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ESE - 2025

MAINS EXAMINATION

QUESTIONS WITH DETAILED SOLUTIONS

CIVIL ENGINEERING

(Paper-2)

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CIVIL ENGINEERING

ESE _MAINS_2025_PAPER – II

Questions with Detailed Solutions

SUBJECT WISE WEIGHTAGE

S.No.	NAME OF THE SUBJECT	Marks
01	Fluid Mechanics & Hydraulic Machines	94
02	Hydrology	12
03	Irrigation Engineering	20
04	Environmental Engineering	114
05	Geotechnical Engineering	114
06	Surveying and Geology	62
07	Transportation Engineering	64
	Total Marks	**480**

SECTION-A

01.

(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 we11 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 M]

Sol:

Given Data:

Well diameter (initial) $D_1 = 0.30$ m → well radius $r_1 = 0.15$ m

New well diameter $D_2 = 0.60$ m → well radius $r_2 = 0.30$ m

Permeability (hydraulic conductivity) k = 60 m/day

Drawdown at the well s = 4.5 m

Initial discharge $Q_1 = 2100$ *l*/min

Radius of influence R = 450 m

For a fully penetrating well under steady-state flow in a confined aquifer, the Thiem equation applies:

$$Q = \left(\frac{2\pi kbs}{\ell n\left(\frac{R}{rw}\right)}\right)$$

For fixed aquifer properties and same drawdown s, Q is inversely proportional to $\ell n\left(\frac{R}{rw}\right)$ Hence:

$$\frac{Q_2}{Q_1} = \frac{\ell n\left(\frac{R}{r_1}\right)}{\ell n\left(\frac{R}{r_2}\right)}$$

$$\frac{R}{r_1} = \frac{450}{0.15} = 3000 \rightarrow \ln(3000) \approx 8.006367568$$

$$\frac{R}{r_2} = \frac{450}{0.30} = 1500 \rightarrow \ln(1500) \approx 7.313220387$$

$$Q_2 = Q_1 \times \left[\frac{\ell n(3000)}{\ell n(1500)}\right]$$

$$Q_2 = Q_1 \times \left(\frac{8.006367568}{7.313220387}\right) = Q_1 \times 1.09478$$

$$= Q_1 + 0.09478\ Q_1 = Q_1 + \left(\frac{9.478}{100}\right)Q_1$$

Therefore, percentage increase in discharge = 9.478 %

$Q_2 = Q_1 \times 1.09478$

$= 2100 \times 1.09478 = 2299.04$ l/min

Conclusion:

- Doubling the well diameter from 0.30 m to 0.60 m does not double the discharge.
- The discharge increases from 2100 l/min to approximately 2299 l/min.
- The percentage in increase is about 9.478%.

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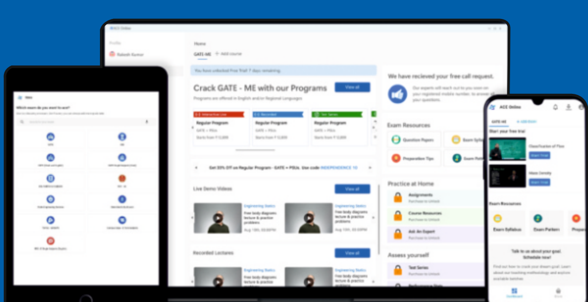

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(b). Describe briefly (1-2 sentences each) with sketch the following hydroelectric power plants:

(i) Run-of-River plant

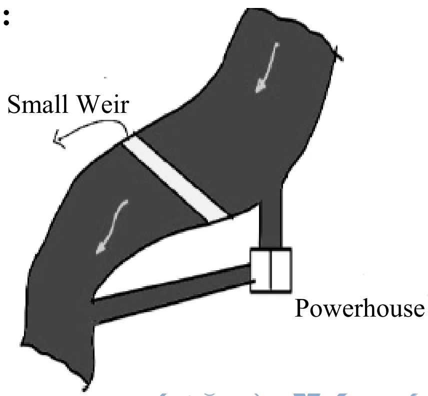
(ii) Valley Dam plant

(iii) Diversion Canal plant

(iv) High head diversion plant **[12 M]**

Sol:

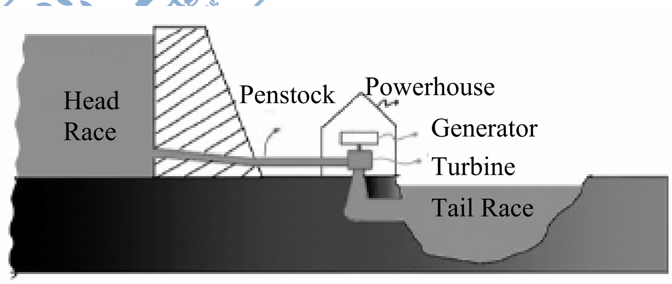
(i). Run of River (ROR) Plants:



→ ROR plant generates electricity using natural flow of river with minimal or no water storage.

→ These plants are small and seasonal.

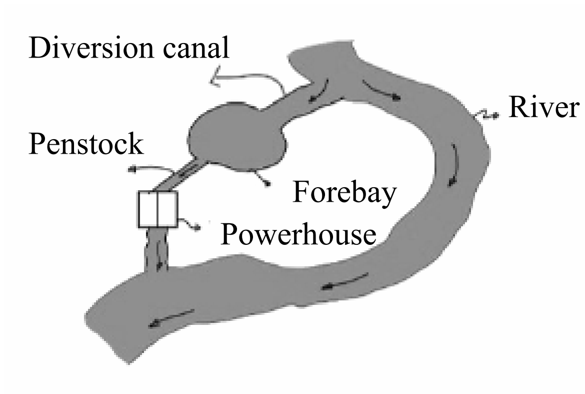
(ii). Valley Dam plants:



→ Valley dam plants also known as storage or reservoir plants where a large dam is constructed on a river valley.

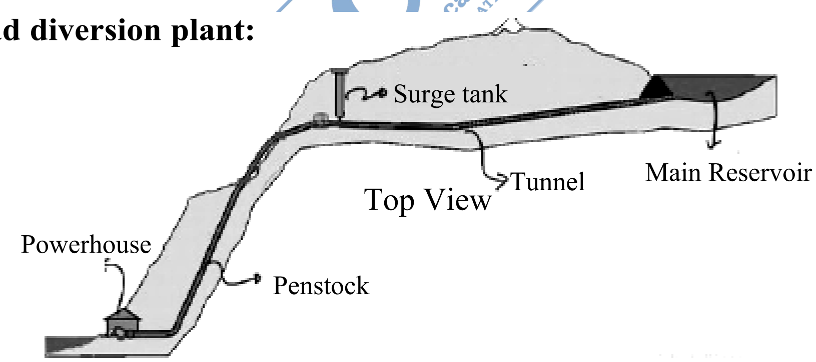
→ The powerhouse is located at the base of reservoir which supplies water to turbine in controlled and reliable manner throughout the year.

(iii). Diversion Canal Plants:



→ A diversion canal plant redirects a portion of river flow into a canal that runs along a gentle slope. After traveling some distance water is dropped through penstock into a powerhouse utilizing the elevation difference between canal and the downstream river to generate the power.

(iv). High head diversion plant:



→ A high head diversion plant is a type of plant specially designed for mountainous regions to utilize large vertical drop.

→ Water is diverted from reservoir at high elevation into power house located deep inside valley through system of tunnels and penstocks.

(c). Consider a 50° triangular channel having a flow rate $Q = 16\ m^3/s$ and $n = 0{\cdot}018$.

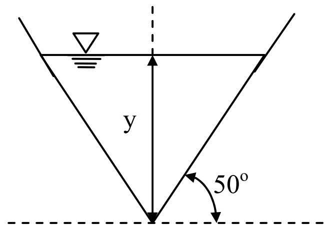
Compute

(i) the critical depth

(ii) critical velocity, and

(iii) critical slope

Take $\alpha = 1.0$ and $g = 9.81\ m/s^2$ **[12 M]**



Sol:

Given

$Q = 16\ m^3/s$

$n = 0.018$

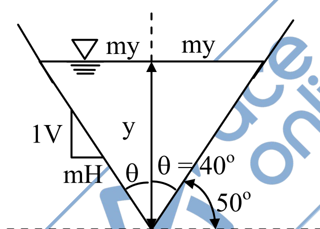
$\alpha = 1$

$g = 9.81\ m/s$

$\therefore\ 2\theta = 80^o$

$m = \tan\theta$

$m = \tan 40^o = 0.839 = 0.84$



Critical flow Condition:

$F_r = 1$

$$\frac{Q^2}{g} = \frac{A^3}{T}$$

$A = my^2;\ T = 2my$

$$\frac{Q^2}{g} = \frac{(my_c^2)^6}{2my_c}$$

$$y_c = \left[\frac{2Q^2}{gm^2}\right]^{\frac{1}{5}}$$

(i). $y_c = \left[\dfrac{2\times16^2}{9.81\times0.84^2}\right]^{\frac{1}{5}} = 2.365\text{ m}$

(ii). $F_r = \dfrac{V_c}{\sqrt{gD}} = 1$

For triangle: $D = \dfrac{y_c}{2}$

$$V_c = \sqrt{g.\frac{y_c}{2}}$$

$$V_c = \sqrt{9.81\times\frac{2.365}{2}} = 3.406\text{ m/s}$$

From Manning's equation

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

At critical state, $V = V_c$

$S = S_c$

$$R = \frac{A}{P} = \frac{my_c^2}{2y_c\sqrt{1+m^2}}$$

$$R = \frac{0.84\times2.365^2}{2\times2.365\times\sqrt{1+0.84^2}} = 0.76$$

$$\therefore 3.406 = \frac{1}{0.018}\times0.76^{2/3}.S_c^{1/2}$$

$$\therefore S_c = 5.42\times10^{-3}\text{ (or) }\frac{1}{184.52}$$

(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*; $C1^-$ = 71 mg/*l*; Ca^{+2} = 100 mg/*l*.

Find the % error in cation-anion balance. Also draw a bar diagram to inpicate cation-anion balance. Comment on the Result of cation-anion balance error %. [12 M]

Sol:

Ion	Given (mg/L)	Mol wt	Eq. wt	m.eq/L
HCO_3^-	300	61	61	492
SO_4^{2-}	240	96	48	5
Cl^-	71	71	35.5	2
Na^+	115	23	23	5
Mg^{2+}	36.6	24	12	3.05
Ca^{2+}	100	40	20	5

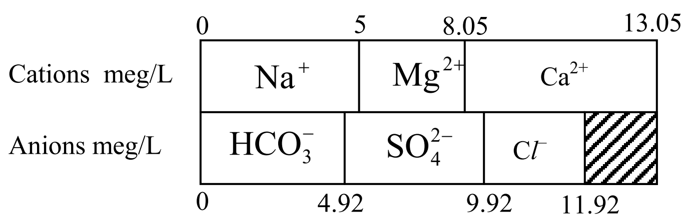
$$\because \frac{\text{m.eq}}{\text{L}} = \frac{\text{mg/L}}{\text{eq.wt}}$$

$$\Sigma\text{Anion} = 4.92 + 5 + 2 = 11.92 \text{ meq/L}$$

$$\Sigma\text{Cations} = 5 + 3.05 + 5 = 13.05 \text{ meq/L}$$

$$\%\,\text{error} = \frac{|\Sigma C - \Sigma A|}{\Sigma C + \Sigma A} \times 100 = 4.5\%$$

Cation-anion balance:



Acceptable % Error:

Cation-Anion balance errors below 5% are generally considered acceptable for water analysis. A value of 4.5% indicates the analysis is sound and reliable.

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

Population of town = 10 lakhs

Wastewater contribution = 100 *l*pcd

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 M]

Sol: Population = 10 lakhs

Percapita generation = 100 LPCD

BOD in settled sludge = 180 mg/L

Effluent BOD = 30 mg/L

F/M = 0.2 d^{-1}

MLSS = 2800 mg/L

SVI = 100

Volume of aeration:

$$F/M = \frac{Q_1 S_i}{VX}$$

$$V = \frac{10^6 \times 100 \times 180\,mg/d}{2800\,mg/L \times 0.2/d} = 3.21 \times 10\ l$$

$V = 32143\ m^3$

HRT: $\frac{V}{Q} = \frac{32143\,m^3}{10^5\,m^3/d}$

H.R.T = 7.71 hr

V.L.R: $\frac{Q_i S_i}{V}\,kg/d/m^3$

$$= \frac{10^8\,\ell/d \times 180\,mg/L}{32143\,m^3} = 0.56\ kg/d/m^3$$

Return sludge ratio:

$$R = \frac{Q_R}{Q} = \frac{X}{X_u - X}$$

$$X_u = \frac{10^6}{SVI} = 10^4\ mg/L$$

$$R = \frac{2800}{10000 - 2800} = 0.388 = 0.39$$

- **HRT (7.7 hr):** Typical HRT for conventional ASP is 6–8hr; thus, matches design standards.
- **Return Sludge Ratio (0.28):** Values between 0.25 – 0.5 are acceptable.
- **SVI (100):** Typical for good settling sludge, so satisfactory.
- **F/M = 0.2 d^{-1}:** lower end of conventional (≈ 0.3 – 0.5)

02.
(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 m^3/m^2/day; Depth of PST = 2.5 m

Rate of filtration = 5000 *l*/m^2/hr; Quantity of backwash water = 15%

Time for backwashing = 1 hr **[12 M]**

Sol: $V_o = 50\ m^3/m^2/d$ (P.S.T)

Depth = 2.5 m (P.S.T)

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

% B.W = 15%

Time of backwash = 1 hr

$Q = 10 \times 10^6\ l/d = 10 \times 10^3\ m^3/d$

(A) Surface area of P.S.T:

$$V_o = \frac{Q}{A_s}$$

$$A_S = \frac{10 \times 10^3\ m^3/d}{50\ m^3/m^2/d}$$

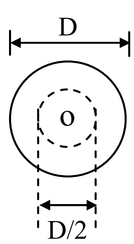
$$A_S = 200\ m^2$$

$$\text{Detention time; } D_t = \frac{V}{Q}$$

$$D_t = \frac{A \times H}{Q} = \frac{200 \times 2.5\ m^3}{10 \times 10^3\ m^3/d}$$

$$D_t = 0.05 d = 1.2\ hr$$

(B) Horizontal velocity (avg):



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

$$D = \sqrt{\frac{4}{\pi} \times 200} = 15.96 \text{ m}$$

$$V = \frac{Q}{A_{C/S}} = \frac{Q}{\text{circumference} \times \text{depth}}$$

$$= \frac{Q}{\pi\left(\frac{D}{2}\right) \times 2.5\,\text{m}}$$

$$= \frac{10^4\,\text{m}^3/\text{d}}{3.14\left(\frac{15.96}{2}\right) \times 2.5\,\text{m}^2}$$

$= 159.5$ m/d

$= 0.11$ m/min

(C) Surface area of R.S.F:

$$Q_{\text{filtration}} = \frac{Q}{[1 - 0.15]}$$

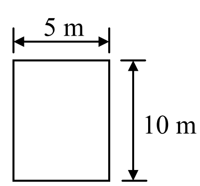
$$\mathbf{= 11.76\ MLD}$$

$$A_{\text{filtration}} = \frac{Q}{\text{ROF}} = \frac{11.76 \times 10^3\,\text{m}^3/\text{d}}{5\,\text{m}^3/\text{m}^2/\text{hr}} = 98\,\text{m}^2$$

(D) Number of Filters:

$$N = \frac{A_F}{A_{\text{each filter}}}$$

(Assume area of each filter = 50 m^2)



$$N = \frac{98}{50} = 1.96 \approx 2\,\text{filters}$$

Let number of stand by filters = 1

$\therefore$ Total filters = 2 + 1 = 3

Let L = 2B $\Rightarrow$ L = 10 m; B = 5 m

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

[8 M]

Sol: Mechanisms Responsible for Removal

The main mechanisms of colloid removal during coagulation are:

(a). Double Layer Compression

- When a coagulant is added, it dissociates into positively charged ions (e.g., Al^{3+} from alum, Fe^{3+} from ferric chloride).
- These counter-ions migrate towards the negatively charged colloid surface, compressing the electrical double layer.
- Compression reduces the thickness of the double layer, thus reducing the range of electrostatic repulsion.
- With less repulsion, colloids can approach closely, and Van der Waals attraction dominates, allowing particles to stick together.

(b). Charge Neutralization

- High-charge cations from the coagulant directly neutralize the negative surface • charge of colloids.
- The zeta potential approaches zero (isoelectric point), and particles lose their mutual repulsion entirely.
- Brownian motion, mixing, and fluid shear then cause particle collisions and sticking.
- Effective with low doses of coagulant in low-turbidity water.

(c). Sweep Flocculation (Enmeshment in Precipitate)

- At higher coagulant doses and appropriate pH, the metal salts hydrolyze to form insoluble metal hydroxide precipitates (e.g., $Al(OH)_3$, $Fe(OH)_3$).
- These precipitates form a voluminous gelatinous floc that physically traps and enmeshes colloidal particles as it settles.

- This mechanism is dominant in conventional water treatment when alum or ferric salts are added at doses sufficient to exceed solubility.
- Sweep flocculation is less sensitive to exact zeta potential values, and it can remove both colloidal and some dissolved organic matter.

(d). Interparticle Bridging

- When high molecular weight polymers are used as coagulants or coagulant aids, long-chain polymer molecules adsorb onto the surfaces of multiple particles simultaneously.
- These chains act as "bridges" between particles, linking them into larger flocs.
- Common with synthetic organic polymers (e.g., polyacrylamides) or natural polyelectrolytes.

(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/m^3. Assume ratio of solid waste to soil cover as 4 : 1. [20 M]

Sol: Given Data:

Population = 5 lakhs = 500,000

Per capita waste generation = 0.5 kg/day

Landfill life = 30 years

Maximum landfill height = 20 m

Density of compacted waste = 450 kg/m^3

Solid waste: Soil cover ratio = 4 : 1

Total Waste Generated in 30 Years

Daily waste = population × per capita waste = 500,000 × 0.5 = 250,000kg/day

Annual waste = 250,000 × 365 = 91,250,000 kg/year

Waste for 30 Years

Total waste (kg) = 91,250,000 × 30 = 2,737,500,000 kg

Convert to Volume (Solid Waste Only)

$$\text{Volume of waste} = \frac{\text{Total waste (kg)}}{\text{Density (kg/m}^3)} = \frac{2737500000}{450} = 6083333.33\,\text{m}^3$$

Add soil cover

Since the solid waste : Soil cover ratio is 4 : 1

$$\text{Soil volume} = \frac{\text{Waste volume}}{4} = \frac{6083333.33}{4} = 7604166.66\ \text{m}^3$$

Total landfill volume =6083333.33+1520833.33=7604166.66 m^3

Required Area

Landfill height = 20 m

$$\text{Required area} = \frac{\text{Total landfill volume}}{\text{Landfill height}} = \frac{7604166.66}{20} = 380208.33\ \text{m}^2$$

1 hectare = 10000 m^2

$$\text{Area in hectares} = \frac{380208.33}{10000} = 38.02$$

Total landfill volume needed (incl. soil cover): 7,604,166.66m^3

Required landfill area (at 20m height): 380,208.33m^2 or 38.02 hectares

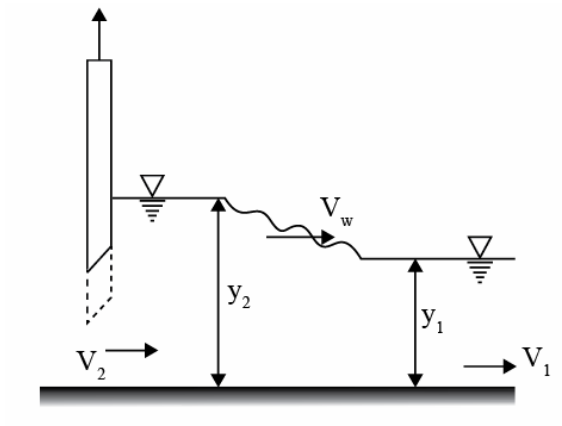
Therefore, the area required for the proposed landfill is approximately 38 hectares

(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 M]

Sol:

If sluice gate is suddenly raised, a +ve surge will generate on downstream and moves towards downstream



Given: $Q_1 = 4.80\ m^3/s$

$V_1 = 0.8$ m/s

B = 4 m

$$y_1 = \frac{Q_1}{V_1 \times B}$$

$$y_1 = \frac{4.8}{0.8 \times 4}$$

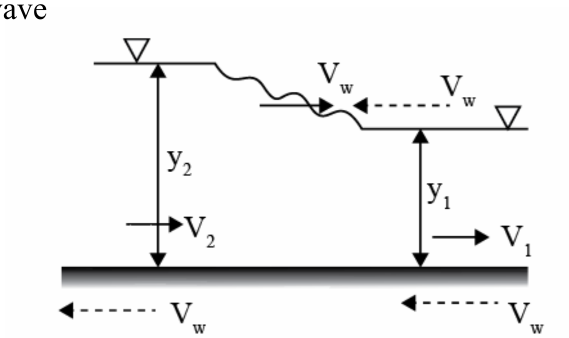
$y_1 = 1.5$ m

Due to sudden lifting, depth increases by 50%.

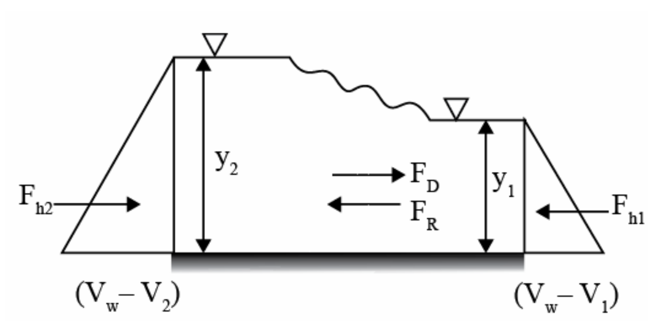
So, $y_2 = 1.5\ y_1$

$= 1.5 \times 1.5 = 2.25$ m

As surge is unsteady in nature, analysis can be done by applying a magnitude of velocity "V_w" opposite to direction of surge wave



Equivalent steady state



From Continuity Equation:

$A_1 (V_w - V_1) = A_2 (V_w - V_2)$

$B.y_1 (V_w - V_1) = B.y_2 (V_w - V_2)$

$V_w y_1 - V_1 y_1 = V_w y_2 - V_2 y_2$

$$V_w = \frac{V_2 y_2 - V_1 y_1}{y_2 - y_1} \ldots\ldots\ldots\ldots \rightarrow (1)$$

From momentum principle

$F_{net} = \rho Q [(V_w - V_2) - (V_w - V_1)]$

$$F_{h_2} + F_D + F_R - F_{h_1} = \rho Q_1 [V_1 - V_2]$$

As surge occurs in short span, channel bottom is assumed as horizontal and frictionless.

$F_D = 0$

$F_R = 0$

$$F_h = \gamma_w A\bar{Z}$$

$$\text{Rectangle: } \bar{Z} = \frac{y}{2}$$

$$\frac{\rho g}{2} \times B[y_2^2 - y_1^2] = \rho \times B y_1 (V_w - V_1)[V_1 - V_2] \ldots\ldots\ldots\ldots \rightarrow (2)$$

From (1) and (2)

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

From data

$$V_w - 0.8 = \sqrt{\frac{g}{2} \cdot \frac{1.5 y_1}{y_1} \times (1.5 + 2.25)}$$

$\therefore\ V_w = 6.053$ m/s

So, absolute velocity of surge wave, $V_w = 6.05$ m/s

From continuity equation

$y_1 (V_w - V_1) = y_2 (V_w - V_2)$

$1.5\,[6.05 - 0.8] = 2.25\,[6.05 - V_2]$

$\therefore\ V_2 = 2.55$ m/s

New flow rate, $Q_2 = By_2\,V_2$

$= 4 \times 2.25 \times 2.55 = 22.95$ m^3/s

03.

(a). A dam discharges 254.7 m^3/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/s^2; ρ = 1000 kg/m^3. [15 M]

(ii) How much energy is lost from the foot of the spillway to the downstream side of jump? [5 M]

Sol:

(i) Given:

$Q = 254.7$ m^3/s

$n = 0.013$

$V = 12.8$ m/s

$B = 54.86$ m

Tail-water depth

$y_t = 3.05$ m

- Hydraulic jump can occur either at foot of spillway (free jump) or away from foot of spillway (Repelled jump)
- Assume free jump occurred. So, pre jump depth is the depth at foot of spillway

$$y_1 = \frac{Q}{B.V_1} = \frac{254.7}{54.86 \times 12.8} = 0.363$$

$$Fr_1 = \frac{V_1}{\sqrt{gD}} = \frac{V_1}{\sqrt{gy_1}}$$

$$Fr_1 = \frac{12.8}{\sqrt{9.81 \times 0.363}} = 6.783$$

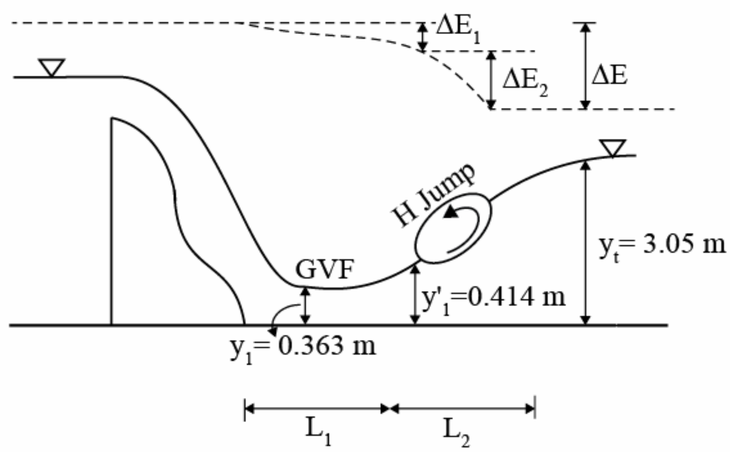
$$\frac{y_2}{y_1} = \frac{-1+\sqrt{1+8Fr_1^2}}{2}$$

$$\frac{y_2}{0.363} = \frac{-1+\sqrt{1+8\times 6.783^2}}{2}$$

$\therefore$ $y_2 = 3.305$ m

Given tail water depth, $y_t = 3.05$ m

As $y_t < y_2$ then jump occurs away from foot of spillway, Repelled jump occurs and pre jump depth is conjugate depth of tail water depth



So, if tail water depth is post-jump depth then its conjugate depth as pre-jump depth can be calculated as

$$\frac{y'_1}{y_t} = \frac{-1+\sqrt{1+8Fr_t^2}}{2}$$

$$V_t = \frac{Q}{B.y_t} = \frac{254.7}{54.86\times 3.05}$$

$V_t = 1.52$ m/s

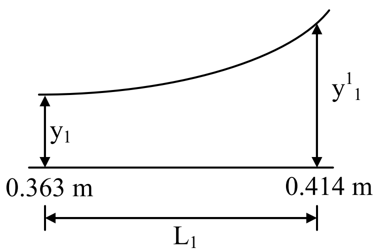
$$Fr_t^2 = \frac{1.52^2}{9.81\times 3.05} = 0.077$$

$$\therefore \frac{y'_1}{3.05} = \frac{-1+\sqrt{1+8\times 0.077}}{2}$$

$\therefore$ $y'_1 = 0.4136 = 0.414$ m

Length of apron = Length of GVF + length of H. Jump

Length of GVF, L_1:



$B = 54.86 \Rightarrow$ As $\frac{B}{y} >> 5$

Consider as wide rectangle

R = y

$$L_1 = \left|\frac{\Delta E}{S_o - \bar{S}_f}\right|$$

From Manning's equation

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

$$S = \frac{q^2 n^2}{y^{10/3}}$$

y: GVF depth

$S = S_f$

y	$V = \frac{Q}{By}$	$E = y + \frac{V^2}{2g}$	$S_f = \frac{q^2n^2}{y^{10/3}} = \frac{3.64\times10^{-3}}{y^{10/3}}$
0.363 m	12.79	8.7	$S_{f1} = 0.1067$
0.414 m	11.214	6.823	$S_{f2} = 0.069$
		$\Delta E = 1.876$ m	$\bar{S}_f = \frac{0.1067+0.069}{2} = 0.088$

$$L_1 = \left|\frac{\Delta E_1}{S_o - S_f}\right| = \left|\frac{1.876}{0-0.088}\right| = 21.318 = 21.32 \text{ m}$$

As apron is horizontal $S_o = 0$

Length of hydraulic jump, $L_2 = 6.1y_t$ As $Fr_1 = 5.56 > 4.5$

$L_2 = 6.1 \times 3.05 = 18.605$ m

Total length of apron $= L_1 + L_2 = 39.925$ m

(ii). Total energy lost from foot of spillway to end of jump

$$\Delta E = \Delta E_1 + \Delta E_2$$

$\Delta E_1 = 1.876$ m

$$\Delta E_2 = \frac{(y_t - y'_1)^3}{4y_t \times y_1^1}$$

$$\therefore \Delta E_2 = \frac{(3.05-0.414)^3}{4\times0.414\times3.05} = 3.626 \text{ m}$$

$\therefore \Delta E = 5.50$ m

(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 M]**

Sol:

Given data:

R.P = 6000 kW

H = 300 m

N = 550 rpm

$\frac{d}{D} = \frac{1}{10}$

$\eta_h = 0.85$

$k_u = 0.46$

$C_v = 0.98$

Find:

(A) Q =

(B) D =

(C) d =

(D) n_j =

$R.P = \eta_h \cdot \rho g Q H$

$6000 \times 10^3 = 0.85 \times 9810 \times Q \times 300$

$\therefore\ Q = 2.399 \simeq 2.4\ m^3/s$

$u = \frac{\pi D N}{60}$

$k_u \sqrt{2gH} = \frac{\pi D N}{60}$

$\therefore D = \frac{60.k_u \sqrt{2gH}}{\pi N}$

$= \frac{60 \times 0.46 \times \sqrt{2 \times 9.81 \times 300}}{\pi \times 550} = 1.225\ m$

$$d = \frac{D}{10} = 0.1225\ \text{m} = 12.25\ \text{cm}$$

$$V = C_v\sqrt{2gH}$$

$$V = 0.98 \times \sqrt{2 \times 9.81 \times 300} = 75.19\ \text{m/s}$$

Discharge through each nozzle is,

$$q = \frac{\pi}{4} \times d^2 \times V = \frac{\pi}{4} \times 0.1225^2 \times 75.19 = 0.886\ \text{m}^3/\text{s}$$

$$\text{Number of jets} = \frac{\text{Total discharge}}{\text{Discharge per jet}}$$

$$= \frac{2.4}{0.886} = 2.71 \simeq 3\ \text{jets are required}$$

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

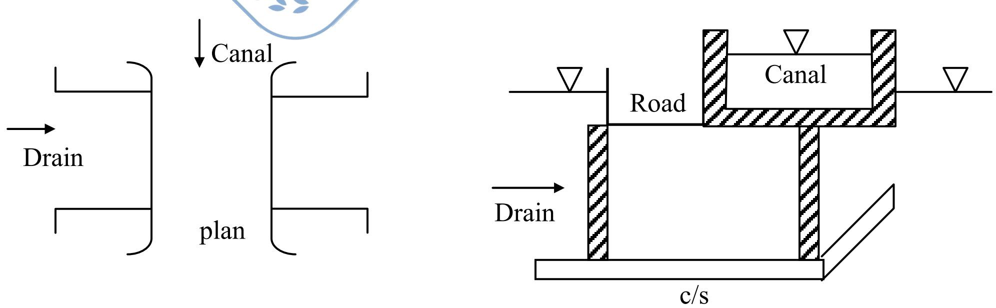
(A) Syphon aqueduct and canal syphon

(B) Aqueduct and superpassage **[10 M]**

Sol:

(A) Siphon aqueduct & canal siphon

Siphon aqueduct



Canal runs over the drain

$Q_{canal} <<< Q_{drain}$

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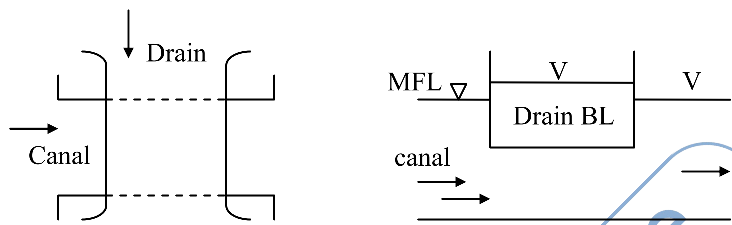
Maximum flood level of drain is at higher elevation than bed level of the canal so that drain water at the junction is subjected to siphonic action.

Canal siphon:

If the positions of canal and drain are swapped, siphon aqueduct becomes canal siphon.

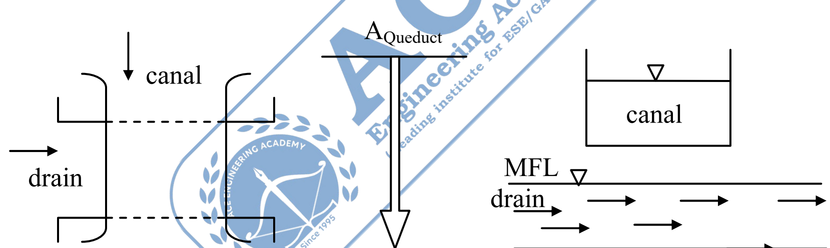


In canal siphon: $Q_{drain} <<< Q_{canal}$

Drain runs over the canal

MFL of canal is at higher elevation than bed level of drain so that canal water travels at –ve pressure at the junction.

(B). Aqueduct and super passage:



Canal runs over drain $Q_c <<<< Q_{drain}$

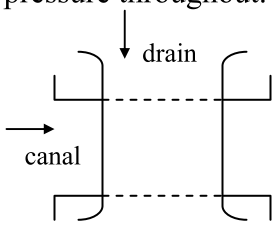
MFL of drain is at lower elevation than bed level of canal so that no siphonic action for drain water. It travels at atmospheric pressure throughout.

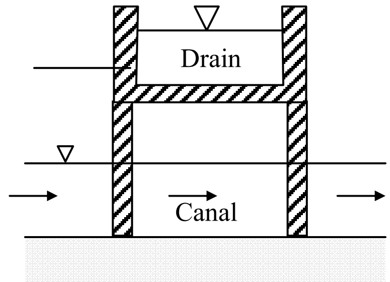
Super passage: drain runs over the canal

Q_{drain} : 15 – 30 m^3/s

Q_{canal} : 200 – 300 m^3/s

MFL of canal is at lower elevation than the bed level of drain so that canal water travels at atmospheric pressure throughout.





(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.

Determine the height of the chimney required for the industry. [10 M]

Sol: Given: Fuel consumption = 10,000 L/day.

Emission factors per 1 ML = 1,000,000 L/yr fuel:

- SPM (PM) = 3 t/yr per 1 ML
- SO_2 = 75 t/yr per 1 ML

Use formulas:

- SO_2: $H = 14\,Q^{0.3}$ (Q in kg/hr)
- PM: $H = 74\,Q^{0.27}$ (Q in t/hr)

Annual fuel consumption

Yearly fuel = 10,000 × 365 = 3,650,000 L/yr = 3.65 ML/yr

Scale factor = 3.65.

Annual emissions

Annual SO_2 = 75 × 3.65 = 273.75 t/yr = 273,750 kg/yr

Annual PM = 3 × 3.65 = 10.95 t/yr

Hourly emission rates Q

Hours/year = 365 × 24 = 8760 h

SO_2 (kg/hr) = 273,750 / 8760 = 31.25 kg/hr

PM (t/hr) = 10.95 / 8760 = 0.00125 t/hr

Compute stack heights

For SO_2:

Q = 31.25 kg/hr

$(31.25)^{0.3} \approx 2.80837$

$H_{SO_2} = 14 \times 2.80837 \approx 39.32$ m

For PM:

Q = 0.00125 t/hr

$(0.00125)^{0.27} \approx 0.16451$

$H_{PM} = 74 \times 0.16451 \approx 12.17$ m

$H_{SO2} \approx 39.32$ m, $H_{PM} \approx 12.17$ m

SO_2 gives larger value.

Adopt physical height = 40 m

(ii). Explaining the major causes for noise pollution, discuss methods used for control of noise pollution in industries. [10 M]

Sol:

Noise pollution is the presence of unwanted or excessive sound that can negatively impact human health, interfere with daily activities, and harm the environment.

Main Sources of Noise Pollution

- **Industrial machinery:** Equipment like heavy machines, compressors, turbines, and generators produce loud noise.
- **Transport systems:** Vehicles such as trucks, trains, forklifts, and internal transport contribute constant background noise within industrial areas.

- **Manufacturing processes:** Operations including metal cutting, pressing, grinding, drilling, and fabrication generate significant noise levels.
- **Construction activities:** Tasks like demolition, pile driving, and concrete mixing create substantial noise around industrial sites.
- **Poor equipment maintenance:** Machines that are worn out or malfunctioning often produce more noise than they should.
- **Non-isolated operations:** When noisy and quiet areas are not properly separated or soundproofed, noise exposure increases.
- **Utilities and auxiliary systems:** Devices like ventilation fans, boilers, pumps, and air compressors add to the ambient noise.

Controlling Noise Pollution in Industries

Effective noise control involves managing the source, blocking the transmission path, and reducing worker exposure. Key approaches include:

1. Source Control

- Maintain equipment regularly - lubricate, tighten parts, and replace worn components to minimize noise from vibrations and friction.
- Choose quieter machines using modern technology, such as low-noise electric motors and sound-reducing pneumatic tools.
- Modify processes to use quieter methods (for example, welding instead of riveting).
- Reduce operating speeds where possible, lowering noise without significantly affecting productivity.

2. Path Control

- Use enclosures and Use enclosures and barriers like soundproof covers, partitions, and curtains to block or absorb noise.
- Isolate vibrations by installing anti-vibration mounts, rubber pads, or springs to prevent noise transfer to building structures.

- Add absorptive materials such as acoustic ceiling tiles, wall panels, and floor mats that soak up sound waves.
- Administrative and

3. Exposure Control

- Separate noisy areas from quiet zones and create buffer zones.
- Rotate workers to limit the time each person spends in high-noise environments.
- Provide personal protective equipment like earplugs and earmuffs when noise cannot be sufficiently reduced.
- Schedule noisy tasks during periods of low occupancy to minimize exposure.

4. Legislation and Standards

- Enforce noise limits according to local and national regulations (e.g., OSHA, CPCB).
- Conduct regular noise assessments and monitor workplace noise levels.
- Educate workers about noise hazards and promote awareness of protective measures.

04.

(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 M]**

Sol: Given Data:

- Wastewater discharge = 2 MLD = 2,000 m^3/day = 2,000,000 L/day
- Influent suspended solids = 200 mg/L
- Suspended solids removal in PST = 60%
- Specific gravity of solids = 1.2
- Moisture content of digested sludge = 90% (Solids = 10% by weight)
- Percentage conversion of fresh sludge solids to liquid & gas = 50%
- Moisture content of fresh sludge = 96% (Solids = 4% by weight)

(i) Volume of fresh sludge produced

Dry solids captured per day

Dry solids mass = Q × SS × Removal Efficiency

= (2,000,000 L/day) × (200 mg/L) × 0.60 = 240,000,000 mg/day = 240 kg/day

Total wet mass of fresh sludge (4% solids by weight)

Wet mass = 240 / 0.04 = 6000 kg/day

Volume of water and solids in sludge

Water volume = (6000 – 240) / 1000 = 5.76 m^3/day

Solids volume = 240 / (1.2 × 1000) = 0.20 m^3/day

Total volume = 5.76 + 0.20 = 5.96 ≈ 6.0 m^3/day

(ii) Unit weight of raw sludge

Density = Total mass / Total volume = 6000 / 5.96 ≈ 1006.7 kg/m^3

Unit weight = (1006.7 × 9.81) / 1000 ≈ 9.88 kN/m^3 (≈ 1.007 t/m^3)

(iii) Volume of digested sludge

Dry solids after digestion (50% reduction) = 240 × (1 – 0.50) = 120 kg/day

Total wet mass (10% solids by weight)

Wet mass = 120 / 0.10 = 1200 kg/day

Volume calculation Water volume = (1200 – 120) / 1000 = 1.08 m^3/day

Solids volume = 120 / (1.2 × 1000) = 0.10 m^3/day

Total volume = 1.08 + 0.10 = 1.18 m^3/day

(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 M]**

Sol:

Given:

$B_P = 1.22$ m

$L_p = 3.66$ m

$H_p = 2.74$ m

$$L_\gamma = \frac{L_m}{L_p} = \frac{1}{16}$$

$V_m = 0.076$ m/s

$F_m = 4$ N

Force acting on pier follows Froude's law of similarity,

$(Fr)_m = (Fr)_p$

$$\left(\frac{V}{\sqrt{gL}}\right)_m = \left(\frac{V}{\sqrt{gL}}\right)_p$$

$g_m = g_p$

$$V_r = \sqrt{L_r}$$

(i). $$V_r = \sqrt{L_r}$$

$$\frac{V_m}{V_p} = \sqrt{L_r}$$

$$V_p = \frac{V_m}{\sqrt{L_r}} = 0.076 \times \sqrt{16} = 0.304 \text{ m/s}$$

Force ratio, $F_r = \rho_r L_r^2 V_r^2$

$F_r = L_r^3 \quad (\rho_r = 1)$

$$\frac{F_m}{F_p} = L_r^3$$

$$F_p = \frac{F_m}{L_r^3}$$

$F_p = 4 \times 16^3 = 16384$ N

$= 16.384$ kN

(ii). Height of standing wave

In model, $(H_w)_m = 0.049$ m

$$\frac{(H_w)_m}{(H_w)_p} = L_r = \frac{1}{16}$$

$\therefore (H_w)_p = 0.049 \times 16 = 0.784$ m

(iii). Drag force, $F = \frac{1}{2} C_D \rho A V^2$

A : Projected area $\Rightarrow$ [Width of pier × Average depth of water]

From prototype details

$$16.384 \times 10^3 = \frac{1}{2} \times C_D \times 1000 \times [1.22 \times 2.74] \times 0.304^2$$

$$C_D = \frac{16.384 \times 2}{1.22 \times 2.74 \times 0.304^2} = 106.07$$

Note: Actually velocity of flow in model should be given as 0.76 m/s then the prototype comes as 3.04 m/s and C_D will get as 1.06

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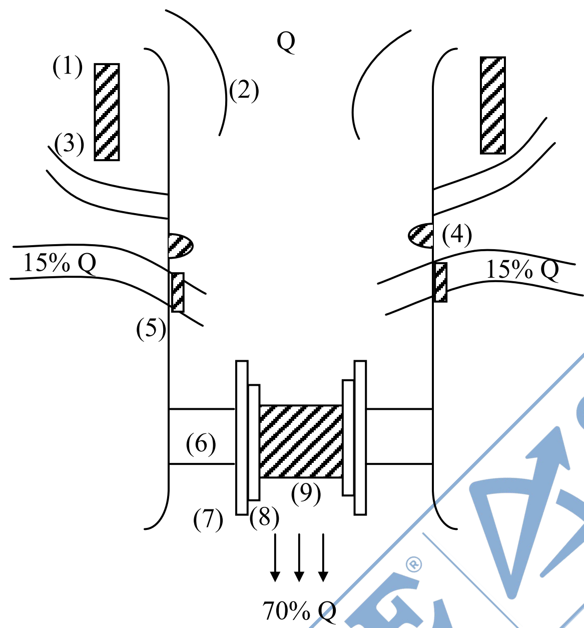
(c). (i). What are the various components of diversion headworks? Describe each in one or two sentences. [10 M]

Sol:



1. **Marginal embankments:** They are the earthen dams provided on both the banks of the river to protect surrounding areas from possible river floods. They are trapezoidal in shape.

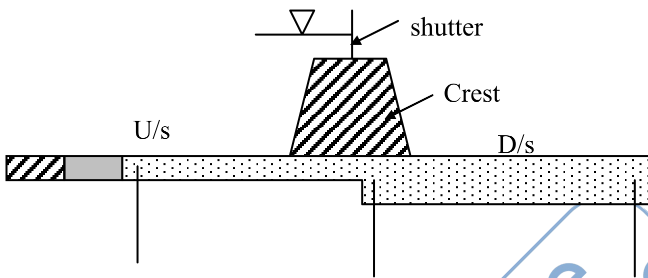
2. **Guide banks (or) Bell bunds:** They are the converging walls to reduce width of river flow so that water approaches the weir with sufficient momentum.

3. **Supporting Banks:** Brick masonry walls extended out around 300 m long, from both the banks of river, to protect the river bed from scanning action.

4. **Silt excluder:** Provided on the river banks to remove silt from the river bed.

5. **Cross head regulator:** Provided to permit river water, by around 15% to get diverted to the off taking canals.

6. Body wall or weir portion: A weir is a structure constructed across a river to raise its water level and divert the water into canal. On the crest of the weirs usually shutters are provided so that part of the raising up of water is carried out by shutters.



7. Divide wall: Long brick masonry wall provided in side the river, parallel to the length of river to divide river water into 3 parts.

15% left diversion

15% right diversion

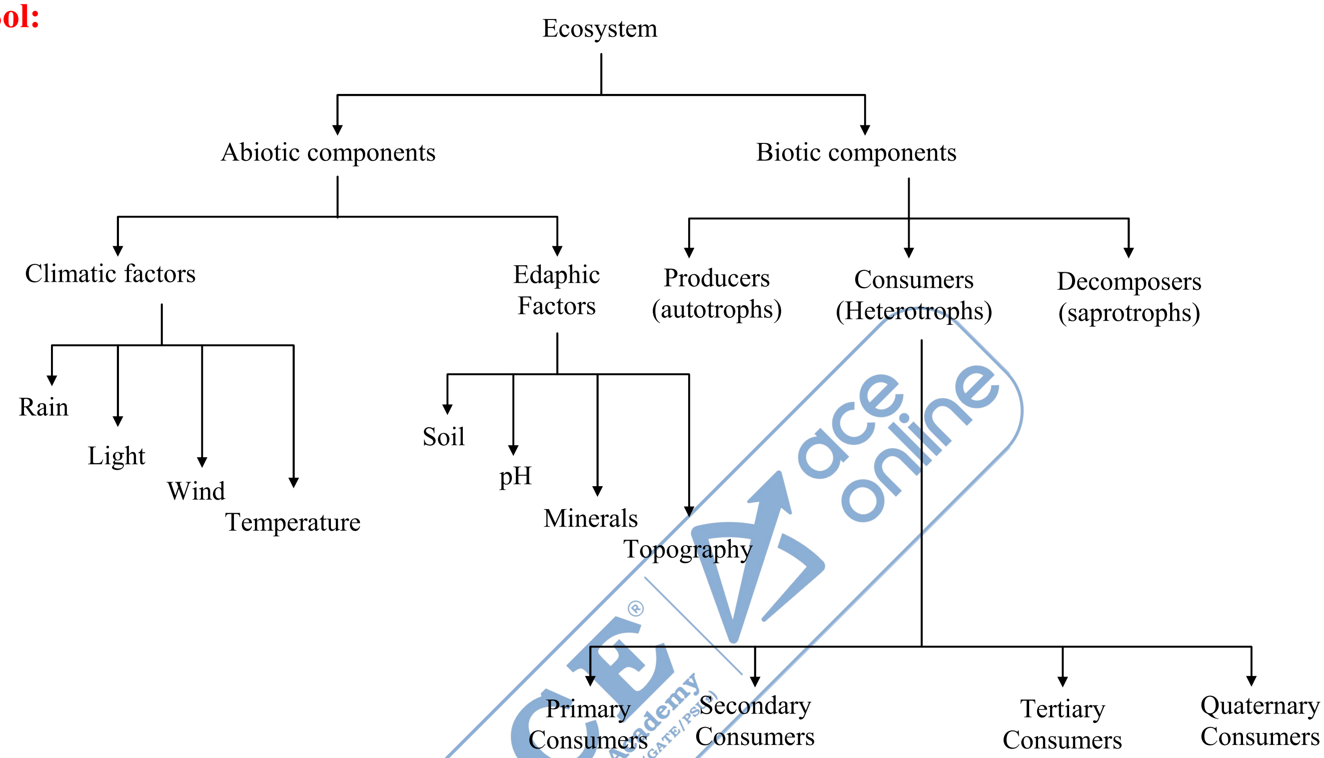
70% central transmission onto d/s

8. Fish ladder: It is a baffled wall, made up of steel or concrete or brick masonry, to permit the migration of fish from u/s to d/s and vice versa, to be in comfortable warmer temperature.

9. Under sluices or scouring sluices: 40 – 50 cement concrete pipes laid very close to the river bed, property supported on the bed, to transmit 70% of river water along with proportionate silt onto d/s. These sluices are overlaid with 4 – 5 parallel layers of gunny bags filled with sand.

(ii). With help of a flow chart, explain various components of an Ecosystem and their functions. [10 M]

Sol:



Abiotic components

Non-living physical and chemical factors that set the environmental template for life and processes. They regulate productivity, species distribution, and ecosystem rates.

(i) Climatic factors

- Weather-related drivers like rain, light, wind, and temperature that control energy input, moisture, and stress. They shape seasons, primary productivity, and organismal adaptations.
- **Rain:** Supplies freshwater, influences soil moisture, runoff, and nutrient transport. Extremes cause droughts or flooding, restructuring communities.
- **Light:** Primary energy source for photosynthesis, setting photoperiod and thermal regimes. Light quality and intensity govern plant growth and aquatic depth zones.

- **Wind:** Moves air masses, seeds, spores, and surface waters, affecting evapotranspiration. Can create mechanical stress or mixing that redistributes heat and nutrients.
- **Temperature:** Controls metabolic rates, enzyme activity, and species ranges. Thermal gradients drive stratification in waters and altitudinal zonation on land.

(ii) Edaphic factors

- Soil-related properties determining rooting, water/nutrient availability, and habitat structure. They influence decomposition, microbe activity, and vegetation types.
- **Soil:** Matrix of minerals, organic matter, air, and water that supports plants. Texture and structure set infiltration, aeration, and root penetration.
- **pH:** Acidity/alkalinity regulating nutrient solubility and microbial processes. Extremes limit species and can mobilize toxic metals or immobilize nutrients.
- **Minerals:** Essential macro/micronutrients (N, P, K, Fe, etc.) for growth and metabolism. Their cycling and availability control productivity and community composition.
- **Topography:** Landform features like slope, aspect, and elevation shaping microclimate and drainage. Creates habitat heterogeneity and movement corridors or barriers.

Biotic components

- Living organisms interacting through feeding, competition, and symbiosis. They drive energy flow and matter cycling across trophic levels.

(i) Producers (autotrophs)

- Photosynthetic/chemosynthetic organisms converting inorganic inputs into biomass. Form the first trophic level and primary energy source for consumers.

(ii) Consumers (heterotrophs)

- Organisms that obtain energy by ingesting other organisms or organic matter. Organized into trophic levels based on diet and position in food chains.
- **Primary consumers:** Herbivores and detritivores feeding on producers or detritus. Transfer plant energy to higher trophic levels.

- **Secondary consumers:** Predators/omnivores feeding on primary consumers. Help regulate herbivore populations and maintain food-web balance.
- **Tertiary consumers:** Higher-level predators preying on secondary consumers. Often fewer in number, sensitive to energy loss across levels.
- **Quaternary consumers:** Apex predators at the top of food webs with minimal natural enemies. Exert top-down control influencing trophic cascades.

(iii) Decomposers (saprotrophs)

- Microbes and fungi that break down dead organisms and wastes externally. Release inorganic nutrients back to abiotic pools, closing nutrient cycles.

SECTION - B

05.

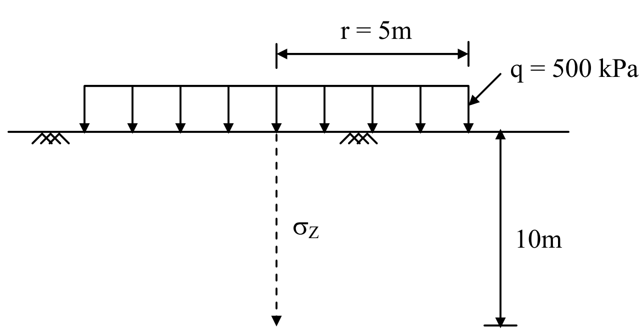
(a). A circular loaded area with radius 5 m is subjected to a load of 500 kN/m^2. Calculate and compare the variation of vertical stress below the centre of the circular area using Boussinesq's theory and Westergaard's theory for the depth from ground level to 10 m below the ground surface. Assume Poisson's ratio as 0.30 [12 M]

Sol:

Boussinesq's theory:

It is independent of Poisson's ratio of soil

$$\sigma_z = q\left[1-\left\{\frac{1}{1+\left(\frac{r}{z}\right)^2}\right\}^{3/2}\right]$$



$$= 500\left[1-\left\{\frac{1}{1+\left(\frac{5}{10}\right)^2}\right\}^{3/2}\right] = 142.23 \text{ kPa}$$

Westergaard's theory:

The equation for circular loaded area with Poisson's ratio (υ) is

$$\sigma_z = q\left[1-\left\{\frac{1}{1+\left(\frac{r}{\eta.z}\right)^2}\right\}^{1/2}\right]$$

$$\eta = \sqrt{\frac{1-2\upsilon}{2-2\upsilon}}$$ υ = Poisson's ratio of root = 0.3 given

$$= \sqrt{\frac{1-2\times0.3}{2-2\times0.3}} = 0.535$$

$$\sigma_z = 500\left[1-\left\{\frac{1}{1+\left(\frac{5}{0.535\times10}\right)^2}\right\}^{1/2}\right] = 134.70\text{ kPa}$$

$$\%\text{ Variation of stress} = \frac{\sigma_{z(W)}-\sigma_{z(B)}}{\sigma_{z(B)}}\times100$$

$$= \frac{134.7-142.23}{142.23}\times100 = -5.29\%$$

Westergaard's theory gives lesser stress compared to Boussinesq's theory

(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 M]

Sol:

Given data:

$H_o = 3$ m, $e_o = 0.85$, $C_c = 0.27$, $C_\alpha = 0.02$

$\sigma'_o = 130$ kN/m^2

$\Delta\sigma' = 300$ kN/m^2

for a normally consolidated clay, the ultimate primary consolidation settlement, S_p is obtained as follows

$$S_P = H_o.\frac{C_c}{1+e_o}.\log_{10}\left[\frac{\sigma'_o+\Delta\sigma'}{\sigma'_o}\right]$$

$$= 3\times\frac{0.27}{1+0.85}\log_{10}\left[\frac{130+300}{130}\right]$$

$$= 0.2275 \text{ m} = 227.5 \text{ mm}$$

Secondary consolidation settlement, S_s

$$S_S = H_P\times\frac{C_\alpha}{1+e_P}.\log_{10}\frac{t_2}{t_1}$$

C_α = Secondary compression index (it is the slope of linear portion of secondary consolidation curve)

= 0.02

e_P = Void ratio at end of primary consolidation

$$\frac{\Delta H}{H_o} = \frac{\Delta e}{1+e_o}$$

$$\frac{S_P}{H_o} = \frac{e_o - e_P}{1+e_o}$$

$$\frac{0.2275}{3} = \frac{0.85-e_P}{1+0.85}$$

$\therefore e_P = 0.71$

H_P = thickness of clay after primary consolidation

$H_P = H_o - S_P$

$= 3 - 0.2275 = 2.773$ m

t_1 = time at end of primary consolidation

= 2 years

$t_2 = t_1 + 5 = 7$ years

Substituting in the above formula,

$$S_S = 2.77 \times \frac{0.02}{1+0.71} \log_{10}\left(\frac{7}{2}\right) = 0.01763 \text{ m} = 17.63 \text{ mm}$$

Total consolidation settlement = $S = S_p + S_s$

$= 227.5 + 17.6$

$= 245.1$ mm

(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 M]

Sol:

Terrain : Rolling terrain

Ruling design speed, V = 100 kmph

Assume e = 7%, f = 0.15 (as per IRC)

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

$$\frac{7}{100} + 0.15 = \frac{100^2}{127(R)}$$

(i) Ruling minimum radius, R = 357.9 ≃ 358 m

(ii) Super elevation for rolling terrain

$$e_{DGN} = \frac{V^2}{225R} = \frac{100^2}{225(358)} = 0.124$$

$$= 12.4\% > 7\%$$

Use super elevation = 7%

(iii) Extra widening:

Assume two lane expressway

$$W_e = \frac{n\ell^2}{2R} + \frac{n}{2}\left[\frac{V}{9.5\sqrt{R}}\right]$$

$$= \frac{(2)(6.1)^2}{2(358)} + \frac{2}{2}\left[\frac{100}{9.5\sqrt{358}}\right] = 0.66 \text{ m}$$

(iv) Length of transition curve:

(a) Comfort criteria

$$C = \frac{80}{75+V} = \frac{80}{75+100} = 0.457 \text{ m/s}^3$$

$[0.5 \le C \le 0.8 \text{ m/s}^3]$ $C < 0.5 \text{ m/s}^3$

Use minimum $C = 0.5 \text{ m/s}^3$

$$\ell_s = \frac{\upsilon^3}{CR} \qquad \left[\upsilon = \frac{5}{18}\times 100 = 27.78\right]$$

$$= \frac{27.78^3}{0.5(358)} = 119.8 \text{ m} \simeq 120 \text{ m}$$

(b) Super elevation criteria:

Assume pavement is rotated about inner edge. The rate of super elevation is 1 in 150 for rolling terrain; W = 7 m (for two lanes)

$\therefore\ l_s = e.\ N\ (W + W_e)$

$$= \frac{7}{100}(150)(7+0.66) = 80.43\,\text{m}$$

(c) Emperical formula

For rolling terrain, $\ell_s = \dfrac{2.7V^2}{R}$

$$\ell_s = \frac{2.7(100^2)}{358} = 75.41 \text{ m}$$

l_s = max of (a), (b) and (c) = 120 m

(v). SSD (use t = 2.5 s ; f = 0.35)

$$\text{SSD} = 0.278Vt + \frac{V^2}{254f}$$

$$= 0.278(100)(2.5) + \frac{100^2}{254(0.35)} = 182 \text{ m}$$

ISD = 2(SSD) = 364 m

(vi) Set back distance

For two lane road

d = distance from centre of entire road to centre of inner lane

$$d = \frac{3.5}{2} = 1.75 \text{ m} \text{ ; use S = 182 m}$$

$$\alpha = \frac{S}{(R-d)} \times \frac{180}{\pi} = \frac{182}{(358-1.75)} \frac{180}{\pi}$$

$\alpha = 29.27$ m

For [L ≥ S]

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

$$= 358 - (358 - 1.75)\cos\left(\frac{29.27}{2}\right)$$

m = 13.3 m from centre of road

(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 M]**

Sol: (a) Rolling resistance due to wagon.

= Weight of wagon × Rolling resistance of wagon × Number of wagon

= 20 × 2.5 × 25

= 1250 kg = 1.25 tonnes

(b) Rolling resistance due to locomotive

= Rolling resistance of locomotive × weight of locomotive

= 3.5 kg/tones × 120

= 420 kg

= 0.42 t

(c) Total rolling resistance = a + b

= 1.25 + 0.42

= 1.67 t

(d) Total weight (W) of train = wt of wagons + wt of locomotive

= (20 × 25) + 120

= 620 tonnes

(e) Total train resistance = Rolling resistance + Resistance dependent on speed + Atmospheric resistance

$$= 1.67t + 0.00008WV^2 + 0.0000006WV^2$$

(f) Total resistance = Train resistance + Resistance due to grade

$$= 1.67 + 0.00008WV + 0.0000006WV^2 + Wg$$

(g) Tractive effort = Total resistance

$$45 = 1.67 + 0.0000(620)\ 60 + 0.0000006 \times 620 \times 60^2 + \frac{620}{g}$$

$$g = \frac{1}{15.89} \approx \frac{1}{16}$$

(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 M]

Sol: Mistakes are the errors arising from carelessness, inexperience, poor judgment and confusion of the observer. Errors are defined as the deviation of a measured value from its true value. If the measured value is greater than the true value the error is positive and it will be negative if otherwise.

Systematic errors: These are the errors which occur from well-understood causes and can be reduced by adopting suitable methods. For example, the error due to sag of a tape. It always has the same magnitude and sign so long as the conditions remain the same, and such an error is called constant systematic error. Whereas, if the conditions change, the magnitude of the error changes and is known as variable systematic error. A systematic error follows a definite mathematical or physical law and, therefore, a correction can always be determined and applied. These errors are also known as cumulative errors.

Accidental Errors: These are the errors due to a combination of causes and are beyond the control of the surveyor. These can be positive or negative. Erroneous calibration of a chain is an example of an accidental error.

The Most Probable Value (MPV) of a single observation is usually the average (arithmetic mean) of all observed values, assuming that all observations are of equal weight (i.e., same precision).

Formula (Equal Weights):

If you have n observations: $x_1, x_2, x_3, \ldots, x_n$

Then the MPV of a single observation (which is also the MPV of the quantity being measured) is:

$$\bar{x} = \frac{\Sigma x}{n}$$

MPV of the Mean

This refers to the uncertainty or probable error in the mean value - basically, how reliable the calculated average (MPV) is. Assuming equal weights and normally distributed random errors, the standard deviation of the mean or probable error of the mean is calculated as:

$$\sigma_{mean} = \frac{\sigma}{\sqrt{n}}$$

n → no. of observations

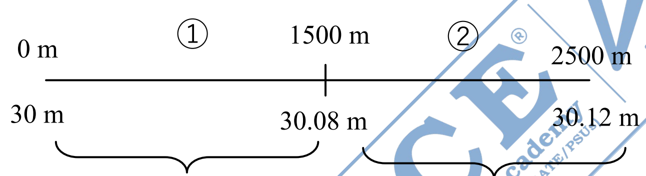
σ → Standard deviation

So, the MPV of the mean is the same as the average value $\bar{x}$, but with a smaller uncertainty, because combining more data reduces random error.

(ii). A distance of 1500 m 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 M]

Sol:



$$L' = \frac{30 + 30.08}{2} = 30.04 \text{ m}$$

$l'_1 = 1500$ m

$$l_1 = 1500 \times \frac{30.40}{30} = 1502 \text{ m}$$

$$L' = \frac{30.08 + 30.12}{2} = 30.10 \text{ m}$$

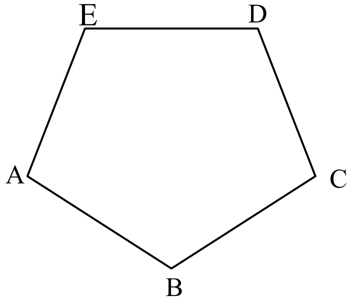
$l'_2 = 1000$ m

$$l_2 = 1000 \times \frac{30.10}{30} = 1003.33 \text{ m}$$

$\therefore\ l = l_1 + l_2 = 2505.33$ m

06.

(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 M]

Sol: Int $\angle A = BB_{EA} - FB_{AB} = 132°10' - 82°30' = 49°40'$

Int $\angle B = BB_{AB} - FB_{BC} = 260°40' - 122°20' = 138°20'$

Int $\angle C = BB_{BC} - FB_{CD} = 303°40' - 172°50' = 130°50'$

Int $\angle D = BB_{CD} - FB_{DE} = 352°30' - 232°10' = 120°20'$

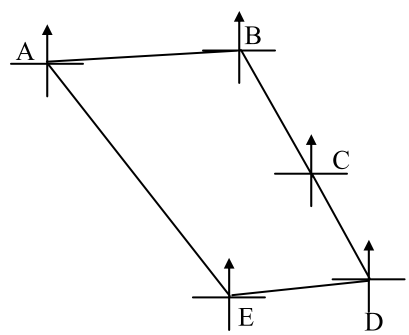
Int $\angle E = FB_{EA} - BB_{DE} = 360° - (312°20' - 51°30') = 99°10'$

$\angle A + \angle B + \ldots\ldots\ldots\ldots \angle E = 538°20'$

For n = 5

Σ Interior angles = (2 (5) – 4) 90° = 540°

$\therefore$ Error = 538°20′ – 540° = – 1°40′



Correction = +1°40′

$\Rightarrow$ Correction / Angle $= \dfrac{+1^\circ 40'}{5} = +20'$

Correction Interior angles:

$\angle A = 49^\circ 40' + 20' = 50^\circ$

$\angle B = 138^\circ 20' + 20' = 138^\circ 40'$

$\angle C = 130^\circ 50' + 20' = 131^\circ 10'$

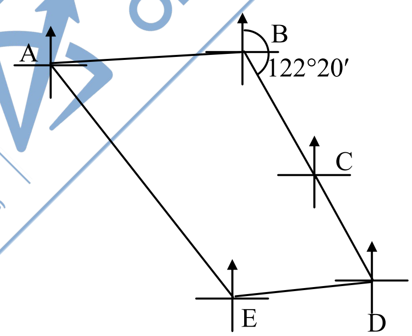
$\angle D = 120^\circ 20' + 20' = 120^\circ 40'$

$\angle E = 99^\circ 10' + 20' = 99^\circ 30'$

Σ Sum = 540°

Calculation of Bearings:

Given $FB_{BC} = 122^\circ 20'$ is correct



$\therefore BB_{AB} = FB_{BC} + \angle B$

$= 122^\circ 20' + 138^\circ 40' = 261^\circ$

$\Rightarrow FB_{AB} = 261^\circ - 180^\circ = 81^\circ$

$\therefore BB_{EA} = FB_{AB} + \angle A$

$= 81^\circ + 50^\circ = 131^\circ$

$FB_{EA} = 131^\circ + 180^\circ = 311^\circ$

$\therefore BB_{DE} = 360^\circ - (BB_{EA} + \angle E)$

$= 360^\circ - (311^\circ + 99^\circ 30') = 50^\circ 30'$

$FB_{DE} = 50^\circ 30' + 180^\circ = 230^\circ 30'$

$\therefore BB_{CD} = FB_{DE} + \angle D$

$= 230^\circ 30' + 120^\circ 40'$

$= 351^\circ 10'$

$\Rightarrow FB_{CD} = 171^\circ 10'$

$BB_{BC} = FB_{CD} + \angle C$

$= 171^\circ + 10' + 131^\circ 10' = 302^\circ 20'$

$\Rightarrow FB_{BC} = 302°20' - 180° = 122°20'$

$\therefore$ Checked

Line	Fore Bearing	Back Bearing
AB	81°	261°
BC	122°20′	302°20′
CD	171°10′	351°10′
DE	230°30′	50°30′
EA	311°	131°

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

(I) Fiducial marks

(II) Isocentre

(III) Relief Displacement

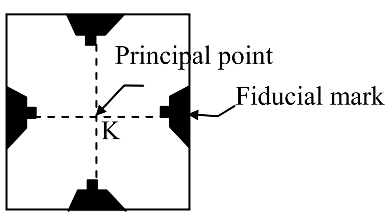
(IV) Tilt and Tip

(V) Principal point **[10 M]**

Sol:

I. Fiducial Marks:

These are also known as collimation marks and are as shown figure. The frame across which the film passes contains the fiducial marks which are printed on each photograph. These marks locate, on the photograph, the geometric axes whose intersection must be on the optional axis of the camera. This point of intersection is known as principal point k.



II. Isocentre:

The isocentre is the point where the bisector of the angle between the optical axis and the principal line intersects the photograph. It's crucial in understanding image geometry and distortion. It lies halfway between the principal point (center of the photo) and the nadir point (point directly beneath the camera).It's crucial for understanding tilt displacement in aerial photographs and is used in rectification and scale calculations.

III. **Relief displacement** refers to the apparent radial shift of objects in an aerial photograph due to variations in elevation. In simpler terms, objects that are higher or lower than the mean ground level appear to be displaced outward or inward from the center of the photo. It is caused by elevation differences in terrain. Occurs because the camera is not infinitely far away-it's at a finite flying height. The effect is radial: displacement increases with distance from the principal point (center of the photo).

IV. **Tilt** is the angle between the camera's optical axis and the vertical (plumb line). It's the deviation from the nadir direction. Tip is the rotation of the camera around its x-axis (side-to- side axis), causing the image to lean forward or backward. Tilted photographs cause displacement of image points, especially noticeable near the edges. Tip and tilt distort scale and geometry, making measurements inaccurate unless corrected. These distortions are addressed during rectification or orthorectification, which reprojects the image to remove the effects of tilt.

IV. **Principal Point:** It's the point on the photograph where the optical axis of the camera intersects the image plane. Essentially, it's the center of the photo as seen from the camera's lens. It's determined using fiducial marks-small reference marks placed on the edges of the photo frame.

(b). Write descriptive notes on : [20 M]

(i). Environmental impacts associated with airport projects [5 M]

(ii). Parking configurations for aircrafts [5 M]

(iii). Cross wind component [5 M]

(iv). Typical layout of an artificial harbour indicating the components and their functions [5 M]

Sol:

(i) **Air Pollution:** The emissions of CO_2, NO_2 and particulate matter causes air pollution.

Noise Pollution: Noise pollution may cause problem to human beings, animals and also to birds in airport vicinity.

Water Pollution: The fuel, oil and other containments from aircrafts will cause water pollution.

Climate change contribution due to airport will be very high.

(ii). Parking configurations for aircrafts:

1. Nose- In parking
2. Angles parking
3. Parallel parking
4. Open apron parking
5. T-configuration

(iii). Cross wind component :

The component of wind which is perpendicular to the direction of motion of air craft. This cross wind may drift the aircraft while take-off and landing.

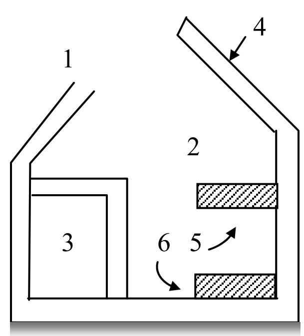
Cross wind $\ngtr$ 15 kmph for small,

$\ngtr$ 25 kmph for medium and

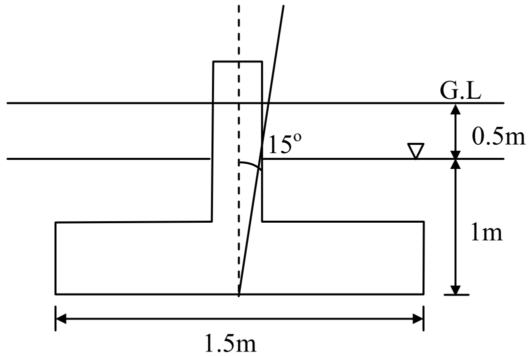
$\ngtr$ 35 kmph for big aircrafts.

(iv). Typical layout of an artificial harbour:

1. Entrance
2. Turning basin
3. Dock
4. Breakwater
5. Pier
6. Wharf



(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 sharing 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:

$N_c = 37.16$, $N_q = 22.46$ and $N_\gamma = 19.13$ **[20 M]**

Sol: IS code method is proposed to be used here to determine the bearing capacity as there is water table effect

The IS code equation to compute net ultimate bearing capacity is given below for cohesionless soils (C = 0)

$q_{nu} = q' (N_q - 1)\, S_q . d_q . i_q + 0.5\, \gamma\, B\, N_\gamma\, S_\gamma . d_\gamma . i_\gamma . W'$

q' = effective stress at base level of footing

$= 0.5\gamma + 1\gamma'$

$= 0.5 \times 16.5 + 1[19.5 - 9.81]$ … taking $\gamma_w = 9.81$ kN/m^3

$= 17.94$ kN/m^2

$N_q = 22.46$ (given)

$S_q = 1.2$ for square footing

$$d_q = d_\gamma = 1 + 0.1\frac{D_f}{B}\tan\left(45 + \frac{\phi}{2}\right) \text{.......... for } \phi > 10^o$$

$$= 1 + 0.1 \times \frac{1.5}{1.5}\tan\left(45 + \frac{30}{2}\right) = 1.173$$

$$i_q = \left[1 - \frac{\alpha}{90}\right]^2 = \left[1 - \frac{15}{90}\right]^2 = 0.694$$

$N_\gamma = 19.13$ (given)

$S_\gamma = 0.8$ for square

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

W′= water table correction factor

= 0.5 as the soil below the footing is submerged

Substituting in the above equation,

$q_{nu} = q' (N_q - 1) S_q .d_q. i_q + 0.5 \gamma B N_\gamma S_\gamma .d_\gamma . i_\gamma .W'$

$= 17.94 (22.46 - 1) 1.2 \times 1.173 \times 0.694 + 0.5 \times 19.5 \times 1.5 \times 19.13 \times 0.8 \times 1.173 \times 0.25 \times 0.5$

$= 376.09 + 32.82 = 408.91 \text{ kN/m}^2$

Assuming a factor of safety of 3, the safe gross bearing capacity,

$$q_s = \frac{q_{nu}}{F} + q' = \frac{408.91}{3} + 17.94 = 154.24 \text{ kN/m}^2$$

Gross safe inclined load, $Q = A \times q_s$

$= 1.5^2 \times 154.24$

$= 347.05$ kN

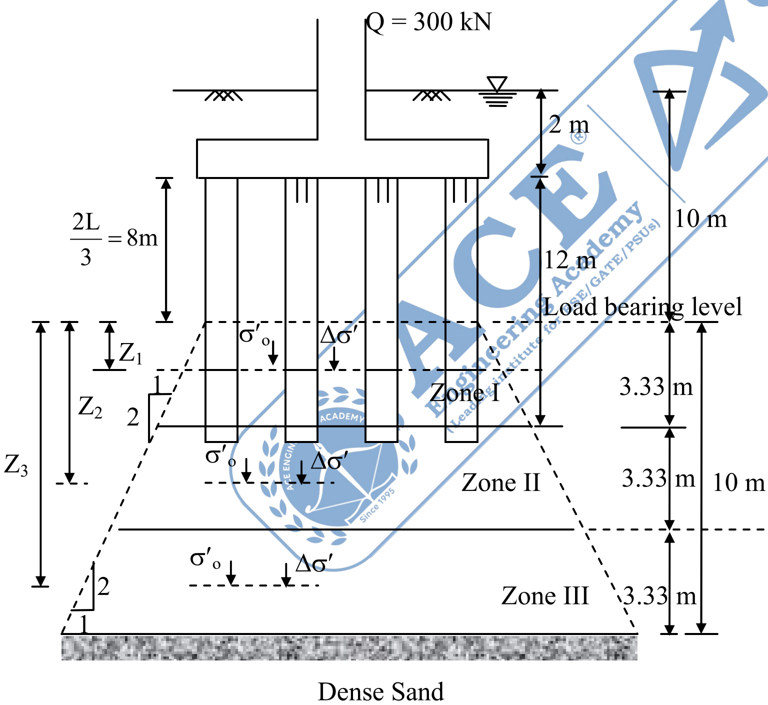
07.

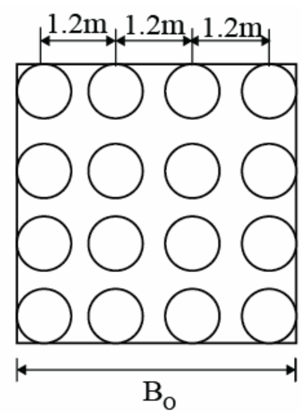
(a). A mat foundation is to be laid at a depth of 2 m below ground surface in a 20 m thick layer of normally consolidated clay underlain by dense sand. The mat foundation is supported by a group of 16 piles of length 12 m and diameter 400 mm arranged in a square pattern. The gross load to be carried 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 M]

Sol:





$B_o = 3S + D$

$= 3 \times 1.2 + 0.4 = 4$ m

The piles are assumed to be friction piles.

The total load is assumed to act at a depth equal to $\frac{2}{3}$rd of pile length as shown above and the load is assumed to be distributed at a slope of 2V to 1H for settlement calculation. The clay layer below the load bearing level (10 m) which is undergoing consolidation is divided into three layers or three zones and the stresses at the centre of each zone is calculated as below

Zone No.	Depth shown	$\Delta\sigma'$ at centre of zone
I	$\frac{3.333}{2} = 1.667$ m	$\frac{Q}{(B_o + Z_1)^2} = \frac{3000}{(4+1.667)^2} = 93.41$ kPa
II	1.667 + 3.333 = 5 m	$\frac{Q}{(B_o + Z_2)^2} = \frac{3000}{(4+5)^2} = 37.04$ kPa
III	5 + 3.333 = 8.333 m	$\frac{Q}{(B_o + Z_3)^2} = \frac{3000}{(4+8.333)^2} = 19.72$ kPa

$$e = \frac{wG}{S} = \frac{0.3 \times 2.65}{1} = 0.795; \quad \text{assume } \gamma_w = 9.81 \text{ kN/m}^3$$

$$\gamma_{sat} = \gamma_w \left[\frac{G+e}{1+e}\right] = 9.81\left[\frac{2.65+0.795}{1+0.795}\right] = 18.83 \text{ kN/m}^3$$

At centre of zone I, the $\sigma'_o = (10 + Z_1)\,\gamma'$

$$= (10 + 1.667)(18.83 - 9.81) = 105.21 \text{ kPa}$$

At centre of zone II, the $\sigma'_o = (10 + Z_2)\,\gamma'$

$$= (10 + 5)(18.83 - 9.81) = 135.3 \text{ kPa}$$

At centre of zone III, the $\sigma'_o = (10 + Z_3)\,\gamma'$

$$= (10 + 8.333)(18.83 - 9.81) = 165.37 \text{ kPa}$$

Consolidation settlement of zone I, S_{f_1}

$$S_{f_1} = H_o . \frac{C_c}{1+e_o} . \log_{10}\left[\frac{\sigma'_o + \Delta\sigma'}{\sigma'_o}\right]$$

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

$= 0.009\,(40 - 10) = 0.27$

$$S_{f_1} = 3.333 \times \frac{0.27}{1+0.795} . \log_{10}\left[\frac{105.21+93.41}{105.21}\right] = 0.13835 \text{ m}$$

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AND MANY MORE...

500+ SELECTIONS
CE : 434 | EE : 61 | ME : 20

Consolidation settlement of zone II, S_{f_2}

$$S_{f_2} = H_o.\frac{C_c}{1+e_o}.\log_{10}\left[\frac{\sigma'_o+\Delta\sigma'}{\sigma'_o}\right]$$

$$= 3.333\times\frac{0.27}{1+0.795}.\log_{10}\left[\frac{135.3+37.04}{135.3}\right] = 0.05269 \text{ m}$$

Consolidation settlement of zone II, S_{f_3}

$$S_{f_3} = H_o.\frac{C_c}{1+e_o}.\log_{10}\left[\frac{\sigma'_o+\Delta\sigma'}{\sigma'_o}\right]$$

$$= 3.333\times\frac{0.27}{1+0.795}.\log_{10}\left[\frac{165.37+19.72}{165.37}\right] = 0.02453 \text{ m}$$

Total settlement of three zones, $S_f = S_{f1} + S_{f2} + S_{f3}$

$$S_f = 0.13835 + 0.05269 + 0.02453$$

$$= 0.21557 \text{ m} = 215.57 \text{ mm}$$

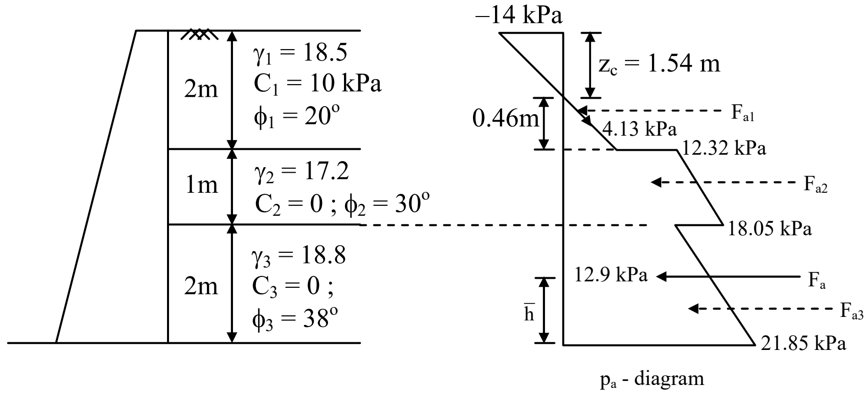
(b). A retaining wall of 5m height has to retain a stratified back fills, The properties of different layers of backfills are shown in following table

Properties	Top layer	Middle layer	Bottom layer
Thickness (m)	2	1	2
Density (kN/m^3)	18.5	17.2	18.8
Type 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 M]

Sol:



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

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

At top:

$\sigma_V = 0$

$$P_a = K_{a_1}\sigma_v - 2C_1\sqrt{K_{a_1}} = 0 - 2\times 10\sqrt{0.49} = -14\,\text{kPa}$$

At 2 m depth:

$\sigma_V = 2\gamma_1 = 37$ kPa

Just above the 2 m depth;

$$P_a = K_{a_1}\sigma_v - 2C_1\sqrt{K_{a_1}}$$

$$= 0.49\times 37 - 2\times 10\sqrt{0.49} = 4.13\text{ kPa}$$

Just below the 2 m depth, $p_a = K_{a_2}\sigma_v - 2C_2\sqrt{K_{a_2}}$

$$= 0.333 \times 37 - 0 = 12.32\text{ kPa}$$

At 3 m depth:

$\sigma_V = 2\gamma_1 + 1\gamma_2$

$= 2 \times 18.5 + 1 \times 17.2 = 54.2$ kPa

Just above, $p_a = K_{a_2}\sigma_v - 2C_2\sqrt{k_{a_2}}$

$= 0.333 \times 54.2 - 0 = 18.05$ kPa

Just below, $p_a = K_{a_3}\sigma_v - 2C_3\sqrt{k_{a_3}}$ = 0.238 × 54.2 – 0 = 12.90 kPa

At 5 m depth:

$\sigma_v = 2\gamma_1 + 1\gamma_2 + 2\gamma_3 = 91.8$ kPa

$p_a = K_{a_3}\sigma_v - 2C_3\sqrt{k_{a_3}}$

= 0.238 × 91.8 – 0 =21.85 kPa

Tension crack depth, $Z_c = \dfrac{2C_1}{\gamma_1\sqrt{K_{a_1}}}$

$$= \frac{2\times 10}{18.5\sqrt{0.49}} = 1.54 \text{ m}$$

Neglecting tension zone,

Total active thrust, F_a = +ve area of the pressure diagram

$= F_{a1} + F_{a2} + F_{a3}$

$$= \frac{1}{2}\times 4.13\times 0.46 + \left[\frac{12.32+18.05}{2}\right]1 + \left[\frac{12.9+21.85}{2}\right]2 = 0.95 + 15.19 + 31.75$$

$F_a = 50.89$ kN/m

Let F_a be acting at $\bar{h}$ from the base

$$\bar{h} = \frac{F_{a1}h_1 + F_{a2}h_2 + F_{a3}h_3}{F_a}$$

h_1, h_2 and h_3 are the vertical distances of F_{a1}, F_{a2} and F_{a3} from the base

$$h_1 = 2 + 1 + \frac{1}{3}\times 0.46 = 3.153 \text{ m}$$

$$h_2 = 2 + \left[\frac{18.05 + 2\times 12.32}{18.05 + 12.32}\right]\times\frac{1}{3} = 2.47 \text{ m}$$

$$h_3 = \left[\frac{21.85 + 2\times 12.9}{21.85 + 12.9}\right]\times\frac{2}{3} = 0.914 \text{ m}$$

$$\therefore \bar{h} = \frac{0.95\times 3.153 + 15.19\times 2.47 + 34.75\times 0.914}{50.89} = 1.42 \text{ m}$$

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(c). (i). Briefly describe the Track Management System (TMS), What are the main advantages of 'TMS'? [10 M]

Sol:

Modern Track Management system deals with the track structure in totality. Inputs in all track operations such as track construction, maintenance, monitoring and renewals are to be analyzed to arrive at the most cost-effective solution to provide the desired level of service. Track renewal in this system is an extension of track maintenance and has to be justified as an economic alternative. Appropriate price tags are to be attached to passenger discomforts, transit delays, safety hazards and such other factors, besides direct costs to work out the cost-benefit analysis.

The track maintenance planning and control under track management system is carried out at three levels.

1. Zonal Level(Chief Track Engineers Level) The TRC data, ultrasonic rail car data and the data obtained from field inspections is processed here in close interaction with the thresh- old values of track maintenance, track standards, degradation modes, cost models and traffic projections. The planning for track maintenance, track renewal, deployment of heavy-duty track machines; allotment of track materials, ballast procurement, etc. is made on the basis of the reports obtained from the computer.
2. Divisional Level (or Regional Level) Planning of all track works such as casual renewals, welding, destressing, attention to switches and crossings, special attention to vulnerable spots.
3. Chief PWI Level patrolling of tracks and only emergent repairs with the help of small mobile gangs.

All planned repair and maintenance work is executed by the divisional or zonal controlled units.

Advantages of Track Management System

- **Improved Safety**

  Detects defects early, reducing the risk of derailments and accidents.

- **Predictive Maintenance**

  Uses data analytics to forecast wear and tear, allowing timely repairs before failures occur.

- **Cost Efficiency**

  Minimizes emergency repairs and optimizes resource allocation, saving money.
- **Real-Time Monitoring**

  Tracks conditions continuously using sensors and GPS, enabling quick response to issues.
- **Data-Driven**

  Decisions Provides insights for better planning and prioritization of track upgrades and renewals.
- **Reduced Downtime**

  Streamlines maintenance schedules to avoid unnecessary disruptions to train services.
- **Asset Lifecycle Management**

  Helps extend the life of track components through informed maintenance strategies.

(ii). What is the role of ground water in the success of tunneling? Explain the bearing of lithology and geological structures in this context [10 M]

Sol:

Role of Groundwater in Tunneling Success:

Groundwater is the **most critical and serious challenge** in tunneling. Its impact includes:

1. **Instability & Collapse:** Water ingress saturates rock/soil, drastically reducing its strength and cohesion. This leads to roof/wall collapses (e.g., Koyna tail tunnel collapse along a fault).
2. **Dewatering Costs:** If the tunnel lies below the water table, continuous pumping is required to keep the working area dry, significantly increasing project expenditure.
3. **Construction Delays:** Water inflow halts excavation, requires installation of support, and complicates operations.
4. **Lining Requirements:** Water seepage necessitates extensive and often reinforced concrete lining to seal the tunnel and handle hydrostatic pressure.
5. **Weakening of Materials:** Water softens clay layers in shales/mudstones, dissolves carbonate cements in sandstones, and corrodes calcareous limestones/marbles, further weakening the tunnel perimeter.

Bearing of Lithology:

Lithology dictates a rock's inherent response to groundwater and tunneling stresses:

1. Igneou Rocks:

- Massive Plutonic/Hypabyssal (Granite, Diorite): Highly competent, impervious. Minimal water issues; lining often unnecessary unless fractured.
- Volcanic (Basalt, Andesite): **Vesicular/Porous types (Amygdaloidal Basalt)** are highly permeable, posing severe water seepage threats (e.g., Bombay-Delhi tunnels). Competence varies.

2. Sedimentar Rocks:

- Well-cemented Siliceous/Ferruginous Sandstone: Competent, less permeable. Manageable water issues if intact.
- Poorly cemented/Argillaceous Sandstone: Weak, permeable when saturated. Highly susceptible to water-induced collapse (e.g., Ramganga diversion tunnel).
- Limestone: **Calcareous/Porous types** highly prone to water seepage and corrosion. **Dolomitic Limestone** is harder/more durable but still susceptible over time.
- Shale/Mudstone: Very weak, clay content becomes plastic/slippery when wet. Highly incompetent under groundwater influence.
- Conglomerate: Generally weak and permeable due to poor consolidation.

3. Meta rphic Rocks:

- Massive Gneiss/Quartzite: Competent, relatively impervious. Handle water well unless fractured.
- Schist/Phyllite/Slate: Foliated and often contain weak minerals (mica, clay). **Highly susceptible to water infiltration along foliation planes**, becoming very weak and requiring lining.
- Marble: Competent but **susceptible to corrosion by groundwater**, necessitating lining.

Bearing of Geological Structures:

Structures control groundwater flow pathways and create zones of weakness:

1. **Joint**
   - **Closely spaced joints** create high permeability pathways, allowing copious water inflow and causing block falls (e.g., Koyna basalt tunnel).
   - Joints **parallel to the tunnel axis** over long distances are particularly undesirable as they expose large continuous surfaces to water inflow and potential roof/wall instability.
   - Joints in folded areas (crests/troughs) or fault zones are especially problematic.
2. **Fault**
   - **Fault zones are the most hazardous** for groundwater. They are zones of:
   - **Intense Fracturing:** Creating highly permeable aquifers.
   - **Rock Displacement:** Causing discontinuity and weakness.
   - **Water Conduits:** Acting as major pathways for large, sudden water inflows ("gushing").
   - Collapses are common within fault zones (e.g., Koyna tunnel).
   - Tunneling parallel to a fault strike or within the footwall is highly unstable. If unavoidable, extensive grouting and heavy lining are mandatory.
3. **Folds:**
   - **Crests (Anticlines) & Troughs (Synclines):** Often highly fractured, acting as conduits for significant groundwater. Tunneling here risks major water inflow and roof falls.
   - **Limb Regions:** Generally preferable to crests/troughs, but stability depends on lithology and dip.
   - **Bedding Planes:** When inclined, they channel groundwater. Tunneling punctures these "aquifers," leading to seepage along bedding.
   - **Tunnel Alignment:**
   - Parallel to Fold Axis: Along limbs is often best, but risks puncturing aquifers on dipping beds. Along crests/troughs is high-risk.
   - Perpendicular to Fold Axis: Undesirable as it traverses multiple rock types with varying permeability and competence, encountering both crest/trough fracture zones and limb aquifers. Synclines often trap groundwater, increasing pressure.


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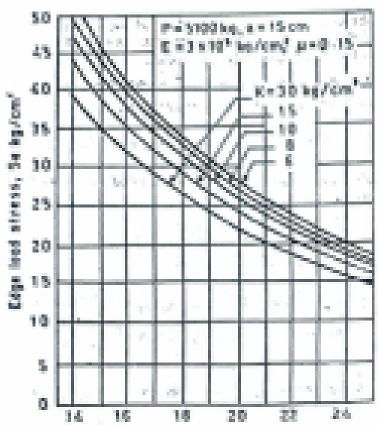
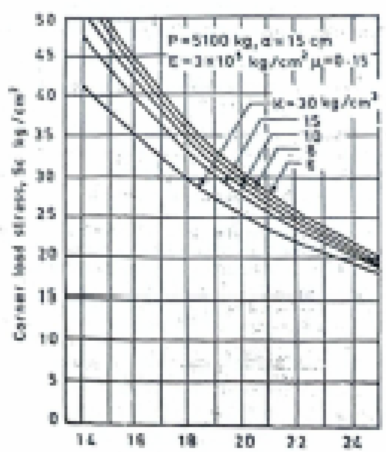
& mamy more....

08.

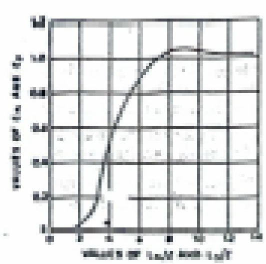
(a). **A CC pavement slab of thickness 20 cm is constructed over a granular sub-base having modulus of reaction 15 kg/cm^2. The maximum temperature difference between the top and bottom of the slab during summer day and night is found to be 18ºC. The spacing between the transverse contraction joint is 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 and 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-2 – Corner Load Stress Chart (IRC)


C-3 – Warping Stress Coefficient

[20 M]

Sol: Data:

$h = 20$ cm $p = 5100$ kg

$K = 15$ kg/cm^3 $a = 15$ cm

$\Delta t = 18^\circ C$ $E_c = 3\times 10^5$ kg/cm^2

$L_c = 4.5$ m $\mu = 0.15$

$B = 3.5$ m $\alpha = 10 \times 10^{-6}/^\circ C$

$f = 1.5$

Worst combination of stress at edge

Radius of relative stiffness

$$\ell = \left[\frac{Eh^3}{12K(1-\mu^2}\right]^{\frac{1}{4}} = \left[\frac{(3\times10^5)(20^3)}{12(15)(1-0.15^2)}\right]^{\frac{1}{4}} = 82.37 \text{ cm}$$

Wheel load stresses

Edge load stress, $\sigma_e = 24$ kg/cm^2

Corner load stress, $\sigma_c = 27$ kg/cm^2

(From charts C-1 & C-2)

Warping stresses

$$\frac{\ell_x}{\ell} = \frac{4.5\times100 \text{ cm}}{82.37} = 5.46$$

$$\frac{\ell_y}{\ell} = \frac{3.5\times100 \text{ cm}}{82.37} = 4.25$$

From chart (C – 3) $C_x = 0.7$

$C_y = 0.6$ ($C_x > C_y$; use C_x)

$$(\sigma_w)_E = \frac{C_x E\alpha\Delta T}{2} = \frac{(0.7)(3\times10^5)(10\times10^{-6})(18)}{2} = 18.9 \text{ kg/cm}^2$$

Frictional stress at edge

$$\sigma_f = \frac{f.\gamma_c.L_c}{2} = \frac{1.5(2400\ kg/m^3)(4.5m)}{2}$$

$\sigma_f = 8100\ kg/m^2 = 0.81\ kg/cm^2$

Critical combination of stress at edge

(1) Summer mid day at edge

$\sigma_R = \sigma_w\ \sigma_e + (\sigma_w)_E + \sigma_f$

$= 24 + 18.9 - 0.81 = 42.09\ kg/cm^2$

(2) Winter Mid day at edge:

$\sigma_R = \sigma_e + (\sigma_w)_E + \sigma_f$

$= 24 + 18.9 + 0.81 = 43.71\ kg/cm^2$

The critical stress at edge = $43.71\ kg/cm^2$

(b). What is geosynthetic clay liner? Discuss its application in Civil Engineering Construction Work. [10 M]

Sol:

A Geosynthetic Clay Liner (GCL) is a factory-manufactured hydraulic barrier consisting of a thin layer of bentonite clay (3-6 mm) sandwiched between two geotextiles or bonded to a geomembrane. Components are held together through needle-punching, stitching, or adhesive bonding.

Key Properties

- **Low Permeability:** 1×10^{9} to 5×10^{11} m/s when hydrated
- **Self-Healing:** Bentonite swells when exposed to water, sealing punctures
- **Flexibility:** Conforms to irregular surfaces and accommodates settlement
- **Thickness:** 6-10 mm manufactured, up to 15 mm when hydrated
- **Chemical Resistance:** Resistant to most chemicals except strong acids/bases

Applications in Civil Engineering Construction

1. **Landfill Engineering:**
   - **Primary Liner Systems:** Main barrier in waste landfills to prevent leachate migration
   - **Landfill Capping**: Final cover to prevent water infiltration and control gas emissions

2. **Containment Structures**
   - **Hazardous Waste Containment:** Secondary containment for chemical storage
   - **Pond Liners:** Agricultural lagoons, industrial ponds, storm water retention systems
3. **Environmental Remediation**
   - **Groundwater Protection:** Vertical/horizontal barriers for contaminated sites
   - **Site Capping:** Isolation of contaminated areas for redevelopment
4. **Water Resources Engineering**
   - **Canal Lining:** Irrigation canal seepage control and water conservation
   - **Reservoir Construction:** Agricultural water storage and decorative ponds
5. **Transportation Infrastructure**
   - **Highway Systems:** Pavement drainage and groundwater protection from road chemicals
   - **Railway Applications:** Track drainage and ballast containment
6. **Mining Applications**
   - **Mine Waste Containment:** Tailings pond liners and heap leach pads
   - **Environmental Protection:** Acid mine drainage control and site closure

Advantages

- **Easy Installation:** Lightweight and quick to install compared to compacted clay
- **Quality Control:** Factory-manufactured ensures consistent performance
- **Cost-Effective:** Lower cost than thick clay liners
- **Self-Healing:** Automatically seals minor punctures
- **Thin Profile:** Minimal space requirements

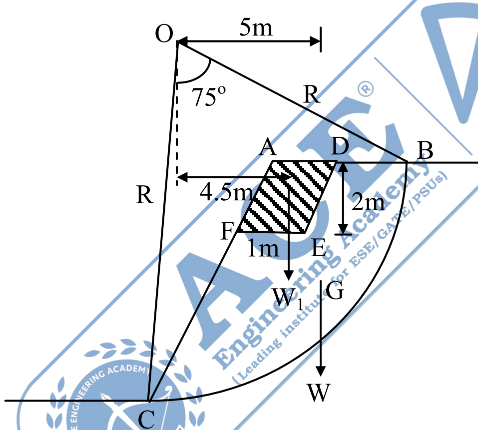
Installation Requirements

- Smooth subgrade preparation free of sharp objects
- Proper overlaps (150-300 mm) with bentonite seaming
- Protection from desiccation during installation
- Quality control testing of seams and hydration

Limitations

- Not suitable for highly acidic/basic environments (pH < 4 or > 10)
- Affected by high salt concentrations and calcium-rich waters
- Requires adequate confining stress for optimal performance
- May be affected by freeze-thaw cycles

(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 = 19 kN/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 M]

Sol: Factor of Safety, $F = \dfrac{C.L_a.R}{W \times 5 - W_1 \times 4.5}$ ….. as per $\phi_n = 0$ analysis method

$C = 21$ kPa, $R = 10$ m

L_a = Arc length $\qquad\qquad W_1 = 1 \times 2 \times \gamma = 38$ kN

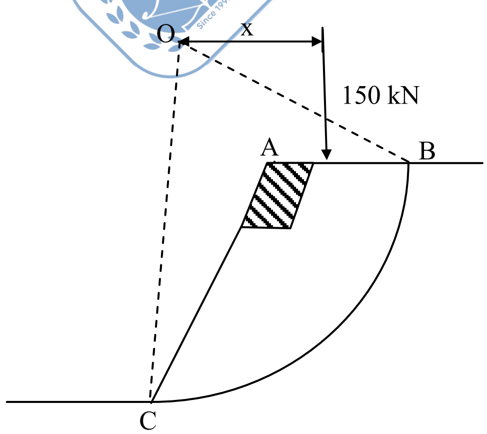
$$= R.\theta^o \frac{\pi}{180}$$

$$= 10 \times 75 \times \frac{\pi}{180} = 13.09 \text{ m}$$

$$F = \frac{C.L_a R}{W \times 5 - W_1 \times 4.5}$$

$$= \frac{21 \times 13.09 \times 10}{350 \times 5 - 38 \times 4.5} = 1.74$$

Let x be horizontal distance of the line load 150 kN acting from the point O, as shown in the following figure



$$F = \frac{C.L_a R}{W \times 5 - W_1 \times 4.5 + 150x}$$

$$1 = \frac{21 \times 13.09 \times 10}{350 \times 5 - 38 \times 4.5 + 150x}$$

Solving, x = 7.8 m

(ii). Explain the effect of sudden drawdown on the stability of unstream slope. [10 M]

Sol:

Mechanism of Sudden Drawdown:

When water levels drop rapidly (such as during reservoir drawdown or flood recession), the external hydrostatic pressure supporting the slope face is immediately removed, while pore water pressures within the soil mass remain temporarily high due to the low permeability of fine-grained soils.

Key Effects on Slope Stability:

1. **Loss of External Support:**
   - The hydrostatic pressure that previously acted against the slope face providing stabilizing force is eliminated instantaneously
   - This removes the beneficial confining pressure that helped maintain slope equilibrium

2. **Pore Pressure Lag Effect**
   - Pore water pressures within the soil mass cannot dissipate immediately due to low soil permeability
   - The soil remains saturated with high pore pressures while external water support is gone
   - This creates a temporary but critical imbalance in the stress state

3. **Adverse Seepage Forces**
   - Water begins flowing from the saturated soil mass toward the new free surface
   - These seepage forces act parallel to the potential failure surface, promoting instability
   - The hydraulic gradient creates additional driving forces for slope failure

4. **Effective Stress Redistribution**
   - Initially, total stresses remain constant, but effective stresses change due to altered pore pressure distribution
   - The effective stress path moves toward conditions that reduce shear strength
5. **Reduced Factor of Safety**
   - The combination of lost external support, high internal pore pressures, and adverse seepage typically causes the factor of safety to drop to its minimum value immediately after drawdown
   - Recovery occurs gradually as pore pressures dissipate, but this process may take considerable time depending on soil permeability

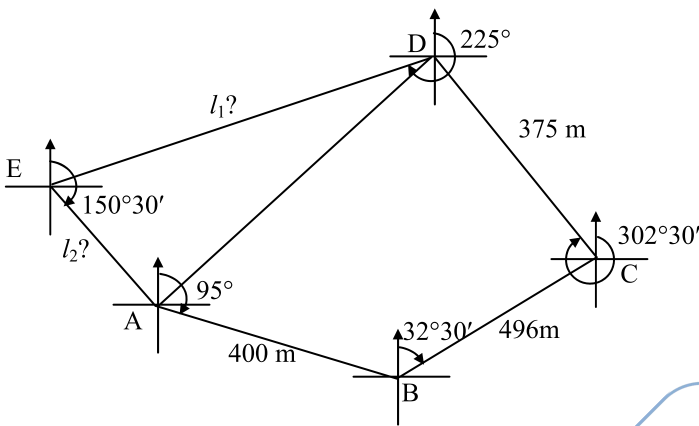
d). (i). A closed traverse was conducted round an obstacle and the following observations were made:

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 M]**

Sol:

Line	Length (m)	Azimuth	Reduced Bearing
AB	400	95°0′	S85°′E
BC	496	32°30′	N32°30′E
CD	375	302°30′	N57°30′W
DE	?	225°0′	S45°′W
EA	?	150°30′	S29°30′E



Consider traverse ABCDA

Line	Length (m)	RB°	Lat	De[
AB	400m	S85°E	–34.862	+398.478
BC	496m	N32°30′E	+418.322	+266.500
CD	375m	N57°30′W	+201.487	–316.272
DA	l	θ	$l\cos\theta$	$l\sin\theta$

Take length and bearing of DA as 'l' m and θ° respectively.

Take $\sum L = 0$

$584.947 + l\cos\theta = 0$

$\Rightarrow l\cos\theta = -584.947$ m

$\sum D = 0$

$348.706 + l\sin\theta = 0$

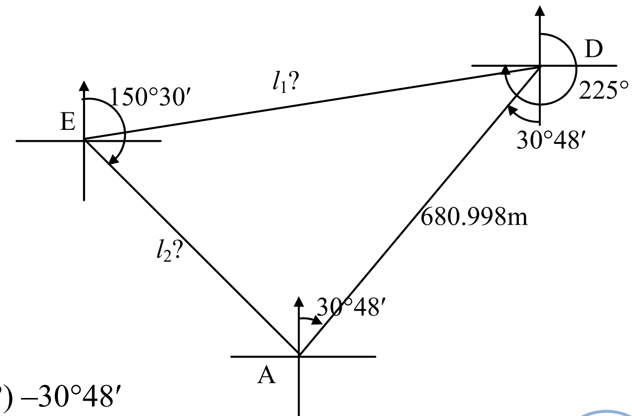
$l\sin\theta = -348.706$ m $\quad\rightarrow(2)$

Solving 1 and 2

$$\ell = \sqrt{(-584.947)^2 + (-348.706)^2} = 680.998 \text{ m}$$

$$\theta = \tan^{-1}\left(\frac{-348.706}{-584.947}\right) = S30°48'W$$

Consider ΔADE



From figure

$\angle D = (225° - 180°) - 30°48'$

$= 14°12'$

$\angle A = (180° - 150°30') + 30°48'$

$= 60°18'$

$\angle E = 150°30' - (225° - 180°)$

$= 105°30'$

Using sine rule

$$\frac{\ell_1}{\sin\angle A} = \frac{680.998\text{m}}{\sin\angle E} = \frac{\ell_2}{\sin\angle D}$$

$$\ell_1 = \frac{\sin 60°18'}{\sin 105°30'} \times 680.998\text{m}$$

$= 613.86$ m

Similarly

$$\ell_2 = \frac{\sin\angle D}{\sin 113°12'} \times 680.998\text{m}$$

$$= \frac{\sin 14°12'}{\sin 113°12'} \times 680.998$$

$= 173.36$ m

∴ Missing length are

DE = 613.86 m

EA = 173.36 m

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AIR 1 EE Rajan Kumar
AIR 1 ME Munish Kumar
AIR 2 CE HARSHIT PANDEY
AIR 2 EE SATYAM CHANDRAKANT
AIR 2 ME RAJESH KASANIYA
AIR 3 CE LAXMIKANT
AIR 3 E&T UNNATI CHANSORIA
AIR 3 EE PRIYANSHU MUDGAL
AIR 3 ME GOLLANGI SATEESH
AIR 4 CE MADHAN KUMAR
AIR 4 E&T RAJIV RANJAN MISHRA
AIR 4 ME AJINKYA DAGDU
AIR 5 CE AMAN PRATAP SINGH
AIR 5 E&T PARAG SAROHA
AIR 5 EE MAYANK KUMAR S
AIR 5 ME BANKURU NAVEEN
AIR 6 CE SANCHIT GOEL
AIR 6 E&T CHANDRIKA GADGIL
AIR 6 EE RITVIK KOK
AIR 6 ME CHANDAN JOSHI
AIR 7 E&T DEBARGHYA CH
AIR 7 EE MANTHAN SHARMA
AIR 7 ME DINESH KUMAR S
AIR 8 CE ROHIT KUMAR
AIR 8 E&T VIDHU SHREE
AIR 8 EE MAYANK JAIMAN
AIR 8 ME SHAILENDRA SINGH
AIR 9 CE ANKIT MEENA
AIR 9 E&T T PIYUSH DAYANAND
AIR 9 EE ANMOL SINGH
AIR 9 ME KRISHNA KUMAR D
AIR 10 CE RAJESH BADUGU
AIR 10 E&T RAJVARDHAN SHARMA
AIR 10 ME AKSHAY VIDHATE
TOTAL 36 SELECTIONS IN TOP 10
CE: 09 | ME: 10 | EE: 08 | E&T: 09

(ii). Discuss how the topographical expressions like faults and folds control civil engineering projects such as tunnels, bridges, dams and reservoirs, [10 M]

Sol:

1. Tunnels

Faults:

- **Instability & Collapse:** Fault zones are zones of intense fracturing, displacement, and weakness. Rock masses within them are highly unstable, leading to collapses (e.g., Koyna Tunnel collapse along a fault zone).
- **Groundwater Ingress:** Faults act as major conduits for groundwater, causing heavy water inflow ("gushing") during excavation. This saturates rock, reduces strength, increases dewatering costs, and necessitates heavy lining.
- Alignment coinciding with fault strike is most hazardous.
- Tunnels in the footwall experience severe roof instability needing reinforcement.
- Tunnels in the hanging wall are relatively less affected.

Folds:

- **Strain Release:** Folded rocks store strain energy. Excavation releases this energy, causing rock falls or bulging into the tunnel.
- **Fracture Zones:** Crests (anticlinal tops) and troughs (synclinal bottoms) are often highly fractured, making them weak zones prone to collapse.
- **Groundwater Pathways:** Dipping bedding planes act as aquifers. Tunneling punctures these, leading to water seepage along the planes.
- **Parallel to Fold Axis:** Preferred if tunneling along the limbs (sides). Avoid crests (fractured, unstable roof) and troughs (hard, difficult excavation).
- **Perpendicular to Fold Axis:** Undesirable. Traverses different rock types with varying competence and encounters fractured crest/trough zones.
- **Fold Type:** Anticlines (less central pressure) are generally preferable to synclines (higher central pressure + potential groundwater pooling).

2. **Bridges**

Faults:

- **Foundation Instability:** Fault movement (even potential) threatens bridge pier foundations, causing differential settlement, tilting, or failure.
- **Ground Rupture:** Surface faulting can directly rupture foundations and abutments.
- **Seismic Hazard:** Faults near bridge sites significantly increase earthquake risk, requiring complex seismic design.

Folds:

- **Foundation Heterogeneity:** Piers founded on different limbs of a fold may experience uneven settlement due to differing rock types/competence.
- **Slope Stability:** Steeply dipping limbs or fractured fold cores create unstable slopes for bridge approaches and abutments, risking landslides.
- **Asymmetric Loading:** Bridges crossing fold axes may have piers on varying rock strengths, leading to uneven load distribution.

3. **Dams**

Faults:

- **Absolute Hazard:** Active faults are unacceptable dam sites due to rupture and seismic risk.
- **Leakage Pathways:** Fault zones are highly permeable, causing catastrophic reservoir leakage under high hydrostatic pressure.
- **Foundation Weakness:** Faults create weak, fractured rock unsuitable for bearing massive dam loads.
- **Grouting Difficulty:** Sealing deep, complex fault zones under dams is extremely challenging and often unreliable.
- **Dip Matters:** Downstream-dipping faults in the upstream side are particularly dangerous (leakage + uplift pressure).

Folds:

- **Bedding Dip Critical:**
- **Upstream Dip (Gentle):** Ideal. Dam load perpendicular to beds; percolated water returns upstream; no uplift.
- **Upstream Dip (Steep):** Acceptable but less ideal than gentle dip.
- **Downstream Dip (Any Angle):** Highly Undesirable. Percolation creates dangerous uplift pressure under the dam and causes leakage losses. Load parallel to weak planes.
- **Vertical Beds:** Generally stable against uplift/leakage but offers no particular advantage.
- **Fracturing:** Fold crests and troughs are fractured zones requiring extensive grouting to ensure foundation competence and water tightness.
- **Complex Folds:** Introduce severe heterogeneity and weakness, making foundation treatment difficult.

4. Reservoirs

Faults:

- **Major Leakage Paths:** Fault zones are primary conduits for reservoir water to escape, potentially draining the reservoir.
- **Buried Channels:** Faults often control ancient buried river channels (common in glaciated areas), which are severe leakage paths if intersected by the reservoir (e.g., Tapoban Dam site).
- **Seismic Triggering:** Reservoir-induced seismicity (RIS) is more likely near faults.

Folds:

- **Leakage Control:** Fold structures control groundwater flow. Synclines may trap water, while anticlines may allow lateral escape.
- **Bedding Planes:** Dipping beds, especially if permeable (e.g., sandstone, fractured limestone), provide pathways for water to leak out laterally from the reservoir sides ("rim leakage").

- **Rock Type Interaction:** Folds bring different rock types to the surface. Permeable rocks (vesicular basalt, conglomerate, porous limestone, schist) exposed in the reservoir rim, especially on dipping limbs, are major leakage risks.
- **Valley Sides:** If beds parallel the valley length (steeply dipping), the reservoir sides are prone to instability and leakage along bedding.