MADE EASY

Leading Institute for ESE, GATE & PSUs

Detailed Solutions

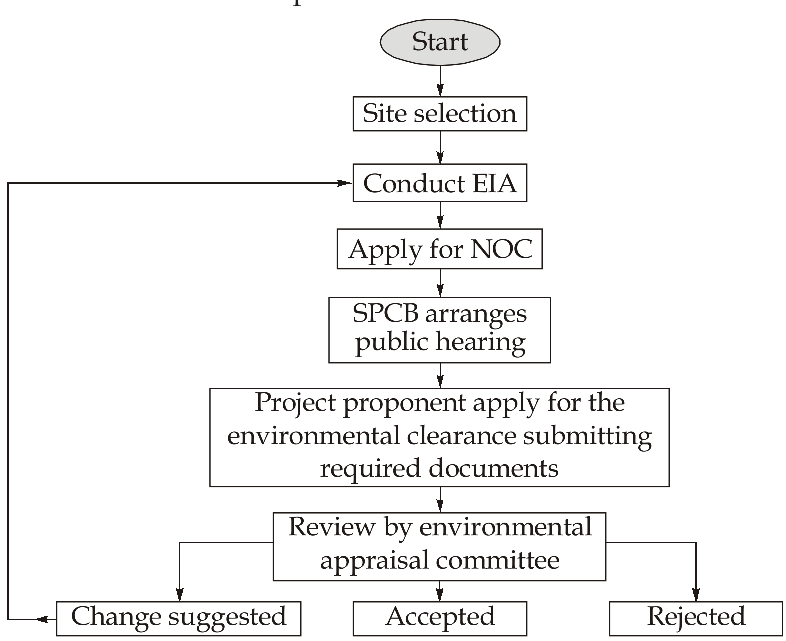
ESE-2024 Mains Test Series

Civil Engineering Test No : 13

Detailed Explanation

Q.1 (a) Solution:

In India, environmental clearance process is as:



- A multipurpose river valley project, involving storage of river water by the construction of a dam across the river, can cause several effects on the environment of the area.
- Some of these impacts may adversely affect the ecology and environment, while most others may prove beneficial to the environment. In general, it can be stated that

the multipurpose water resources projects, do not by themselves, cause any environmental degradation and do generally justify their nature of being in environmental harmony.

- It is the haphazard and unplanned development and industralization, encouraged by the execution of such water resources projects, which causes all round environmental degradation, and this must be checked.
- The environmental clearance process for a new projects will comprise of a maximum of four stages, such as:

Screening: This stage will entail the scrutiny of an application seeking prior environmental clearance made in Form 1 by the concerned State Expert Appraisal Committee (SEAC) for determining whether or not the project or activity requires further environmental studies for preparation of an Environmental Impact Assessment (EIA) for its appraisal prior to the grant of environmental clearance, depending upon the nature and location specificity of the project.

Scoping: Scoping refers to the process by which the Expert Appraisal Committee in the case of category A projects; and state expert appraisal committee in the case of category 'B-1' project, including applications for expansion and/or modernization and/or change in product mix of existing projects or activities, determine detailed and comprehensive terms of reference (TOR) addressing all relevant environmental concerns for the preparation of an Environmental Impact Assessment (EIA). Report in respect of the project or activity for which prior environmental clearance is sought.

Public hearing: It refers to the process by which the concerns of locally affected persons and others who have plausible stake in the environmental impacts of the project or activity are ascertained with a view to take into account all the material concerns in the project or activity design as appropriate.

Appraisal: It means the detailed scrutiny by the Expert Appraisal Committee or state Expert Appraisal Committee of the application and other documents like final EIA report, outcome of the public consultations including, public hearing proceedings submitted by the applicant to the regulatory authority concerned for grant of environmental clearance.

Q.1 (b) Solution:

Given:

$$\psi = U_\infty \sin\theta r\left(\frac{1-a^2}{r^2}\right)$$

where U_∞ = Free stream velocity parallel to horizontal axis

$$a = \text{radius of circular cylinder}$$

In radial coordinates:

$$\frac{\partial \phi}{\partial r} = \frac{1}{r}\frac{\partial \psi}{\partial \theta} = \frac{1}{r}U_\infty \cos\theta r\left[1-\frac{a^2}{r^2}\right]$$

$$= U_\infty \cos\theta r\left[1-\frac{a^2}{r^2}\right] \quad ...(1)$$

$$\frac{\partial \phi}{\partial \theta} = -r\frac{\partial \psi}{\partial r} = -rU_\infty \sin\theta \times\left[1+\frac{a^2}{r^2}\right] \quad ...(2)$$

From equation (1)

$$\phi = U_\infty \cos\theta\left[r+\frac{a^2}{r}\right]+f(r)$$

$$\Rightarrow \quad \frac{\partial \phi}{\partial \theta} = -U_\infty \sin\theta\left[r+\frac{a^2}{r}\right]+f'(r) \quad ...(3)$$

From equations (2) and (3), we get

$$-U_\infty \sin\theta\left[r+\frac{a^2}{r}\right] = -U_\infty \sin\theta\left[r+\frac{a^2}{r}\right]+f'(r)$$

$$\Rightarrow \quad f'(r) = 0$$

$$\Rightarrow \quad f(r) = C = \text{Constant}$$

$$\Rightarrow \quad \phi = U_\infty r\cos\theta\left[1+\frac{a^2}{r^2}\right]+C$$

Now, velocity components are:

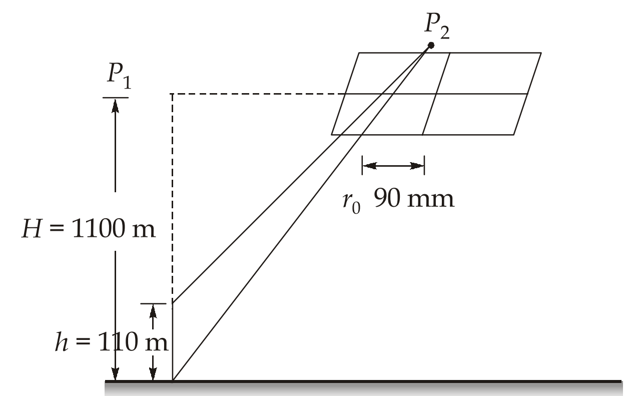
$$V_r = \frac{-1}{r}\frac{\partial \psi}{\partial \theta} = \frac{1}{r}\times U_\infty \times\left[1-\frac{a^2}{r^2}\right]r\cos\theta$$

$$= (-1)U_\infty\left[1-\frac{a^2}{r^2}\right]\cos\theta$$

$$V_\theta = \frac{\partial \psi}{\partial r} = -U_\infty \sin\theta\left[1-\frac{a^2(-1)}{r^2}\right]$$

$$= U_\infty \sin\theta\left[1+\frac{a^2}{r^2}\right]$$

Q.1 (c) Solution:



(i) Radial distance of the base of chimney,

$$r_0 = \frac{Rf}{H}$$

$$\Rightarrow \quad \text{Ground distance, } R = \frac{H_{ro}}{f} = \frac{1100 \times 90}{150} = 660 \text{ m}$$

Now, radial distance of top of chimney,

$$r_2 = \frac{Rf}{H - h_1} = \frac{660 \times 150}{1100 - 110} = 100 \text{ mm}$$

(ii) $$\text{Scale, } S = \frac{H}{f} = \frac{1100 \times 1000}{150} = \frac{22000}{3}$$

$$l = 300 \text{ mm} = 0.3 \text{ m}$$

$$\therefore \quad R = (1 - p) \times S \times l$$

$$\Rightarrow \quad 660 = (1 - p) \times \frac{22000}{3} \times 0.3$$

$$\Rightarrow \quad p_1 = 0.3$$

Hence, percentage overlap = 30%

Q.1 (d) Solution:

Given: Residential population = 5000@150 lpcd water consumption

Floating population = 5000@ 45 lpcd water consumption

90% of water consumed emerged as wastewater.

To design the main sewer:

Sewer is running full at peak discharge,

$$\text{Peak factor} = 3$$

$$\text{Minimum discharge factor} = \frac{1}{3}$$

$$\text{Slope of ground, } S_o = \frac{1}{4000}$$

$$\text{Manning's coefficient, } n = 0.013$$

$$\text{Average sewage discharge} = \left[5000 \times 150 \times \frac{0.9 \times 10^{-3}}{86400} + 5000 \times 45 \times \frac{0.9 \times 10^{-3}}{86400}\right]$$

$$= 0.0102 \text{ m}^3/\text{sec}$$

$$\text{Peak discharge of sewage, } Q_{design} = 3 \times \text{Average sewage discharge}$$

$$= 3 \times 0.0102 = 0.0306 \text{ m}^3/\text{s}$$

Also,
$$Q_{design} = \frac{1}{n} \times A \times R^{2/3} \times S^{1/2}$$

$$\Rightarrow \quad 0.0306 = \frac{1}{0.013} \times \frac{\pi}{4} \times D^2 \times \left[\frac{D}{4}\right]^{2/3} \times \left[\frac{1}{400}\right]^{1/2}$$

where D is diameter of sewer

$$\Rightarrow \quad D^{8/3} = 0.0255$$

$$\Rightarrow \quad D = (0.0255)^{3/8} = 0.253 \text{ m}$$

Check for self cleansing velocity at maximum discharge,

$$V = \frac{1}{n} \times R^{2/3} \times S_0^{1/2}$$

$$= \frac{1}{0.013} \times \left[\frac{0.253}{4}\right]^{2/3} \times \left[\frac{1}{400}\right]^{1/2}$$

$$= 0.6106 \text{ m/sec} > 0.6 \text{ m/sec.}$$

As the velocity is greater than 0.6 m/s at peak flow, it will ensure that at maximum flow, the velocity generated will be more than the self cleaning velocity.

Check for self cleansing velocity at minimum discharge

$$Q_{min} = \frac{1}{3} \times (0.0102) = 3.4 \times 10^{-3} \text{ m}^3/\text{sec}$$

$$V_{min.} = \frac{Q_{min}}{\frac{\pi}{4} \times D^2} = \frac{3.4 \times 10^{-3}}{\frac{\pi}{4} \times (0.253)^2} = 0.0676 \text{ m/sec.}$$

$$< 0.6 \text{ m/sec}$$

As the velocity is less than 0.6 m/sec at minimum flow, velocity generated will not be satisfactory and thus we have either to increase the slope or try with increased diameter of sewer.

Q.1 (e) Solution:

Structure of GPS: The GPS system comprises of three parts: Space segment, User segment and Control segment. The diagram of the structure of GPS is shown below.

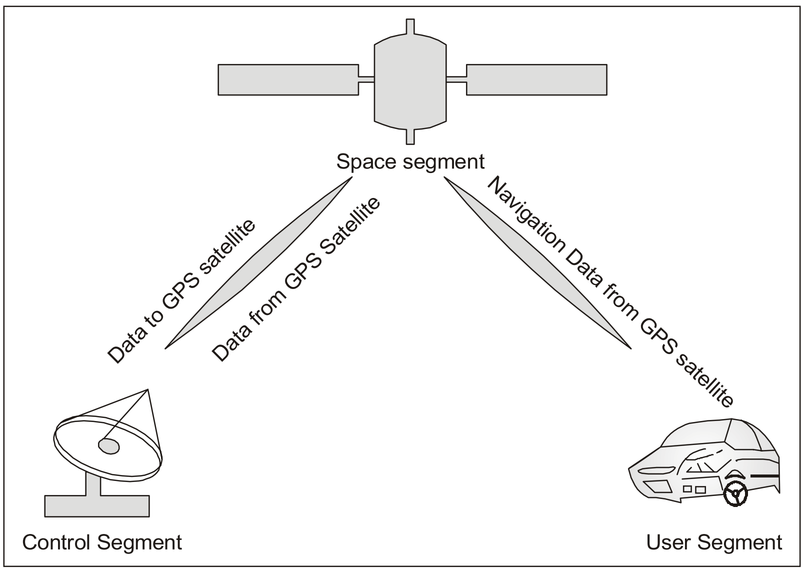


Fig. Strucure of GPS

- **Space segment:** The satellites are the heart of the global positioning system which helps to locate the position by broadcasting the signal used by the receiver. The signals are blocked when they travel through buildings, mountains, and people. To calculate the position, the signals of four satellites should be locked. You need to keep moving around to get clear reception.
- **User segment:** This segment includes military and civilian users. It comprises of a sensitive receiver which can detect signals (power of the signal to be less than a quadrillionth power of a light bulb) and a computer to convert the data into useful information. GPS receiver helps to locate your own position but disallows you being tracked by someone else.
- **Control segment:** This helps the entire system to work efficiently. It is essential that the transmission signals have to be updated and the satellites should be kept in their appropriate orbits.

Advantages:

- Intervisibilily between different stations not required

- Not dependent on weather conditions, day or night.
- Positional accuracy irrespective of network geometry acts as a function for two or more different stations distance.
- Homogeneous accuracy affects geodetic network planning and could easily establish point with the sites where stations are not visible e.g. Mountains.
- Comparatively more flexible, consuming less time and also more effective.
- High accuracy with three-dimensional geographic information irrespective of place and time.

Limitations of GPS:

- Clear and fine visibility of sky and no obstructions through any obstacles e.g. Branches etc.
- Limited application especially in urban areas.
- High efficiency generally not needed.
- GPS coordinates in WGS-84 datum are not easily convertible into local geodetic system. It is only possible via reliable transformation scheme.
- Comparison of GPS accuracy and terrestrial accuracy could create confusion or conflict for many years which is yet to come.
- Not easily universally acceptable.
- Highly skilled workers are required.

Q.2 (a) Solution:

(i)

Given: Discharge, $Q = 400$ litre/sec $= 0.4$ m^3/sec

Bed slope, $\dot{S} = \dfrac{1}{9000}$

Manning's $n = 0.015$

Let the diameter of channel $= D$

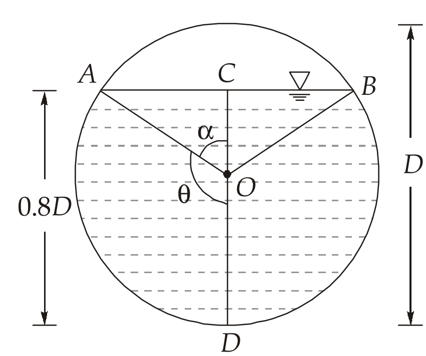
$\therefore$ Depth of flow, $d = 0.8D$

Now, $OC = CD - OD$

$= 0.8D - 0.5D = 0.3D$

and, $AO = \dfrac{D}{2} = 0.5D$

$$\cos\alpha = \frac{OC}{AO} = \frac{0.3D}{0.5D} = 0.6$$



$$\alpha = 53.13°$$

and, $$\theta = 180° - 53.13° = 126.87°$$

$$= 126.87° \times \frac{\pi}{180°} = 2.214 \text{ radians}$$

Now, wetted perimeter, $$P = 2R\theta = 2 \times \frac{D}{2} \times 2.214 = 2.214\text{ D}$$

Now, wetted area, $$A = R^2\left[\theta - \frac{\sin 2\theta}{2}\right]$$

$$= \left[\frac{D}{2}\right]^2\left[2.214 - \frac{\sin(2 \times 126.87°)}{2}\right]$$

$$= \frac{D^2}{4}\left[2.214 - \sin\frac{253.74°}{2}\right]$$

$$= \frac{D^2}{4}\left[2.214 - (-0.48)\right] = 0.6735D^2$$

Hydraulic mean depth, $$R = \frac{A}{P} = \frac{0.6735D^2}{2.214D} = 0.3042D$$

Now, Discharge, $$Q = \frac{1}{n}A \times R^{2/3} \cdot S^{1/2}$$

$$\Rightarrow \quad 0.4 = \frac{1}{0.015} \times 0.6735D^2 \times (0.3042D)^{2/3} \times \sqrt{\frac{1}{9000}}$$

$$\Rightarrow \quad 0.4 = 0.214D^{8/3}$$

$$\Rightarrow \quad D^{8/3} = \frac{0.4}{0.214} = 1.869$$

$$\Rightarrow \quad D = (1.869)^{3/8} = 1.26 \text{ m}$$

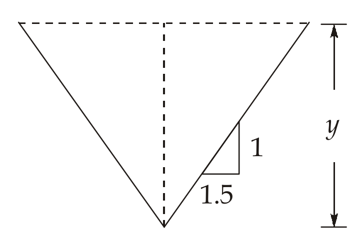
(ii)

Given: $m = 1.5$

Bed slope, $S_o = 0.009$

Manning's $n = 0.015$

Discharge, $Q = 2.0 \text{ m}^3/\text{sec}$



Area, $A = my^2 = 1.5y^2$

Wetted perimeter, $$P = 2y\sqrt{m^2 + 1}$$

$$= 2y\sqrt{(1.5)^2+1} = 3.605\,y$$

$$\text{Hydraulic radius, } R = \frac{A}{P} = \frac{1.5y^2}{3.6056y} = 0.416y$$

$$\text{Top width, } T = 2my = 2 \times 1.5 \times y = 3.0\text{ y}$$

Critical depth, y_c:

$$\frac{Q^2}{g} = \frac{A_c^3}{T_c}$$

$$\Rightarrow \quad \frac{(2)^2}{9.81} = \frac{\left(1.5y_c^2\right)^3}{3.0\,y_c}$$

$$\Rightarrow \quad 0.4077 = 1.125\,y_c^{\,5}$$

$$y_c = 0.816\text{ m}$$

Normal depth, y_o:

$$Q = \frac{1}{n} \times A \times R^{2/3} \cdot S^{1/2}$$

$$\Rightarrow \quad 2 = \frac{1}{0.015} \times \left(1.5y_0^2\right) \times \left(0.416y_0\right)^{2/3} \times (0.009)^{1/2}$$

$$\Rightarrow \quad 2 = 5.2867y_0^{8/3}$$

$$\Rightarrow \quad y_0 = 0.695\text{ m}$$

Since $y_0 < y_c$, the channel is steep sloped channel for this discharge.

If 'y' is the depth of flow,

(i) For S_1 curve; $y_0 < y_c < y$ i.e. $y > 0.816$ m

(ii) For S_2 curve; $y_0 < y < y_c$ i.e. $0.695\text{ m} < y < 0.816\text{ m}$

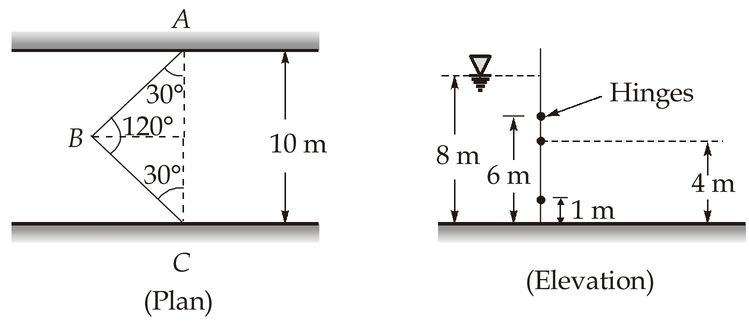
Q.2 (b) Solution:

(i)

Given: Height of gate = 10 m

Inclination of gate = 120°

$$\theta = \frac{180° - 120°}{2} = 30°$$



Width of lock = 10 m

∴ Width of each lock, $l = \dfrac{5}{\cos 30°}$

⇒ $l = 5.7735$ m

Depth of water on upstream side, $H_1 = 8$ m

Depth of water on downstream side, $H_2 = 4$ m

1. Water pressure on upstream side:

$$F_1 = \rho g A_1 \cdot \bar{h}_1$$

where, $A_1 = l \times H_1 = 5.7735 \times 8 = 46.188\ \text{m}^2$

$$\bar{h}_1 = \frac{H_1}{2} = \frac{8}{2} = 4\ \text{m}$$

∴ $F_1 = 1000 \times 9.81 \times 46.188 \times 4$

$= 1812260\ \text{N} = 1812.26\ \text{kN}$

2. Water pressure on downstream side,

$$F_2 = \rho g A_2 \cdot \bar{h}_2$$

where, $A_2 = l \times H_2 = 5.7735 \times 4 = 23.094\ \text{m}^2$

$$\bar{h}_2 = \frac{4}{2} = 2\ \text{m}$$

∴ $F_2 = 1000 \times 9.81 \times 23.094 \times 2$

$= 453104\ \text{N} = 453.104\ \text{kN}$

∴ Resultant water pressure $= F_1 - F_2$

$= 1812.26 - 453.104 = 1359.156\ \text{kN}$

2. Reaction between the gates *AB* and *BC*:

The reaction (P) between the gates *AB* and *AC* is given by

$$P = \frac{F}{2\sin\theta} = \frac{1359.156}{2\times\sin 30°} = 1359.155 \text{ kN}$$

3. Force on each hinge:

If R_T and R_B are the reactions at the top and bottom hinges then,

$$R_T + R_B = R$$

we know that, $R = P$

$\therefore$ $R_T + R_B = 1359.156$

The force F_1 is acting at $\frac{H_1}{3} = \frac{8}{3} = 2.67\text{ m}$ from bottom and F_2 at $\frac{H_2}{3} = \frac{4}{3} = 1.33\text{ m}$ from bottom is given by,

$$F \times x = F_1 \times 2.67 - F_2 \times 1.33$$

$$\Rightarrow \quad x = \frac{F_1 \times 2.67 - F_2 \times 1.33}{F}$$

$$\Rightarrow \quad x = \frac{1812.26 \times 2.67 - 453.104 \times 1.33}{1359.156} = 3.11 \text{ m}$$

Hence R is also acting at a distance 3.12 m from bottom. Taking moments of R_T and R about the bottom hinge.

$$R_T \times (6 - 1) = R \times (x - 1)$$

$$\Rightarrow \quad R_T = \frac{R \times (3.12 - 1)}{5} = 576.28 \text{ N}$$

$$R_B = R - R_T$$

$$= 1359.156 - 576.28$$

$$= 782.876 \text{ kN}$$

(ii)

Velocity potential function: It is defined as a scalar function of space and time such that its negative derivative with respect to any direction gives the fluid velocity in that direction. It is defined by 'ϕ'. Mathematically, the velocity potential is defined as $\phi = f(x, y, z)$ for steady flow such that,

$$u = -\frac{\partial\phi}{\partial x}$$

$$v = \frac{-\partial\phi}{\partial y}$$

$$\omega = \frac{-\partial\phi}{\partial z} \quad \text{...(1)}$$

The continuity equation for an incompressible steady flow is,

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z} = 0$$

Putting values of u, v and w here, we get

$$\frac{\partial}{\partial x}\left(\frac{-\partial\phi}{\partial x}\right)+\frac{\partial}{\partial y}\left(-\frac{\partial\phi}{\partial y}\right)+\frac{\partial}{\partial z}\left(-\frac{\partial\phi}{\partial z}\right) = 0$$

$$\Rightarrow \quad \frac{\partial^2\phi}{\partial x^2}+\frac{\partial^2\phi}{\partial y^2}+\frac{\partial^2\phi}{\partial z^2} = 0$$

It is Laplace equation.

Now,

The rotational components are given by,

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

$$\omega_y = \frac{1}{2}\left(\frac{\partial u}{\partial z}-\frac{\partial w}{\partial x}\right)$$

$$\omega_x = \frac{1}{2}\left(\frac{\partial w}{\partial y}-\frac{\partial v}{\partial z}\right)$$

Putting the values of u, v and w, we get

$$\omega_z = \frac{1}{2}\left[\frac{\partial}{\partial x}\left(\frac{-\partial\phi}{\partial y}\right)-\frac{\partial}{\partial y}\left(-\frac{\partial\phi}{\partial x}\right)\right]$$

$$= \frac{1}{2}\left[\frac{-\partial^2\phi}{\partial x\partial y}+\frac{\partial^2\phi}{\partial y\cdot\partial x}\right] = 0$$

$$\omega_y = \frac{1}{2}\left[\frac{\partial}{\partial z}\left(\frac{-\partial\phi}{\partial x}\right)-\frac{\partial}{\partial x}\left(-\frac{\partial\phi}{\partial z}\right)\right]$$

$$= \frac{1}{2}\left[\frac{-\partial^2\phi}{\partial z\partial x}+\frac{\partial^2\phi}{\partial x\cdot\partial z}\right] = 0$$

$$\omega_x = \frac{1}{2}\left[\frac{\partial}{\partial y}\left(\frac{-\partial\phi}{\partial z}\right)-\frac{\partial}{\partial z}\left(-\frac{\partial\phi}{\partial y}\right)\right]$$

$$= \frac{1}{2}\left[\frac{-\partial^2\phi}{\partial y\partial z}+\frac{\partial^2\phi}{\partial z\cdot\partial y}\right] = 0$$

$\therefore$ $\omega_z = \omega_y = \omega_n = 0$ [It means flow is irrotational]

Hence properties of the potential function are:

(i) If velocity potential exists, the flow should be irrotational.

(ii) If velocity potential satisfies the Laplace equation, it represents the possible steady incompressible irrotational flow.

Q.2 (c) Solution:

(i)

For $d < 0.1$ mm

$$\text{Settling velocity, } V_s = 418(G-1)d^2\left[\frac{3T+70}{100}\right]$$

$$= 418(2.65-1)\times(0.045)^2\times\left[\frac{3\times 20+70}{100}\right]$$

$$= 1.816 \text{ mm/sec.} \simeq 1.8156 \text{ cm/sec.}$$

Also, $$\frac{V_f}{V_s} = \frac{L}{H}$$

$$\Rightarrow \quad V_f = 0.1856\times\frac{L}{H} \text{ cm/sec.}$$

where V is the maximum flow velocity in the tank.

Also, L = Flow velocity × Detention time (t)

$$= 0.1816\times\left(\frac{L}{H}\right)\times t\times 60\times 60$$

where t is in hours

$$\therefore \quad L = \left[0.1816\times\frac{L}{H}\times\frac{3600t}{100}\right]\text{m}$$

$$\Rightarrow \quad L = 6.5376\frac{L.t}{H}$$

$$\therefore \quad t = \frac{H}{6.5376} \quad \text{...(i)}$$

$$\text{Now, capacity of tank, } V = \frac{12\times 10^6}{10^3}\times\frac{t}{24}\text{m}^3 = 500t \text{ m}^3$$

$$\Rightarrow \quad \text{B.L.H} = 500t$$

$$\Rightarrow \quad 3B^2\cdot H = 500\text{t} \qquad \left[\because \frac{B}{L} = \frac{1}{3}\right] \quad \text{...(ii)}$$

Using equation (i) and (ii), we get

$$3B^2 \cdot H = 500 \times \frac{H}{6.5376}$$

$$\Rightarrow \quad 3B^2 = \frac{500}{6.5376}$$

$$\therefore \quad B = 5.049 \text{ m} \simeq 5.05 \text{ m}$$

Since, $H = 3.5$ m

$$\therefore \quad \text{Detention time, } t = \frac{H}{6.5376} = \frac{3.5}{6.5376}$$

where, $t = 0.53536$ hr = 32.12 minutes

(ii)

Significance of $\frac{BOD}{COD}$ ratio:

The typical values of ratio of $\frac{BOD}{COD}$ for untreated municipal wastewater are in the range from 0.3 to 0.8. If the $\frac{BOD}{COD}$ ratio for untreated wastewater is 0.5 or greater, the waste is considered to be easily treatable by biological means. If the ratio is below about 0.3, either the waste may have some toxic components or acclimated microorganisms may be required in its stabilization.

Type of wastewater	**$\frac{BOD}{COD}$**
Untreated	0.3 - 0.8
After primary setting	0.4 - 0.6
Final effluent	0.1 - 0.3

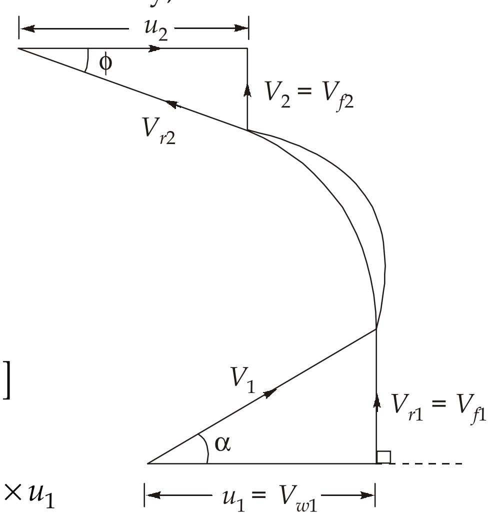
As BOD is predominantly a biochemical parameter, it generally reflects biodegradability of organic matter, thus making $\frac{BOD}{COD}$ ratio, a good indicator of the proportion of biochemically degradable organic matter to total organic matter. Thus $\frac{BOD}{COD}$ is typically a measurement used to describe the organic composition of wastewater.

Q.3 (a) Solution:

Given:

$$\text{Head on turbine, } H = 30 \text{ m}$$
$$D_1 = 1.2 \text{ m}$$
$$D_2 = 0.6 \text{ m}$$
$$\text{Vane angle at inlet, } \theta = 90°$$
$$\text{Guide blade angle, } \alpha = 15°$$

The water at exit leaves the vane without any tangential velocity,



∴ $$V_{w2} = 0$$

and $$V_2 = V_{f2}$$

∴ Velocity of flow is constant in runner,

∴ $$V_{f1} = V_{f2}$$

(i) Speed of turbine:

$$H - \frac{V_2^2}{2g} = \frac{1}{g}[V_{w1}u_1 \pm V_{w2}u_2]$$

$$= \frac{1}{g}V_{w1} \cdot u_1 \quad \frac{1}{g} \times u_1 \times u_1$$

∴ $$30 - \frac{V_{f2}^2}{2g} = \frac{1}{g}u_1^2 \qquad [\text{As } V_2 = V_{f2} = V_{f1}]$$

But from inlet velocity triangle, we have

$$\tan\alpha = \frac{V_{f1}}{u_1}$$

⇒ $$u_1 = \frac{V_{f1}}{\tan\alpha} = \frac{V_{f1}}{\tan 15°} = 3.732\,V_{f1}$$

Now, $$30 - \frac{V_{f2}^2}{2g} = \frac{13.928 V_{f2}^2}{g}$$

⇒ $$30 = \frac{14.428 V_{f1}^2}{g}$$

$$V_{f1} = \sqrt{\frac{30 \times 9.81}{14.428}} = 4.52 \text{ m/sec.}$$

Now, $$u_1 = 3.732 \times 4.52 = 16.87 \text{ m/sec.}$$

$$u_1 = \frac{\pi D_1 N}{60}$$

$$\Rightarrow \quad 16.87 = \frac{\pi \times 1.2 \times N}{60}$$

$$\Rightarrow \quad N = 268.5 \text{ rpm}$$

(ii) Vane angle at exit:

$$u_2 = \frac{\pi D_2 N}{60} = \frac{\pi \times 0.6 \times 268.5}{60} = 8.435 \text{ m/sec.}$$

$$V_{f2} = V_{f1} = 4.52$$

Now, from velocity triangle at outlet,

$$\tan\phi = \frac{V_{f2}}{u_2} = \frac{4.52}{8.435} = 0.5359$$

$$\Rightarrow \quad \phi = 28.185°$$

(iii) For a turbine which is directly coupled to the alternator of 50 cycles, the synchronous speed (N*) is given by

$$f = \frac{P.N^*}{60}$$

$$\Rightarrow \quad N^* = \frac{60 \times 50}{12} = 250 \text{ rpm}$$

But the speed of turbine is 263.72 and synchronous speed (N*) is equal to 250. Hence the speed of turbine is not synchronous. The speed of turbine should be 250 rpm.

Q.3 (b) Solution:

(i)

Permanent adjustments of a compass:

- Permanent adjustments are those adjustments which are not done in a routine manner but are carried out only when it is suspected that the instrument is not functioning well or are done in the factory.

Permanent adjustment of Surveyor's compass

1. **Adjustment of levels:** This adjustment is required in the compass which is provided with two level tubes at right angles to each other. When the bubble is at the center of tube then the tangential line to the bubble will be normal to the direction of vertical

axis of rotation. Thus level adjustments are done to make the vertical axis perfectly vertical when bubbles of both the level tubes are at the center.

2. **Adjustment of sight vanes:** When the instrument is levelled, the sight vanes must be vertical. For this a plumb bob is hanged with a string at a short distance away from the compass. Level the compass and look at the string through the sight vanes. Check whether the vertical hair in one vane and the edges of slit in the other vane are parallel to the string. If not, then adjustment is required. For this, remove the affected vane from the compass and do filing of higher side of its base where it rests on the compass. Alternatively, insert a suitable packing at the other end of the base of vane. Repeat the adjustment till the sight vanes are exactly vertical when the compass is levelled.

3. **Adjustment of sensitivity of bubble:** Level the compass and lower the needle gently on its pivot. If the needle comes to rest quickly, then the needle is not sensitive and it requires adjustment. Loss of sensitivity is due to the loss of magnetism of needle or due to wear of the pivot point or both.

   For adjustment, re-magnetize the needle by placing it into a solenoid coil powered with strong *DC*. Sharpen the pivot by rubbing it with fine sand paper.

4. **Adjustment of straightness of the needle:** The needle must be absolutely straight. If bent, it requires adjustment. The bending of needle may be either in the horizontal plane or the vertical plane.

   - **Bending of needle in vertical plane :** Lower the needle gently on the pivot and observe if the needle is accompanied by vertical sea-saw motion of the ends. If yes then it needs adjustment. For adjustment, take the needle out, bend it in the vertical plane. Repeat this process till the sea-saw motion ceases.
   - **Bending of needle in horizontal plane:** Take readings of both the ends of the needle for different positions of zero mark. If difference of these readings is always same constant other than 180°, then needle is bent in horizontal plane but pivot coincides with the center of graduated ring. If the difference is not constant and it varies with different positions of zero mark, then both needle and pivot needs adjustment. In this case also, needle is adjusted first and pivot is adjusted later.

5. **Pivot adjustment:** The pivot must lie at the geometric center of the graduated ring. Read both ends of the needle for different positions of graduated ring. If the difference is not 180° and it varies with various positions of graduated ring, then pivot needs adjustment.

   Permanent adjustment of prismatic compass:

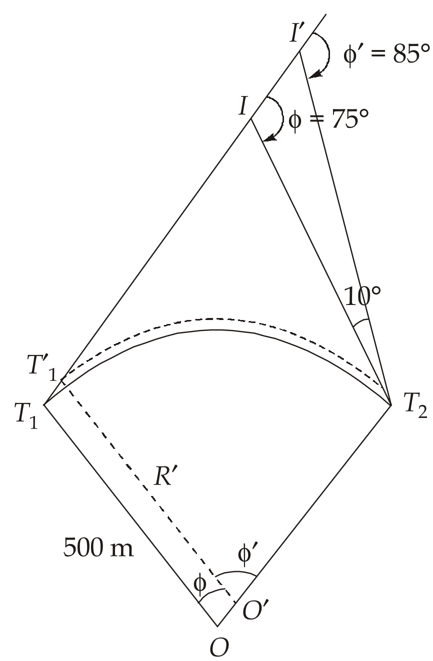
- The permanent adjustments of prismatic compass are similar to those of Surveyor's compass with slight differences which are as follows:

(a) **Adjustment of levels:** In prismatic compass, there are no level tubes and thus adjustment of levels is not required.

(b) **Adjustments of sight vanes:** The sight vanes in prismatic compass are not adjustable.

(c) **Adjustments of needle and pivot:** Needle in the prismatic compass cannot be straightened.

(ii)



$$\text{Initial tangent length, } IT_2 = R\tan\frac{\phi}{2}$$

$$= 500\tan\frac{75^\circ}{2} = 383.66\,\text{m}$$

From $\Delta IT_2I'$, using sine rule,

$$\frac{II'}{\sin 10^\circ} = \frac{I'T_2}{\sin 75^\circ} = \frac{IT_2}{\sin(180^\circ - 85^\circ)}$$

$$\Rightarrow \quad II' = IT_2 \times \frac{\sin 10^\circ}{\sin 95^\circ}$$

$$= 383.66 \times \frac{\sin 10^\circ}{\sin 95^\circ} = 66.88\,\text{m}$$

$$I'T_2 = 383.66 \times \frac{\sin 75°}{\sin 95°} = 372 \text{ m}$$

$\therefore$ New radius, $R' = \dfrac{I'T_2}{\tan\left(\dfrac{85°}{2}\right)}$

$$= \frac{372}{\tan 42.5°} = 405.97 \text{ m}$$

Now, $T_1T_1' = T_1I + II' - T_1'I'$ $[\because T_1I = T_2I \text{ and } T_1'I' = T_2I']$

$= 383.66 + 66.88 - 372 = 78.54$ m

Given chainage of $T_1 = 987$ m

Chainage of $T_1' = 987 + 78.54 = 1065.54$ m

Chainage of I' = Chainage of $T_1' + T_1'I$

$= 1065.54 + 372 = 1437.54$ m

Length of new arc $= 405.97 \times 85 \times \dfrac{\pi}{180} = 602.27$ m

$\therefore$ Chainage of T_2 = Chainage of T_1' + Length of new arc

$= 1065.54 + 602.27 = 1667.81$ m

Q.3 (c) Solution:

(i)

1. Total suspended solids in waste water = 250 mg/lt.

Since 55% of these solids are removed in sedimentation,

$\therefore$ Solids removed in sedimentation as sludge = 55% × 250 mg/lt

= 137.5 mg/lt

If volume of wastewater is 1 million litre, then solids removed as sludge,

$$= \frac{137.5}{10^6} \times 10^6 \text{ kg} = 137.5 \text{ kg}$$

Sludge produced will, thus have 137.5 kg solids and the rest will be water.

Now, moisture content = 96%

Water contained in 4 kg of solids = 96 kg

Water contained in 137.5 kg of solids $= \dfrac{96}{4} \times 137.5 = 3300$ kg

Hence volume of sludge produced per million litre of waste water,

$$= \frac{\text{Mass of solids}}{\text{Density of solids}} + \frac{\text{Mass of water}}{\text{Density of water}}$$

$$= \frac{137.5}{1.2 \times 1000} + \frac{3300}{1000}$$

$$= 0.115 + 3.3 = 3.415 \text{ m}^3$$

2. Density of raw sludge:

$$= \frac{\text{Mass of solids} + \text{Mass of water}}{\text{Volume of sludge}}$$

$$= \frac{137.5+3300}{3.415} = \frac{3437.5}{3.415} = 1006.59 \simeq 1007 \text{ kg/m}^3$$

(c) 45% of raw sludge is changed to liquid and gas, means that 45% of solids are digested.

$\therefore$ Mass of dry solids left in the digested sludge

$$= [100 - 45]\% \text{ of total solids}$$

$$= \frac{55}{100} \times 137.5 \text{ kg} = 75.625 \text{ kg}$$

Since digested sludge contains 90% moisture content, we have,

$$\text{Volume of digested sludge} = \left[\frac{\text{Mass of solids left in digested sludge}}{\text{Density of solids}}\right] + \left[\frac{\text{Mass of water}}{\text{Density of water}}\right]$$

$$= \left[\frac{75.625}{1.2 \times 1000} + \frac{\frac{75.625 \times 90}{10}}{1000}\right] \text{m}^3$$

$$= [0.063 + 0.681] \text{ m}^3 = 0.744 \text{ m}^3$$

(ii)

1. Manholes are masonary or RCC chambers, constructed at suitable intervals along the sewer linear for providing access into them. The manhole thus help in joining sewer lengths and also help in their inspection, cleaning and maintenance.

- **Location and spacing of manholes**: The manholes are generally provided at every bend, junction, change of gradient or change of sewer dia. The spacing between the manholes depends mainly upon the size of the sewer line. The larger is the diameter of the sewer, the greater will be spacing between manholes.

2. **Drop Manholes:** When a branch sewer enters a manhole by more than 0.5 to 0.6 m above the main sewer, the sewage is generally not allowed to fall directly into the manhole but is brought into it through a downpipe taken from the branch sewer to the bottom of manhole. If the drop is only a few meters, the down pipe can be kept stopping and if the drop is more, a vertical pipe is found to be economical. the manhole, in which a vertical pipe is used, is called a drop manhole.
3. **Lamp Holes:** Lampholes are the small openings on sewers to permit the inseration of a lamp into the sewer. The lamp light is then viewed from stream manholes. The obstructed light confirms the obstructions is the sewers.

Q.4 (a) Solution:

Given:

Parameters	Wastewater	Stream
Discharge	$Q_w = 1.25\,\text{m}^3/\text{sec}$	$Q_s = 8\,\text{m}^3/\text{sec}$
Velocity	–	$V_s = 0.8\,\text{m/sec}$
Temperature	$T_w = 20°\text{C}$	$T_s = 15°\text{C}$
Dissolved oxygen	$DO_w = 0$	$DO_s = 0.9C_s$
BOD_5 at 20°C	250 mg/lt	2.0 mg/lt.

DO of the stream:

Since, saturation concentration of DO at 15°C = 10.15 mg/lt.

$$\text{DO of the stream, } \text{DO}_s = 0.9 \times 10.15 = 9.135 \text{ mg/lt}$$

Characteristics of the mixture:

(i)
$$(\text{Temp.})_{\text{mix}} = \frac{Q_w \times T_w + Q_s \times T_s}{(Q_w + Q_s)}$$
$$= \frac{1.25 \times 20 + 8 \times 15}{1.25 + 8} = 15.676°\text{C}$$

(ii)
$$(\text{BOD})_{5\,\text{mix}} \text{ at } 20°\text{C} = \frac{1.25 \times 250 + 8 \times 2}{1.25 + 8} = 35.51 \text{ mg}/l$$

(iii)
$$\text{Ultimate BOD, } (L_o)_{\text{mix}} = \frac{35.51}{1 - e^{-0.3 \times 5}} = 45.709 \text{ mg/lt}$$

(iv)
$$(\text{DO})_{\text{mix}} = \frac{1.25 \times 0 + 8 \times 9.135}{(1.25 + 8)} = 7.90 \text{ mg/lt}$$

Initial dissolved oxygen deficit at 15.676°C. From table saturation DO concentration at 15.676°C is,

$$= 10.15 - \frac{[10.15 - 9.95]}{[16 - 15]} \times (15.676 - 15) = 10.015 \text{ mg/lt.}$$

∴ Initial deficit, D_o = (10.015 – 7.90) = 2.115 mg/lt

Rate constant at 15.675°C:

$$k_D{}' = 0.3(1.135)^{15.676 - 20} = 0.1735 \text{ day}^{-1}$$

$$k_R{}' = 0.9(1.024)^{15.676 - 20} = 0.8123 \text{ day}^{-1}$$

Determination of t_c and x_c:

$$\text{Critical time, } t_c = \frac{1}{k'_R - k'_D} \ln\left[\frac{k'_R}{k'_D}\left\{1 - \frac{D_o}{L_o}\left(\frac{k'_R - k'_D}{k'_D}\right)\right\}\right]$$

$$\Rightarrow \quad t_c = \frac{1}{(0.8123 - 0.1735)} \ln\left[\frac{0.8123}{0.1735}\right]\left\{1 - \frac{2.115}{45.709}\left(\frac{0.8123 - 0.1735}{0.1735}\right)\right\}$$

$$\Rightarrow \quad t_c = 2.12 \text{ d}$$

Distance, x_c = 0.8 × 2.12 × 24 × 3600 = 146534.4 m = 146.53 km

Determination of critical DO deficit (D_o) at t_c is :

$$D_c = \frac{k'_D}{k'_R} L_o \cdot e^{-k'_D t_c}$$

$$= \frac{0.1735}{0.8123} \times 45.709 \times e^{-0.1735 \times 2.12}$$

$$= 6.758 \text{ mg/lt}$$

Determination of $(BOD)_5$ of sample taken at x_c:

$$L_t = L_o e^{-k'_D \cdot t_c}$$

$$\Rightarrow \quad L_t = 45.709 \cdot e^{-0.1735 \times 2.121}$$

$$= 31.642 \text{ mg/lt}$$

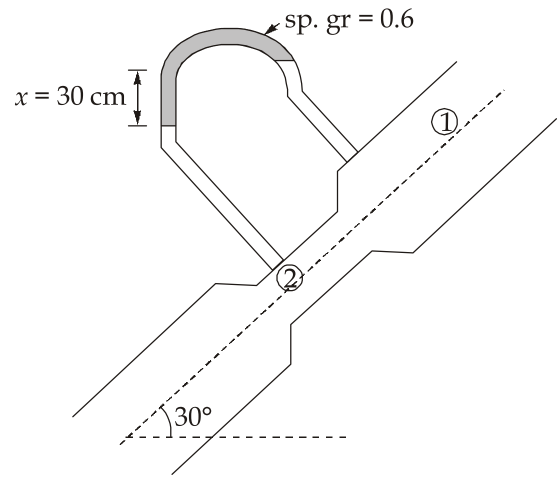
So, at 20°C, (BOD_5) = $31.642\ (1 - e^{-0.3 \times 5})$

$$= 24.582 \text{ mg/lt.}$$

Q.4 (b) Solution:

(i)

Diameter of inlet, d_1 = 30 cm



Cross-sectional area of main pipe, $a_1 = \frac{\pi}{4} \times 30^2$ = 706.86 cm^2

Diameter at throat, d_2 = 15 cm

$\therefore$ Cross-sectional area of throat, $a_2 = \frac{\pi}{4} \times (15)^2 = 176.71\,\text{cm}^2$

Reading of differential manometer, x = 30 cm

Now, $\left(\frac{P_1}{\rho g} + z_1\right) - \left(\frac{P_2}{\rho g} + z_2\right) = h$

Also, $h = x\left[1 - \frac{S_l}{S_0}\right]$

where, S_l = 0.6 and S_0 = 1.0

$h = 30 \times \left[1 - \frac{0.6}{1.0}\right]$ = 30 × 0.4 = 12 cm of water

Loss of head, h_L = 0.2 × kinetic head of pipe

$= 0.2 \times \frac{V_1^2}{2g}$

Now, applying Bernoulli's equation at section (1) and (2), we get

$$\frac{P_1}{\rho g}+\frac{V_1^2}{2g}+z_1 = \frac{P_2}{\rho g}+\frac{V_2^2}{2g}+z_2+h_L$$

$$\Rightarrow \left[\frac{P_1}{\rho g}+z_1\right]-\left[\frac{P_2}{\rho g}+z_2\right]+\frac{V_1^2}{2g}-\frac{V_2^2}{2g} = h_L$$

$$\Rightarrow \quad 0.12+\frac{V_1^2}{2g}-\frac{V_2^2}{2g} = 0.2\times\frac{V_1^2}{2g}$$

$$\Rightarrow \quad 0.12+0.8\frac{V_1^2}{2g}-\frac{V_2^2}{2g} = 0$$

Apply continuity equation at sections (1) and (2),

$$a_1V_1 = a_2V_2$$

$$\Rightarrow \quad V_1 = \frac{a_2}{a_1}\times V_2 = \frac{\frac{\pi}{4}\times(15)^2}{\frac{\pi}{4}\times(30)^2}\times V_2$$

$$\Rightarrow \quad V_1 = \frac{V_2}{4}$$

Now, $$0.12+\frac{0.8}{2g}\left[\frac{V_2}{4}\right]^2-\frac{V_2^2}{2g} = 0$$

$$\Rightarrow \quad \frac{V_2^2}{2g}[0.05-1] = -0.12$$

$$\Rightarrow \quad \frac{0.95V_2^2}{2g} = 0.12$$

$$\Rightarrow \quad V_2 = \sqrt{\frac{2\times9.81\times0.12}{0.95}} = 1.57 \text{ m/sec.}$$

$\therefore$ Discharge, $Q = a_2V_2$

$= 176.71 \times 10^{-4} \times 1.57 = 0.028 \text{ m}^3\text{/s} = 28\ l\text{/s}$

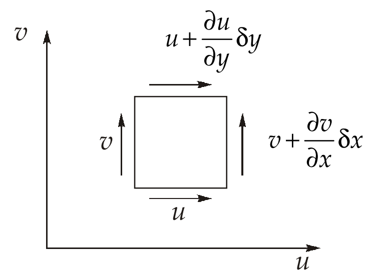
(ii)

1. **Circulation**: The flow along a closed curve is called circulation. This refers to the tendency of fluid particles to follow a circular or curved path when in motion. It is often associated with rotating or swirling motions within the fluid. It is more convenient to relate rotation to the sum of products of velocity and distance around

the contour of the element. Such a sum is a line integral of velocity around the element and it is called as circulation (Γ).

Thus, $$\Gamma = \oint V_s \cdot d_s$$

Generally, circulation is regarded as positive for counter clockwise direction of integration.



The circulation around an elementary rectangle is,

$$\Gamma = [u \times \delta x] + \left[\left(v + \frac{\partial v}{\partial x}\,\delta x\right) \times \delta y\right] - \left[\left(u + \frac{\partial y}{\partial y}\,\delta y\right) \times \delta x\right] - [v \times \delta y]$$

- **Vorticity**: Vorticity measures the local rotation of fluid elements. It is a vector quantity. It is defined as the ratio of circulation around an infinitesimal closed curve at that point to the area of curve i.e. circulation per unit area.

$$\text{Vorticity, } \Omega = \frac{\text{Circularity}}{\text{Area}} = \frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}$$

As per rotational velocity (w_z),

$$\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y} = 2w_z$$

$$\Rightarrow \qquad \Omega = 2w_z$$

i.e. the vorticity is equal to twice the rotation component about an axis perpendicular to the plane in which area is lying.

Q.4 (c) Solution:

(i)

1. Bowditch's Rule

- This method of traverse adjustment is suitable where linear and angular measurements are made with equal precision.
- This method is usually used for balancing a compass traverse but can be used for theodolite traverse also, provided angular and linear measurements are done with

same precision.

- This method assumes that the errors/mistakes are accidental in nature and the probable error in a traverse line is proportional the square root of its length.
- As per Bowditch's rule,

  Error in latitude or departure of a traverse line

  $$= \text{Total error in latitude or departure of traverse} \times \frac{\text{Length of traverse line}}{\text{Perimeter of traverse}}$$

- The required correction will be numerically equal to the value of error but its sign will be opposite to that of error.

  NOTE: When a traverse is adjusted by Bowditch's rule, then both the lengths and bearings of the traverse get affected but here lengths get changed less and angles get changed more.

Advantages of Bowditch's Rule:

(a) Bowditch's rule is quite easy to apply.

(b) The altered bearings of the traverse lines do not significantly affect the plotted position of the traverse points.

(c) This method is backed up by a logical mathematical reason and is not an empirical one.

2. Transit Rule:

- This method of traverse adjustment is used in situations where angular measurements are made with more precision as compared to linear measurements.
- In theodolite traverse, angular measurements are more precise as compared to linear measurements and thus this method is quite suitable for theodolite traverse.
- As per Transit rule,

  Error in latitude or departure of a traverse line

  = Total error in latitude or departure of traverse ×

  $$\frac{\text{Numerical value of latitude or departure of traverse line}}{\text{Arithematic sum of latitudes or departures of traverse}}$$

(ii)

Instrument P is at station A and staff is held vertical at B,

$$S = 1.79 - 1.09 = 0.7 \text{ M}, \theta = 5°50'$$

Distance between A and B, $D = kS\cos^2\theta + C\cos\theta$ [∵ Staff is held vertical]

$$= 100 \times 0.7 \times \cos^2(5°50') + 0.4\cos(5°50')$$
$$= 69.675 \text{ m}$$

Now, $$V = \frac{kS\sin 2\theta}{2} + C\sin\theta$$
$$= \frac{100 \times 0.7 \times \sin(2 \times 5°50')}{2} + 0.4\sin(5°50')$$
$$= 7.118 \text{ m}$$

$\therefore$ $$\text{R.L. of } B = \text{R.L. of } A + H.I + V - h$$
$$= 105 + 1.3 + 7.118 - 1.44$$
$$= 111.978 \text{ m}$$

Instrument Q is at station A and staff is held normal to the line of sight at B.

Distance between A, B and D $= (kS + C)\cos\theta + h\sin\theta$
$$= (90S + 0.35)\cos(5°50') + h\sin(5°50')$$
$$\Rightarrow \quad 69.675 = 89.534S + 0.348 + 0.102h$$
$$\Rightarrow \quad 69.327 = 89.534S + 0.102h$$
$$\Rightarrow \quad h = 679.676 - 877.784S \quad \text{...(1)}$$

Also, $$V = (kS + C)\sin\theta$$
$$= (90S + 0.35)\sin 5°50'$$
$$= (90S + 0.35) \times 0.102$$

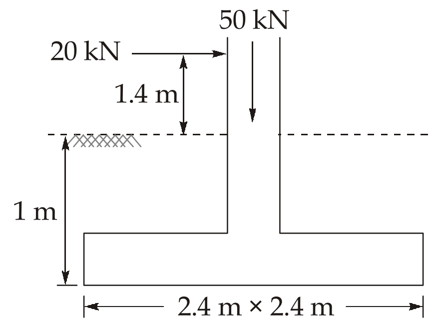
$\therefore$ $$\text{R.L. of } B = \text{R.L. of } A + H.I + V - h\cos\theta$$
$$\Rightarrow \quad 111.978 = 105 + 1.4 + (90S + 0.35) \times 0.102 - h(0.995)$$
$$\Rightarrow \quad 111.978 = 106.436 + 9.18S - 0.995h$$
$$\Rightarrow \quad 0.995h = 9.18S - 5.542$$
$$\Rightarrow \quad h = 9.226S - 5.57 \quad \text{...(2)}$$

From (1) and (2),
$$9.226S - 5.57 = 679.676 - 877.784S$$
$$\Rightarrow \quad S = 0.773 \text{ m}$$
$$\therefore \quad h = 1.562 \text{ m}$$

$\therefore$ Upper stadia wire reading $= 1.562 - \frac{0.773}{2} = 1.176$ m

$\therefore$ Lower stadia wire reading $= 1.562 + \frac{0.773}{2} = 1.949$ m

Q.5 (a) Solution:



Horizontal wind load will introduce both inclination and eccentricity.

Now, $$\tan\alpha = \frac{\text{Horizontal wind force}}{\text{Weight of chimney}}$$

$$= \frac{20}{50}$$

where α is angle of inclination of resultant force with vertical

⇒ $$\alpha = 21.8°$$

Now, height of horizontal load above base = 1.4 + 1 = 2.4 m

Eccentricity, e_x can be given as

$$\frac{e_x}{2.4} = \tan\alpha$$

⇒ $$e_x = 0.96 \text{ m}$$

Now, reduced width, $$B' = B - 2e_x$$

$$= 2.4 - 2 \times 0.96 = 0.48 \text{ m}$$

Area of footing, $$A' = B'L$$

$$= 0.48 \times 2.4 = 1.152 \text{ m}$$

For $\phi = 0°$, $N_C = 5.14$, $N_q = 1$ and $N_\gamma = 0$

$$S_C = 1 + \frac{0.2B'}{L}\tan^2\left(45° + \frac{\phi}{2}\right)$$

$$= 1 + 0.2 \times \frac{0.48}{2.4}\tan^2\left(45° + \frac{0}{2}\right)$$

$$= 1.04$$

$$S_q = 1$$

$$d_c = 1 + 0.2 \times \frac{D_f}{B}\tan\left(45° + \frac{\phi}{2}\right)$$

where D_f is depth of footing below ground level.

$$= 1 + 0.2 \times \frac{1}{0.48} \tan\left(45° + \frac{\phi}{2}\right)$$

$$= 1.42$$

$$d_q = 1$$

$$i_c = i_q = \left(1 - \frac{\alpha}{90°}\right) = \left(1 - \frac{21.8°}{90°}\right) = 0.76$$

Now, ultimate bearing capacity,

$$q_u = CN_C S_C d_C i_C + qN_q S_q d_q i_q \qquad [\because N_\gamma = 0]$$

where, $C = \frac{50}{2} = 25 \text{ kN/m}^2$

$$\therefore \quad q_u = 25 \times 5.14 \times 1.04 \times 1.42 \times 0.76 + 19 \times 1 \times 1 \times 1 \times 1 \times 0.76$$

$$= 144.22 + 14.44$$

$$= 158.66 \text{ kN/m}^2$$

So, maximum load, $Q_u = q_u \times A'$

$$= 158.66 \times 1.152 = 182.78 \text{ kN}$$

So, factor of safety $= \frac{182.78}{50} = 3.66$

Q.5 (b) Solution:

Quality control checks during the construction of WMM base course are the following:

1. The samples of aggregates collected are subjected to relevant laboratory tests to check the values of Los Angeles abrasion value or aggregate impact value, combined flakiness and elongation index.
2. Plasticity index (PI) is checked on the fraction of the mixed aggregates that pass through 0.425 mm sieve
3. The gradation of the combined mix of coarse and fine aggregates is checked
4. Laboratory compaction test (by IS heavy compaction) is carried out on the selected mixed aggregates to determine the OMC and maximum dry density.
5. The moisture content of the WMM mix is determined while being fed into the mechanical paver to ensure that it is within the permissible limits of the OMC.
6. The field density and moisture content of the compacted WMM layer are determined by one of the approved methods to ensure that the dry density achieved is not less than 98% of standard laboratory density.
7. The steps (5) and (6) are repeated for each subsequent WMM layer.

8. The finished surface levels of the WMM base course are checked with reference to desired longitudinal and cross profile of the road. If these are found to exceed the permissible tolerance of (+10 mm and - 10 mm), then affected area is scarified (not less than 5 m in length and 2 m in width), reshaped with added premix and re-compacted by rolling.

   The Ministry of Road Transport and Highways (MORTH) have suggested that minimum of one set of aggregate impact, flakiness index and elongation index tests are to be conducted per 200 m^3 of aggregates and the grading of the mixed aggregates to be checked at one test per 100 m^2 of aggregates. Minimum of one density test per 500 m^2 on each compacted layer is also to be carried out.

Q.5 (c) Solution:

Total weight of train, W = Weight of locomotive + Weight of wagon

$= 110 + 25 \times 20 = 610$ tonnes

Rolling resistance of each wagon = $2 \times 20 = 40$ kg

Rolling resistance of all wagon = $25 \times 40 = 1000$ kg = 1 tonne

Rolling resistance of locomotive = $110 \times 2.5 = 275$ kg = 0.275 tonne

Total resistance (rolling of train) = $1 + 0.275 = 1.275$ tonnes

Resistance depending upon speed = 0.00008 WV

$= 0.00008 \times 610 \times 65$

$= 3.172$ tonnes

Atmospheric resistance = $0.0000006\ WV^2$

$= 0.0000006 \times 610 \times 65^2$

$= 1.546$ tonnes

On straight track,

Train resistance = Rolling resistance + Resistance depending on speed + Atmospheric resistance + Resistance due to gradient

$$\Rightarrow \quad 18 = 1.275 + 3.172 + 1.546 + \frac{620}{n}$$

$$\Rightarrow \quad n = 51.64 \simeq 52 \text{ (approx)}$$

So, steepest gradient that can be provided is 1 in 52.

Q.5 (d) Solution:

Considering a channel reach having a flood flow, the total volume in storage can be considered under two categories as

1. **Prism Storage:** It is the volume that would exist if the uniform flow occurred at downstream depth, i.e. the volume formed by an imaginary plane which of parallel to channel bottom drawn at outflow section water surface. It is similar to a reservoir and can be expressed as a function of outflow discharge.
2. **Wedge Storage:** It is a wedge like volume formed between the actual water surface profile and top surface of prism storage. It is a function of inflow discharge.

At a fixed depth at a downstream section of a river reach, the prism storage is constant while the wedge storage changes from positive value at an advancing flood to a negative value during receding flood. Total storage in channel reach can be expressed as

$$S = K\left[xI^m + (1-x)Q^m\right]$$

where k, x are coefficients and m is a constant

Using $m = 1$ for natural channels

$$S = K\left[xI + (1-x)Q\right] \quad \ldots(i)$$

For a given channel, by selecting a routing interval Δt and using the equation (i)

$$S_1 = k[xI_1 + (1-x)Q_1] \quad \ldots(ii)$$

$$S_2 = k[xI_2 + (1-x)Q_2] \quad \ldots(iii)$$

where conditions at 1 and 2 represent beginning and end of interval Δt.

Subtracting (ii) from (iii), we get

$$S_2 - S_1 = k[x(I_2 - I_1) + (1-x)(Q_2 - Q_1)] \quad \ldots(iv)$$

As per continuity equation

$$S_2 - S_1 = \left(\frac{I_2 + I_1}{2}\right)\Delta t - \left(\frac{Q_2 + Q_1}{2}\right)\Delta t \quad \ldots(v)$$

Comparing (iv) and (v), we get

$$Q_2 = C_0I_2 + C_1I_1 + C_2Q_1$$

where,

$$C_0 = \frac{-kx + 0.5\Delta t}{k - kx + 0.5\Delta t}$$

$$C_1 = \frac{kx + 0.5\Delta t}{k - kx + 0.5\Delta t}$$

$$C_2 = \frac{K - Kx + 0.5\Delta t}{K - kx + 0.5\Delta t}$$

Q.5 (e) Solution:

For base load station

$$\text{Installed capacity} = 25 \text{ MW} = 25 \times 10^3 \text{ kW}$$

$$\text{Yearly output} = 110 \times 10^6 \text{ kWh}$$

$$\text{Peak load taken} = 18 \text{ MW} = 18 \times 10^3 \text{ kW}$$

(i)
$$\text{Annual load factor} = \frac{\text{Total energy generated per year}}{\text{Maximum power demand} \times 365 \times 24}$$

$$= \frac{110\times10^6}{18\times10^3\times365\times24} = 69.8\%$$

(ii)
$$\text{Plant use factor} = \frac{\text{Maximum power utilised}}{\text{Maximum power available}}$$

$$= \frac{18\times10^3}{25\times10^3} = 0.72 = 72\%$$

(iii)
$$\text{Capacity factor} = \frac{\text{Average energy utilised in a period}}{\text{Maximum energy that can be produced in that period}}$$

$$= \frac{110\times10^6}{25\times10^3\times365\times24} = 50.23\%$$

2. For standby station

$$\text{Installed capacity} = 30 \text{ MW} = 30 \times 10^3 \text{ kW}$$

$$\text{Yearly output in 2500 hours} = 11 \times 10^6 \text{ kWh}$$

$$\text{Peak load} = 13 \text{ MW} = 13 \times 10^3 \text{ kW}$$

Number of working hours during the year = 2500 hour

(i)
$$\text{Annual load factor} = \frac{11\times10^6}{13\times10^3\times(24\times365)} = 9.66\%$$

(ii)
$$\text{Plant use factor} = \frac{13\times10^3}{30\times10^3} = 43.33\%$$

(iii)
$$\text{Capacity factor} = \frac{11\times10^6}{30\times10^3\times2500} = 14.67\%$$

Q.6 (a) Solution:

1. Active earth pressure coefficient, k_a

- **For upper layer**

$$k_{a1} = \frac{\cos\beta - \sqrt{\cos^2\beta - \cos^2\phi_1}}{\cos\beta + \sqrt{\cos^2\beta - \cos^2\phi_1}}$$

$$= \frac{\cos 20° - \sqrt{\cos^2 20° - \cos^2 30°}}{\cos 20° + \sqrt{\cos^2 20° - \cos^2 30°}} = 0.44$$

For lower layer

$$k_{a2} = \frac{1-\sin\phi_2}{1+\sin\phi_2} = \frac{1-\sin 35°}{1+\sin 35°} = 0.27$$

2. Active pressure on wall

- **Top layer AB**

Active earth pressure, $p_{a1} = k_{a1}\gamma_z$

At point A(z = 0), $p_{a1} = 0$

At point B(z = 3m), $p_{a1} = 0.44 \times 16 \times 3$

$= 21.12 \text{ kN/m}^2$

Thrust contribution, $P_{a1} = \frac{1}{2} \times 21.12 \times 3 = 31.68 \text{ kN/m}$

Line of action of P_{a1} $\bar{H}_1 = \frac{3}{3} + 3 = 4 \text{ m}$ from base at an angle β i.e. 20° with the horizontal.

It is to be noted that P_{a1}, will have a horizontal component of 31.68 cos 20° i.e. 29.77 kN/m and a vertical component of 31.68 sin 20° i.e. 10.84 kN/m.

- **Lower soil layer BC**

1. Effect of uniform surcharge, *q* due to top layer

$q = \gamma H_1 = 16 \times 3 = 48 \text{ kN/m}^2$

Active earth pressure, $p_{a2} = k_{a2} \times q$

$= 0.27 \times 48 = 12.96 \text{ kN/m}^2$ (constant)

Thrust contribution, $P_{a2} = 12.96 \times 3 = 38.88 \text{ kN/m}$

Line of action of P_{a2}, $\bar{H}_2 = \frac{3}{2} = 1.5 \text{ m}$ from base.

2. Effect of soil grains

Active earth pressure, $p_{a3} = k_{a2}\gamma_{sub}z$

At point B(z = 0), $p_{a3} = 0$

At point C(z = 3 m), $p_{a3} = 0.27 \times (19 - 9.81) \times 3$

$= 7.44 \text{ kN/m}^2$

Thrust contribution, $P_{a3} = \frac{1}{2} \times 7.44 \times 3 = 11.20 \text{ kN/m}$

Line of action of P_{a3} $\bar{H}_3 = \frac{3}{3} = 1$ m from base

3. Effect of pore water

Active earth pressure, $p_{a4} = \gamma_w Z$

At point B ($z = 0$), $p_{a4} = 0$

At point C ($z = 3$ m), $p_{a4} = 9.81 \times 3 = 29.43$ kN/m²

Thrust contribution, $P_{a4} = \frac{1}{2} \times 29.43 \times 3 = 44.145$ kN/m

Line of action of Pa_4, $\bar{H}_4 = \frac{3}{3} = 1$ m from base.

(i) Total active thrust per unit length of wall,

$$P_a = P_{a1}\cos\beta + P_{a2} + P_{a3} + P_{a4}$$
$$= 29.77 + 38.88 + 11.2 + 44.145$$
$$= 123.995 \text{ kN/m}$$

(ii) Line of action of total thrust,

$$\bar{H} = \frac{\sum P_{ai}\bar{H}_i}{\sum P_{ai}} = \frac{29.77 \times 4 + 38.88 \times 1.5 + 11.20 \times 1 + 44.145 \times 1}{123.995}$$
$$= 1.88 \text{ m from base}$$

Q.6 (b) Solution:

Case-I: When the construction is carried without delay.

1. For heavy commercial vehicles

Initial traffic, $P_1' = 1000$ on 31.03.2018 in each direction.

As per IRC, undivided road with two lane single carriage way, heavy vehicles along both the directions is considered.

So, Initial traffic, $P_1 = 2 \times 1000 = 2000$ cpvd

Period of construction $x_1 = 2$ years

So,traffic after construction $A_1 = P_1(1 + r_1)x_1$

where r_1 is rate of growth i.e. 10%

So, $$A_1 = 2000\left(1 + \frac{10}{100}\right)^2 = 2420 \text{ cvpd}$$

Now, lane distribution factor $D_1 = 0.75$

Vehicle damage factor, $F_1 = 1.8$

Design life, $n_1 = 10$ years

Now, Design traffic (in msa) $= \dfrac{365 \times A_1 \times \left[(1+r_1)^{n_1} - 1\right] \times D_1 \times F_1}{r_1 \times 10^6}$

$$= \frac{365 \times 2420 \times \left[(1+0.1)^{10} - 1\right] \times 0.75 \times 1.8}{0.1 \times 10^6}$$

$= 19$ msa

2. Buses

Initial traffic, P_2 $= 2 \times 800 = 1600$ vpd

Traffic after construction, $A_2 = P_2(1+r_2)^{x_2}$

$$= 1600\left(1+\frac{8}{100}\right)^2$$

$= 1866.24$ cvpd

Vehicle damage factor, $F_2 = 2$

Lane distribution factor, $D_2 = 0.75$

Design life, $n_2 = 10$ years

Now, Design traffic in msa $= \dfrac{365 \times A_2 \times \left[(1+r_2)^{n_2} - 1\right] \times D_2 \times F_2}{r_2 \times 10^6}$

$$= \frac{365 \times 1866.24 \times \left[(1+0.08)^{10} - 1\right] \times 0.75 \times 2}{0.08 \times 10^6}$$

$= 14.8$ msa

Now, Total design traffic $= (19 + 14.8)$ msa

$= 33.8$ msa

Case-II:

When there is delay in construction i.e. construction started from 01.04.2023 and ended on 1.04.2025.

1. **For heavy commercial vehicles**

Now, traffic after construction,

$$A_1' = P_1'(1+r_1)^{x_1'}$$

where, x'_1 = 7 years

It is to be noted that for four lane dual carriageway, vehicles in each direction is considered.

So, $A'_1 = 1000\left(1+\frac{10}{100}\right)^7 = 1948.72$ cvpd

$$\text{Design traffic in msa} = \frac{365 \times A'_1 \times \left[(1+r_1)^{n'} - 1\right] \times D_1 \times F_1}{r_1 \times 10^6}$$

where n' is new design life.

$$= \frac{365 \times 1948.72 \times \left[(1+0.1)^{n'} - 1\right] \times 0.45 \times 1.8}{0.1 \times 10^6}$$

2. For buses

Traffic after construction, $A'_2 = P'_2(1+r_2)^{x'_2}$

$= 800(1+0.08)^7$

$= 1371.06$ cvpd

$$\text{Design traffic in msa} = \frac{365 \times A'_2 \times \left[(1+r_2)^{n'} - 1\right] \times D_2 \times F_2}{r_2 \times 10^6}$$

$$= \frac{365 \times 1371.06 \times \left[(1+0.08)^{n'} - 1\right] \times 0.45 \times 2}{0.08 \times 10^6}$$

Now, the design traffic for both the cases will be same

$$\therefore \quad 33.8 = \frac{365 \times 1948.72 \times \left(1.1^{n'} - 1\right) \times 0.45 \times 1.8}{0.1 \times 10^6} + \frac{365 \times 1371.06 \times \left(1.08^{n'} - 1\right) \times 0.45 \times 2}{0.08 \times 10^6}$$

$n' = 15.86$ years

Q.6 (c) Solution:

Field capacity, FC = 19%

Permanent wilting point, PWP = 8%

So, available moisture = FC – PWP

= 19 – 8 = 11%

Now, ,moisture content at which irrigation must start

$$MC_1 = \text{PWP} + \frac{1}{3} \times \text{Available moisture}$$

$$= 8 + \frac{1}{3} \times 11 = 11.67\%$$

Now, water required, d_w to increase moisture content from MC_1 to FC is given as

$$d_w = \frac{\gamma_d}{\gamma_w} \times d \times (FC - MC_1)$$

$$= 1.35 \times 1.3 \times (0.19 - 0.1167)$$

$$= 0.1286 \text{ m} = 12.86 \text{ cm}$$

1. **From 1st Nov. to 4th Jan when there is no rainfall.**

   Water content on Ist November = 19% [∵ Given]

   Water consumed from Ist November to 4th January

   $$= 1.2 \times 30 + 1.8 \times 31 + 2.4 \times 4$$

   $$= 101.4 \text{ mm} = 10.14 \text{ cm} < 12.86 \text{ cm}$$

   Hence, no irrigation is required in this duration.

2. **From 5th January to 19th January during the period of rainfall**

   Total rainfall = 20 mm = 2 cm

   Water depletion upto 19 January = 10.14 + 0.24 × 15 – Total rainfall

   $$= 10.14 + 3.6 - 2$$

   $$= 11.74 \text{ cm} < 12.86 \text{ cm}$$

   So, no irrigation is required upto 19th January.

   Now, water left in soil before irrigation

   $$= (12.86 - 11.74) \text{ cm}$$

   $$= 1.12 \text{ cm}$$

   Let, it will be consumed in 'x' days.

   Now, $$x = \frac{1.12}{0.24} = 4.67 \simeq 4 \text{ days} \quad \text{(say)}$$

   So, after 4 days from 19th January, i.e. on 24th, 25th and 26th January i.e. 3 days (given), irrigation will be done.

   Now, water required for irrigation = 11.74 + 4 × 0.24 + 0.24 × 3 (compensate for depletion in 3 days.)

   $$= 13.42 \text{ cm}$$

3. From 26th January to 25th March

$$\text{Water depleted} = 0.24 \times 6 + 0.3 \times 28 + 0.32 \times 25$$
$$= 17.84 \text{ cm} > 12.86 \text{ cm}$$

Hence, another water is required after x days of 28 Feb

where
$$x = \frac{12.86 - (0.24 \times 6 + 0.3 \times 28)}{0.32}$$
$$= 9.4375 \text{ days}$$
$$\simeq 9 \text{ days}$$

Hence, 2nd irrigation should start from 10th March.

Now, $$\text{Irrigation depth} = 16.4 - 12.86$$
$$= 3.54 \text{ cm}$$

Q.7 (a) Solution:

1. Plate load test on subgrade or single layer

$\Delta_1 = 0.5$ cm, $p = 1.2$ kg/cm^2, $a = 15$ cm, $F_2 = 1$ [for single layer]

Now,
$$\Delta_1 = \frac{1.18pa}{E_s} \times F_2$$

Where E_s is modulus of elasticity of subgrade

$$\Rightarrow \quad 0.5 = \frac{1.18 \times 1.2 \times 15 \times 1}{E_s}$$
$$\Rightarrow \quad E_s = 42.48 \text{ kg/cm}^2$$

2. Plate load test on base course of thickness 45 cm

$\Delta_1 = 0.5$ cm, $p' = 8.5$ kg/cm^2, $a = 15$ cm, $h = 45$, $E_s = 42.48$ kg/cm^2

Now,
$$\Delta_1 = \frac{1.18 \times 8.5 \times p'a}{E_s} \times F_2$$
$$\Rightarrow \quad 0.5 = \frac{1.18 \times 8.5 \times 15}{42.48} \times F_2$$
$$\Rightarrow \quad F_2 = 0.14$$

Now, from the chart given,

For
$$\frac{h}{a} = \frac{45}{15} = 3$$

and
$$F_2 = 0.14$$
$$\frac{E_b}{E_s} = 50$$

3. Design wheel load

$$P = 5000 \text{ kg}, \; p_2 = 7 \text{ kg/cm}^2$$

Now, radius of circular load,

$$a_2 = \sqrt{\frac{P}{p\pi}}$$

$$= \sqrt{\frac{5000}{7\pi}} = 15.08 \text{ cm}$$

$$E_s = 42.48 \text{ kg/cm}^2, \; \Delta = 0.5$$

Now,
$$\Delta = \frac{1.5 paF_2}{E_s}$$

$$\Rightarrow \quad 0.5 = \frac{1.5 \times 7 \times 15.08 \times F_2}{42.48}$$

$$\Rightarrow \quad F_2 = 0.134$$

From the chart given,

For
$$\frac{E_b}{E_s} = 50 \text{ and } F_2 = 0.134$$

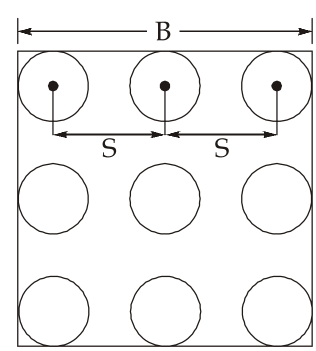
$$\frac{\text{Pavement thickness}}{\text{Radius of wheel load}} = 2.5$$

$$\Rightarrow \quad \text{Pavement thickness} = 2.5 \times 15.08$$

$$= 37.7 \text{ cm}$$

Q.7 (b) Solution:

(i) When water table is at ground level:



Pile diameter, D = 250 mm

C/C spacing of piles, S = 500 mm

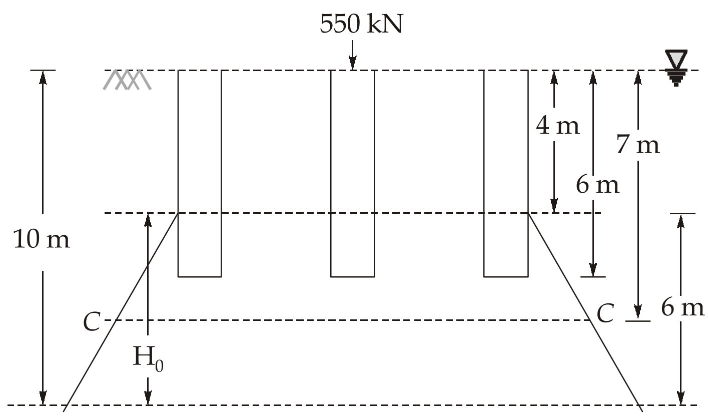
Length of piles, L = 6 m

Side of pile group, B = 2S + D

= 2 × 500 + 250

= 1250 mm

= 1.25 m



Load on piles, P = 550 kN

Depth of top point of compressible layer from ground level

$$= \frac{2}{3} \times 6 = 4 \text{ m}$$

Height of compressible layer, $H_0 = 10 - 4 = 6$ m

Depth of centre of compressible layer C-C, from ground level

$$= 4 + \frac{6}{2} = 7 \text{ m}$$

Effective stress at C-C, $\overline{\sigma_0}$ = $\gamma_{sub} \times 7 = (21 - 9.81) \times 7$

$$= 78.33 \text{ kN/m}^2$$

Increase in stress at C-C due to load

$$\Delta\overline{\sigma} = \frac{550}{\left(1.25 + \frac{3 \times 2}{2}\right)^2}$$

$$= 30.45 \text{ kN/m}^2$$

So,final effective stress at C-C, $\overline{\sigma_1} = 78.33 + 30.45$

$$= 108.78 \text{ kN/m}^2$$

Now, void ratio effective stress relation is given as

$$e = 1.45 - 0.5 \log p$$

$\Rightarrow$ $$e_0 = 1.45 - 0.5 \log \overline{\sigma_0} \quad \text{...(i)}$$

And, $$e_1 = 1.45 - 0.5 \log \overline{\sigma_1} \quad \text{...(ii)}$$

Now, compression index, $C_C = \dfrac{e_0 - e_1}{\log\left(\dfrac{\overline{\sigma_1}}{\overline{\sigma_0}}\right)}$ ...(iii)

Subtracting (ii) from (i)

$$e_0 - e_1 = 0.5 \log \overline{\sigma_1} - 0.5 \log \overline{\sigma_0}$$

$$\Rightarrow \quad \frac{e_0 - e_1}{\log\left(\dfrac{\overline{\sigma_1}}{\sigma_0}\right)} = 0.5$$

$$\Rightarrow \quad C_C = 0.5$$

Also, Initial void ratio, $e_0 = 1.45 - 0.5 \log \overline{\sigma_0}$

$$= 1.45 - 0.5 \log 78.33 = 0.5$$

Now, settlement is given as

$$S = \frac{C_C H_0}{1 + e_0} \log\left(\frac{\overline{\sigma_1}}{\overline{\sigma_0}}\right)$$

$$= \frac{0.5 \times 6}{1 + 0.5} \log\left(\frac{108.78}{78.33}\right) = 0.2852 \text{ m} = 285.2 \text{ mm}$$

(ii)

Now, effective pressure at C-C,

$$\overline{\sigma_0} = \gamma_{sat} \times 7 = 21 \times 7 = 147 \text{ kN/m}^2$$

Increase in pressure due to load,

$$\Delta\overline{\sigma} = 30.45 \text{ kN/m}^2$$

$$C_C = 0.5$$

$$e_0 = 1.45 - 0.5 \log \overline{\sigma_0} = 1.45 - 0.5 \log 147 = 0.366$$

$$\text{Settlement, } S = \frac{H_0 C_C}{1 + e_0} \log_{10}\left(\frac{\overline{\sigma_1}}{\overline{\sigma_0}}\right)$$

$$= \frac{6 \times 0.5}{1 + 0.366} \log_{10}\left(\frac{147 + 30.45}{147}\right)$$

$$= 0.1796 \text{ m} = 179.6 \text{ mm}$$

Q.7 (c) Solution:

(i)

1.

Water content	6.1	8.2	9.9	11.6	12.3	13.3
Bulk unit weight (kN/m^3)	16.9	18.6	19.6	20.4	20.2	19.9
Dry unit weight, $\gamma_d = \frac{\gamma}{1+w}$	15.93	17.19	17.83	18.28	17.99	17.56

From the above table,

Maximum dry unit weight, $\gamma_{d\,(max)}$ = 18.28 kN/m^3

Optimum moisture content, OMC = 11.6%

2. At 95% compaction

$$\text{Dry density, } \gamma_d = 0.95 \times \gamma_{dmax}$$
$$= 0.95 \times 18.28$$
$$= 17.366 \text{ kN/m}^3$$

From the table, water content can be found as

$$w = 8.2 + \frac{9.9-8.2}{17.83-17.19} \times (17.36 - 17.19)$$
$$= 8.65\%$$

3. $$\gamma_{d(max)} = \frac{G\gamma_w}{1+\frac{Gw}{S}}$$ where S is degree of saturation

$$\Rightarrow \quad 18.28 = \frac{2.7 \times 9.81}{1+\frac{2.7 \times 0.116}{S}}$$

$$\Rightarrow \quad S = 69.76\%$$

4. 10% air void lines

Now, $$\gamma_d = \frac{(1-\eta_a)G\gamma_w}{1+Gw} = \frac{(1-0.1)\times 2.7 \times 9.81}{1+2.7w}$$
$$= \frac{23.84}{1+2.7w}$$

Water content	6.1	8.2	9.9	11.6	12.3	13.3
Dry unit weight $\gamma_d = \frac{23.84}{1+2.7w}$	20.47	19.52	18.81	18.15	17.9	17.54

(ii)

Sight distance: The safe and efficient operation of vehicle on roads depends, among other factors, on the road length at which an obstruction, if any, becomes visible to the driver in the direction of travel. In other words the feasibility to see ahead, i.e. adequate visibility is very important for safe vehicle operation on a highway.

Sight distance available from a point is the actual distance along the road surface, which a driver from a specified height above the carriageway can see stationary or moving objects. In other words, sight distance is the length of road visible ahead to the driver at any instance.

Restrictions to sight distance may be caused at horizontal curves, by objects obstructing vision at the inner side of the road or at vertical summit curves or at intersections.

Sight distance required by drivers applies to both geometric design of highways and for traffic control.

Significance of sight distances:

1. **Stopping sight distance:** It is the required minimum sight distance that has to be provided, in order to avoid collision with any other obstruction at design speed. It is a very important requirement for safety of passenger.
2. **Overtaking sight distance:** In circumstances when vehicles are moving slower than design speed, for fast moving vehicle, it is the minimum sight distance that need to be provided for safety against traffic coming from opposite direction during overtaking.
3. **Intermediate sight distance:** It is the sight distance which is provided when overtaking sight distance can not be provided. It is twice the stopping sight distance.

Q.8 (a) Solution:

(i)

Ballast performs the following functions:

1. It transfers the load from the sleeper to the subgrade soil and then distributes it uniformly over a large area of the formation.
2. It holds the sleeper in position and prevents the lateral and longitudinal movement due to dynamic loads.
3. It imparts some degree of elasticity to the track.

4. It provides easy means of maintaining the correct levels of the two lines of the track and for correcting track alignment.
5. It provides good drained foundation immediately below the sleepers and helps to protect the top surface of the foundation.

Requirements of good ballast: To perform the above mentioned functions, the ballast should have the following characteristics:

- It should be able to withstand high stresses without disintegrating. In other words, it should resist crushing under dynamic loads.
- It should allow for easy drainage with minimum soakage and the voids should be large enough to prevent capillary action.
- It should offer resistance to abrasion and weathering.
- It should not make the track dusty or muddy due to powder formation under dynamic wheel loads.
- It should retain its position laterally and longitudinally under all conditions of traffic.
- It should not produce any chemical action with rail and sleepers.

(ii) Given,

Water content, $w = 25\%$

Specific gravity of soil solids, $G_s = 2.65$

Specific gravity of gasoline, $G_g = 0.9$

Given, Volume of gasoline, $V_g = 0.22\ V_w$

where V_w is volume of water.

Now, $V_g + V_w = 0.76\ V_V$

Where V_V is volume of voids

$$\Rightarrow \quad 0.22\ V_W + V_W = 0.76\ V_V$$

$$\Rightarrow \quad V_W = \frac{0.76 V_V}{1.22} = 0.62 V_V$$

Now, $$\text{Water content, } w = \frac{\text{Weight of water}\,(W_w)}{\text{Weight of solids}\,(W_s)}$$

$$\Rightarrow \quad 0.25 = \frac{\text{Volume of water} \times \text{Density of water}}{W_s}$$

$$\Rightarrow \quad W_S = \frac{0.62V_V \times 10}{0.25} = 24.8V_V$$

Volume of solids, $$V_S = \frac{W_s}{G_s \gamma_w}$$

where G_S is specific gravity of soil solids

$$\Rightarrow \quad V_S = \frac{24.8V_V}{2.65 \times 10} = 0.936\,V_V$$

Now, Void ratio, $$e = \frac{V_V}{V_S} = \frac{V_V}{0.936V_V} = 1.068$$

Bulk density, $$\gamma_b = \frac{W_s + W_g + W_{water}}{V_{total}}$$

where W_g is mass of gasoline and V_{total} is volume of soil

Now,
$$W_g = V_g\,\gamma_g$$
$$= 0.22 \times 0.62\ V_V \times 0.9 \times 10$$
$$= 1.23\ V_V$$
$$V_{total} = V_V + V_S$$
$$= V_V + 0.935\ V_V = 1.935\ V_V$$
$$W_W = V_W\,\gamma_w$$
$$= 0.62\ V_V \times 10 = 6.2\ V_V$$

So, $$\gamma_b = \frac{24.8V_V + 1.23V_V + 6.2V_V}{1.935V_V} = 16.66\ \text{kN/m}^3$$

Q.8 (b) Solution:

The effective rainfall hydrograph is obtained below.

Interval	Ist 4 hours	IInd 4 hours
Rainfall depth (cm)	4 cm	3 cm
Loss @ 0.25 cm/hr for 4 hr	1 cm	1 cm
Effective rainfall (cm)	3 cm	2 cm

Let the ordinates of unit hydrograph be U_i

Now, flood hydrograph is given from which DRH of 5 cm can be obtained by subtracting base flow (10 m^3/s) from its ordinates. Now unit hydrograph ordinates are multiplied by 3 and then these ordinates are multiplied by 2 lagged by 4 hours and then these two are added and equated to DRH of 5 cm.

Time (hr) (1)	Ordinates 4 hr UH (m^3/s) (2)	Ordinates of 3 cm DRH (col. 2) × 3 (3)	Ordinates of 2 cm DRH (col. 2 lagged by 4 hr) × 2 (4)	Flood hydrograph (m^3/s) (5)	Ordinates of 5 cm DRH (Col. 5-10) (6)
0	U_0	$3U_0$	–	0	0
4	U_1	$3U_1$	$2U_0$	70	60
8	U_2	$3U_2$	$2U_1$	290	280
12	U_3	$3U_3$	$2U_2$	560	550
16	U_4	$3U_4$	$2U_3$	720	710
20	U_5	$3U_5$	$2U_4$	700	690
24	U_6	$3U_6$	$2U_5$	540	530
28	U_7	$3U_7$	$2U_6$	346	336
32	U_8	$3U_8$	$2U_7$	195	185
36	U_9	$3U_9$	$2U_8$	109	99
40	U_{10}	$3U_{10}$	$2U_9$	55	45
44	U_{11}	$3U_{11}$	$2U_{10}$	20	10
48			$2U_{11}$	0	0

Now, Col (3) + (Col (4) = Col (6)

- $3U_0 + 0 = 0$

$\Rightarrow$ $U_0 = 0$

- $3U_1 + 2U_0 = 60$

$\Rightarrow$ $U_1 = 20\ m^3/s$

- $3U_2 + 2U_1 = 280$

$\Rightarrow$ $U_2 = 80\ m^3/s$

- $3U_3 + 2U_2 = 550$

$\Rightarrow$ $U_3 = 130\ m^3/s$

- $3U_4 + 2U_3 = 710$

$\Rightarrow$ $U_4 = 150\ m^3/s$

- $3U_5 + 2U_4 = 690$

$\Rightarrow$ $U_5 = 130\ m^3/s$

- $3U_6 + 2U_5 = 530$

$\Rightarrow$ $U_6 = 90\ m^3/s$

- $3U_7 + 2U_6 = 336$

$\Rightarrow$ $U_7 = 52\ m^3/s$

- $3U_8 + 2U_7 = 185$

$\Rightarrow$ $U_8 = 27\ m^3/s$

- $3U_9 + 2U_8 = 99$

$\Rightarrow$ $U_9 = 15\ m^3/s$

- $3U_{10} + 2U_9 = 45$

$\Rightarrow$ $U_{10} = 5\ m^3/s$

- $3U_{11} + 2U_{10} = 10$

$\Rightarrow$ $U_{11} = 0$

So, the 4 hr UH can be tabulated below:

Time (hr)	0	4	8	12	16	20	24	28	32	36	40	44
Discharge (m^3/s)	0	20	80	130	150	130	90	52	27	15	5	0

Q.8 (c) Solution:

(i)

Flow nets can be used to obtain solution of many seepage problems such as:

- Estimation of seepage losses from reservoirs.
- Determination of uplift pressures below dam.
- Checking the possibility of piping beneath dams.

Limitations of flow nets:

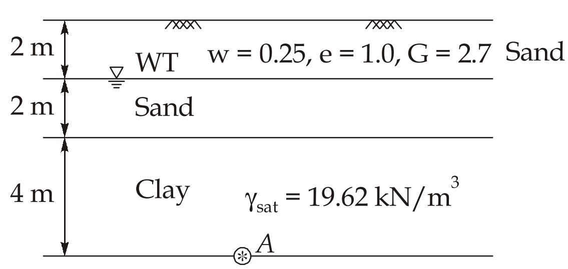
- It is implied that Darcy's law is valid, which may not be true everywhere.
- Soil is assumed to be homogeneous, which is not always true.
- Volume of soil may change during flow.

Approximate methods to draw flow net:

- Finite elements method
- Method of relaxation
- Stochastic method
- Point estimate method
- Finite differences method
- Electrical analogy method
- Analytical methods
- Graphical method

(ii)

1.



Unit weight of the partially saturated sand above the water table.

$$\gamma_{t\ (sand)} = \left(\frac{G_s + Se}{1+e}\right)\gamma_w = \frac{G_s(1+w)\gamma_w}{1+e}$$

$$= \frac{2.70(1+0.25)\times 9.81}{1+1} = 16.55\ \text{kN/m}^3$$

Unit weight of saturated sand,

$$\gamma_{sat\ (sand)} = \left(\frac{G_s + e}{1+e}\right)\gamma_w = \left(\frac{2.7+1}{1+1}\right)\times 9.81 = 18.15\ \text{kN/m}^3$$

Given, $\gamma_{sat\ (clay)} = 19.62\ kN/m^2$

At point A;

Total stress, $\sigma = \gamma_{t\ (sand)} \times 2 + \gamma_{sat\ (sand)} \times 2 + \gamma_{sat\ (clay)} \times 4$

$= 16.55 \times 2 + 18.15 \times 2 + 19.62 \times 4$

$= 147.88\ kN/m^2$

Effective stress, $\bar{\sigma} = \sigma - u$

$u = 10 \times 6 = 60\ kN/m^2$

$\therefore \quad \bar{\sigma} = 147.88 - 60 = 87.88\ kN/m^2$

2. If the ground water table rises upto ground surface, the soil mass changes its state from partially saturated to submerged state.

At point *A*;

Total stress, $\sigma = \gamma_{sat\ (sand)} \times 4 + \gamma_{sat\ (clay)} \times 4$

$= 18.15 \times 4 + 19.62 \times 4$

$= 151.08\ kN/m^2$

Neutral stress, $u = 8 \times 10 = 80\ kN/m^2$

Effective stress, $\bar{\sigma} = 151.08 - 80 = 71.08\ kN/m^2$

3. A rise in free water level above the ground surface by 2 m would result in increase in total stress at any every location by $2\gamma_w = 20\ kN/m^2$.

Similarly, the pore water pressure would also increase at every location by same magnitude i.e., $20\ kN/m^2$. Thus, effective stress distribution will remain the same.

At point 'A'

$\therefore \quad \bar{\sigma} = 71.08\ kN/m^2$

Any fluctuation in the level of free water above the ground surface would not result in any change in effective stress at any depth within the soil deposit.

■■■■