ESE 2025

Main Exam Detailed Solutions

Civil Engineering

PAPER-II

EXAM DATE : 10-08-2025 | 02:00 PM to 05:00 PM

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ANALYSIS

Civil Engineering Paper-II
ESE 2025 Main Examination

Sl.	Subjects	Marks
1.	Fluid Mechanics & Hydraulic Machines	82
2.	Engineering Hydrology	12
3.	Water Resource Engineering	32
4.	Environmental Engineering	114
5.	Soil Mechanics & Foundation Engg.	114
6.	Surveying and Geology	52
7.	Transportation Engineering	74
		Total 480

Scroll down for detailed solutions

SECTION : A

Q.1 (a) A 30 cm diameter well completely penetrates a confined aquifer of permeability 60 m/day. Under steady state of pumping, the drawdown at the well was observed to be 4.5 m and the discharge was 2100 *l*pm for a radius of influence of 450 m.

If someone says "double the diameter of the well to 60 cm to get double discharge", will it be correct?

Compute the discharge for 60 cm diameter well and the percentage increase in the discharge. All other data remains the same.

[12 marks : 2025]

Solution:

Given:

Diameter of well, $D_{w_1} = 30\text{ cm},\ R_{w_1} = 15\text{ cm}$

Coefficient of permeability $K = 60\text{ m/day}$

Drawdown, $S = (H - h) = 4.5\text{ m}$

Discharge $Q_1 = 2100\ l/\text{min} = 2100 \times 10^{-3} \times 60 \times 24 = 3024\text{ m}^3/\text{day}$

Radius of influence, $R = 450\text{ m}$

$$D_{w_2} = 60\text{ cm},\ R_{w_2} = 30\text{ cm}$$

Discharge from confined aquifer is given by

$$Q = \frac{2\pi KB(H-h)}{\log_e\left(\frac{R}{R_w}\right)} = \frac{2\pi TS}{\log_e\left(\frac{R}{R_{w_1}}\right)}$$

Where, $T = kB$ = Coefficient of transmissibility

$$\therefore \quad Q_1 = \frac{2\pi TS}{\log_e\left(\frac{R}{R_{w_1}}\right)}$$

$$\Rightarrow \quad 3024 = \frac{2\pi T \times 4.5}{\log_e\left(\frac{450}{0.15}\right)}$$

$$\Rightarrow \quad T = 856.298\text{ m}^2/\text{day}$$

Now, double the diameter of the well, i.e. $R_{w_2} = 30\text{ cm}$

$$\therefore \quad Q_2 = \frac{2\pi TS}{\log_e\left(\frac{R}{R_{w_2}}\right)}$$

$$\Rightarrow \quad Q_2 = \frac{2 \times \pi \times 856.298 \times 4.5}{\log_e\left(\frac{450}{0.30}\right)} = 3310.6\text{ m}^3/\text{day}$$

$$\therefore \quad Q_2 \neq 2\,Q_1$$

If diameter of well gets doubled, discharge won't be doubled.

Percentage increase in discharge

$$= \left(\frac{Q_2 - Q_1}{Q_1}\right) \times 100$$

$$= \left(\frac{3310.6 - 3024}{3024}\right) \times 100 = 9.47\%$$

If diameter of well gets double, then the discharge increased by 9.47%.

End of Solution

Q.1 (b) Describe briefly (1-2 sentences each) with sketch the following hydroelectric power plants:

(i) Run-of-River plant

(ii) Valley Dam plant

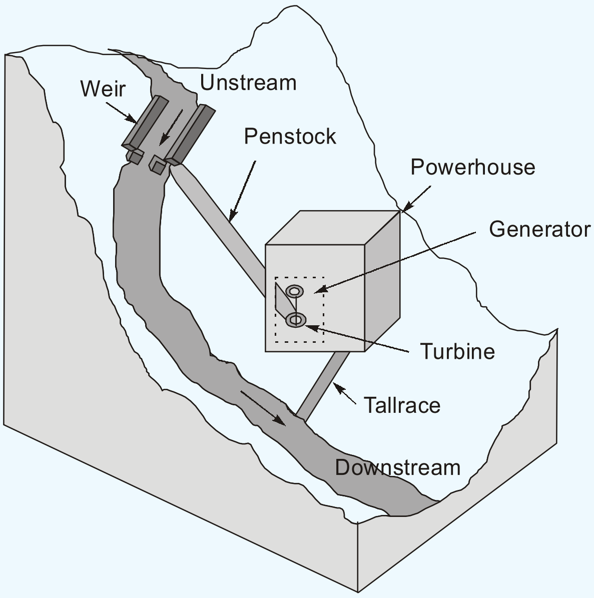
(iii) Diversion Canal plant

(iv) High head diversion plant

[12 marks : 2025]

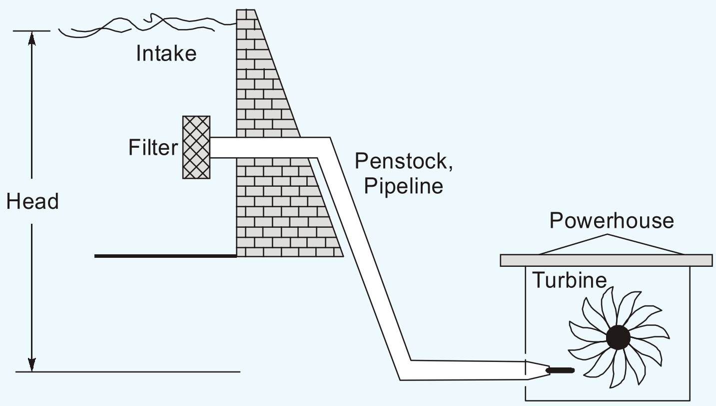
Solution:

i. Run-of-river plant: These plants utilize the natural flow of a river without significantly altering its course. It uses elevation drop of a river with little or no water storage.

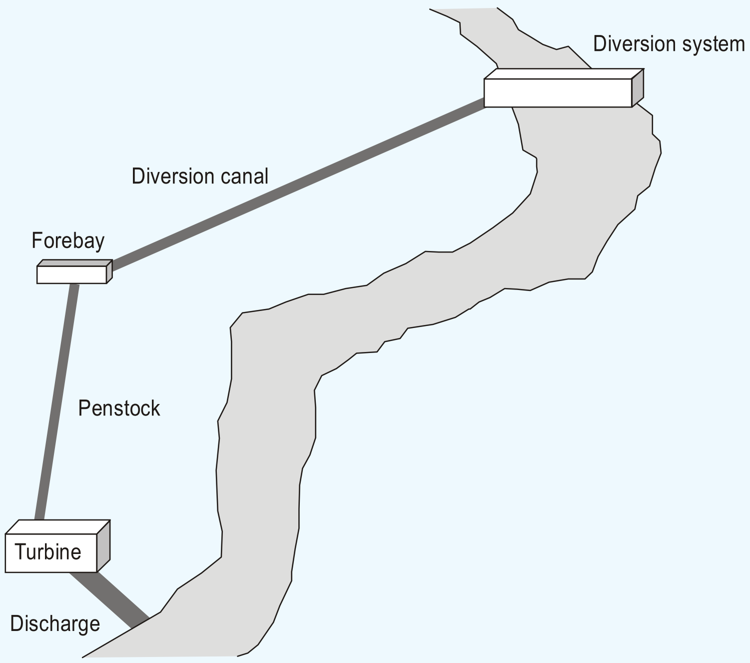


ii. Valley dam plant: It utilizes a dam built in a vally to create a large reservoir, storing water for controlled releases to generate power.

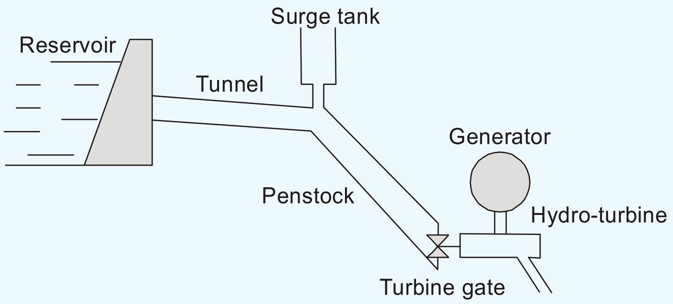
Water when released, reaches the powerhouse at lower level and rotates the turbine.



iii. **Diversion canal plant:** This plant diverts part of a river's flow through a canal to a powerhouse, usually with minimal storage, making use of a drop in elevation from canal to downstream river.



iv. **High head diversion plant:** It uses terrain where water is diverted from a high elevation to a low level powerhouse through long penstocks, producing high pressure flow.



End of Solution

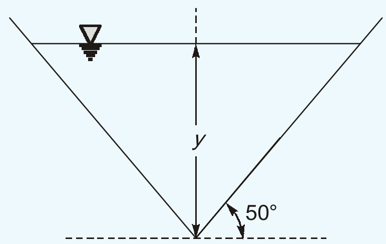
Q.1 (c) Consider a 50° triangular channel having a flow rate Q = 16m^3/s and n = 0.018
Compute

(i) the critical depth

(ii) critical velocity, and

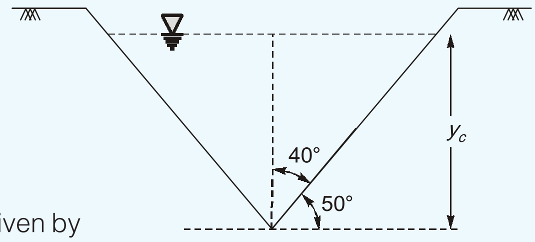
(iii) critical slope

Take α = 1.0 and g = 9.81m/s^2



[12 marks : 2025]

Solution:



Given:

Discharge, $Q = 16\ \text{m}^3/\text{sec}$

Manning's coefficient, $\eta = 0.018$

$g = 9.81\ \text{m/sec}^2$

(i) Critical depth (y_c):

For triangular channel critical depth is given by

$$y_c = \left(\frac{2Q^2}{gm^2}\right)^{1/5}$$

$$\Rightarrow \quad y_c = \left(\frac{2\times 16^2}{9.81\times \tan^2 40°}\right)^{1/5}$$

$$\Rightarrow \quad y_c = 2.366\ \text{m}$$

Now: Hydraulic depth, $D_h = \dfrac{A}{T} = \dfrac{my_c^2}{2my_c} = \dfrac{y_c}{2}$

(ii) Critical velocity (V_c)

$$V_c = \sqrt{gD_h} = \sqrt{9.81\times\frac{2.366}{2}}$$

$$\Rightarrow \quad V_c = 3.4\ \text{m/sec}$$

(iii) Critical slope (S_o)

Hydraulic radius, $R_h = \dfrac{A}{P} = \dfrac{my_c^2}{2y_c\sqrt{1+m^2}}$

$$\Rightarrow \quad R_h = \frac{\tan 40° \times 2.366}{2\sqrt{1+\tan^2 40}}$$

$$\Rightarrow \quad R_h = 0.760418\ \text{m}$$

Cross-sectional area

$$A = my_c^2 = \tan 40° \times (2.366)^2$$

$$\Rightarrow \quad A = 4.697\ \text{m}^2$$

From Manning's formula velocity is given by

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

$$a = AV$$

$$\text{Discharge, } Q = \frac{A}{n} R^{2/3} S_o^{1/2}$$

$$\Rightarrow \quad 16 = \frac{4.697}{0.018}(0.760418)^{2/3} S_o^{1/2}$$

$$\Rightarrow \quad S_o = 5.4167 \times 10^{-3}$$

Bed slope, S_o = 1 in 184.6

End of Solution

Q.1 (d) A water sample was analysed in the laboratory and the following were reported:

HCO_3^- = 300 mg/*l*; Na^+ = 115 mg/*l*; SO_4^{-2} = 240 mg/*l* Mg^{+2} = 36.6 mg/*l*;

Cl^- = 71 mg/*l*; Ca^{+2} = 100 mg/*l*,

Find the % error in cation-anion balance. Also draw a bar diagram to indicate cation-anion balance. Comment on the result of cation-anion balance error %.

[12 marks : 2025]

Solution:

Given:

HCO_3^- = 300 mg/*l*, Na^+ = 115 mg/*l*, SO_4^{-2} = 240 mg/*l*

Mg^{+2} = 36.6 mg/*l*, Cl^- = 71 mg/*l*, Ca^{+2} = 100 mg/*l*

% Error in cation-anion balance (Charge Balance Error) = ?

$$\because \text{Charge Balance Error (CBE)} = \frac{\Sigma(\text{Cations}) - \Sigma(\text{Anions})}{\Sigma(\text{Cations}) + \Sigma(\text{Anions})} \times 100$$

Where, concentration of cation and anion in meq/*l*

Now: Concentration in meq/*l*

For cations:

$$Na^+ = 115 \text{ mg}/l = \frac{115}{23} = 5 \text{ meq}/l$$

$$Mg^{+2} = 36.6 \text{ mg}/l = \frac{36.6}{12} = 3.05 \text{ meq}/l$$

$$Ca^{+2} = 100 \text{ mg}/l = \frac{100}{20} = 5 \text{ meq}/l$$

$$\Sigma(\text{Cations}) = 13.05 \text{ meq}/l$$

For anions:

$$HCO_3^- = 300 \text{ mg}/l = \frac{300}{61} = 4.918 \text{ meq}/l$$

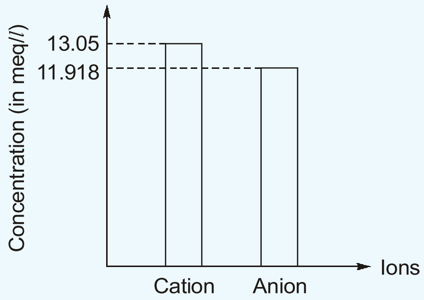
$$SO_4^{-2} = 240 \text{ mg}/l = \frac{240}{48} = 5 \text{ meq}/l$$

$$Cl^- = 71 \text{ mg}/l = \frac{71}{35.5} = 2 \text{ meq}/l$$

$$\Sigma(\text{Cations}) = 11.918 \text{ meq}/l$$

$$\% \text{ CBE} = \left(\frac{13.05 - 11.918}{13.05 + 11.918}\right) \times 100 = 4.53\% < 5\%$$

Bar Diagram



$\because$ % Error $\leq$ 5%

$\therefore$ It is usually considered adequate.

End of Solution

Q.1 (e) Data pertaining to a conventional ASP is given below:

Population of town	=	10 lakhs
Wastewater contribution	=	100 lpcd
BOD in settled sludge	=	180 mg/l
Effluent BOD required	=	30 mg/l
F/M ratio	=	0.2
MLSS concentration	=	2800 mg/l
SVI	=	100

Find the volume of aerator, Hydraulic Retention time (HRT), Volumetric loading and Return Sludge Ratio. Also comment if the parameters match with design conditions.

[12 marks : 2025]

Solution:

Given:

Population of town = 10 lakhs

Waste water contribution = 100 *lpcd*

BOD in settled sludge = 180 mg/l

Effluent BOD required = 30 mg/l

$\frac{F}{M}$ ratio = 0.2/day

MLSS concentration, X = 2800 mg/l

Sludge volume index, SVI = 100

Volume of aerator, $V = ?$

Hydraulic retention time, $Q_c = ?$

Volumetric loading rate, $VLR = ?$

Return sludge ratio, $(Q_R/Q_O) = ?$

Now, discharge, $Q = 10^6 \times 100\ l/\text{day} = 10^5\ \text{m}^3/\text{day}$

$$\because \quad \frac{F}{M} = \frac{Q \times (BOD)_o}{VX}$$

$$\Rightarrow \quad 0.2 = \frac{10^5 \times 180}{V \times 2800}$$

$$\Rightarrow \quad V = 32142.857\ \text{m}^3$$

Hydraulic retention time,

$$HRT = \frac{V}{Q} = \frac{32142.857}{10^5}\ \text{days}$$

$$= 0.3214\ \text{days} = 7.714\ \text{hours}$$

Volumetric loading rate (organic loading rate)

$$VLR = \frac{Q \times (BOD)_o}{V}$$

$$\Rightarrow \quad VLR = \frac{10^8\ l/\text{day} \times 180\text{mg}/l}{32142.857\ \text{m}^3} = \frac{100 \times 180\ \text{kg/day}}{32142.857\ \text{m}^3}$$

$$VLR = 0.56\ \text{kg/day/m}^3$$

Return sludge ratio, $$\frac{Q_R}{Q_o} = \frac{X}{X_R - X}$$

Where: $$X_R = \frac{10^6}{SVI}$$

$$\therefore \quad \frac{Q_R}{Q_o} = \frac{2800}{\frac{10^6}{100} - 2800} = 0.389$$

End of Solution

Q.2 (a) (i) In a water treatment plant which treats 10 MLD of water, it is proposed to design a circular PST and RSF. Using the data given below, find

(A) Surface area, DT (Detention Time) of the PST and diameter

(B) Horizontal velocity

(C) Surface area of RSF

(D) No. of filter units

PST surface loading	=	$50\ \text{m}^3/\text{m}^2/\text{day}$
Depth of PST	=	2.5m
Rate of filtration	=	$5000\ l/\text{m}^2/\text{hr}$
Quantity of backwash water	=	15%
Time for backwashing	=	1hr

[12 marks : 2025]

Solution:

Given: Discharge, $Q = 10$ MLD

Surface loading, $V_o = 50\ m^3/day/m^2 = 50 \times 10^3\ l/day/m^3$

Depth of PST, $H = 2.5$ m

Rate of filtration, $f_r = 5000\ l/m^2/hr$

Quantity of back wash water = 15%

Time for backwashing = 1 hr

Surface area of PST

$$A_{PST} = \frac{Q}{V_o} = \frac{10 \times 10^6}{50 \times 10^3} = 200\ m^2$$

Diameter of PST

$$\frac{\pi}{4} D^2 = 200$$

$\Rightarrow$ $D = 15.96\ m \simeq 16\ m$

Detention time for PST

$$D_t = \frac{\text{Volume}}{Q}$$

$$\Rightarrow \quad D_t = \frac{D^2(0.011\,D + 0.785\,H)}{Q}$$

$$\Rightarrow \quad D_t = \frac{16^2(0.011 \times 16 + 0.785 \times 2.5)\,m^3}{\frac{10 \times 10^3}{24}\ \frac{m^3}{hr}}$$

$\Rightarrow$ $D_t = 1.314$ hr

Horizontal velocity, $(V_t)_{horizontal} = \dfrac{V_o}{H}$

$$\Rightarrow \quad V_f = \frac{50}{2.5} = 20\ m/day$$

Now, for rapid sand filter

Discharge, $Q = 10$ MLD

Design discharge for RSF, $Q_{design} = Q + 15\%$ of Q

$= 1.15 \times 10$ MLD

$Q_{design} = 11.5$ MLD

Number of filter units, $n = 1.22\sqrt{Q_{design}}$

$\Rightarrow$ $n = 1.22\sqrt{11.5}$

$\Rightarrow$ $n = 4.137 \simeq 5$ filters

Surface area for RSF, $$A_{RSF} = \frac{Q_{Design}}{\text{Filtration rate}} = \frac{11.5 \times 10^6\ l/day}{5000 \times (24 - 1)\ l/day/m^2}$$

$\Rightarrow$ $A_{RSF} = 100\ m^2$

Surface area of single unit

$$A_1 = \frac{100\ m^2}{5} = 20\ m^2$$

Assume $\frac{L}{B} = 2$

$\therefore$ $B \times L = 20\ m^2$

$\Rightarrow$ $B \times 2B = 20$

$\Rightarrow$ $B = 3.16\ m$

$\therefore$ $L = 6.32\ m$

End of Solution

Q.2 (a) (ii) Explain the mechanisms responsible for removal of colloidal solids by coagulation.

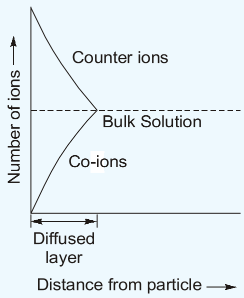
[8 marks : 2025]

Solution:

Mechanisms responsible for removal of colloidal solids by coagulation are :

1. **Ionic layer compression:** The quantity of ions present in the water surrounding a colloid has an effect on the decay function of the electrostatic potential.

   High ionic concentration compresses the layers composed predominantly of counter ions towards the surface of the colloid. If this layer is sufficiently compressed, then the Van der Waal's force will be predominant across the entire area of influence, so that the net force will be attractive and no energy barriers will exist. An example of ionic layer compression occurs in nature when a turbid stream flows in the ocean and deltas are formed from material which was originally so small that it could not have settled without coagulation.



2. **Adsorption and charge neutralization:**
   - The nature rather than quantity of the ions is of prime importance in the theory of adsorption and charge neutralization.
   - The ionisation of $Al_2(SO_4)_3$ and $FeCl_3$ in water produces SO_4^{2-} and Cl^- along with Al^{3+} and Fe^{3+}. The Al^{3+} and Fe^{3+} cations react immediately with water to form a variety of aquametallic ions and hydrogen.

     $Al^{3+} + H_2O \longrightarrow Al(OH)_3 + 3H^+$

     $Fe^{3+} + H_2O \longrightarrow Fe(OH)_3 + 3H^+$
   - The aquametallic ions thus formed become part of the ionic cloud surrounding colloid and because they have a great affinity for surfaces are adsorbed onto the surface of the colloid where they neutralize the surface charge.
   - Once the surface charge has been neutralized, the ionic cloud dissipates and the electrostatic potential disappears so that contact occurs freely.

3. Sweep coagulation

- The last product formed in the hydrolysis of alum is $Al(OH)_3$.
- The $Al(OH)_3$ forms in amorphous, gelatinous flocs that are heavier than water and settle by gravity.
- Colloids may become entrapped in a floc as it is formed, or they may become enmeshed by its sticky surface as the flocs settle.
- The process by which colloids are swept from suspension in this manner is known as sweep coagulation.

4. Interparticle bridging:

- Large molecules may be formed when aluminium or ferric salts dissociate in water.
- Synthetic polymers may also be used instead of, or in addition to, metallic salts which may be linear or branched and are highly surface reactive.
- Several colloids may become attached to one polymer and several of the polymer-colloid groups may become enmeshed resulting in a settleable mass.
- In addition to the adsorption forces, charges on the polymer may assist in the coagulation process.

End of Solution

Q.2 (b) Determine the area required for a proposed landfill for a town with population of 5 lakhs. The per capita waste generation is about 0.5 kg. It is proposed that the landfill life to be 30 years with maximum height of 20 m. Density of compacted waste is 450 kg/m³. Assume ratio of solid waste to soil cover as 4:1.

[20 marks : 2025]

Solution:

Given: Population of town = 5 lakhs

Per capita waste generated = 0.5 kg

Landfill life = 30 years

Height of fill, H = 20 m

Density of compacted waste $\rho_{compacted} = 450\ \text{kg/m}^3$

$$\frac{\text{Solid waste}}{\text{Soil cover}} = \frac{4}{1}$$

Required area for landfill = ?

Total amount of solid waste generated in 30 years is:

$$M = 5 \times 10^5 \times 0.5 \times 365 \times 30$$

$$\Rightarrow \quad M = 2.7375 \times 10^9\ \text{kg}$$

Volume of compacted solid waste

$$V_{compacted} = \frac{M}{\rho_{compacted}} = \frac{2.7375 \times 10^9\ \text{kg}}{450\ \text{kg/m}^3}$$

$$\Rightarrow \quad V_{compacted} = 6.0833 \times 10^6\ \text{m}^3$$

Required volume of land fill

$$V_{\text{land fill}} = V_{\text{compacted}} \times \frac{5}{4}$$

$$= 6.0833 \times 10^6 \times \frac{5}{4} = 7604125 \text{ m}^3$$

Area required for landfill

$$A = \frac{V_{\text{land fill}}}{\text{Depth}} = \frac{7604125}{20}$$

$\Rightarrow$ $$A = 380206.25 \text{ m}^2$$

$\Rightarrow$ $$A = 38.02 \text{ ha}$$

End of Solution

Q.2 (c) A 4.0 m wide rectangular channel has a flow of 4.80 m^3/s with a velocity of 0.8 m/s. After a heavy rainfall event in the upstream catchment, a sluice gate on the upstream is suddenly raised. This causes a surge to travel downstream and a quick increase in depth by 50%. Calculate the absolute velocity of the resulting surge and the new flow rate. Given g = 9.81 m/s^2.

[20 marks : 2025]

Solution:

Given: width of channel, $B = 4$ m

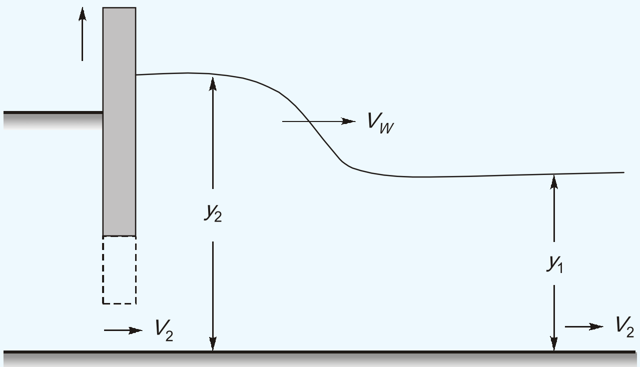
Discharge, $Q_1 = 4.8$ m^3/sec

Velocity, $V_1 = 0.8$ m/sec

$$\text{Depth of water, } y_1 = \frac{Q}{V_1 B} = \frac{4.8}{0.8 \times 4} = 1.5\text{m}$$

Depth increases by 50%

$\therefore$ $$y_2 = 1.5y_1 = 1.5 \times 1.5 = 2.25 \text{ m}$$



Celerity of surge $$C = V_1 - V_w$$

$\because$ $$V_1 - V_w = \sqrt{\frac{g}{2} \cdot \frac{y_2}{y_1}(y_1 + y_2)}$$

$\therefore$ $$C = (V_1 - V_w) = \sqrt{\frac{g}{2} \cdot \frac{y_2}{y_1}(y_1 + y_2)}$$

$$\Rightarrow \quad V_1 - V_w = \sqrt{\frac{9.81}{2} \times 1.5(1.5 + 2.25)} = 5.25$$

$$\Rightarrow \quad 0.8 - V_w = \sqrt{\frac{9.81 \times 1.5(1.5 + 2.25)}{2}}$$

$$\Rightarrow \quad V_w = -4.45 \text{ m/sec}$$

(– ve sign indicates that surge travels in opposite direction).

New discharge, $Q = A_1(V_1 - V_w) = By_1(V_1 - V_w)$

$= 4 \times 1.5 \times 5.25$

$= 31.5 \text{ m}^3\text{/sec}$

End of Solution

Q.3 (a) A dam discharges 254.7 m³/s of water over the spillway. The flow then passes over a level concrete apron (n = 0.013) The velocity of water at the bottom of the spillway is 12.8 m/s and the width of the apron is 54.86 m. The flow conditions produce a hydraulic jump, the depth in channel below the apron being 3.05 m.

(i) If the jump has to be contained in the apron, how long should the apron be built? Take g = 9.81 m/s²; ρ = 1000 kg/m³.

(ii) How much energy is lost from the foot of the spillway to the downstream side of jump?

[15 + 5 = 20 marks : 2025]

Solution:

Given: Discharge, $Q = 254.7 \text{ m}^3\text{/sec}$

$n = 0.013$

Velocity of water at bottom of the spillway,

$V_1 = 12.8 \text{ m/sec}$

Width of the apron, $B = 54.86$ m

depth in channel below the apron, $y_2 = 3.05$ m

Let, depth of water before jump = y_1

$\therefore \quad Q = AV = By_1V_1$

$\Rightarrow \quad 254.7 = 54.86 y_1 (12.8)$

$\Rightarrow \quad y_1 = 0.3627$ m

$\therefore$ Height of jump = $y_2 - y_1 = 3.05 - 0.3627$

$= 2.6873$ m

Length of apron = $6.1(y_2 - y_1)$

$= 6.1 \times 2.6873$

$= 16.39$ m

$$\text{Energy loss, } h_L = \frac{(y_2 - y_1)^3}{4y_1y_2} = \frac{(3.05 - 0.3627)^3}{4 \times 3.05 \times 0.3627} = 4.386 \text{ m}$$

End of Solution

Q.3 (b) (i) A Pelton wheel has to be designed for the following specifications:

Power to be developed	=	6000 kW
Net head available	=	300 m
Speed	=	550 RPM
Ratio of jet diameter to wheel diameter	=	1/10
Hydraulic efficiency	=	0.85
Velocity coefficient C_v	=	0.98
Speed Ratio ϕ	=	0.46
ρ	=	1000 kg/m^3
g	=	9.81 m/s^2

Determine

(A) the required discharge,

(B) diameter of the wheel,

(C) diameter of each jet, and

(D) the number of jets.

[10 marks : 2025]

Solution:

Given that,

$$H = 300 \text{ m},\ P = 6000 \text{ kW},\ N = 550 \text{ rpm},\ \frac{d_j}{d_w} = \frac{1}{10}$$

$$\eta_H = 0.85,\ C_v = 0.98,\ \phi = 0.46$$

(i) As we know

$$\text{Power developed} = \rho g Q H \times \eta_H$$

$$\Rightarrow \quad 6000 \times 1000 = 1000 \times 9.81 \times Q \times 300 \times 0.85$$

$$\Rightarrow \quad Q = 2.398 \text{ m}^3/\text{s}$$

(ii) Jet velocity, $v_1 = C_v\sqrt{2gH}$

$$\Rightarrow \quad v_1 = 0.98\sqrt{2 \times 9.81 \times 300}$$

$$\Rightarrow \quad v_1 = 75.186 \text{ m/s}$$

Speed ratio, $\phi = \dfrac{u}{v_1}$

$$\therefore \quad u = \phi \times v_1$$

$$= 0.46 \times 75.186$$

$$u = 34.586 \text{ m/s}$$

Also, $u = \dfrac{\pi d_w N}{60}$

$$\Rightarrow \quad 34.586 = \frac{\pi \times d_w \times 550}{60}$$

$$\Rightarrow \quad d_w = 1.2 \text{ m}$$

(iii) Given, $\dfrac{d_j}{d_w} = \dfrac{1}{10}$

$\therefore$ $d_j = \dfrac{d_w}{10}$

$\Rightarrow$ $d_j = \dfrac{1.2}{10} = 0.12\text{ m} = 120\text{ mm}$

(iv) $n \times \dfrac{\pi}{4} \times (d_j)^2 \times 75.186 = 2.398$

$\Rightarrow$ $n \times \dfrac{\pi}{4} \times (0.12)^2 \times 75.186 = 2.398$

$\Rightarrow$ $n = 2.82 \simeq 3$

$\therefore$ Total number of jets = 3

End of Solution

Q.3 (b) (ii) With the help of sketches, explain in one or two sentences the difference between the following cross-drainage works:

(A) Syphon aqueduct and canal syphon

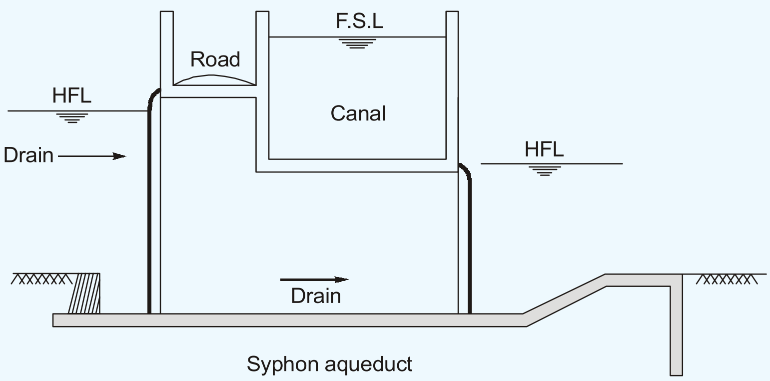
(B) Aqueduct and super passage

[10 marks : 2024]

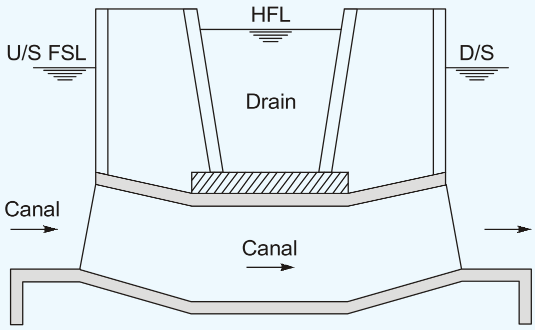
Solution:

(A) Difference between syphon aqueduct and canal syphon:

- In a syphon aqueduct, the natural drain flows under the canal under syphoning pressure and highest flood level (HFL) of drain is above the canal bed level.
- While in a canal syphon, the full supply level (FSL) of canal is above the drainage bed level and the canal flows under the natural drain under syphoning pressure.



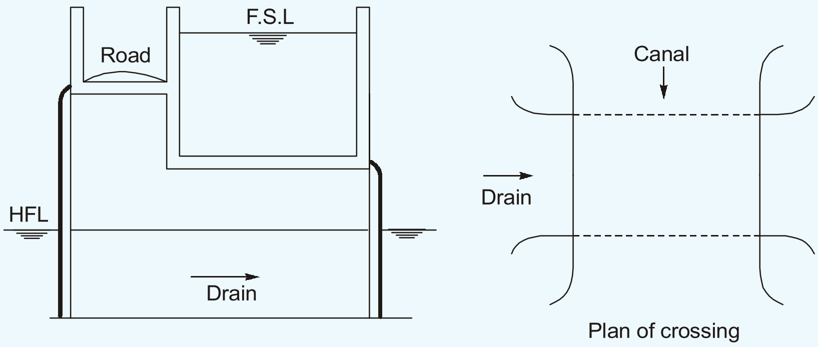
Syphon aqueduct



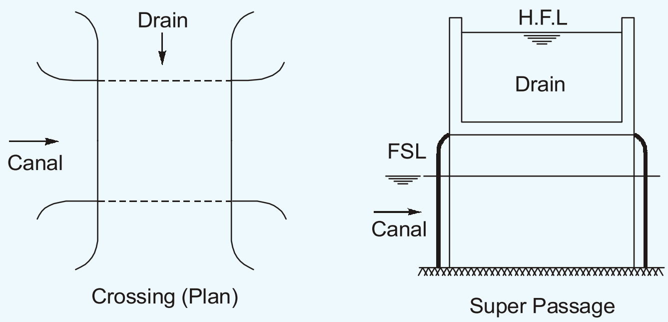
Syphon

(B) Difference between aqueduct and super passage :

- In an aqueduct, the natural drain flows under the canal freely under gravity and the highest flood level (HFL) of drain is below the canal bed level.
- In a super passage, the canal flows under the natural drain freely under gravity and the full supply level (FSL) of canal is below drainage bed level.



Aqueduct



Super passage

End of Solution

Q.3 (c) (i) An industry consumes 10,000 lit. of fuel per day for generation of steam. Based on quality of the fuel, the emission data indicates the following average emissions for 1 ML of fuel consumed per year.

SPM = 3 t/yr; SO_2 = 75 t/yr; NO_x = 12 t/yr; HC = 0.6 t/yr; CO = 0.75 t/yr.

Determine the height of the chimney required for the industry.

[10 marks : 2025]

Solution:

Given: Fuel consumption = 10000 *l*/day

$= 10000 \times 365$ *l*/year

$= 3.65 \times 10^6$ *l*/year = 3.65 M*l*/year

The emission data indicated the following average emissions for 1 M*l* of fuel SPM = 3 *t*/year, SO_2 = 75 *t*/year

$$\text{Minimum height of the chimney, } H_{min} = \max{}^m \begin{cases} 14\left(Q_{SO_2}\right)^{0.3} \\ 74\left(Q_{SPM}\right)^{0.27} \\ 30\,\text{m} \end{cases}$$

Where:

Q_{SO_2} is in kg/hr

Q_{SPM} is in t/hr

Q_{SO_2} = 75 t/year (for 1 M*l* of fuel)

$\Rightarrow$ $Q_{SO_2} = 75 \times 3.65$ t/year (for 3.65 M*l* of fuel)

$$\Rightarrow \quad Q_{SO_2} = \frac{75 \times 3.65 \times 10^3}{24 \times 365} \text{ kg/hr}$$

$\Rightarrow$ Q_{SO_2} = 31.25 kg/hr

Q_{SPM} = 3 *t*/year (for 1 M*l* of fuel)

$\Rightarrow$ $Q_{SPM} = 3 \times 3.65$ t/year (for 3.65 M*l* of fuel)

$$\Rightarrow \quad Q_{SPM} = \frac{3 \times 3.65}{24 \times 365}\ t/\text{hr}$$

$Q_{SPM} = 1.25 \times 10^{-3}$ *t*/hr

$$\text{Now,} \quad H_{min} = \max{}^m \begin{cases} 14\left(31.25\right)^{0.3} = 39.317\text{ m} \\ 74\left(1.25 \times 10^{-3}\right)^{0.27} = 12.173\text{ m} \\ 30\text{ m} \end{cases}$$

$\therefore$ $H_{min} = 39.317\text{ m} \simeq 40\text{ m}$

End of Solution

Q.3 (c) (ii) Explaining the major causes for noise pollution, discuss methods used for control of noise pollution in industries.

[10 marks : 2025]

Solution:

Noise pollution refers to unwanted or harmful sound that disturbs human health, comfort and surrounding environment. Major causes for noise pollution are:

1. **Road traffic:** Continuous honking of horns, high engine revs, use of loud silencers and movement of heavy vehicles etc all contribute to noise pollution.
2. **Railways and aircraft noise:** Train horns, whistles, and low-altitude flights produce extremely high levels of noise pollution.
3. **Construction activities:** Operation of bulldozers, jackhammers, cranes and other construction equipments during urban expansions or maintenance increase noise levels.
4. **Industries:** Processing plants, textile mills, refineries, etc. use heavy machineries and generators, producing a lot of noise.

Causes for noise pollution in industries and methods to control them:

1. Operation of heavy machineries such as large turbines, compressors, pumps, boilers produce continuous high-decibel noise. This problem can be eliminated by selecting low-noise equipments, performing regular maintenance works such as lubrication, alignment and tightening of loose parts and by installing silencers on exhausts.
2. Manufacturing processes like metal cutting, grinding and welding create both continuous and impulsive noises. Use of sound mufflers or enclosing loud equipments in soundproof cabins or booths can contain noise.
3. Noise produced due to vibration can be reduced by fitting machinery with vibration dampers, pads and mounts reducing transmission of sounds through structures.
4. Use of acoustic panels, insulation and sound-absorbing tiles on walls, ceilings and surfaces can diminish reflected noise.
5. Installation of physical barriers around the source of noise can reduce the decibels and impact on surrounding area.
6. Fans, blowers, ducts and compressed air systems create aerodynamic noises. Designing ducts to reduce turbulence and imparting aerodynamic balancing will reduce such noise.

End of Solution

Q.4 (a) Using the data given below, estimate

(i) Volume of fresh sludge produced

(ii) Unit weight of raw sludge

(iii) Volume of digested sludge

Wastewater discharge	=	2 MLD
Influent suspended solids	=	200 mg/*l*
Suspended solids removal in PST	=	60%
Specific gravity of solids	=	1 : 2
Moisture content of digested sludge	=	90%
% conversion of fresh sludge to liquid and gas	=	50%
Moisture content of fresh sludge	=	96%

[20 marks : 2025]

Solution:

Mass of influent suspended solids = $200 \times 2 \times 10^6 = 4 \times 10^8$ mg/d = 400 kg/d

Mass of solids in fresh sludge $= \frac{60}{100} \times 400 = 240$ kg/d

Moisture content of fresh sludge = 96% (given)

$\therefore$ Concentration of solids in fresh sludge = 4% = 0.04

$\therefore$ Mass of total fresh sludge $= \frac{240}{0.04} = 6000$ kg/d

Now,

Volume of fresh sludge = Volume of solids + Volume of water

$$\Rightarrow \quad \frac{M_{sl}}{\rho_{sl}} = \frac{M_s}{\rho_s} + \frac{M_w}{\rho_w}$$

$$\Rightarrow \quad \frac{6000}{\rho_{sl}} = \frac{240}{1.2 \times 1000} + \frac{(6000-240)}{1000}$$

$$\Rightarrow \quad \rho_{sl} = 1006.71 \text{ kg/m}^3$$

$\therefore$ Unit weight of raw sludge = 1006.71 kg/m^3

Volume of fresh sludge produced $= \frac{M_{sl}}{\rho_{sl}} = \frac{6000}{1006.71} = 5.96$ m^3/d

Percentage of fresh sludge digested = 50% (given)

$\therefore$ Mass of solids after digestion = $0.5 \times 240 = 120$ kg/d

Moisture content of digested sludge = 90% (given)

$\therefore$ Concentration of solids in digested sludge = 10% = 0.1

$\therefore$ Mass of total digested sludge $= \frac{120}{0.1} = 1200$ kg/d

Now,

Volume of digested sludge $= \frac{M_{ds}}{\rho_{ds}} + \frac{M_w}{\rho_w}$

$$\Rightarrow \quad V_{dsl} = \frac{120}{1.2 \times 1000} + \frac{(1200-120)}{1000}$$

$$\Rightarrow \quad V_{dsl} = 1.18 \text{ m}^3/\text{d}$$

End of Solution

Q.4 (b) A rectangular pier in a river is 1.22 m wide by 3.66 m long, and the average depth of water is 2.74 m. A model is built to a scale of 1 : 16. A velocity of flow of 0.076 m/s is maintained in the model, and the force acting on the model is 4.0 N.

(i) What are the values of velocity in and force on the prototype?

(ii) If a standing wave in the model is 0.049 m high, what is the height of wave at the nose of the pier?

(iii) What is the coefficient of drag resistance?

Take density of water ρ = 1000 kg/m^3.

[20 marks : 2025]

Solution:

Given: Width of pier, $B_P = 1.22$ m

Length of pier, $L_P = 3.66$ m

Depth of water in river, $H_P = 2.74$ m

$$\text{Scale, } L_r = \frac{1}{16} = \frac{L_m}{L_P}$$

Velocity of water in model, $V_m = 0.076$ m/sec

Force acting on the model, $F_m = 4$ N

(i) Velocity in prototype (V_P)

From Froude's law of similarity,

$$(F_r)_m = (F_r)_P$$

$$\Rightarrow \quad \frac{V_m}{\sqrt{gL_m}} = \frac{V_P}{\sqrt{gL_P}}$$

$$\Rightarrow \quad V_P = \frac{V_m}{\sqrt{L_r}} = 0.076 \times \sqrt{16} = 0.304 \text{ m/sec}$$

$$\text{Force, } F = \frac{1}{2}\rho A V^2$$

$$F_r = L_r^3 \qquad (\because A_r = L_r^2)$$

$$\Rightarrow \quad \frac{F_m}{F_P} = L_r^3$$

$$\Rightarrow \quad \frac{4}{F_P} = \left(\frac{1}{16}\right)^3$$

$$\Rightarrow \quad F_P = 16384 \text{ N} = 16.384 \text{ kN}$$

(ii) Standing wave in model, $(H_{wave})_m = 0.049$ m

$$\frac{(H_{wave})_m}{(H_{wave})_P} = L_r$$

$$\Rightarrow \quad \frac{0.049}{(H_{wave})_P} = \frac{1}{16}$$

$$\Rightarrow \quad (H_{wave})_P = 0.784 \text{ m}$$

(iii) Coefficient of drag resistance

$$\therefore \quad F_P = \frac{1}{2} C_D \rho A_P V_P^2$$

$$\Rightarrow \quad 16384 = \frac{1}{2} C_D \times 1000 \times (1.22 \times 2.74) \times 0.304^2$$

$$\Rightarrow \quad C_D = 106.07$$

Alternatively,

$$F_m = \frac{1}{2} C_D \rho A_m V_m^2$$

$$\Rightarrow \quad 4 = \frac{1}{2} C_D \times 1000 \times \left(\frac{1.22 \times 2.74}{16 \times 16}\right) \times 0.076^2$$

$$\Rightarrow \quad C_D = 106.07$$

End of Solution

Q.4 (c) (i) What are the various components of diversion headworks? Describe each in one or two sentences.

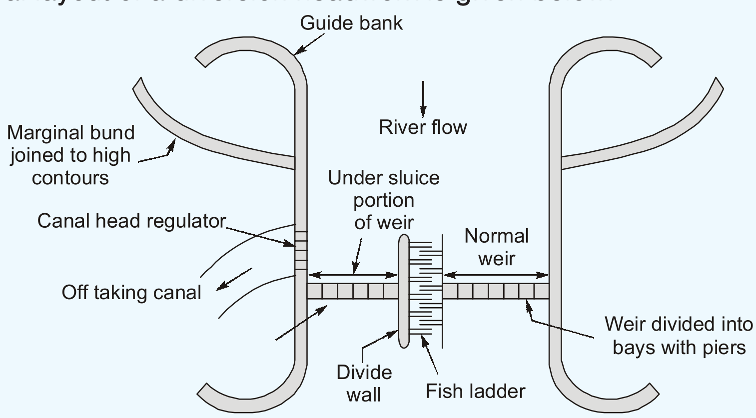
(ii) With help of a flow chart, explain various components of an Ecosystem and their functions.

[10 + 10 = 20 marks : 2025]

Solution:

(i)

The typical layout of a diversion headwork is given below:



Diversion head works consists of:

1. **Weir proper:** It stores and raises the water level on upstream side.
2. **Under sluice or scouring sluices:** Under sluices help in bypassing the excess supplies to the downstream side of the river. These also help in scouring and removing the deposited silt from the under sluiced pocket and hence are also called scouring sluices.
3. **Divide wall:** The divide wall is a masonry or concrete wall constructed at right angles to the axis of the weir and separates the weir proper from the under sluices. It helps in providing a comparatively less turbulent pocket near the canal head regulator, resulting in deposition of silt in this pocket and thus to help in the entry of silt free water into the canal.
4. **River training works such as marginal bunds, guide banks, groynes etc:** River training works are required near the weir site in order to ensure a smooth and an axial flow of water, and thus, to prevent the river from out flanking the works due to change in its course. The guide banks force the river into a restricted channel and thus ensuring

a smooth and an almost axial flow near the weir site. Marginal bunds are provided on the upstream side of the works in order to protect the area from submergence due to rise in HFL caused by afflux. These bunds are therefore, continued till they join contours higher than the new HFL.

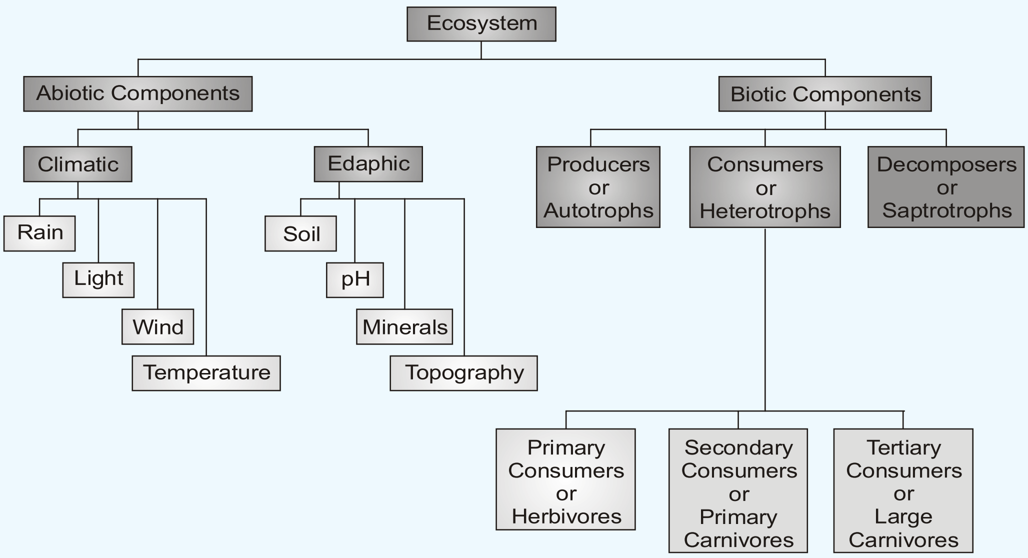
5. **Fish ladder:** A structure which enables the fishes to pass upstream is called a fish ladder. It is a device by which the flow energy can be dissipated in such a manner as to provide smooth flow at sufficiently low velocity.

6. **Canal head regulator:** A canal head regulator serves the following functions:
   (i) It regulates the supply of water entering the canal.
   (ii) It controls the entry of silt in the canal.
   (iii) It prevents the river floods from entering the canal.

7. **Silt regulation works:** The entry of silt into a canal which takes off from a headworks can be reduced by constructing certain special works, called silt control works.
   These works can be of two types:
   (i) **Silt excluder :** These are constructed on the bed of river upstream of head regulator. The clear water enters the head regulator and the silted water enters the silt excluder. In this type of work, the silt is therefore removed from water before it enters canal.
   (ii) **Silt ejector :** These devices extract the silt from the canal water after the silted water has travelled a certain distance in the off-take canal. These works are therefore constructed on the bed of the canal, and a little distance downstream from the head regulator. It is also called as **silt extractor.**

(ii)

Structure of Ecosystem



Schematic Representation of the Structure of an Ecosystem

Ecosystem is a subset of biosphere, wherein various species, their populations and communities interact with each other along with non-living things like land, sunlight, wind, humidity, etc., called as abiotic elements, whereas, the living things are called as biotic elements.

Biotic Components : Biotic components include living organisms comprising plants, animals and microbes. These are classified according to their functional attributes into producers and consumers.

(i) Producers

- Producers are also known as autotrophs, or self-feeders. Producers manufacture the organic compounds that they use as sources of energy and nutrients. Most producers are green plants or algae that make organic compounds through photosynthesis.
- A few producers, including specialized bacteria, can extract inorganic compounds from the environment and convert them to organic nutrients in the absence of sunlight. This process is called chemosynthesis.

(ii) Consumers

- Consumers are incapable of producing their own food. These are also known as heterotrophs or phagotrophs (nourishing on others).
- Consumers depend on organic food derived from plants, animals or both.

The consumers are generally grouped as:

(a) Primary consumers: These are mainly herbivores and feed on autotrophs.
Eg,: Deer, rabbit, cow etc.

(b) Secondary consumers: It consists of animals that depend on primary consumers for nutrition. These are mostly carnivorous animals.
Eg. Snake, small carnivores etc.

(c) Tertiary consumers: Organisms who predate on both primary and secondary consumers are said to be tertiary consumers. They are usually at the top of their food chains.
Eg. Eagle, Lion, Gocodiles etc.

(iii) Decomposers: They breakdown the complex organic matter into simpler forms including dead tissues of living beings. The decaying actions turn the complex compounds into nutrients that enrich the soil and are then consumed by the producers, completing the food cycle.

Abiotic Components:

- Abiotic components are the inorganic and non-living parts of an ecosystem. These consist of soil, water, air, light energy, etc. They also involve a large number of gases like oxygen, nitrogen, etc. and physical processes including volcanoes, earthquakes, floods, forest fires, climate and weather conditions.
- Abiotic factors are the most important determinants of where and how well an organism exists in its environment.

Some of the important abiotic factors are:

(i) **Energy (Sunlight) :** Sunlight is the primary source of energy in nearly all ecosystems. It is the energy that is used by green plants (which contain chlorophyll) during the process of photosynthesis; a process during which plants manufacture organic substances by combining inorganic substances.

(ii) **Water :** Water is essential for all living beings. It helps to regulate body temperature. Further, water bodies form the habitat for many aquatic plants and animals.

(iii) **Temperature :** Temperature is a critical factor of the environment which greatly influences survival of organisms. Organisms can tolerate only a certain range of temperature and humidity.

(iv) **Atmospheric gases :** Atmospheric gases like oxygen, nitrogen and carbon dioxide are imperative for the survival of flora and fauna of this planet. In addition to keeping the planet warm by greenhouse gas effect, they are vital as:

(a) all organisms require oxygen for respiration.

(b) Carbon dioxide is used by green plants to make food by the process of photosynthesis.

(c) Nitrogen is necessary for all plants and atmospheric nitrogen is fixed by nitrogen fixing bacteria through the action of lightening.

(v) **Soil (Edaphic factors) :** These factors include soil texture, soil temperature, soil water, soil solution and pH, together with soil organisms and decaying matter.

(vi) **Climate :** Climate of a region includes the average rainfall, temperature and the patterns of winds that occur. Climate is one of the most important abiotic factor of an ecosystem.

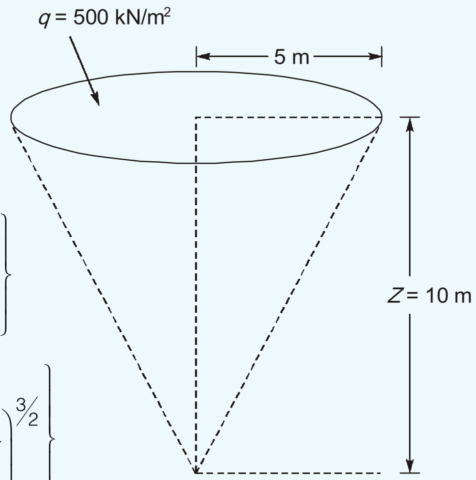
End of Solution

SECTION : B

Q.5 (a) A circular loaded area with radius 5 m is subjected to a load of 500 kN/m^2. Calculate and compare the variation of vertical stress below the centre of the circular area using Boussinesq's theory and Westergaard's theory for the depth from ground level to 10m below the ground surface. Assume Poisson's ratio as 0.30.

[12 marks : 2025]

Solution:



Given:

Radius of circular loaded area,

$r = 5$ m

Depth, $z = 10$ m

By Boussinesq's theory

$$\sigma_{z=10\,m} = q\left\{1-\left(\frac{1}{1+\frac{r^2}{z^2}}\right)^{3/2}\right\}$$

$$\Rightarrow \quad \sigma_{z=10\,m} = 500\left\{1-\left(\frac{1}{1+\frac{5^2}{10^2}}\right)^{3/2}\right\}$$

$$\Rightarrow \quad \sigma_{z=10\,m} = 142.229 \text{ kN/m}^2$$

By Westergaard's theory,

$$\sigma_{z=10\,m} = q\left\{1-\left[\frac{1}{1+\left(\frac{r}{\eta z}\right)^2}\right]^{1/2}\right\}$$

where, η depends upon Poisson's ratio

$$\eta = \sqrt{\frac{1-2\mu}{2-2\mu}} = \sqrt{\frac{1-2\times 0.3}{2-2\times 0.3}} = 0.5345$$

$$\therefore \quad \sigma_{z=10\,m} = 500\left\{1-\left[\frac{1}{1+\left(\frac{5}{0.5345\times 10}\right)^2}\right]^{1/2}\right\}$$

$$\Rightarrow \quad \sigma_{z=10\,m} = 134.859 \text{ kN/m}^2$$

Vertical stress computed by Boussinesq's equation is higher than by Wastergaard's equation

by $\left(\frac{142.229-134.859}{134.859}\right) = 5.46\%$

End of Solution

Q.5 (b) At a site the data related to a normally consolidated clay layer is as follows:

Thickness of the clay layer = 3.0 m

Initial void ratio = 0.85

Compression index = 0.27

Average effective pressure on the clay layer = 130 kN/m^2

Increment of pressure due to construction of foundation with load of superstructure is 300 kN/m^2.

The secondary compression index C_α = 0.02. What is the total consolidation settlement of the clay layer five years after the completion of primary consolidation settlement? The time of completion of primary settlement is 2 years.

[12 marks : 2025]

Solution:

Thickness of the clay layer; H_o = 3.0 m

Initial void ratio, e_o = 0.85

Coefficient of compression, C_c = 0.27

Effective stress on clay layer, $\bar{\sigma}_o$ = 130 kN/m^2

Increment of pressure, $\bar{\sigma}_o$ = 300 kN/m^2

Secondary compression index, C_α = 0.02

Time of completion of primary settlement, t_o = 2 years

Total consolidation settlement of the clay layer after primary consolidation settlement = ?

Primary consolidation settlement:

$$\Delta H_P = \frac{C_C H_o}{1+e_o}\log_{10}\left(\frac{\bar{\sigma}_o + \Delta\bar{\sigma}_o}{\bar{\sigma}_o}\right)$$

$$\Rightarrow \quad \Delta H_P = \frac{0.27\times 3}{1+0.85}\log_{10}\left(\frac{130+300}{130}\right)$$

$$\Rightarrow \quad \Delta H_P = 0.22746 \text{ m} = 227.46 \text{ mm}$$

Secondary consolidation settlement:

$$\Delta H_S = \frac{C_\alpha H_{100}}{1+e_{100}}\log_{10}\left(\frac{t}{t_o}\right)$$

$$H_{100} = H_o - \Delta H_p = 3 - 0.22746 = 2.77254 \text{ m}$$

$$\because \quad \frac{\Delta H}{H_o} = \frac{\Delta e}{1+e_o} = \frac{e_o - e_{100}}{1+e_o}$$

$$\Rightarrow \quad \frac{0.22746}{3} = \frac{0.85 - e_{100}}{1+0.85}$$

$$\Rightarrow \quad e_{100} = 0.709$$

$\therefore \quad \Delta H_S = \dfrac{0.02 \times 2.77254}{1 + 0.709} \log_{10}\left(\dfrac{5+2}{2}\right)$

$\Rightarrow \quad \Delta H_S = 0.017653 \text{ m} = 17.653 \text{ mm}$

$\therefore$ Total consolidation settlement

$$\Delta H_T = \Delta H_P + \Delta H_S = 245.113 \text{ mm}$$

End of Solution

Q.5 (c) An expressway passing through a rolling terrain has a horizontal curve of radius equal to the ruling minimum radius. Design the following geometric elements of this expressway for ruling design speed of 100 kmph, assuming any missing data suitably:

(i) Ruling minimum radius

(ii) Super elevation

(iii) Extra widening

(iv) Length of transition curve

(v) SSD, ISD and set-back distance

(vi) The minimum set-back distance from the center line of the two lane expressway on the inner side of the curve to provide a clear vision assuming the length of circular curve greater than the sight distance.

[12 marks : 2025]

Solution:

Given: Design speed, $V = 100$ km/hr

Radius of horizontal curve = Ruling minimum radius

(i) Ruling minimum radius

$$R_{min} = \frac{V^2}{127(e+f)}$$

Assume: $e = 7\%,\ f = 0.15$

$$R_{min} = \frac{100^2}{127(0.07+0.15)} = 357.9 \text{ m} \simeq 358 \text{ m}$$

(ii) Super elevation

$$\Rightarrow \quad e_{cal} = \frac{V^2}{225R} = \frac{100^2}{225 \times 358}$$

$$e_{cal} = 0.124 > 0.07$$

Provide super elevation 7%

Now, $$e + f = \frac{V^2}{127R}$$

$$\Rightarrow \quad 0.07 + f = \frac{100^2}{127 \times 358}$$

$$\Rightarrow \quad f = 0.149 < 0.15 \quad \text{(OK)}$$

(iii) Extra widening

$$w_e = \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$$

Assume, $l = 6$ m

$$\therefore \quad w_e = \frac{2 \times (6)^2}{2 \times 358} + \frac{100}{9.5\sqrt{358}}$$

$$\Rightarrow \quad w_e = 0.657 \text{ m}$$

(iv) Length of transition curve

- On the basis of rate of change of centrifugal acceleration

$$L_T = \frac{v^3}{CR}$$

where $C = \frac{80}{75+V} = \frac{80}{75+100} = 0.457 < 0.5$

Take, $C = 0.5 \text{ m/sec}^3$ $(\because 0.5 \le C \le 0.8)$

$$\therefore \quad L_T = \frac{\left(100 \times \frac{5}{18}\right)^3}{0.5 \times 358} = 119.74 \text{ m}$$

- On the basis of super elevation

Assume, $N = 150$, Pavement is rotated about centreline

$$L_T = \frac{e(w + w_e)N}{2}$$

$$\Rightarrow \quad L_T = \frac{0.07(7.5 + 0.657) \times 150}{2}$$

$$\Rightarrow \quad L_T = 42.82 \text{ m}$$

- As per IRC

$$L_T = \frac{2.7\,V^2}{R} = \frac{2.7(100)^2}{358} = 75.419 \text{ m}$$

$$\therefore \quad L_T = \text{Maximum}\{119.74, 42.82 \text{ m}, 75.418 \text{ m}\}$$

$$\Rightarrow \quad L_T = 119.74 \text{ m}$$

(v) Stopping sight distance

Assume, $t_r = 2.5$ sec, $f = 0.35$

$$\text{SSD} = 0.278\,Vt_r + \frac{(100)^2}{254 \times 0.35}$$

$$\Rightarrow \quad \text{SSD} = 181.99 \text{ m} \simeq 182 \text{ m}$$

$$\therefore \quad \text{ISD} = 2 \times (\text{SSD}) = 2 \times 182 = 364 \text{ m}$$

(vi) Set-back distance

Here, $L_S >$ ISD, $n = 2$

$$m = R - (R - d)\cos\frac{\alpha}{2}$$

Where: $\frac{\alpha}{2} = \frac{180°S}{2\pi(R-d)}$

$$d = \frac{W + W_e}{4} = \frac{7.5 + 0.657}{4} = 2.04 \text{ m}$$

$$\therefore \quad \frac{\alpha}{2} = \frac{180° \times 364}{2\pi(358 - 2.04)} = 29.3°$$

Now,

$$m = 358 - (358 - 2.04)\cos(29.3°)$$
$$= 47.578 \text{ m}$$

End of Solution

Q.5 (d) Find out the steepest gradient on a straight track using the following data for a train having 25 wagons:

Weight of each wagon	=	20 tonnes
Rolling resistance of wagon	=	2.5 kg/tonne
Speed of the train	=	60 kmph
Weight of locomotive with tender	=	120 tonnes
Tractive effort of locomotive	=	45 tonnes
Rolling resistance of locomotive	=	3.5 kg/tonne

[12 marks : 2025]

Solution:

Given:

Number of wagons in the train	=	25
Weight of each wagon	=	20 tonnes
Rolling resistance of wagon	=	2.5 kg/tonne
Speed of the train, V	=	60 km/hr
Weight of locomotive with tender	=	120 tonnes
Tractive effort of locomotive	=	45 tonnes
Rolling resistance of locomotive	=	3.5 kg/tonne
Gradient	=	?

Now, Total weight of wagons $= 25 \times 20 = 500$ tonnes

Total weight of train, $W = 120 + 500 = 620$ tonnes

Total train resistance, $R_T = R_{T1} + R_{T2} + R_{T3} + W\tan\theta$ ...(i)

Where, R_{T1} = Resistance which is independent of speed

$= (3.5 \times 120 + 2.5 \times 500) = 1670 \text{ kg} = 1.67$ tonnes

R_{T2} = Resistance dependent on speed

$= 0.00008\,WV = 0.00008 \times 620 \times 60 = 2.976$ tonnes

R_{T3} = Atmospheric resistance

$= 0.0000006\,WV^2 = 0.0000006 \times 620 \times 60^2$

$= 1.3392$ tonnes

$W\tan\theta$ = Resistance due to gradient

From equation (i)

$$R_T = 1.67 + 2.976 + 1.3392 + 620 \tan\theta$$

$$\Rightarrow \quad 45 = 5.9852 + 620 \tan\theta$$

$$\Rightarrow \quad \tan\theta = 0.0629$$

$$\Rightarrow \quad \frac{1}{\tan\theta} = 15.89 \simeq 16$$

∴ Steepest gradient is 1 in 16

End of Solution

Q.5 (e) (i) Distinguish clearly between mistake and error. Also differentiate between systematic and accidental errors. How the most probable values of a single observation and the mean of a number of observations are computed?

[6 marks : 2025]

Solution:

- Mistakes are the error arising from the carelessness, inexperience, poor judgement and confusion of the observer while error is the difference after blunders have been eliminated between a measured or calculated value of a quantity and the true or established value of that quantity.

Systematic errors	Accidental errors
These errors are called as systematic because they always follow a definite pattern or a mathematical/physical law.	This type of error occurs due to human limitation in reading an observation.
These are also called as *cumulative errors.*	These are also called as *random errors* or *compensating errors.*
This type of error makes the result either too large or too small.	When a large number of observations are made, then they use to cancel out because there is equal probability of the error to be positive or negative.

Most probable value (MPV) of an observation or a set of observations is the one which has the most chances of being true.

For quantities having observations of equal weights, the MPV is equal to the arithmetic mean while for those having observations of unequal weights, the MPV is equal to the weighted arithmetic mean.

The most probable value can be fixed within limits by adding or subtracting the most probable error from it. Let $\bar{x}$ be the mean of observations of a measured quantity, then:

For single observation,

$$MPV = \bar{x} \pm 0.6745\sqrt{\frac{\Sigma\left[w_n(x_n-\bar{x})^2\right]}{n-1}}$$

For mean of a number of observation,

$$MPV = \bar{x} \pm 0.6745\sqrt{\frac{\Sigma\left[w_n(x_n-\bar{x})^2\right]}{(n-1)\Sigma w_n}}$$

Where,

$x_1, x_2 \dots x_n$ are observations and $w_1, w_2 \dots w_n$ are their weights respectively.

End of Solution

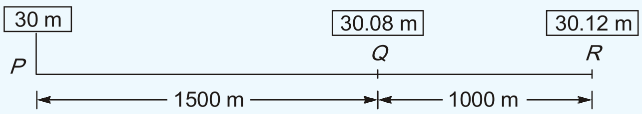
Q.5 (e) (ii) A distance of 1500m was measured by a 30 m chain. Later, it was detected that the chain was 8 cm too long. Thereafter, another 1000 m was measured and it was detected that the chain was 12 cm too long. If the chain was correct initially, determine the exact length that was measured.

[6 marks : 2025]

Solution:

Given:

Correct length of chain, $l = 30$ m



Corrected length, $$L = \frac{l' \times L'}{l}$$

where

l' = Incorrect length of chain

l = Correct length of chain

L' = Incorrect measured length of line

$$\text{Corrected length of line } PQ = \frac{\left(\frac{30 + 30.08}{2}\right) \times 1500}{30} = 1502 \text{ m}$$

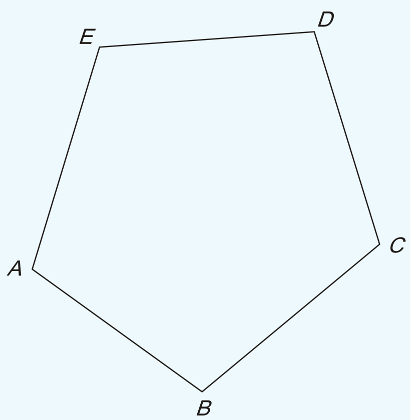
$$\text{Corrected length of line } QR = \frac{\left(\frac{30.08 + 30.12}{2}\right) \times 1000}{30} = 1003.33 \text{ m}$$

Corrected measured length = 1502 + 1003.33

= 2505.33 m

End of Solution

Q.6 (a) (i) The following are the bearings taken on a closed compass traverse:



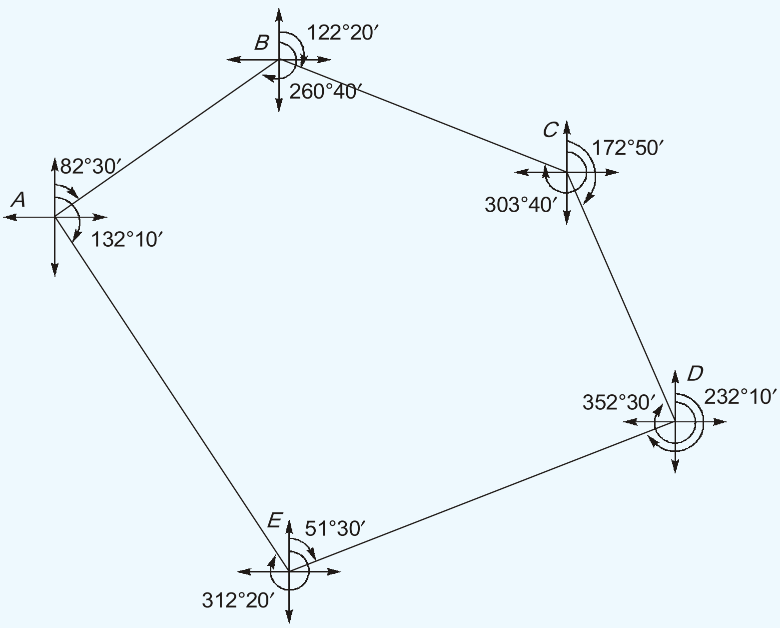
Line	Fore Bearing	Back Bearing
AB	82°30′	260°40′
BC	122°20′	303°40′
CD	172°50′	352°30′
DE	232°10′	51°30′
EA	312°20′	132°10′

Compute the interior angles and correct them for observational errors. If the observed bearing of the line BC is correct, adjust the bearings of the remaining sides.

[10 marks : 2025]

Solution:

Line	Fore Bearing	Back Bearing
AB	82°30′	260°40′
BC	122°20′	303°40′
CD	172°50′	352°30′
DE	232°10′	51°30′
EA	312°20′	132°10′



Incorrect interior angles:

$$\angle A = 132°10' - 82°\,30' = 49°\,40'$$
$$\angle B = 260°40' - 122°\,20' = 138°\,20'$$
$$\angle C = 303°40' - 172°\,50' = 130°\,50'$$
$$\angle D = 352°30' - 232°\,10' = 120°\,20'$$
$$\angle E = 360° - (312°20' - 51°\,30') = 99°\,10'$$

Sum of all interior angles = 538°20′

Correct sum of interior angle = $(n-2)\times 180$

$= (5-2)\times 180$

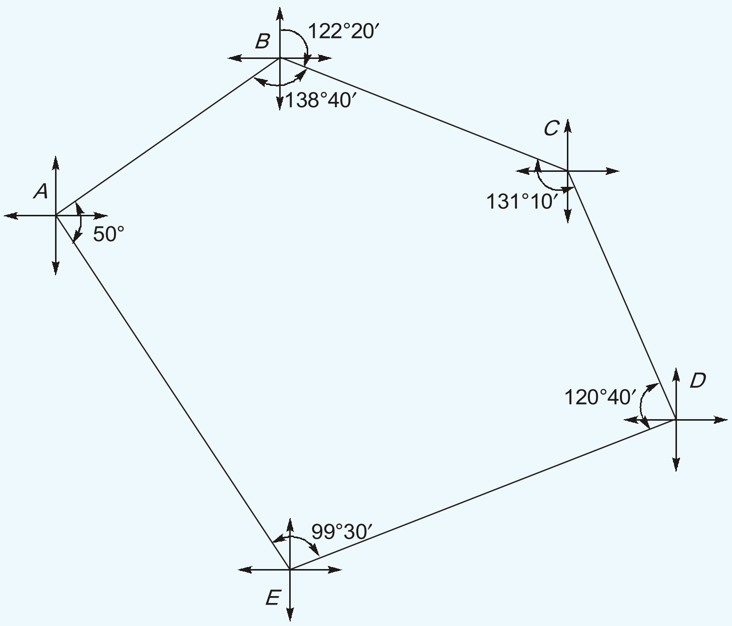
$= 540°$

Error = 538°20′ – 540° = – 1°40′

Correction at each station $= \dfrac{+1°40'}{5} = +20'$

Station	Incorrect interior angle	Correction	Corrected interior angle
A	49°40′	+20′	50°
B	138°20′	+20′	138°40′
C	130°50′	+20′	131°10′
D	120°20′	+20′	120°40′
E	99°10′	+20′	99°30′
		Sum =	540°

Given: Bearing of line *BC* is correct.



Correct *FB* of *BC* = 122°20′

Correct *BB* of *AB* = 122°20′ + 138°40′ = 261°

FB of *AB* = 261° – 180° = 81°

Correct *BB* of *EA* = 81° + 50° = 131°

Correct *FB* of *EA* = 131° + 180° = 311°

Correct *BB* of *DE* = 99°30′ – (360° – 311°) = 50°30′

Correct *FB* of *DE* = 50°30′ + 180° = 230°30′

Correct *BB* of *CD* = 230°30′ + 120°40′ = 351°10′

$$\text{Correct } FB \text{ of } CD = 351°10' - 180° = 171°10'$$
$$\text{Correct } BB \text{ of } BC = 171°10' + 131°10' = 302°20'$$
$$\text{Correct } FB \text{ of } BC = 302°20' - 180° = 122°20'$$

Line	Corrected FB	Corrected BB
AB	81°	261°
BC	122°20′	302°20′
CD	171°10′	351°10′
DE	230°30′	50°30′
EA	311°	131°

End of Solution

Q.6 (a) (ii) Define the following terms used in aerial survey:

(I) Fiducial marks

(II) Isocentre

(III) Relief Displacement

(IV) Tilt and Tip

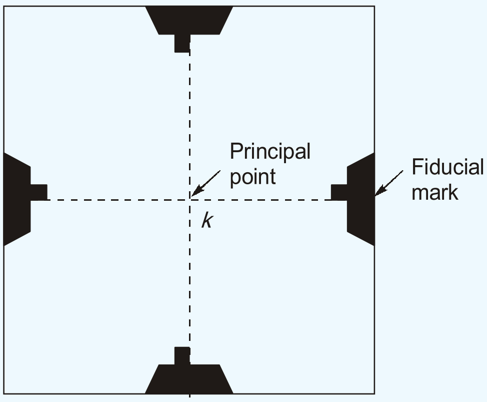
(V) Principal point

[10 marks : 2025]

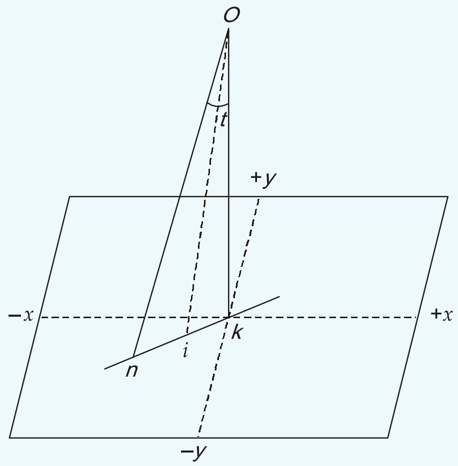
Solution:

(ii)

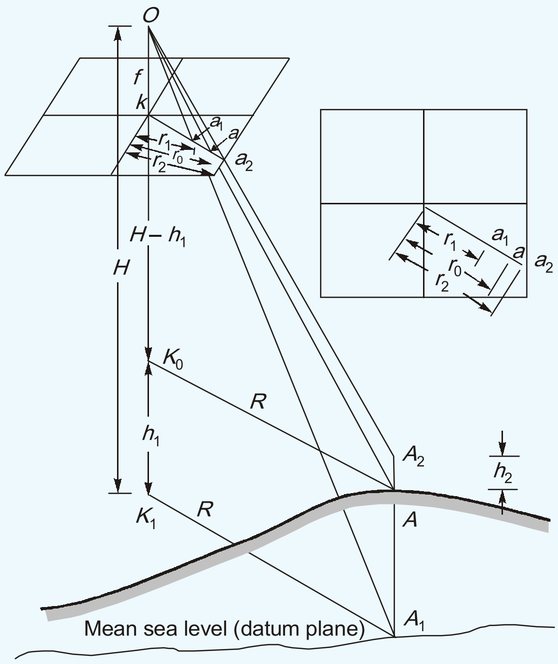
1. **Fiducial marks:** These are reference points or markers that are imprinted or etched on the edges of the film inside an aerial camera. These marks locate, on the photograph, the geometric axes whose intersection must be on the optical axis of the camera. They appear on every aerial photograph and are used for geometric corrections and accurate measurements by defining the internal orientation of photograph.



2. **Isocentre**: It is the point on an aerial photograph (i) that lies halfway between the principal point (k) and nadir point (n). It can also be defined as the point on an aerial photograph in which the bisector of the angle of tilt (t) meets the photograph.



3. **Relief displacement**: It refers to the radial shift of an object's image on an aerial photograph due to the height differences of the object above or below the average datum. Objects higher than the datum are displaced radially outwards from the nadir, while objects lower are displaced inwards. This displacement is crucial for understanding terrain elevation.



Topographic relief displacement

Relief displacement, $d_1 = r_0 - r_1$

$d_2 = r_2 - r_0$

4. **Tilt and tip:** These are two types of camera orientation errors in aerial photography where:
   - Tilt is the angle between the axis of the camera lens and the vertical direction (plumb line). The aerial camera rotates about the line of flight.

- Tip is specifically the rotation of the camera about its axis perpendicular to the direction of flight.

5. **Principal point:** It is the point on the photograph where the optical axis of the camera lens intersects the image plane. It is ideally at the geometric centre of the photograph and serves as a fundamental reference for various photogrammetric operations including measurements and corrections.

End of Solution

Q.6 (b) Write descriptive notes on:

(i) Environmental impacts associated with airport projects

(ii) Parking configurations for aircrafts

(iii) Cross wind component

(iv) Typical layout of an artificial harbour indicating the components and their functions

[5 + 5 + 5 + 5 = 20 marks : 2025]

Solution:

(i)

Airport projects have a profound impact on the environment, both during the construction phase and throughout their operation. The major environmental concerns associated with airports are:

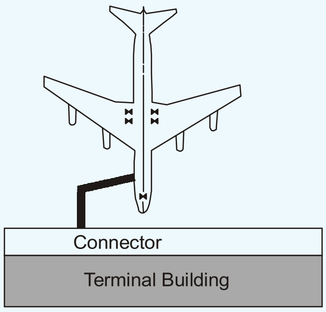
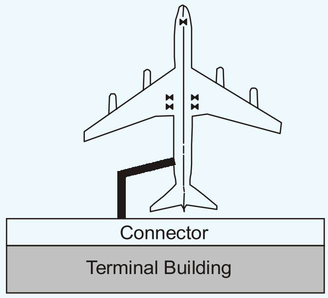
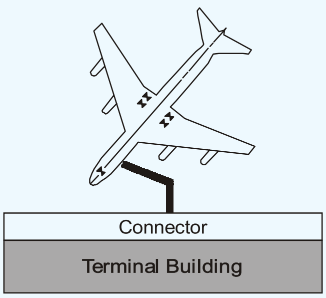
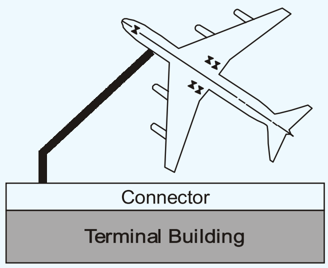
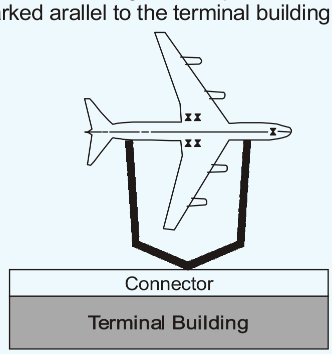
- **Land use and loss of natural habitat:** Construction of airports requires vast amounts of land, often resulting in the destruction of forests, filling of wetlands, and loss of natural habitats of wildlife, altering the existing ecosystems in the process. This leads to reduction in biodiversity and loss of flora and fauna. Such activities may also displace residents requiring the relocation of local communities and destruction of agricultural lands. Scenic landscapes may get altered or lost, affecting the aesthetic value and recreation potential of the region.
- **Noise Pollution:** Noise is one of the most significant adverse effects caused by airport projects. Aircrafts take-offs and landings, ground operations generate high levels of noise, affecting the quantity of life and disturbing both human and wildlife population in the vicinity. Such exposure to noises can lead to change in migration patterns of fauna.
- **Air and Water pollution:** Airports contribute substantially to air pollution due to emissions from aircraft engines, ground service vehicles and auxiliary power units. Pollutants such as nitrogen oxides (NO_x), carbon monoxide (CO), particulate matter (PM) and volatile organic compounds (VOC_s) are released into the atmosphere. Spillage of aviation fuel, de-icing fluids, lubricants and other chemicals may run off into nearby rivers, lakes or groundwater sources harming aquatic life and threatening quality of drinking water.

Airport operations can also contribute to the urban heat island effect. Given these potential impacts, it is essential that all environmental effects of an airport project are thoroughly studied and included in the Environmental Impact Assessment statement accompanying the project report.

(ii)

Parking configuration for aircrafts: Aircraft parking type refers to the manner in which the aircraft is positioned with respect to terminal building and to the manner in which aircraft maneuvers in and out of parking positions.

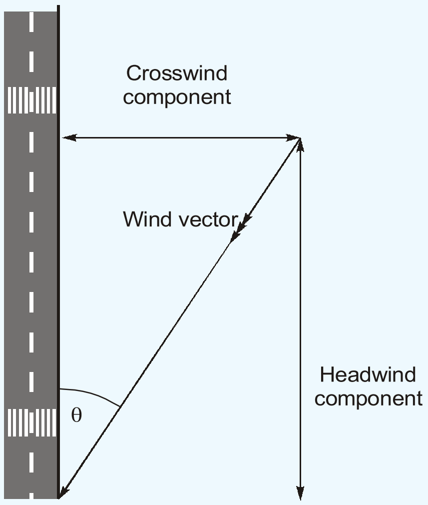
Aircraft parking types which have been used are as follows:

Aircraft parking types	
1. **Nose-in parking:** Here parking is done perpendicular to building line with nose as close to building as possible.  Noise-in Parking	2. **Nose out parking:** Here parking is done perpendicular to building line with tail as close to building as possible.  Noise out Parking
3. **Angled Nose-in parking:** This is similar to nose in parking but the aircraft is not parked perpendicular to the terminal building. Aircrafts use 30, 45, 60 degree angles for parking.  Angled Nose-in Parking	4. **Angled Nose-out parking:** In the configuration the aircraft is parked with its nose pointing away from terminal building.  Angled Nose-out Parking
5. **Parallel Parking:** In this type aircrafts are parked arallel to the terminal building.  Parallel Parking	6. **Remote Parking:** Here parking of aircrafts is done at designated areas at an airport where aircrafts are parked away from main terminal building without access to jet bridges or other passenger service facilities.

(iii)

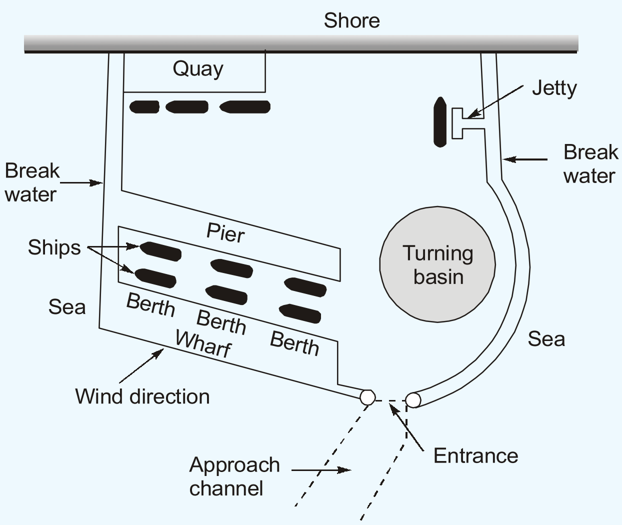
Cross wind component: If the direction of wind is at an angle to the runway centre line, the normal component to the movement of aircraft is called cross wind component.

- It interrupts safe landing and take off operations.
- Runway orientation is so selected that cross wind components are minimal.
- Centre line of runway should not make an angle with the wind direction, including 30° otherwise it may significantly impact landing operations by cousing the aircraft to drift sideways requiring pilots to use techniques like crabbing and side slipping to maintain alignment with the runway.



(iv)

Typical layout of an artificial harbour:



The components of an artificial harbour and their functions are as below:

Harbour Entrance Channel: Usually the entrance to a harbour is more exposed to waves compared to the harbour itself. Due to this fact depth and width required at the entrance are more than those required in the channel. The entrance should be wide enough for navigational requirements.

Approach channel: When the ideal conditions do not exist, a channel with sufficient depth and width is dredged to provide passage to ships between the harbour entrance and the docks. The terminology "approach channel" is used for the dredged fair way through which ships proceed from the open sea to the harbour basin.

Outer channel: The portion of the channel which lies beyond the harbour entrance in the open sea is called an outer channel.

Inner channel: The portion of the channel lying between the harbour entrance and harbour basin is called an inner channel. It is protected from storms and waves by natural configurations or break waters.

Turning basin: This is the area required for maneuvering or controlling the movements of the ship when it goes or leaves the berth, so that it can leave head on.

Sheltered basin: It is the area protected by shore and break waters. In this area other elements of the harbour are located. It also includes area for anchorage for vessels.

Break waters: The structure constructed to protect the enclosed area of water from storm waves is called break waters. The main function of break water or system of break waters is to protect the enclosed area of water from storms and waves.

Pier head: The monolithic structure usually provided at the tip of break water is known as pier head.

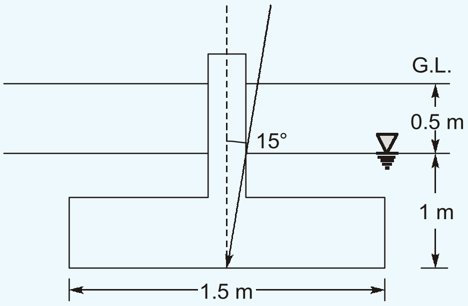
Wharves and Quays: The structures constructed parallel to the shore or break water with in the harbour to permit berthing of vessel alongside for cargo working are known as wharves and quays. They have back fill of earth or other materials and have wide platform at the top.

Jetties and Piers: These are solid or open type structures with a wide platform on top to provide space for loading and unloading of cargo from vessels berthed alongside them. They are built from the shore towards sea water to reduce silting and dredging to allow free flow of tidal currents.

Lock and Locked Basin: Locked basin is an enclosed basin where a number of vessels can be berthed. It has an entrance which is controlled by lock gates. The water with in locked basin is independent of outside water level changes.

Dry-docks and Slip ways: Essentially these are provided for maintenance, repairs and construction of ships. A dock for the construction of ships is known as a building dock. They can be kept dry for easy working. Dry dock has a gate in the entrance which is closed after taking the vessel in and the water is pumped out to make it dry. End of Solution

Q.6 (c) Determine the safe gross inclined load for a square footing as shown in the diagram.



The base of the foundation is 1.5 m below ground level and depth of water table is 0.5 m below ground level.

The properties of the soil are as follows :

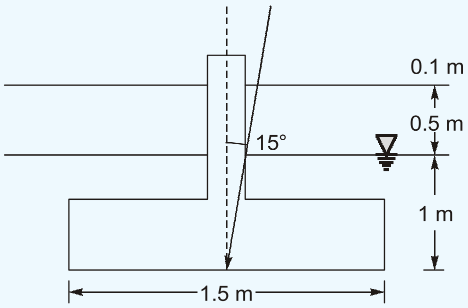
Cohesion	=	0
Angle of shearing resistance	=	30°
Bulk density	=	16.5 kN/m^3
Saturated density	=	19.5 kN/m^3

The values of non-dimensional bearing capacity factors are:

$N_e = 37.16$, $N_q = 22.46$ and $N_\gamma = 19.13$.

[20 marks : 2025]

Solution:



Width of square footing, $B = 1.5$ m
Depth of footing, $D_f = 1.5$ m
Cohesion $C = 0$
Angle of shearing resistance, $\phi = 30°$
Bulk density, $\gamma_t = 16.5$ kN/m^3
Saturated unit weight, $\gamma_{sat} = 19.5$ kN/m^3
$N_C = 37.16$, $N_q = 22.46$, $N_\gamma = 19.13$
Net ultimate bearing capacity is given by

$$q_{net} = CN_c S_c i_c d_c + \bar{\sigma}(N_q - 1)s_q i_q d_q + \frac{1}{2}\gamma_{avg} B N_\gamma S_\gamma i_\gamma d_\gamma w^*$$

Shape factor, $S_c = 1.3$ (for square footing)

$S_q = 1.2$ (for square footing)

$S_\gamma = 0.8$ (for square footing)

Inclination factor,

$$i_c = i_q = \left(1-\frac{\alpha}{90^\circ}\right)^2 = \left(1-\frac{15^\circ}{90^\circ}\right)^2 = 0.694$$

$$i_\gamma = \left(1-\frac{\alpha}{\phi}\right)^2 = \left(1-\frac{15^\circ}{30^\circ}\right)^2 = 0.25$$

Depth factor

$$d_c = 1 + 0.2\frac{D_f}{B}\tan\left(45+\frac{\phi}{2}\right) = 1 + 0.2 \times \frac{1.5}{1.5}\tan\left(45+\frac{30}{2}\right)$$

$$= 1.346$$

$$d_q = d_\gamma = 1 + 0.1\ \frac{D_f}{B}\tan\left(45+\frac{\phi}{2}\right) = 1 + 0.1 \times \frac{1.5}{1.5}\tan\left(45+\frac{30}{2}\right)$$

$$= 1.173$$

Effective stress at base of footing

$$\bar{\sigma} = 16.5 \times 0.5 + (19.5 - 9.81) \times 1 = 17.94\ \text{kN/m}^2$$

$$\gamma_{avg} = \frac{16.5 \times 0.5 + 19.5 \times 1}{0.5 + 1} = 18.5\ \text{kN/m}^3$$

Water table correction factor,

$$w = \frac{1}{2}\left(1+\frac{z_3}{D_f}\right) = 0.5\left(1+\frac{0.5}{1.5}\right) = 0.667$$

Now

$$q_{nu} = 0 \times 37.16 \times 1.3 \times 0.694 \times 1.346 + 17.94 \times (22.46 - 1) \times 1.2 \times 0.694 \times 1.173 + \frac{1}{2} \times 18.5$$
$$\times 1.5 \times 19.13 \times 0.8 \times 0.25 \times 1.173 \times 0.667$$

$$q_{nu} = 417.623\ \text{kN/m}^2$$

Safe bearing capacity (Assume FOS = 2.5)

$$q_s = \frac{q_{nu}}{FOS} + \bar{\sigma} = \frac{417.623}{2.5} + 18.5$$

$$q_s = 185.549\ \text{kN/m}^2$$

Safe load

$$Q_S = q_S(\text{Area}) = 185.549 \times 1.5 \times 1.5$$

$\Rightarrow$ $Q_S = 417.48$ kN

End of Solution

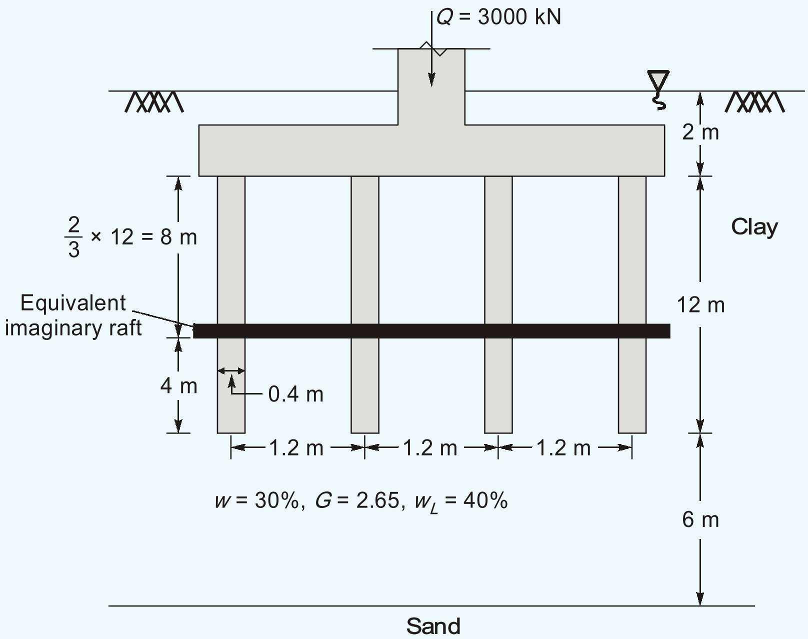
Q.7 (a) A mat foundation is to be laid at a depth of 2 m below ground surface in a 20 m thick layer of normally consolidated clay underlain by dense sand. The mat foundation is supported by a group of 16 piles of length 12 m and diameter 400 mm arranged in a square pattern. The gross load to be carried by the pile group is 3000 kN. The piles are spaced at 1.2 m c/c. The water table is at ground surface. The geotechnical properties of the foundation soil are as follows :

Water content = 30%, Specific gravity = 2.65, Liquid limit = 40%

Determine the probable consolidation settlement of the pile group. While estimating the settlement divide the sublayers into three zones suitably.

[20 marks : 2025]

Solution:



$$\therefore \quad eS = Gw$$

$$\Rightarrow \quad e \times 1 = 2.65 \times 0.3$$

$$\Rightarrow \quad e = 0.795$$

Saturated unit weight, $\gamma_{sat} = \left(\dfrac{G+e}{1+e}\right)\gamma_w$

$$\Rightarrow \quad \gamma_{sat} = \left(\frac{2.65+0.795}{1+0.795}\right)\times 9.81$$

$$\Rightarrow \quad \gamma_{sat} = 18.828 \text{ kN/m}^3$$

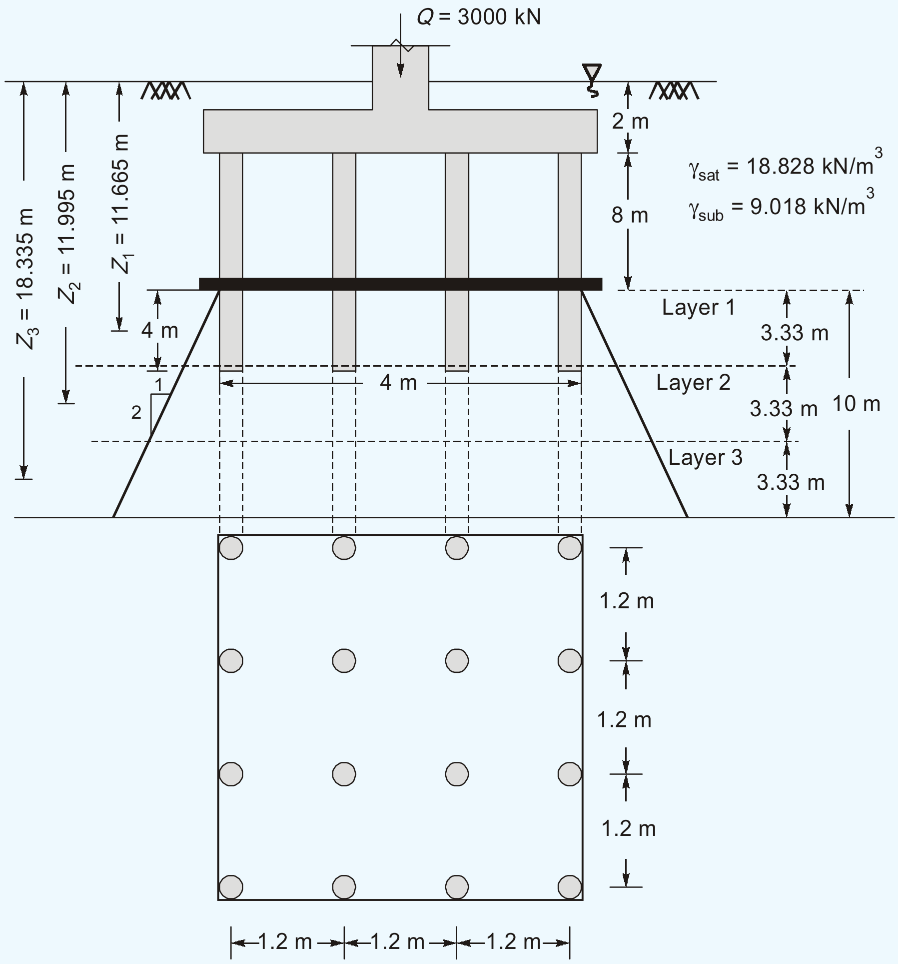
$$\therefore \quad \gamma_{sub} = \gamma_{sat} - \gamma_w = 9.018 \text{ kN/m}^3$$

Coefficient of compression

$$C_c = 0.009(w_L - 10) = 0.27$$

Estimation of settlement by dividing the sublayers into three zones.

Assume load distribution as 1H : 2V



Consolidation settlement Layer-1:

Effective stress at mid of Layer-1

$$\bar{\sigma}_1 = \gamma_{sub} Z_1 = 9.018 \times 11.665 = 105.195 \text{ kN/m}^2$$

$$\Delta\bar{\sigma}_1 = \frac{3000}{(4+1.665)^2} = 93.48 \text{kN/m}^2$$

$$\therefore \quad S_1 = \frac{C_c H_1}{1+e_0} \log_{10}\left(\frac{\bar{\sigma}_1 + \Delta\bar{\sigma}_1}{\bar{\sigma}_1}\right)$$

$$\Rightarrow \quad S_1 = \frac{0.27 \times 3.33}{1+0.795} \log_{10}\left(\frac{105.195+93.48}{105.195}\right)$$

$$S_1 = 0.13832 \text{ m} = 138.32 \text{ mm}$$

Consolidation settlement Layer-2:

Effective stress at mid of Layer-2

$$\bar{\sigma}_2 = \gamma_{sub} Z_2 = 9.018 \times 14.995 = 135.225 \text{ kN/m}^2$$

$$\Delta\bar{\sigma}_2 = \frac{3000}{(4+5)^2} = 37.037 \text{kN/m}^2$$

$$\Rightarrow \quad S_2 = \frac{C_c H_2}{1+e_0}\log_{10}\left(\frac{\bar{\sigma}_2+\Delta\bar{\sigma}_2}{\bar{\sigma}_2}\right)$$

$$\Rightarrow \quad S_2 = \frac{0.27\times 3.33}{1+0.795}\log_{10}\left(\frac{135.225+37.037}{135.225}\right)$$

$$S_2 = 0.052659\text{ m} = 52.659\text{ mm}$$

Consolidation settlement Layer-3:

Effective stress at mid of Layer-3

$$\bar{\sigma}_3 = \gamma_{sub} Z_3 = 9.018 \times 18.335 = 165.345\text{ kN/m}^2$$

$$\Delta\bar{\sigma}_3 = \frac{3000}{(4+8.335)^2} = 19.72\text{kN/m}^2$$

$$\therefore \quad S_3 = \frac{C_c H_3}{1+e_0}\log_{10}\left(\frac{\bar{\sigma}_3+\Delta\bar{\sigma}_3}{\bar{\sigma}_3}\right)$$

$$\Rightarrow \quad S_3 = \frac{0.27\times 3.33}{1+0.795}\log_{10}\left(\frac{165.345+19.75}{165.345}\right)$$

$$\Rightarrow \quad S_3 = 0.0245102\text{ m} = 24.51\text{ mm}$$

Consolidation settlement of the pile group.

$$S = S_1 + S_2 + S_3$$
$$= 215.489\text{ mm}$$

End of Solution

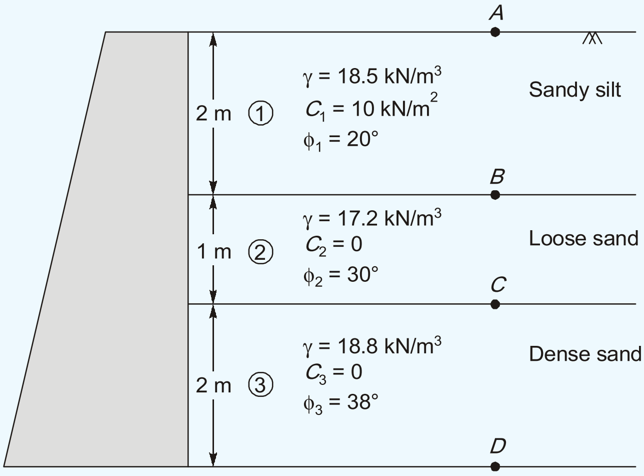
Q.7 (b) A retaining wall of 5 m height has to retain a stratified backfills. The properties of different layers of backfills are shown in following table :

Properties	Top layer	Middle layer	Bottom layer
Thickness (m)	2	1	2
Density (kN/m^3)	18.5	17.2	18.8
Types of soil	Sandy silt	Loose sand	Dense sand
Cohesion (kN/m^2)	10	0	0
Angle of shearing resistance (degree)	20°	30°	38°

Determine the magnitude of total active pressure on the wall and its point of application.

[20 marks : 2025]

Solution:



$$k_{a_1} = \frac{1-\sin 20°}{1+\sin 20°} = 0.49$$

$$k_{a_2} = \frac{1-\sin 30°}{1+\sin 30°} = 0.333$$

$$k_{a_3} = \frac{1-\sin 38°}{1+\sin 38°} = 0.238$$

For Layer-1

Stress at any depth 'z'

$$\sigma_z = k_{a_1}\gamma z - 2C_1\sqrt{k_{a_1}}$$

At point A (just below ground level)

$$(\sigma_z)_{A\text{ just below}} = -2 \times 10\sqrt{0.49} = -14 \text{ kN/m}^2$$

At point B (just above)

$$(\sigma_z)_{B\text{ just above}} = 0.49 \times 18.5 \times 2 - 2 \times 10\sqrt{0.49} = 4.13 \text{ kN/m}^2$$

For layer-2

At point B, (just below)

$$(\sigma_z)_{B\text{ just below}} = k_{a_2}\sigma_v - 2C_2\sqrt{k_{a_2}}$$

$$= 0.333\,(18.5 \times 2) - 2 \times 0 \times \sqrt{0.333} = 12.32 \text{ kN/m}^2$$

At point C (just above)

$$(\sigma_z)_{C\text{ just above}} = 0.333\,(18.5 \times 2 + 17.2 \times 1) - 2 \times 0 \times \sqrt{0.333} = 18.05 \text{ kN/m}^2$$

For layer-3

At point C, (just below)

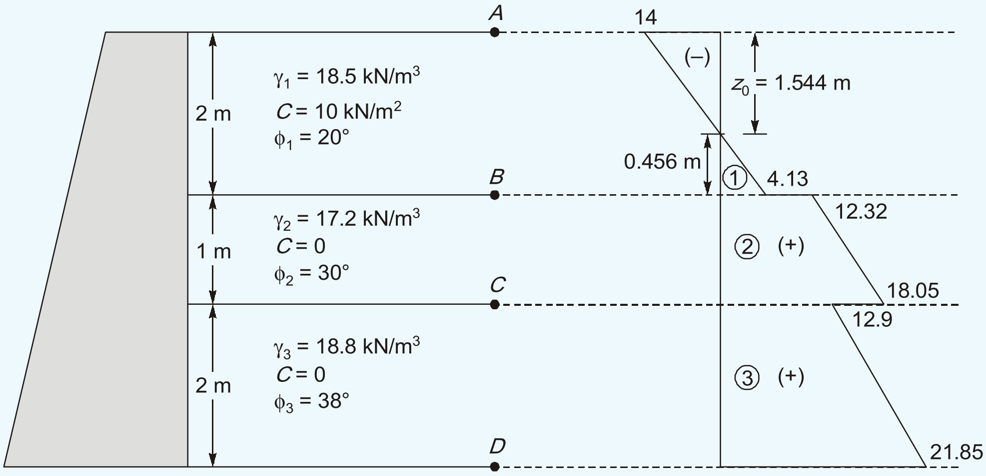
$$(\sigma_z)_{C\text{ just below}} = k_{a_3}\sigma_v - 2C_3\sqrt{k_{a_3}}$$

$$= 0.238\,(18.5 \times 2 + 17.2 \times 1) - 2 \times 0 \times \sqrt{0.238} = 12.9 \text{ kN/m}^2$$

At point D (just above)

$$(\sigma_z)_{D\text{ just above}} = 0.238\,(18.5 \times 2 + 17.2 \times 1 + 18.8 \times 2) - 2 \times 0 \times \sqrt{0.238}$$

$$= 21.85 \text{ kN/m}^2$$



(Earth Pressure diagram)

Depth of tension crack in top layer

$$Z_o = \frac{2C_1}{\gamma_1\sqrt{K_1}} = \frac{2\times 10}{18.5\sqrt{0.49}} = 1.544 \text{ m}$$

Case 1: Consider tensile crack to be developed

$$F_1 = \frac{1}{2}\times 0.456\times 4.13 = 0.94164 \text{ kN}$$

$$\bar{x}_1 \text{ (from } D) = 2 + 1 + \frac{1}{3}\times 0.456 = 3.152 \text{ m}$$

$$F_2 = \frac{1}{2}(12.32 + 18.05)\times 1 = 15.185 \text{ kN}$$

$$\bar{x}_2 \text{ (from } D) = 2 + \frac{1}{3}\times\frac{(2\times 12.32 + 18.05)}{(12.32 + 18.05)} = 2.468 \text{ m}$$

$$F_3 = \frac{1}{2}(12.9 + 21.85)\times 2 = 34.75 \text{ kN}$$

$$\bar{x}_3 \text{ (from } D) = \frac{2}{3}\times\frac{(2\times 12.9 + 21.85)}{(12.9 + 21.85)} = 0.914 \text{ m}$$

Total active earth pressure acting on wall

$$F_a = F_1 + F_2 + F_2 = 0.94164 + 15.185 + 34.75$$

$$\Rightarrow \quad F_a = 50.876 \text{ kN}$$

Position of resultant active earth pressure from base of wall i.e. from D is,

$$\bar{x} = \frac{F_1\bar{x}_1 + F_2\bar{x}_2 + F_3\bar{x}_3}{F_1 + F_2 + F_3}$$

$$\Rightarrow \quad \bar{x} = \frac{0.94164\times 3.152 + 15.185\times 2.468 + 34.75\times 0.914}{0.94164 + 15.185 + 34.75}$$

$$\Rightarrow \quad \bar{x} = 1.419 \text{ (from } D)$$

Case 2: Consider tensile crack has not developed

$$F_a = F_1 + F_2 + F_3 - 1/2 \times 1.544 \times 14$$

$$\Rightarrow \quad F_a = 50.876 - 10.808 = 40.068 \text{ kN}$$

Position of resultant active earth pressure,

$$\bar{x} = \frac{F_1\bar{x}_1 + F_2\bar{x}_2 + F_3\bar{x}_3 - 10.808\left(2 + 1 + 0.456 + \dfrac{2 \times 1.544}{3}\right)}{F_1 + F_2 + F_3 - 10.808}$$

$$\bar{x} = \frac{0.94164 \times 3.152 + 15.185 \times 2.468 + 34.75 \times 0.914 - 10.808 \times 4.485}{0.94164 + 15.185 + 34.75 - 10.808}$$

$$\Rightarrow \quad \bar{x} = 0.59 \text{ m (from } D)$$

End of Solution

Q.7 (c) (i) Briefly describe the Track Management System (TMS). What are the main advantages of TMS?

[10 marks : 2025]

Solution:

A track management system is a digital system used to manage and maintain railway tracks. It digitizes track data, inspection records and maintenance schedules, enabling proactive planning, optimized resource allocation and improved safety.

TMS helps to track the health of railway assets and facilitates efficient track maintenance by automating the process and providing real time tracking of track condition.

Following are the features of TMS:

1. **Digitalization of data:** TMS converts paper based records into digital format.
2. **Centralized database:** Provides centralised platform for storing and managing track information.
3. **Proactive maintenance:** TMS helps in maintaining activities based on data analysis and asset condition, enables proactive maintenance and preventing potential issues.
4. **Enhanced safety:** By identifying potential track defects early and facilitating timely maintenance.

Following are the advantages of track management system (TMS).

1. **Asset management:** TMS keeps a track of all track components (rails, sleepers, ballast etc. This enables efficient maintenance and planning.
2. **Track inspection and monitoring:** TMS integrates with technology like laser sensor and ultrasonic testing to monitor track geometry. Rail wear and other parameters.
3. **Maintenance planning and scheduling:** TMS collects data to schedule routine maintenance repairs and track renewals. It optimises resource allocation.
4. **Material Management:** TMS tracks the inventory of track materials including their location quantity and usage.

End of Solution

Q.7 (c) (ii) What is the role of ground water in the success of tunnelling? Explain the bearing of lithology and geological structures in this context.

[10 marks : 2025]

Solution:

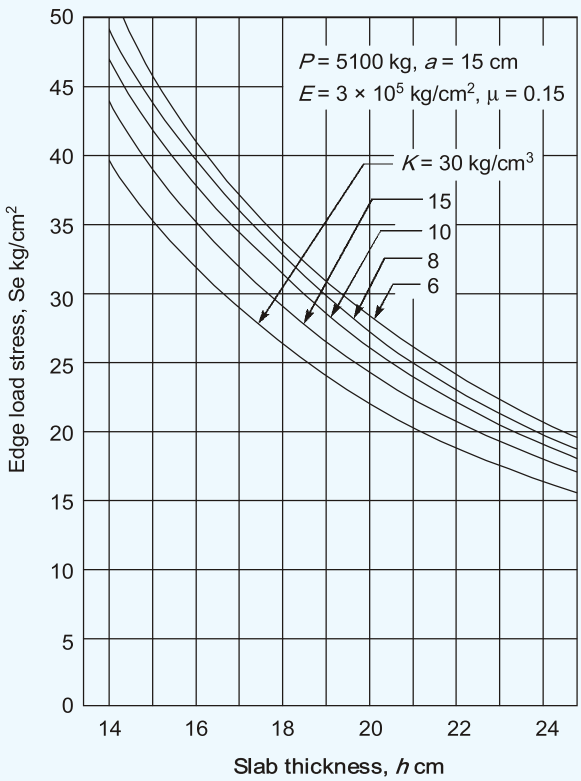
Ground water plays a decisive role in how smoothly or safely a tunneling project progresses. Its presence can either be a manageable factor or a major obstacle depending on how it is handled,

- Influence on stability: If groundwater around tunnel is not controlled it can weaken surrounding soil, increasing the risk of collapse.
- Impact on construction method: Level and movement of groundwater often determines the method of excavation and lining system.
- Safety and working conditions: Excess water infiltration can make working conditions unsafe by creating slippery condition.
- Cost and time factors: Effective groundwater management systems helps reduce construction delays and unexpected cost.

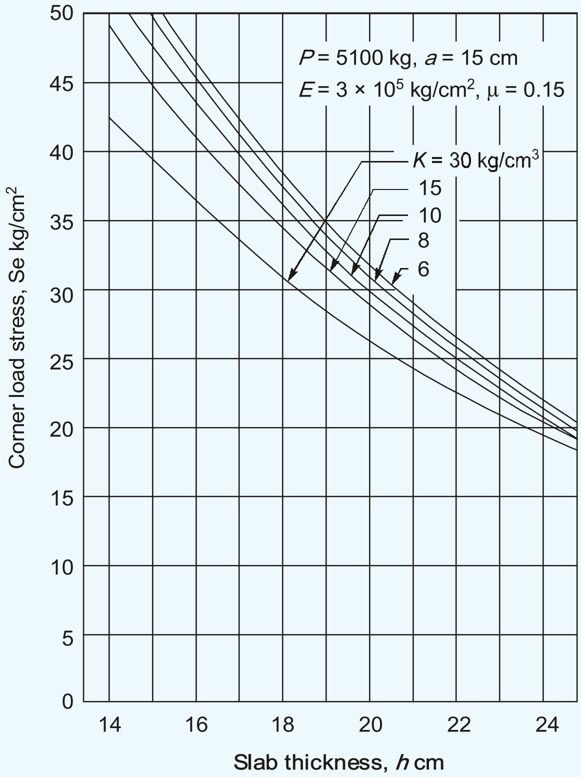
  Just like groundwater, type of rock (lithology) and arrangement of geological structures. Such as faults, joints and bedding planes, have a decisive role on success of tunneling.
- Role of lithology: The physical properties of rock or soil-whether it is hard granite, soft clay or fractured shale-directly control how easy or difficult it is to excavate strong and massive rocks provide natural support, whereas weak or weathered materials demand reinforcement and careful excavation method.
- Role of geological structures: Discontinuities like joints, faults, beding planes act like plane of weakness. Their orientation relative to tunneling can either aid excavation by breaking rock easily or create instability by forming shading or collapsing blocks.
- Combined effect: Lithology decides the inherent strength of ground while geological structures decide how that strength is distributed.

End of Solution

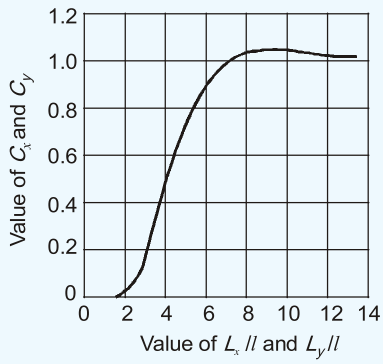
Q.8 (a) A CC pavement slab of thickness 20 cm is constructed over a granular sub-base having modulus of reaction 15 kg/cm^2. The maximum temperature difference between the top and bottom of the slab during summer day and night is found to be 18°C. The spacing between the transverse contraction joint is 4.5 m and that between longitudinal joint is 3.5 m. The design wheel load is 5100 kg, radius of contact area is 15 cm, E value of CC is 3×10^5 kg/cm^2, Poisson's ratio is 0.15 and coefficient of thermal expansion of CC is 10×10^{-6} per °C and friction coefficient is 1.5. Using the edge and corner load stress charts given by IRC and the chart for the warping stress coefficient (given below), find the worst combination of stresses at the edge.



C-1 – Edge Load Stress Chart (IRC)



C-1 – Corner Load Stress Chart (IRC)



C-3 – Warping Stress Coefficient

[10 marks : 2025]

Solution:

Thickness of slab, $h = 20$ cm

Modulus of reaction, $k = 15$ kg/cm^2

Temperature difference $\Delta T = 18°C$

Spacing between transverse contraction joints, $L_x = 4.5$ m

Spacing between longitudinal joint, $L_y = 3.5$ m

Design wheel load, $P = 5100$ kg

Radius of contact area, $a = 15$ cm

E value of CC $= 3 \times 10^5$ kg/cm^2

Poisson's ratio, $\mu = 0.15$

Coefficient of thermal expansion, $\alpha = 10 \times 10^{-6}/°C$

Coefficient of friction, $f = 1.5$

Worst combination of stresses at the edge = ?

- **Edge load stress:**

  For, $h = 20$ cm, $k = 15$ kg/cm^3

  From given Edge Load Stress chart

  $$S_e = 24 \text{ kg/cm}^2$$

- **Warping stress**

  Radius of relative stiffness

$$l = \left[\frac{Eh^3}{12K(1-\mu^2)}\right]^{\frac{1}{4}}$$

$$\Rightarrow \quad l = \left[\frac{3\times10^5\times20^3}{12\times15(1-0.15^2)}\right]^{\frac{1}{4}} = 60.77 \text{ cm}$$

$$\therefore \quad \frac{L_x}{l} = \frac{4.5\text{ m}}{60.77\text{ cm}} = \frac{450}{60.77} = 7.4$$

$$\frac{L_y}{l} = \frac{3.5\text{ m}}{60.77\text{ cm}} = \frac{350}{60.77} = 5.76$$

From given Warping stress coefficient chart

$$C_x = 1.01 \text{ and } C_y = 0.86$$

Warping stress at edge

$$S_{ew} = \max\left\{\frac{C_x E\alpha\Delta T}{2}, \frac{C_y E\alpha\Delta T}{2}\right\}$$

$$\Rightarrow \quad S_{ew} = \frac{1.01\times 3\times 10^5 \times 10\times 10^{-6}\times 18}{2} = 27.27 \text{ kg/cm}^2$$

- **Frictional stress**

$$S_{ef} = \frac{WLf}{2\times 10^4}$$

Assume: Unit weight of concrete, $W = 2400$ kg/m^3

$$\therefore \quad S_{ef} = \frac{2400\times 4.5\times 1.5}{2\times 10^4}$$

$$\Rightarrow \quad S_{ef} = 0.81 \text{ kg/cm}^3$$

Critical combination of stresses at the edge bottom during mid day in summer

$$= S_e + S_{ew} - S_{ef}$$
$$= 24 + 27.27 - 0.81$$
$$= 50.46 \text{ kg/cm}^2$$

End of Solution

Q.8 (b) What is geosynthetic clay liner? Discuss its application in Civil Engineering Construction Work.

[10 marks : 2025]

Solution:

A geosynthetic clay liner is an engineered material used as a barrier in construction. It is an impermeable material typically consisting of sodium bentonite clay placed between two layers of geotextile or bonded to geomembrane.

Types of geosynthetic clay liners (GCLs):

GCLs are characterized based on how they are constructed and needs of a specific project. The main types are:

1. **Non reinforced GCL:** Made from bentonite clay with a basic geotextile cover.
2. **Reinforced GCL:** Reinforced with methods such as needle punching or stitch bonding which improve their strength.
3. **Composite GCL:** A reinforced type of GCL that also includes an geomembrane layer. This increases the permeability and makes it move durable.

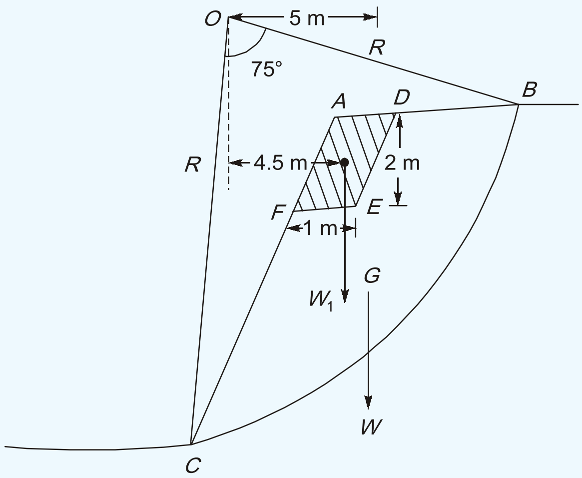
Following are its uses in civil engineering:

1. **Landfill liners:** GCLs are widely used in landfill construction as both base liners and final covers system to contain leachate and prevent contamination of groundwater.
2. **Ponds and Reservoirs:** GCLs are employed to line ponds, reservoirs and canals, minimizing water loss through seepage and covering water resources.

3. **Secondary containment:** They are used to create protective barriers and around industrial storage tanks for fuel, chemicals and other hazardous materials, preventing spills from reaching environment.
4. **Erosion control:** GCLs can be used in conjunction with other geosynthetic to stabilize slopes and prevent erosion.

End of Solution

Q.8 (c) (i)



Find the factor of safety at the slope shown in the diagram, if the shaded portion *ADEF* is removed. At what distance the line load of 150 kN will act for a minimum factor of safety as 1?

The properties of the soil of the slope are:

Cohesion = 21 kN/m^2

Bulk density = 19kN/m^3

Angle of shearing resistance = 0

Weight of the area *ABC* = *W* = 350 kN

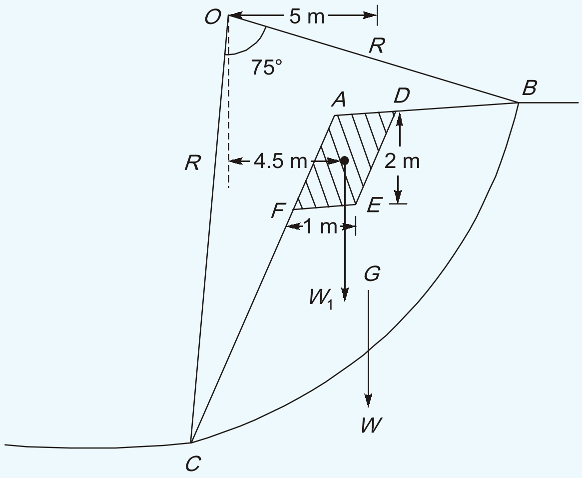
Distance of centre of gravity of the area *ABC* is 5 m.

Distance of centre of gravity of shaded portion *ADEF* is 4.5 m

The radius of Arc is 10 m

[10 marks : 2025]

Solution:



Given:

Cohesion, $C = 21\ \text{kN/m}^2$

Bulk unit weight, $\gamma_t = 19\text{kN/m}^3$

Weight of the area *ABC*, $W = 350$ kN, $\bar{x}_w = 5$ m

Distance of centre of gravity of shaded portion *ADEF* is $\overline{x_{w1}} = 4.5$ m

The radius of arc, $R = 10$ m

$$\text{FOS} = \frac{\text{Resisting moment}}{\text{Overturning moment}}$$

$$\text{FOS} = \frac{C\widehat{L}_{CB}R}{W\bar{x}_w - W_1\bar{x}_{w_1}}$$

Where;

$$\widehat{L}_{CB} = R\theta = 10 \times 75 \times \frac{\pi}{180} = 13.0899 \text{ m}$$

$\Rightarrow$ W_1 = Volume of portion ADEF) γ_t

$\Rightarrow$ $W_1 = (1 \times 2 \times 1) \times 19$

$\Rightarrow$ $W_1 = 38$ kN

$$\text{FOS} = \frac{21 \times 13.0899 \times 10}{350 \times 5 - 38 \times 4.5}$$

$\Rightarrow$ FOS = 1.74

Let distance of line load of 150 kN from center of arc is x

FOS = 1

$$\Rightarrow \frac{C\widehat{L}_{CB}R}{w\bar{x}_w - w_1\bar{x}_{w_1} + (\text{line load})x} = 1$$

$$\Rightarrow \frac{21 \times 13.0899 \times 10}{350 \times 5 - 38 \times 4.5 + 150x} = 1$$

$\Rightarrow$ $x = 7.799 \text{ m} \simeq 7.8 \text{ m}$

End of Solution

Q.8 (c) (ii) Explain the effect of sudden drawdown on the stability of unstream slope.

[10 marks : 2025]

Solution:

When a reservoir is maintained at a high level for a sufficiently long time, the upstream slope becomes fully saturated and steady-state seepage conditions are established. If the water level in the reservoir is lowered rapidly, the stabilising hydrostatic pressure exerted by the water on the upstream face is removed instantly while the soil mass in the slope remains saturated because pore water pressure does not have time to dissipate. It is one of the most critical cases for upstream slope stability.

The immediate effect is that the saturated weight of the slope continues to act, producing large shearing stresses along potential slip surfaces, whereas the shearing resistance is reduced due to the high pore water pressure that develops within the embankment. As effective stress is decreased, the shear strength of the soil decreases sharply. Thus, the factor of safety under sudden drawdown is much lower than under steady seepage or full reservoir conditions.

As time progresses, pore water pressures within the embankment dissipate gradually, effective stress is restored and the stability of slope improves. However, immediately after drawdown, absence of external water support combined with internal pore pressure makes the slope highly susceptible to sliding.

End of Solution

Q.8 (d) (i) A closed traverse was conducted round an obstacle and the following observations were made:

Line	Length (m)	Azimuth
AB	400	95°0′
BC	496	32°30′
CD	375	302°30′
DE	?	225°0′
EA	?	150°30′

Compute the missing quantities.

[10 marks : 2025]

Solution:

Assume missing lengths of traverse are, l_1 and l_2.

Line	Length (m)	Bearing (WCB)
AB	400	95°0′
BC	496	32°30′
CD	375	302°30′
DE	l_1	225°0′
EA	l_2	150°30′

Sum of latitudes

$$\Sigma(L) = 400\cos(95°\,0') + 496\cos(32°\,30') + 375\cos(302°\,30') + l_1\cos(225°\,0') + l_2\cos(150°\,30')$$

For a closed traverse, $\Sigma(L) = 0$

$\Rightarrow \quad -0.7071\, l_1 - 0.87035\, l_2 = -584.9472$

$0.7071\, l_1 + 0.87035\, l_2 = 584.9472 \quad \text{...(i)}$

Sum of departures

$\Sigma(D) = 400 \sin(95° \, 0') + 496 \sin(32° \, 30') + 375 \sin(302° \, 30') + l_1 \sin(225° \, 0') + l_2 \sin(150° \, 30')$

For a closed traverse, $\Sigma(D) = 0$

$\Rightarrow \quad -0.7071\, l_1 + 0.49242\, l_2 = -348.7067 \quad \text{...(ii)}$

Solving equations (i) and (ii)

$l_1 = 613.87$ m

$l_2 = 173.35$ m

End of Solution

Q.8 (d) (ii) Discuss how the topographical expressions like faults and folds control civil engineering projects such as tunnels, bridges, dams and reservoirs.

[10 marks : 2025]

Solution:

Faults are fractures in the rock along which some relative movement has taken place, whereas folds are bends or curvatures formed in rock strata due to compressive forces in the Earth's crust. Both of these geological features are frequently encountered in hilly or tectonically disturbed regions, and they have a direct impact on the planning, design and execution of major civil engineering projects such as tunnels, bridges, dams and reservoirs. If these features are not properly studied, they can lead to cost overruns, delays or even failures of structures.

In the case of tunnels, the presence of faults makes excavation extremely challenging. The rock along a fault plane is usually crushed, sheared and highly jointed, which means it has very low strength and cannot stand unsupported. These zones are also often water-bearing because faults act as conduits for groundwater. As a result, the tunneling face may collapse unexpectedly, there may be sudden inflows of water and the ground may deform excessively. Sometimes, even the alignment of tunnel has to be modified to avoid crossing any major faults. If bridge piers or abutments are located on such faulty or sheared rocks, there is a risk of differential settlement or even tilting of structure over time. An active fault is even more dangerous because any seismic movement can directly damage the foundation. Faults under a dam axis or in the reservoir basin are hazardous since they act as seepage paths which not only cause loss of water but also generate uplift pressure below the dam.

On the other hand, folds pose different kinds of challenges to civil engineering projects. When a tunnel passes through anticlines and synclines, the overburden thickness keeps changing, and the bedding dips may expose alternating hard and soft layers. This causes varying rates of advance, frequent changes in drilling and blasting patterns, and uneven load on the lining. If the folded strata dips steeply in different directions at each end of the bridge, the bearing capacity becomes uneven. This condition will possibly require unequal foundation depths for bridges. Although, tight well-cemented folds made of impervious rocks like granite or basalt may hold water well and be suitable for dams, open folds with fractured crests or weak layers can allow seepage along bedding planes.

End of Solution

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