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ESE 2021

Main Exam Detailed Solutions

CIVIL ENGINEERING

PAPER-II

EXAM DATE : 21-11-2021 | 2:00 PM to 5:00 PM

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ANALYSIS

Civil Engineering Paper-II
ESE 2021 Main Examination

Sl.	Subjects	Marks
1.	Fluid Mechanics & Hydraulic Machines	116
2.	Engineering Hydrology	30
3.	Water Resource Engineering	0
4.	Environmental Engineering	74
5.	Soil Mechanics & Foundation Engg.	104
6.	Surveying and Geology	52
7.	Transportation Engineering	104
	Total	**480**

Scroll down for detailed solutions

Section-A

Q.1 (a) If the velocity components for two dimensional flow are given by

$$u = \frac{x}{x^2 + y^2} \text{ and } v = \frac{y}{x^2 + y^2}$$

determine the acceleration components in X and Y direction and rotation in Z direction at two points in the flow field (i) (2, 3) and (ii) (4, 5). Coordinates are in meters.

[12 Marks]

Solution:

Acceleration:

$$a_x = u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}$$

$$\frac{\partial u}{dx} = \frac{\partial}{\partial x}\left(\frac{x}{x^2 + y^2}\right)$$

$$= \frac{(x^2 + y^2) - x(2x)}{(x^2 + y^2)^2} = \frac{y^2 - x^2}{(x^2 + y^2)^2}$$

$$\frac{\partial u}{\partial y} = \frac{\partial}{\partial y}\left(\frac{x}{x^2 + y^2}\right)$$

$$= \frac{-2xy}{(x^2 + y^2)^2}$$

$$a_x = \left(\frac{x}{x^2 + y^2}\right)\left[\frac{y^2 - x^2}{(x^2 + y^2)^2}\right] + \left(\frac{y}{x^2 + y^2}\right)\left[\frac{-2xy}{(x^2 + y^2)^2}\right]$$

$$= \frac{xy^2 - x^3 - 2xy^2}{(x^2 + y^2)^3}$$

$$= \frac{-x^3 - xy^2}{(x^2 + y^2)^3} = \frac{-x(x^2 + y^2)}{(x^2 + y^2)^3} = \frac{-x}{(x^2 + y^2)^2}$$

$$\frac{\partial v}{\partial x} = \frac{\partial}{\partial x}\left(\frac{y}{x^2 + y^2}\right) = -\frac{2xy}{(x^2 + y^2)^2}$$

$$\frac{\partial v}{\partial y} = \frac{\partial}{\partial y}\left(\frac{y}{x^2 + y^2}\right)$$

$$= \frac{(x^2 + y^2) - y(2y)}{(x^2 + y^2)^2} = \frac{x^2 - y^2}{(x^2 + y^2)^2}$$

$$a_y = u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}$$

$$= \left(\frac{x}{x^2+y^2}\right)\left[\frac{-2xy}{\left(x^2+y^2\right)^2}\right] + \left(\frac{y}{x^2+y^2}\right)\left[\frac{x^2-y^2}{\left(x^2+y^2\right)^2}\right]$$

$$= \frac{-2x^2y + x^2y - y^3}{\left(x^2+y^2\right)^3} = \frac{-y\left(x^2+y^2\right)}{\left(x^2+y^2\right)^3}$$

$$a_y = \frac{-y}{\left(x^2+y^2\right)^2}$$

$$a_x = \frac{-x}{\left(x^2+y^2\right)^2} \text{ and } a_y = \frac{-y}{\left(x^2-y^2\right)^2}$$

At point (2, 3)

$$a_x = \frac{-2}{\left(2^2+3^2\right)^2}, \quad a_y = \frac{-3}{\left(2^2+3^2\right)^2}$$

$$a_x = \frac{-2}{169} \text{ m/s}^2, \quad a_y = \frac{-3}{169} \text{ m/s}^2$$

At point (4, 5)

$$a_x = \frac{-4}{\left(4^2+5^2\right)^2}, \quad a_y = \frac{-5}{\left(4^2+5^2\right)^2}$$

$$a_x = \frac{-4}{1681} \text{ m/s}^2, \quad a_y = \frac{-5}{1681} \text{ m/s}^2$$

Angular velocity (w_z),

$$w_z = \frac{1}{2}\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)$$

$$= \frac{1}{2}\left[\left\{\frac{-2xy}{\left(x^2+y^2\right)^2}\right\} - \left\{\frac{-2xy}{\left(x^2+y^2\right)^2}\right\}\right]$$

$$w_z = 0$$

End of Solution

Q.1 (b) What are the different forces acting in a moving fluid? Also discuss different similarity model laws used to study the dynamic similarity of a prototypes.

[12 Marks]

Solution:

Forces acting on a moving fluid are:

(i) Inertia force

(ii) Viscous force

(iii) Gravity force

(iv) Pressure force

(v) Elastic force

(vi) Surface tension force

For dynamically similar model:

(i) **Reynold's model law:** For the flow where in addition to inertia, viscous force is the only other predominant force, the similarity of flow in the model and its prototype can be established if the Reynold's number is same for both the system, thus,

$$(\text{Re})_{\text{model}} = (\text{Re})_{\text{prototype}}$$

or
$$\frac{\rho_m V_m L_m}{\mu_m} = \frac{\rho_p V_p L_p}{\mu_p}$$

or
$$\frac{\rho_r V_r L_r}{\mu_r} = 1$$

or
$$\frac{V_r L_r}{\nu_r} = 1$$

Reynold's model law in valid for:

- Flow of incompressible fluid is closed pipes.
- Motion of submarines completely under water.

(ii) **Froude model law:** The gravity force is the only predominant force in addition to the inertia force, which controls the motion

$$(\text{Fr})_{\text{model}} = (\text{Fr})_{\text{prototype}}$$

or
$$\frac{V_m}{\sqrt{g_m L_m}} = \frac{V_p}{\sqrt{g_p L_p}}$$

or
$$\frac{V_r}{\sqrt{g_r L_r}} = 1$$

$$V_r = \sqrt{g_r L_r}$$

Since, in most of the cases $g_r = 1$,then

$$V_r = \sqrt{L_r}$$

Froude model is valid for:

- Free surface flows such as flow over spillways, sluices etc.
- Flow of jet from an orifice or nozzle.

(iii) **Euler Model Law:** This model is applicable where pressure force controls flow in addition to inertial force. Thus,

$$(Eu)_m = (Eu)_p$$

or
$$\frac{V_m}{\sqrt{\frac{p_m}{\rho_m}}} = \frac{V_p}{\sqrt{\frac{p_p}{\rho_p}}}$$
or
$$\frac{V_r}{\sqrt{\frac{p_r}{\rho_r}}} = 1$$

Euler model is applicable in case of cavitation.

(iv) **Weber Model Law:** When surface tension effects predominates in addition to inertia force, this model is used in order to establish similarity between model and prototype.

$$(We)_{model} = (We)_{prototype}$$

or
$$\frac{V_r}{\sqrt{\frac{\sigma_r}{\rho_r L_r}}} = 1$$

Weber model law is applicable for capillary rise in narrow passages

(v) **Mach Model Law:** When elastic compression forces are significant in addition to inertia force then this model is used.

$$(M_a)_{model} = (M_a)_{prototype}$$

or
$$\frac{V_r}{\sqrt{\frac{k_r}{\rho_r}}} = 1$$

This model is applicable for hydraulic model testing in unsteady flow (water hammer).

End of Solution

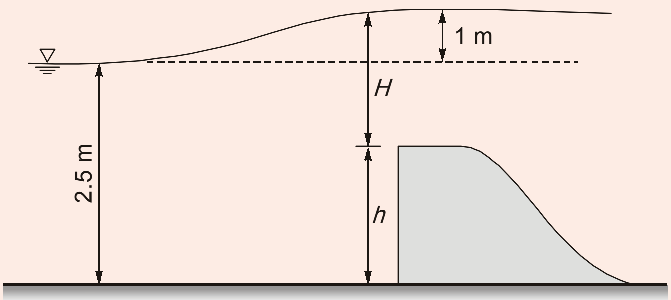
Q.1 (c) A stream has a width of 25 m, depth of 2.5 m and mean velocity of 1.5 m/sec. Find the height of weir to be constructed on the stream floor to raise the water level by 1 m. Assume value of discharge coefficient as 0.95.

[12 Marks]

Solution:

Given,
$$B = 25 \text{ m}$$
$$C_D = 0.95$$
$$y = 2.5 \text{ m}$$
$$v = 1.5 \text{ m/s}$$

Discharge,
$$Q = A \times v = (B \times y) \times v$$
$$Q = 25 \times 2.5 \times 1.5 \text{ m}^3\text{/s}$$
$$Q = 93.75 \text{ m}^3\text{/s}$$



Assuming the weir to be rectangular crested,

$$Q = \frac{2}{3} C_D \sqrt{2g} B H^{3/2}$$

$$93.75 = \frac{2}{3} \times 0.95 \times \sqrt{2 \times 9.81} \times 25 \times (3.5 - h)^{3/2}$$

$$h = 2.2865 \text{ m}$$

End of Solution

Q.1 (d) Define 'noise' and explain as to why and how it should be regarded as an environmental pollutant. Also explain briefly the major factors and actions that may help in noise abatement in a modern society.

[12 Marks]

Solution:

Sound in the environment is caused by vibrations in the air (or some other medium) that reach human ears and stimulate a sensation of hearing. When the sound becomes loud, or disagreeable, or unwanted, it becomes noise. Since the unwanted sound (i.e., noise) certainly produces severs undesirable effects on our body health, it can be termed as an environmental pollutant. The air (prevention and control of Pollution) Act 1981, includes noise as one of the air pollutant.

Noise can, therefore, also be defined as that unwanted sound pollutant, which produces undesirable physiological and psychological effects in the individual, by interfering with one's social activities like work, rest, recreation, sleep, etc.

Harmful effects of noise include:

- **Noise induces annoyance:** One of the most important effect of noise on humans is annoyance and irritation due to disturbance.
- **Noise induced disease:** Noise may produce several undesirable physiological and psychological diseases in human beings. The disease caused may include: anxiety, tenses, nervousness, headaches, fatigue, nausea, insomnia, high blood pressure, high pulse rate, greater perspiration, gastric secretions, etc.
- **Sleeplessness:** The noise may induce sleep disturbances including shorter sleep durations, more frequent awakenings, etc.
- **Communication interference:** Noise can badly disturb communication when a person is speaking on telephone, or when individuals are talking face to face.
- **Noise induced hearing loss:** Exposure of human ears to intense noise for a long enough duration may cause damage to the inner ear, thereby decreasing ones ability to hear.
- **Effect of noise on wild life:** Wildlife, like humans, is also badly affected by noise. Health of several zoo-animals, particularly those of deers, rhinos, lions, etc. are adversely affected by noise. Several migratory birds have stopped resting in habitates close to noise cities.

Control of Noise Source by Design

(a) Some kind of noise can be controlled by keeping them under control of legal laws and ordinance.

(b) By providing walls on both sides of roads and railways line, noise can be abated.

(c) By raising obstruction and barrier between noise source and residence in a such away attenuation of 15 dB can become possible.

(d) Raising of thick and high vegetation and tree growing along sides of road and railway lines.

End of Solution

Q.1 (e) A waste water treatment plant discharge 1.0 m^3/sec of effluent having an ultimate BOD of 45.0 mg/*l* into a river flowing at 10.0 m^3/sec. Just upstream from the discharge point, the river water has an ultimate BOD of 4.0 mg/*l*. The deoxygenation constant (k_d) is 0.22/day. Answer the following:

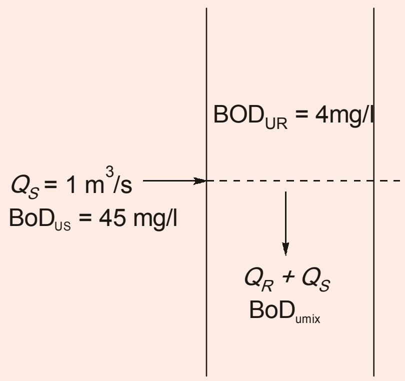
(i) Assuming complete and instantaneous mixing, what would be the ultimate BOD of the mixture of waste and river just downstream from the outfall?

(ii) Assuming a constant cross-sectional area for the river equal to 60 m^2, what ultimate BOD would you expect to find at a point 10.0 km downstream?

[12 Marks]

Solution:

$$k_D = 0.22/\text{day.}$$



Q_s - discharge of sewage
BOD$_{us}$ - ultimate BOD of sewage
Q_R - discharge of river
BOD$_{UR}$ - ultimate BOD of river.
BOD$_{umix}$ - Ultimate BOD of the mix

(i)
$$\text{BOD}_{umix} = \frac{BOD_{US}Q_s + BOD_{UR}Q_R}{Q_S + Q_R}$$

$$= \frac{45 \times 1 + 4 \times 10}{11} \text{mg}/l = 7.727 \text{ mg}/l$$

(ii) Avg velocity of the mix,

$$V = \frac{Q_S + Q_R}{Area} = \frac{11 m^3/s}{60 m^2} = 0.183 \text{ m/s}$$

Time required to travel 10 km,

$$= \frac{10 \times 10^3 \text{ m}}{0.183 \text{ m/s} \times 86400 \text{ s/d}} = 0.6324 \text{ day}$$

BOD consumed in 0.6324 day

$$= 7.727 \text{mg}/l \left(1 - e^{-0.22 d^{-1} \times 0.6324 d}\right) = 1 \text{ mg}/l$$

(Assuming the k_D given is w.r.t base 'e')

BOD Remaining $= 7.727 - 1 = 6.727$ mg/l

End of Solution

Q.2 (a) A cylindrical gate of 3.0 m dia. and having 4.0 m length is made of 60 mm thick steel sheet of 7.8 ton/m^3 density. The gate has water on both its sides.

(i) Water level is up to 2.0 m depth from bottom of gate on the left side and up to 1.5 m depth on the right side of the gate. Determine the magnitude, location and direction of the resultant hydrostatic force. Also determine whether the gate will float in this case or not.

(ii) If the water level rises up to 3.0 m on the left of the gate (up to the top of the gate), determine whether the gate will float or not. If yes, what should be the thickness of the gate sheet to prevent it from floating?

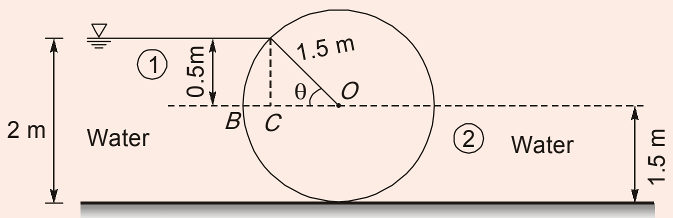
[20 Marks]

Solution:

(i) Length, $L = 4$ m

Diameter, $D = 3$ m

$t = 60$ mm



For horizontal force,

Due to lift side water, $F_{H_1} = \rho_w . g \bar{h}_1 A_{V_1}$

$$= (10^3)(9.81)\left(\frac{2}{2}\right)(2 \times 4)$$

$$= 78.48 \text{ kN } (\rightarrow)$$

Due to right side water, $F_{H_2} = \rho_w g \bar{h}_2 A_{V_2}$

$$= (10^3)(9.81)\left(\frac{1.5}{2}\right)(1.5 \times 4)$$

$$= 44.145 \text{ kN } (\leftarrow)$$

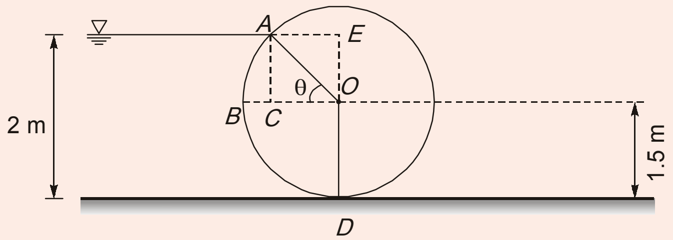
Net horizontal force, $F_H = F_{H_1} - F_{H_2}$

$$= 34.335 \text{ kN } (\rightarrow)$$

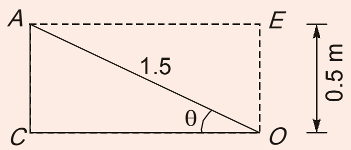
For vertical force,

Due to left side water, $F_{V_1} = \rho g \forall_1$

$\forall_1$ = (Area of sector OBD + Area of sector OBA + Area of ΔOAE) × 4



$$AE = \sqrt{1.5^2 - 0.5^2} = 1.414 \text{ m}$$



$$\sin\theta = \frac{AC}{OA} = \frac{0.5}{1.5}$$

$$\theta = 19.47$$

$$= \left[\frac{\pi(1.5)^2}{4} + \frac{19.47°}{360°} \times \pi(1.5)^2 + \left(\frac{1}{2} \times 1.414 \times 0.5\right)\right]4$$

$$= 10.01 \text{ m}^3$$

When, $F_{V_1} = (10^3)(9.81)(10.01)$

$$= 98.2 \text{ kN } (\uparrow)$$

Due to right side water, $F_{V_2} = \rho g \bar{V}_2$

$$= (10^3)(9.81)\left(\frac{\pi(1.5)^2}{4} \times 4\right)$$

$$= 69.34 \text{ kN } (\uparrow)$$

Net vertical force due to water on gate

$$F_V = F_{V_1} + F_{V_2}$$

$$= 98.2 + 69.34$$

$$= 167.54 \text{ kN } (\uparrow)$$

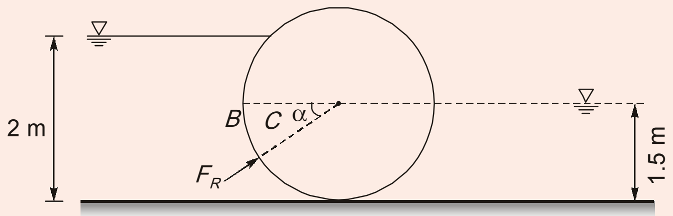
Resultant force due to water on gate

$$F_R = \sqrt{F_H^2 + F_V^2}$$

$$= \sqrt{34.335^2 + 167.54^2}$$

$$= 171.02 \text{ kN}$$

Direction of resultant force



$$\tan \alpha = \frac{F_V}{F_H} = \frac{167.54}{34.335}$$

$$\alpha = 78.418°$$

Resultant force due to water acts normal to the cylindrical surface and passes through the centre O.

$$\text{Weight of gate} = \rho_s \forall g$$

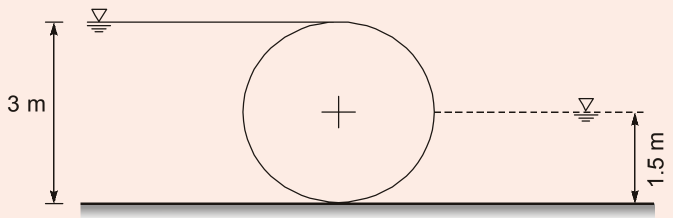
$$= \rho_s(\pi DLt)g$$

$$= (7.8 \times 10^3)\pi(3)(4)(0.06)(9.81)$$

$$= 173.08 \text{ kN}$$

Since weight of gate is higher than net vertical force due to water on gate so gate will not float.

(ii)



Net vertical force due to water on gate

$$F_V = \rho g\left(\frac{3}{4}\pi R^2\right)\times 4$$

$$= \left(10^3\right)(9.81)\left(\frac{3}{4}\pi(1.5)^2\times 4\right) = 208.03 \text{ kN } (\uparrow)$$

Weight of cylindrical gate = 173.08 kN

Since F_V is greater than weight of cylindrical gate so gate will float.

Thickness of gate sheet to prevent floating

$$F_V = \text{Weight of gate}$$

$$10^3\times 208.03 = (7.8)(\pi DLt)\times 9.81\times 10^3$$

$$208.03 = 7.8\times\pi(3)(4)t(9.81)$$

$$t = 0.072116 \text{ m}$$

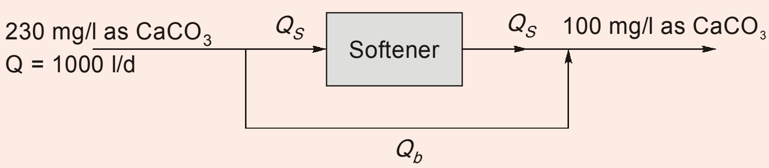
$$= 72.12 \text{ mm}$$

End of Solution

Q.2 (b) A water softener has 0.05 m^3 of ion exchange resin with an ion exchange capacity of 40 kg/m^3. the water requirement of users is 1000 litres per day. If the water contains 230 mg/l of hardness as $CaCO_3$ and users want to soften it to 100 mg/l as $CaCO_3$, how much water should bypass the softener daily? What is the time between regeneration cycles if it is assumed that the complete saturation of the resin occurs before regenerating?

[20 Marks]

Solution:



Q_S - discharge passing through the softener

Q_b - bypass discharge

Q - total discharge

Assuming ion exchange resin works at an efficiency of 100% as long as it has the ions to exchange.

$$\therefore\ 100 \text{ mg/l as } CaCO_3 = \frac{Q_S\times O + Q_b\times 230 \text{ mg/l as } CaCO_3}{1000 \text{ l/d}}$$

$$Q_b = 434.782 \text{ l/d}$$

Now, the time of regeneration will come when the bed is exhausted.

$$\text{Volume of resin} = 0.05 \text{ m}^3$$

$$\text{Total qty of ions exchanged} = 40 \text{ kg/m}^3\times 0.05 \text{ m}^3 = 2 \text{ kg}$$

$$\text{Hardness loading rate} = Q_s\times(\text{Initial hardness})$$

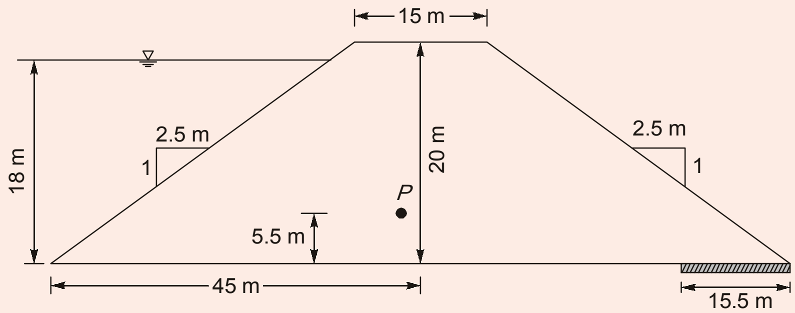
$$= (1000 - 434.782) \times 230 \times 10^{-6} \text{ kg/d}$$
$$= 0.13 \text{ kg/d}$$

$$\text{Time of regeneration} = \frac{\text{Total quantity of ions exchanged}}{\text{Hardness loading rate}}$$

$$= \frac{2}{0.13} \text{ days} = 15.385 \text{ days}$$

End of Solution

Q.2 (c) A homogeneous anisotropic embankment dam section is shown in the figure, the coefficient of permeability in the x and z directions being 5×10^{-8} and 2×10^{-8} m/s respectively. Construct the flow net and determine the quantity of seepage through the dam What is the pore water pressure at point 'P'?



[20 Marks]

Solution:

The scale factor for transformation in x-direction is

$$\sqrt{\frac{k_z}{k_x}} = \sqrt{\frac{2}{5}} = 0.632$$

The focus of the basic parabola is at point A. The basic parabola passes through point G such that GC = 0.3 HC = 0.3 (2.5 × 18) = 0.3 × 27.00 = 8.10 m i.e., the coordinate of G are x= –40.80, z = +18.00

As per A Casagrande

$$x = x_0 - \frac{z^2}{4x_0}$$

where $2x_0$ = focal length = S

substituting these coordinates in above eq. (–40.80, 18.00)

$$-40.80 = -x_0 - \frac{(18.00)^2}{4x_0}$$

$$x_0 = +1.90$$

Using Casagrande's equation coordinates of a number of points on the basic parabola are now calculated.

x	1.90	0	–5.00	–10.00	–20.00	–30.00
Z	0	3.80	7.24	9.51	12.90	15.57

The basic parabola can be plotted.

$$N_f = 3.8$$

$$N_d = 18$$

$$\Delta h = \frac{H}{N_d} = \frac{18}{18} = 1$$

$$(T.H.) = H - 2.4\,\Delta h$$

$$P = 18 - 2.4 \times 1 = 15.6$$

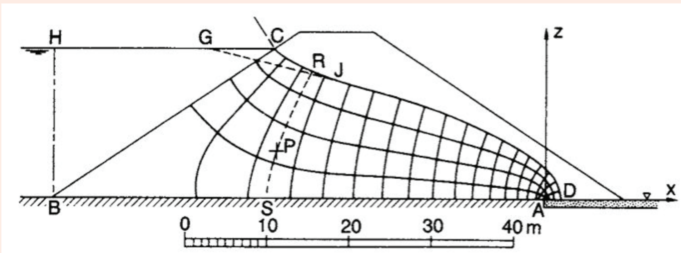
$$(D.H.)_P = 5.5 \text{ m}$$

$$PH = TH - DH$$

$$= 10.1$$

$$u = (PH)\gamma_w$$

$$= 9.81 \times 10.1 = 99 \text{ kN/m}^2$$



$$q = k's$$

$$k' = \sqrt{k_x k_z} = \sqrt{2 \times 10^{-8}\left(5 \times 10^{-8}\right)}$$

$$= 3.16 \times 10^{-8}$$

$$S = \sqrt{d_T^2 + H^2} - d_T$$

d = Base width – 0.7 L – Filter length

$$\text{Base width} = (20 \times 2.5) + 15 + (20 \times 2.5) = 115 \text{ m}$$

$$L = 2.5 \times 18 = 45.0 \text{ m}$$

$$d = 115 - 0.7 \times 45 - 15.5 = 68 \text{ m}$$

$$d_T = d\sqrt{\frac{k_z}{k_x}} = 68\sqrt{\frac{2 \times 10^{-8}}{5 \times 10^{-8}}} = 43 \text{ m}$$

$$S = \sqrt{43^2 + 18^2} - 43 = 3.615 \text{ m}$$

$$q = 3.16 \times 10^{-8} \times 3.615$$

$= 11.42 \times 10^{-8}$ m^3/s/m length of dam

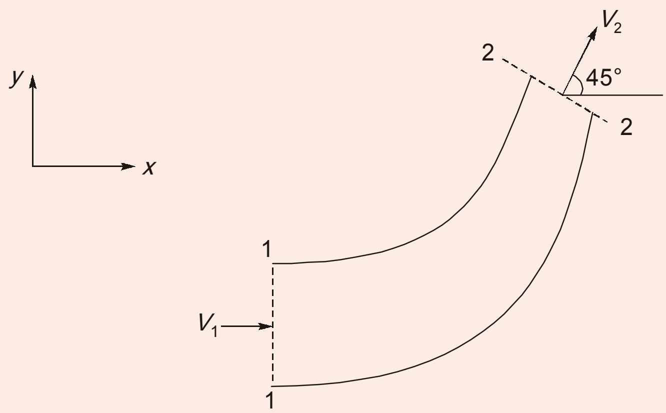
$= 1.142 \times 10^{-7}$ m^3/s/m length

End of Solution

Q.3 (a) Alignment of a water pipeline has been changed by 45° in horizontal plane using reducing bend having 40 cm and 20 cm dia. at the beginning and end of the bend respectively. A discharge of 400 lit/sec is flowing in the pipeline. The pressure in the pipeline at the starting end of the bend is 3000 bar. The frictional head loss due to the bend may be assumed as 5% of the kinetic energy at the exit off the bend. Determine the force exerted on the bend. Also determine the direction of resulting force.

[20 Marks]

Solution:



Given:

$$Q = 0.4 \text{ m}^3/\text{s}$$
$$D_1 = 0.4 \text{ m}$$
$$D_2 = 0.2 \text{ m}$$
$$P_1 = 3000 \text{ bar} = 3 \times 10^8 \text{ Pa}$$

Head loss, $$h_L = 0.05\frac{V_2^2}{2g}$$

$$V_1 = \frac{Q}{\frac{\pi}{4}D_1^2} = \frac{0.4}{\frac{\pi}{4}(0.4)^2} = 3.183 \text{ m/s}$$

$$V_2 = \frac{Q}{\frac{\pi}{4}D_2^2} = \frac{0.4}{\frac{\pi}{4}\times(0.2)^2} = 12.73 \text{ m/s}$$

Apply energy eq. between section (1) and section (2)

$$\frac{P_1}{\rho g}+\frac{V_1^2}{2g}+Z_1 = \frac{P_2}{\rho g}+\frac{V_2^2}{2g}+Z_2+h_L$$

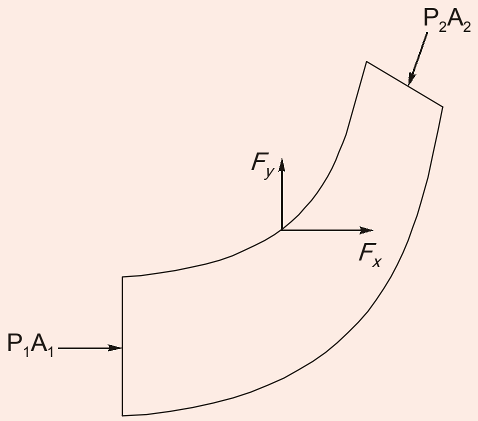
$(Z_1 = Z_2)$

$$\frac{P_1}{\rho g} + \frac{V_1^2}{2g} = \frac{P_2}{\rho g} + \frac{V_2^2}{2g} + 0.05\frac{V_2^2}{2g}$$

$$= (3\times 10^8) + \left(\frac{10^3}{2}\right)\left[3.183^2 - 1.05(12.73)^2\right] = P_2$$

$$P_2 = 2.999 \times 10^8 \text{ Pa}$$

In x-y plane
Water system



F_x and F_y = Force exerted by bend on water in x and y direction respectively.

Apply Newton's 2nd law in x-direction

$$P_1A_1 - P_2A_2\cos 45° + F_x = \dot{m}V_2\cos 45° - \dot{m}V_1$$

$$(3\times 10^8)\frac{\pi}{4}(0.4)^2 - (2.999\times 10^8)\frac{\pi}{4}(0.2)^2\cos 45° + F_x$$

$$= (10^3)(0.4)(12.73\cos 45° - 3.183)$$

$$= -31034.68 \text{ kN}$$

Apply Newton's 2nd law in y-direction

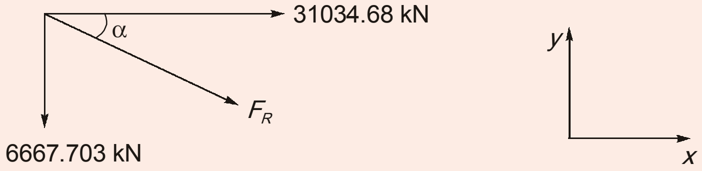
$$-P_1A_2\sin 45° + F_y = \dot{m}V_2\sin 45°$$

$$F_y = \dot{m}V_2\sin 45° + P_2A_2\sin 45°$$

$$= (10^3)(0.4)12.73\sin 45° + (2.999\times 10^8)\frac{\pi}{4}(0.2)^2\sin 45°$$

$$= 6667.703 \text{ kN}$$

Force exerted on bend



$$\tan \alpha = \frac{6667.703}{31034.68}$$

$$\alpha = 12.12°$$

End of Solution

Q.3 (b) Determine the size and depth of a high rate single stage trickling filter for treating the following domestic and industrial wastewater of a town of 50,000 population. Also determine the efficiency of filter and BOD_5 of the effluent.

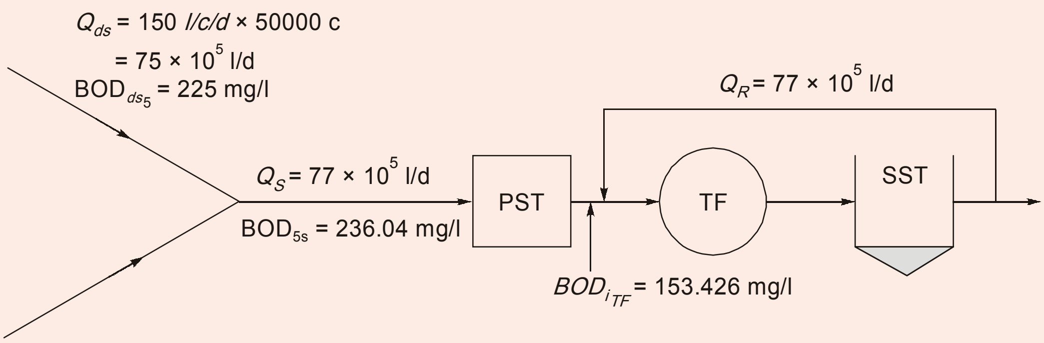
- Domestic sewage @ 150 litres per capita per day having 225 mg/l of BOD_5, and
- Industrial wastewater @ 2,00,000 litres per day having 650 mg/l of BOD_5.

Assume the following data:

— BOD_5 removal in primary clarifier = 35%
— Permissible organic loading of trickling filter = 900 g/day/m^3 (excluding recirculated sewage)
— Recirculation ratio = 1.0
— Permissible hydraulic loading = 20 m^3/day/m^2 (including recirculated sewage)

[20 Marks]

Solution:



$$Q_{is} = 2 \times 10^5 \text{ l/d} = 2 \times 10^5 \text{ l/d}$$

$$BOD_{is_5} = 650 \text{ mg/l}$$

BOD_5 of the sewage after mixing,

$$BOD_{58} = \frac{(75 \times 10^5 \text{ l/d} \times 225 \text{mg/l}) + (2 \times 10^5 \text{ l/d} \times 650 \text{ mg/l})}{77 \times 10^5 \text{ l/d}}$$

$$= 236.04 \text{ mg/l.}$$

Influent BOD into the $TF = BOD_{iTF} = 153.426$ mg/l

$R = 1$

$\therefore \quad F = \frac{1+R}{[1+(1-F)R]^2}$;

$F \rightarrow$ treatability factor

$f = 0.9$ (for sewage)

$F =$ Recirculation factor

$F = \frac{1+1}{(1.1)^2} = 1.653$

$$\text{OLR} = 900\ \text{g/d/m}^3 = \frac{\text{Qty. of BOD entering the filter}}{\text{Volume of the filter medium}}$$

Volume of the filter medium,

$$V = \frac{153.426\ \text{mg/l} \times 77 \times 10^5\ \text{l/d}}{900\ \text{g/d/m}^3 \times 10^3\ \text{mg/g}} = 1312.64\ \text{m}^3$$

$$\text{HLR} = 20\ \text{m}^3/\text{d/m}^2 = \frac{\text{Discharge passing through the filter}}{\text{Surface area of the filter}}$$

$\therefore$ Surface area of the filter,

$$SA = \frac{(77 \times 10^2 + 77 \times 10^2)\ \text{m}^3/\text{d}}{20\ \text{m}^3/\text{m}^2/\text{d}} = 770\ \text{m}^2$$

$\therefore \quad \frac{\pi D^2}{4} = 770\ \text{m}^2$; where D-diameter of the filter

$D = 31.31$ m

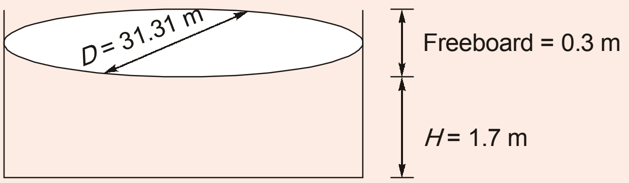
$\because$ Maximum diameter permitted is 60 m, hence, OK.

$V = \frac{\pi D^2}{4} \times H$; where H - height of the filter medium

$H = \frac{1312.64}{770} = 1.7$ m

$\because$ H is between 0.9 m – 2.5 m.

Final dimensions:



Now, $\eta = \frac{100}{1+0.44\sqrt{\frac{OLR}{F}}} = \frac{100}{1+0.44\sqrt{\frac{0.9}{1.653}}} = 75.49 \approx 75.5\%$

Now, BOD_5 of the effluent $= (1 - 0.755) \times 153.426 = 37.589 \approx 37.6$ mg/l.

End of Solution

Q.3 (c) Calculate the infiltration rate and cumulative infiltration after 1.50 hours of rainfall of 4.0 cm/hr intensity on a silt loam soil with an initial effective saturation of 25%. Value of saturated hydraulic conductivity is 0.65 cm/hr, effective porosity of silt loam soil is 0.486, and wetting front soil suction head is 16.70 cm.

[20 Marks]

Solution:

For the silt loam

Effective saturation, $\sigma_e = 0.25$

Hydraulic conductivity, $k = 0.65$ cm/hr

Effective porosity, $\theta_e = 0.486$

Suction head, $\psi = 16.70$ cm

$\therefore \quad \Delta\theta = \theta_e(1-\sigma_e) = 0.486(1-0.25) = 0.3645$

$\therefore \quad |\psi|\Delta\theta = 16.70 \times 0.3645 = 6.0871$

From Green Ampt. equation,

Cumulative infiltration is given by

$$F - |\psi|\Delta\theta \ln\left(1+\frac{F}{|\psi|\Delta\theta}\right) = kt$$

$$\Rightarrow \quad F - 6.0871\ln\left(1+\frac{F}{6.0871}\right) = 0.65\,t$$

$$\therefore \quad F - 6.0871\ln\left(1+\frac{F}{6.0871}\right) = 0.65 \times 1.50$$

$$\Rightarrow \quad F - 6.0871\ln\left(1+\frac{F}{6.0871}\right) - 0.975 = 0$$

$$\Rightarrow \quad \frac{(F-0.975)}{6.0871} = \ln\left(1+\frac{F}{6.0871}\right)$$

Take $x = \dfrac{F}{6.0871}$

$\therefore \quad x - 0.184 = \ln(1+x)$

$\Rightarrow \quad x = 0.735$

$\therefore \quad F = 0.735 \times 6.0871$

$= 4.744$ cm

Infiltration capacity is given by,

$$f = k\left[\frac{|\psi|\Delta\theta}{F}+1\right] = 0.65\left[\frac{6.0871}{F}+1\right]$$

$$= 0.65\left[\frac{6.0871}{3.8940}+1\right]$$

$= 1.666$ cm/hr

End of Solution

Q.4 (a) An inward flow reaction turbine works under a head of 40.0 m and discharge of 12 cu.m/sec. The speed of the runner is 350 rpm. At the inlet tip of runner vane, the peripheral velocity of wheel is 25.20 m/s and the radial velocity of flow is 8.40 m/s. If the overall efficiency and hydraulic efficiency of the turbine are 80% and 90% respectively, determine
(i) power developed by the turbine in kW, (ii) diameter and width of runner at inlet, (iii) guide blade angle at inlet, (iv) inlet angle at runner vane, and (v) diameter of runner at outlet.
Assume flow is radial at outlet. Also assume no blade friction and radial velocities at inlet and outlet are equal.

[20 Marks]

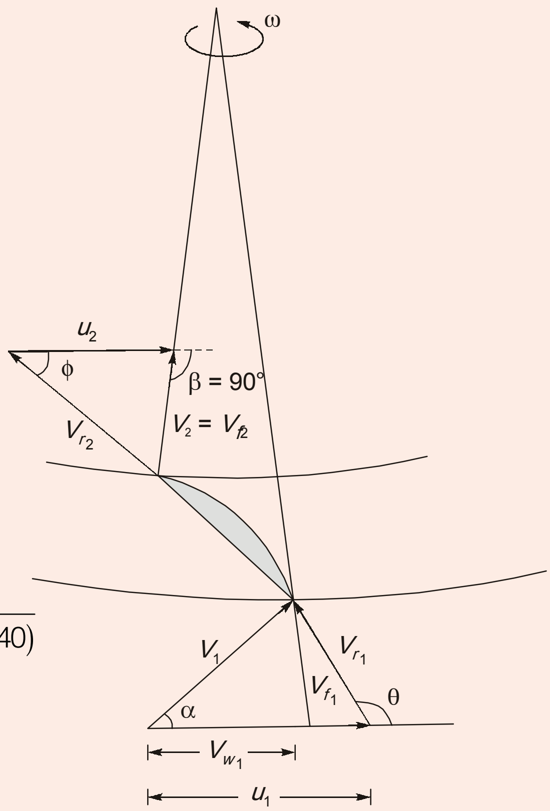
Solution:

Inward flow reaction turbine

	Determine
$H = 40\text{ m}$	(i) S.P.
$Q = 12\text{ m}^3/\text{s}$	(ii) D_1 & B_1
$N = 350\text{ rpm}$	(iii) α
$u_1 = 25.20\text{ m/s}$	(iv) θ
$V_{f1} = 8.4\text{ m/s}$	(v) D_2
$\eta_0 = 80\%$	
$\eta_h = 90\%$	

$$V_2 = V_{f_2},\ \beta = 90^\circ$$

$$V_{f_1} = V_{f_2} = 8.4\text{ m/s}$$



(i)
$$\eta_0 = \frac{S.P.}{W.P.}$$

$$0.8 = \frac{S.P.}{\dot{m}gH}$$

$$0.8 = \frac{S.P.}{\rho QgH}$$

$$0.8 = \frac{S.P.}{(10^3)(12)(9.81)(40)}$$

$$SP = 3767.4\text{ kW}$$

(ii)
$$u_1 = \frac{\pi D_1 N}{60}$$

$$25.20 = \frac{\pi D_1(350)}{60}$$

$$D_1 = 1.375\text{ m}$$

$$Q = \pi D_1 B_1 V_{f_1}$$

$$12 = \pi(1.375)B_1(8.4)$$

$$B_1 = 0.331\text{ m}$$

(iii)
$$\eta_h = \frac{V_{w_1}u_1}{gH}$$

$$0.9 = \frac{V_{w_1} u_1}{gH}$$

$$V_{w_1} = 14.014 \text{ m/s}$$

$$\tan\alpha = \frac{V_{f_1}}{V_{w_1}} = \frac{8.4}{14.014}$$

$$\alpha = 30.94°$$

(iv) $$\tan(180° - \theta) = \frac{V_{f_1}}{u_1 - V_{w_1}} = \frac{8.4}{25.2 - 14.014}$$

$$\theta = 143.09°$$

(v) $$D_2 = \frac{D_1}{2} = \frac{1.375}{2} = 0.6875 \text{ m}$$

End of Solution

Q.4 (b) (i) The depth of flow of water at a certain section of a rectangular channel 3 m wide is 0.45 m. The discharge through the channel is 3.1 m^3/s. Determine whether a hydraulic jump will occur, and if so, determine its height and loss of energy per kg of water.

(ii) The inflow hydrograph a river reach is given in the table below. Determine the outflow hydrograph from this reach if coefficient K = 2.4 h, X = 0.15. Initial outflow in the reach in 85 m^3/s. Routing time step Δt = 1 h.

S.No.	Routing Period (hr)	Inflow (m^3/s)
1	1	93
2	2	137
3	3	208
4	4	320
5	5	442
6	6	546
7	7	630
8	8	678
9	9	691
10	10	675
11	11	634
12	12	571
13	13	477
14	14	390
15	15	329
16	16	247
17	17	184
18	18	134
19	19	108
20	20	90

[10 + 10 = 20 Marks]

Solution:

(i) Rectangular channel,

$$\text{Width } (B) = 3 \text{ m}$$
$$\text{depth } (y_1) = 0.45 \text{ m}$$
$$\text{Discharge } (Q) = 3.1 \text{ m}^3/\text{s}$$

For critical depth of flow,

$$y_c = \left(\frac{q^2}{g}\right)^{\frac{1}{3}} = \left(\frac{\left(\frac{3.1}{3}\right)^2}{9.81}\right)^{\frac{1}{3}} = 0.477 \text{ m}$$

Hence, $y_c > y_1$

So, flow will be supercritical and therefore, hydraulic jump will occur.

For sequent depth of H.J,

$$\frac{y_2}{y_1} = \frac{-1+\sqrt{1+8F_{r1}^2}}{2}$$

$$F_{r1}^2 = \frac{q^2}{gy_1^3} = \frac{\left(\frac{3.1}{3}\right)^2}{9.81\times 0.45^3} = 1.194$$

$$\frac{y_2}{y_1} = \frac{-1+\sqrt{1+8\times 1.194}}{2}$$

$$y_2 = 0.506 \text{ m}$$

Height of the jump, $H_j = y_2 - y_1 = (0.506 - 0.477) \text{ m} = 0.029 \text{ m}$

Energy loss (ΔE), $$\Delta E = \frac{(y_2-y_1)^3}{4y_1y_2} = 2.526\times 10^{-5} \text{ m}$$

$$\text{Energy loss per kg of water} = \frac{\rho Qg\,(\Delta E)}{\rho Q} = 2.478\times 10^{-4} \text{ N.m/kg}$$

(ii)

$$C_0 = \frac{-kx+0.5\Delta t}{k(1-x)+0.5\Delta t} = \frac{-2.4\times 0.15+0.5\times 1}{2.4(1-0.15)+0.5\times 1} = \frac{0.14}{2.54} = 0.055$$

$$C_1 = \frac{kx+0.5\Delta t}{k(1-x)+0.5\Delta t} = \frac{2.4\times 0.15+0.5x_1}{2.4(1-0.15)+0.5\times 1} = \frac{0.86}{2.54} = 0.339$$

$$C_2 = \frac{k(1-x)0.5\Delta t}{k(1-x)+0.5Dt} = \frac{2.4(1-0.15)-0.5\times 1}{2.4(1-0.15)+0.5\times 1} = \frac{1.54}{2.54} = 0.606$$

Time(hr)	Inflow (m^3/sec)	Outflow (m^3/sec)
1	$I_1 = 93$	$Q_1 = 85$
2	$I_2 = 137$	$Q_2 = 90.57$
3	$I_3 = 208$	$Q_3 = 112.77$
4	$I_4 = 320$	$Q_4 = 156.45$
5	$I_5 = 442$	$Q_5 = 227.59$
6	$I_6 = 546$	$Q_6 = 317.79$
7	$I_7 = 630$	$Q_7 = 412.32$
8	$I_8 = 678$	$Q_8 = 426.93$
9	$I_9 = 691$	$Q_9 = 526.57$
10	$I_{10} = 675$	$Q_{10} = 590.40$
11	$I_{11} = 634$	$Q_{11} = 621.53$
12	$I_{12} = 571$	$Q_{12} = 622.98$
13	$I_{13} = 477$	$Q_{13} = 597.33$
14	$I_{14} = 390$	$Q_{14} = 545.13$
15	$I_{15} = 329$	$Q_{15} = 480.65$
16	$I_{16} = 247$	$Q_{16} = 416.39$
17	$I_{17} = 184$	$Q_{17} = 416.39$
18	$I_{18} = 134$	$Q_{18} = 279.54$
19	$I_{19} = 108$	$Q_{19} = 220.77$
20	$I_{20} = 90$	$Q_{20} = 175.34$

$$Q_2 = C_0 I_2 + C_1 I_1 + C_2 Q_1$$
$$= (0.055 \times 137) + (0.339 \times 93) + (0.606 \times 85)$$
$$= 90.57 \text{ m}^3/\text{sec}$$
$$Q_3 = C_0 I_3 + C_1 I_2 + C_2 Q_2$$
$$= (0.055 \times 208) + (0.339 \times 137) + (0.666 \times 90.57)$$
$$= 112.77 \text{ m}^3/\text{sec}$$

Similarly we can identify, Q_4, Q_5 ... Q_{20}

End of Solution

Q.4 (c) (i) A city has its catchment area of 7500 hectares. If the population density of the city is 200 persons per hectare and the water is supplied at the rate of 175 litres per capita per day, what would be the design flow for a combined sewer? Take intensity of rainfall equal to 30 mm/hour, average runoff coefficient equal to 0.50 and only 75% of water supplied contributes to the sewage. Also, peak discharge factor should be taken as 3.0.

(ii) What do you understand by aerobic digestion? What are its advantages and disadvantages?

[10 + 10 = 20 Marks]

Solution:

(i)

Total water supplied = 175 l/c/d × 200 c/ha × 7500 ha

= 262.5×10^6 l/d

Average sewage production = $0.75 \times 262.5 \times 10^6$ l/d

= 196.875×10^6 l/d = 2.278 m^3/s

$$\text{Total volume of runoff} = ciA = \frac{30 \text{ mm}}{h} \times 0.5 \times 7500 \text{ ha} = 312.5 \text{ m}^3/\text{s}$$

Peak discharge for sewage = 3 × 2.278 = 6.834 m^3/s

Combined sewer is designed on the basis of peak discharge

= $(Q_{peak})_{sewage} + Q_{runoff}$

= 6.834 + 312.5 = 319.334 m^3/s

(ii) The sludge withdrawn from the primary sedimentation tank, which is less biological in nature can be digested aerobically i.e., decomposing the organic matter under aerobic conditions and then disposed of suitably after drying on drying beds.

This process of stabilization of primary sludge is aerobically sludge digestion.

Advantages:

1. As incoming sludge has less BOD concentration, so supernatant liquid will also have very less BOD concentration.
2. The end product is odourless, humus which are quite stable and can be used for sewage farming.
3. Operation is relatively easier than anaerobic digestion.
4. Capital cost is also comparatively lower.

Disadvantages:

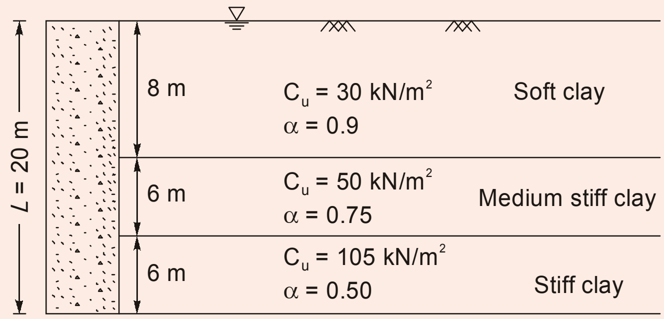
1. In aerobic digestion as external food source is not supplied, so aerobic digestion is an endogenous respiration 'Processing' which organism are forced to metabolize. Now as dead cell mass of microorganism retains moisture, so dewatering is difficult.
2. It is associated with high power cost, as supply of oxygen required.
3. As incoming sludge is less biological in nature, so no useful by product like CH_4 is recovered.
4. The process is significantly by temperature, location and type of tank material etc.

Section-B

Q.5 (a) A concrete pile 450 mm in diameter and 20 m long is driven through a system of layered cohesive soil. The top layer is 8 m thick and comprises of soft clay with cohesion of 30 kN/m^2 and adhesion factor of 0.90. The middle layer which is medium stiff clay has a thickness of 6 m and undrained cohesion of 50 kN/m^2 with adhesion factor of 0.75. The bottom-most layer which is stiff strata extends to a great depth with undrained cohesion of 105 kN/m^2 and adhesion of 0.50. Compute the ultimate and allowable capacity of pipe if the factor of safety assumed is 3.0. The water table is observed to be at ground level.

[12 Marks]

Solution:



Dia. of pile, $D = 450$ mm

$FOS = 3.0$

To determine ultimate load capacity:

$$Q_{up} = Q_{eb} + Q_{fs}$$

$$Q_{eb} = \text{Ultimate bearing capacity}$$

$$= C_u N_c A_b$$

$$= 105 \times 9 \times \frac{\pi}{4} \times (0.45)^2 = 150.3 \text{ kN}$$

$$Q_{fs} = \text{Skin friction resistance}$$

$$= \Sigma \alpha C_u A_s$$

$$= 0.9 \times 30 \times \pi \times 0.45 \times 8 + 0.75 \times 50 \times \pi \times 0.45 \times 6 + 0.50 \times 105 \times \pi \times 0.45 \times 6$$

$$= 1068.77 \text{ kN}$$

$\therefore$ $$Q_{up} = 150.3 + 1068.77 = 1219.07 \text{ kN}$$

Allowable load on the pile,

$$Q_{ep} = \frac{Q_{up}}{FOS} = \frac{1219.07}{3.0} = 406.35 \text{ kN}$$

End of Solution

Q.5 (b) With a neat labelled sketch of stress conditions and failure envelope in a triaxial compression test, derive the relation between major and minor principal stress in terms of cohesion and angle of internal friction.

$$\sigma_1 = \sigma_3 N_\phi + 2c\sqrt{N_\phi}$$

s_1 = Major principal stress

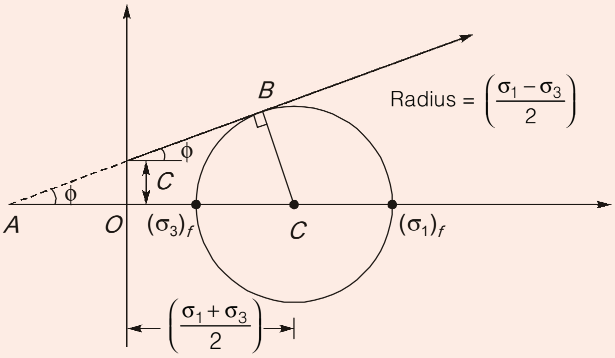
σ_3 = Minor principal stress

c = Cohesion

ϕ = Angel of internal fiction

[12 Marks]

Solution:



In ΔABC,

$$\sin\phi = \frac{BC}{AC} = \frac{BC}{AO+OC} = \frac{\left(\frac{\sigma_1-\sigma_3}{2}\right)}{c\cot\phi + \left(\frac{\sigma_1+\sigma_3}{2}\right)} \qquad \left(\because \tan\phi = \frac{C}{AO}\right)$$

$$\frac{\sigma_1-\sigma_3}{2} = c\cot\phi\sin\phi + \left(\frac{\sigma_1+\sigma_3}{2}\right)\sin\phi$$

$$\sigma_1 - \sigma_3 = 2c\cos\phi + (\sigma_1+\sigma_3)\sin\phi$$

$$\sigma_1(1-\sin\phi) = \sigma_3(1+\sin\phi) + 2c\cos\phi$$

$$\sigma_1 = \sigma_3\left(\frac{1+\sin\phi}{1-\sin\phi}\right) + 2c\times\frac{\cos\phi}{1-\sin\phi}$$

$$\because \quad \cos\phi = \sqrt{1-\sin^2\phi}$$

$$\therefore \quad \cos\phi = \sqrt{(1-\sin\phi)(1+\sin\phi)}$$

$$\therefore \quad \frac{\cos\phi}{1-\sin\phi} = \frac{\sqrt{(1-\sin\phi)(1+\sin\phi)}}{1-\sin\phi} = \sqrt{\frac{1+\sin\phi}{1-\sin\phi}}$$

$$\therefore \quad \sigma_1 = \sigma_3\left(\frac{1+\sin\phi}{1-\sin\phi}\right) + 2c\sqrt{\frac{1+\sin\phi}{1-\sin\phi}} \qquad \left\{\because \tan^2\left(45^\circ+\frac{\phi}{2}\right) = \frac{1+\sin\phi}{1-\sin\phi}\right\}$$

$$\sigma_1 = \sigma_3\tan^2\left(45^\circ+\frac{\phi}{2}\right) + 2c\tan\left(45^\circ+\frac{\phi}{2}\right) \quad \text{(At plastic equilibrium)}$$

End of Solution

Q.5 (c) Write a note on ten requirements of track drainage system for typical B.G. railway line.

[12 Marks]

Solution:

- Water considered as greatest threat to railway track. A poor drainage system may lead to settlement of embankment, reduced bearing capacity of formation, shrinkage and cracking of banks and formation of ballast pockets etc.
- So, to overcome these adverse conditions a good track drainage system should be planned in such a way that-

(a) Surface and underground water should be well away from track
(b) Surface water of adjoining land should be prevented to enter into track
(c) The side drains should have enough capacity and slope.
(d) Flow of surface after should not cause erosion of banks and embankment.
(e) Sub surface water should be drained off by subsurface drainage system.
(f) High water table area should be avoided
(g) The track alignment should be made to rest on pervious, naturally drained soil
(h) Water logged areas should be avoided
(i) The drains or pipe should be kept at closer spacing to keep water table well below formation to prevent capillary rise.
(j) Underground water pocket, water bearing strata on the sides, blank cotton soil etc. should be avoided for track construction

End of Solution

Q.5 (d) Clearly state the nine goals and objectives of National Transport Plan of India.

[12 Marks]

Solution:

The following are the broad goals and objectives for National Transport Plan:

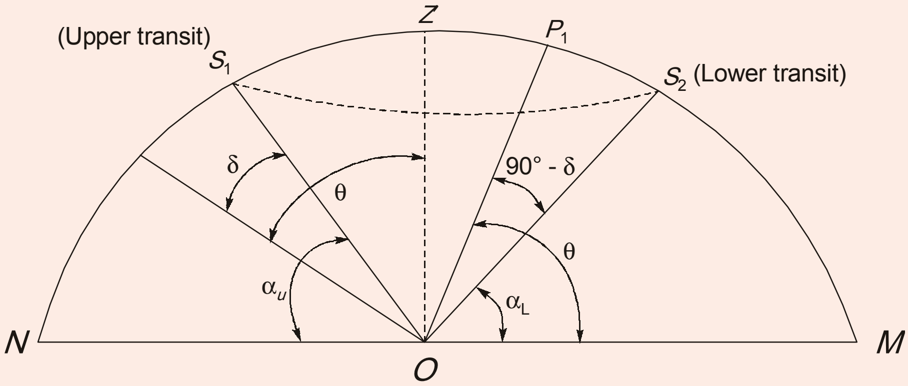
1. Balanced development for the total road network comprising three functional groups viz., the primary system (National Highway (NH) and expressway(s)), secondary system (State Highways and Major District Roads) and rural roads.
2. Development of roads to be considered an integral part of the total transport system supplementing other modes, integrating the development plans with railways and other modes of transport.
3. Completion of the National Highways Development Project comprising the golden Quadrilateral and the North-South and East-West corridors.
4. Phased removal of deficiencies in the existing NH network in tune with traffic for the next 10-15 years with emphasis on four-laning of high-density corridors.
5. To plan and take preliminary action for expressways to be built in future in those sections where these can be economically justified.
6. To make long distance travel safer and faster so as to give a boost to the economy.
7. Priority is to be accorded to areas like overloading of trucks, control of encroachments and unplanned ribbon development, energy conservation and environment protection.
8. Greater attention to be paid to rehabilitation and reconstruction of weak/dilapidated bridges for traffic safety.
9. Special attention is to be paid to the development of roads in the North-Eastern region.

End of Solution

Q.5 (e) A star of declination 40°30′30″ S is to be observed at lower and upper transit at a place of latitude 75°30′30″ S. Draw a neat labelled figure depicting declination, latitude, altitude in upper transit, altitude in lower transit and find the approximate apparent altitude at which the star should be sought.

[12 Marks]

Solution:



$$\delta = 42° 30' 30''S;$$

$$\theta = 75° 30' 30'' S; \quad \alpha = \text{corrected altitude}$$

At lower transit:

$$\alpha_L = \theta - (90° - \delta)$$

$$= 75° 30' 30'' - (90° - 42° 30' 30'') = 28° 1' 0''$$

Hence apparent altitude $= 28° 1' 0'' + 58'' \times \cot(28° 1'0'') = 28° 2' 40 \cdot 01''$

At upper transit:

$$\alpha_u = 90° - \theta + \delta$$

$$= 90° - 75° 30' 30'' + 42° 30' 30'' = 57° 0' 0''$$

Apparent altitude $= 57°0'0'' + 58'' \cot(57°0'0'') = 57°0'37.67''$ N

End of Solution

Q.6 (a) A square footing 2 m wide in resting on soft saturated clay. The depth of foundation is 1.5 m from existing ground level. The thickness of clay layer is 4.0 m and is underlain by a firm sand stratum. The properties of clay are as under : Liquid limit 30%, natural moisture content 40%, specific gravity 2.7, angle of internal friction zero and undrained cohesion 0.5 kg/cm^2. The clay stratum is normally consolidated. Determine the net safe bearing capacity using the Vesic equation. Compute the settlement that would result if the load intensity were allowed to act on the footing. Natural water table is at ground level. Assume load spread 2 : 1.

[20 Marks]

Solution:

$$e = \frac{wG}{S} = \frac{0.4 \times 2.7}{1} = 1.08$$

$$\gamma = \frac{(G + Se)\gamma_w}{1+e} = \frac{(2.7 + 1.08) \times 9.81}{1 + 1.08} = 17.82 \text{ kN/m}^3$$

Vesic's theory:

For $\phi = 0$

$$N_c = 5.14$$
$$N_q = 1$$
$$N_\gamma = 0$$

$$S_c = 1 + \frac{N_q}{N_c} = 1.194$$

$$S_q = 1$$
$$S_\gamma = 0.6$$

$$d_c = 1 + 0.4\frac{D_f}{B} = 1 + 0.4\left(\frac{1.5}{2}\right) = 1.3$$

$$d_q = 1 + 2\tan\phi(1 - \sin\phi)\frac{D_f}{B} = 1$$

$$d_\gamma = 1$$
$$i_c = i_q = i_\gamma = 1$$

Ultimate bearing capacity $\left(C_u = 0.5 \times \frac{9.81\text{N}}{10^{-4}\text{ m}^2} = 49.05 \text{ kN/m}^2\right)$

$$q_u = CN_c(S_c d_c i_c) + \gamma' D_f N_q (S_q d_q i_q) + 0.5B\gamma' N_\gamma (S_\gamma d_\gamma i_\gamma)$$

$$q_u = 49.05 \times 5.14(1.194 \times 1.3 \times 1) + 8.01(1.5)(1 \times 1 \times 1)$$

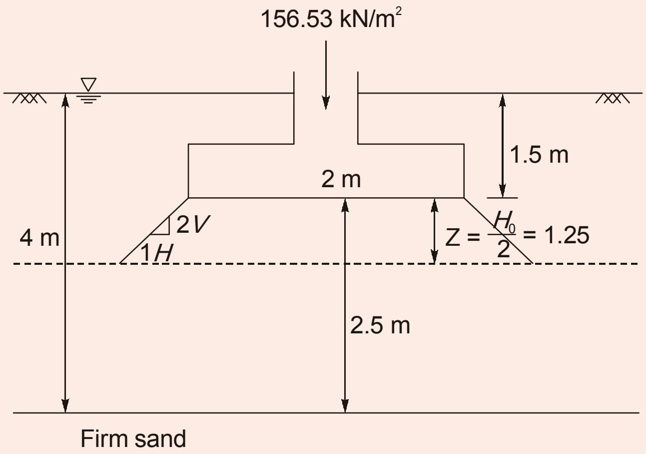
$$q_u = 403.35 \text{ kN/m}^2$$

Net safe bearing capacity (Assuming FOS = 2.5)

$$q_{ns} = \frac{q_{nu}}{F} = \frac{q_u - \bar{\sigma}}{F}$$

$$= \frac{q_u - \gamma' D_f}{F} = \frac{403.35 - 8.01 \times 1.5}{2.5}$$

$$q_{ns} = 156.53 \text{ kN/m}^2$$



$$C_c = 0.009\,(w_L - 10) = 0.009\,(30 - 10) = 0.18$$

1. $$H_0 = 2.5\text{ m}$$

2. $$\bar{\sigma}_0 = (1.5 + 1.25)\gamma' = 2.75 \times (17.82 - 9.81) = 22.0275\text{ kN/m}^2$$

3. $$\Delta\bar{\sigma} = \frac{q(B^2)}{(B + 2nz)^2} = \frac{156.53(2)^2}{\left(2 + 2 \times \frac{1}{2} \times 1.25\right)^2} = 59.277\text{ kN/m}^2$$

4. $$\Delta H = \frac{H_0 C_c}{1 + e_0}\log\left(\frac{\bar{\sigma}_0 + \Delta\bar{\sigma}}{\bar{\sigma}_0}\right) = \frac{2.5 \times 0.18}{1 + 1.08}\log\left(\frac{22.0275 + 59.27}{22.0275}\right)$$

$$= 0.1226\text{ m} = 12.26\text{ cm}$$

End of Solution

Q.6 (b) List the five traffic surveys and elaborate all of them.

[20 Marks]

Solution:

Traffic studies or surveys are carried out to analyze the traffic characteristics.

(a) Traffic volume study

Volume of traffic is a very important variable and is essentially the quantity of movement per unit of time at a specified location. It is expressed as vehicles per day and vehicles per hour

Traffic volume, $$q = \frac{n \times 3600}{T}$$

Volume studies are basically useful to establish:

(i) the relative importance of any route
(ii) the fluctuations in flow
(iii) the distribution of traffic on the road system
(iv) the trends in the road use

(b) Speed studies

Speed is the rate of travel expressed in kmph or in m/s. Over a particular route, the actual speed of vehicle may vary. Speed of a vehicle depends upon several factors such as geometric features, traffic conditions, time, place, environment and driver.

Types of Speed

(i) **Spot Speed**: It is the instantaneous speed of a vehicle at any specified point. The spot speeds are affected by physical features of road such as pavement width, curve, sight distance, gradient, pavement unevenness and road side developments.

(ii) **Average Speed:** It is the average of spot speed of vehicles at a particular section or location. There are two types of average speed or mean speed:

(a) **Time Mean Speed:** It is defined as the average speed of all the vehicles passing a point on a highway over some specified time interval.

Time mean speed, $$V_t = \frac{\sum_{i=1}^{n} V_i}{n}$$

(b) **Space Mean Speed:** It is the average speed of all vehicle at a certain road length over some specified time period. It is obtained from the observed travel time of the vehicles over a relatively long stretch of the road. Space mean speed is the harmonic mean of the speed of the vehicles passing a point on a highway during a particular interval of time.

Space mean speed, $$V_s = \frac{3.6\,dn}{\sum_{i=1}^{n} t_i} = 3.6\left[\frac{n}{\frac{t_1}{d_1}+\frac{t_2}{d_2}+\ldots\frac{t_n}{d_n}}\right]$$

$$= 3.6\left[\frac{n}{\frac{1}{V_1}+\frac{1}{V_2}+\ldots\frac{1}{V_n}}\right]$$

(iii) **Running Speed:** It is the average speed maintained by a vehicle over a particular stretch of road, while the vehicle is in motion.

$$\text{Running speed} = \frac{\text{Total distance travelled}}{\text{Total running time}}$$

(iv) **Travel Speed or Journey Speed:** It is defined as the total distance travelled upon total time taken including all stoppage and delay.

(c) Origin and destination study

This study is generally carried out to

(i) Plan the road network and other facilities for vehicular traffics.

(ii) Plan the schedule of different modes of transportation for the trip demand.

(iii) To judge the adequacy of existing routes and to use in planning new network to roads.
(iv) To locate expressway or major routes along the desires lines.
(v) To establish preferential routes for various categories to vehicle including by pass.
(vi) To locate intermediate stops of public transport.
(vii) It is also used for mass rapid transit system.

There are number of methods for collecting the *O* and *D* data:
(i) Road Side Interview Method
(ii) License Plate Method
(iii) Return Post Car Method
(iv) Tag on Car Method
(v) Home Interview Method
(vi) Work Spot Interview Method

(d) **Traffic flow characteristics and studies**

Traffic flow characteristics are divided under two categories:

1. **Macroscopic characteristics:** Traffic flow theory assumes that there is a fundamental relationship among the three principle variables of traffic flow, speed, and density as follows:

$$q = k \times U$$

2. **Microscopic characteristics:**

Time Headway: The time interval between the passage of successive vehicles moving in the same lane and measured from head to head as they pass a point on the road is known as the time headway.

Space Headway: The distance between successive vehicles moving in the same lane measured from head at any instance is the space headway.

(e) **Traffic capacity studies**

Some important related terms which are often used are:

(i) **Traffic Volume (q):** It is the number of vehicles moving in a specified direction on a given lane or roadway that pass a given point during specified unit of time. It is expressed as vehicles per hour or vehicles per day.

(ii) **Traffic Density (k):** It is defined as the number of vehicles occupying a unit length of lane of roadway at a given instant. It is expressed in vehicles per kilometre.

(iii) **Traffic Capacity:** It is the ability of a roadway to accommodate traffic volume. It is expressed as vehicles per hour per lane. The capacity of roadway depends on a number of prevailing roadway and traffic conditions. Traffic capacity is always greater than or equal to traffic volume.

(iv) **Basic Capacity:** It is the maximum number of vehicles that can pass a given point on a lane or roadway during one hour under the most nearly ideal roadway and traffic conditions which can possibly be at trained.

(v) **Possible Capacity:** It is the maximum number of vehicles that can pass a given point on a lane or roadway during one hour under prevailing roadway and traffic conditions. The value of possible capacity varies between zero to basic capacity.

(vi) **Practical Capacity:** It is the maximum number of vehicle that can pass a given point on a lane or roadway during one hour, without traffic density being so great as to cause unreasonable delay, hazard or restriction to the drivers freedom to manoeuvre under the prevailing roadway and traffic conditions. This is also known as design capacity.

End of Solution

Q.6 (c) (i) **With a neat labelled sketch, derive the relation between superelevation (e), for a broad gauge railway with a speed 'V' (km/h) and radius of curvature (R).**

(ii) **If the wheel base of a vehicle moving on BG track is 6 m, the diameter of wheel is 1.50 m and the depth of flanges below the top of rail is 3.20 cm, determine the extra width required to be provided on gauge, if the radius of the curve is 150 m.**

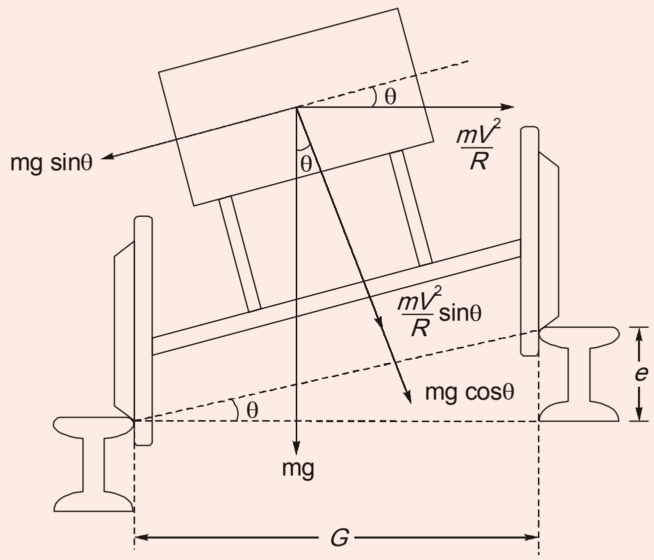
[10 + 10 Marks]

Solution:

(i)
- Raising of outer track with respect to inner track to generate centripetal force against the centrifugal force which works outward from C.G, of train when it moves on a curve, is known as super elevation.
- Super elevation not only gives counteracting force for i.e. but also reduces centrifugal force.

Where,

$$\frac{mV^2}{R}\cos\theta = \text{Centrifugal force at superelevated track}$$



$$mg\sin\theta = \text{Counteracting centripetal force}$$
V = Speed of train (m/s)
R = Radius of curvature (m)
G = Gauge distance (m)
e = Superelevation (m)

From me figure shown above,

$$mg\sin\theta = \frac{mV^2}{R}\cos\theta$$

$$\tan\theta = \frac{V^2}{gR} \quad \text{...(i)}$$

$$\tan\theta = \frac{e}{G} \quad \text{...(ii)}$$ Equating equation (i) and (ii)

$$\frac{e}{G} = \frac{V^2}{gR}$$

$$e = \frac{GV^2}{gR}$$

If we put g value and V in kmph

$$e = \frac{GV^2}{127R}$$

(ii)
$$d = \frac{13(B+L)^2}{R}$$

Where d = extra width of gauge in cm, B = wheel base (m) i.e. 6 m, R = Radius of curve (m) i.e. 150 m

L = lap length of flange in (m) i.e. $L = 0.02\sqrt{h^2 + Dh}$
h = depth of flange below rail top in cm i.e. 3.2 cm
D = diameter of wheel in cm i.e. 150 m

$$\therefore \quad L = 0.02\sqrt{3.20^2 + 150\times 3.20} = 0.4428 \text{ m}$$

$$\therefore \quad d = \frac{13(6+0.4428)^2}{150} = 3.59 \text{ cm}$$

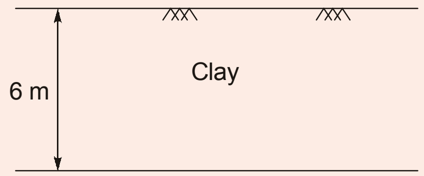
End of Solution

Q.7 (a) Soft saturated clay has a thickness of 6 m. After one year, when the clay consolidated by 50%, the observed settlement was to the tune of 10 cm. For an identical clay and loading condition, what will be the magnitude of settlement at the end of one year and five years if the thickness of the clay layer was 25 m?

[20 Marks]

Solution:

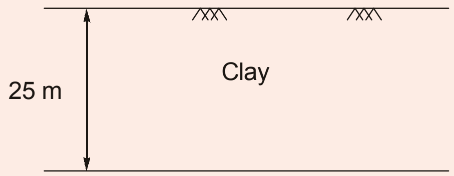
Case-1:



After 1year,

$$U = 50\%$$
$$\Delta h = 10 \text{ cm}$$
$$U = \frac{\Delta h}{\Delta H}$$
$$0.5 = \frac{100}{\Delta H}$$
$$\Delta H = 200 \text{ mm}$$

Case-2:



For 25 m clay layer

$$\Delta H = \frac{200}{6} \times 25 = 833.33 \text{ mm}$$
$$(\Delta h) \text{ After 1 year} = ?$$
$$(\Delta h) \text{ After 5 years} = ?$$

For identical clay and loading condition

$$T_v = \frac{C_v t}{d^2}$$

For $U < 50\%$

$$T_v \propto U^2 \propto \left(\frac{\Delta h}{\Delta H}\right)^2$$

$\Rightarrow$ $t \propto d^2U^2$

After 1 year

$$\frac{t_2}{t_1} = \frac{d_2^2 U_2^2}{d_1^2 U_1^2}$$

$\Rightarrow$
$$\frac{1}{1} = \frac{(25)^2 \times \left(\frac{\Delta h_2}{833.33}\right)^2}{6^2 \times (0.5)^2}$$
$$\Delta h_2 = 99.99 \text{ mm} \simeq 100 \text{ mm}$$

After 5 years

$$\frac{5}{1} = \frac{(25)^2 \times \left(\frac{\Delta h_2}{833.33}\right)^2}{6^2 \times (0.5)^2}$$

$$\Delta h_2 = 223.6 \text{ mm}$$

In 25 m clay layer

∴ Settlement after 1 year = 100 mm

After 5 years =223.6 mm

End of Solution

Q.7 (b) **(i)** **How do the methods of tunnel construction in hard rock differ from the methods of tunnel construction in soft ground? State the various operations involved in hard rock tunnelling and soft ground tunnelling.**

(ii) **List the ten typical features of a harbour. Elaborate any three at length.**

[10 + 10 Marks]

Solution:

(i) Rocks are strong materials that are difficult to cut. Tunnelling in rock involves using tunnel boring machines with special hardened steel drill tools to cut into rock and remove the spoils. Rock cutting may even require drilling and blasting. If the rock is strong, massive and without discontinuities, then tunnels can be permanently stable without support. Since such rock formations are impervious, water does not seep into tunnels. Presence of joints and fissures causes instability in the rock mass. The rock mass can slip along these discontinuities and water can gush in from them. Tunnels in such formations require support and waterproof lining.

In contrast, soils are soft materials that are easy to cut. Excavation in soils is much easier than in rocks. However, tunnels in soils are usually unstable and seepage of water is always a problem beneath water table. Hence side support and waterproof lining in invariably provided in them.

Actual operations in the construction of a tunnel depend upon the size of the tunnel, kind of formation encountered and method of attacking the heading etc. However , following operations may be carried out during construction of a tunnel.

1. Setting up and drilling
2. Loading holes with explosives and firing them
3. Ventilations and removing the dust after explosion
4. Loading and hauling muck
5. Removing ground water if necessity arises.
6. Erecting supports for sides and roof if necessary
7. Placing reinforcement
8. Placing concrete lining.

(ii) Following are the constituents of a harbour:

1. Harbour Depth
2. Harbour Entrance Channel

3. Anchorage Area
4. Turning Basin
5. Breakwaters
6. Fenders
7. Wharf and Quays
8. Jetties
9. Spillway
10. Docks

Harbour Layout Elements

Harbour Depth

- Depth of harbour should be sufficient for navigation at low water level when ship is fully loaded.
- The maximum harbour depth below lowest low water is given as:
  Maximum harbour depth = Loaded draft + 1.2 m (when bottom is soft)
  Maximum harbour depth = Loaded draft + 1.8 m (when bottom is rock).
  where, loaded draft means submerge depth of ship when it is fully loaded.

Harbour Entrance Channel

- Entrance without gates is known as tidal entrance and entrance with gate is known as impounded entrance.
- The entrance to a harbour is more exposed to waves as compared to the harbour itself. Thus, depth and width required at the entrance are more than those required in the channel.
- The entrance should be wide enough for navigational requirements. But should not be too wide to increase wave height within harbour.

Anchorage Area

- The place where ships are held for inspection and waits to enter port is called anchorage area.

Turning Basin

- It is an enlargement of the channel used for turning of a ship.
- The minimum diameter of turning basin for which the ship turns without tug assistance is 4 times the length of the ship.
- When the ship has assistance, the turning diameter is 1.7 to 2 times the length of ship.

Breakwaters

- Its function is to protect the enclosed area of water from storm waves.

Fenders

- They are wooden members or rubbing strips fastened to the dock i.e. on the face of the dock to prevent a ship or dock from being damaged during mooring.
- These absorbs the kinetic energy of impact of the ship and hence protect them from damage.

Wharf and Quays

- These are constructed parallel to shore or breakwater within the harbour to permit berthing of vessel. They give necessary depth for navigation.
- The have backfill of a suitable material and have wide platform at top.
- When built along and parallel to the shore, then they are called as quays.
- The space required alongside a wharf for berthing depends upon following factors
  1. Availability of materials.
  2. Wharf configuration
  3. Size and type of ship served

Jetties

- These are structures in the form of piled projections. And they are built out from the shore to deep water and they may be constructed either for a navigable river or in the sea.
- In the sea, the jetties are provided at places where harbour entrance is affected by littoral drift or the sea is shallow for a long distance. Thus, they extend from the shore to the deep sea to receive the ships.
- In a limiting sense, a jetty is defined as a narrow structure projecting from the shore into water with berths on one or both sides and sometimes at the end also.

End of Solution

Q.7 (c) **Write a detailed note on ideal and real remove-sensing system by highlighting their six components as well as their six shortcomings.**

[20 Marks]

Solution:

Ideal and Real Remote-Sensing Systems:

An ideal remote-sensing system is wherein electromagnetic energy of all wavelengths and of known uniform intensity is produced by an ideal source; the energy propagates from the source without loss to a homogeneous target; and the energy of various wavelengths selectively interacts with the target, resulting in a return signal of reflected and emitted energy.

The returned signal propagates without loss to a sensor that responds linearly to energy of all wavelengths of any intensity. In real time, an intensity versus wavelengths response is recorded, processed into an interpretable format, and recognized as being unique to the particular target in its particular chemical state. The information obtained without the particular target is made readily available in a useful form to the users.

The basis components of an ideal remote sensing system include the following:

1. **Uniform energy source: This** source would provide energy over all wavelengths, at a constant, known, high level of output, irrespective of time and place.
2. **Non-interfering atmosphere:** This would be an atmosphere that would not modify the energy from the source in any manner, whether that energy were on its way to the earth's surface of coming form it.

3. **Series of unique energy/matter interactions at the earth:** These interactions would generate reflected and/or emitted signals that are not only selective with respect to wavelength, but are also known, invariant, and unique to each and every earth surface features type and subtype of interest.
4. **Super sensor:** This would be a sensor, highly sensitive to all wavelengths, yielding spatially detailed data on the absolute brightens (or radiance) from a scene as a function of wavelength, throughout the spectrum. This super sensor would be simple and reliable, require virtually no power or space, and be accurate and economical to operate.
5. **Real-time data handling system:** In this system, the instant the radiance versus wavelength response over a terrain element were generated, it would be processed into an interpretable format and recognized as being unique to the particular terrain element from which it came.
6. **Multiple data users:** These people would have knowledge of great depth, both of their respective disciplines and of remote sensing data acquisition and analysis technique.

Unfortunately, an ideal remote sensing system does not exist. The elements of ideal system discussed above have the following general shortcomings:

1. **Energy source:** All passive remote sensing system rely energy that is either reflected and /or emitted from earth surface features.
2. **Atmosphere:** To some extent, the atmosphere always modifies the strength and spectral distribution of energy received by the sensor.
3. **Energy/matter interaction at the earth surface:** Remote sensing would be simple if every material reflected and/or emitted energy in a unique, known way. Although spectra response patterns (signatures) play a central role in detecting identifying and analyzing earth surface materials, the spectral world is full of ambiguity.
4. **Sensor:** No single sensor is sensitive to all wavelengths. All real sensors have fixed limit of spectral sensitivity. They also have a limit on how small an object on the earth's surface can be "seen" by a sensor being separate from its surroundings.
5. **Data handling system:** Processing sensor data into an interpretable format can be—and often is—an effort entailing considerable thought, instrumentation, time experience and reference data.
6. **Multitype data users:** Central to the successful application to any remote sensing system is the person (or persons) using the remote sensor data from that system.

End of Solution

Q.8 (a) Two sets of tacheometric readings were taken from an instrument station A (R.L. = 100.50 m) to a staff station B as given below:

Instrument	P	Q
Multiplying constant	95	90
Additive constant	0.25	0.35
Height of instrument	1.35 m	1.40 m
Staff held	Vertical	Normal

Instrument	Instrument station	Staff station	Vertical angle	Stadia readings (m)		
P	*A*	*B*	8°12′	0.905	1.305	1.555
Q	*A*	*B*	8°12′	?	?	?

Determine:
(i) The distance between instrument station and staff station.
(ii) The reduced level of staff station B.
(iii) The stadia readings with instrument Q.

[20 Marks]

Solution:

Instrument *P*

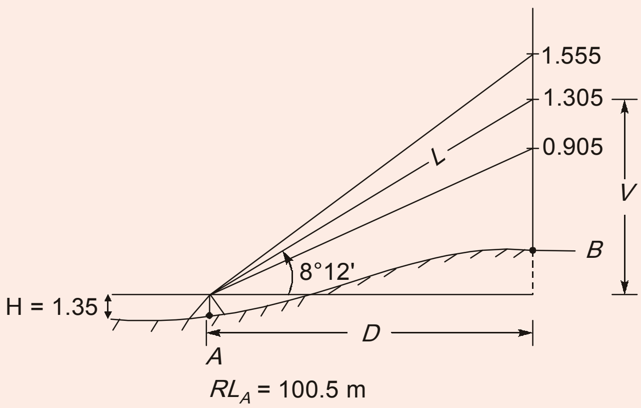
$$K = 95,\ C = 0.25 \quad \Big| \quad H = 1.35\text{ m},\ S = (1.555 - 0.905) = 0.65\text{ m}$$

$$L = KS\cos\theta + C$$
$$= 95 \times 0.65 \cos 8°\,12' + 0.25 = 61.368\text{m}$$
$$RL_A = 100.5\text{ m}$$

Distance $\quad D = L\cos\theta = 61.368 \cos 8°12' = 60.74\text{ m}$

Elevation, $\quad V = L\sin\theta = 61.368 \sin 8°12' = 8.75\text{ m}$

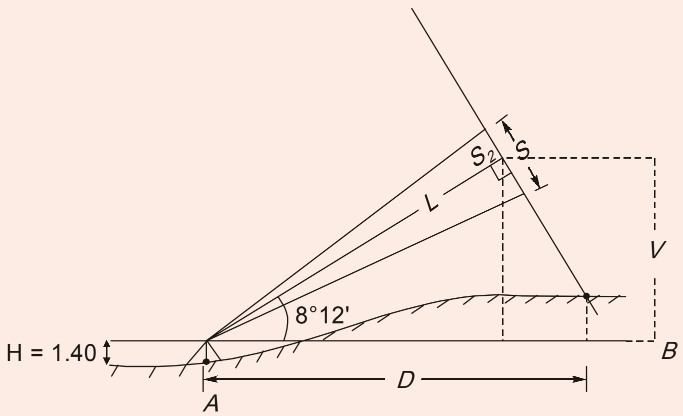
$$RL_B = (RL_A + H + V - S_2) = (100.5 + 1.35 + 8.75 - 1.305)$$
$$= 109.295\text{ m}$$



Instrument Q

$$\left.\begin{array}{l} K = 95 \\ C = 0.35 \end{array}\right| H = 1.40 \text{ m}$$

$$\text{Staff intercept} = S$$
$$\text{Axial reading} = S_2$$
$$L = KS + C$$
$$L = (90\,S + 0.35)$$



Horizontal distance, $D = L\cos\theta + S_2\sin\theta$

$\Rightarrow$ $D = (90S + 0.35)\cos 8°\,12' + S_2 \sin 8°\,12'$

$\Rightarrow$ $60.74 = (90\,S + 0.35)\cos 8°12' + S_2 \sin 8°\,12'$

$\Rightarrow$ $60.74 = 89.08\,S + 0.346 + S_2\,(0.1426)$

$\Rightarrow$ $89.08S + 0.1426\,S_2 = 60.394$ ...(i)

$RL_B = RL_A + H + V - S_2\cos\theta$

$\Rightarrow$ $109.295 = 100.5 + 1.40 + [90S + 0.35]\sin 8°\,12' - S_2\cos 8°\,12'$

$\Rightarrow$ $109.295 = 100.5 + 1.40 + 12.836\,S + 0.0499 - S_2 \times 0.989$

$\Rightarrow$ $7.345 = 12.836\,S - 0.989\,S_2$

$\Rightarrow$ $12.836\,S - 0.989\,S_2 = 7.345$ ...(ii)

From equation (i) and (ii)

$$S = 0.6758$$
$$S_2 = 1.344$$
$$S_1 = S_2 - \frac{S}{2} = 1.344 - \frac{0.6758}{2} = 1.0061$$
$$S_3 = S_2 + \frac{S}{2} = 1.344 + \frac{0.6758}{2} = 1.6819$$

Readings are: $\begin{cases} S_1 = 1.006 \\ S_2 = 1.344 \\ S_3 = 1.682 \end{cases}$

(i) Distance: 60.74 m

(ii) $RL_B = 109.295$ m

(iii) Readings at B $\begin{cases} S_1 = 1.006 \\ S_2 = 1.344 \\ S_3 = 1.682 \end{cases}$

End of Solution

Q.8 (b) (i) The mass specific gravity of a fully saturated specimen of clay having a water content of 29% is 2.00. On oven drying, the mass specific gravity drops to 1.60. Calculate the specific gravity of clay assuming the void ratio to remain unchanged.

(ii) A footing 2 m × 2 m in plan, transmits a pressure of 100 kN/m^2 on a cohesive soil layer having E = 6 × 10^4 kN/m^2 and μ =0.50. Determine the immediate settlement of the footing at the centre, assuming it to be (I) a flexible footing, and (ii) a rigid footing.

Influence Factor I_f for Vertical Displacement

Shape	I_f Flexible Foundation			I_f Rigid Foundation
	Centre	Corner	Average	
Circular	1.00	0.64	0.85	0.86
Squre	1.12	0.56	0.95	0.82
Rectangular				
L/B = 1.5	1.36	0.68	1.20	1.06
L/B - 2	1.52	0.76	1.30	1.20
L/B = 5	1.10	1.05	1.83	1.70
L/B = 10	2.52	1.26	2.25	2.10
L/B = 100	3.38	1.69	2.96	3.40

[10 +10 = 20 Marks]

Solution:

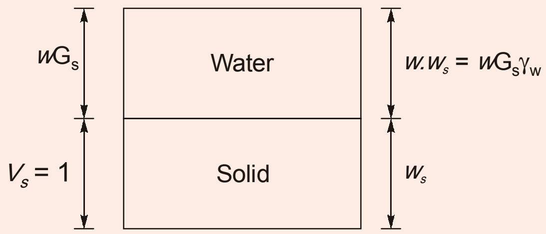
(i) (i) Given that:

$w \rightarrow 29\% \rightarrow G_m = 2.00 \rightarrow \gamma_{sat} = 2\gamma_w$

$w \rightarrow 0\% \rightarrow G_m = 1.60 \rightarrow \gamma_d = 1.6\,\gamma_w$

Determining (G_s):

$$\gamma_{sat} = \frac{G_s \gamma_w (1+w)}{1+wG_s}$$



$$W_s = G_s\gamma_w$$

$$\Rightarrow \qquad 2\gamma_w = \frac{G_s\gamma_w(1+0.29)}{1+0.29G_s}$$

$$\Rightarrow \qquad 2 = \frac{G_s(1.29)}{1+0.29G_s}$$

$$G_s = 2.82$$

(ii) Given: size of footing 2 m × 2 m

$$L/B = 1.0$$

$$q = 100 \text{ kN/m}^2$$

$$E = 6 \times 10^4 \text{ kN/m}^2,\ \mu = 0.5$$

Immediate settlement, $S_i = \dfrac{qB(1-\mu^2)}{E} I_f$

Immediate settlement, at centre

(i) Flexible footing, $I_f = 1.12$ (From table given)

$$S_i = \frac{100\times 2\times(1-0.5^2)}{6\times 10^4}\times 1.12\times 1000 \text{ mm} = 2.8 \text{ mm}$$

(ii) Rigid footing, $I_f = 0.82$ (From table given)

$$S_i = \frac{100\times 2\times(1-0.5^2)}{6\times 10^4}\times 0.82\times 1000 \text{ mm}$$

$$= 2.05 \text{ mm}$$

End of Solution

Q.8 (c) Design a summit curve for a National Highway for a stopping sight distance of 200 m at the junction of a rising gradient of 1 in 60 and a falling gradient of 1 in 30. Set out the curve with a chord 25 m long. Determine the R.L. of the point immediately below the intersection point of the grade line and also the R.L. of the highest point on the curve. Assume sight distance is less than the length of vertical curve, R.L. at the start f the curve as 10.0. h_1 and h_2 as per current Indian practice IRC 66-1976.

[20 Marks]

Solution:

$$SSD = 200 \text{ m}$$

$$n_1 = +\frac{1}{60},\ n_2 = -\frac{1}{30}$$

$$N = \left|\frac{1}{60} + \frac{1}{30}\right| = \frac{1}{20}$$

Assume:

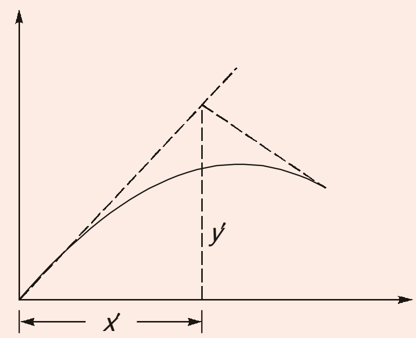
$$L_S > SD$$

$$L_S = \frac{NS^2}{2\left(\sqrt{H} + \sqrt{h}\right)^2}$$

As per IRC, $H = 1.2$ m

$h = 0.15$ m

$$= \frac{NS^2}{4.4} = \frac{\left(\frac{1}{20}\right) \times 200^2}{4.4} = 454.54 \text{ m} > 200 \text{ m}$$



$$y' = \left[\frac{-N}{2L_S}\right]x^2 + n_1 x$$

(a) RL of point just below VPI

we know that VPI exist at $x = \frac{L_S}{2}$

$$= RL_A + y'_{@x} = \frac{L_S}{2}$$

$$= RL_A + \left(-\frac{N}{2L_S}\right) \times \frac{L_S^2}{4} + n_1 \frac{L_S}{2}$$

$$= RL_A + n_1 \frac{L_S}{2} - N\frac{L_S}{8}$$

$$= 10 + \left(\frac{1}{60}\right) \times \frac{454.54}{2} - \frac{1}{20} \times \frac{454.584}{8} = 10.947 \text{ m}$$

(b) RL of highest point on the curve:

Position of summit point,

$$x = \frac{n_1}{N} L_S = \frac{\frac{1}{60}}{\frac{1}{20}} \times 454.54 = 151.51 \text{ m}$$

RL of highest point

$$= RL_A + y'_{@x} = 151.51$$

$$= 10 + \left[\frac{-N}{2L_S}\right] x^2 + n_1 x$$

$$= 10 + \left(\frac{-\left(\frac{1}{20}\right)}{2 \times 454.54}\right) \times 151.51^2 + \frac{1}{60} \times 151.51 = 11.263 \text{ m}$$

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