17 to 0.50.

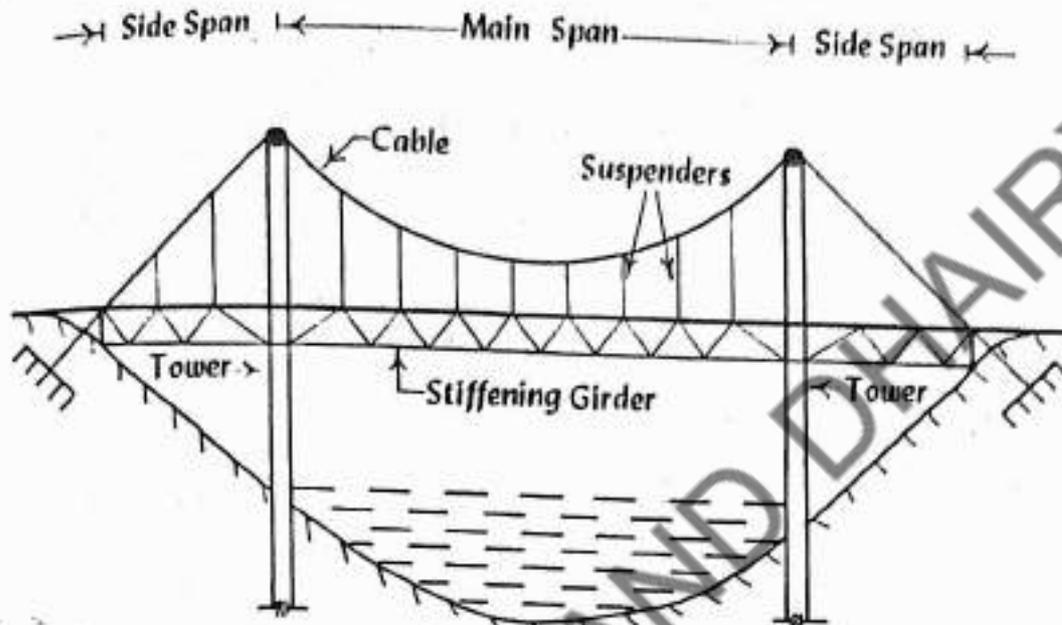
The suspension bridges may either be *unstiffened* or *stiffened*. Fig. 4-22 shows an unstiffened suspension bridge. It can be adopted for light traffic and for foot bridges where dead load will be just sufficient to prevent any appreciable change in the shape of bridge.



Unstiffened suspension bridge

FIG. 4-22

Fig. 4-23 shows a stiffened suspension bridge. The stiffening girder assists the cable to become more rigid and to prevent changes in shape and gradient of the roadway platform. It is, therefore, adopted for heavy traffic. The load from the bridge floor is transferred to the stiffening girder and it is conveyed to the cables through the suspenders.



Stiffened suspension bridge

FIG. 4-23

Following are the *advantages* of the suspension bridges:

- (1) The construction of piers in bed of river is avoided.
- (2) The design is comparatively simple.
- (3) They are economical in cost as compared to the cost for other bridges.
- (4) They are light in weight.
- (5) They can be constructed for long spans exceeding 600 m and can be considered as competitive for spans down to 300 m.
- (6) They can be easily and rapidly constructed.
- (7) They present better architectural effect.

Following are the *disadvantages* of the suspension bridges:

- (1) There are very few suppliers of bridge cables and machined sockets, which are essential parts of a suspension bridge.
- (2) Painting is essential for all steel components at regular intervals.

- (3) The superstructure cost proves to be higher than other types of spans particularly in span ranges of less than 250 m.

Suspension bridge is one of the earliest technologies known to mankind and it is originated in the Indian sub-continent more than 2000 back. The suspension bridges with longer and longer spans have been developed. In 1816, a suspension bridge with a span of 124 m was built in Philadelphia, U.S.A. and the longest suspension bridge having a span of 1400 m has been constructed in 1982 for the Humber bridge in U.K. As a matter of fact, the suspension bridges can be theoretically constructed for as large a span as 3000 m.

VIII. Cable-stayed bridges:

The cable-stayed bridges became popular in France during the earlier part of eighteenth century. However, after the collapse of the Dryburgh-Abbey Bridge, U.K. in 1818 and the Saale River Bridge, Germany in 1824, the French scientist Navier recommended that suspension bridge be built as alternative to cable-stayed bridges. After World War II, the European community reviewed the development of cable-stayed bridge. The first modern cable-stayed bridge was the Stormsund Bridge built in 1955 in Sweden.

The first three major cable-stayed bridges constructed in the United States were the Pasco - Kennewick Bridge built in 1978 across the Columbia River in Washington, the Luling Bridge built in 1983 across the Mississippi River in Louisiana; and the East Huntington Bridge built in 1985 across the Ohio River in West Virginia. At present, about 15 major cable-stayed bridges have been constructed in the United States.

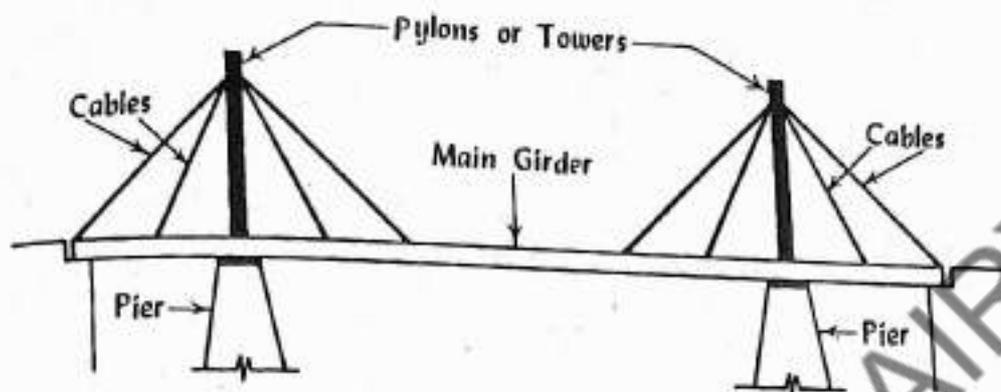
The cable-stayed bridges are similar to the suspension bridges except that there are no suspenders in the cable-stayed bridges and the cables are directly stretched from towers to connect with the decking. Thus, no special external anchorage is required for the cables as in case of the suspension bridges because the anchorage at one end is done in the girder and at the other on top of tower.

Each anchorage in girder introduces horizontal and vertical forces. The cross girders or diaphragms take up the vertical forces. The stiffening girders are designed to take bending stresses and also a compressive force which is induced by the horizontal component of the force in the cable.

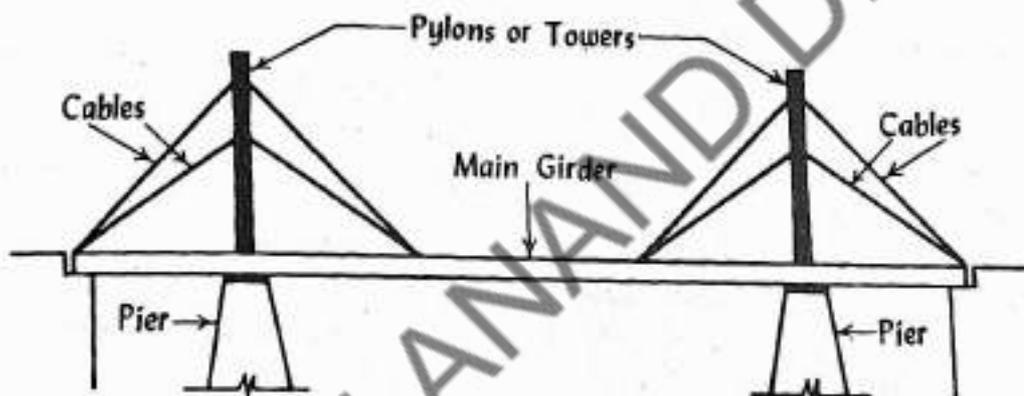
Fixed-Span Superstructures

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Fig. 4-24 and fig. 4-25, show the cable-stayed or one plane system as shown in fig. 4-24 and fig. 4-25 respectively.



Cable-stayed bridge with two plane system
FIG. 4-24



Cable-stayed bridge with one plane system
FIG. 4-25

The *two plane system* requires additional widths to accommodate the towers and deck anchorages. In case of one plane system, the anchorage at deck level can be accommodated in the traffic median and it results in the least value of the total width of deck. The one plane system is also more aesthetically pleasing because it provides an unobstructed view on one side of the motorist or vehicle driver. On the other hand, a side view of the bridge in the *two plane system* gives the impression of the intersection of the cables.

In principle, the cable-stayed bridge essentially consists of the following *three* elements:

- (1) bridge deck,
- (2) pylons or towers, and
- (3) stay-cables.

Chapter 5

MOVABLE-SPAN SUPERSTRUCTURES

General:

In case of bridges with movable-span superstructures, it is so arranged that the superstructure of the bridge does not remain in a fixed position permanently. But it is possible to move the superstructure so as to put the bridge out of use, when necessary. It sometimes so happens that the ships may have to pass through the high level bridges requiring the provision of very high clearance. Such bridges will require very high approaches or highly graded approaches even if the maximum clearance is to be provided in the middle portion only. Where the traffic on the bridge is such that suspension of traffic for a short duration on the road or railway will not materially affect the overall traffic, the high level bridges are built with decks with minimum clearance above H.F.L. for normal passage of water and the middle one or two spans or the entire span will be provided with girders which can be moved for clearing the navigation vessels.

It should be remembered that the movable bridges represent specially designed structures and it is therefore necessary to pay special attention to the machinery involved and the housing, operation and maintenance of such machinery. If an attempt is made to reduce the weight of bridge by using material such as aluminium alloy, the reduction in dead weight of the structure will considerably bring down the cost of power required for the working of the bridge.

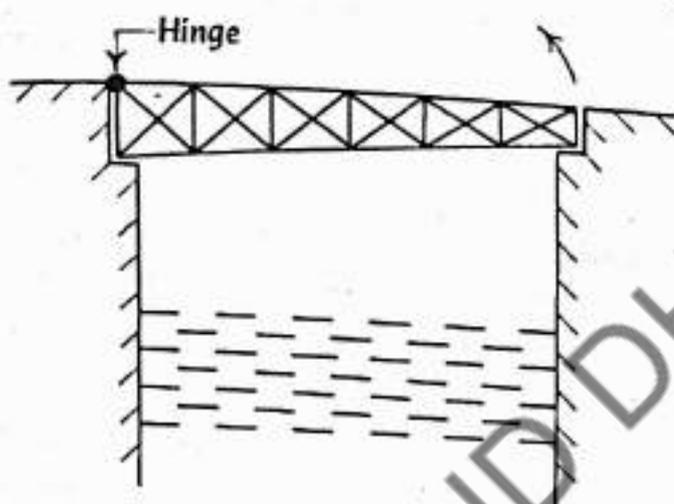
Following are the various bridges with movable-span superstructures:

- I. Bascule bridges
- II. Cut-boat bridges
- III. Flying bridges
- IV. Lift bridges
- V. Swing bridges
- VI. Transporter bridges
- VII. Traversing bridges.

Each of the above type of bridge will now be briefly described in this chapter.

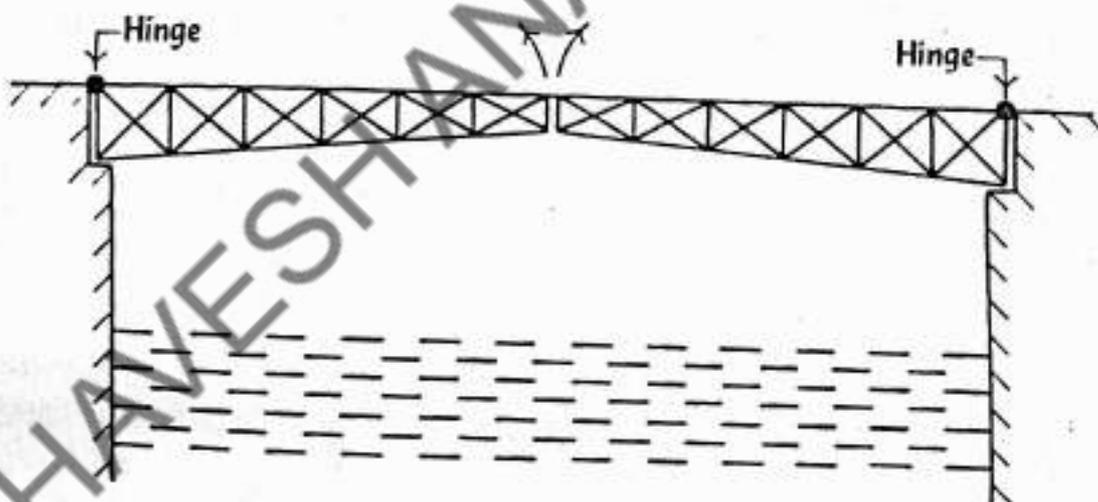
1. Bascule bridges:

In case of a bascule bridge, the entire superstructure is rotated in a vertical plane about a horizontal axis. Suitable rack and pinion arrangement and counter-weights are provided for easy operation of hinge at the bank end of the bascule. An angle of 70° to 80° with the horizontal is formed, when the bridge is in the lifted position.



Single bascule bridge

FIG. 5-1



Double bascule bridge

FIG. 5-2

Depending upon the width of channel, the bascule bridge may either be single or double. Fig. 5-1 shows a single bascule bridge and fig. 5-2 shows a double bascule bridge. It is quite evident that two smaller leaves of the double bascule bridge can be raised faster than a single larger one of the single bascule bridge and in addition, the double bascule bridge will require smaller counter-weights and moving parts. The bascule bridge may either be of deck type or through type.

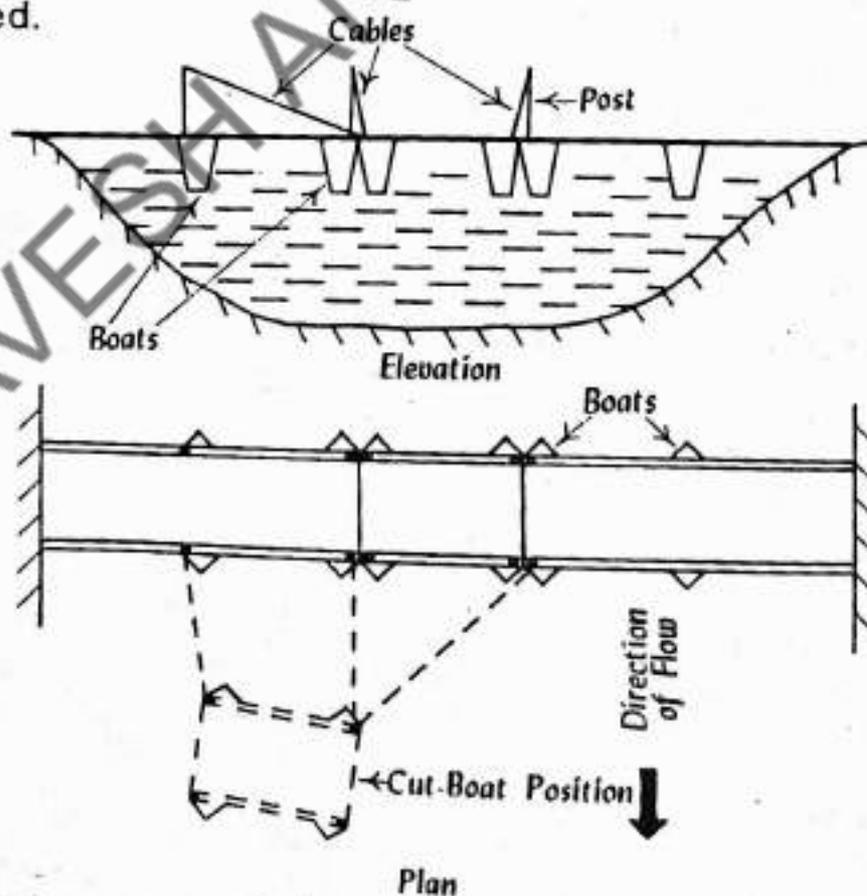
The bascule bridge is generally favoured as it possesses the following *advantages* especially over the swing bridge:

- (1) It can be opened easily and rapidly.
- (2) It is easy to construct another bascule adjacent to the existing one in future, if need arises.
- (3) Its initial cost is low.
- (4) The opening can be adjusted in the sense that it can either be made large to allow large vessels or can be made small to allow small vessels.
- (5) When it is in the lifted position, the entire span of bridge is available. Hence, the vessels get more space for navigation.

The only drawback of this bridge is that its working is seriously disturbed, when the wind is blowing with high velocity.

II. Cut-boat bridges:

The arrangement of cut-boat bridge is provided for boat bridges i.e. when the superstructure of bridge is resting on the boats. It is so arranged that some portion of the entire span of bridge can be moved on the downstream side with the help of cables attached to adjacent portions as shown in fig. 5-3. This small portion is specially designed and constructed.

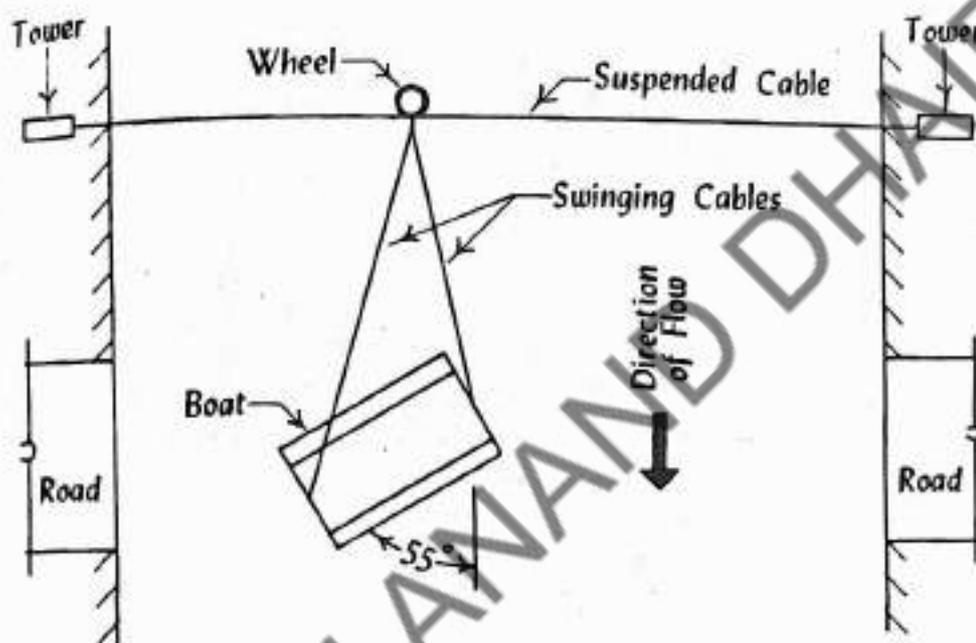


Plan
Cut-boat bridge
FIG. 5-3

The cut-boat bridge is provided when it is necessary to provide some passage for the navigation traffic. When the ships pass out, the movable-span is pulled back and it is placed in its normal position.

III. Flying bridges:

In case of flying bridges, a boat or a raft is attached to a suspended cable by means of the swinging cables. It is so arranged that the boat makes an angle of about 55° with the direction of flow. The suspended cable is stretched across the river and it is kept above the level of the highest flood of the stream.



Plan of a flying bridge
FIG. 5-4

The boat moves from one bank to the other by the pressure exerted by current of flow. When the boat reaches the other end, the direction of swinging cables is changed.

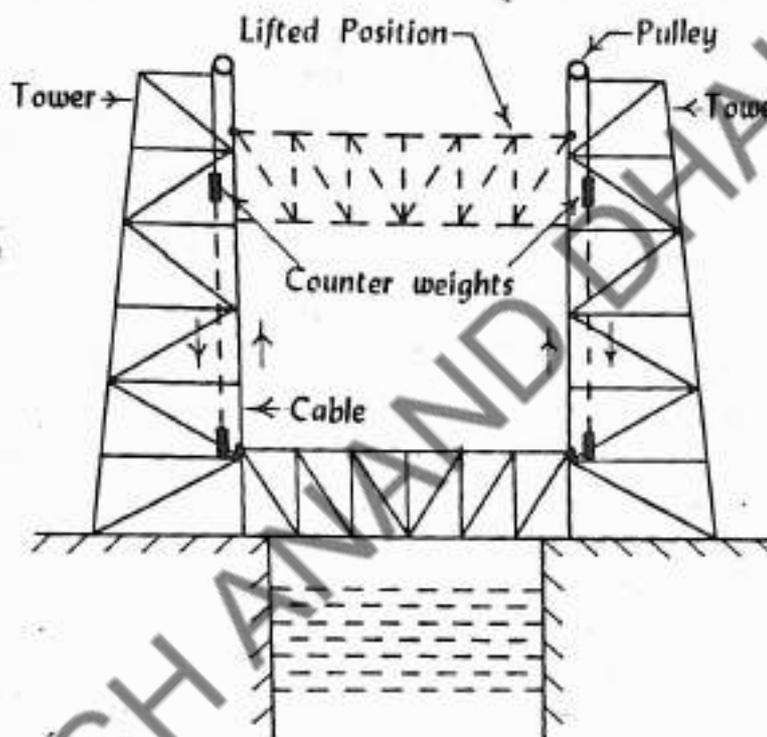
The flying bridges can be used only to carry light passenger traffic. They can be adopted for short spans only and at places where enough materials are not available for the construction of permanent bridge across the stream and the available funds are also too small.

IV. Lift bridges:

In case of lift bridges, the whole span is vertically lifted up by means of suitable arrangement of the pulley and counter-weight as shown in fig. 5-5.

The towers are provided on either side with sheaves or grooves. The rigid trusses of the bridge are moved up and down by the cables which pass over pulleys mounted

at the top of the towers and the pulleys in turn are connected to the counter-weights at the other end. When the truss is lifted up in vertical plane, it allows navigation in the channel. A light over-head truss is generally provided at the top connecting the two towers. Such an arrangement results in better bracing and it permits support to a walkway during maintenance work. The lift bridge compares very favourably with the bascule bridge and is found to be cheap in cost for long spans.



Lift bridge
FIG. 5-5

Following points should be noted:

(1) *Number of towers:* The total number of towers may be two or four i.e. one on either side of bank or two on either side of the bank.

(2) *Construction:* The lift bridges are simple to design and construct. It is also easy to operate them.

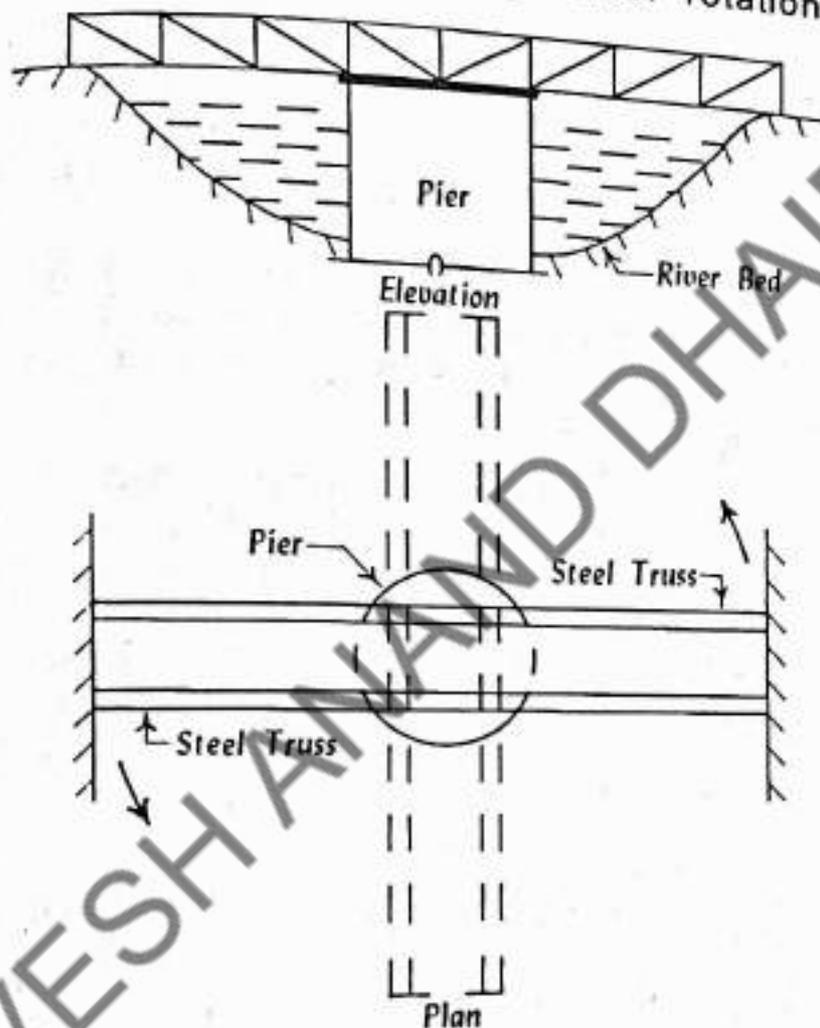
(3) *Overhead trusses:* To give more rigidity to the bridge, the towers may be connected at their tops by the overhead trusses.

(4) *Span:* The span of lift bridge may be equal to the width of stream or river. But if the width of stream or river is more, it may even form the part of total length of the bridge.

(5) *Wind pressure:* The effect of wind pressure on a lift bridge is not appreciable and as such, its working is not seriously disturbed even when the wind is blowing with high velocity.

V. Swing bridges:

In case of swing bridges, a central pier is provided with suitable bearings or rollers. The superstructure consists of a pair of steel trusses and it can be rotated in a horizontal plane about a vertical axis by some suitable equipment. Fig. 5-6 shows plan and elevation of a swing bridge. The dotted lines indicate the position of the bridge after rotation.



Swing bridge
FIG. 5-6

Following points should be noted:

(1) *Flooring*: Depending upon the alignment of road, the flooring of bridge may be placed at the top or bottom boom of the trusses.

(2) *Locking arrangements*: The bridge should be provided with such locking arrangements that it remains parallel to the flow during open position and that it remains in line with road in normal position.

(3) *Position of pier*: It is usually so arranged that the pier divides the length of bridge into two equal spans. But if it is not possible to have equal spans, the shorter span

should be provided with necessary extra weight to counterbalance the excess weight of longer span.

The swing bridge is not favoured at present because of its following *disadvantages*:

(1) *Land traffic*: When the swing span is rotated, there is no protection to the land traffic at the water edge.

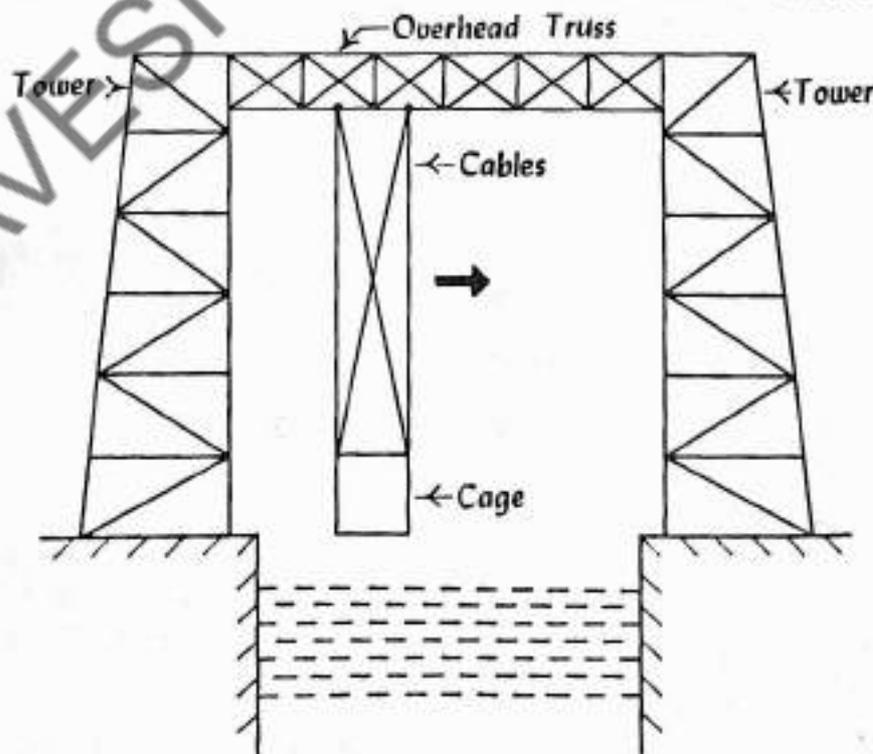
(2) *Navigational capacity*: The bridge divides the waterway into two narrower halves and hence, the navigational capacity of the waterway is reduced.

(3) *Obstruction to the flow of water*: The pier causes obstruction to the flow of water and it deflects the currents of water towards the banks.

(4) *Time of operation*: The bridge has to be swung for ninety degrees even to allow passage to a small vessel. Thus, it requires a long time for each operation.

VI. Transporter bridges:

In case of transporter bridges, a moving cage is suspended from an overhead truss with the help of cable or wire ropes as shown in fig. 5-7. The overhead truss rests on two towers and it contains rails for cage to roll. The cage is loaded with persons or goods and it is then allowed to move from one end to the other end of river. This type of bridge is used within a harbour area to provide an arrangement for shifting of men and materials across a channel.



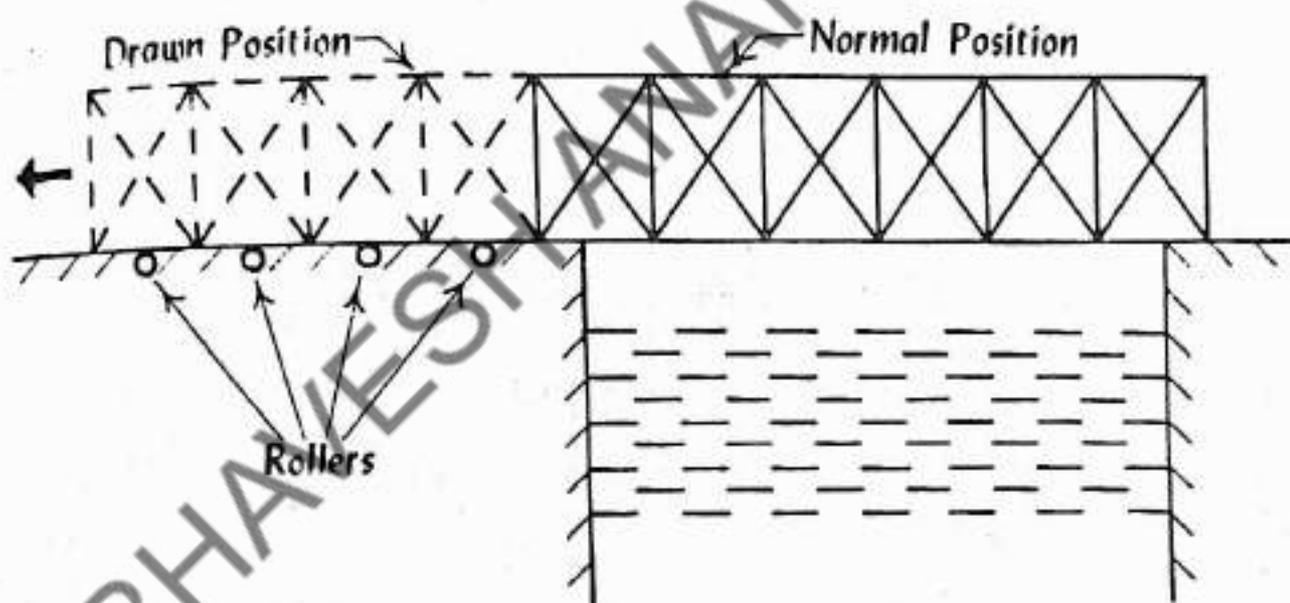
Transporter bridge

FIG. 5-7

The transporter bridge behaves more or less as a ferry than a bridge for the vehicular transport.

VII. Traversing bridges:

In case of traversing bridges, it is so arranged that the whole bridge can fully or partly be rolled forward or backward across the opening as shown in fig. 5-8. The bridge is provided with rollers on the approaches. The traversing bridges are now obsolete.



Traversing bridge

FIG. 5-8

Chapter 7

FLOORING

General:

The top surface of bridge floor is covered up with suitable flooring material. In this chapter, the various flooring materials suitable for bridge floors will be discussed.

Factors affecting the choice of flooring material:

Following factors should be carefully considered while deciding the type of flooring material for the bridge:

- (1) availability of local materials and labour,
- (2) climatic conditions,
- (3) fund available for flooring,
- (4) importance of the bridge,
- (5) intensity of traffic,
- (6) nature of the bridge,
- (7) nature of traffic, and
- (8) use of the bridge.

Requirements of a good flooring material:

Following are the requirements of a good flooring material for a bridge:

- (1) It should be able to absorb the vibrations and impact caused by the traffic.
- (2) It should be capable of being easily drained.
- (3) It should be cheap in construction as well as in maintenance.
- (4) It should be fire-proof.
- (5) It should be non-absorbent, dust-proof and non-slippery during monsoon.
- (6) It should be strong and durable.
- (7) It should grant a sense of safety to the bridge users.
- (8) It should not create noise when traffic passes over it.
- (9) It should not give glare to the traffic.
- (10) It should provide a smooth riding surface for the traffic.

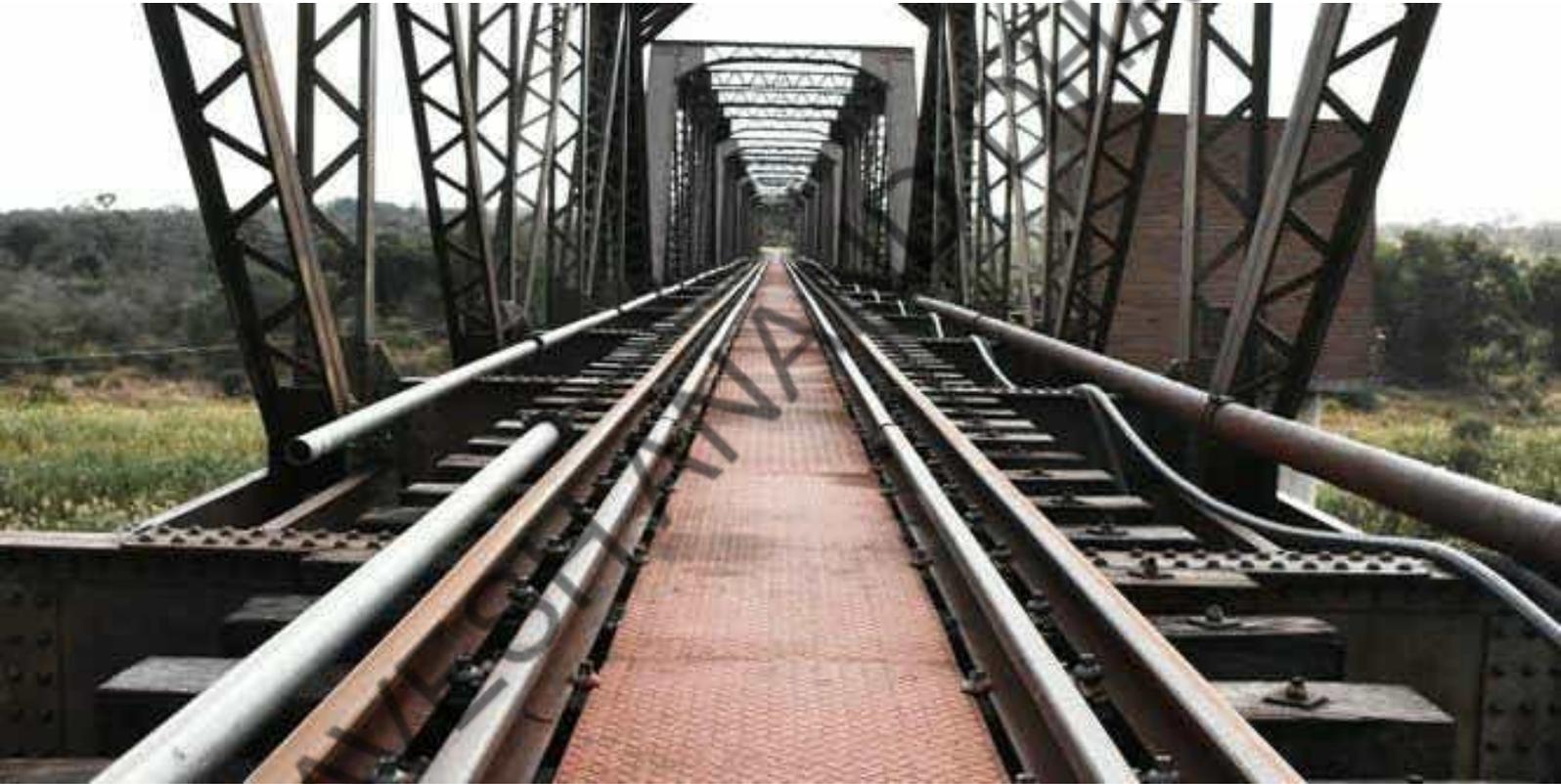
Types of floors:

The bridge floors may broadly be divided into the following two categories:

- (1) Open floors
- (2) Solid floors.

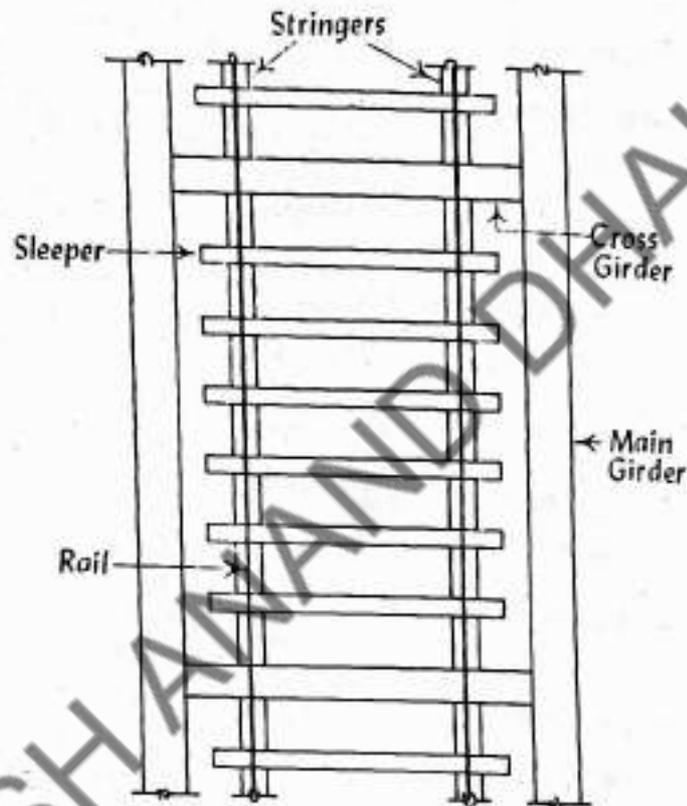






Each of the above type of bridge floor will now be described in brief.

(1) Open floors: In case of open floors, the space between the main girders is covered by the required parts of floor only and the remaining space, as such, is kept open. Hence, no flooring material will be required for such floors and as such, the open floors will not require any drainage provisions.



Open floor
FIG. 7-1

The open floors are adopted for the railway bridges which are situated outside the limits of town or city. Fig. 7-1 shows the plan of a typical open floor for a single track railway bridge. The open floors can be easily inspected and they prove to be economical.

(2) Solid floors: In case of solid floors, the top surface of the floor of highway bridge or railway bridge is covered up by a suitable flooring material.

Flooring materials:

Following are the common flooring materials which are adopted for the solid floors:

- (1) Jack arch
- (2) Mild steel buckle plates
- (3) Mild steel plates

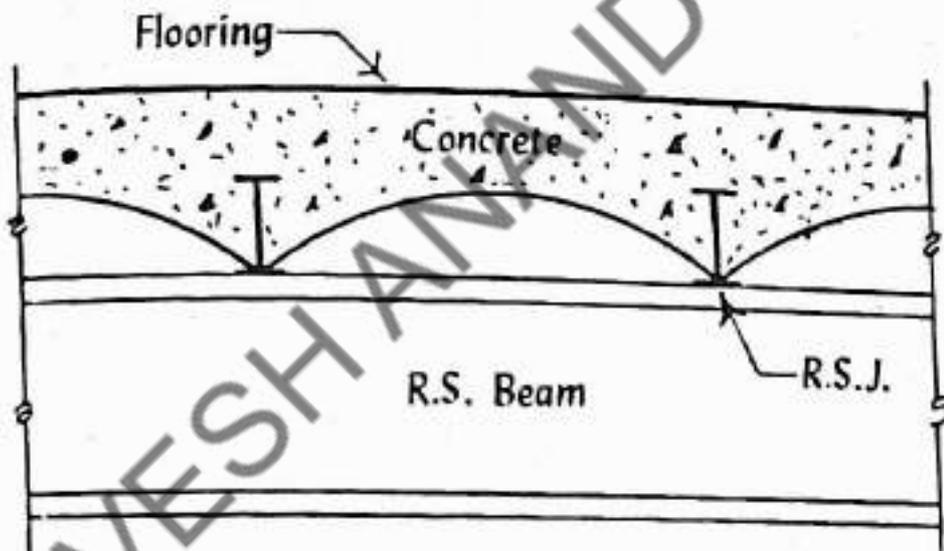
Flooring

129

- (4) Mild steel troughs
- (5) Reinforced cement concrete
- (6) Timber.

Each of the above type of flooring material will now be briefly described.

(1) **Jack arch:** In this type of floor, the cement concrete arches are constructed and these arches rest on the lower flanges of mild steel joists as shown in fig. 7-2. The joists in turn rest on R.S. beam.



Jack arch floor

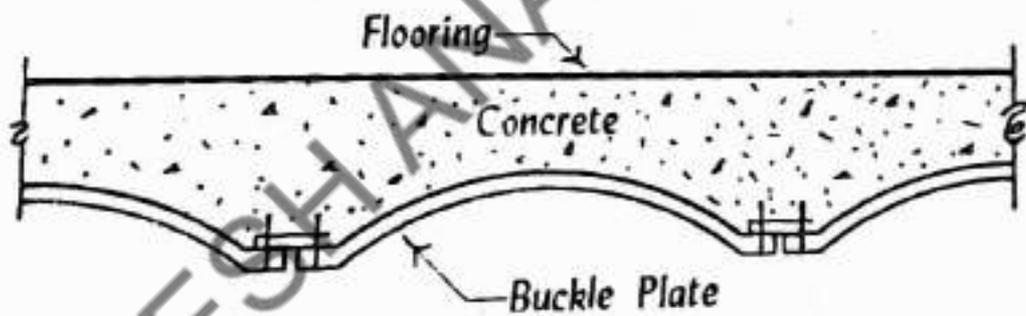
FIG. 7-2

The joists are placed at a distance of about 800 mm to 1200 mm centre to centre. The rise of arch should be 100 mm to 200 mm and the minimum depth of concrete at the crown should be 150 mm. A suitable elastic material is provided at the top of arches to absorb the shocks due to impact.





(2) **Mild steel buckle plates:** The mild steel buckle plates are bent in the form of an arch and they are available in the standard sizes. The thickness of buckle plates varies from 6 mm to 11 mm and the rise is about 60 mm to 90 mm. The space above the buckle plates is filled up by the asphalt or concrete. The minimum depth of filling at the crown should be 75 mm. The buckle plates are connected as shown in fig. 7-3.



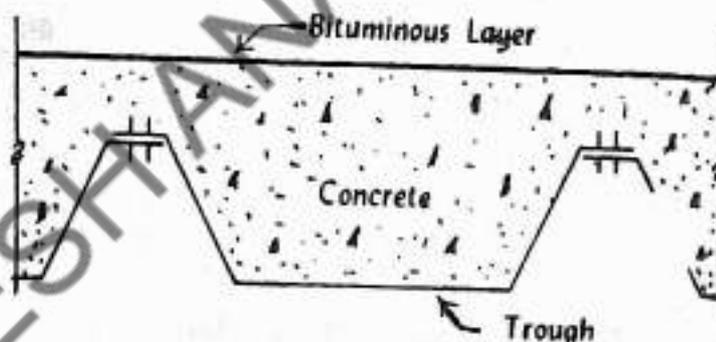
Buckle plate floor
FIG. 7-3

The buckle plates may be fixed either between the main girders or between the cross-girders. If they are fixed between the main girders, the cross-girders and stringers will not be required. If they are fixed between the cross-girders, only the stringers will be eliminated.

The buckle plates flooring is very common for the highway bridges.

(3) **Mild steel plates:** In this case, the flat mild steel plates of thickness about 15 mm, are provided to act as flooring material for the bridge. The steel plates are suitably supported and enough holes are provided to drain off the rain water.

(4) **Mild steel troughs:** A trough is a steel section prepared in a particular shape as shown in fig. 7-4. The trough floor is similar to the buckle plate floor except that the troughs are used in place of the buckle plates. The troughs are usually filled up with concrete with a depth of about 75 mm above the top of trough. A bituminous layer is provided over the concrete.

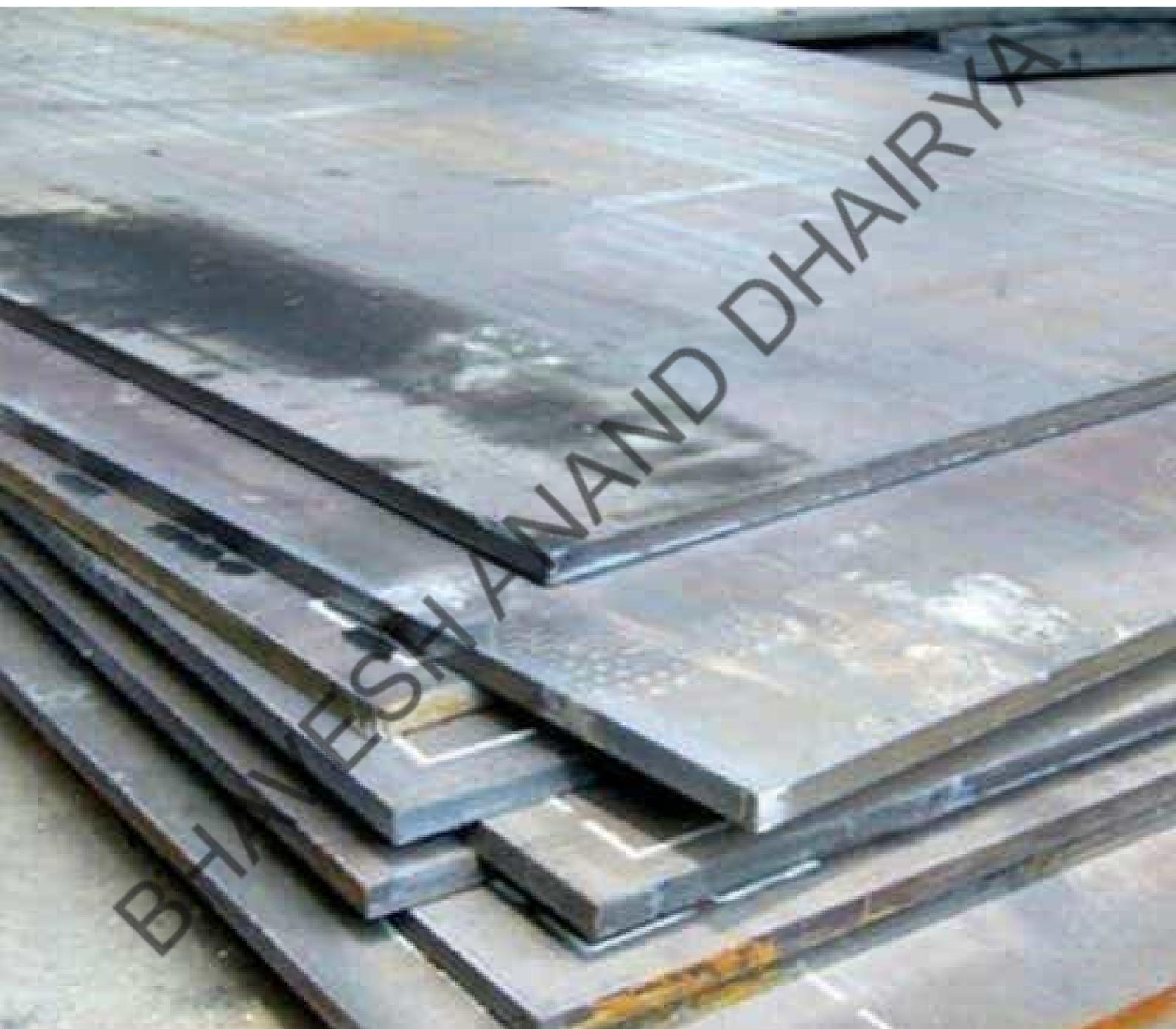


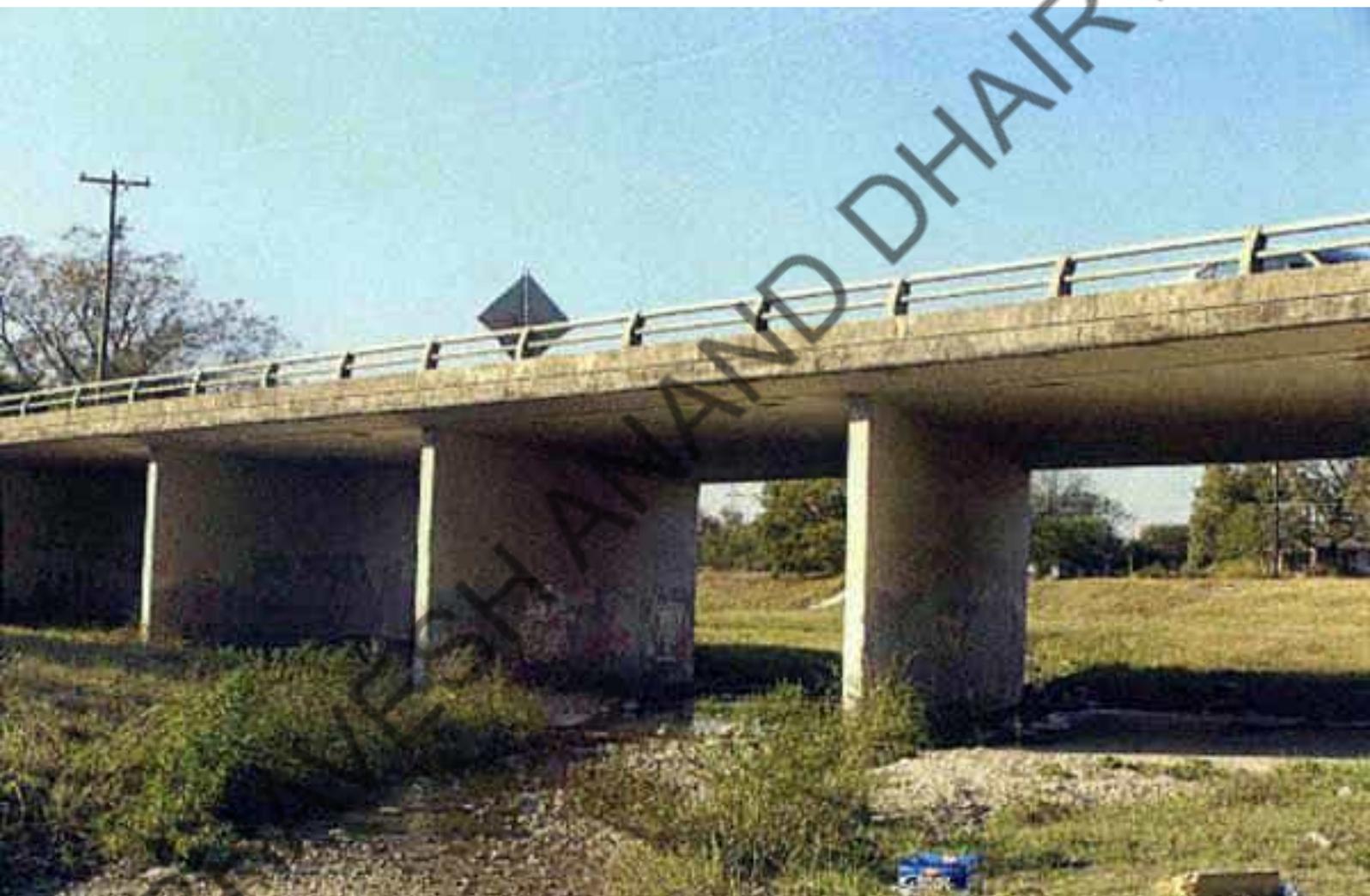
Trough floor

FIG. 7-4

The troughs may be fixed transversely or longitudinally as in case of the buckle plates. In the first case, the troughs are fixed between the main girders and it results in the elimination of cross-girders and stringers. In the second case, the troughs are placed longitudinally across the cross-girders and it results in the elimination of stringers.

The trough flooring is used for road bridges or railway bridges. If it is to be adopted for a road bridge, a wearing coat is provided over the bituminous layer. If it is to be adopted for a railway bridge, the ballast is spread over the bituminous layer. Alternatively, the sleepers may directly be placed over the troughs and the troughs may be filled up with the ballast instead of the concrete.



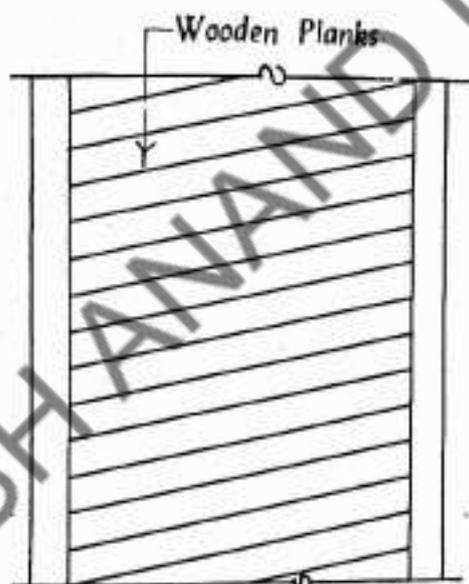


(5) **Reinforced cement concrete:** In case of R.C.C. floor, a slab of suitable thickness is provided with necessary reinforcement. The R.C.C. flooring is not adopted for the railway bridges. But it has become very popular for the highway bridges.

(6) **Timber:** In case of the timber flooring, the wooden planks of suitable thickness are used. However, they are liable to catch fire. The wooden floor is light in the weight as compared to the floors of other materials. The wooden floor is suitable for the foot-overs only to carry the light traffic.

Following points should be noted in connection with the timber flooring:

(i) **Arrangement:** The wooden planks are placed slightly in an inclined position as shown in fig. 7-5.



Timber floor
FIG. 7-5

(ii) **Layers:** The wooden planks may be placed either in single layer or double layer. For single layer, the minimum thickness is 75 mm. For double layer arrangement, the minimum thicknesses of upper and lower layers should respectively be 40 mm and 75 mm.

(iii) **Life:** If wood of superior quality is used and if wooden planks are well maintained, the timber flooring is quite durable and it can have a useful life of 5 to 10 years. However, they are liable to catch fire.

(iv) **Weight:** The timber flooring is light in weight as compared to other flooring materials.



Lecture Material

Prepared by :-

Aayush Singh Bais

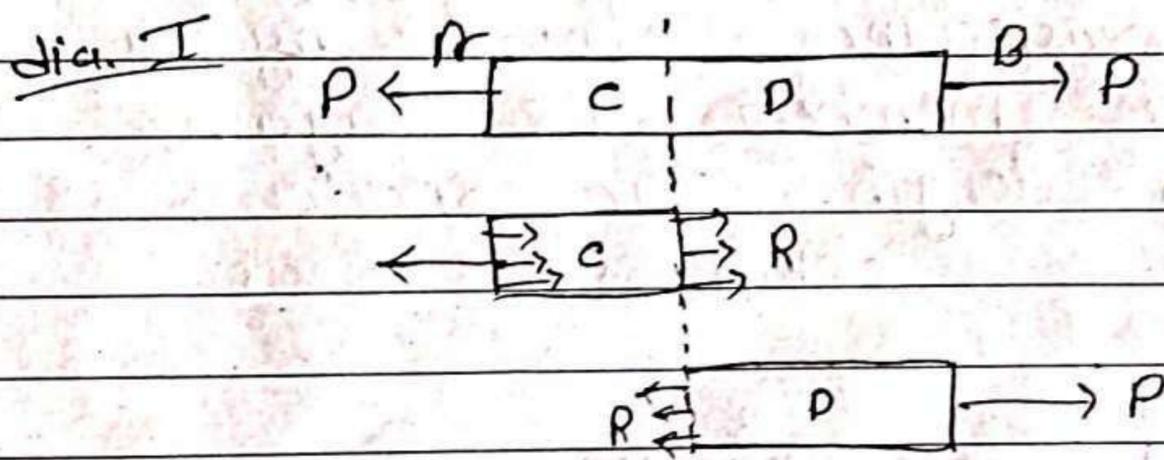
Subject - Strength of Material

Code - 2020 472 (020)

* Stress (σ) (निष्पन्न)

\Rightarrow The external force acting on a body is called load

\Rightarrow The load is applied on the body while stress is induced in the material of the body



intensity of stress = $\frac{R}{A} = \frac{P}{A}$ चूँकि $R=P$
वैयक्तिक
विषय के
विषय
प्रति

$= \frac{\text{force}}{A}$

Stress के 3 types होते हैं

- 1) Tensile
- 2) Compressive
- 3) Shear

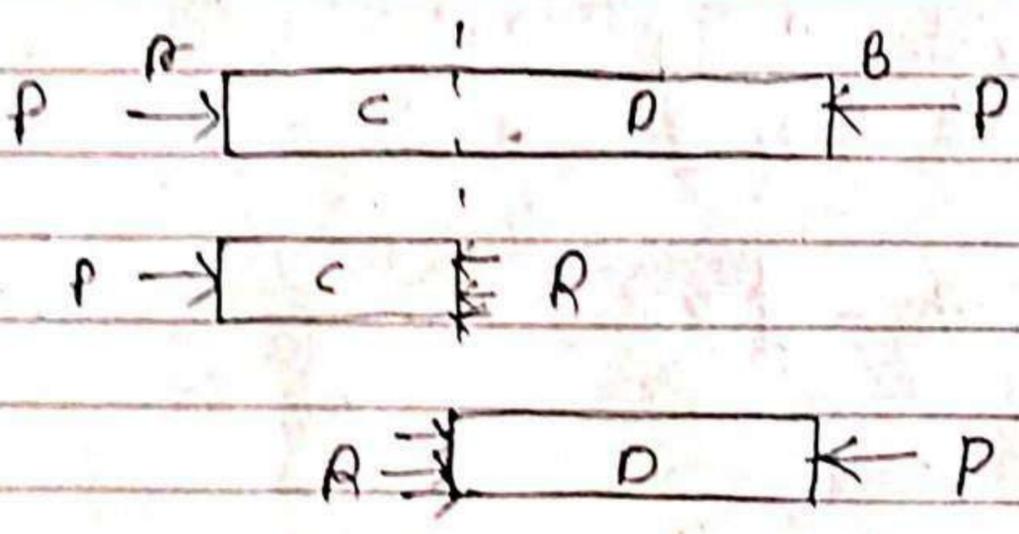
① TENSILE STRESS (σ)

⇒ When the resistance offered by a section of a member is against an increase in length, the section is said to offer a tensile stress.

for example · diagram - I $\sigma = \frac{F}{A}$ m.kg/m²

② COMPRESSIVE STRESS ($-\sigma$)

⇒ When the resistance offered by a section of a member is against a decrease in length, the section is said to offer a compressive stress.

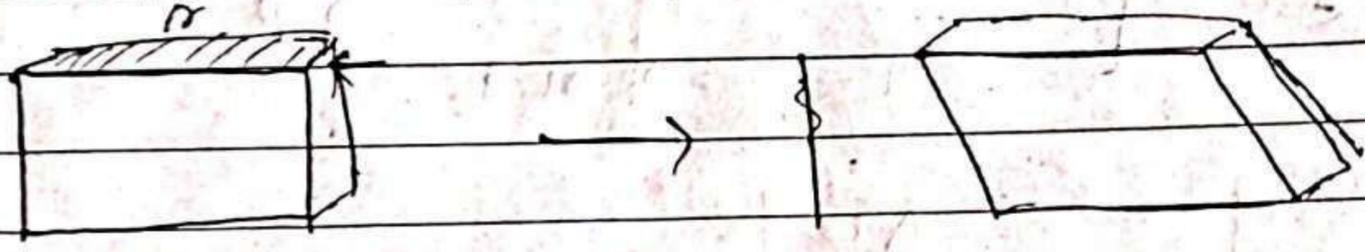


compressive stress = $\frac{R}{A} = \frac{P}{A}$ (-ve)

③ SHEAR STRESS (τ) (τ) (τ)

⇒ It is defined as the ratio of tangential force to the area over which it acts.

force to the cross section area of the surface upon which it acts



$$\text{Stress} = \frac{P \text{ force}}{A \text{ area}}$$

THE UNIT OF STRESS - $\frac{N}{m^2}$; $\frac{N}{mm^2}$; $\frac{K.N}{m^2}$; $\frac{K.N}{mm^2}$

Note

$$\frac{N}{m^2} = \frac{1 \text{ Mega N}}{m^2} = \frac{1 N}{mm^2}$$

$$1 \text{ Mega Pascal} = 1 N/mm^2$$

★ STRAIN (e)

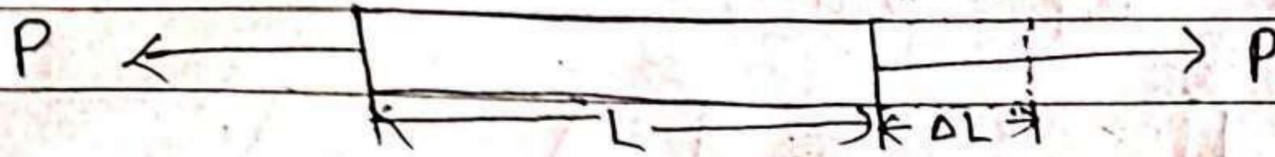
⇒ Any element in a material subjected to stress is said to be in strain

⇒ The strain (e) is defined as change in length upon original length

* i.e. it is a unit less quantity

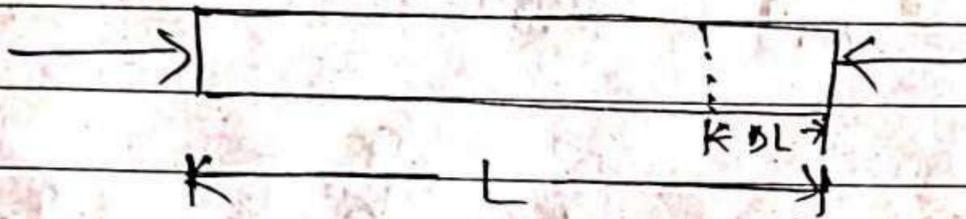
- types of strain -
- ① Tensile
 - ② Compressive
 - ③ shear
 - ④ Volumetric

① TENSILE STRAIN (e)



$$e_t = \frac{\Delta L}{L}$$

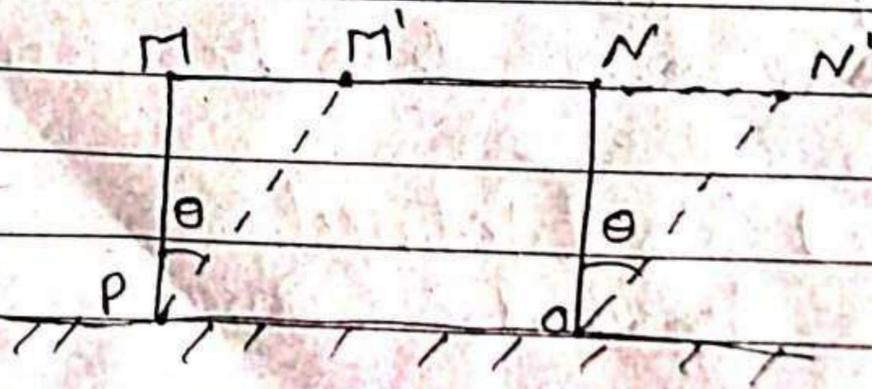
② COMPRESSIVE STRAIN ($-e$)



$$e_c = \frac{\Delta L}{L}$$

③ SHEAR STRAIN (e_s)

⇒ Shear strain is measured by the angle through which the body deforms



$$e_s = \tan \theta = \frac{MN''}{MN}$$

④ VOLUMETRIC STRAIN (e_v)

⇒ It is defined as the ratio between change in volume upon original volume

$$e_v = \frac{\Delta V}{V}$$

* HOOKE'S LAW

⇒ According to "Hooke's Law" within elastic limit stress is directly proportional to the strain

i.e. $\sigma \propto e$

$$\sigma = Ee$$

$$E = \frac{\sigma}{e}$$

$E =$ Young's Modulus / Modulus of Elasticity

* YOUNG'S MODULUS

It is defined as the ratio between tensile stress and tensile strain OR compressive stress and compressive strain.

It is denoted by "E": also known as modulus of elasticity.

$$E = \frac{\sigma}{e}$$

$$E = \frac{\sigma_E}{e_E} = \frac{\sigma_c}{e_c}$$

E = elasticity

* MODULUS OF RIGIDITY

⇒ It is defined as the ratio of shear stress and shear strain

⇒ It is denoted by "C" / "N" / "G"

⇒ It is also known as shear modulus of elasticity.

$$C / N / G = \frac{\tau}{e_s}$$

UNIT - N/mm², N/m²

* BULK MODULUS (K)

⇒ It may be defined as the ratio of Normal stress to volumetric strain

$$K = \frac{\sigma_v}{e_v}$$

UNIT - N/mm² / N/m²

axial load - axis पर लागने वाला force

Page No. 4

Date

Q \Rightarrow A square steel rod $20\text{mm} \times 20\text{mm}$ in section is to carry an axial load (compressive) of 100 kN , calculate the shortening in length of 50mm . Take Young's modulus (E) = $2.14 \times 10^8 \text{ kN/m}^2$

given :-

$$\text{cross sectional area (A)} = 20 \times 20 = 400 \text{ mm}^2$$
$$= \frac{400}{1000 \times 1000} = 0.0004 \text{ m}^2$$

$$(A) = 0.0004 \text{ m}^2$$

$$\text{Length (L)} = 50 \text{ mm} = \frac{50}{1000} = 0.05 \text{ m}$$

$$(L) = 0.05 \text{ m}$$

$$\text{Load (P)} = 100 \text{ kN}$$

$$E = 2.14 \times 10^8 \text{ kN/m}^2$$

$$\text{Stress} = \frac{P}{A} = \frac{100000}{0.0004 \text{ m}^2} = 250000 \text{ kN/m}^2$$
$$= 25 \times 10^4 \text{ kN/m}^2$$

$$\text{Stress} = 25 \times 10^4 \text{ kN/m}^2$$

We know that stress $\sigma = E \times e$

$$\frac{25 \times 10^4 \text{ kN/m}^2}{2.14 \times 10^8 \text{ kN/m}^2} = e$$

$$e = 1.168 \times 10^{-3}$$

change in length $\Delta L = e_c \times L$

$$\Delta L = 1.168 \times 10^{-3} \times 0.05 \text{ m}$$

$$\Delta L = 5.84 \times 10^{-5} \text{ m}$$

$$\Delta L = 0.0584 \text{ mm}$$

Q \Rightarrow A hollow cast iron cylinder 4 m long, 300 mm outer diameter and thickness of 50 mm is subjected to a central load on the top when standing straight. The stress produced is 75,000 KN/m^2 . Assume $\sigma_c (E_c)$ for cast iron is $1.5 \times 10^8 \text{ KN/m}^2$ and find :-

- (1) Magnitude of load?
- (2) Longitudinal strain produced?
- (3) Total decrease in length?

Solve :- given

outer diameter $d_1 = 300 \text{ mm}$

thickness = 50 mm

therefor, inner diameter $d_2 = 300 - 2 \times 50$
 $= 200 \text{ mm}$

Area cross sectional area of hollow cylinder

$$= \frac{\pi}{4} d_1^2 - \frac{\pi}{4} d_2^2$$

$$\text{Area } (A) = \frac{\pi}{4} (300)^2 - \frac{\pi}{4} (100)^2$$

$$= 70685.83 \text{ mm}^2 - 31415.92 \text{ mm}^2$$

$$A = 39269.91 \text{ mm}^2$$

$$A = 0.03927 \text{ m}^2$$

$$\text{Stress } (\sigma) = 75,000 \text{ kN/m}^2$$

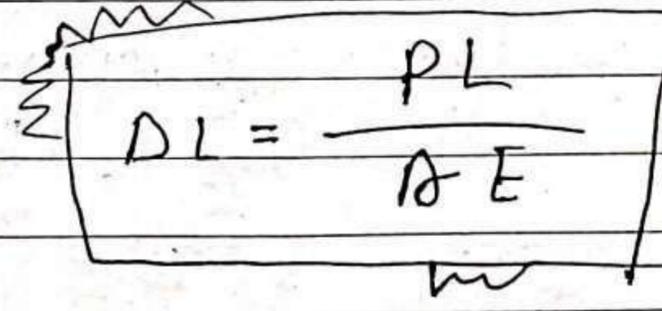
$$E = 1.5 \times 10^8 \text{ kN/m}^2$$

$$L = 4 \text{ m}$$

1.

$$\text{Stress } (\sigma) = \frac{\text{load}}{\text{area}}$$

$$75,000 \text{ kN/m}^2 = \frac{\text{load}}{0.03927 \text{ m}^2}$$



$$\text{load} = 75,000 \times 0.03927$$

$$\boxed{\text{load} = 2945.5 \text{ kN}}$$

2.

$$\text{Stress } (\sigma) = E \times \text{strain } (e)$$

$$\text{strain } (e) = \frac{\sigma}{E} = \frac{75,000 \text{ kN/m}^2}{1.5 \times 10^8 \text{ kN/m}^2}$$

$$\boxed{\text{strain } (e) = 5 \times 10^{-4}}$$

3.

$$e = \frac{\Delta L}{L}$$

$$5 \times 10^{-4} = \frac{\Delta L}{4}$$

$$4 \times 5 \times 10^{-4} = \Delta L$$

$$\Delta L = 2 \times 10^{-3} \text{ m}$$

$$\Delta L = 2 \times 10^{-3} \text{ m}$$

$$\boxed{\Delta L = 2 \text{ mm}}$$

Q.11 \Rightarrow A steel wire 2m long and 3mm in diameter is extended by 0.75mm when a weight (W) is suspended from the wire. If the same weight is suspended from a brass wire, 2.5m long and 2mm in diameter, it is elongated by 4.64mm. Determine modulus of elasticity of brass if that of steel is $2 \times 10^5 \text{ N/mm}^2$

Solve:- given:- for steel.

(L) length of steel wire = $2 \text{ m} = 2000 \text{ mm}$

(ϕ) dia. of steel wire = 3 mm

$\Delta L_s = 0.75 \text{ mm}$

$$r_s = \frac{\pi}{4} (2000)^2 = 3141592.654$$

7.0685

$E = 2 \times 10^5 \text{ N/mm}^2$

for Brass

$L_B = 2.5 \text{ m} = 2500 \text{ mm}$

Dia_B = 2 mm

$\Delta L_B = 4.64 \text{ mm}$

$$r_B = \frac{\pi}{4} (2500)^2 = 4908738.54$$

3.1415

$$\Delta L_s = \frac{W L_s}{r_s E_s}$$

$$\Delta L_B = \frac{W L_B}{r_B E_B}$$

$$k_B = \frac{\Delta L_S \times A_S \times E_S}{L_S}$$

$$k_B = \frac{\Delta L_B \times A_B \times E_B}{L_B}$$

$$\frac{\Delta L_S \times A_S \times E_S}{L_S} = \frac{\Delta L_B \times A_B \times E_B}{L_B}$$

$$\frac{7.0685 \times 0.75 \times 3141592.654 \times 2 \times 10^5}{2000} = \frac{4.64 \times 3.1415 \times E_B}{2500}$$

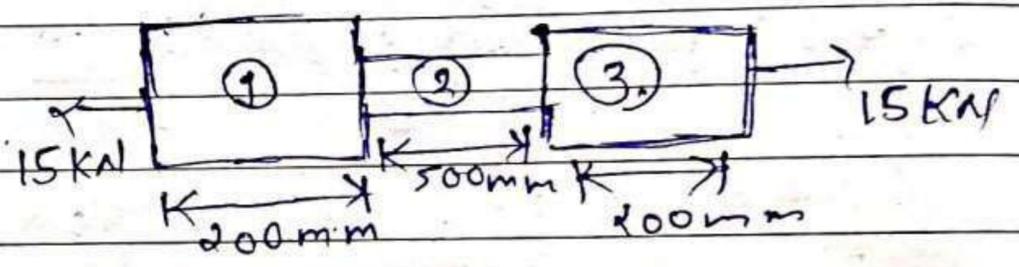
$$\frac{530.1325 \times 2500}{4.64 \times 3.1415} = E_B$$

$$E_B = 90922.9441 \text{ N/mm}^2$$

$$E_B = 0.90 \times 10^5 \text{ N/mm}^2$$

Q \Rightarrow A steel bar is 900mm long, its 2 ends are 40mm and 30mm in diameter and length of each rod is 200mm. The middle portion of the bar is 15mm in diameter and 500mm long. If the bar is subjected to an axial tensile load of 15 kN, find its total extension take $E = 200 \text{ GN/m}^2$

Solve :-



Given -

$$L_1 = 200 \text{ mm} = 0.2 \text{ m}$$

$$D_1 = 40 \text{ mm} = 0.04 \text{ m}$$

$$L_2 = 500 \text{ mm} = 0.5 \text{ m}$$

$$D_2 = 15 \text{ mm} = 0.015 \text{ m}$$

$$L_3 = 200 \text{ mm} = 0.2 \text{ m}$$

$$D_3 = 30 \text{ mm} = 0.03 \text{ m}$$

Their area

$$\text{Area } (A_1) = \frac{\pi}{4} (d_1)^2 = \frac{\pi}{4} (0.04)^2$$

$$A_1 = 1.256 \times 10^{-3} \text{ m}^2$$

$$A_2 = \frac{\pi}{4} (0.015)^2 = 1.767 \times 10^{-4} \text{ m}^2$$

$$A_3 = \frac{\pi}{4} (0.03)^2 = 7.068 \times 10^{-4} \text{ m}^2$$

$$\Delta L = \Delta L_1 + \Delta L_2 + \Delta L_3$$

$$\Delta L = \frac{PL_1}{A_1 E} + \frac{PL_2}{A_2 E} + \frac{PL_3}{A_3 E}$$

~~1.42 x 10⁻⁴~~

$$2.4538 \times 10^{-4}$$

$$\Delta L = \frac{P}{E} \left[\frac{L_1}{A_1} + \frac{L_2}{A_2} + \frac{L_3}{A_3} \right]$$

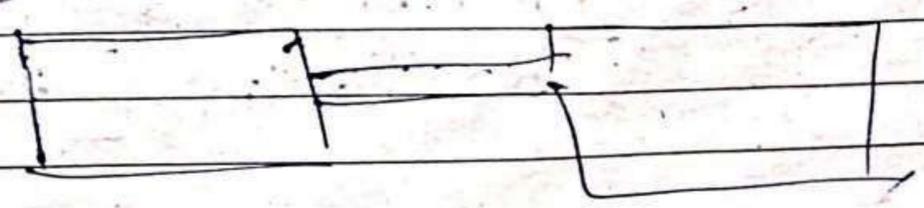
$$\Delta L = \frac{15}{200 \times 10^6} \left[\frac{0.2}{1.256 \times 10^3} + \frac{0.5}{1.767 \times 10^4} + \frac{0.2}{7.068 \times 10^{-4}} \right]$$

$$\Delta L = \frac{15}{200 \times 10^6 \times 10^4} \left[\frac{0.2}{1.256} + \frac{0.5}{1.767} + \frac{0.2}{7.06} \right]$$

$$\Delta L = 2.4538 \times 10^{-4} \text{ m}$$

$$\Delta L = 0.2453 \text{ mm}$$

Q => A bar 0.3 m long is 50 mm square in section for 120 mm of its length, 25 mm diameter for 80 mm and 40 mm diameter for the remaining length. If a tensile force of 100 kN is applied to the bar, calculate the maximum and the minimum stress produced in it, and the total elongation. Take (E) = 200 GN/m²



Given :-

$$L_1 = 120 \text{ mm} = 0.12 \text{ m}$$

$$L_2 = 80 \text{ mm} = 0.08 \text{ m}$$

$$L_3 = 100 \text{ mm} = 0.1 \text{ m}$$

$$D_1 = 50 \times 50 \text{ mm} = 0.05 \text{ m} \times 0.05 \text{ m}$$

$$D_2 = 25 \text{ mm} = 0.025 \text{ m}$$

$$D_3 = 40 \text{ mm} = 0.04 \text{ m}$$

$$\text{Area}, A_1 = 0.05 \times 0.05 = 2.5 \times 10^{-3} \text{ m}^2$$

$$A_2 = \frac{\pi}{4} (D_2)^2 = \frac{\pi}{4} (25)^2$$

$$A_2 = 4.908 \times 10^{-4} \text{ m}^2$$

$$A_3 = \frac{\pi}{4} (D_3)^2 = \frac{\pi}{4} (40)^2$$

$$A_3 = 1.256 \times 10^{-3} \text{ m}^2$$

$$\Delta L = \Delta L_1 + \Delta L_2 + \Delta L_3$$

$$\Delta L = \frac{PL_1}{A_1 E} + \frac{PL_2}{A_2 E} + \frac{PL_3}{A_3 E}$$

$$\Delta L = \frac{P}{E} \left[\frac{L_1}{A_1} + \frac{L_2}{A_2} + \frac{L_3}{A_3} \right]$$

$$\Delta L = \frac{100 \text{ kN}}{200 \times 10^6 \text{ kN/m}^2} \left[\frac{0.12}{2.5 \times 10^{-3}} + \frac{0.08}{4.908 \times 10^{-4}} + \frac{0.1}{1.256 \times 10^{-3}} \right]$$

$$\Delta L = \frac{100}{200 \times 10^6 \times 10^{-4}} \left[\frac{0.12}{25.0 \times 10^{-3}} + \frac{0.08}{4.90} + \frac{0.1}{12.5} \right]$$

$$\Delta L = 1.4563 \times 10^{-4} \text{ m}$$

$$\Delta L = 0.1456 \text{ mm}$$

0.404×10^3

$$\text{Stress } \sigma_1 = \frac{P}{A_1} = \frac{100 \text{ kN}}{2.5 \times 10^{-3} \text{ m}^2}$$

$$\sigma_1 = 40000 \text{ MN/m}^2 \text{ kN/m}^2$$

$$\sigma_1 = 0.40000 \times 10^5 \text{ kN/m}^2$$

$$\sigma_1 = 40 \text{ MN/m}^2$$

10^6

$$\text{Stress } \sigma_2 = \frac{P}{A_2} = \frac{100}{4.908 \times 10^{-4}}$$

$$\sigma_1 = 203748.9813 \text{ kN/m}^2$$

$$\sigma_2 = 0.204 \times 10^6 \text{ kN/m}^2 = 204 \text{ MN/m}^2$$

$$\text{Stress } \sigma_3 = \frac{P}{A_3} = \frac{100}{1.456 \times 10^{-3}}$$

$$\sigma_3 = 709617.883 \text{ kN/m}^2$$

$$\sigma_3 = 0.79 \times 10^5 \text{ kN/m}^2$$

$$\sigma_3 =$$

Q \Rightarrow A brass Rod of ~~30~~³⁰ mm diameter has a length of 180 mm, middle rod has diameter of 20 mm and 260 mm in length and last rod 32.5 mm in diameter 160 mm in length is subjected to a pull of 40 kN. Find the total extension if $E = 100.45 \text{ GN/m}^2$

Given :-

$$L_1 = 180 \text{ mm} = 0.18 \text{ m}$$

$$L_2 = \cancel{20} \cancel{32.5} \text{ mm} = 0.0325 \text{ m}$$

$$L_3 = 20 \text{ mm} = 0.02 \text{ m}$$

$$L_4 = 260 \text{ mm} = 0.26 \text{ m}$$

$$L_5 = 160 \text{ mm} = 0.16 \text{ m}$$

$$D_1 = 30 \text{ mm} = 0.03 \text{ m}$$

$$D_2 = 20 \text{ mm} = 0.02 \text{ m}$$

$$D_3 = 32.5 \text{ mm} = 0.0325 \text{ m}$$

$$A_1 = \frac{\pi}{4} (D_1)^2 = \frac{\pi}{4} (0.03)^2$$

$$A_1 = 7.068 \times 10^{-4} \text{ m}^2$$

$$A_2 = \frac{\pi}{4} (D_2)^2 = \frac{\pi}{4} (0.02)^2$$

$$A_2 = 3.141 \times 10^{-4} \text{ m}^2$$

$$A_3 = \frac{\pi}{4} (0.0325)^2 = 8.495 \times 10^{-4} \text{ m}^2$$

0.176

$$\Delta L = \Delta L_1 + \Delta L_2 + \Delta L_3$$

$$\Delta L = \frac{P}{E} \left[\frac{L_1}{A_1} + \frac{L_2}{A_2} + \frac{L_3}{A_3} \right]$$

$$1.4 \times 10^{-4} = \frac{87.5}{200 \times 10^6} \left[\frac{0.06}{3.6 \times 10^{-3}} + \frac{L_2}{6.45 \times 10^{-4}} + \frac{0.06}{3.6 \times 10^{-3}} \right]$$

$$1.4 \times 10^{-4} = \frac{87.5}{200 \times 10^6 \times 10^{-3}} \left[\frac{0.06}{3.6} + \frac{L_2}{0.645} + \frac{0.06}{3.6} \right]$$

$$1.4 \times 10^{-4} = 4.375 \times 10^{-4} \left[0.033 + \frac{L_2}{0.645} \right]$$

$$\frac{1.4 \times 10^{-4}}{4.375 \times 10^{-4}} = 0.033 + \frac{L_2}{0.645}$$

$$0.32 - 0.33 = \frac{L_2}{0.645}$$

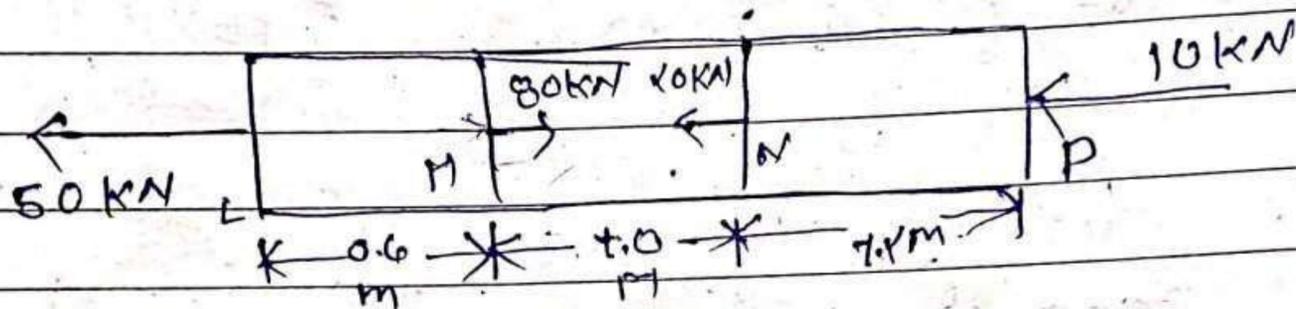
$$L_2 =$$

0.179

$$0.3296 = 0.033 + \frac{L_2}{0.645}$$

[PRINCIPLE OF SUPERPOSITION]

Q \Rightarrow A brass bar having cross sectional area 1000 mm^2 is subjected to axial forces as shown in fig. find the total elongation of the bar, modulus of elasticity of bar (E) = 200 GN/m^2



Given

$$\text{Area } (A) = 1000 \text{ mm}^2 = 10^{-3} \text{ m}^2$$

$$(E) = 100 \text{ GN/m}^2 = 100 \times 10^6 \text{ kN/m}^2$$

$$L_1 = 0.6 \text{ m}$$

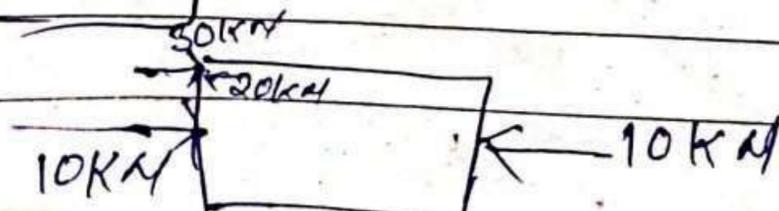
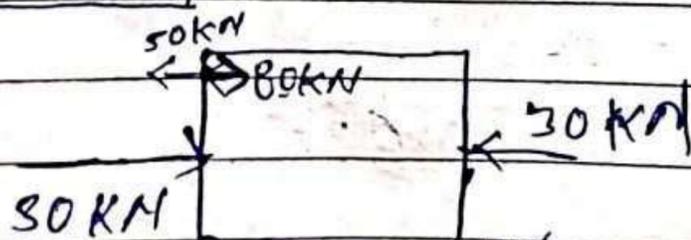
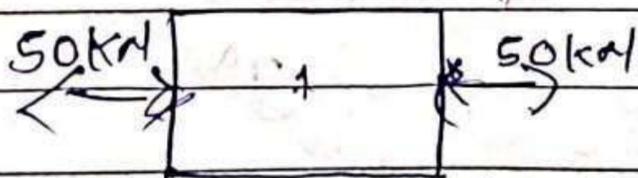
$$L_2 = 1.0 \text{ m}$$

$$L_3 = 1.2 \text{ m}$$

$$P_1 = 50 \text{ kN}$$

$$P_2 = 30 \text{ kN}$$

$$P_3 = 10 \text{ kN}$$



$$\Delta L = \Delta L_1 - \Delta L_2 - \Delta L_3$$

$$\Delta L = \frac{P_1 L_1}{AE} - \frac{P_2 L_2}{AE} - \frac{P_3 L_3}{AE}$$

$$\Delta L = \frac{1}{AE} [P_1 L_1 - P_2 L_2 - P_3 L_3]$$

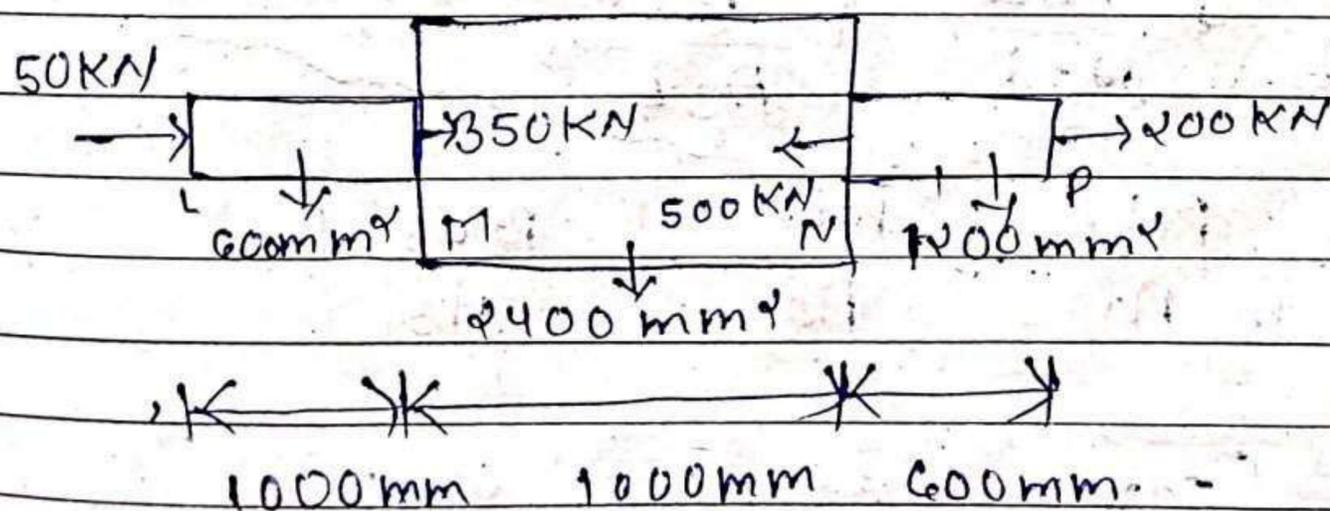
$$\Delta L = \frac{1}{10^{-3} \times 100 \times 10^6} [50 \times 0.6 - 30 \times 1.0 - 10 \times 1.2]$$

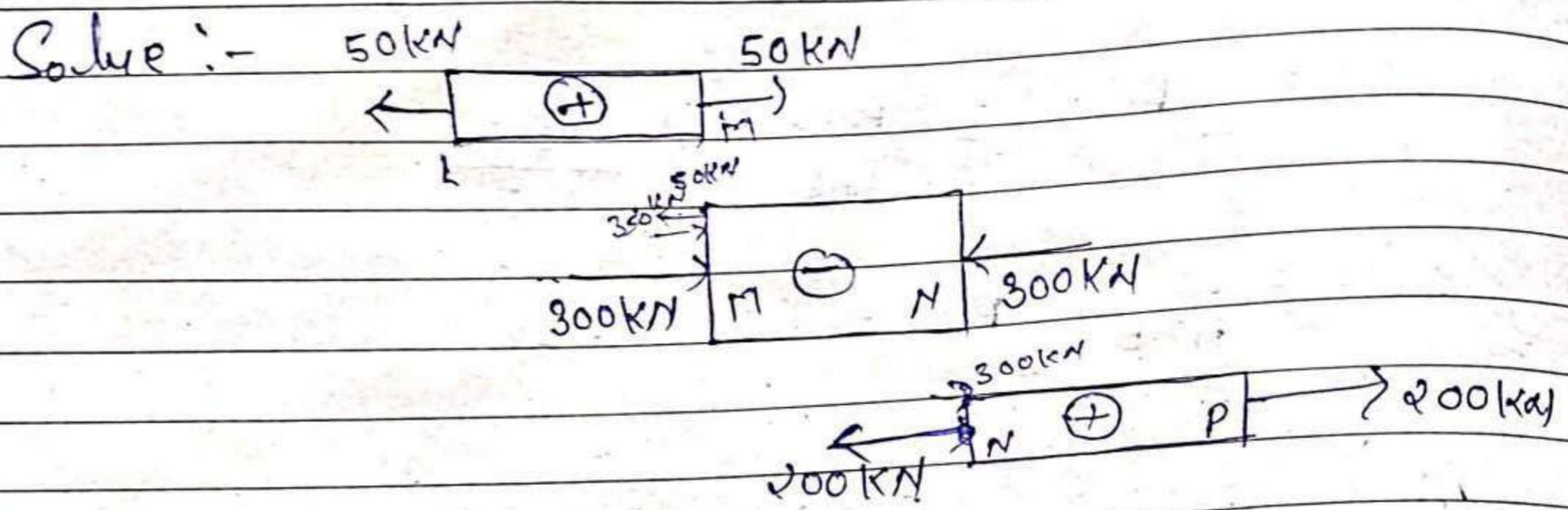
$$\Delta L = \frac{1}{100 \times 10^3} [30 - 30 - 12]$$

$$\Delta L = -1.2 \times 10^{-4} \text{ m}$$

$$\Delta L = -0.12 \text{ mm} \quad \underline{\text{Ans}}$$

Q \Rightarrow A member LMNP is subjected to a point load as shown in figure calculate the total elongation take $[E] = 200 \times 10^6 \text{ N/m}^2$





Given :-

$(E) = 210 \text{ GN/m}^2 = 210 \times 10^6 \text{ KN/m}^2$
 $L_1 = 1000 \text{ mm} = 1 \text{ m}$, $A_1 = 600 \text{ mm}^2 = 6 \times 10^{-4} \text{ m}^2$
 $L_2 = 1000 \text{ mm} = 1 \text{ m}$, $A_2 = 2400 \text{ mm}^2 = 2.4 \times 10^{-3} \text{ m}^2$
 $L_3 = 600 \text{ mm} = 0.6 \text{ m}$, $A_3 = 1400 \text{ mm}^2 = 1.4 \times 10^{-3} \text{ m}^2$

$P_1 = 50 \text{ KN}$, $P_2 = 300 \text{ KN}$, $P_3 = 200 \text{ KN}$

$\Delta L = \Delta L_1 - \Delta L_2 + \Delta L_3$

$$\Delta L = \frac{P_1 L_1}{A_1 E} - \frac{P_2 L_2}{A_2 E} + \frac{P_3 L_3}{A_3 E}$$

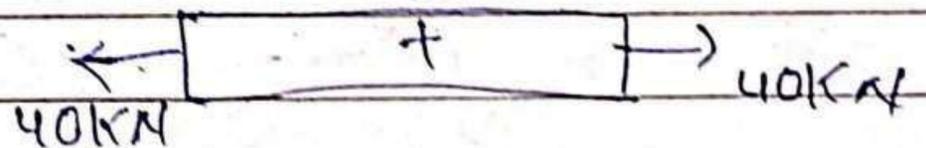
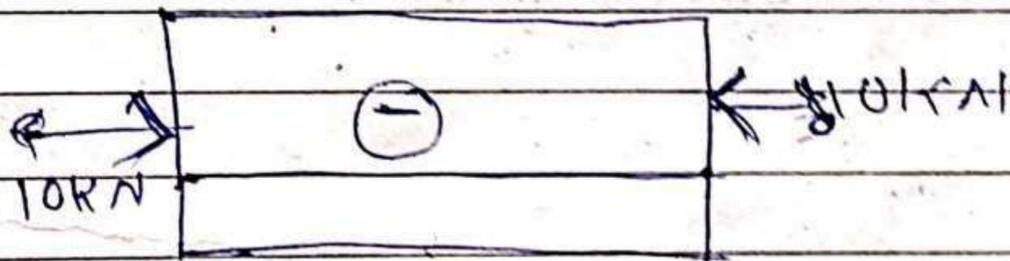
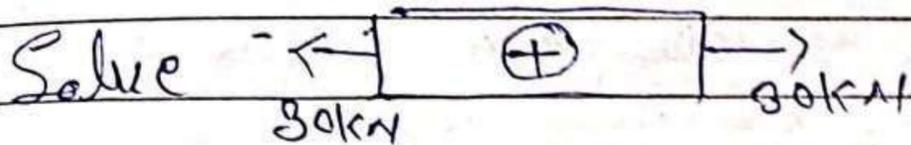
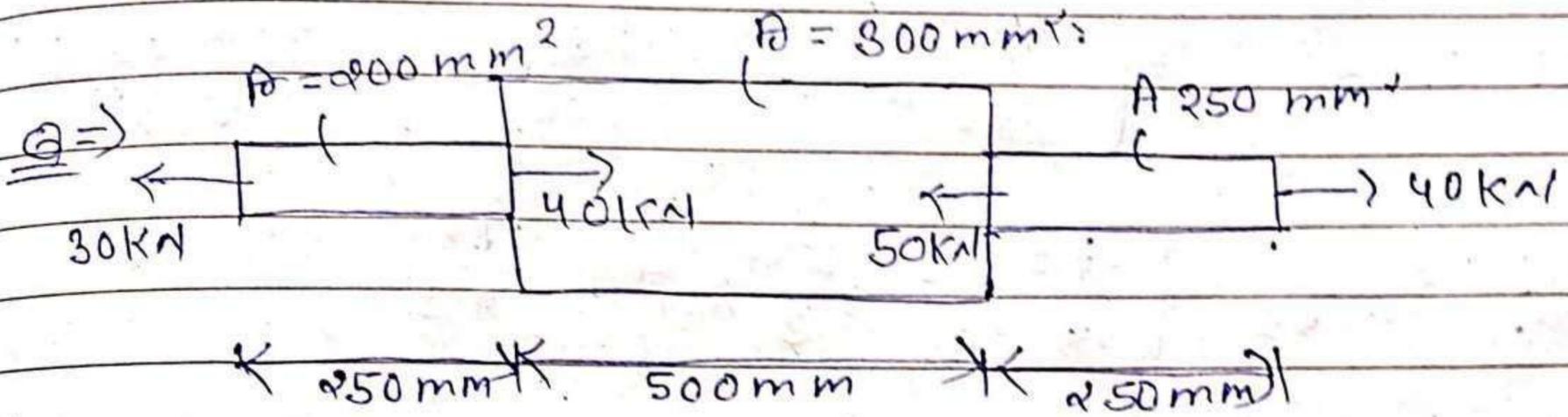
$$\Delta L = \frac{1}{E} \left[\frac{P_1 L_1}{A_1} - \frac{P_2 L_2}{A_2} + \frac{P_3 L_3}{A_3} \right]$$

$$\Delta L = \frac{1}{210 \times 10^6} \left[\frac{50 \times 1}{6 \times 10^{-4}} - \frac{300 \times 1}{2.4 \times 10^{-3}} + \frac{200 \times 0.6}{1.4 \times 10^{-3}} \right]$$

$$\Delta L = \frac{1}{210 \times 10^6} \left[\overset{83333.33}{8.33 \times 10^7} - 175000 + 10 \times 10^4 \right]$$

$$\Delta L = 0.3967 \text{ m} \quad 2.777 \times 10^{-4} \text{ m}$$

$$\Delta L = 0.277 \text{ mm} \quad \text{Ans.}$$



given :- $P_1 = 30 \text{ kN}$ $A_1 = 200 \text{ mm}^2 =$
 $P_2 = 10 \text{ kN}$ $A_2 = 300 \text{ mm}^2$
 $P_3 = 40 \text{ kN}$ $A_3 = 250 \text{ mm}^2$

$E = 2 \times 10^5 \text{ N/mm}^2$ $L_1 = 250 \text{ mm}$
 $= 200 \text{ kN/mm}^2$ $L_2 = 500 \text{ mm}$
 $L_3 = 250 \text{ mm}$

$$\Delta L = \Delta L_1 - \Delta L_2 + \Delta L_3$$

$$\Delta L = \frac{P_1 L_1}{A_1 E} - \frac{P_2 L_2}{A_2 E} + \frac{P_3 L_3}{A_3 E}$$

$$\Delta L = \frac{1}{E} \left[\frac{P_1 L_1}{A_1} - \frac{P_2 L_2}{A_2} + \frac{P_3 L_3}{A_3} \right]$$

$$\Delta L = \frac{1}{200} \left[\frac{30 \times 250}{200} - \frac{10 \times 500}{300} + \frac{40 \times 250}{250} \right]$$

$$\Delta L = \frac{1}{200} \left[\frac{75}{2} - \frac{5000}{3} + \frac{1000}{25} \right]$$

$$\Delta L = 5 \times 10^{-3} [37.5 - 16.666 + 40]$$

$$\Delta L = 0.30417 \text{ mm}$$

Q for a given material young's modulus is ~~100~~ 110 GN/m² and shear modulus is 44 GN/m² find the bulk modulus and lateral contraction of a round bar 37.5mm diameter and 2.4m length when stretched 2.5mm.

Given :-
 $E = 110 \text{ GN/m}^2$
 $C.N.G = 44 \text{ GN/m}^2$
 $K = ?$
 $\Delta d = ?$
 $d = 37.5 \text{ mm} = 0.0375 \text{ m}$
 $L = 2.4 \text{ m}$
 $\Delta L = 2.5 \text{ mm} = 2.5 \times 10^{-3} \text{ m}$

Ans $E = \frac{9KC}{3K+C}$

$$110 = \frac{9 \times \overset{K}{110} \times 44}{3 \times 110 + 44}$$

$$110 = \frac{9K \times 44}{3K + 44}$$

$$K = \frac{36.95}{0.1799} \text{ GN/m}^2$$

$$E = 2C \left(1 + \frac{1}{m} \right)$$

$$110 = 84 \left(1 + \frac{1}{m} \right)$$

$$\frac{110}{84} = 1 + \frac{1}{m}$$

$$1.309 - 1 = \frac{1}{m}$$

$$\frac{1}{m} = 0.309$$

$$\frac{1}{m} = \frac{\frac{\Delta b d}{B d}}{\frac{\Delta L}{L}}$$

$$0.309 = \frac{\frac{\Delta b}{0.0375}}{\frac{2.4}{2.5 \times 10^{-3}}}$$

$$0.309 \times \frac{2.5 \times 10^{-3}}{2.4} = \frac{\Delta b}{0.0375}$$

$$3.21875 \times 10^{-4} = \frac{\Delta b}{0.0375}$$

$$\Delta b = 1.2070 \times 10^{-5} \text{ m}$$

$$\Delta d = 0.0120 \text{ mm}$$

Lecture Notes

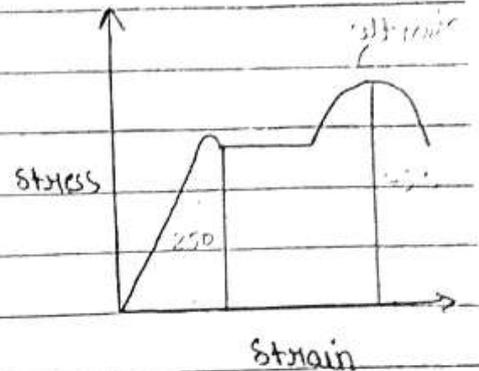
Name - Leana Gardner.

Subject - SDD-II

Course code - 2020672(020)

Steel

- IS 800 : 2007 \rightarrow LSM
- steel table



Unit - 01 - Properties of structural steel

① Properties \Rightarrow

- (1) Unit mass of steel = 7850 kg/m^3
- (2) Modulus of elasticity $E = 2 \times 10^5 \text{ N/mm}^2$
- (3) Poisson's ratio $\mu = 0.3$
- (4) Modulus of Rigidity $G = 0.769 \times 10^5 \text{ N/mm}^2$
- (5) Yield strength (f_y) :- For MS, $f_y \approx 250 \text{ N/mm}^2$
(Approx)
 $\approx 240 \text{ N/mm}^2$

(6) Ultimate strength of steel (f_u) :-

* f_{250} / f_{410} - MS

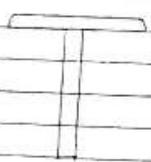
* (Fe-410) - MS, For MS, $f_u = 410 \text{ N/mm}^2$

(7) Toughness :- Ability to absorb energy / impact.

(8) Hardness :- Ability to resist abrasion.
(Wear / tear)

(4) Rolled steel T-section

- (a) Indian Standard Normal T-section (ISNT)
- (b) Indian Standard wide T-section (ISWT)
- (c) Indian Standard Light T-section (ISLT)



- (5) Rolled steel bar
- (6) Indian standard Round bar
- (7) Indian Standard Square bar
- (8) Rolled steel plate
- (9) Rolled steel sheet
- (10) Mild steel flat

WAM (Working stress method) or Elastic Method.



- Linear method
- Economical
- Easy

LSM (Limit State method)



- Non-linear method
- uneconomical
- Tough

Limit state of strength (IS-900:2007, 5.2.2.1)

The limit states of strength are those associated with failure (or imminent failure), under the action of probable & most unfavourable combination of loads on the structure using the appropriate partial safety factors, which may endanger the safety of life and property. The limit state of strength includes:

- (a) Loss of equilibrium of the structure as a whole or any of its parts or components
- (b) Loss of stability of the structure (including the effect of sway where appropriate & overturning) or any of its parts including supports and foundations
- (c) Failure by excessive deformation, rupture of the structure or any of its parts or components
- (d) Fracture due to fatigue.
- (e) Brittle fracture

Limit state of serviceability (IS-900:2007, 5.2.2.2)

The limit state of serviceability include:

- (a) Deformation and deflections, which may adversely affect the appearance or effective use of the structure or may cause improper functioning of equipment or services or may cause damages to finishes and non-structural members.
- (b) Vibration in the structure or any of its components causing discomfort to people, damages to the structure

its contents or which may limit its functional effectiveness. Special consideration shall be given to systems susceptible to vibration, such as large open floor areas free of partitions to ensure that such vibrations are perceptible for the intended use and occupancy.

- (v) Repairable damage or wear due to fatigue
- (vi) Corrosion, durability
- (vii) Fire

IS-800:2007 Table 5 (Clause 5.4.1)

Partial Safety Factor for materials γ_m

Sl. No.	Definition	Partial Safety Factor	
(i)	Resistance governed by yielding		1.10
(ii)	Resistance of member to buckling		1.10
(iii)	Resistance governed by ultimate stress		1.25
(iv)	Resistance of connection:	Shop Fabrication	Field Fabrication
(a)	Bolts - Friction Type	1.25	1.25
(b)	Bolts - Bearing Type	1.25	1.25
(c)	Rivets	1.25	1.25
(d)	Welds	1.25	1.50

3.2 Loads & Load Combination :->

3.2.1 For the purpose of designing any element, member or a structure, the following loads (actions) & their effects shall be taken into account, where applicable with partial safety factors and combinations. IS: 800: 2007

- (a) Dead loads
- (b) Imposed loads (Live load, crane load, snow load, dust load, wave load, earth pressures, etc.)
- (c) Wind loads
- (d) Earthquake loads
- (e) Erection loads
- (f) Accidental loads such as those due to blast, impact of vehicles etc. and
- (g) Secondary effects due to contraction or expansion resulting from temperature changes, differential settlements of the structure as a whole or of its supports, eccentric connections, rigidity of joints differing from design assumptions.

3.5 Load Combinations :->

3.5.1 Load combinations for design purpose shall be those that produce maximum forces & effects and consequently maximum stresses and deformations. The following combination of loads with appropriate partial safety factors may be considered.

- (a) Dead load + imposed load
- (b) Dead load + imposed load + wind or earthquake load
- (c) Dead load + wind or earthquake load
- (d) Dead load + erection load

Maximum effective slenderness ratio (λ)

Slenderness ratio = $\frac{\text{Effective length}}{\text{min radius of gyration}}$

$$\lambda = \frac{l_{eff}}{r_{min}}$$

$$r_{min} = \sqrt{\frac{I_{min}}{A}}$$

$$I = A r^2$$

IS: 800: 2007

Table 3. Maximum value of effective slenderness ratio of various types of members

3.2 (Table 3)

No.	Members	Maximum effective slenderness ratio λ_{lim}
(i)	A member carrying compressive loads resulting from dead loads & imposed loads	180
(ii)	A tension member in which a reversal of direct stress occurs due to loads other than wind or seismic forces	180
(iii)	A member subjected to compression force resulting only from combination with wind or earthquake actions, provided the deformation of such member does not adversely affect the stress in any part of the structure	250
(iv)	Compression flange of a beam against lateral torsional buckling	300
(v)	A member normally acting as a tie in a roof truss or a bracing system not considered effective when subject to possible reversal of stress into compression resulting from the action of wind or earthquake forces	350
(vi)	Member always under tension (other than pre-tensioned members)	400

Plastic Analysis

Assumption in Plastic Analysis

- (1) Steel possess ductility that is deformation in the plastic range without fracture
- (2) Strain distribution is linear
- (3) steel is to be assume ideal elastic-plastic material
- (4) Elastic deformation is not considered
- (5) The beam is not subjected to longitudinal force

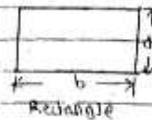
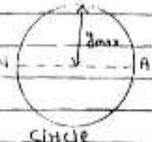
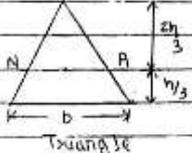
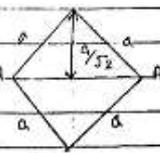
Elastic Section Modulus | Elastic Modulus (Z)

$$Z = \frac{I}{y_{max}}$$

- I = Moment of inertia about Neutral Axis
- y_{max} = Distance of Neutral Axis from extreme fibre

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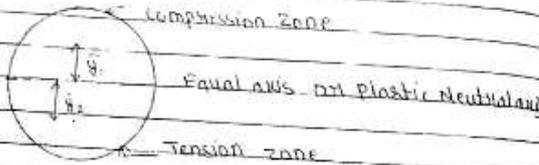
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S.No	Shape	I	y_{max}	$Z = \frac{I}{y_{max}}$
(1)	 <p>Rectangle</p>	$\frac{bd^3}{12}$	$\frac{d}{2}$	$\frac{bd^2}{6}$
(2)	 <p>Circle</p>	$\frac{\pi D^4}{64}$	$\frac{D}{2}$	$\frac{\pi D^3}{32}$
(3)	 <p>Square</p>	$\frac{a^4}{12}$	$\frac{a}{2}$	$\frac{a^3}{6}$
(4)	 <p>Triangle</p>	$\frac{bh^3}{36}$	$\frac{2h}{3}$	$\frac{bh^2}{24}$
(5)	 <p>Diamond</p>	$\frac{a^4}{12}$	$\frac{a}{\sqrt{2}}$	$\frac{a^3}{6\sqrt{2}}$

Plastic Modulus / Plastic section Modulus (Z_p)

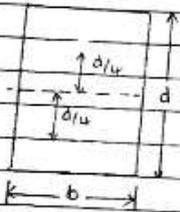
Definition :->

The sum of the moments of the compression and tension zone about elastic neutral axis is called Plastic Modulus / Plastic section Modulus (Z_p).



$$Z_p = A \times (\bar{y}_1 + \bar{y}_2)$$

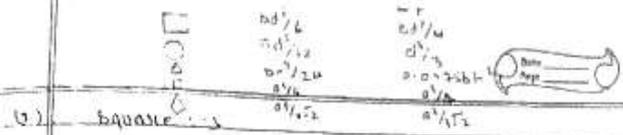
Example :- (1) Rectangle



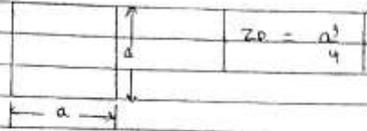
$$Z_p = A \times (\bar{y}_1 + \bar{y}_2)$$

$$= \frac{bd}{2} \times \left(\frac{d}{4} + \frac{d}{4} \right)$$

$$Z_p = \frac{bd^2}{4}$$

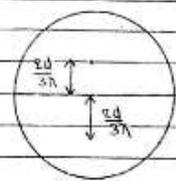


(1) Square :->



$$Z_p = \frac{a^3}{4}$$

(2) Circle :->



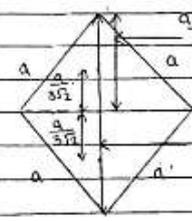
$$Z_p = A \times (\bar{y}_1 + \bar{y}_2)$$

$$= \frac{\pi \cdot d^2}{4} \times \left(\frac{2d}{3\pi} + \frac{2d}{3\pi} \right)$$

$$= \frac{\pi \cdot d^2}{4 \times \pi} \times \frac{4d}{3} = \frac{d^3}{6}$$

$$Z_p = \frac{D^3}{6}$$

(3) Diamond :->



$$Z_p = A \times (\bar{y}_1 + \bar{y}_2)$$

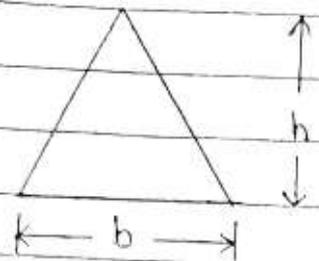
$$= \frac{a^2}{2} \times \left(\frac{a}{3\sqrt{3}} + \frac{a}{3\sqrt{3}} \right)$$

$$= \frac{a^2}{2} \times \frac{2a}{3\sqrt{3}}$$

$$\sqrt{a^2 + a^2} = a\sqrt{2}$$

$$Z_p = \frac{a^3}{3\sqrt{3}}$$

(5) Triangle \Rightarrow



$$Z_p = 0.0975 bh^2$$

25/3/22

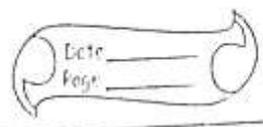
Shape factor (SF) = $\frac{\text{Plastic Moment}}{\text{Yield Moment}} = \frac{\text{Plastic moment}}{\text{Elastic moment}}$

$$S.F. = \frac{M_p}{M_y} = \frac{f_y Z_p}{f_y Z} \quad \left| \quad S.F. = \frac{Z_p}{Z} \right|$$

Calculation shape factor for

- (1) Rectangle $\Rightarrow SF = \frac{Z_p}{Z} = \frac{bd^2/4}{bd^2/6} = \underline{1.5}$
- (2) Square $\Rightarrow SF = \underline{1.5}$
- (3) Circle $\Rightarrow SF = \frac{d^3/6}{\frac{\pi}{32}d^3} = \underline{1.7}$
- (4) Diamond $\Rightarrow SF = \frac{a^3/352}{a^3/652} = \underline{2}$
- (5) Triangle $\Rightarrow SF = \frac{0.0975bh^2}{bh^2/24} = \underline{2.34}$
- (6) Hollow circle $\Rightarrow SF = \underline{1.27}$

Shape Factor \Rightarrow



Shape Factor = $\frac{\text{Plastic Moment}}{\text{Yield Moment}} = \frac{\text{Plastic section Mo.}}{\text{Elastic section Mo.}}$

$$S.F = \frac{Z_p}{Z}$$

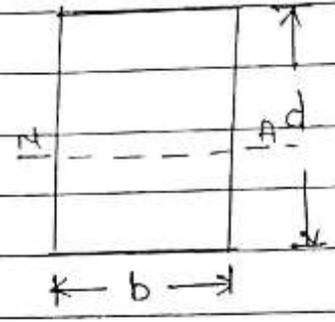
► calculation shape factor for different section \Rightarrow

(1) Rectangle \Rightarrow

\rightarrow calculation of Elastic section (Z) \Rightarrow

$$\therefore Z = \frac{I}{y_{max}}$$

\rightarrow I = Moment of inertia
 y_{max} = Distance from of NA from extreme fibre



$$I \text{ for Rectangle} = \frac{bd^3}{12}$$

$$y_{max} \text{ for Rectangle} = \frac{d}{2}$$

$$\therefore Z = \frac{I}{y_{max}} = \frac{bd^3/12}{d/2}$$

$$Z = \frac{bd^2}{6}$$

\rightarrow calculation of plastic section \Rightarrow

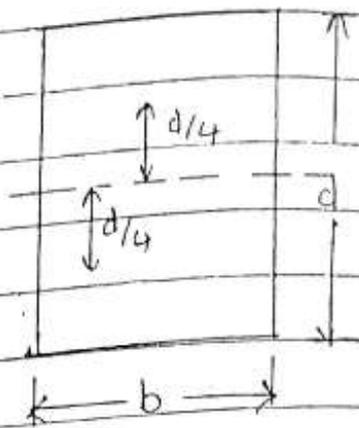
$$\therefore Z_p = \frac{A}{2} \times (\bar{y}_1 + \bar{y}_2)$$

$$\text{Area of Rectangle} = bd$$

$$Z_p = \frac{bd}{2} \times \left(\frac{d}{4} + \frac{d}{4} \right)$$

$$= \frac{bd}{2} \times \frac{2d}{4}$$

$Z_p = \frac{bd^2}{4}$

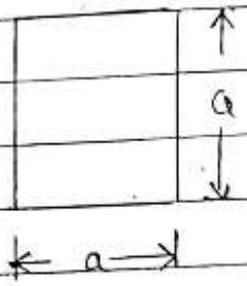


Shape factor for Rectangle section

$S.F = \frac{Z_p}{Z} = \frac{bd^2/4}{bd^2/6} = 1.5$

(2) Square :->

→ Calculation of Elastic section (Z) :->



$$\therefore Z = \frac{I}{y_{max}}$$

I = Moment of inertia about
Neutral axis

y_{max} = Distance of Neutral axis from extreme fibres

$$I = \frac{a^4}{12} \quad \& \quad y_{max} = \frac{a}{2}$$

$Z = \frac{a^4/12}{a/2}$	$Z = \frac{a^3}{6}$
--------------------------	---------------------

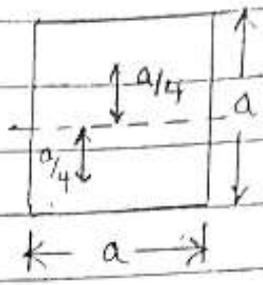
→ Calculation of Plastic section (Z_p) :->

$$\therefore Z_p = \frac{A}{2} \times (\bar{y}_1 + \bar{y}_2)$$

$$A = a^2$$

$$\bar{y}_1 = \frac{a}{4}$$

$$\bar{y}_2 = \frac{a}{4}$$



$$\therefore Z_p = \frac{a^2}{2} \times \left(\frac{a}{4} + \frac{a}{4} \right)$$

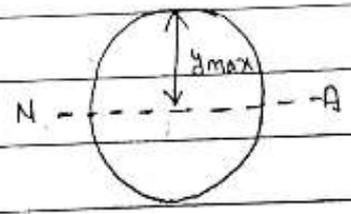
$$= \frac{a^2}{2} \times \frac{2a}{4} \quad \boxed{Z_p = \frac{a^3}{4}}$$

Shape factor for square section

$$S.F = \frac{Z_p}{Z} = \frac{a^3/4}{a^3/6} \quad \boxed{S.F = 1.5}$$

(3) Circle \Rightarrow

\rightarrow Calculation of Elastic section modulus (Z)



$$\therefore Z = \frac{I}{y_{max}}$$

where,

I = Moment of inertia about N.A

y_{max} = Distance of NA from Extreme fibre

$$I = \frac{\pi \cdot d^4}{64}$$

$$y_{max} = \frac{d}{2}$$

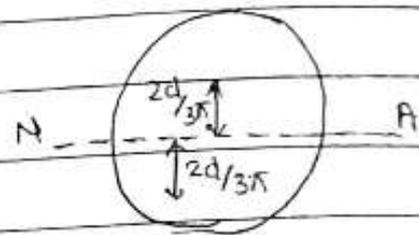
$$Z = \frac{\pi/64 d^4}{d/2} \rightarrow$$

$$Z = \frac{\pi d^3}{32}$$

→ Calculation of plastic modulus section (Z_p):

$$\therefore Z_p = \frac{A}{2} \times (\bar{y}_1 + \bar{y}_2)$$

$$A = \frac{\pi \cdot d^2}{4}$$



$$\bar{y}_1 = \frac{2d}{3\pi}, \quad \bar{y}_2 = \frac{2d}{3\pi}$$

$$\therefore Z_p = \frac{\pi/4 \cdot d^2}{2} \times \left(\frac{2d}{3\pi} + \frac{2d}{3\pi} \right)$$

$$\Rightarrow Z_p = \frac{\pi d^2}{8} \times \frac{4d}{3\pi}$$

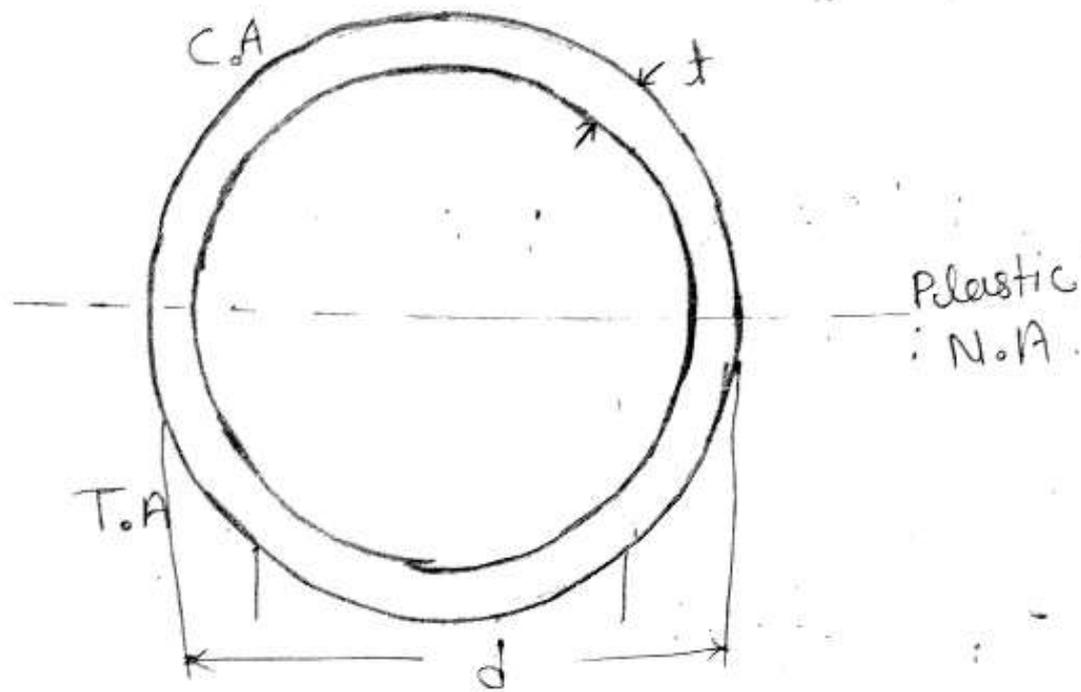
$$Z_p = \frac{d^3}{6}$$

Shape factor for circle section: \Rightarrow

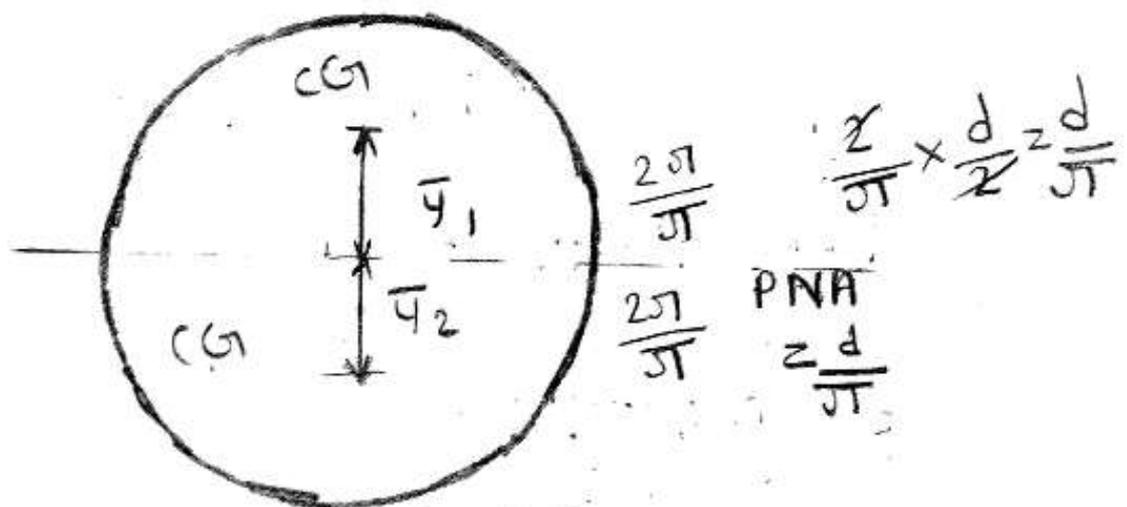
$$S.F = \frac{Z_p}{Z} = \frac{d^3/6}{\pi d^3/32} = 1.69$$

$$S.F = 1.7$$

* Shape factor for hollow circular section



Note — in implies that d^2 and d^3 terms are neglected in our calculation area are treated as line area



$$d = 2R, R = \frac{d}{2}$$

$$S_f = \frac{Z_p}{Z}$$

$$Z_p = A (\bar{y}_1 + \bar{y}_2)$$

from 1st axis theorem

$$I_{zz} = I_{xx} + I_{yy} \quad \{ I_{xx} = I_{yy} \}$$

$$I_{zz} = I_{xx} + I_{yy}$$

$$I_{xx} = \frac{I_{zz}}{2}$$

$$I_{xx} = \frac{\sigma T d^3}{8}$$

$$z = \frac{I_{xx}}{y}$$

$$z = \frac{I d^3}{8} \cdot \frac{1}{d/2}$$

$$\boxed{z = \frac{\sigma T d^2}{4}}$$

Section Modulus

Plastic Section Modulus

$$z_p = \frac{A}{2} (\bar{y}_1 + \bar{y}_2)$$

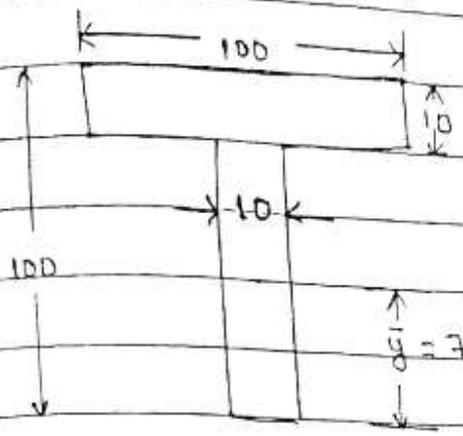
$$= \frac{\sigma T d}{2} \left[\frac{d}{\sigma T} + \frac{d}{\sigma T} \right] = \frac{\sigma T d}{2} \times \frac{2d}{\sigma T}$$

$$z_p = d^2$$

Shape factor

$$= \frac{z_p}{z}$$

▶ To calculate centroid :->

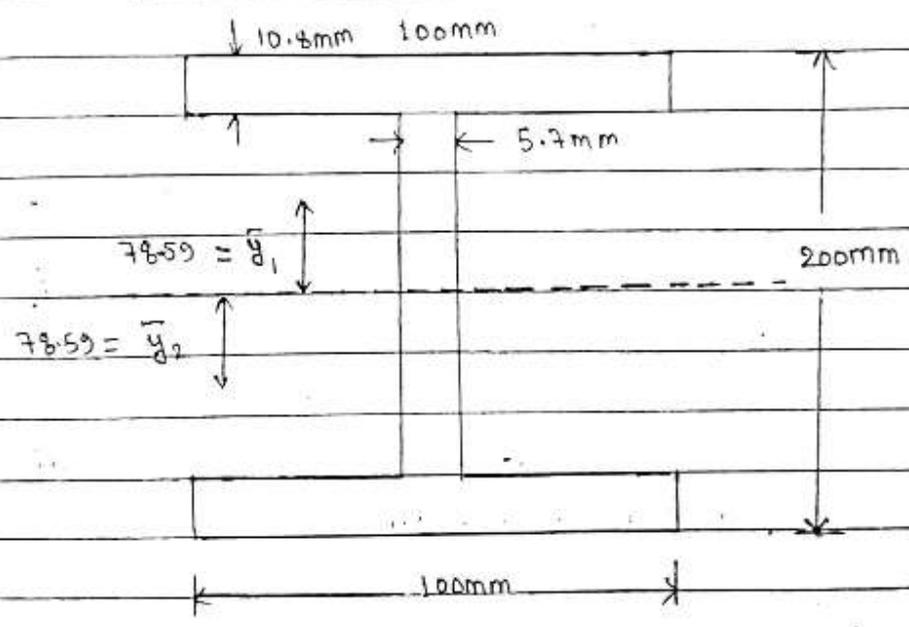


$$\therefore \bar{y} = \frac{a_1 y_1 + a_2 y_2}{a_1 + a_2}$$

$$= \frac{(100 \times 10) \times 90 + 10 \times 90 \times 90/2}{(100 \times 10) + (90 \times 10)}$$

$$\bar{y} = 71.31 \text{ mm}$$

▶ Calculation S.F for ISMB 200 :->



$$D = 200 \text{ mm}$$

$$b = 100 \text{ mm}$$

$$t_f = 10.8 \text{ mm}$$

$$t_w = 5.7 \text{ mm}$$

$$\bar{y}_1 = \frac{100 \times 10.8 \times (100 - 5.4) + (100 - 10.8) \times 5.7 \times (100 - 10.8)}{100 \times 10.8 + (100 - 10.8) \times 5.7}$$

$$\bar{y}_1 = 78.50 \text{ mm}$$

$$\bar{y}_2 = 78.59 \text{ mm}$$

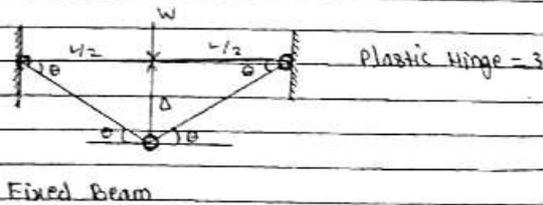
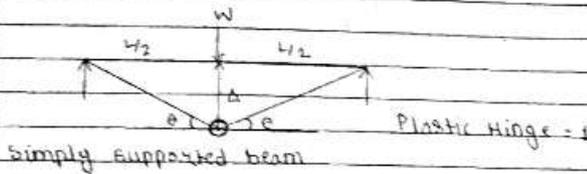
$$Z_P = A_p \times (\bar{y}_1 + \bar{y}_2)$$

$$= 52.37 \times 10^2 \times (78.6 + 78.6)$$

$$Z_P = 25413 \text{ mm}^3$$

$$SF = \frac{Z_P}{Z} = \frac{25413}{223.5 \times 10^3}$$

$$= 1.136$$



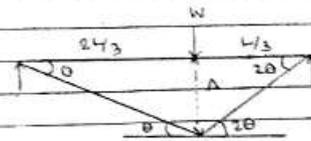
Principle of Virtual work :->

$$\text{External work done} = \text{Internal work done}$$

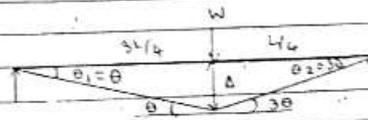
$$W \times \Delta = \sum M_P \times \theta$$

θ = Angle जहाँ पर plastic hinge है M_P और

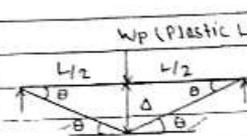
(1)



(2)



(3)



W_P (Plastic Load / Collapse Load)

From principle of virtual work

$$W \times \Delta = \sum M_P \times \theta$$

$$W_P \times \Delta = M_P \times \theta + M_P \times \theta$$

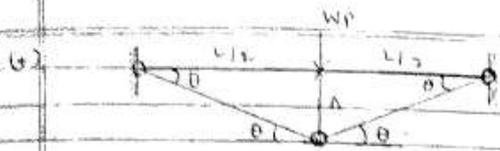
$$W_P \times \Delta = 2 M_P \times \theta$$

$$W_P \times \Delta \times \frac{L}{2} = 2 M_P \times \theta$$

$$\theta = \frac{\Delta \times L}{2 \times \text{Radius}}$$

$$\Delta = \theta \times \text{Radius}$$

$$W_P = \frac{4 M_P}{L}$$

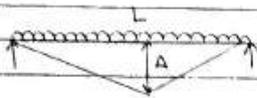


External work done = Internal work done

$$W_p \times \Delta = 5M_p \times \theta$$

$$\rightarrow W_p \times \theta \times \frac{L}{2} = M_p \times \theta + M_p \times \theta + M_p \times \theta + M_p \times \theta$$

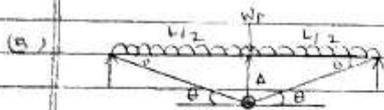
$$\rightarrow W_p = \frac{8M_p}{L}$$



If Udl

$$w \times A \times \Delta$$

$$w \times \frac{1}{2} \times L \times \Delta$$



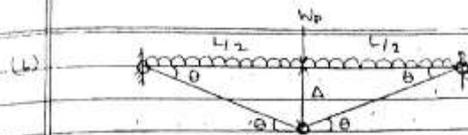
External work done = Internal work done

$$\rightarrow w \times A = 5M_p \times \theta$$

$$\rightarrow w \times \frac{1}{2} \times L \times \Delta = 2M_p \theta$$

$$\rightarrow w \times \frac{1}{2} \times L \times \theta \times \frac{L}{2} = 2M_p \theta$$

$$\rightarrow W_p = \frac{8M_p}{L^2}$$

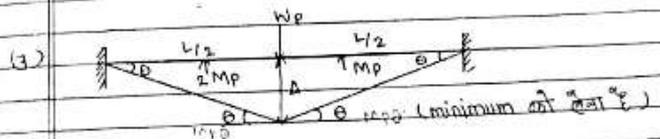


$$W_p \times \Delta = 5M_p \theta$$

$$\rightarrow W_p \times \frac{1}{2} \times L \times \Delta = M_p \theta + M_p \theta + M_p \theta + M_p \theta$$

$$\rightarrow W_p \times \frac{1}{2} \times L \times \theta \times \frac{L}{2} = 4M_p \theta$$

$$W_p = \frac{16M_p}{L^2}$$

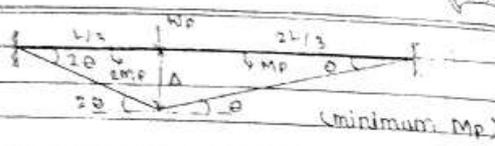


External work done = Internal work done

$$\rightarrow W_p \times \Delta = 5M_p \times \theta$$

$$\rightarrow W_p \times \theta \times \frac{L}{2} = M_p \theta + M_p \theta + 2M_p \theta + M_p \theta$$

$$\rightarrow W_p = \frac{10M_p}{L}$$



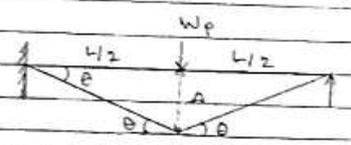
External work done = Internal work done

$$\Rightarrow W_p \times \Delta = \sum M_p \times \theta$$

$$\Rightarrow W_p \times 2\theta \times \frac{L}{2} = 2M_p \times \theta + M_p \times \theta + M_p \times \theta + M_p \times \theta$$

$$\Rightarrow W_p \times \theta \times L = 4M_p \theta$$

$$\Rightarrow W_p = \frac{4M_p}{L}$$



From principle of virtual work

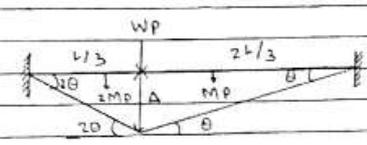
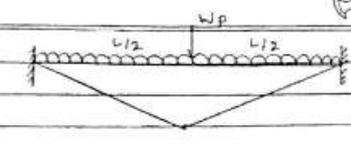
External work done = Internal work done

$$\Rightarrow W_p \times \Delta = \sum M_p \times \theta$$

$$\Rightarrow W_p \times \theta \times \frac{L}{2} = M_p \theta + M_p \theta + M_p \theta$$

$$\Rightarrow W_p \times \theta \times \frac{L}{2} = 3M_p \theta$$

$$\Rightarrow W_p = \frac{6M_p}{L}$$



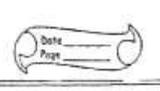
$$W_p \times \Delta = \sum M_p \times \theta$$

$$\Rightarrow W_p \times 2\theta \times \frac{L}{2} = 2M_p \times \theta + M_p \times \theta + M_p \times \theta + M_p \times \theta$$

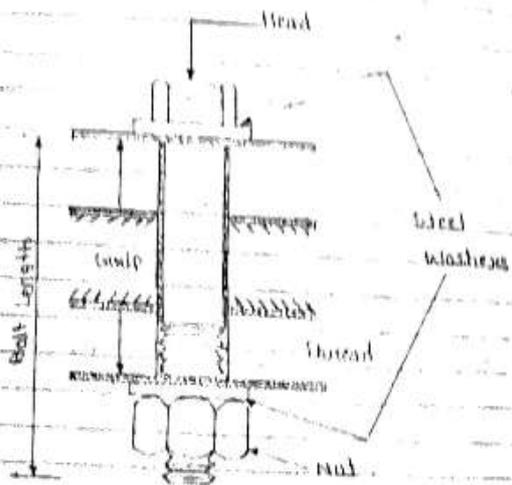
$$\Rightarrow W_p \times \theta \times L = 4M_p \theta + 2M_p \theta + M_p \theta + M_p \theta$$

$$\Rightarrow W_p = \frac{3 \times 4 M_p}{2 L}$$

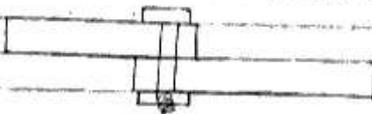
$$\Rightarrow W_p = \frac{12 M_p}{L}$$



A bolt may be defined as material with a head at one of the end and a shank threaded at the other end to receive a nut.



High strength friction grip bolt :-



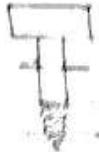
These bolts may be tightened until they have very high tensile stresses, Two or more times that of ordinary bolts. So that the connected parts are clamp tightly & loads are transferred

primarily by friction & not by shear.

Terms related to bolting :-

(1) Nominal Diameter (d) :-

shank diameter



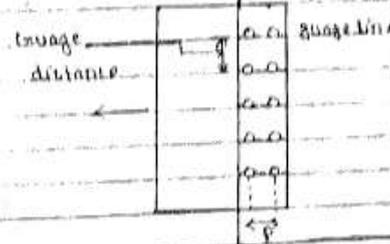
The diameter of unthreaded portion of shank is called Nominal Diameter.

(2) Gross Diameter :-

For bolts Gross Diameter is same as Nominal Diameter.

(3) Pitch (P) :-

Proportional to the force
by gauge (g)



The distance between centres of any two adjacent bold parallel to the forces is known as 'Pitch'.

Minimum edge distance e_{min}

$e_{min} = 1.7 \times d_o \rightarrow$ If hand plane cut

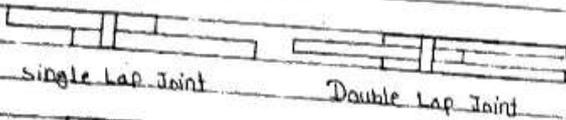
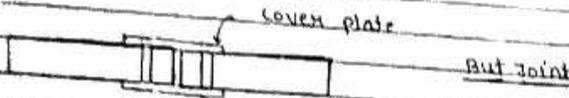
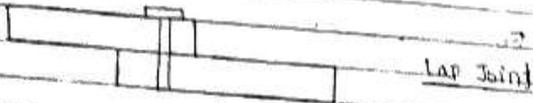
$e_{min} = 1.5 \times d_o \rightarrow$ If machine plane cut

Maximum edge distance e_{max}

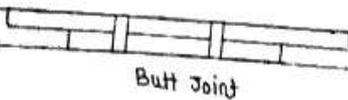
$$e_{max} = 12.5 \phi$$

$$e = \sqrt{\frac{250}{F_y}}$$

Type of bolted joints \rightarrow



Double Lap Joint



Bolted Joints

Lap Joint

Butt Joint

Single Bolted
Lap Joint

Single
Butt Joint

Double
Butt Joint

Double Bolted
Lap Joint

Single cover Single
Bolted Butt Joint

Triple Bolted
Lap Joint

Single cover Double
Bolted Butt Joint

Multi-bolted
Lap Joint

Single cover Multi
Bolted Butt Joint

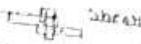
Double cover Single Bolted Butt Joint

Double cover Double Bolted Butt Joint

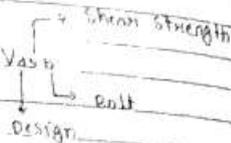
Double cover Multi Bolted Butt Joint

Failure of bolted joint

1) shearing of bolt



shear strength of bolt =



$$V_{asb} = \frac{V_{asb}}{\gamma_{mb}}$$

V_{asb} = Design shear strength of bolt

V_{asb} = Normal shear capacity of bolt

γ_{mb} = Partial factor of safety

f_u = Ultimate strength of bolt (400 N/mm^2)

$$V_{asb} = \left(\frac{f_u}{\sqrt{3}} \right) \times [n_s \times A_{sb} + n_c \times A_{sb}]$$

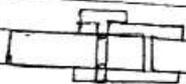
$$V_{asb} = \frac{f_u}{\sqrt{3} \times 1.25} \times [n_s \times A_{sb} + n_c \times A_{sb}]$$

For double cover butt joint

$$V_{asb} = \frac{f_u}{\sqrt{3} \times 1.25} \times [n_s \times A_{sb} + n_c \times A_{sb}] \times 2$$

$$A_{sb} = 0.78 \times \pi \times d^2 / 4$$

$n_s = 1$ if n_s is not given

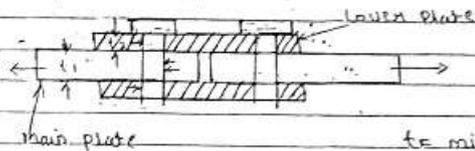
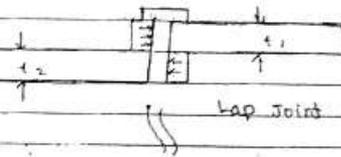


Bearing strength of Bolt

Force = Bearing stress \times Area
Partial factor of safety

$$= \left[2.5 \times k_b \times f_u \right] \times d \times t$$

k_b = constant
 f_u = Ultimate strength of bolt



$$V_{asb} = \frac{2.5 \times k_b \times f_u \times d \times t \times n}{1.25}$$

n = no. of bolt

k_b = maximum $\left\{ \begin{array}{l} \frac{e}{3d_0} \\ \frac{p}{3d_0} \\ \frac{f_{ub}}{f_{up}} \left(\frac{400}{410} = 0.97 \right) \end{array} \right.$ if not given

- $e = 1.5 \times d_0$
- $p = 2.5 \times d$

► Shear stress & strain \rightarrow Shearing deformation, Strain, Shear stress

$E_s = \frac{\text{shear stress}}{\text{shear strain}}$

► Joint strength of Rivet \Rightarrow

- \rightarrow Shear force for tearing
- \rightarrow Shear force for compression



$T_s = \text{Shear stress} \times \text{Area}$

$T_c = \text{Crushing strength} \times \text{Area}$

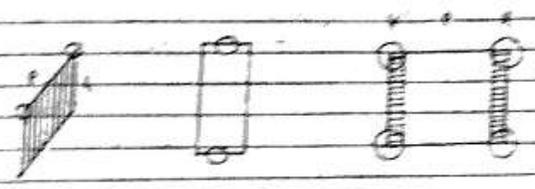
$P_u = 410 \text{ MPa} \times \text{Area of rivet}$

$P_{te} = \sigma_t \times d \times t$
 $P_{cs} = (P - d) \times t$

Factorial factors of safety:

- for tearing - 1.25
- for crushing - 1.75

► For Rivet \Rightarrow If P is not given



$P_t = d \times t$

$P_{cs} = (P - d) \times t$

Joint $\hat{=}$ min of strength

► Strength of Joint - min. $\left\{ \begin{array}{l} \text{Tearing strength} \\ \text{Shearing strength} \\ \text{Crushing / Tensile strength} \\ \text{of plate} \end{array} \right.$

► Efficiency of joint \Rightarrow

$\eta = \frac{\text{Joint strength}}{\text{Strength of plate}} \times 100$

Joint strength = $\text{Strength} \times \text{Area}$

$$= \frac{0.9 \times f_u \times (B \times t)}{1.25}$$

If B is not given $= \frac{0.9 f_u (P \times t)}{1.25}$

$$\eta = \frac{\min \{ V_{sb}, V_{pb}, T_d \}}{0.9 f_u P t / 1.25} \times 100$$

Q4) Calculate strength of 16mm dia. bolt
Bolt grade = 4.6
 $f_u = 410 \text{ N/mm}^2$

10mm

$f_u = 410 \text{ N/mm}^2$

$P = 40 \text{ mm}$

$e = 30 \text{ mm}$

Thread intercepting

soln:-> Given

$d = 16 \text{ mm}$

$d_n = 18 \text{ mm}$

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

$f_{up} = 410 \text{ N/mm}^2$

$P = 40 \text{ mm}$

$e = 30 \text{ mm}$

$t = 10 \text{ mm}$

(1) Shearing strength of Bolt (V_{sb})

$$\therefore V_{sb} = \frac{f_u}{\sqrt{3}} (n_s \times A_{nb})$$

$$A_{nb} = 0.79 \times \frac{\pi}{4} \times d^2$$

$$V_{sb} = \frac{400}{1.25 \times \sqrt{3}} (1 \times 0.79 \times \frac{\pi}{4} \times 16^2)$$

$$V_{sb} = 29.97 \text{ kN}$$

(2) Bearing strength of Bolt (V_{pb})

$$\therefore V_{pb} = \frac{2.5 \times k_b \times f_u \times d \times t}{1.25}$$

$$V_{pb} = \frac{2.5 \times 0.49 \times 400 \times 16 \times 10}{1.25}$$

$$V_{pb} = 62.7 \text{ kN}$$

$$k_b = \min \left\{ \begin{array}{l} \frac{e}{3d_b} = \frac{30}{3 \times 18} = 0.55 \\ \frac{P}{3d_b} = \frac{40}{3 \times 18} = 0.25 = 0.49 \\ f_{ub} = 400 = 0.97 \\ f_{up} = 410 \end{array} \right.$$

$K_b = \text{minimum}$

$$\frac{e}{3d_o} = \frac{33}{3 \times 22} = 0.5$$

$$\frac{p}{3d_o} = \frac{0.25 \times 50}{3 \times 22} = 0.25$$
$$= 0.507$$

$$\frac{f_{ub}}{f_{up}} = \frac{400}{410} = 0.97$$

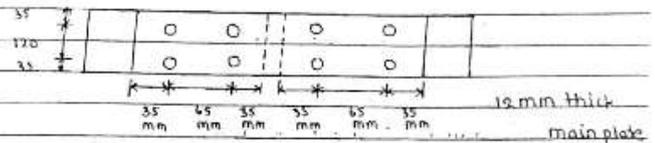
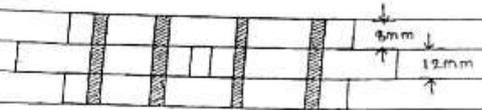
$$(3) \text{ Bolt Value} = \min \begin{cases} V_{dsb} = 58.04 \text{ kN} \\ V_{dph} = 128 \text{ kN} \end{cases}$$

$$\text{Bolt Value} = 58.04 \text{ kN}$$

$$(4) \text{ Number of Bolt} = \frac{\text{Load}}{\text{Bolt Value}}$$
$$= \frac{562.5}{58.04}$$
$$= 9.69 \text{ Bolt}$$
$$= \approx 10 \text{ Bolt}$$

Ans.

Q.3) Calculate design strength and η (Efficiency) of connection 20mm bolt, grade 4.6, $f_{ub} = 410 \text{ N/mm}^2$



Given data ->

Given data.

$$\text{Pitch (P)} = 65 \text{ mm}$$

$$\text{Edge distance (e)} = 35 \text{ mm}$$

$$\text{Bolt Dia. (d)} = 20 \text{ mm}$$

$$\text{Hole Dia. (d}_o\text{)} = 20 + 2 = 22 \text{ mm}$$

$$\text{Ultimate strength of bolt (f}_{ub}\text{)} = 410 \text{ N/mm}^2$$

$$\text{Ultimate strength of plate (f}_{up}\text{)} = 410 \text{ N/mm}^2$$

$$t = \min \begin{cases} 2 \times 8 = 16 \text{ mm} \\ 12 \text{ mm} \end{cases}$$

$$t = 12 \text{ mm}$$

available

The row of bolts parallel to the direction of force is known as "Gauge line"

The normal distance between two bolts is called "Gauge Distance"

Properties of steel

Grade of steel 4.6

- Ultimate strength $f_u = 400 \text{ N/mm}^2$
- Yield strength $f_y = 240 \text{ N/mm}^2$

Minimum clearance for bolts \Rightarrow

Bolt diameter (d)	Clearance (Hole dia) d_0
12 - 14 mm	+1 mm
16 - 24 mm	+2 mm
> 24 mm	+3 mm

IS 800

According to IS 800:2007

Minimum Spacing = $2.5 \times$ Nominal diameter

$P_{min} = 2.5 \times d$

Ex: 14mm bolt
 $P_{min} = 2.5 \times 14$

Maximum Spacing \Rightarrow

in tension
in shear
min $\left\{ \begin{array}{l} 16t \\ 200mm \end{array} \right.$

in tension
max = min $\left\{ \begin{array}{l} 16t \\ 200mm \end{array} \right.$

For compression
max = min $\left\{ \begin{array}{l} 12t \\ 200mm \end{array} \right.$

Edge distance \Rightarrow "e"

Edge distance		
	1.5d	
	2d	
	2.5d	
	4t	

Edge distance

Maximum edge distance e

$e_{min} = 1.5 d_b \rightarrow$ If hand flame cut

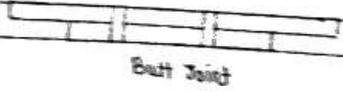
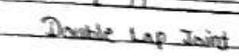
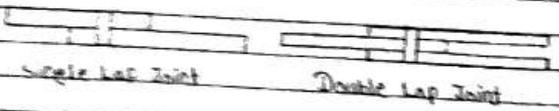
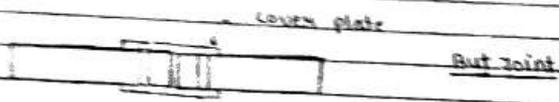
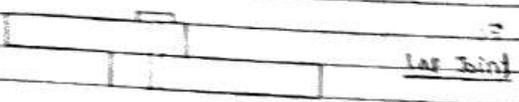
$e_{min} = 1.5 \times d_b \rightarrow$ If machine flame cut

Maximum edge distance e

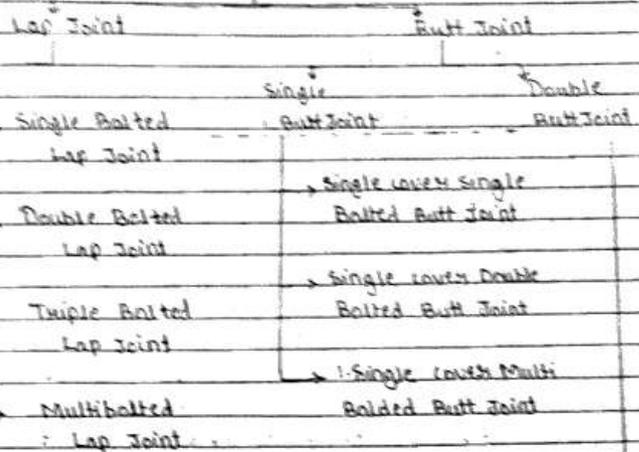
$$e_{max} = 12t$$

$$t = \frac{E_s}{E_p}$$

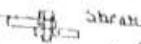
Type of Bolted Joints \Rightarrow



Bolted Joints

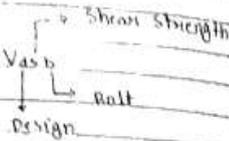


① failure of bolted joint :->



(a) Shearing of bolt

► Shear strength of bolt :-



$$V_{dab} = \frac{V_{shb}}{\gamma_{mb}}$$

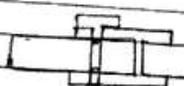
- V_{shb} = Design shear strength of bolt
- V_{shb} = Normal shear capacity of bolt
- γ_{mb} = Partial factor of safety
- f_u = Ultimate strength of bolt (400 N/mm^2)

$$V_{shb} = \left(\frac{f_u}{\sqrt{3}} \right) \times [n_s \times A_{nb} + n_s \times A_{sb}]$$

$$V_{dab} = \frac{f_u}{\sqrt{3} \times 1.25} \times [n_s \times A_{nb} + n_s \times A_{sb}]$$

~ For double cover butt joint ~

$$V_{dab} = \frac{f_u}{\sqrt{3} \times 1.25} \times [n_s \times A_{nb} + n_s \times A_{sb}] \times 2$$



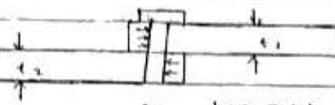
$$A_{nb} = 0.78 \times \pi \times d^2$$

$n_b = 1$ If n_s is not given

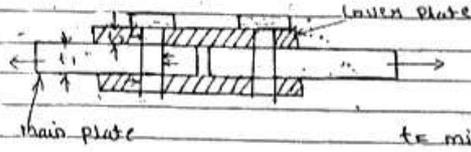
► Bearing strength of Bolt :->

Force = Bearing stress \times Area
Partial factor of safety

$$= \frac{[2.75 k_b f_u] \times d \times t}{\gamma_{mb}} \quad \begin{matrix} k_b = \text{Constant} \\ f_u = \text{Ultimate strength of bolt} \end{matrix}$$



Lap joint $t = \min \{ t_1, t_2 \}$



$t = \min \{ t_1, 2t_2 \}$

$$V_{dab} = \frac{2.5 \times k_b \times f_u \times d \times t \times n}{1.25} \quad \text{no. of Bolt}$$

$k_b = \text{minimum} \left\{ \begin{matrix} e_1 \\ 2d_o \\ P \\ 3d_g \end{matrix} \right\}$ $t = \text{thickness of thinner plate}$

$$\frac{f_{ub}}{f_{up}} = \left(\frac{400}{410} = 0.97 \right)$$

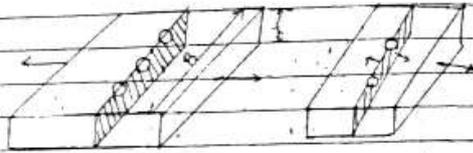
- $e = 1.5 \times d_o$ if not given
- $P = 2.5 \times d$

Bolt Value = $\min \left\{ \begin{array}{l} \text{shearing strength} \\ \text{bearing strength} \end{array} \right.$

$B_v = \min \left\{ \begin{array}{l} N_d s_b \\ N_d r_b \end{array} \right.$

Tensile strength of Plate \Rightarrow

- \rightarrow Net Area for Tension
- \rightarrow Gross Area for compression



$T_d = \frac{\text{Stress} \times \text{Area}}{\text{Fos}}$

$T_d = \frac{(0.9 P_u) \times A_{net}}{1.25}$

$P_u = 410 \text{ N/mm}^2$ for plate

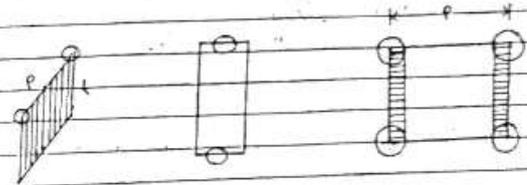
$A_{net} = Bt - d \times t \times n$

$A_{net} = (B - nd) t$

Partial factor of safety:

- For Yielding - 1.10
- For Ultimate - 1.25

Pert Pitch \Rightarrow If B is not given.



$P_t = d \times t$

$A_{net} = (P - d) \times t$

Joint ke bare ka strength

Strength of Joint = $\min \left\{ \begin{array}{l} \text{Bearing strength} \\ \text{shearing strength} \\ \text{Tearing / Tensile strength} \\ \text{of plate} \end{array} \right.$
on strength of plate =

Efficiency of joint \Rightarrow

$\eta = \frac{\text{Joint ke bare ka strength} \times 100}{\text{Joint ke bare ka strength}}$

Joint ke bare ka strength = $\frac{\text{Stress} \times \text{Area}}{\text{Fos}}$

$$= 0.9 \times f_{ut} (A_t) / 1.25$$

If B is not given = $0.9 f_{ut} (A_t) / 1.25$

$$\eta = \min \left\{ \frac{V_{sh}, V_{br}, T_d}{0.70 \cdot P / 1.25} \right\} \times 100$$

Qd) Calculate strength of 16mm dia. bolt

Bolt grade = 4.6

Fe-410 N/mm²

10mm

Fe-410 N/mm²

P = 40mm

e = 30mm

Thread intersecting

Solve: Given

d = 16mm

d_n = 18mm

f_{ub} = 400 N/mm²

f_{up} = 410 N/mm²

P = 40mm

e = 30mm

t = 10mm

(1) Shearing strength of Bolt (V_{sh})

$$\therefore V_{sh} = \frac{f_u (n_s \times A_{sh})}{\sqrt{3} \times 1.25}$$

$$A_{sh} = 0.79 \times \frac{\pi}{4} \times d^2$$

$$V_{sh} = \frac{400 (1 \times 0.79 \times \frac{\pi}{4} \times 16^2)}{1.25 \times \sqrt{3}}$$

$$V_{sh} = 29.97 \text{ kN}$$

(2) Bearing strength of Bolt (V_{br})

$$\therefore V_{br} = \frac{2.5 \times k_b \times f_u \times d \times t}{1.25}$$

$$V_{br} = \frac{2.5 \times 0.49 \times 400 \times 16 \times 10}{1.25}$$

$$V_{br} = 62.7 \text{ kN}$$

$$k_b = \min \left\{ \begin{array}{l} \frac{e}{3d_0} = \frac{30}{3 \times 18} = 0.55 \\ \frac{P}{3d_0} = \frac{40}{3 \times 18} = 0.74 \\ \frac{f_{ub}}{f_{up}} = \frac{400}{410} = 0.97 \end{array} \right.$$

strength of 16mm dia. bolt

$$\text{Strength} = \min \begin{cases} V_{dsb} = 28.97 \text{ kN} \\ V_{dpb} = 62.7 \text{ kN} \end{cases}$$

$$\therefore \text{strength} = \text{minimum} = 28.97 \text{ kN} \quad \text{Ans.}$$

$$\text{Number of Bolt} = \frac{\text{Load}}{\text{Bolt Value}}$$

$$\text{Bolt Value} = \min \begin{cases} \text{Shearing strength} \\ \text{Bearing strength} \end{cases}$$

Q.2) Two flats = 300mm x 16mm

($F_u = 410 \text{ N/mm}^2$)

20mm bolt

Grade 4.6

Service load or working load = 375 kN

Factored Load = 1.5×375

$$= 562.5 \text{ kN}$$

No. of Bolt = ?

Pitch (P) = minimum

Edge distance (e) = minimum

Thread not intercepting

Solve \rightarrow Given

$$B = 300 \text{ mm}$$

$$t = 16 \text{ mm}$$

$$f_{up} = 410 \text{ N/mm}^2$$

$$d = 20 \text{ mm}$$

$$d_o = 22 \text{ mm}$$

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

$$P_u = 562.5 \text{ kN}$$

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

$$E_{min} = 1.5 \times d_o = 1.5 \times 22 = 33 \text{ mm}$$

(1) Shear strength of Bolt \rightarrow

$$V_{dsb} = \frac{f_u}{1.25 \sqrt{3}} (n_s \times A_{ns})$$

$$= \frac{410}{1.25 \times \sqrt{3}} (1 \times \pi \times 20^2)$$

$$V_{dsb} = 58.04 \text{ kN}$$

(2) Bearing strength of Bolt \rightarrow

$$\therefore V_{dpb} = \frac{2.5 \times k_b \times f_{ub} \times d \times t}{1.25}$$

$$= \frac{2.5 \times 0.5 \times 400 \times 20 \times 16}{1.25}$$

$$V_{dpb} = 128 \text{ kN}$$

(Ans. 5/19/23)

$$k_b = \text{minimum} \left\{ \begin{array}{l} \frac{e}{3d_o} = \frac{33}{3 \times 22} = 0.5 \\ \frac{p}{3d_o} = \frac{0.25 \times 50}{3 \times 22} = 0.25 \\ \frac{f_{ub}}{f_{up}} = \frac{400}{410} = 0.97 \end{array} \right.$$

$$= 0.25$$

$$= 0.503$$

$$f_{ub} = 400 = 0.97$$

$$f_{up} = 410$$

(*) Bolt Value = min $\left\{ \begin{array}{l} V_{dsb} = 58.04 \text{ kN} \\ V_{dph} = 128 \text{ kN} \end{array} \right.$

Bolt Value = 58.04 kN

(*) Number of Bolt = $\frac{\text{Load}}{\text{Bolt Value}}$

$$= \frac{562.5}{58.04}$$

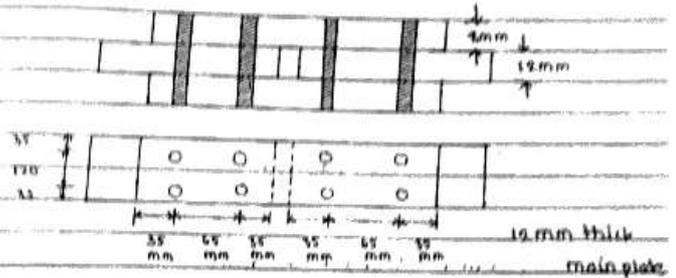
$$= 9.69 \text{ Bolt}$$

$$= \approx 10 \text{ Bolt}$$

Ans.

(Ans. 5/19/23)

(Q.5) Calculate design strength and η (efficiency) of connection 20mm bolt, grade 4.6, $f_{ub} = 410 \text{ N/mm}^2$



soln. \rightarrow

Given data,

Pitch (P) = 65 mm

Edge distance (e) = 35 mm

Bolt Dia. (d) = 20 mm

Hole Dia. (d_o) = 20 + 2 = 22 mm

Ultimate strength of bolt (f_{ub}) = 400 N/mm²

Ultimate strength of plate (f_{up}) = 410 N/mm²

$$t = \min \left\{ \begin{array}{l} 2 \times 3 = 6 \text{ mm} \\ 12 \text{ mm} \end{array} \right.$$

$$t = 12 \text{ mm}$$