MADE EASY

Leading Institute for ESE, GATE & PSUs

Detailed Solutions

ESE-2024 Mains Test Series

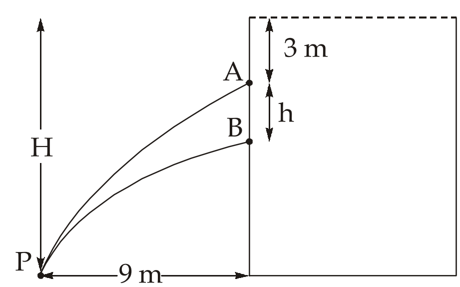
Civil Engineering Test No : 11

Section-A

Q.1 (a) Solution:

Let, the jets intersects at point P.

For upper orifice.



Now, $$9 = u_1 t \quad \text{...(i)}$$

where u_1 = Initial velocity of fluid particle at upper orifice.

t = Time taken by fluid particle from upper orifice to reach point P

$$\therefore \quad H - 3 = \frac{1}{2} \times g t^2 \quad \text{...(ii)}$$

Putting value of t in equation (ii), we get

$$H - 3 = \frac{1}{2} \times g \times \left(\frac{9}{u_1}\right)^2$$

$$\Rightarrow \quad \frac{u_1^2}{g}(H-3) = 40.5 \quad \text{...(iii)}$$

Now, $u_1 = \sqrt{2\times g\times 3} = \sqrt{6g}$

Substituting μ_1 in (iii)

$$\frac{\left(\sqrt{6g}\right)^2}{g}(H-3) = 40.5$$

$$\Rightarrow \quad 6(H-3) = 40.5$$

$$\Rightarrow \quad H = 9.75 \text{ m}$$

For lower orifice

$$9 = u_2 t \quad \text{...(iv)}$$

and, $(H-3-h) = \frac{1}{2}gt^2$ ...(v)

$$\Rightarrow \quad H-3-h = \frac{1}{2}\times g\times\left(\frac{9}{u_2}\right)^2$$

$$\Rightarrow \quad \frac{u_2^2}{g}(H-3-h) = 40.5$$

where $u_2 = \sqrt{2g(3+h)}$

$$\Rightarrow \quad u_2^2 = 2g(3+h)$$

$$\therefore \quad \frac{2g(3+h)}{g}(H-3-h) = 40.5$$

$$\Rightarrow \quad (3+h)(H-3-h) = 20.25$$

$$\Rightarrow \quad (3+h)(9.75-3-h) = 20.25$$

$$\Rightarrow \quad (3+h)(6.75-h) = 20.25$$

$$\Rightarrow \quad 20.25 - 3h + 6.75h - h^2 = 20.25$$

$$\Rightarrow \quad -h^2 + 3.75h = 0$$

$$\Rightarrow \quad h = 0, 3.75 \text{ m}$$

So, distance between orifices = 3.75 m

Q.1 (b) Solution:

Let suffixes 1 and 2 represent the sections upstream and downstream of the transition respectively.

$$\therefore \qquad V_1 = \frac{Q}{B_1 y_1} = \frac{15}{3 \times 2.5} = 2 \text{ m/sec}$$

Froude number,
$$F_1 = \frac{V_1}{\sqrt{g y_1}} = \frac{2}{\sqrt{9.81 \times 2.5}} = 0.4039 < 1$$

$\therefore$ The upstream flow is subcritical and the transition will cause a drop in the water surface.

$$E_1 = y_1 + \frac{V_1^2}{2g} = 2.5 + \frac{2^2}{2 \times 9.81} = 2.704 \text{ m}$$

Let, $B_{2\,min}$ = Minimum width at section 2 which does not cause choking.

Then, $E_{cm} = E_1 = 2.704$ m

$$y_{cm} = \frac{2}{3} E_{cm} = \frac{2}{3} \times 2.704 = 1.8027 \text{ m}$$

Since,
$$y_{cm} = \left[\frac{\left(\frac{Q}{B_{2\min}} \right)^2}{g} \right]^{1/3}$$

$$\Rightarrow \qquad (1.8027)^3 = \frac{15^2}{9.81 \times (B_{2\min})^2}$$

$$\Rightarrow \qquad B_{2\,min} = 1.979 \text{ m}$$

when $B_2 = 1.8$ m

Since, $B_2 < B_{2\,min}$, hence choking condition will prevail.

$\therefore$ The depth at the section-2, $y_2 = y_{c2}$

and the depth at upstream y_1 will increase to y_1'.

$\therefore$ At downstream section,

$$y_2 = y_{c2} = \left(\frac{q_2^2}{g} \right)^{1/3} = \left[\frac{\left(\frac{15}{1.8} \right)^2}{9.81} \right]^{1/3}$$

$$\therefore \qquad y_2 = 1.92 \text{ m}$$

$$\therefore \qquad E_{c2} = 1.5\, y_{c2} = 1.5 \times 1.92 = 2.88 \text{ m}$$

At upstream section 1,

$$E_1' = E_{c2} = 2.88 \text{ m}$$

$$\Rightarrow \quad y_1' + \frac{V_1'^2}{2g} = 2.88$$

$$\Rightarrow \quad y_1' + \frac{\left(\frac{15}{3}\right)^2}{2 \times 9.81 \times y_1'^2} = 2.88$$

$$\Rightarrow \quad y_1' + \frac{1.274}{y_1'^2} = 2.88$$

$$\Rightarrow \quad y_1'^3 - 2.88y_1'^2 + 1.274 = 0$$

$$\therefore \quad y_1' = 2.706 \text{ m}, 0.7786 \text{ m}, -0.6046 \text{ m}$$

Since, upstream flow is subcritical.

So, $\quad y_1' > y_1$

Hence, water surface elevation at upstream section is 2.706 m and at downstream section is 1.92 m.

Q.1 (c) Solution:

Given

Volume before drying, $V_1 = 18.9 \text{ cm}^3$

Volume after drying, $V_d = 9.9 \text{ cm}^3$

Mass specific gravity before drying, $G_{m1} = 1.6$

Mass specific gravity after drying, $G_{m2} = 1.8$

Now, $\quad G_{m1} = \frac{M_1}{V_1 \rho_w}$

Here M_1 is mass of specimen before drying.

$$\therefore \quad 1.6 = \frac{M_1}{18.9 \times 1}$$

$$\Rightarrow \quad M_1 = 30.24 \text{ gm}$$

Similarly, $\quad G_{m2} = \frac{M_d}{V_d \rho_w}$

where M_d is mass of specimen after drying

$$\therefore \quad 1.8 = \frac{M_d}{9.9 \times 1}$$

$$\Rightarrow \quad M_d = 17.82 \text{ gm}$$

(i)

$$\text{Now, shrinkage limit, } w_s = \left[\frac{M_1 - M_d}{M_d} - \left(\frac{V_1 - V_d}{M_d}\right)\rho_w\right] \times 100$$

$$= \left[\frac{30.24 - 17.82}{17.82} - \left(\frac{18.9 - 9.9}{17.82}\right) \times 1\right] \times 100$$

$$= [0.697 - 0.505] \times 100 = 19.2\%$$

(ii) $$\text{Specific gravity, } G = \frac{1}{\frac{\rho_w}{\rho_d} - \frac{W_s}{100}} = \frac{1}{\frac{9.9 \times 1}{17.82} - \frac{19.2}{100}} = 2.75$$

(iii) $$\text{Shrinkage ratio, } SR = \frac{\rho_d}{\rho_w} = \frac{17.82}{9.9} = 1.8$$

(iv) $$\text{Volumetric shrinkage, } VS = \left(\frac{V_1 - V_d}{V_d}\right) \times 100$$

$$= \left(\frac{18.9 - 9.9}{9.9}\right) \times 100 = 90.91\%$$

Q.1 (d) Solution:

(i)

- **Contour interval** : It is the difference in elevation between successive contour lines. It is selected based upon many factors such as nature of ground and purpose of contour plan.
- **Horizontal equivalent**: It is the horizontal distance between two successive contour lines. If the distance is small, it indicates steeper slope. It will not be same at every point on lines.
- **Contour map**: It is a map showing contour lines of different elevations at some selected contour inteval. It provides considerable information about the topography of terrain, as it indicates both horizontal and vertical distances.

(ii)

Characteristics of contour lines:

1. Two contour lines cannot intersect eath other as this would mean that point of intersection has two elevations as mentioned against the contour lines. However, contour lines may interest at a point as in case of a vertical cliff.
2. A contour line must necessarily close upon itself, may be not within the boundary of contour map.
3. Closely spaced contour lines indicate a steeper slope and widely spaced contour lines indicate a gentle slope.
4. A series of contour lines straight and parallel shows a plane surface. A uniform slope is indicated by equally spaced contour lines.
5. A contour passing through any point is perpendicular to line of steepest slope at that point.
6. A closed contour line with one or more higher values insides it represents a hill. Similarly, a closed contour line with one or more lower values indicate a depression with an outlet.

Two contour lines of same elevation cannot unite and continue as one line, nor can a contour line split and continue in different directions.

Q.1 (e) Solution:

All modern hydraulic turbines are directly coupled to the electric generator. The generators are always required to run at constant speed irrespective of the variations in the load. The speed of the generator can be maintained constant only if the speed of the turbine runner is constant. The speed of generator is to be maintained constant because the varying speed of generator may result in varying the frequency of power generation which is not desirable. The constant speed of the turbine runner is maintained by regulating the quantity of water flowing through the runner in accordance with the variations in the load. Such an operation of regulation of speed of turbine runner is known as governing of turbine. It is usually done automatically by means of a governor.

Working of an oil pressure governor:

The component parts of an oil pressure governor are as follows:

(i) Oil sump
(ii) Gear pump also called oil pump which is driven by the power obtained from turbine shaft.
(iii) The servomotor or relay cylinder
(iv) The control valve or the distribution valve or relay valve

(v) The centrifugal governor or pendulum which is driven by belt or gear from the turbine shaft.

(vi) Pipes connecting the oil sump with the control valve and control valve with servomotor

(vii) The spear rod or needle

When the load on generator decreases, the speed of the generator increases. This increases the speed of the turbine beyond the normal speed. The centrifugal governor, which is connected to the turbine shaft, will be rotating at an increased speed. Due to increase in the speed of the centrifugal governor, the fly balls move upward due to the increased centrifugal force on them. Due to the upward movement of the fly balls, the sleeve will also move upward. A horizontal lever supported over a fulcrum, connects the sleeve and the piston load of the control valve. As the sleeve moves up, the lever turns about the fulcrum and the piston rod of the control valve moves downward. This closes the valve, V_1 and opens the valve V_2 as shown in figure.

The oil pumped from the oil pump to the control valve or relay valve, under pressure will flow through valve V_2 to the servomotor and will exert force on the face A of the piston of the servomotor. This piston along with piston rod and spear will move towards right. This will decrease the area of flow of water at the outlet of nozzle. As a result the rate of flow of water to the turbine is reduced which consequently reduces the speed of the turbine.

When the speed of the turbine becomes normal, the flyballs, sleeve, lever and piston rod of control valve come to its normal position. When the load on the generator increases, the speed of the generator decreases which results in the decrease in speed of turbine. Thus, the cycle gets reversed from the earlier case when the load on generator gets decreased.

Q.2 (a) Solution:

(i)

1. Applying Bernoulli's equation between E and D, we get

$$\frac{p_{atm}}{\rho g} + \frac{V_E^2}{2g} + (1.5+4) = \frac{p_D}{\rho g} + \frac{V_D^2}{2g} + 0$$

where V_D is velocity of oil through siphon.

As $V_E << V_D$ So V_E can be neglected. Also, the siphon discharges into atmosphere at D, so, $p_D = p_{atm}$

$$\therefore \quad \frac{p_{atm}}{\rho g} + 0 + 5.5 = \frac{p_{atm}}{\rho g} + \frac{V_D^2}{2g} + 0$$

$$\Rightarrow \quad V_D = \sqrt{2 \times 9.81 \times 5.5}$$

$$= 10.39 \text{ m/s}$$

2. Pressure at A, $p_A = p_{atm} + \rho g \times 1.5$

$$= 101 \times 10^3 + 0.8 \times 1000 \times 9.81 \times 1.5$$

$$= (101 + 11.77) \times 10^3$$

$$= 112.77 \times 10^3 \text{ Pa}$$

Applying Bernoulli's equation between A and B taking D as datum, we get

$$\frac{p_A}{\rho g} + \frac{V_A^2}{2g} + 4 = \frac{p_B}{\rho g} + \frac{V_B^2}{2g} + 4$$

$$\Rightarrow \quad \frac{p_B}{\rho g} = \frac{p_A}{\rho g} - \frac{V_A^2}{2g} - \frac{V_B^2}{2g}$$

$$\Rightarrow \quad p_B = p_A - \frac{\rho V_B^2}{2} \qquad [\because V_A = 0]$$

$V_A = 0$ [Fluid is at rest]

$V_B = V_D$ = Velocity of oil through siphons

$$\therefore \quad p_B = 112.77 \times 10^3 - 0.8 \times 1000 \times \frac{10.39^2}{2}$$

$$\Rightarrow \quad p_B = 69.59 \times 10^3 \text{ Pa}$$

3. Apply Bernoulli's equation between E and C taking D as datum, we get

$$\frac{p_E}{\rho g} + \frac{V_E^2}{2g} + 5.5 = \frac{p_C}{\rho g} + \frac{V_C^2}{2g} + 7$$

Now, $p_E = p_{atm}$

$V_E \simeq 0$

$V_C = V_B = V_D$

$$\Rightarrow \quad \frac{p_{atm}}{\rho g} + 5.5 = \frac{p_c}{\rho g} + \frac{10.39^2}{2 \times 9.81} + 7$$

$$\Rightarrow \quad \frac{p_{atm}}{\rho g} + 5.5 = \frac{p_C}{\rho g} + 5.5 + 7$$

$$\Rightarrow \quad \frac{p_C}{\rho g} = \frac{p_{atm}}{\rho g} - 7$$

$$\Rightarrow \quad p_C = p_{atm} - 7\rho g$$

$$= (101 \times 10^3) - 7 \times 0.8 \times 1000 \times 9.81$$

$$= 46.06 \times 10^3 \text{ Pa}$$

(ii)

$$\mu = 0.143 \text{ Ns/m}^2$$

$$d = 2.5 \text{ cm} = 2.5 \times 10^{-2} \text{ m}$$

$$L = 300 \text{ cm} = 3 \text{ m}$$

Critical Reynold's number,

$$\text{Re}_{cr} = \frac{\rho V_{cr} d}{\mu}$$

$$\Rightarrow \quad 2500 = \frac{0.9 \times 10^3 \times V_{cr} \times 2.5 \times 10^{-2}}{0.143}$$

$$\Rightarrow \quad V_{cr} = 15.89 \text{ m/s}$$

Velocity of flow through pipe $= \frac{1}{10} V_{cr} = 1.589 \text{ m/s}$

Here, $\text{Re} < \text{Re}_{cr}$

$\therefore$ Laminar flow in pipe.

Head loss across pipe length, $h = \frac{32 \mu v L}{\rho g d^2}$

$$\Rightarrow \quad h = \frac{32 \times 0.143 \times 1.589 \times 3}{0.9 \times 10^3 \times 9.81 \times (0.025)^2}$$

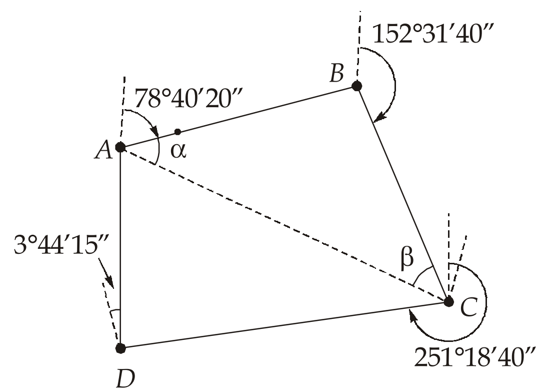
$$\Rightarrow \quad h = 3.95 \text{ m}$$

$\therefore$ Power required $= \rho g Q h$

$$= 0.9 \times 10^3 \times 9.81 \times \frac{\pi}{4}(0.025)^2 \times 1.589 \times 3.95 = 27.2 \text{ W}$$

Q.2 (b) Solution:

(i) The included angles can be calculated with the help of bearings given as shown in figure below:



As the line of sight is horizontal, so length of side, D can be found out as

$$D = kS + C$$

Length of *AB*

Staff intercept, s = 2.893 – 1.535 = 1.358 m

So, length of AB, L_{AB} = 100 × 1.358 + 0.3 = 136.1 m

Length of *BC*

Staff intercept, s = 2.432 – 1.033 = 1.399 m

So, length of BC = 100 × 1.399 + 0.3 = 140.2 m

Length of *CD*

Staff intercept, s = 3.123 – 1.363 = 1.76 m

Length of CD = 100 × 1.76 + 0.3 = 176.3 m

Length of *DA*

Staff intercept, s = 3.708 – 2.018 = 1.69 m

Length of DA = 100 × 1.69 + 0.3 = 169.3 m

In ΔABC, AB and BC are known.

Now, $\angle ABC = (180° + 78°40'\,20'') - 152°31'\,40''$

$=106°8'\,40''$

Now, as per cosine rule

$$AC^2 = AB^2 + BC^2 - 2 \times AB \times AC \times \cos(\angle ABC)$$

$$= 136.1^2 + 140.2^2 - 2 \times 136.1 \times 140.2 \times \cos(106°8'40'')$$

$$= 48790.69 \text{ m}^2$$

$\therefore \quad AC = 220.89$ m

Now, as per sine rule

$$\frac{BC}{\sin(\angle BAC)} = \frac{AC}{\sin(\angle ABC)}$$

$$\Rightarrow \quad \frac{140.2}{\sin(\angle BAC)} = \frac{220.89}{\sin(106°8'40'')}$$

$$\Rightarrow \quad \angle BAC = 37°33'58''$$

So, bearing of AC = 78°40′20″ + 37°33′58″

= 116°14′18″

Now, difference in elevations of A and C = 2.415 – 0.645 = 1.77 m

$$\text{Gradient from } A \text{ to } C = \frac{1.77}{220.89} = 1 \text{ in } 124.8$$

(ii) Smpson's rule require an odd number of ordinates. The 5 m offset interval has six ordinates and one section has to be calculated separately using trapzeoidal method. The 10 m offset interval has five ordinates. Therefore using Simpson's rule

$$\text{Area between first and second ordinate} = \frac{5}{2}(2.5+3.8) = 15.75 \text{ m}^2$$

$$\text{Area between second and sixth ordinate} = \frac{5}{3}\left(3.8+9.3+4(8.4+10.5)+2\times7.6\right)$$

$$= 173.17 \text{ m}^2$$

$$\text{Area between sixth and tenth ordinate} = \frac{10}{3}(9.3+8.4+4(5.8+6.9)+2\times7.8)$$

$$= 280.33 \text{ m}^2$$

So, Total area = 15.75 + 173.17 + 280.33 = 469.25 m^2

Q.2 (c) Solution:

(i)

- **Case-1**: Seepage is in downward direction and datum is at 'D'. Here, firstly elevation head and total heads are determined at each point and then pressure head at each point is determined by subtracting elevation head from total head at that point as tabulated below.

Point	Elevation head (cm)	Total head (cm)	Pressure head(cm)	Head loss(cm)
B	60	100	40	0
C	20	0	-20	100
D	0	0	0	100
X	30	25	-5	75

At point X′.

Total head upto B = 100 cm

Head loss through soil, h = 100 cm

Length of soil sample, L = 40 cm

$$\text{Hydraulic gradient, } i = \frac{h}{L} = \frac{100}{40} = 2.5$$

Head loss upto X = $2.5 \times 30 = 75$ cm

So, total head at X = $100 - 75 = 25$ cm

Hence, pressure head at X = $25 - 30 = -5$ cm

- **Case-2**: Seepage is in upward direction and datum is at ‘D’. Here, also pressure head at a point is determined by subtracting elevation head from total head at that point as tabulated bleow.

Point	Elevation head (cm)	Total head(cm)	Pressure head (cm)	Head loss (cm)
B	–50	40	90	0
C	–10	0	10	40
D	0	0	0	40
X	–40	30	70	10

At point X′.

Total head upto B = 40 cm

Head loss through soil, h = 40 cm

Length of soil, L = 40 cm

$$\text{Hydraulic gradient, } i = \frac{h}{L} = \frac{40}{40} = 1$$

Head loss upto X = $1 \times 10 = 10$ cm

So, total head at X = $40 - 10 = 30$ cm

Hence, pressure head at X = $30 - (-40) = 70$ cm

(ii)

Given: Specific gravity, $G = 2.65$

Void ratio, $e = 0.6$

Now, saturated unit weight for both the soils,

$$\gamma_{sat} = \left(\frac{G+e}{1+e}\right)\gamma_w$$

$$= \left(\frac{2.65+0.6}{1+0.6}\right)\times 10 = 20.3 \text{ kN/m}$$

For both the cases, firstly total stress is calculated and then pore water pressure is obtained by multiplying the pressure head at that point by unit weight of water and finally effective stress is found out by subtrcacting pore water pressure from total stress.

Case-1:

Points	**Total stress $(\sigma)(\text{kN/m}^2)$**	**Pore water pressure(u)**	**Effective stress($\bar{\sigma}$)**
B	$10 \times 0.4 = 4$	$10 \times 0.4 = 4$	0
C	$10 \times 0.4 + 20.3 \times 0.4 = 12.12$	$10 \times (-0.2) = -2$	14.12
D	$10 \times 0.4 + 20.3 \times 0.4 + 10 \times 0.2 = 14.12$	$10 \times 0 = 0$	14.12
X	$10 \times 0.4 + 20.3 \times 0.30 = 10.09$	$10 \times (-0.05) = -0.5$	10.59

Case-2:

Points	**Total stress $(\sigma)(\text{kN/m}^2)$**	**Pore water pressure(u)**	**Effective stress($\bar{\sigma}$)**
B	$10 \times 0.1 + 20.3 \times 0.4 = 9.12$	$10 \times 0.9 = 9$	0.12
C	$10 \times 0.1 = 1$	$10 \times 0.1 = 1$	0
D	0	$10 \times 0 = 0$	0
X	$10 \times 0.1 + 20.3 \times 0.3 = 7.09$	$10 \times 0.7 = 7$	0.09

Q.3 (a) Solution:

(i)

Given:

$$\text{Cohesion}, C = 15 \text{ kN/m}^2$$

$$\text{Angle of inclination}, \beta = 20°$$

$$\text{Angle of internal friction}, \phi = 32°$$

$$\text{Specific gravity}, G = 2.66$$

$$\text{Void ratio}, e = 0.65$$

Now, saturated unit weight of soil, $\gamma_{sat} = \left(\frac{G+e}{1+e}\right)\gamma_w$

$$= \left(\frac{2.66+0.65}{1+0.65}\right)\times 9.81 = 19.68 \text{ kN/m}^3$$

$$\text{Dry unit weight of soil}, \gamma_d = \frac{G\gamma_w}{1+e} = \frac{2.66\times 9.81}{1+0.65} = 15.81 \text{ kN/m}^3$$

$$\text{Submerged unit weight}, \gamma_{sub} = \gamma_{sat} - \gamma_w$$

$$= 19.68 - 9.81$$

$$= 9.87 \text{ kN/m}^3$$

1. When there is no water in slope

$$\text{Factor of safety, FOS} = \frac{C + \gamma_d z \cos^2\beta \tan\phi}{\gamma_d z \cos\beta \sin\beta}$$

$$= \frac{15 + 15.81\times 5\times \cos^2 20° \tan 32°}{15.81\times 5\times \cos 20° \sin 20°}$$

$$= 2.31$$

2. When seepage is parallel to surface and slope is completely submerged.

$$\text{Factor of safety, FOS} = \frac{C + \gamma_{sub} z \cos^2\beta \tan\phi}{\gamma_{sat} z \cos\beta \sin\beta}$$

$$= \frac{15 + 9.87\times 5\times \cos^2 20° \tan 32°}{19.68\times 5\times \cos 20° \sin 20°} = 1.34$$

3. When seepage is at 2.5 m depth

$$\text{Factor of safety, FOS} = \frac{C + (\gamma_{avg} z - \gamma_w h)\cos^2\beta \tan\phi}{\gamma_{avg} z \cos\beta \sin\beta}$$

where, $h = 2.5$ m

and
$$\gamma_{avg} = \frac{\gamma_{dry} \times (z-h) + \gamma_{sat} \times h}{z}$$

$$= \frac{15.81 \times (5-2.5) + 19.68 \times 2.5}{5}$$

$$= 17.745 \text{ kN/m}^3$$

So,
$$\text{FOS} = \frac{15 + (17.745 \times 5 - 9.81 \times 2.5)\cos^2 20° \tan 32°}{17.745 \times 5 \times \cos 20° \times \sin 20°} = 1.77$$

(ii)

Following assumptions are made in Terzaghi's 1-D consolidation theory:

1. Compression and flow are one-dimensional.
2. Darcy's law is valid.
3. Soil is homogenous.
4. Soil is completely saturated.
5. The soil grains and water are both incompressible.
6. Strains are small, i.e. is, the applied load increment produces virtually no change in thickness.
7. There is a unique relationship, independent of time, between void ratio and effective stress.
8. The coefficient of permeability and coefficient of volume compressibility remain constant throughout the consolidation process.

Q.3 (b) Solution:

(i)

Variables involved are P, N, D, ρ, μ

$$\Rightarrow \quad f(P, N, D, \rho, \mu) = 0$$

Number of variables = 5

Number of fundamental variables = 3

Number of π-terms = 5 – 3 = 2

Here, N, D and ρ are taken as repeating variables in determining the π-terms. Since N represents flow property, D represents geometry and ρ represents fluid property.

$$\pi_1 = N^a D^b \rho^c P$$

$$\pi_2 = N^a D^b \rho^c \mu$$

$$\therefore \quad M^\circ L^\circ T^\circ = (T^{-1})^a (L)^b (ML^{-3})^C ML^2T^{-3}$$

$$\therefore \quad -a-3 = 0$$

$$b - 3c + 2 = 0$$

$$c + 1 = 0$$

Solving above three equations, we get

$$a = -3, b = -5, c = -1$$

$$\therefore \quad \pi_1 = N^{-3} D^{-5} \rho^{-1} P$$

$$\Rightarrow \quad \pi_1 = \frac{P}{N^3 D^5 \rho}$$

Determination of π_2

$$M^\circ L^\circ T^\circ = (T^{-1})^a (L)^b (ML^{-3})^c ML^{-1}T^{-1}$$

$$\therefore \quad c + 1 = 0$$

$$\Rightarrow \quad b - 3c - 1 = 0$$

$$\Rightarrow \quad -a - 1 = 0$$

Solving above three equations, we get

$$a = -1, b = -2, c = -1$$

$$\therefore \quad \pi_2 = N^{-1} D^{-2} \rho^{-1} \mu$$

$$\Rightarrow \quad \pi_2 = \frac{\mu}{N \rho D^2}$$

Now, the given problem statement in terms of independent dimensionless parameter can be expressed as

$$f\left(\frac{P}{\rho N^3 D^5}, \frac{\mu}{\rho N D^2}\right) = 0$$

$$\Rightarrow \quad f'\left(\frac{P}{\rho N^3 D^5}, \frac{\rho N D^2}{\mu}\right) = 0$$

$$\Rightarrow \quad \frac{P}{\rho N^3 D^5} = \phi\left(\frac{\rho N D^2}{\mu}\right)$$

$$\Rightarrow \qquad P = \rho N^3 D^5 \phi\left(\frac{\rho N D^2}{\mu}\right)$$

(ii) Given: $D_1 = 300$ mm, $D_2 = 750$ mm, $N_1 = 25$ rev/s, $N_2 = ?$

$$\rho_1 = 1000 \text{ kg/m}^3,\ \rho_2 = 1.2 \text{ kg/m}^3$$

$$\mu_1 = 1.01 \times 10^{-3} \text{ Pa-s},\ \mu_2 = 1.86 \times 10^{-5} \text{ Pa-s}$$

$$P_1 = 2\pi NT = 2\pi \times 25 \times 1.2 \text{ W},\ P_2 = ?$$

From the condition of similarity as established above.

$$\frac{\rho_2 N_2 D_2^2}{\mu_2} = \frac{\rho_1 N_1 D_1^2}{\mu_1}$$

$$\Rightarrow \qquad N_2 = N_1\left(\frac{D_1}{D_2}\right)^2 \frac{\rho_1}{\rho_2} \times \frac{\mu_2}{\mu_1}$$

$$= 25 \times \left(\frac{300}{750}\right)^2 \times \frac{1000}{1.2} \times \frac{1.86 \times 10^{-5}}{1.01 \times 10^{-3}}$$

$$= 61.39 \text{ rev/s}$$

Also,

$$\frac{P_1}{\rho_1 N_1^3 D_1^5} = \frac{P_2}{\rho_2 N_2^3 D_2^5}$$

$$\Rightarrow \qquad \frac{P_2}{P_1} = \left(\frac{\rho_2}{\rho_1}\right)\left(\frac{N_2}{N_1}\right)^3\left(\frac{D_2}{D_1}\right)^5$$

$$\Rightarrow \qquad \frac{T_2}{T_1} = \left(\frac{\rho_2}{\rho_1}\right)\left(\frac{N_2}{N_1}\right)^2\left(\frac{D_2}{D_1}\right)^5 \qquad (\because P = 2\pi NT)$$

$$\Rightarrow \qquad T_2 = T_1\left(\frac{\rho_2}{\rho_1}\right)\left(\frac{N_2}{N_1}\right)^2\left(\frac{D_2}{D_1}\right)^5$$

$$= 1.2 \times \left(\frac{1.2}{1000}\right) \times \left(\frac{61.39}{25}\right)^2 \times \left(\frac{750}{300}\right)^5$$

$$= 0.85 \text{ Nm}$$

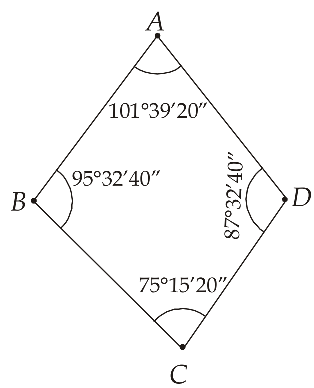
Q.3 (c) Solution:

Sum of included angles $= \angle A + \angle B + \angle C + \angle D$

$$= 101°39'30'' + 95°\,32'\,50'' + 75°15'\,30'' + 87°\,32'\,50''$$

$$= 360°\,0'\,40''$$

The error of 40″ is distributed equally among all angles of the traverse. Each angle will be reduced by $\frac{40''}{4} = 10''$. The corrected included angles and bearings of the lines are tabulated below with the help of rough sketch shown below.



Station	Included angle	Line	Bearing(θ)	length(L)(m)	Lat. = Lcosθ(m)	Dep = Lsinθ(m)
A	101°30'20"	AB	222°01'30"	155.25	–115.33	–103.93
B	95°32'40"	BC	137°34'10"	170.4	–125.77	114.9
C	75°15'20"	CD	32°49'30"	202.6	170.25	109.8
D	87°32'40"	DA	300°22'10"	139.4	70.48	–120.27
				Σ =	–0.37m	0.5m

Calculation of bearings,

$$\begin{aligned}
\text{Bearing of } AB &= 222°01'\,30'' \\
\text{Bearing of } BC &= (222°\,01'\,30'' - 180°) + 95°\,32'\,40'' \\
&= 137°\,34'\,10'' \\
\text{Bearing of } CD &= 75°\,15'\,20'' - [360° - (137°\,34'\,10'' + 180°)] \\
&= 32°49'\,30'' \\
\text{Bearing of } DA &= (180° + 32°\,49'\,30'') + 87°\,32'\,40'' \\
&= 300°\,22'10''
\end{aligned}$$

Now, as per transit method

$$\text{Correction to latitude of a line} = \text{Total error in latitude} \times \frac{\text{Arithmetic latitude of line}}{\text{Arithmetic sum of latitudes}}$$

$$\text{Correction to departarure a of line} = \text{Total error in departure} \times \frac{\text{Arithmetic departure of line}}{\text{Arithmetic sum of departures}}$$

Now, arithmetic sum of latitudes = 481.83 m

Arithmetic sum of departure = 448.9 m

The corrections based on above two equations are tabulated below.

Line	length(m)	Correction to latitude(m)	Correction to departure(m)	Corrected latitude	Corrected departure
AB	155.25	0.0885	–0.1158	–115.2415	–104.0458
BC	170.4	0.0965	–0.1510	–125.6735	114.749
CD	202.6	0.1307	–0.1443	170.3807	109.6557
DA	139.4	0.0541	–0.1580	70.5341	–120.428

Q.4 (a) Solution:

(i)

Given:

Unconfined compressive strength, UCS = 160 kN/m^2

Now, cohesion, $C_u = \frac{UCS}{2} = \frac{160}{2} = 80 \text{ kN/m}^2$

As per Skempton's approach,

Net ultimate bearing capacity, $q_{nu} = C_u N_C$

where $$N_C = 5\left(1+\frac{0.2D_f}{B}\right)\left(1+\frac{0.2B}{L}\right) \text{ if } \frac{D_f}{B} \le 2.5$$

where D_f is depth of footing,

So, $$N_C = 5\left(1+0.2\times\frac{D_f}{10}\right)\left(1+0.2\times\frac{10}{20}\right)$$

$$= 5.5\left(1+0.2\times\frac{D_f}{10}\right) = 5.5 + 0.11\, D_f$$

So, $q_{nu} = C_u N_c = 440 + 8.8\, D_f$

Now,net safe bearing capacity, $q_{ns} = \frac{q_{nu}}{FOS} = \frac{440+8.8D_f}{3} = 146.67 + 2.93\, D_f$

Since, the excavated soil is not going to be used as backfill since the building will have basement floor(s). Thus, it is possible to allow a loading intensity equal to 'γD_f' in addition to q_{ns} calculated above.

So, $q_{ns} + \gamma D_f = 300$

$\Rightarrow \quad 146.67 + 2.93D_f + 18D_f = 300$

$$\Rightarrow \quad D_f = \frac{153.33}{20.93} = 7.33\,\text{m}$$

(ii)

Limitations of dynamic formulae:

1. Dynamic formulae are suitable for coarse grained soils. However Hiley's formula does not give consistent results for pile in coarse grained soils.
2. Engineering news record formula neglects weight of pile and its inertia effect.
3. Loss of energy due to vibration and heat, etc. is not accounted for.
4. Not applicable for group action of pile to find ultimate load.
5. If the pile is driven into loose sand and silt, liquefactions may result, reducing the pile capacity.
6. These formulae are not suitable for clays because there may be apparent increase in driving resistance due to development of pore pressure. On other hand, remolding of clays may reduce the resistance.

Q.4 (b) Solution:

(i) Given:

Thickness of clay layer, $H_o = 8$ m

Consolidation settlement, $\Delta h = 40$ mm

Ultimate settlement, $\Delta H = 160$ mm

1. Now,degree of consolidation,

$$U = \frac{\Delta h}{\Delta H} \times 100 = \frac{40}{160} \times 100 = 25\%$$

As $U < 60\%$

So, $$T_v = \frac{\pi}{4} U^2$$

$$= \frac{\pi}{4} \times (0.25)^2 = 0.049$$

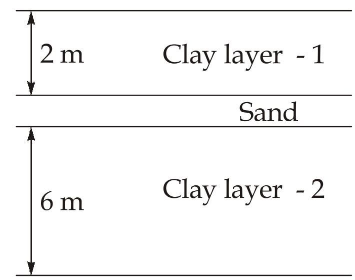
Now, $T_v = \dfrac{C_v t}{d^2}$ where C_v is coefficient of consolidation and $$d = \frac{H_0}{2} = \frac{8\,\text{m}}{2} = 4\,\text{m}$$

∴ $$T_v = 0.049 = \frac{C_v \times 4}{4^2}$$

⇒ $$C_V = 0.196\ \text{m}^2/\text{year}$$

2. Now,

For upper clay layer (Layer -1)



$$C_V = 0.196\ \text{m}^2/\text{year}$$

$$t = 6\ \text{years}$$

$$d_1 = \frac{H_1}{2} = \frac{2}{2} = 1\,\text{m}$$

Now, $$T_{V1} = \frac{C_V t}{d_1^2} = \frac{0.196 \times 6}{1^2} = 1.176$$

Now, $$T_{V1} = 1.781 - 0.933 \quad \log_{10}(100 - U_1\%)$$

where U_1 is degree of consolidation of upper clay layer.

∴ $$1.176 = 1.781 - 0.933 \log_{10}(100 - U_1\%)$$

⇒ $$U = 95.55\%$$

Also, $$T_{V2} = \frac{C_V t}{d_2^2} = \frac{0.196 \times 6}{(6/2)^2} = 0.13$$

Now, $$T_{V2} = \frac{\pi}{4} U_2^2$$

where U_2 is degree of consolidation of bottom clay layer

∴ $$0.13 = \frac{\pi}{4} U_2^2$$

⇒ $$U_2 = 0.4068 = 40.68\%$$

Now, ultimate settlement of clay layer of 8 m thickness will be 160 mm with or witout sand layer.

Ultimate settlement of upper layer, $\Delta_{H1} = 160 \times \frac{2}{8} = 40$ mm

Ultimate settlement of bottom layer, $\Delta_{H2} = 160 \times \frac{6}{8} = 120\,\text{mm}$

Settlement of upper layer, $\Delta h_1 = U_1 \times \Delta H_1$

$= 0.9555 \times 40 = 38.22$ mm

Settlement of bottom layer, $\Delta h_2 = U_2 \times \Delta H_2$

$= 0.4068 \times 120 = 48.82$ mm

Total settlement after 6 years, $\Delta h' = \Delta h_1 + \Delta h_2$

$= 38.22 + 48.82 = 87.04$ mm

(ii)

Some of the factors affecting shear strength of soil are:

1. Drainage conditions:

- It is well known that effective stress governs the shearing strength of soil as,

$$\tau = c + \bar{\sigma}\tan\phi'$$

- Drained condition occurs when the excess pore water pressure developed during loading of a soil dissipates i.e. $\Delta u = 0$.
- Undrained conditions occur when the excess pore water pressure is not drained from the soil. i.e., $\Delta u \neq 0$.
- The existence of either condition–drained or undrained depends on the soil type, geological formation (fissures, sand layer in clays etc.), and the rate of loading.
- The values of shear strength parameters depend on the drainage conditions in saturated soils.

$\phi = \phi'$ in case of drained test

$\phi = 0$ in case of an undrained test

2 Density index:

- The most important factor affecting the shear strength of granular soil is density index.
- For the same composition of the soil, higher the density, higher the angle of friction. Hence higher will be the shear strength.

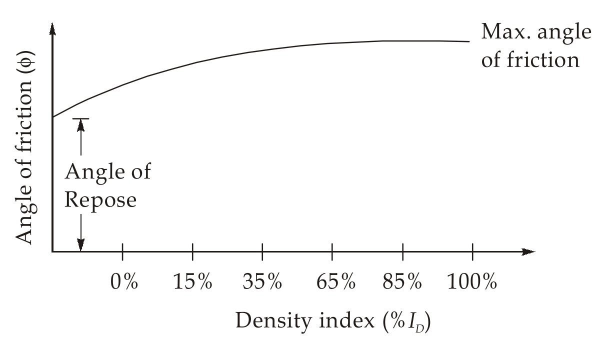


Fig. Relationship between density index and angle of friction

3. **Water content and saturation:**
   - In case of fine grained soils, cohesion between soil particles is inversely proportional to water content.
   - The degree of saturation also affects the cohesion and the cohesion increases water content upto an optimum value above which it decreases with increasing water content for a given void ratio.

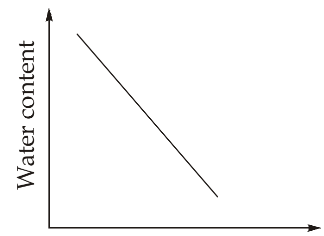


Fig. Relationship between cohesion and water content

   - On the other hand, in unsaturated soils negative excess pore water pressure increases the effective stress ($\bar{\sigma} = \sigma - u$). Thus, if the pore water pressure is negative, the effective stress increases.
4. **Composition and particle characteristics:**
   - Angle of internal friction depends on grading of the soil. A well graded soil with high uniformity coefficient has a higher angle of friction as compared to poorly graded (i.e. uniform) soil.
   - Similarly, sharp angular grains which can interlock well with adjacent grain will show higher friction angles. Hence, minerals such as mica and flaky particles will show low angles of internal friction.

Q.4 (c) Solution:

(i)

The fundamenal lines of a theodolite are as follows:

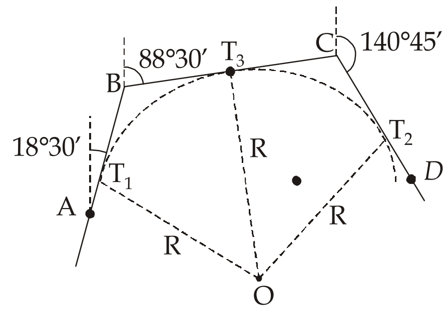
1. Vertical axis.
2. Horizontal axis or trunnion axis.
3. Line of collimation or line of sight.
4. Axis of plate level.
5. Axis of altitude level.
6. Axis of stadia level, if provided.

The desired relationships among these lines are:

1. The axis of plate level must lie in a plane perpendicular to vertical axis.
2. The line of collimation must be perpendicular to horizontal axis. The line of collimation, the vertical axis and horizontal axis must intersect at a point.
3. The horizontal axis must be perpendicular to vertical axis.
4. The axis of altitude bubble must be parallel to line of collimation.

5. The vertical circle should read zero when line of collimation is horizontal.

(ii)



From figure, $T_1B = T_3B = R\tan(88°30' - 18°30')$

where R is the radius of curve which is tangential to all the three lines.

$$= R\tan\left(\frac{70°}{2}\right) = R\tan 35° \quad \text{...(i)}$$

Similarly, $$T_2C = T_3C = R\tan\left(\frac{140°45' - 88°30'}{2}\right)$$

$$= R\tan\left(\frac{52°15'}{2}\right)$$

$$= R\tan(26°7'30'') \quad \text{...(ii)}$$

Now, $BC = T_3B + T_3C$

$\Rightarrow$ $235 = R\tan 35° + R\tan(26°7'30'')$

$\Rightarrow$ $R = 197.37$ m

Now, Tangent length, $T_1B = T_3B = 197.37\tan 35° = 138.2$ m

Tangent length, $T_2C = 197.37\tan 26°7'30''$

$= 96.8$ m

Section-B

Q.5 (a) Solution:

Anerobic digestion of waste having the chemical formula $C_aH_bO_cN_d$ is given by the chemical equation given below:

$$C_aH_bO_cN_d + \frac{4a-b-2c+3d}{4}H_2O \rightarrow \frac{4a+b-2c-3d}{8}CH_4 + \frac{4a-b+2c+3d}{8}CH_2 + dNH_3$$

Now, here $a = 50, b = 100, c = 40$ and $d = 1$

So, putting these values in (i), we get

$$C_{50}H_{100}O_{40}N + 5.75H_2O \rightarrow 27.125CH_4 + 22.875\ CO_2 + NH_3$$

Now, molecular weight of $C_{50}H_{100}O_{40}N$ = 12 × 50 + 1 × 100 + 16 × 40 + 14 = 1354 g

Molecular weight of CH_4 = 12 × 1 + 4 × 1 = 16 g

Now, mass of methane produced per tonne of waste = $\frac{27.125 \times 16}{1354} \times 1000/\text{tonne}$

$= 320.5\ \text{kg/tonne}$

Now, volume of methane produced per tonne of waste = $\frac{320.5\,\text{kg/tonne}}{0.72\,\text{kg/m}^3}$

$= 451.1\ \text{m}^3/\text{tonne of waste}$

Q.5 (b) Solution:

There are a number of methods of collecting origin and destinatino data. Some of the methods commonly adopted are follows:

1. **Road side interview method:** In this method, vehicles are stopped at selected interview stations by a group of persons and answer to prescribed questionnaire are collected on spot and entered in prescribed forms. The information collected include the place and time of origin and destination, route, locations of intermediate stoppages if any, purpose of trip, type of vehicle, number of passangers in each vehicle etc.

   In this method, data can be collected in short duration and field organisation is simple and team can be trained quickly.

2. **License plate method**: The entire area under study is cordened out and enumerators are simultaneously stationed at all observation stations at locations of entry and exit on all the roads leading in and out of the area. In addition, some important intermediate observation stations are also selected in advance for locating the enumerators. Each group of enumerators at observation station is given synchronized timers and they note down the license plate numbers of vehicles entering and leaving the area and time.

   This method is quite easy and quick as far as field work is concerned. It is suitable for a small study area.

3. **Return post card method**: Pre paid business reply post cards with return address are distributed to road users at some selected points along the route or cards are mailed to owner of vehicles. The questionnaire to be filled in by road user is printed on the card, along with a request for co-operation and purpose of the study. The distributing stations for the the cards may be selected where vehicles have to stop as in case of a toll booth or signals. The method is suitable where the traffic is heavy.

The personnel need not be skilled or trained just for distributing the cards.

4. **Tag on car method**: In this method, a pre coded card is stuck on the vehicles as it enters the area under study. When the car leaves cordon area, the observations are recorded on tag. This method is useful where the traffic is heavy and moves continuously.

Q.5 (c) Solution:

(i) As we know,

$$\text{Specific capacity of well, } \frac{C'}{A} = \frac{1}{T}\ln\frac{s_1}{s_2}$$

where, s_1 = Initial drawdown = 3 m

s_2 = Final drawdown = (3 – 2) = 1 m

T = Time = 60 minutes = 1 hr

So, $$\frac{C'}{A} = \frac{1}{1\,\text{hr}}\ln\frac{3}{1} \simeq 1.1 \text{ m}^3/\text{hr}/\text{m}^2/\text{m of depression head}$$

2. Now, yield from well, $$Q = \left(\frac{C'}{A'}\right)\times A\times s$$

where, $A = \frac{\pi}{4}\times d_w^2$ where d_w is diameter of well

$$= \frac{\pi}{4}\times 2.5^2 = 4.91 \text{ m}^2$$

and s = 4 m

So, $Q = 1.1 \times 4.91 \times 4 = 21.604 \text{ m}^3/\text{hr} = 6$ litres/sec

(ii) When $Q = 10\ l/\text{sec} = 36 \text{ m}^3/\text{hr}$ and $s = 3$ m

$$Q = \left(\frac{C'}{A'}\right)\times A_w\times s$$

where A_w is required area of well.

$\therefore$ $36 = 1.1 \times A_w \times 3$

$\Rightarrow$ $A_w = 10.91 \text{ m}^2$

$\Rightarrow$ $$\frac{\pi}{4}\times d_w^2 = 10.91$$

$$\Rightarrow \quad d_w = 3.73 \text{ m}$$

Hence, diameter of required well = 3.75 m (say)

Q.5 (d) Solution:

(i) Reliability, R = 85%

Life of hydraulic structure, n = 40 years

Now,
$$R = \left(1-\frac{1}{T}\right)^n$$

where T is the required recurrence interval

$$\therefore \quad 0.85 = \left(1-\frac{1}{T}\right)^{40}$$

$$\Rightarrow \quad T = 246.63 \text{ years}$$

As per Gumbel's method, for large sample size

$$\bar{y}_n = 0.577, \; S_n = 1.2825$$

and
$$y_T = -\left[\ln\cdot\ln\frac{T}{T-1}\right]$$

$$= -\left[\ln\cdot\ln\frac{246.63}{246.63-1}\right] = 5.506$$

Now,
$$k = \frac{y_T - \bar{y}_n}{S_n}$$

$$= \frac{5.506-0.577}{1.2825} = 3.843$$

Now,
$$X_T = \bar{X} + k\sigma_{n-1}$$

$$= 8520 + 3.843 \times 3900$$

$$= 23507.7 \text{ m}^3/\text{s}$$

(ii) Safety factor, SF $= \dfrac{\text{Actual value of discharge}, Q_a}{\text{Calculated value of discharge}, Q}$

$$\Rightarrow \quad 1.3 = \frac{Q_a}{23507.7}$$

$$\Rightarrow \quad Q_a = 30560 \text{ m}^3/\text{s}$$

Now, safety margin of flood = $30560 - 23507.7 = 7052.3 \text{ m}^3/\text{s}$

Q.5 (e) Solution:

Full face method: This method is adopted for large size tunnels. In this method, vertical columns are fixed at face of tunnel to which a large number of drills may be mounted or fixed at suitable heights. A series of drill holes are drilled at about 120 cm centre to centre in preferably two rows. The size of these holes may vary from 10 mm to 40 mm. These holes are then charged with explosives and ignited. The muck is removed before next operation of drilling holes.

Advantages:

1. It is simple in operation.
2. Magnitude of ground settlement and disturbance is minimum.
3. Work is easily and speedily completed by this method.
4. It is found advantageous in sensitive ground conditions where multiple phase excavation could generate excessive pressure and settlement effects.

Drift method: Drift is a small tunnel of size 300 cm × 300 cm usually. In driving a large tunnel, it has been advantageous to drive a drift first through full length or in a portion of length of tunnel prior to excavating the full bore. The drift may be provided at centre, sides, bottom or top as desired. In this method after drifting the drift, drill holes are drilled all around the drift in the entire cross-section of tunnel filled with explosives and ignited. The rock shatters, the muck is removed and tunnel is expanded to full cross-section.

Advantages:

1. Using this method, any bad rock or excessive water will be discovered prior to driving full tunnel enabling to take corrective measures at the earliest.
2. The drift assist in ventilating the tunnel during later operations.
3. The quantity of explosive required is reduced.
4. The side drifts provide facility to install timbering to provide support to the roof, especially when the tunnel is driven in broken rock.

Q.6 (a) Solution:

Given:

$$\text{Wheel load, } P = 7000 \text{ kg}$$

$$\text{Contact pressure, } p = 7.5 \text{ kg/cm}^2$$

Now, $P = p\,\pi a^2$ where a is radius of load.

$$\Rightarrow \quad 7000 = 7.5 \times \pi \times a^2$$

$$\Rightarrow \quad a = 17.24 \text{ cm}$$

Now, $k = 30 \text{ kg/cm}^3$,

$E = 3 \times 10^5 \text{ kg/cm}^2$, $\mu = 0.15$, $h = 25$ cm

Now, radius of relative stiffness,

$$l = \left[\frac{Eh^3}{12k(1-\mu^2)}\right]^{1/4} = \left[\frac{3\times10^5\times25^3}{12\times30\times(1-0.15^2)}\right]^{1/4} = 60.41$$

cm

Also, $\dfrac{a}{h} = \dfrac{17.24}{25} = 0.69 < 1.724$

So, radius of resisting section, $b = \sqrt{1.6a^2 + h^2} - 0.675h$

$$= \sqrt{1.6\times17.24^2 + 25^2} - 0.675\times25$$

$= 16.3$ cm

Now, load stress at edge, $S_e = \dfrac{0.572P}{h^2}\left[4\log_{10}\left(\dfrac{l}{b}\right) + 0.359\right]$

$$= \frac{0.572\times7000}{25^2}\left[4\log_{10}\left(\frac{60.41}{16.3}\right) + 0.359\right]$$

$= 16.88 \text{ kg/cm}^2$

For $h = 25$ cm, temperature differential,

$$\Delta t = \frac{15.6+16.2}{2} = 15.9°\text{C}$$

Now, $L_x = 4.2 \text{ m} = 420$ cm

$L_y = 3.75 \text{ m} = 375$ cm

So, $\dfrac{L_x}{l} = \dfrac{420}{60.41} = 6.95$ and $\dfrac{L_y}{l} = \dfrac{375}{60.41} = 6.21$

Using chart,

for $\dfrac{L_x}{l} = 6.96$, $C_x = 0.99$

and for $\dfrac{L_y}{l} = 6.21$, $C_y = 0.93$

Now, warping stress at edge,

$$S_{t(e)} = \text{Max}\left[\frac{C_x E\alpha\Delta t}{2}, \frac{C_y E\alpha\Delta t}{2}\right]$$

$$= \left[\frac{0.99\times 3\times 10^5 \times 1\times 10^{-5}\times 15.9}{2}\right] \quad [\because C_x > C_y]$$

$$= 23.61 \text{ kg/cm}^2$$

Total stress, $(S_e + S_{t(e)})$ = $16.98 + 23.61 = 40.59 \text{ kg/cm}^2$

Flexural strength of CC = 45 kg/cm^2

So, factor of safety = $\frac{45}{40.59} = 1.109$

Now, warping stress at interior, $S_{t(i)} = \frac{E\alpha\Delta t}{2}\left[\frac{C_x + \mu C_y}{1-\mu^2}\right]$

$$= \frac{3\times 10^5 \times 1\times 10^{-5}\times 15.9}{2}\left[\frac{0.99+0.15\times 0.93}{1-0.15^2}\right]$$

$$= 27.56 \text{ kg/cm}^2$$

Warping stress at corner, $S_{t(c)} = \frac{E\alpha\Delta t}{3(1-\mu)}\sqrt{\frac{a}{l}}$

$$= \frac{3\times 10^5 \times 1\times 10^{-5}\times 15.9}{3\times(1-0.15)}\times\sqrt{\frac{17.24}{60.41}}$$

$$= 9.99 \text{ kg/cm}^2$$

Q.6 (b) Solution:

Average daily supply = $180 \times 200000 = 36$ ML

Average hourly demand = $\frac{36\,\text{ML}}{24} = 1.5\,\text{ML}$

1. When pumping is done for all 24 hours.

Time in hours of the day (1)	Demand in units of avg. hourly demand (2)	Cumulative demand in terms of avg. hourly demand (3)	Cumulative demand in ML = Col.3 × 1.5 ML (4)	Constant pumping rate in million litres per hour (5)	Cumulative Pumping in ML (6)	Excess demand in ML Col.(4) – Col. (6) only positive (7)	Excess supply in ML Col.(6) – Col. (4) only positive (8)
1	0.25	0.25	0.375	1.5	1.5	0	1.125
2	0.25	0.50	0.75	1.5	3.0	0	2.25
3	0.25	0.75	1.125	1.5	4.5	0	3.375
4	0.25	1	1.5	1.5	6.0	0	4.5
5	0.35	1.35	2.025	1.5	7.5	0	5.475
6	0.45	1.8	2.7	1.5	9.0	0	6.3
7	1.0	2.8	4.2	1.5	10.5	0	6.3
8	1.5	4.3	6.45	1.5	12.0	0	5.55
9	1.9	6.2	9.3	1.5	13.5	0	4
10	2.5	8.7	13.05	1.5	15.0	0	1.95
11	2.1	10.8	16.2	1.5	16.5	0	0.3
12	1.5	12.3	18.45	1.5	18.0	0.45	0
13	1.2	13.5	20.25	1.5	19.5	0.75	0
14	0.9	14.4	21.6	1.5	21.0	0.6	0
15	1.0	15.4	23.1	1.5	22.5	0.6	0
16	1.2	16.6	24.9	1.5	24.0	0.9	0
17	1.5	18.1	27.15	1.5	25.5	1.65	0
18	1.6	19.7	29.55	1.5	27.0	2.55	0
19	1.3	21.0	31.5	1.5	28.5	3	0
20	1.0	22.0	33	1.5	30.0	3	0
21	0.8	22.8	34.2	1.5	31.5	2.7	0
22	0.5	23.3	34.95	1.5	33.0	1.95	0
23	0.4	23.7	35.55	1.5	34.5	1.05	0
24	0.3	24	36	1.5	36.0	0	0

Cumulative demand = 36 million litres per day

So, constant pumping hourly rate $= \frac{36}{24}$ = 1.5 million litres per hour

Now, maximum excess of demand = 3 million litres

Maximum excess of supply = 6.3 million litres

Hence, total storage required = 3 + 6.3 = 9.3 million litres

2. When pumping is done for limited period.

Time in hours of the day (1)	Demand in units of avg. hourly demand (2)	Cumulative demand in terms of avg. hourly demand (3)	Cumulative demand in ML = Col.3 × 1.5 ML (4)	Constant pumping rate in million litres per hour (5)	Cumulative Pumping in ML (6)	Excess demand in ML Col.(4) – Col. (6) only positive (7)	Excess supply in ML Col.(6) – Col. (4) only positive (8)
1	0.25	0.25	0.375	0	0	0.375	0
2	0.25	0.50	0.75	0	0	0.75	0
3	0.25	0.75	1.125	0	0	1.125	0
4	0.25	1	1.5	0	0	1.5	0
5	0.35	1.35	2.025	0	0	2.025	0
6	0.45	1.8	2.7	3	3.0	0	0.3
7	1.0	2.8	4.2	3	6.0	0	1.8
8	1.5	4.3	6.45	3	9.0	0	2.55
9	1.9	6.2	9.3	3	12.0	0	2.7
10	2.5	8.7	13.05	3	15.0	0	1.95
11	2.1	10.8	16.2	3	18.0	0	1.8
12	1.5	12.3	18.45	0	18.0	0	0
13	1.2	13.5	20.25	0	18.0	0.45	0
14	0.9	14.4	21.6	0	18.0	2.25	0
15	1.0	15.4	23.1	3	21.0	3.6	0
16	1.2	16.6	24.9	3	24.0	2.1	0
17	1.5	18.1	27.15	3	27.0	0.9	0
18	1.6	19.7	29.55	3	30.0	0.15	0.45
19	1.3	21.0	31.5	3	33.0	0	1.5
20	1.0	22.0	33	3	36.0	0	3
21	0.8	22.8	34.2	0	36.0	0	1.8
22	0.5	23.3	34.95	0	36.0	0	1.05
23	0.4	23.7	35.55	0	36.0	0	0.45
24	0.3	24	36	0	36.0	0	0

Cumulative demand = 36 million litres per day

Total pumping hours = 12 hours

So, pumping rate $= \frac{36}{12}$ = 3 million litres per hour

Now, maximum excess of demand = 3.6 million litres

Maximum excess of supply = 2.7 million litres

Hence, total storage required = 3.6 + 2.7 = 6.3 million litres

Q.6 (c) Solution:

1. Daily discharge, $Q = 50000 \text{ m}^3/\text{day}$

   Dosage of alum $= 40 \text{ mg}/l$

   So, monthly alum requirement $= 50000 \times 30 \times 40 \times 10^{-3} = 60000$ kg per month

2. Value of $G = 30 \text{ sec}^{-1}$

   Value of $Gt = 4 \times 10^4$

   So, Detention time, $t_d = \dfrac{4 \times 10^4}{30} = 1333.33 \text{ sec} = 22.22 \text{ min}$

   Now volume of tank, $V = Q \times t_d$

   $$= \frac{50000}{24 \times 60} \times 22.22 = 771.5 \text{ m}^3$$

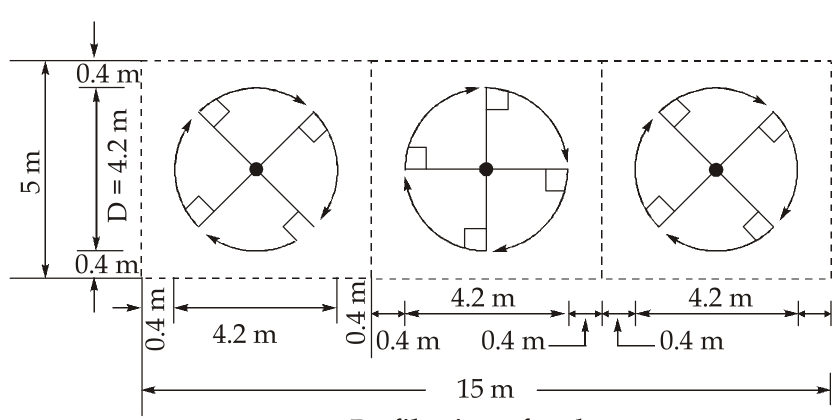
   As the tank is to contain three paddles, so whole length of tank will be divided into 3 compartments. To have equal distribution of velocity gradient, keep length of each compartment equal to depth of compartment. Taking depth of compartment, d as 5 m.

   Length of tank $= 3 \times d = 3 \times 5 = 15$ m

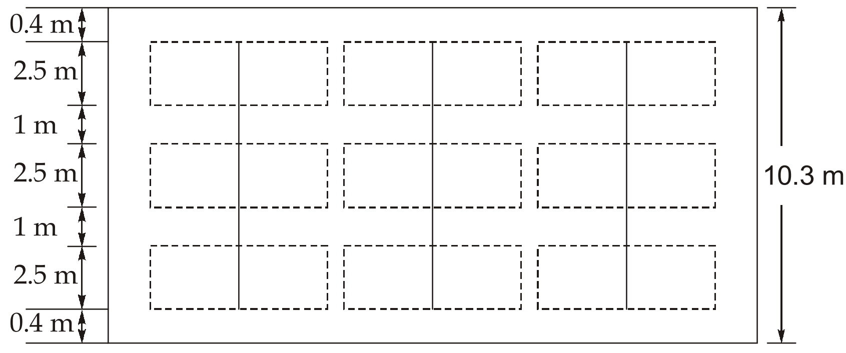
   Now, Width of tank, $B = \dfrac{\text{Volume of tank}}{\text{Length} \times \text{Depth}}$

   $$= \frac{771.5}{15 \times 5} = 10.3 \text{ m}$$

   The configuration of tanks and paddles are as follows:



Profile view of tank



Plan view

3. Power requirement

Value of 'G' is decreased from I[st], III[rd] compartment.

Let,Value of G in 1[st] compartment, $G_1 = 40\ \text{sec}^{-1}$

Value of G in II[nd] compartment, $G_2 = 30\ \text{sec}^{-1}$

Value of G in III[rd] compartment, $G_3 = 20\ \text{sec}^{-1}$

Now, power required in 1st compartment, $P_1 = G^2 \times \mu V_1$

where V_1 is volume of 1st compartment i.e. (771.5/3) = 257.2 m^3

So, $P_1 = 40^2 \times 1.1 \times 10^{-3} \times 257.2 \times 10^{-3} = 0.45$ kW

Similarly, $P_2 = G_2^2\,\mu V_2 = 30^2 \times 1.1 \times 10^{-3} \times 257.2 \times 10^{-3} = 0.25$ kW

$P_3 = G_3^2\,\mu V_3 = 20^2 \times 1.1 \times 10^{-3} \times 257.2 \times 10^{-3} = 0.103$ kW

4. As shown in figures above, each compartment has three paddles having four boards each of length 2.5 m.

Let, the width of each board = 'W' m

Now, Power, $P = \frac{1}{2} C_D \rho A V_p^3$

where ρ is density of water i.e. 1000 kg/m^3.

V_p is velocity of paddles i.e. $\frac{3}{4} \times 0.67 = 0.5$ m/s [Assumed]

C_D is coefficeint of drag i.e. 1.8. [Assumed]

Now, A_p = Number of board × length × width

= 4 × 3 × 2.5 × W = 30 W

So, $0.47 \times 10^3 = \frac{1}{2} \times 1.8 \times 1000 \times 30W \times 0.5^3$

$\Rightarrow$ $W = 0.14$ m

Q.7 (a) Solution:

(i) For slow moving train

$$\text{Cant, } e_{slow} = \frac{GV^2}{127R}$$

$$= \frac{1.75 \times 50^2}{127 \times \frac{1750}{2}} \text{m} = 39.37 \text{ mm}$$

Now,permissible cant excess = 75 mm

So, actual cant provided, e_{act} = 39.37 + 75

= 114.37 mm

< 165 mm (O.K.)

So, cant to be provided on track is 114.37 mm

Now, $e_{th} = e_{act} + CD$

where e_{th} is cant corresponding to maximum permissible speed, $V_{max.}$

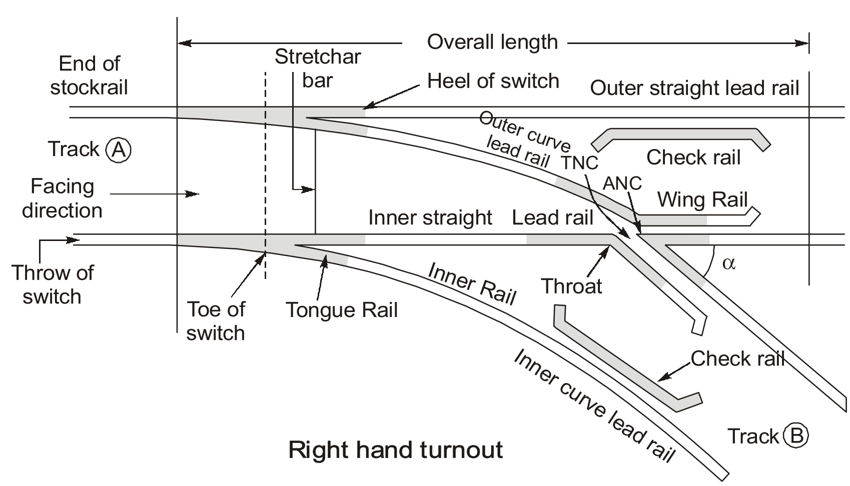
$$\therefore \quad \frac{GV_{max}^2}{127R} = 114.37 + 100$$

$$\Rightarrow \quad \frac{1750 \times V_{max}^2}{127 \times \frac{1750}{2}} = 214.37$$

$$\Rightarrow \quad V_{max} = 116.67 \text{ kmph} \simeq 116 \text{ kmph (say)}$$

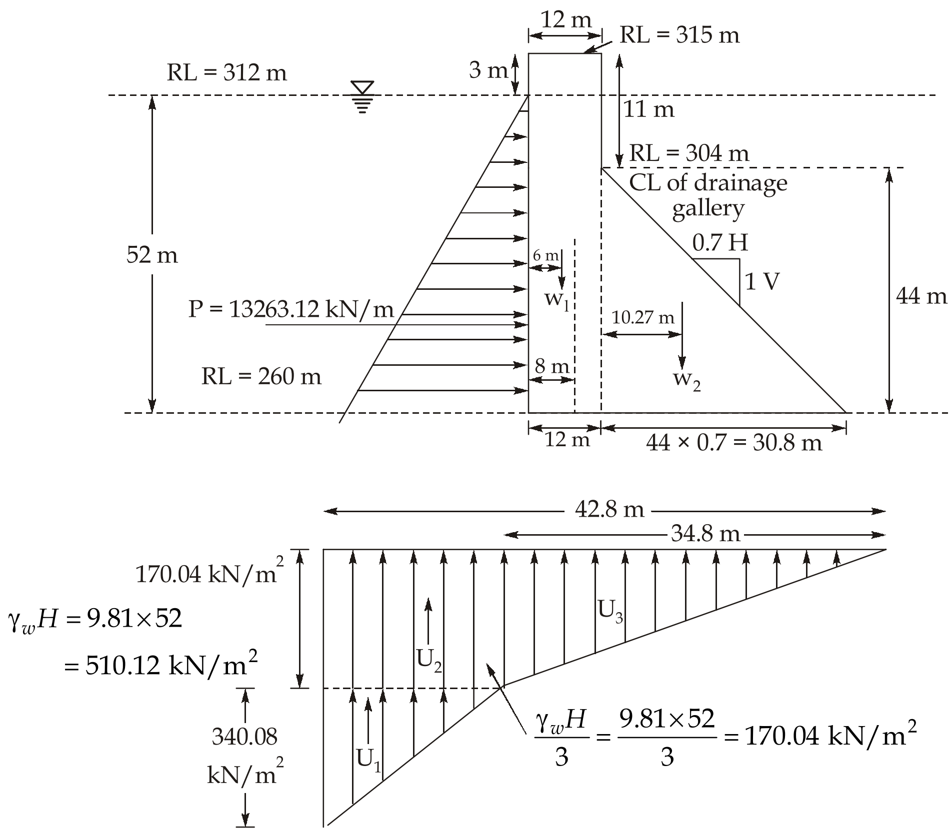
So, permissible speed on track is 116 kmph.

(ii)



Q.7 (b) Solution:

Assuming γ_w = 9.81 kN/m^3, the various forces acting on dam are shown in figure below.



The various forces and their moments about the toe taking anticlockwise moments as positive are tabulated below.

Name of force	Designation	Magnitude (in kN/m)	Lever arm (in m)	Moment (in kN-m/m)
1. Vertical forces (a) Downward weight	W_1	$(+)\ 12 \times 55 \times 23 = 15180$	$30.8 + 6 = 36.8$	558624
	W_2	$(+)\ \frac{1}{2} \times 30.8 \times 44 \times 23 = 15584.8$	$30.8 \times \frac{2}{3} = 20.53$	319955.94
		$\Sigma V_1 = 30764.8$		$\Sigma M_1 = +878579.94$
(b) Uplift pressure	U_1	$-\frac{1}{2} \times 8 \times 340.08 = -1360.32$	$34.8 + \frac{2}{3} \times 8 = 40.13$	–54589.64
	U_2	$-8 \times 170.04 = -1360.32$	38.8	–52780.42
		$-\frac{1}{2} \times 34.8 \times 170.04 = -2958.7$	23.2	–68641.84
		$\Sigma V_2 = -5679.34$		$\Sigma M_2 = -176011.9$
2. Horizontal forces (a) Water pressure	P	$- — \times 510.12 \times 52 = 13263.12$	$\frac{52}{3} = 17.33$	–229849.87
		$\Sigma H_1 = 13263.12$		$\Sigma M_3 = -229849.87$

Now, Resisting moment, $\Sigma M_R = \Sigma M_1 = 878579.94$ kN-m/m

Overturning moment, $\Sigma M_0 = \Sigma M_2 + \Sigma M_3 = (176011.9 + 229849.87)$

$= 405861.77$ kN-m/m

Vertical force, $\Sigma V = \Sigma V_1 + \Sigma V_2 = 30764.8 - 5679.34$

$= 25085.46$ kN/m

Horizontal force, $\Sigma H = 13263.12$ kN/m

(i) Factor of safety against overturning $= \dfrac{\Sigma M_R}{\Sigma M_0} = \dfrac{878579.94}{405861.77} = 2.16$

(ii) Factor of safety against sliding $= \dfrac{\mu \Sigma V}{\Sigma H} = \dfrac{0.8 \times 25085.46}{13263.12} = 1.51$

(iii) Distance of resultant vertical force from toe, $\bar{x} = \dfrac{\Sigma M_R - \Sigma M_0}{\Sigma V}$

$$= \frac{878579.94 - 405861.77}{25085.46} = 18.84 \text{ m}$$

Eccentricity, $e = \dfrac{B}{2} - \bar{x} = \dfrac{42.8}{2} - 18.84 = 2.56$ m

Now, maximum vertical stress, p_v is given as

$$p_v = \frac{\Sigma V}{B}\left[1+\frac{6e}{B}\right] = \frac{25085.46}{42.8}\left[1+\frac{6\times 2.56}{42.8}\right] = 796.45 \text{ kN/m}^2$$

Q.7 (c) Solution:

(i)

In a gravitational settling chamber,

$$\frac{V_f}{L} = \frac{V_0}{H}$$

where V_f is horizontal velocity and V_0 is terminal settling velocity corresponding to 100% removal of particles.

So, $$\frac{0.4}{8} = \frac{V_0}{1.6}$$

$\Rightarrow$ $$V_0 = 0.08 \text{ m/s}$$

Now, $\frac{V_s}{V_0} = 0.96$ where V_s is settling velocity corresponding to 96 percent removal.

$\Rightarrow$ $$V_s = 0.96 \times 0.08 = 0.0768 \text{ m/s}$$

Now, as per Stoke's law

$$V_s = \frac{g}{18}\frac{(\rho_p - \rho_a)d_p^2}{\mu}$$

where ρ_p and ρ_a are density of particle and air respectively.

d_p is diameter of particle

μ is viscosity of air.

Now, $\rho_p = 2000 \text{ kg/m}^3$ $[\because G = 2]$

ρ_a ($= 1.2 \text{ kg/m}^3$) can be neglected as it is very small compared to density of particle.

So, $$0.0768 = \frac{9.81}{18}\times\frac{2000\times d_p^2}{2.1\times 10^{-5}\times 9.81}$$

$\Rightarrow$ $$d_p = 120.48 \times 10^{-6} \text{ m} \simeq 120.5\ \mu\text{m}$$

(ii)

Equivalent noise level (L_{eq}) is that statical value of sound pressure level that can be equated to any fluctuating noise levels. Using the concept of 'L_{eq}', various sounds lasting for their individual period composing a fluctuating noise level, can be represented by a certain dB value which is indicative of producing the same effect over the entire time duration of those sounds. Thus, L_{eq} is defined as constant noise level, which over a given time, expends the same amount of energy, as is expended by the fluctuating levels over the same time. This value is expressed by the equation,

$$L_{eq} = 10\log \sum_{i=1}^{n} 10^{\frac{L_i}{10}} \times t_i$$

where n = Total number of sound samples

L_i = Noise level of i^{th} sample

t_i = Time duration of i^{th} sample expressed as fraction of total sample time.

For the given sound level

Total time duration = 110 minutes

$$\text{So, } L_{eq} = 10\log\left[10^{\frac{80}{10}} \times \frac{10}{110} + 10^{\frac{60}{10}} \times \frac{80}{110} + 10^{\frac{100}{10}} \times \frac{5}{110} + 10^{\frac{50}{10}} \times \frac{10}{110} + 10^{\frac{60}{10}} \times \frac{5}{110}\right]$$

$$= 10\log\left[10^8 \times \frac{1}{11} + 10^6 \times \frac{8}{11} + 10^{10} \times \frac{1}{22} + 10^5 \times \frac{1}{11} + 10^6 \times \frac{1}{22}\right]$$

$$= 10\log(9090909.091 + 727272.73 + 454545454.5 + 9090.909 + 45454.55)$$

$$= 10\log[464418181.8]$$

$$= 10 \times 8.667 = 86.67 \text{ dB}$$

Average sound level, $\bar{L}_p$ is given as

$$\bar{L}_p = 20\log\left[\frac{1}{N}\left[\sum_{i=1}^{N} 10^{\frac{L_i}{20}}\right]\right]$$

$$= 20\log\left[\frac{1}{5}\left[10^{\frac{80}{20}} + 10^{\frac{60}{20}} + 10^{\frac{100}{20}} + 10^{\frac{50}{20}} + 10^{\frac{60}{20}}\right]\right]$$

$$= 20\log\left[\frac{1}{5}[10^4 + 10^3 + 10^5 + 10^{2.5} + 10^3]\right]$$

$$= 20\log\left[\frac{1}{5}\times 112316.23\right]$$

$$= 20 \times 4.35 = 87 \text{ dB}$$

Q.8 (a) Solution:

(i)

On the basis of rate of change of acceleration

Length of transition curve, $L_{s1} = \dfrac{v^3}{RC}$

where, R is radius of circular curve = (16 × 20) m = 320 m and

C is rate of change of acceleraton which is given as,

$$C = \frac{80}{75+V} = \frac{80}{75+80} = 0.516 \text{ m/s}^3$$

which lies between 0.5 and 0.8 and hence. (OK)

Now,
$$L_{s1} = \frac{\left(\frac{5}{18}\times 80\right)^3}{320\times 0.516} = 66.46\,\text{m}$$

(ii) On the basis of rate of change of superelevation.

Length of transition curve, $L_{s2} = \dfrac{eN(W+W_e)}{2}$

where e is superelevation provided

Now,
$$e = \frac{V^2}{225R} = \frac{80^2}{225\times 320} = 0.089 \text{ which is greater than } 0.07$$

So, provide $e = 0.07$

$N = 150$ for rolling terrain

W is width of road i.e. 7 m

As the radius of curve is greater than 300 m, so extrawidening need not to be provided.

So,
$$L_{s2} = \frac{0.07\times 150\times 7}{2} = 36.75\,\text{m}$$

(iii) On the basis of IRC

As per IRC,

Length of transition curve, $L_{s3} = 2.7\dfrac{V^2}{R} = 2.7 \times \dfrac{80^2}{320} = 54$ m

Now, length of transition curve, $L_s = \max(L_{s1}, L_{s2}, L_{s3})$

$= \max(66.46, 36.75, 54) = 66.46 \text{ m} \simeq 70 \text{ m (say)}$

Adopt length of transition curve as 70 m or 3.5 chains.

Now, shift, $S = \dfrac{L_s^2}{24R} = \dfrac{70^2}{24 \times 320} = 0.638\,\text{m}$

Tangent length of curve, $L_T = (R+S)\tan\dfrac{\Delta}{2} + \dfrac{L_s}{2}$

where Δ is deflection angle and is given as

$\Delta = (180° - 146°) = 34°$

So, $L_T = (320 + 0.368)\tan\dfrac{34°}{2} + \dfrac{70}{2}$

$= 132.95 \text{ m} = 6.65 \text{ chain}$

Angle made by half length of transition curve,

$\phi = \dfrac{L_s}{2R} = \dfrac{70}{2 \times 320} = 0.109 \text{ radians} = 6.25°$

Now, length of circular curve $= R \times (\Delta - 2\phi)$

$= 320 \times \left[(34° - 2 \times 6.25°) \times \dfrac{\pi}{180°}\right]$

$= 120.08 \text{ m} = 6 \text{ chains}$

Now, chainage of intersection = 82.5 chains

Chainage at beginning of first transition curve = 82.5 – 6.65 = 75.85 chains

Chainage at beginning of circular curve = 75.85 + 3.5 = 79.35 chains

Chainage at beginning of second transition curve = 79.35 + 6 = 85.35 chains.

Q.8 (b) Solution:

(i) Gauge discharge relation is given as

$$Q = C_r (G - a)^{\beta}$$

Taking log on both sides

$$\log Q = \beta \log(G - a) + \log C_r \quad \text{...(i)}$$

Comparing (i) with standard equaiton i.e. $Y = \beta X + b$

we get

$$Y = \log Q$$

$$X = \log(G - a)$$

$$b = \log C_r$$

Values of X, Y and XY are calculated in table below with a = 20.5 m and N = 7

S. No.	Stage (G) m	(G - a) m	Discharge Q(m^3/s)	log (G - a) = X	Log Q = Y	XY	X^2	Y^2
1	21.95	1.45	100	0.161	2	0.322	0.026	4
2	22.80	2.3	295	0.36	2.47	0.889	0.129	6.1
3	23.40	2.9	490	0.46	2.69	1.237	0.212	7.24
4	23.75	3.25	640	0.51	2.81	1.433	0.26	7.896
5	24.55	4.05	1010	0.61	3.00	1.83	0.372	9
6	25.10	4.6	1300	0.66	3.11	2.053	0.436	9.672
7	25.55	5.05	1550	0.70	3.19	2.233	0.49	10.176
			Sum	**3.461**	**19.27**	**9.997**	**1.925**	**54.084**

Now,

$$\beta = \frac{N(\Sigma XY) - (\Sigma X)(\Sigma Y)}{N(\Sigma X^2) - (\Sigma X)^2} = \frac{7 \times 9.997 - 3.461 \times 19.27}{7 \times 1.925 - (3.461)^2}$$

$$= 2.196$$

$$b = \frac{\Sigma Y - \beta(\Sigma X)}{N} = \frac{19.27 - 2.196 \times 3.461}{7} = 1.667$$

As

$$b = \log C_r$$

$\Rightarrow$

$$C_r = 10^{1.667} = 46.452$$

Hence, the required stage discharge relationship is given as

$$Q = 46.452\,(G - 20.5) \quad \text{...(ii)}$$

(ii) Now, coefficient of correlation, r is given as

$$r = \frac{N(\Sigma XY) - (\Sigma X)(\Sigma Y)}{\sqrt{\left[N(\Sigma X^2) - (\Sigma X)^2\right]\left[N(\Sigma Y^2) - (\Sigma Y)^2\right]}}$$

$$= \frac{7\times(9.997)-3.461\times19.27}{\sqrt{[7\times1.925-3.461^2][7\times54.084-19.27^2]}} = 0.997$$

As value of r is nearer to 1, correlation is very good.

(iii) When discharge, $Q = 2600\ m^3/s$, then 'G' can be found out using eq. (ii)

$$Q = 46.452(G - 20.5)^{2.196}$$

$$\Rightarrow \quad 2600 = 46.452 \times (G - 20.5)^{2.196}$$

$$\Rightarrow \quad (G - 20.5) = 6.251$$

$$\Rightarrow \quad G = 6.251 + 20.5 = 26.751\ m$$

Q.8 (c) Solution:

(i)

The following factors affect the selection of a particular lining for a given canal project:

1. **Size and importance of canal**: For smaller canals, which may be used only intermittently, a lining may be chosen having low construction cost. Larger canals on the other hand, may permit use of cast in-situ operations. Moreover, large and important canal may require continuous operations, and hence may need stronger linings such as concrete lining.
2. **Canal slopes and alignments**: These factors also need consideration since frequent changes in alignment and steeper slopes may encounter higher flow velocities, leading to selection of stronger linings. The limiting safe velocities, in he commonly used types of linings are as follows:

S. No.	Types of lining	Safe limiting velocity
1	Boulder lining	1.5 m/s
2	Burnt clay tile lining	1.8 m/s
3	Cement concrete lining	2.7 m/s

3. **Climate of area**: Superior quality linings should be used in areas which are susceptible to severe frosts and temperature changes such as in western countries.
4. **Availability of material:** Every type of lining will require certain materials and indegredients. Some of these materials may be easily available at a certain place, and other may not be easily available. The type of lining should be such that the required materials are most easily available locally or in vicinity of area from where they can be carried to site with least cost.

5. **Initial expenditure**: Mathematically speaking, the most economic type of lining is the one which shows maximum annual benefit-cost ratio. This lining may have higher initial cost but longer life than some other kind of lining having lesser value of annual benefit-cost ratio. From long term perspective, the former type of lining should be chosen.

(ii)

Given: Discharge, $Q = 60 \text{ m}^3/\text{s}$

Silt factor, $f = 1.1$

As per Lacey's theory

$$\text{Velocity, } V = \left(\frac{Qf^2}{140}\right)^{1/6} = \left(\frac{60\times 1.1^2}{140}\right)^{1/6} = 0.896 \text{ m/s}$$

Now, $$\text{Flow area, } A = \frac{Q}{V} = \frac{60}{0.896} = 66.96 \text{ m}^2$$

Also, $$\text{Wetted perimeter, } P = 4.75\sqrt{Q} = 4.75\sqrt{60} = 36.79 \text{ m}$$

For a trapezoidal channel with 0.5 H : 1V slope,

$$P = B+\sqrt{5}y$$

and $$A = (B+0.5y)y$$

$\therefore$ $$P = 36.79 = B+\sqrt{5}y \quad \text{...(i)}$$

and $$A = 66.96 = (B+0.5y)y \quad \text{...(ii)}$$

Multiplying (i) wth y and subtracting it from (ii), we get

$$\left(\sqrt{5}-0.5\right)y^2 - 36.79y + 66.96 = 0$$

$\Rightarrow$ $$y = 19.18 \text{ m}, 2.01 \text{ m}$$

Adopting depth as 2.01 m, we get $B = 36.79-\sqrt{5}y$

$$= 36.79-\sqrt{5}\times 2.01 = 32.29 \text{ m}$$

$$\text{Adopt } B = 32.3 \text{ m}, y = 2 \text{ m}$$

Now, $$\text{bed slope, } S_0 = \frac{f^{5/3}}{3340Q^{1/6}} = \frac{(1.1)^{5/3}}{3340\times 60^{1/6}} \simeq 1 \text{ in } 5638$$

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