

Notes by-

Pravin S Kolhe,

BE(Civil), Gold Medal, MTech (IIT-K)

Assistant Executive Engineer,

Water Resources Department,

www.pravinkolhe.com

Gravity Dam

Gravity Dam Forces on gravity dam:- 1) Water pressure 2) Weight of dam 3) Uplift pressure 4) Earthquake pressure 5) Silt pressure 6) Wave pressure 7) Ice pressure 8) Wind Pressure (All forces are calculated /m length of dam)

1) Water pressure: P_h - Horizontal water pressure on u/s side
 P_v - Vertical " " " " d/s side
 P_h' - Horizontal " " " " u/s side
 P_v' - Vertical " " " " d/s side

$$P_h = \frac{1}{2} \gamma_w \cdot H^2 ; P_v = \text{Wt. of water in prism ABCD}$$

$$P_h' = \frac{1}{2} \gamma_w' H^2 ; P_v' = \text{Wt. of water in prism EFG.}$$

4) Silt pressure.

(i) Silt separate water separate

$$P_{sh} = \frac{\gamma_{sh} h_1^2}{2} \left[\frac{1 - \sin \phi}{1 + \sin \phi} \right] ; 2h_1/3$$

γ_{sh} - submerged sp. wt. of silt = 9.074 kN/m³

h_1 - depth of silt deposited in m (Dead storage level)

ϕ - angle of internal friction of silt

(ii) Silt and water

$$P_{sh} = \frac{1}{2} \gamma_{sh}' h_1^2$$

γ_{sh}' - sp. wt. of (silt and water) = 13.342 kN/m³

γ_{sh} - 18.884 kN/m³

Mollifiers Formula

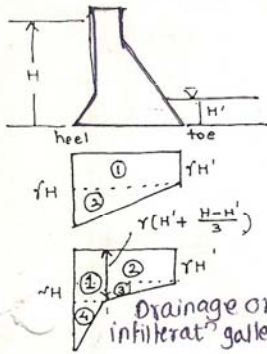
2) Self weight of dam:- Area of dam cross-section $\times \gamma_{\text{concrete}}$
 $\gamma_{\text{concrete}} = 23.544 \text{ kN/m}^3$ $\gamma_{\text{stone}} = 22.563 \text{ kN/m}^3$

3) Uplift pressure: Area factor - % of area on which uplift acts ($\frac{1}{3} \text{ to } \frac{2}{3}$)
 Intensity of uplift: % of uplift force to be considered. Area factor

Uplift press = area of uplift pressure diagram. acts at CG of diagram

* In case of dam without gallery, area of U_1 & U_2 can be calculated.

* In case of dam with infiltration gallery U_1, U_2, U_3, U_4 can be calculated



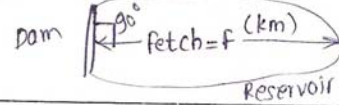
5) Wave Pressure: $h_w = 0.0322 \sqrt{FV} + 0.763 - 0.271 \sqrt{FV}$ h_w - wave ht. in m

F - fetch or straight length of water expanse normal to the dam axis in km

V - velocity of wind on the water surface in km/hr.

$$\text{if } F > 32 \text{ km } h_w = 0.0322 \sqrt{FV}$$

$$P_w = 19.62 h_w^2$$



Ice Pressure - 245.25 kN/m² applied to the face of dam over the anticipated contact of ice with the face of dam.

Wind Pressure:-

1 to 1.5 kN/m² over exposed area to the wind.

Earthquake forces:-

(a) Seismic coeff. method $\alpha = \beta I \alpha_0$

(b) Response spectrum method $\alpha = \beta I F_0 \left(\frac{S_a}{g} \right)$

where β - Soil foundation system factor = 1.0 ; I - importance factor = 2.0 ; α_0 - Basic seismic coeff.

F_0 - Seismic zone factor

Zone No.	α_0	F_0
I	0.01	0.05
II	0.02	0.10
III	0.04	0.20
IV	0.05	0.25
V	0.08	0.40

$$T = 5.55 \frac{H^2}{B} \sqrt{\frac{\gamma_c}{g E}}$$

for dams $H < 100 \text{ m}$

for dams $H > 100 \text{ m}$

H - ht of dam, B - base width

γ_c - sp. wt. of material E - modulus of elasticity

T - Time period of oscillation.

% Dampness: Gravity Dam = 5% ; Earth Dam = 10%

(A) Effect of Horizontal Acceleration:-

(a) Inertia force = Mass $\cdot \alpha \cdot g$

(b) Hydrodynamic force:-

$$P_e = 0.726 \rho h \dot{x} ; P_{eh} = C_m \cdot \alpha_h \cdot \gamma_w h$$

$$C = \frac{C_m}{2} \left[\frac{y}{h} \left(2 - \frac{y}{h} \right) + \sqrt{\frac{y}{h} \left(2 - \frac{y}{h} \right)} \right]$$

C_m - max. value of C , y - depth of section under consideration
 h - total depth of reservoir

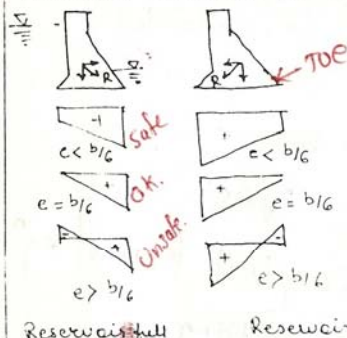
$$\alpha_h = \frac{F_x}{W_y}$$

(B) Effect of vertical Acceleration = $W \cdot (1 + \alpha_v) \uparrow$ or $W(1 - \alpha_v) \downarrow$

Combinations

- A: Construction condition / Empty reservoir: dam completed but no water in reservoir
- B: Normal operating condition: Full reservoir elevation, normal dry weather tailwater, normal uplift ice and silt.
- C: Flood discharge condition: Max. flood pool elevation, gates open, tailwater at flood elevation, normal uplift and silt.
- D: Combination A with earthquake ; E: Combination B with earthquake but no ice
- F: Combination C with extreme uplift (drains inoperative) G: Combination E but with extreme uplift

Vertical Stresses at the base of the dam



$$\sigma_y = \frac{\Sigma V}{b} \left[1 \pm \frac{12 e}{b^2} x \right]$$

Reservoir full

Reservoir empty

$$\sigma_{yD} = \frac{\Sigma V}{b} \left(1 + \frac{6e}{b} \right)$$

$$\sigma_{yD} = \frac{\Sigma V}{b} \left(1 - \frac{6e}{b} \right)$$

At toe

$$\sigma_{yU} = \frac{\Sigma V}{b} \left(1 - \frac{6e}{b} \right)$$

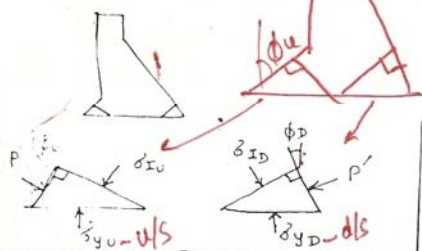
$$\sigma_{yU} = \frac{\Sigma V}{b} \left(1 + \frac{6e}{b} \right)$$

At heel

Reservoir full

Reservoir empty

Principal stresses



Max

$$\sigma_{Id} = \sigma_{yd} \sec^2 \phi_d - (p' - p_e) \tan^2 \phi_d$$

$$\sigma_{Iu} = \sigma_{yu} \sec^2 \phi_u - (p + p_e) \tan^2 \phi_u$$

Max

$$\sigma_{Id} = \sigma_{yd} \sec^2 \phi_d$$

$$\sigma_{Iu} = \sigma_{yu} \sec^2 \phi_u$$

Modes of Failure.

- (1) Overturning (2) Sliding (3) Overstressing

(1) Overturning

$$FS = \frac{\sum \text{Stabilizing Moments}}{\sum \text{Destabilizing moments}} > 1.5$$

(2) Sliding

$$F_1 = \frac{M \sum V}{H} \quad F_2 = \frac{M \sum V + A \cdot Q}{\sum H}$$

$$F = \tan \theta$$

load comp.

ABC	$F_1 > 2$	$F_2 > 4$
DE	$F_1 > 1.5$	$F_2 > 3$
FG	$F_1 > 1.2$	$F_2 > 1.5$

(3) Overstressing

Stresses must not increase the allowable working stress.

Elementary Profile:-

Base width for no tension = $(\frac{1}{2} b \cdot H \cdot s \cdot \gamma_w) \frac{b}{3} - (\frac{1}{2} \gamma_w H^2) \frac{H}{3} - (\frac{1}{2} \cdot b \cdot c \cdot \gamma_w H) \frac{b}{3} = 0 \Rightarrow b = \frac{H}{\sqrt{s-c}} = \frac{H}{\sqrt{s-1}}$ for $c=0$

Base width for no sliding = $\mu \left[(\frac{1}{2} b \cdot H \cdot s \cdot \gamma_w) - \frac{1}{2} (b \cdot c \cdot \gamma_w H) \right] = \frac{1}{2} \gamma_w H^2 \Rightarrow b = \frac{H}{\mu(s-c)} = \frac{H}{\mu(s-1)}$

Minimum base width = $\frac{H}{\sqrt{s-c}}$

Limiting Height of elementary profile:- $f = \sigma_{Id} = \frac{1}{2} \gamma_w (s-c+1) \Rightarrow H = \frac{f}{\gamma_w (s-c+1)} = \frac{f}{\gamma_w (s+1)}$ if $c=0$
if $\gamma_w = 9810 \text{ N/m}^3$, $s = 2.4$, $f = 2943 \text{ kN/m}^2$ then $H = 88 \text{ m}$

Lacey's Method

Canal Design

Kennedy's Method

Given Q , for design, side slope

- Calculate silt factor $f = 1.76 \sqrt{m}$ $m = d_{50} \text{ (mm)}$
- Calculate the velocity V , $V = [Q f^{1/4} / 1.40]^{1/6}$
- Calculate A $A = Q/V$
- Calculate Perimeter P $P = 4.75 \sqrt{Q}$
- $A = BD + \frac{3}{2} D^2$ } Solve simultaneously & find B & D
 $P = B + \sqrt{3^2 + 1} D$
- Calculate HMR 'R' $R = A/P$
- Verify R $R = 5/2 V^{7/3}$
- Calculate bed slopes $S = f^{5/3} / 3340 Q^{1/6}$

Method 1 Given Q, N, m, S

- Assume trial value of D in m.
- Calculate the velocity V , $V = 0.55 \text{ m } D^{0.64}$
- $A = Q/V$
- Assume $z = 0.5$ find bed width B
 $A = BD + 0.5 D^2$
- Compute the perimeter P
 $P = B + \sqrt{3^2 + 1} D$ $R = A/P$
- Calculate R
- Calculate actual mean velocity from Kutter's eq:
 $V = \frac{23 + \frac{1}{N} + \frac{0.00155}{S}}{1 + (23 + \frac{0.00155}{S}) N / \sqrt{R}}$

Solve eq. by trial & error & check Velocity of step (2) & (6) to be closer to each other.

Method 2 Given Q, N, m & B/D

- Calculate A in terms of D as $B/D = x \Rightarrow B = Dx$ $A = D^2 (x + 0.5)$
- Calculate V $V = 0.55 \text{ m } D^{0.64}$
- Calculate D as $Q = A \cdot V \Rightarrow D = \left[\frac{Q}{0.55 \text{ m } (x + 0.5)} \right]^{1/2.64}$
- Calculate B from $B = x \cdot D$
- Calculate $V = 0.55 \text{ m } D^{0.64}$
- Knowing V, R, N determine S from
 $V = \frac{23 + \frac{1}{N} + \frac{0.00155}{S}}{1 + (23 + \frac{0.00155}{S}) N / \sqrt{R}}$

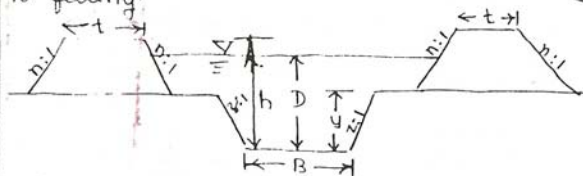
by trial & error

Implicit form of eq.

solve by putting

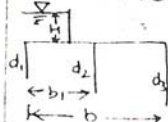
$S = \frac{1}{1000}$, then $\frac{1}{200}$ & so on

Balancing Depth: Depth at which cutting equal to filling



$$y^2 (2n-3) - (B+4nh+2t)y + h(2t+2nh) = 0$$

Weir on Permeable foundation



creep length = $2d_1 + 2d_2 + 2d_3 + b$

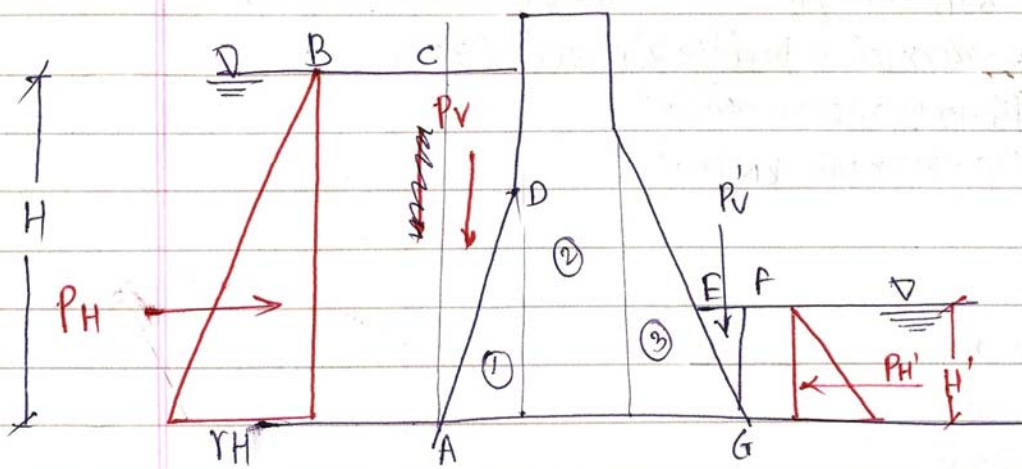
residual head = $H(1 - \frac{d_1}{H})$

Uplift pressure = $\gamma_w \cdot h$

Thickness of floor = $\frac{4}{3} \frac{h_1}{(S-1)}$

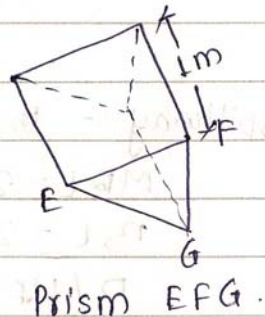
$S = 2.24$

Gravity dam



$$P_H = \frac{1}{2} \gamma H^2$$

$$P_H' = \frac{1}{2} \gamma H'^2$$



Uplift acts due to seepage through dam.

Irrigatⁿ: DHS:

Pro: No. 6]
Last

$$\Sigma M_r = 14.715 \times 10^5 \text{ kNm}$$

$$\Sigma M_o = 9.81 \times 10^5 \text{ kNm}$$

$$\Sigma V = 49.05 \times 10^3 \text{ kN/m}$$

$$\bar{x} = \frac{\Sigma M_r - \Sigma M_o}{\Sigma V} = \frac{(14.715 - 9.81) \times 10^5}{49.05 \times 10^3} = 10 \text{ m.}$$

$$e = \frac{b}{2} - \bar{x} = \frac{50}{2} - 10 = 15 \text{ m.} > \frac{b}{6} = 8.33 \text{ m.}$$

Vertical stress:- $\sigma_{yd} = \frac{\Sigma V}{b} \left[1 + \frac{6e}{b} \right]$

$$= \frac{49.05 \times 10^3}{50} \left[1 + \frac{6 \times 15}{50} \right]$$

$$= 2.747 \times 10^3 \text{ kN/m}^2 \text{ (comp)} - \text{safe.}$$

$$\sigma_{yu} = \frac{\Sigma V}{b} \left(1 - \frac{6e}{b} \right) = -784.8 \text{ kN/m}^2 \text{ Unsafe for tension}$$

Allowable comp. stress in concrete = 6867 kN/m²
Tensial ~~~~~ = 500 kN/m²

* Max. Principal stresses:- (at toe)

$$\begin{aligned}\sigma_{ID} &= \sigma_{VD} \cdot \sec^2 \phi_D \quad \tan \phi_D = 0.7 \quad \phi_D = 35^\circ \\ &= 2.747 \times 10^3 \times \sec^2(35^\circ) \\ &= 40.927 \times 10^2 \text{ kN/m}^2\end{aligned}$$

Pro: ① Spillway :-

$$MRL = 252 \text{ m}$$

$$B.L = 230 \text{ m}$$

$$D/HFL = 235$$

$$Q = 5000 \text{ cumec}$$

$$L_e = 400 \text{ m}$$

$$C = 2.1$$

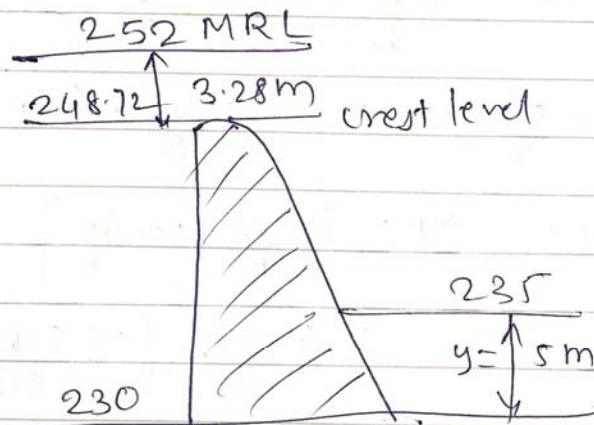
Solⁿ:-

$$Q = C \cdot L_e \cdot H_e^{3/2}$$

$$\therefore 5000 = 2.1 \times 400 \times H_e$$

$$\therefore H_e = 4.52 \text{ m}$$

$$H_e = 3.28 \text{ m}$$



Types:-

$$z = \text{fall} = 252 - 230 = 22 \text{ m.}$$

$$F_1 = \frac{V_1}{\sqrt{g y_1}}$$

$$; V_1 = \sqrt{2g(z + H_e - y_1)} \quad \text{d/s tail water depth.}$$

$$z = \text{Fall}$$

Head due to vel. of approach = Neglect

$$\therefore V_1 = \sqrt{2 \times 9.81 \times (22 + 3.28 - y_1)}$$

$$V_1 = 23.04 \text{ m/s.}$$

$$A = \frac{Q}{V} = \frac{5000}{18.26} = 273.78 \text{ m}^2$$

$$\Rightarrow L_e \times y_1 = 273.78 \Rightarrow y_1 = 0.684 \text{ m}$$

$$\therefore F_1 = \frac{V_1}{\sqrt{g y_1}} = \frac{18.26}{\sqrt{0.684 \times 9.81}} = 7.04$$

(2)

Provide $F_1 > 4.5$, $V_1 > 15 \text{ m/s}$

USBR, Type III skilling basin or
 $F_1 > 4.5$, type II, is skilling basin.

(2)

$$Q = C \cdot L \cdot H_e^{3/2}$$

assume $C = 2.1$

$$8500 = 2.1 \times L \times 10^{3/2}$$

$$\therefore L = 128 \text{ m}$$

$$L_e = L' - 2 [N \cdot k_p + k_a] \cdot H_e$$

↑ No. of piers

Net length.

Σ (of pier span)

Assume $N = 11$

const. based on condⁿ of piers.

Pier & abut. are rounded type.
 For rounded pier,

$$k_a = 0.1$$

$$k_p = 0.01$$

$$\therefore 128 = L' - 2 [11 \times 0.01 + 0.1] \times 10$$

$$L' = 132.2 \text{ m}$$

$\therefore$ No. of pier = 11

$\therefore$ No. of span = 12

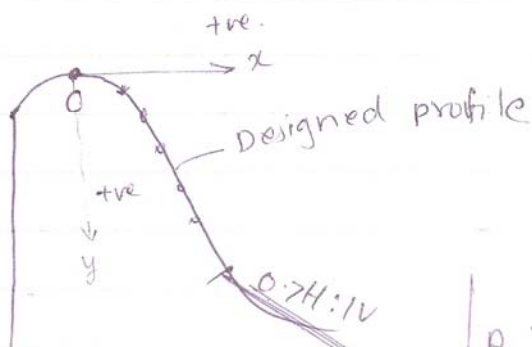
$\therefore$ width of one span = 11m < 12.5m $\therefore$ OK.

$\therefore$ Total length of spillway :-

$$L = 11 \times 12 + 11 \times 3$$

$$= 165 \text{ m}$$

Ans: 9]



See Notes
 for fig.

$$R = \frac{H_d}{4}$$

stilling basin.

$$H_d = 15.5 \text{ m}$$

$$\therefore r_1 = 7.75 \text{ m}$$

$$r_2 = 3.1$$

$$a = 2.7125$$

$$b = 4.485 \text{ } 4.371$$

$$X^{1.85} = 2 H d^{0.85} Y = 2 \times 15.5^{0.85} \times Y \text{ --- WES Eq.}$$

$$\therefore X = 20.55 Y^{1.85}$$

$$\therefore Y = 0.0487 X^{1.85}$$

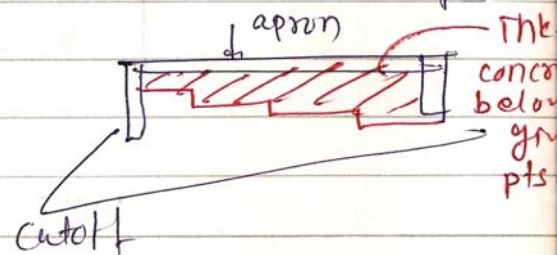
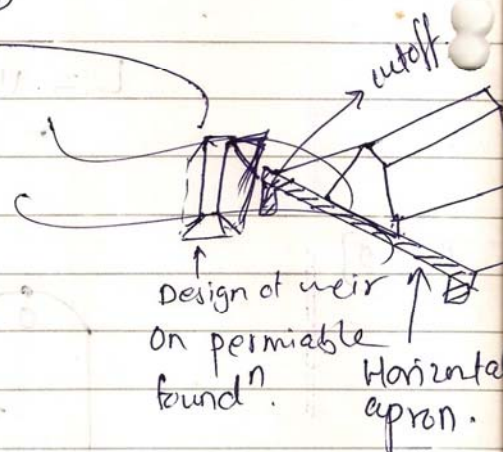
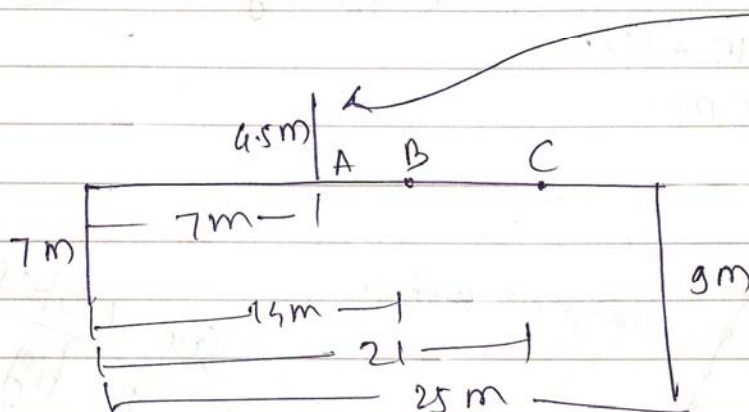
$$x = 0.27 H d \dots \text{Max.}$$

$$= 4.185 \text{ m.}$$

	Y	X
1	1	0.0487
2	2	0.176
3	3	0.372
4	4	0.633
4.185		0.688

$$\text{Provide } R = b \frac{1}{4} \text{ Ht. of spillway} = 3.875 \text{ m.}$$

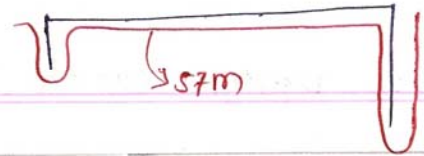
Pro: ③



Total creep length = $7 \times 2 + 25 + 9 \times 2 = 57 \text{ m}$
 water creeps below cutoff & apron as.

(2)

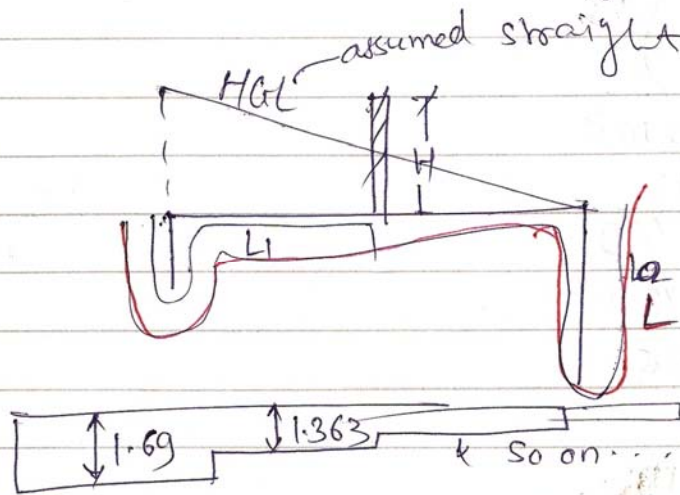
By Bligh's creep theory.



① At pt. A (7m)

(a) creep length $L_1 = 7 \times 2 + 7 = 21 \text{ m}$.

(b) Hydraulic gradient Residual seepage head at A = h_1

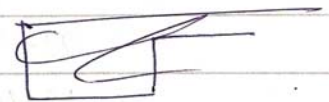


$$h_1 = H \left(1 - \frac{L_1}{L} \right)$$

$$\begin{aligned} h_1 &= H \left(1 - \frac{L_1}{L} \right) \\ &= 4.5 \left(1 - \frac{21}{57} \right) \\ &= 2.84 \text{ m.} \end{aligned}$$

$$\begin{aligned} \text{(c) Uplift pres} &= \gamma_w \cdot h_1 \\ &= 9.810 \times 2.84 \\ &= 27.88 \text{ KN/m}^2 \end{aligned}$$

$$\begin{aligned} \text{(d) Thk. of floor at pt. A} &= \frac{4}{3} \frac{h_1}{S - \text{sp. Gr. of matl.}} \\ &= \frac{4}{3} \times \frac{27.88}{2.24} \\ &= 16.6 \text{ m} \end{aligned}$$



These same are same for all the points i.e. B, C.

ii) pt. B (14m)

(a) creep length $L_2 = 7 \times 2 + 14 = 28 \text{ m}$

(b) Residual seepage head at B = $h_2 = 4.5 \left(1 - \frac{28}{57} \right) = 2.29 \text{ m}$

$$\text{(c) Uplift pres} = \gamma_w \cdot h_2 = 9.81 \times 2.29 = 22.46 \text{ KN/m}^2$$

$$\text{(d) Thk. of floor at B} = \frac{4}{3} \times \frac{h_2}{S} = \frac{4 \times 2.29}{3 \times 2.24} = 1.363 \text{ m.}$$