Chapter 4

Gravity Dams, Spillways, Diversion Head Works and Silt Theories

CHAPTER HIGHLIGHTS

- *Gravity dams*
- *Spillway*
- *Diversion head works*
- *Design of weirs*
- *Design of unlined alluvial canals by silt theories*

Gravity Dams

A gravity dam is a dam in which the external forces are resisted by weight of the dam itself. They are constructed either of masonry or of concrete. The gravity dams are strong and stable one and is more cheaper in long run. But the only disadvantage of gravity dam is that it needs skilled labour.

Forces Acting on Gravity Dam

There are many forces which act on the gravity dam they are water pressure, weight of dam, uplift pressure, earthquake forces, ice pressure, wave pressure, etc.

1. **Over turning pressure:**

$$\text{Factor of safety} = \frac{\text{Stabilizing moment}}{\text{Overturning moment}}$$

2. **Sliding:** At any horizontal section of dam, the factor of safety against sliding, $\text{FS} = \dfrac{\mu \Sigma P_V}{\Sigma P_H}$

Where

ΣP_V = Algebraic sum of vertical forces

ΣP_H = Algebraic sum of horizontal forces causing sliding.

$$\text{Sliding factor, } \tan\theta = \frac{\Sigma P_H}{\Sigma P_V}$$

$$\text{Factor of safety against sliding} = \frac{\mu}{\tan\theta}$$

$$\text{Shear friction factor} = \frac{\mu \Sigma P_V + B\cdot q}{\Sigma P_H}$$

Where

B = Width of joint or section area = $B \times 1$

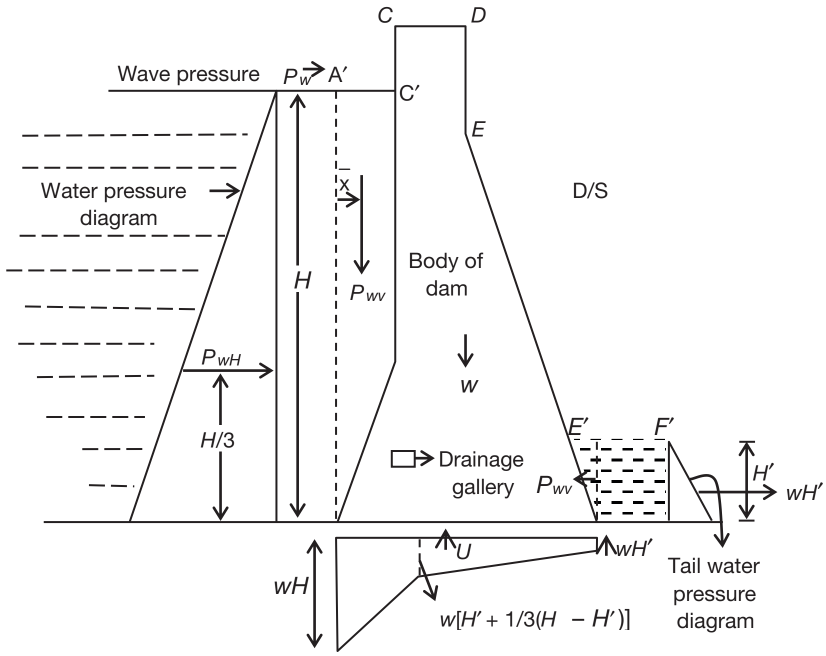
q = Shear strength of joint = 14 kg/cm^2 (for rock foundation)

3. **Compression or crushing at base:** The maximum pressure on the foundation soil due to dam construction shall be less than safe bearing capacity of foundation soil. The pressure at base on the soil is found as follows:

$$p = \frac{\Sigma P_V}{B}\left[1 \pm \frac{6e}{B}\right], \quad e = \text{eccentricities}$$

$$p_{\max} = \frac{\Sigma P_V}{B}\left[1 + \frac{6e}{B}\right]$$

$$p_{\min} = \frac{\Sigma P_V}{B}\left[1 - \frac{6e}{B}\right]$$



Elementary profile of gravity dam

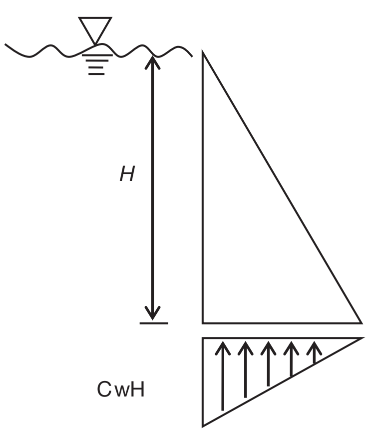
4. **Tension:** For no tension to develop, the eccentricity should be less than $B/6$. In other words the resultant should always lie within middle third of base.
5. The mixture of slit and water behaves as liquid with unit weight taken as 1360 kg/m^3. This is known as slit pressure.
6. **Elementary profile of a gravity dam:**
   - For no tension condition, minimum base width

$$B = \frac{H}{\sqrt{(G-C)}}$$

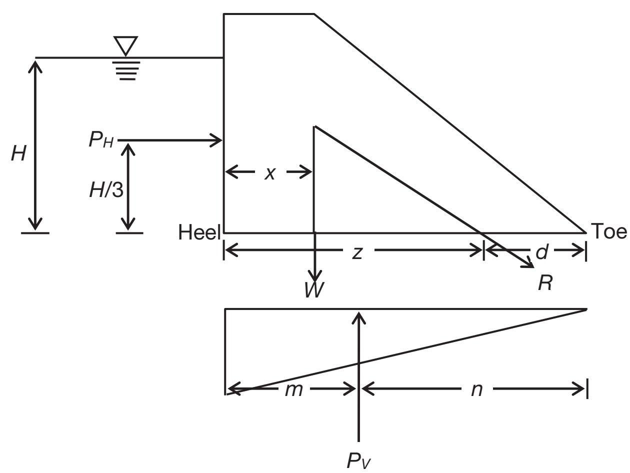
If uplift is not considered, $B = \dfrac{H}{\sqrt{G}}$

   - For no sliding condition $B = \dfrac{H}{\mu(G-C)}$

If uplift is not considered, $B = \dfrac{H}{\mu G}$



Stability Calculations for a Gravity Dam



- The resultant distance from heel is

$$Z = \frac{P_H\left(\frac{H}{3}\right) + W(x) - P_V \cdot m}{(W - P_V)}$$

$$= \frac{\text{Algebraic sum of moments about heel}}{\text{Net weight of dam}}$$

Eccentricities, $e = z - \left(\dfrac{B}{2}\right)$

- The resultant distance from toe is

$$Z = \frac{P_H\left(\frac{H}{3}\right) + P_V \cdot n - W(B - x)}{(W - P_V)}$$

$$= \frac{\text{Algebraic sum of moments about toe}}{\text{Net weight of dam}}$$

Eccentricity, $e = \left(\frac{B}{2}\right) - d$

- For no tension condition, $e \le \left(\frac{B}{6}\right)$

$$p_{\max} = \frac{\Sigma P_V}{B}\left(1 + \frac{6e}{B}\right)$$

$$p_{\min} = \frac{\Sigma P_V}{B}\left(1 - \frac{6e}{B}\right)$$

$$\Sigma P_V = (W - P_V)$$

- Factor of safety against overturning

$$= \frac{W(B-x)}{P_H\left(\frac{H}{3}\right) + P_V \cdot n}$$

- Shear stress at the toe, $\tau = (p_n - p)\tan\beta$
- Principal stress in the dam material near the toe.

Maximum principal stress in the dam material at the toe is:

$$\sigma_1 = p_n \sec^2\beta - p \tan^2\beta$$

when there is no tail water, then $p = 0$

$$\Rightarrow \sigma_1 = p_n \sec^2\beta$$

Where

γ_w = Unit weight of water = 1 ton/m^3
P_u = Total uplift pressure $= \frac{1}{2} \cdot cWHB$
d = Distance of resultant from toe
W = Total weight of dam
c = Uplift coefficient (varies from 0 to 1)
z = Distance of resultant from heel
p_n = Maximum stress on the soil at the toe
p = water pressure at the toe $= \gamma_w \times h$
β = slope of D/S face of dam with vertical
x = CG of W from heel

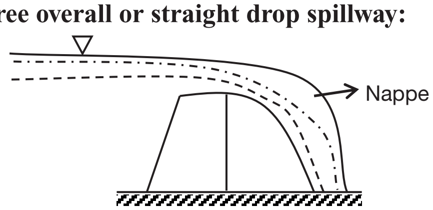
Spillway

They are the openings provided at the body of the dam to discharge safely the excess water or flood water when the water level rises above the normal pool level.

Types of spillways

- Free overfall (or) Straight drop spillway
- Ogee spillway (or) Overflow spillway
- Siphon spillway
- Volute siphon spillway
- Chute (or) Tough spillway
- Channel spillway

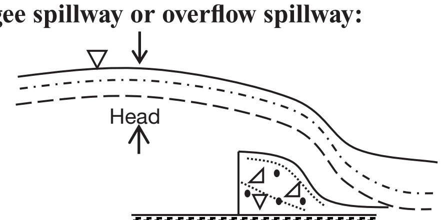
1. Free overall or straight drop spillway:



Straight drop spillway

- The D/S apron is subjected to large impact pressure. These type of spillways are generally used in low earth dams.
- The downstream face is vertical.

2. Ogee spillway or overflow spillway:



Ogee spillway

- It is generally used in gravity and arch dams. The nape shaped profile for the crest of ogee spillway is an ideal profile.
- If discharge at head < design head then positive hydrostatic pressure is exerted on spillways.
- If discharge at head > design head, then negative pressure or suction is created and thereby the discharge is increased.
- The equation of ogee shape is

$$X^{1.85} = 2 \times H^{0.85} \times y$$

Where

H = Design head
x, y = Coordinates of crest profile

- Discharge in Ogee spillway

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

Where

Q = Discharge
C = Variable coefficient of value 2.1 to 2.5
L_e = Effective length of crest

H_e = Total head on crest = $H + h_a$

$$h_a = \frac{V_a^2}{2g}$$

Where

h_a = Head due to velocity of approach

V_a = Velocity of approach

3. **Siphon spillway:** The spillway which acts on the principle of siphon is known as siphon spillway.

$$\text{Discharge } Q = C \cdot A \cdot \sqrt{2gH}$$

Where

A = Area of cross-section at crown

H = Operating head = Reservoir level – Centre of outlet (if outlet is discharging freely) (or) Reservoir – downstream tail water level (if outlet is submerged)

C = Coefficient of discharge

4. **Volute siphon spillway:** The funnel is at the top end and the bottom end is connected to a bend pipe. When the water level rises the water flows in spiral motion through it.
5. **Chute or trough spillway:** This spillway is rectangular open channel provided on dam to discharge the surplus water from reservoir to the same river at the downstream side.
6. **Channel spillway:** It is the spillway which is constructed at right angles to the dam and is completely separated from the main body of the dam.

Wave height: $h_w = 0.0322\sqrt{F \cdot V}$ metres

$F > 32$ km

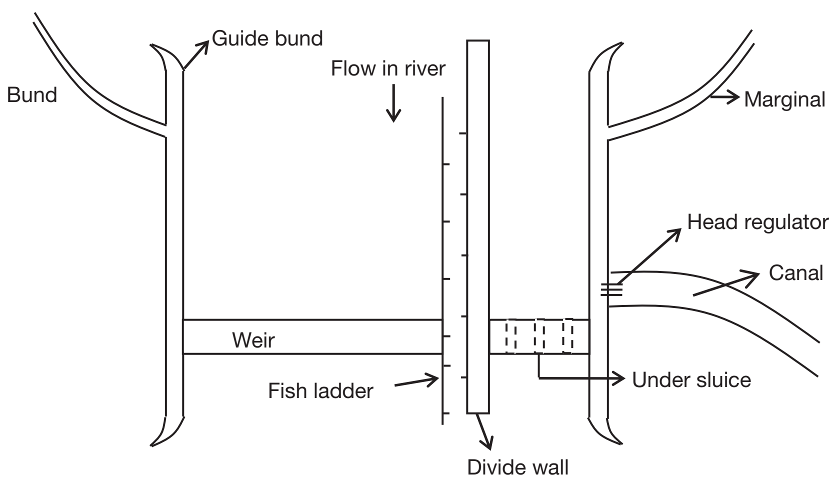
V = Wind velocity in km/h

F = Fetch of reservoir in km

Where fetch is the straight length of water expanse measured normal to the axis of dam.

Wave force $P_w = 2 \times \gamma_w \times h_w^2$, where p_w acts at a height of $0.375h_w$ above the still water level.

Diversion Head Works



Works constructed across the river to raise water level and to divert into canal are known as diversion head works.

Weir: The structures which are constructed across the river to raise the water level and divert into the canal.

Barrage: The raising up of water level is much better controlled by the barrage.

Under sluices: The openings provided on the same side of the off taking canal. Discharge of under sluice is greater of:

1. Maximum winter discharge.
2. 10 to 15% of maximum flood discharge.
3. 2 times maximum discharge of off taking canal.

Divide wall: Constructed at right angles to the axis of the weir to separate under sluices from rest of the weir.

Silt excluder: It excludes silt from entering the canal and is provided on the river bed in front of head regulator.

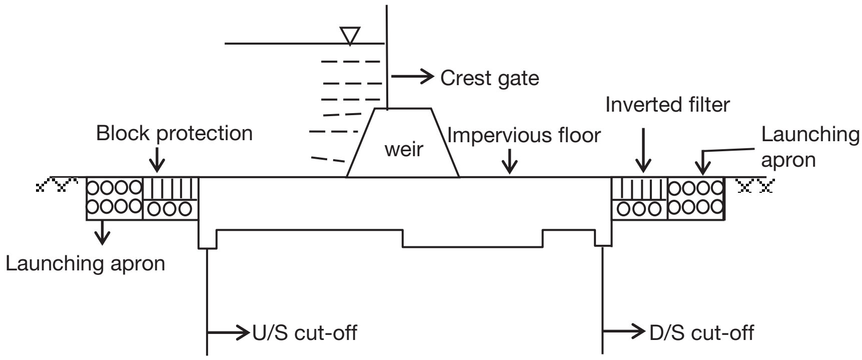
Silt extractor: It removes silt which has already entered the canal from the head.

Fish ladder: It is provided to allow the migration of fish from upstream to downstream side.

Cross-section of a Weir

Impervious floor: It is provided to resist the uplift pressure on the downstream side.

Cut-off: It is provided to increase the creep length and thereby reducing the hydraulic gradient.



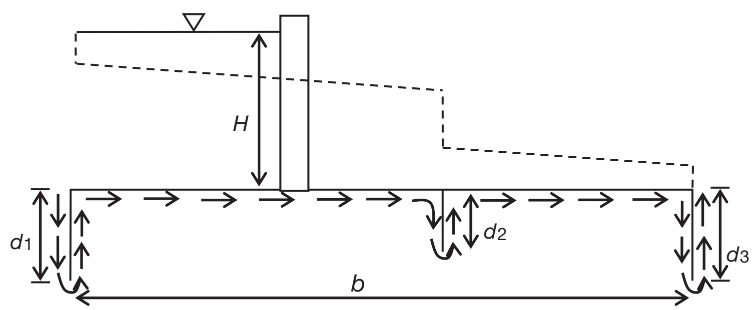
Inverted filter: It consists of layers of materials of increasing permeability from bottom to top. It allows seepage water to escape without dislocating soil particles.

Launching apron: It is loosely packed stones to protect the impervious floor and sheet piles from scour holes progressing towards the impervious floor and piles.

Block protection: It is provided on the U/S side to protect impervious floor from the effect of scouring. It is made of concrete blocks over a bed of loose stone packing.

Design of Weirs

Bligh's Creep Theory



Total creep length is the length of path traversed by percolating water.

Thus total creep length $L = b + 2d_1 + 2d_2 + 2d_3$

Bligh assumed that head loss per unit length of creep is constant throughout percolation passage.

Bligh's creep coefficient $C = \frac{1}{i} = \frac{L}{H}$

$$L = CH.$$

Safety Against Piping

To avoid piping, the minimum length of creep

$L = CH$ or hydraulic gradient, $i \leq (1/C)$

H = seepage head (the difference between water levels on upstream and downstream)

C value ranges from 5 to 18 depending on type of soil.

$C = 18 \rightarrow$ for Fine sand

$C = 12 \rightarrow$ for coarse sand

$C = 5$ to $9 \rightarrow$ for gravel

Safety Against Uplift Pressure

As per Bligh's theory, thickness to be provided $t = \frac{4}{3}\frac{h}{(G_c - 1)}$

Where

h = Ordinate of hydraulic gradient line from top of floor

G_C = Specific gravity of floor material (concrete)

Limitations of Bligh's Creep Theory

1. There is no difference between vertical and horizontal creep.
2. Significance of exit gradient is not considered.
3. There is no difference between effectiveness of outer and inner faces of sheet pile.

Lanes Weighed Creep Theory

Lane proposed that horizontal creep is less effective in reducing uplift or causing loss of head, than the vertical creep. A weightage factor of 1/3 is proposed for horizontal creep and 1.0 for vertical creep.

Weighted creep length,

$$L = \left(\frac{1}{3}\right)H + V$$

Where

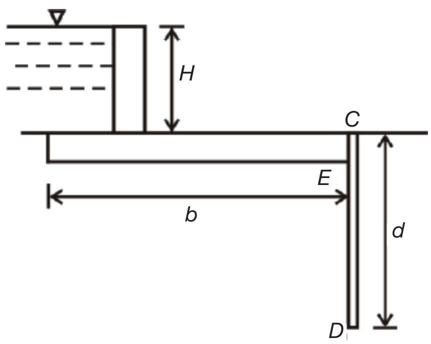
H = Horizontal length

V = Vertical length

For safety against piping, $\frac{H}{L} \le \frac{1}{C_1}$

C_1 = Lanes coefficient of creep

Khosla's Theory



Exit gradient, $G_E = \frac{H}{d} \times \frac{1}{\pi\sqrt{\lambda}}$

$$\lambda = \frac{1+\sqrt{1+\alpha^2}}{2}$$

$$\alpha = \frac{b}{d}$$

The allowable exit gradient should be within $\frac{1}{5}$ to $\frac{1}{6}$.

Features of Khosla's Theory

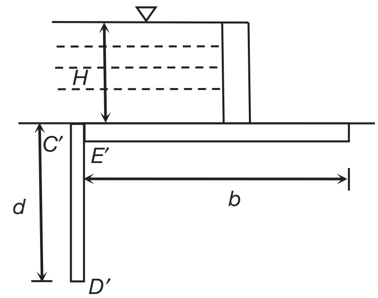
1. The vertical cut-off at downstream end is needed to prevent undermining.
2. Intermediate sheet piles must be larger in length than the outer ones, else they are ineffective.
3. Outer faces of sheet piles are more effective than inner ones.
4. Undermining of floor starts from downstream and if $i > i_c$ (critical hydraulic gradient):
   - Uplift pressure heads at points D, E and C for sheet pile at downstream end:

$$h_\varepsilon = \frac{H}{\pi}\cos^{-1}\left(\frac{\lambda-2}{\lambda}\right)\frac{\pi}{180}$$

$$h_D = \frac{H}{\pi}\cos^{-1}\left(\frac{\lambda-1}{\lambda}\right)\frac{\pi}{180}$$

$$h_c = 0$$

   - Uplift pressure heads at points D', E' and C' for sheet pile at upstream end as shown below are



$$h_{C'} = H - h_C$$

$$h_{D'} = H - h_D$$

$$h_{E'} = H - h_E$$

SOLVED EXAMPLES

Example 1

Uplift pressure at points E and D (figure A) of a straight horizontal floor of negligible thickness with a sheet pile at downstream end are 28% and 20% respectively. If the sheet pile is at upstream end of the floor and the uplift pressure at points D_1 and C_1 are **[GATE, 2005]**

Solution

At point D_1: $h_{D_1} = (100 - h_D)\%$

$= 100 - 20 = 80\%$

At point C_1: $h_{C_1} = (100 - h_E)\%$

$= 100 - 28 = 72\%$

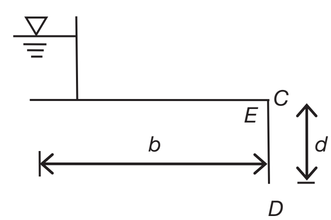


Figure (A)

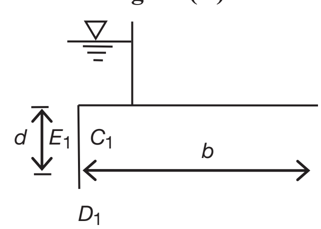


Figure (B)

Design of Unlined Alluvial Canals by Silt Theories

Kennedy's Theory

1. Critical velocity V_0: Velocity which will keep the channel free from silting and scouring is known as critical velocity.

   $V_0 = 0.55\ D^{0.64}$ (applicable for Punjab region only)

   Where V_0 = Critical velocity, in m/sec

   D = depth of flow, in m

2. Critical velocity ratio $m = \dfrac{V_K}{V_0}$

   $\Rightarrow V_0 \times m = V_K$

   $V_K = m(0.55\ D^{0.64})$

3. According to Kutter's equation,

$$V = \frac{23 + \dfrac{1}{N} + \dfrac{0.00155}{S}}{1 + \left(23 + \dfrac{0.00155}{S}\right)\dfrac{N}{\sqrt{R}}} \times \sqrt{RS}$$

   Where

   V = Mean velocity of flow, in m/s

   R = Hydraulic radius, m

   S = Bed slope

   N = Rugosity coefficient

4. Design of channel:
   (a) $Q = AV$
   (b) Kutter's equation for V
   (c) $V_K = 0.55$ m $D^{0.64}$
   (d) Data required is Q, N, m and S (or) B/D ratio
   (e) Assume a trial value of D in meters
   (f) Calculate velocity V from equation
   $V_K = 0.55$ m $D^{0.64}$
   (g) Calculating cross-sectional area $A = Q/V$
   (h) Assuming side slope of channel as 1/2 horizontal to 1 vertical
   (i) The actual mean velocity of flow from Kutters equation is calculated
   (j) If velocity calculated by Kutters equation is nearly equal to V_K, then the assumed depth is correct. If not the trial is repeated again.

The above procedure can be carried out with the help of Garret's diagram.

Drawbacks of Kennedy's Theory

1. Kutter's equation is not accurate in all cases.
2. No equation for bed slope(s) by Kennedy.
3. Silt transportation is incorporated in a single factor 'm'.
4. Involves trial and error process.

Lacey's Theory

This theory is known as regime theory. A stable channel which has been altered due to the scouring and silting effects is known as regime channel. Cross-section of regime channel is semi-elliptical section.

The conditions for a channel to be regime are:

1. Channel should be flowing uniformly in unlimited incoherent alluvium of same character as that transported by channel
2. Silt grade and silt charge should be constant
3. Discharge should be constant

Lacey's Regime Equations

1. Silt factor: $f = 1.76\sqrt{d}$
   Where, d = Mean soil particle size, in mm
2. Velocity $V = \left(\dfrac{Qf^2}{140}\right)^{1/6}$
3. Wetted perimeter $P = 4.75\sqrt{Q}$
   P in m
   Q in m^3/s
4. Longitudinal slope $S = \dfrac{f^{5/3}}{3340\,Q^{1/6}}$
5. Velocity, $V = \sqrt{(2/5)\,f \cdot R}$
6. Scour depth, $R = 1.35\left(\dfrac{q^2}{f}\right)^{1/3}$

   Where

   q = Discharge per metre width = Q/B

   R = Depth measured from HFL (in m)
7. Assuming side slopes as $\dfrac{1}{2}$ horizontal to 1 vertical.

Drawbacks of Lacey's Theory

1. Regime conditions are only theoretical, they may not be achieved in practice.
2. Equations are derived based on single factor 'f'.
3. Silt charge and silt grade have not been defined
4. This equation is empirical

Example 2

Design an irrigation channel in alluvial soil according to Lacey's silt theory with following data:

Discharge, $Q = 50$ m^3/s ; Lacey's silt factor, $f = 1$; Slope = 0.5 : 1. **[GATE, 1994]**

Solution

$$V = \left(\frac{Qf^2}{140}\right)^{1/6}$$

$$= \left(\frac{50 \times 1^2}{140}\right)^{1/6} = 0.842 \text{ m/s}$$

$$Q = A.V \Rightarrow 50 = A \times 0.842$$

$$A = \frac{50}{0.842} = 59.38 \text{ m}^2$$

$$\Rightarrow 59.38 = (B + \eta D)D$$

$$(B + 0.5D)D = 59.38 \quad (1)$$

$$P = 4.75\sqrt{Q} = 4.75\sqrt{50} = 33.58$$

$$B + 2D\sqrt{1+\eta^2} = 33.58$$

$$B + 2.23D = 33.58$$

$$B = 33.58 - 2.23D \quad (2)$$

$$\Rightarrow (33.58 - 2.23D + 0.5D)D = 59.38$$

(From Eqs. (1) and (2))
On solving,
$D = 1.97$ m
$\Rightarrow B = 33.58 - (2.23 \times 1.88) = 29.18$ m

$$S = \frac{f^{5/3}}{3340\,Q^{1/6}} = \frac{1}{3340(50)^{1/6}} = \frac{1}{64}.$$

Exercises

1. Which one of the following equations represents the downstream profile of Ogee spillway with vertical upstream face? (x, y) are the co-ordinates of point on the downstream profile with origin at the crest of spillway and H_d a design head.

(A) $\dfrac{y}{H_d} = -0.5\left[\dfrac{x}{H_d}\right]^{1.85}$

(B) $\dfrac{y}{H_d} = -0.5\left[\dfrac{x}{H_d}\right]^{1/1.85}$

(C) $\dfrac{y}{H_d} = -2.0\left[\dfrac{x}{H_d}\right]^{1.85}$

(D) $\dfrac{y}{H_d} = -2.0\left(\dfrac{x}{H_d}\right)^{1/1.85}$

2. **Assertion (A):** A seepage passing through the body of an earth dam affects the weight of dam.

Reason (R): The specific weight of submerged soil is not dependent on the porosity of soil.

(A) Both A and R are true and R is the correct explanation of A.
(B) Both A and R are true but R is not a correct explanation of A.
(C) A is true but R is false.
(D) A is false but R is true.

3. If ρ is the specific gravity of the material used in the design of a masonry dam of triangular section, then the ratio between the height and base width of the dam for structural safety and stability is equal to

(A) $\sqrt{2\rho}$ (B) $\sqrt{\rho}$
(C) $\dfrac{1}{\rho}$ (D) $\dfrac{1}{\sqrt{\rho}}$

4. In connection with the design of barrage, identify correct matching of List I (Criteria of design) with List II (Items of design).

	List I		List II
i.	Width of waterway	**a.**	Scour depth and exit gradient
ii.	Level and length of downstream floor	**b.**	Lacey's formula for wetted perimeter and discharge capacity of barrage as computed by weir equation
iii.	Depth of sheet piles and total length of barrage floor	**c.**	Uplift pressure variation
iv.	Barrage floor thickness	**d.**	Hydraulic jump consideration

Codes:

	(i)	(ii)	(iii)	(iv)		(i)	(ii)	(iii)	(iv)
(A)	a	b	c	d	(B)	d	c	b	a
(C)	b	a	d	c	(D)	b	d	a	c

5. While designing a hydraulic structure, the peizometric head at bottom of the floor is computed as 10 m. The datum is 3 m below floor bottom. The assured standing water depth above the floor is 2 m. The specific gravity of floor material is 2.5. The floor thickness should be

(A) 2 m (B) 3.33 m
(C) 4.4 m (D) 6 m

6. The minimum size of gravel that will not move in the bed of a wide rectangular channel of depth 0.8 m and longitudinal slope 0.0041 is:
(A) 11 mm (B) 23 mm
(C) 36 mm (D) 57 mm

7. Uplift pressures at points E and D (figure A) of a straight horizontal floor of negligible thickness with a sheet pile at downstream end are 28% and 20% respectively. If the sheet pile is at upstream end of floor (figure B), the uplift pressures at points D_1 and C_1 are

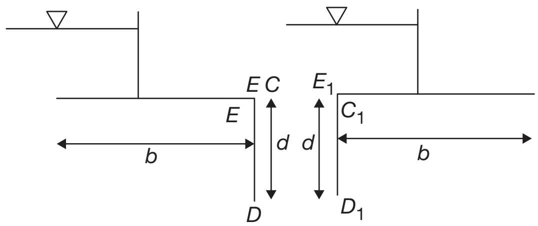


Figure A **Figure B**

(A) 68% and 60% respectively.
(B) 80% and 72% respectively.
(C) 88% and 70% respectively.
(D) 100% and zero respectively.

8. At a certain point in the floor of weir, the uplift pressure head due to seepage is 4.5 m. If the relative density of concrete is 2.5, the minimum thickness of floor required at this point to counteract the uplift pressure is
(A) 1 m
(B) 2 m
(C) 3 m
(D) 4 m

9. A launching apron is to be designed at downstream of a weir for discharge intensity of 6.5 $m^3/s/m$. For design of launching aprons the scour depth is taken two times of lacey's scour depth. The silt factor of the bed material is unity. If tail water depth is 4.4 m. The length of launching apron in the launched position is
(A) $\sqrt{5}$ m
(B) 4.7 m
(C) 5 m
(D) $5\sqrt{5}$ m

10. On which of the canal systems, R.G. Kennedy, executive engineer in Punjab irrigation dependent made his observations for proposing his theory on stable channels?
(A) Krishna western delta canals
(B) Lower bari doab canals
(C) Lower Chenab canals
(D) Upper bari doab canals

11. Match List I (Theory) with List II (Propounded by) and select the correct answer using the codes given in the following lists:

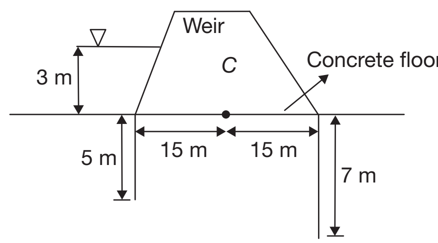
	List I		List II
a.	Exit gradient	**1.**	G. Lacey
b.	Alluvial canal	**2.**	L. K. Sherman
c.	Unit hydrograph	**3.**	A. N. Khosla
d.	Boundary layer	**4.**	C. Inglis
		5.	T. V. Karman
		6.	L. Prandtl

Codes:

	a	b	c	d		a	b	c	d
(A)	1	3	2	6	(B)	6	2	3	5
(C)	3	1	2	6	(D)	3	1	4	2

12. Design an irrigation channel in alluvial soil according to lacey's silt theory with following data, discharge is 50 m^3/s. Lacey's silt factor = 1, side slope $\frac{1}{2H}:1V$. The bed slope is
(A) $\frac{1}{6410}$ (B) $\frac{1}{4280}$
(C) $\frac{1}{3748}$ (D) $\frac{1}{8432}$

13. The cross-section of a weir is shown in the following figure. Relative density of concrete is 2.5.



Match the following:

P.	Uplift pressure head as per bligh's theory	**1.**	0.67 m
Q.	Uplift pressure head as perlane's theory	**2.**	0.645 m
R.	Thickness of floor as per bligh's theory	**3.**	1.676 m
S.	Thickness of floor as per lane's theory	**4.**	1.612 m

Codes:

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

14. The cross-section of weir in order from upstream to downstream is ________.
(A) launching apron → block protection → sheet pile → impervious floor → sheet pile → filter → launching apron
(B) block protection → sheet pile → filter → sheet pile → impervious floor → launching apron
(C) impervious floor → launching apron → sheet pile → block protection → sheet pile → filter → launching apron

(D) filter → impervious floor → sheet pile → block protection → launching apron → sheet pile → launching apron

15. According to Lacey's method for design of alluvial channel, the velocity of flow
(A) increases with increase in design discharge.
(B) increases with increase in diameter of silt particle.
(C) increases with increase in silt factor.
(D) All of these

16. Drainage gallery in a dam is used
(A) to provide drainage of the dam.
(B) for post cooling of concrete.
(C) Both A and B
(D) None of these

17. _______ are called safety valves of a dam.
(A) Diversion headwork's
(B) Canal outlets
(C) Spillways
(D) Drainage gallery

18. Non-modular outlet is the one in which discharge
(A) is independent of water levels in the distributing channel and water course.
(B) varies only with water level in the distributing channel.
(C) varies only with water level in the water course.
(D) depends on difference in water levels in distributing channel and water course.

19. Match the following.

	Group A		Group B
1.	Aqueduct	**P.**	Bed of drain well above the canal FSL
2.	Siphon aqueduct	**Q.**	FSL of Canal higher than bed of drain
3.	Super passage	**R.**	High flood level (HFL) of drain higher than canal bed
4.	Siphon	**S.**	Bed of canal is well above the HFL of drain

Codes:

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

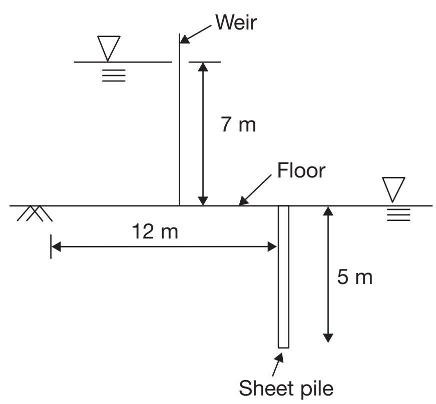
20. The slope of a channel in alluvium is $\frac{1}{3036}$, mean soil particle size is 0.5 mm, velocity = 0.618 m/s. Find the wetted perimeter of the regime channel in metres.
(A) 10.62 (B) 9.46
(C) 11.58 (D) 12.9

21. In a gravity dam the friction coefficient is 0.8. Sum of vertical forces = 7000*t* and sum of horizontal forces = 4000*t*. Base width is 80 m and shear strength is 150*t*/m^2. Find FOS against sliding and shear friction factor at base.
(A) 4.4 and 1.4 (B) 1.4 and 4.4
(C) 3.2 and 1.6 (D) 1.6 and 3.2

22. The limiting height of gravity dam with material of concrete having specific gravity of 2.5 is equal to 100 m. Find crushing stress of concrete (in kg/cm^2).
(A) 20 (B) 25
(C) 30 (D) 35

23. Find the design head (H_d) of the Ogee spillway when a coordinate (–10, 5) of the point on the downstream profile with origin at the crest of the spillway is _______.
(A) 0.56 m (B) 0.72 m
(C) 0.98 m (D) 1.1 m

24. A weir on the permeable foundation with downstream sheet pile is shown in the following figure. The exit gradient as per Khosla's method is _______.



(A) 1 in 2 (B) 1 in 3
(C) 1 in 4 (D) 1 in 5

25. Match the following:

	Group A		Group B
1.	Bligh's theory	**P.**	Upper bari doab canal
2.	Khosla's theory	**Q.**	Regime channel
3.	Lacey's theory	**R.**	Sheet pile is more useful at D/S end
4.	Kennedy's theory	**S.**	Sheet pile is more useful at U/S end

Codes:

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

26. For a channel to be in regime, conditions to be established are:
(A) Channel should be flowing uniformly in unlimited coherent alluvium.
(B) Silt grade and silt charge should be constant.
(C) Both A and B
(D) None of these

27. Calculate the bed width for an irrigation channel to carry a discharge of 6 cumecs and side slopes of the

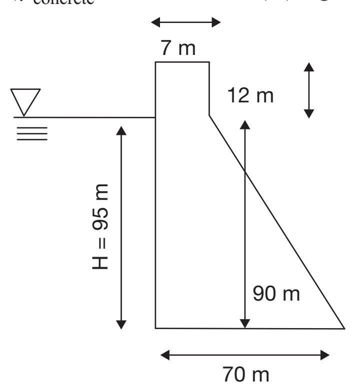
channel are $\frac{1}{2}H : 1V$. The critical velocity ratio is 0.9 and depth of flow is 0.8 m. Bed slope is 0.3 m/km.
(A) 13.75 m (B) 15.25 m
(C) 17.04 m (D) 19.21 m

28. Find the spacing of drains in case of closed drains where the depth of impermeable layer from GL is 10 m and depth of drain below GL is 2 m. Minimum depth of drained WT below GL is 1.5 m. Permeability of soil = 1 cm/s. Discharge through drain is 0.02 m^3/s.
(A) 14.5 m (B) 16.5 m
(C) 18.5 m (D) 20.5 m

29. As a result of the construction of a diversion structure across a river, there will be a rise in the flood level on the upstream side of the structure and it is called as
(A) free board (B) uplift
(C) aggradation (D) afflux

30. Coefficient of discharge of Ogee spillway is
(A) 2 (B) 1.8
(C) 2.2 (D) 2.4

31. The given figure gives the profile of a gravity dam with reservoir level as shown. If the coefficient of friction is 0.75, find the FOS against sliding and if the dam is safe? ($\gamma_{concrete}$ = 2.4 tonnes/m^3) (Neglect uplift pressure)



(A) 1.1 and not safe (B) 1.42 and safe
(C) 2.1 and not safe (D) 1.8 and safe

32. A weir across an alluvial river has a horizontal floor of length 70 m and retains 7 m of water under full pond condition. If the downstream sheet pile is driven to a depth of 6 m below the average bed level, calculate the exit gradient if porosity is 30% and the relative density of soil particles as 2.7. Estimate the vertical exit gradient.
(A) $G_E = 0.181$ and $i_C = 1.48$
(B) $G_E = 0.147$ and $i_C = 2.12$
(C) $G_E = 0.147$ and $i_C = 1.19$
(D) $G_E = 0.181$ and $i_C = 2.12$

33. Which of the statement is incorrect among the drawbacks in Lacey's theory?
(A) Silt transportation is incorporated in a single factor.
(B) Equations are empirical.
(C) Regime conditions are only theoretical.
(D) Silt charge and silt grade have not been properly defined.

34. Match the terms of List A with List B

	List A		List B
P.	Nappe (sheet of water)	**1.**	Canal regulation work
Q.	Aqueduct	**2.**	Spillways
R.	Rigid module	**3.**	Cross drainage work
S.	Canal drop	**4.**	Canal outlet

Codes:

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

35. Find the discharge over an ogee weir with coefficient of discharge equal to 2.4 at a head of 3 m. The length of spillway is 100 m. Crest of weir is 10 m above the bottom of the approach channel having the same width as that of the spillway.
(A) 1247 m^3/s (B) 1276 m^3/s
(C) 1301 m^3/s (D) 1348 m^3/s

36. A check dam is a
(A) flood control structure.
(B) soil conservation structure.
(C) river training structure.
(D) water storage structure.

37. The following parameters relate to the design of weirs on permeable foundation.
I. Scour depth
II. Exit gradient
III. Uplift pressure
IV. Unbalanced head
Design of downstream end pile of the weir depends upon:
(A) I and II (B) I and IV
(C) II and III (D) III and IV

38. Which one of the following is the purpose of providing the downstream sheet pile in a barrage?
(A) To control failure due to piping by high value of exit gradient.
(B) To control failure due to scour.
(C) To stop failure due to sliding.
(D) To stop failure due to uplift pressure.

39. The base width of gravity dam in 25 m. the material of the dam has a specific gravity of 2.56 and the dam is designed as an elementary profile ignoring uplift. What is the approximate allowable height of the dam?
(A) 64 m (B) 40 m
(C) 164 m (D) 80 m

40. Which of the following equations represent the downstream curve of the Ogee spillway? (Where x and y are the co-ordinates of the crest profile measured from the apex of the crest and H is the designed head)

(A) $x^{1.85} = 2H^{0.85}y$
(B) $x = 2H^{1.85}y^{0.85}$
(C) $x^{0.85} = 2H^{1.85}y$
(D) $x = 2H^{0.85}y^{1.85}$

41. What is the regime scour depth for channel is soil with the silt factor of unity and carrying 8 m^2/s of discharge intensity in accordance with Lacey's regime theory?
(A) 3.6 m (B) 4 m
(C) 5.4 m (D) 25.6 m

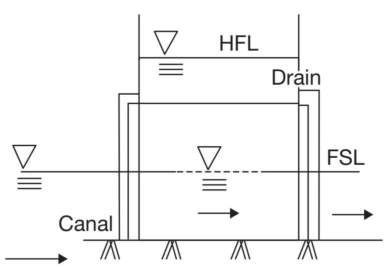
42. In the eccentricity of total self weight W of a masonry dam at its base is equal to one fourth of base width B, then the maximum pressure at the base is given by
(A) $\frac{2W}{3B}$ (B) $\frac{4W}{3B}$
(C) $\frac{5W}{3B}$ (D) $\frac{8W}{3B}$

43. A channel designed by Lacey's theory has a velocity of 0.88 m/s. The silt factor is 1.1, then hydraulic mean depth will be
(A) 1.95 m (B) 1.76 m
(C) 1.63 m (D) 1.5 m

44. The maximum height of a low gravity dam of elementary profile made of concrete of relative density 2.5 and safe allowable stress of foundation material 3.8 Mpa without considering uplift force is about.
(A) 113 m (B) 217m
(C) 279 m (D) 325 m

45. A discharge of 72 m^3/s is to be allowed through siphon spillway of 2 m width and 75 cm depth with working head of 8 m. The number of spillways to be provided will be (Take coefficient of discharge Ogee spillways = 0.64)
(A) 2 (B) 4
(C) 6 (D) 8

46. The following figure represents which type of cross drainage work?



(A) Aqueduct (B) Syphon aqueduct
(C) Super passage (D) Syphon

47. The outlet which falls under Rigid Module category is
(A) Kennedy's gauge module.
(B) Crump's open flume outlet.
(C) Pipe–cum open flume outlet.
(D) Gibb's module.

48. When hydraulic jump takes place on sloping glacis, the vertical component of velocity
(A) increases
(B) decreases
(C) unaffected
(D) decreases and then increases

49. Match List I with List II and select the correct option.

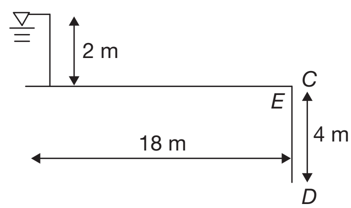
	List I		List II
P.	Vertical drop weir	**1.**	consists of a body wall/ weir wall
Q.	Masonry sloping weir	**2.**	suitable for soft sandy foundations
R.	Dry stone sloping weir	**3.**	Cistern is provided at downstream side to dissipate energy
S.	Parabolic weir	**4.**	Suitable for any type of foundation

Codes:

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

Direction for questions 50 and 51:

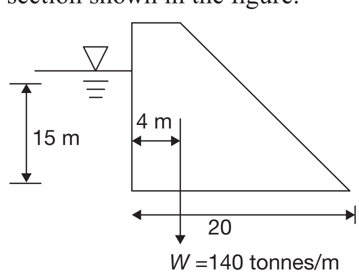
A horizontal impervious floor of length 18 m is provided with a cut-off pile of 4 m depth at its downstream end as shown in figure below. The head causing flow is 2 m and the FOS against piping if for the soil $G = 2.7$ and void ratio is 0.7.



50. Find uplift pressure at point D.
(A) 0.21 m (B) 0.38 m
(C) 0.56 m (D) 0.74 m

51. Find the exit gradient as per Khosla's theory.
(A) 0.091 (B) 0.095
(C) 0.29 (D) 0.36

52. Find the factor of safety against overturning for dam section shown in the figure.



(A) 1 (B) 2
(C) 3 (D) 4

53. Choose the correct statement(s)

The following are some points related to Kennedy's and Lacey's theories.

I. Kennedy used woods table for longitudinal slope of the canal.

II. Lacey proposed that the shape of a regime channel should be a semi ellipse.

III. Kennedy gave the idea that non-sitting and non-sourcing channel will be a regime channel.

IV. Lacey's equation includes a concentration of silt as variable.

The correct statements from the above are

(A) Only I and II (B) III and IV

(C) I, II, and III (D) All of these

Previous Years' Questions

1. As per Lacey's method for design of alluvial channels, identify the true statement from the following: **[GATE, 2007]**

(A) Wetted perimeter increases with an increase in design discharge.

(B) Hydraulic radius increases with an increase in silt factor.

(C) Wetted perimeter decreases with an increase in design discharge.

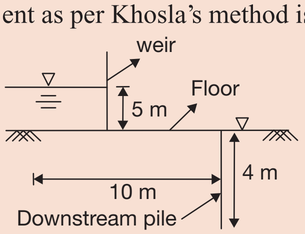
(D) Wetted perimeter increases with an increase in silt factor.

2. The base width of an elementary profile of gravity dam of height H is b. The specific gravity of material of dam is G and uplift pressure coefficient is K. The correct relationship for no tension at the heel is given by **[GATE, 2008]**

(A) $\dfrac{b}{H} = \dfrac{1}{\sqrt{G-K}}$ (B) $\dfrac{b}{H} = \dfrac{1}{G\sqrt{1-K}}$

(C) $\dfrac{b}{H} = \dfrac{1}{G-K}$ (D) $\dfrac{b}{H} = \dfrac{1}{K\sqrt{G-K}}$

3. A weir on a permeable foundation with downstream sheet pile is shown in the figure below. The exit gradient as per Khosla's method is **[GATE, 2008]**



(A) 1 in 6 (B) 1 in 5

(C) 1 in 3.4 (D) 1 in 2.5

4. A stable channel is to be designed for a discharge of Q m^3/s with silt factor f as per Lacey's method. The mean flow velocity (m/s) in channel is obtained by **[GATE, 2008]**

(A) $\left(\dfrac{Qf^2}{140}\right)^{1/6}$ (B) $\left(\dfrac{Qf}{140}\right)^{1/3}$

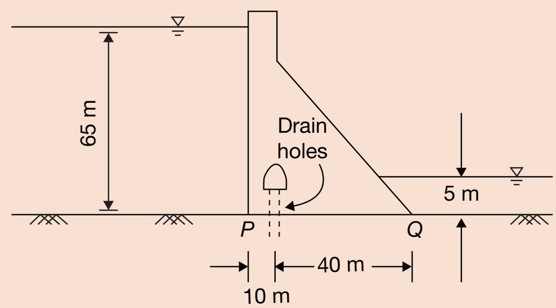
(C) $\left(\dfrac{Q^2 f^2}{140}\right)^{1/6}$ (D) $0.48\left(\dfrac{Q}{f}\right)^{1/3}$

5. The depth of flow in an alluvial channel is 1.5 m. If critical velocity ratio is 1.1 and Manning's constant n = 0.018, the critical velocity of channel as per Kennedy's theory is **[GATE, 2009]**

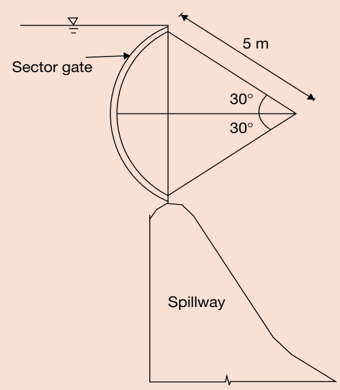
(A) 0.713 m/s (B) 0.784 m/s

(C) 0.879 m/s (D) 1.108 m/s

6. A concrete gravity dam section is shown in the figure. Assuming unit weight of water as 10 kN/m^3 and unit weight of concrete as 24 kN/m^3, the uplift force per unit length of the dam (expressed in kN/m) at PQ is ______. **[GATE, 2016]**



7. A sector gate is provided on a spillway as shown in the figure. Assuming g = 10 m/s^2, the resultant force per metre length (expressed in kN/m) on the gate will be ______. **[GATE, 2016]**



8. A hydraulically efficient trapezoidal channel section has a uniform flow depth of 2 m. The bed width (expressed in m) of the channel is ______. **[GATE, 2016]**

9. Profile of a weir on permeable foundation is shown in figure 1 and an elementary profile of 'upstream pile only case' according to Khosla's theory is shown in figure 2. The uplift pressure heads at key points Q, R and S are 3.14 m, 2.75 m and 0 m, respectively (refere figure 2). **[GATE, 2016]**

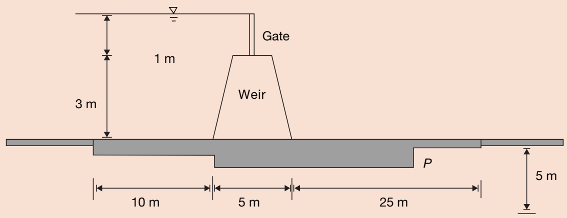


Figure 1

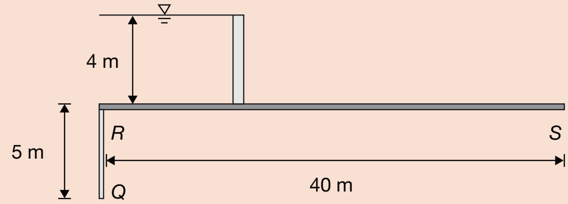


Figure 2

What is the uplift pressure head at point P downstream of the weir (junction of floor and pile as shown in the figure 1)?

(A) 2.75 m
(B) 1.25 m
(C) 0.8 m
(D) Data not sufficient

Answer Keys

Exercises

1. A	**2.** B	**3.** B	**4.** D	**5.** A	**6.** C	**7.** B	**8.** C	**9.** C	**10.** D
11. C	**12.** A	**13.** C	**14.** A	**15.** D	**16.** C	**17.** C	**18.** D	**19.** A	**20.** A
21. B	**22.** D	**23.** C	**24.** B	**25.** D	**26.** C	**27.** C	**28.** B	**29.** D	**30.** C
31. B	**32.** C	**33.** A	**34.** D	**35.** B	**36.** A	**37.** C	**38.** A	**39.** B	**40.** A
41. C	**42.** D	**43.** B	**44.** A	**45.** C	**46.** C	**47.** D	**48.** C	**49.** A	**50.** C
51. B	**52.** D	**53.** C							

Previous Years' Questions

1. A	**2.** A	**3.** C	**4.** A	**5.** B	**6.** 10500	**7.** 127.03	**8.** 2.3	**9.** B