MADE EASY

Leading Institute for ESE, GATE & PSUs

Detailed Solutions

ESE-2026 Mains Test Series

Civil Engineering Test No : 2

Section A : Highway Engineering + Surveying and Geology

1. (a) (i) Solution:

1.

Feature	Prime Coat	Tack Coat
Applied On	Granular base or prepared non-bituminous surface	Existing bituminous surface
Purpose	Penetrates into base, binds loose particles, and improves adhesion	Provides proper bond in between old and new bituminous layers
Bitumen Type	Low-viscosity bitumen (cutback or emulsion)	Bitumen emulsion or residual bitumen
Application Rate	0.7 to 1.5 L/m^2	0.25 to 0.5 L/m^2
Function	Stabilizes base and provides waterproofing	Ensures bonding between layers
Timing	Applied before the first bituminous layer (initial surfacing)	Applied before laying are overlay or new bituminous layer

2.

Feature	Bitumen Emulsion	Cutback Bitumen
Composition	Bitumen + water + emulsifier	Bitumen + petroleum solvent
Application Temperature	Applied cold (ambient temperature)	Applied cold or with slight heating
Types	RS (Rapid Setting), MS (Medium Setting), SS (Slow Setting)	RC (Rapid Curing), MC (Medium Curing), SC (Slow Curing)
Safety	Non-flammable	Flammable
Environmental Impact	Low (eco-friendly)	Higher (due to solvent vapors causing pollution)
Uses	Prime coat, tack coat, surface dressing	Prime coat, surface dressing, cold mix asphalt

1. (a) (ii) Solution:

Requirements of Highway Drainage System

(i) The surface water from the carriageway and shoulder should be effectively drained off without allowing it to percolate into the subgrade.

(ii) Surface water from the adjoining land should be prevented from entering the roadway.

(iii) Side drain should have sufficient capacity and longitudinal slope to carry away all the surface water collected.

(iv) The Flow of surface water across the road, shoulders and along slopes should not cause formation of cross ruts or erosion.

(v) Seepage and other sources of under ground water should be removed by a subsurface drainage system.

(vi) The highest level of groundwater table should be kept well below the level of subgrade, preferably by at least 1.2 m.

(vii) In waterlogged areas, special precautions should be taken, especially if detrimental salts are present or flooding is likely to occur.

1. (b) Solution:

Bubble tube *A*:

The distance of bubble from center of its run

(i) $n_1 = \frac{1}{2}\times(14-6) = 4$ divisions

(ii) $n_2 = \frac{1}{2}\times(13-9) = 2$ divisions

Total number of division bubble has moved

$$n = n_1 + n_2 = 4 + 2 = 6 \text{ divisions}$$

The staff intercept, $S = 1.867 - 1.718 = 0.149$ m,

The sensitivity of bubble tube A is given by

$$S_A = 206265 \times \frac{S}{nD} \text{ seconds} = 206265 \times \frac{0.149}{6 \times 75}$$

$$S_A = 68.297'' = 1°8.3''$$

Similarly,

For bubble tube *B*:

$$n = \frac{1}{2} \times (16 - 4) + \frac{1}{2} \times (15 - 7) = 10$$

$$S = 1.888 - 1.735 = 0.153 \text{ m}$$

Sensitivity of bubble tube B

$$S_B = 206265 \times \frac{0.153}{10 \times 75} = 42.08''$$

$\because$ $S_A > S_B$, so bubble tube A is more sensitive

1. (c) Solution:

Given: Wheel load, $P = 4200$ kg

$E = 2.8 \times 10^5 \text{ kg/cm}^2$

$k = 10 \text{ kg/cm}^3$

Poission ratio, $\mu = 0.15$

$a = 14$ cm

$h = 20$ cm

Radius of relative stiffness,

$$l = \left[\frac{Eh^3}{12k(1 - \mu^2)}\right]^{1/4} = \left[\frac{2.8 \times 10^5 \times 20^3}{12 \times 10 \times (1 - 0.15^2)}\right]^{1/4}$$

$\Rightarrow$ $l = 66.105$ cm

Radius of equivalent resisting section

$$b = \sqrt{1.6a^2 + h^2} - 0.675\,h \qquad (\because \quad a < 1.724\,h)$$

$\Rightarrow$ $$b = \sqrt{1.6 \times 14^2 + 20^2} - 0.675 \times 20 = 13.21 \text{ cm}$$

Stress at interior (σ_i),

$$\sigma_i = \frac{0.316P}{h^2}\left[4\log_{10}\left(\frac{l}{b}\right)+1.069\right]$$

$$\Rightarrow \qquad \sigma_i = \frac{0.316\times 4200}{20^2}\left[4\log_{10}\left(\frac{66.105}{13.21}\right)+1.069\right]$$

$$\Rightarrow \qquad \sigma_i = 12.828 \text{ kg/cm}^2$$

Stress at edge (σ_e)

$$\sigma_e = \frac{0.572P}{h^2}\left[4\log_{10}\left(\frac{l}{b}\right)+0.359\right]$$

$$\Rightarrow \qquad \sigma_e = \frac{0.572\times 4200}{20^2}\left[4\log_{10}\left(\frac{66.105}{13.21}\right)+0.359\right]$$

$$\Rightarrow \qquad \sigma_e = 18.957 \text{ kg/cm}^2$$

Stress at corner (σ_c):

$$\sigma_c = \frac{3P}{h^2}\left[1-\left(\frac{a\sqrt{2}}{l}\right)^{0.6}\right]$$

$$\Rightarrow \qquad \sigma_c = \frac{3\times 4200}{20^2}\left[1-\left(\frac{14\sqrt{2}}{66.105}\right)^{0.6}\right]$$

$$\Rightarrow \qquad \sigma_c = 16.219 \text{ kg/cm}^2$$

1. (d) Solution:

Given: Average normal flow of traffic,

Cross roads A (q_A) = 460 PCU/hr

Cross roads B (q_B) = 240 PCU/hr

Saturation flow of traffic on

Cross roads A (S_A) = 1300 PCU/hr

Cross roads (S_B) = 1000 PCU/hr

All red time R = 12 seconds

Amber time for each phase = 2 seconds

As per Webster's design, optimum cycle length

$$C_o = \frac{1.5L+5}{1-y}$$

Where, L = total lost time, n = number of phase

$$L = 2n + R = 2 \times 2 + 12 = 16 \text{ sec}$$

Now, $y = y_A + y_B$

$\because$ $y_A = \dfrac{q_A}{S_A}$, $y_B = \dfrac{q_B}{S_B}$

$$y_A = \frac{460}{1300} = 0.354 \qquad y_B = \frac{240}{1000} = 0.24$$

$\therefore$ $C_o = \dfrac{1.5 \times 16 + 5}{1 - (0.354 + 0.24)} = 71.428 = 72$ second

Effective green time for phase A.

$$g_A = \frac{y_A}{y} \times (C_o - L)$$

$\Rightarrow$ $g_A = \dfrac{0.354}{0.354 + 0.24} \times (72 - 16) = 33.37$ sec

Effective given time for phase B,

$$g_B = \frac{0.24}{0.354 + 0.24} \times (72 - 16) = 22.63 \text{ sec}$$

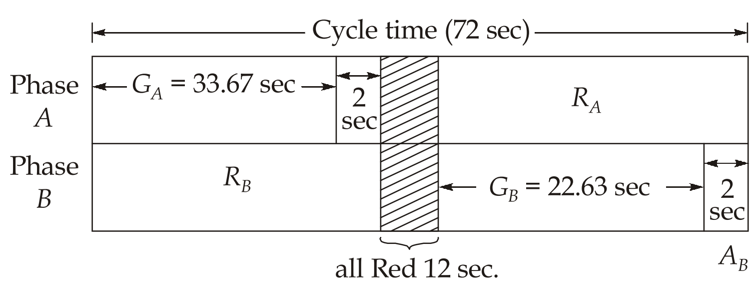
Green time for phase A,

$G_A = g_A$ – amber time for A + loss during start-up & amber

$= 33.37 - 2 + 2 = 33.37$ sec

Similarly for phase B,

$$G_B = 22.63 - 2 + 2 = 22.63 \text{ sec}$$



Signal phase diagram

1. (e) Solution:

Given: Focal length of camera, f = 30 mm

Flying height, H = 1200 m

Now,
$$X_A = \left(\frac{H-h_a}{f}\right)x_a = \left(\frac{1200-250}{30}\right)\times(20.5)$$

$$\Rightarrow \quad X_A = 649.17 \text{ m}$$

$$Y_A = \left(\frac{H-h_a}{f}\right)y_a = \left(\frac{1200-250}{30}\right)\times(15.5)$$

$$\Rightarrow \quad Y_A = 490.83 \text{ m}$$

$$X_B = \left(\frac{H-h_b}{f}\right)x_b = \left(\frac{1200-210}{30}\right)\times(-15.5)$$

$$\Rightarrow \quad X_B = -511.5 \text{ m}$$

$$Y_B = \left(\frac{H-h_b}{f}\right)y_b = \left(\frac{1200-210}{30}\right)\times(-20.5)$$

$$Y_B = -676.5 \text{ m}$$

Now, horizontal distance between points A and B on ground is

$$AB = \sqrt{(X_A - X_B)^2 + (Y_A - Y_B)^2}$$

$$\Rightarrow \quad AB = \sqrt{(649.17+511.5)^2 + (490.83+676.5)^2}$$

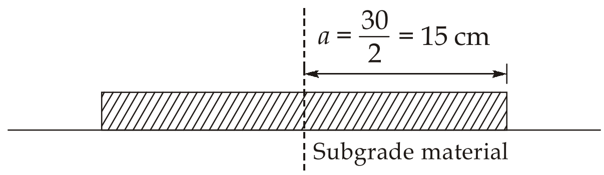
$$\Rightarrow \quad AB = 1646.15 \text{ m}$$

$$\text{Average scale} = \frac{f}{H - h_{avg}}$$

$$= \frac{30\times 10^{-3}\text{ m}}{\left[1200 - \left(\frac{250+210}{2}\right)\right]\text{m}} = \frac{1}{32333.33}$$

2. (a) (i) Solution:

Given: **Case 1:** Test is performed over the subgrade



$$\text{Pressure } p = 1.25 \text{ kg/cm}^2$$

$$\Delta = 5 \text{ mm}$$

Using the formula for rigid plate–

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

Where, F_2 = Deflection factor-depends upon $\left(\frac{E_s}{E_p} \text{ and } \frac{h}{a}\right)$

As in this case, test is carried out directly over subgrade, so thickness of pavement material $h = 0$, this is called single layer system.

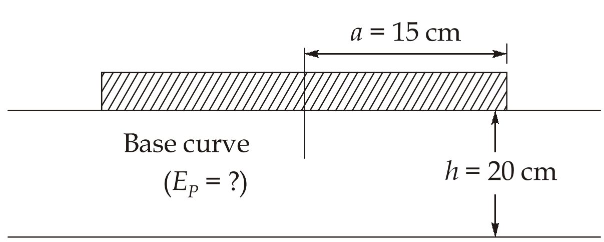
For single layer system $F_2 = 1$

So,
$$\Delta = \frac{1.18\, pa}{E_s}$$

$$0.5 = \frac{1.18 \times 1.25 \times 15}{E_s}$$

$$E_s = 44.25 \text{ kg/cm}^2$$

Case 2: Test is performed over pavement material



Subgrade

$$(E_s = 44.25 \text{ kg/cm}^2) \text{ as obtained above}$$

$$p = 5 \text{ kg/cm}^2$$

$$\Delta = 5 \text{ mm}$$

Again $\Delta = \dfrac{1.18\, p_a}{E_s} F_2$

$$0.5 = \frac{1.18 \times 5 \times 15}{44.25} \times F_2$$

$\Rightarrow$ $F_2 = 0.25$

For $\dfrac{h}{a} = \dfrac{20}{15} = 1.33$

and $F_2 = 0.25$

From given graph, $\dfrac{E_s}{E_p} = \dfrac{1}{50}$

$\therefore$ $E_p = 50 \times 44.25 = 2212.5 \text{ kg/cm}^2$

Now design of pavement under wheel load.

Wheel load, $P = 4100$ kg

Allowable deflection, $\Delta = 5$ mm

Tyre pressure, $p = 6 \text{ kg/cm}^2$

For radius of contact $p \times \pi a^2 = P$

$$a = \sqrt{\frac{4100}{6\pi}} = 14.748 \text{ cm}$$

For flexible plate $\Delta = \dfrac{1.5pa}{E_s} \times F_2$

$$0.5 = \frac{1.5 \times 6 \times 14.748}{44.25} \times F_2$$

$$F_2 = 0.167$$

By using chart, for $\dfrac{E_s}{E_p} = \dfrac{1}{50}$ and $F_2 = 0.167$

$\dfrac{h}{a} = 2.5$ $\Rightarrow$ $h = 2.5 \times 14.748$

$\Rightarrow$ $h = 36.87$ cm

2. (a) (ii) Solution:

Feature	Rigid Pavement	Flexible Pavement
Definition	Pavement in which load is distributed over a wide area of subgrade by the slab action of the concrete	Pavement in which load is transmitted gradually through successive layers by grain-to-grain contact and the pavement bends under load
Material	Made of Portland Cement Concrete (PCC)	Made of bituminous materials (asphalt), with aggregate layers
Structural Action	Acts like a rigid stab beam load is distributed over a large area due to high stiffness	Acts like a flexible plate; load spreads gradually through multiple layers
Thickness	Thicker (typically 20-40 cm)	Thinner (typically 10-30 cm)
Maintenance	Low maintenance; cracks repaired individually	Requires frequent maintenance, resurfacing, and patching
Design Life	Longer life (20-30 years or more)	Shorter life (10-15 years)
Cracks	Cracks may develop due to temperature changes, shrinkage, or foundation movement	Cracks develop due to traffic loads, fatigue, or subgrade failure
Initial Cost	High initial construction cost	Lower initial cost
Deflection under Load	Very low; slab is stiff	High; pavement bends under wheel load
Traffic Bearing Capacity	Suitable for heavy traffic with high axle loads	Suitable for moderate traffic

2. (b) (i) Solution:

Given $V = 110$ kmph

(i) Ruling minimum radius:

$$e + f = \frac{V^2}{127R} \qquad \text{where, } V \text{ in kmph}$$

As per IRC, for flat terrain

$$e_{max} = 0.07$$

and $f = 0.15$

$$\therefore \quad R_{min} = \frac{V^2}{127(e+f)_{max}} = \frac{110^2}{127(0.15+0.07)}$$

$$\Rightarrow \quad R_{min} = 433.07 \text{ m}$$

(ii) Super elevation:

For mix traffic, $e = \frac{(0.75V)^2}{127R} = \frac{V^2}{225R}$

$\Rightarrow$ $e = \frac{110^2}{225 \times 433.07}$

$\Rightarrow$ $e = 0.124 > (e_{max} = 0.07)$

check, $e + f = \frac{V^2}{225R}$

$\Rightarrow$ $0.07 + f = \frac{110^2}{225 \times 433.07}$

$\Rightarrow$ $f = 0.054 < 0.15$ OK

So, provide $e = 0.07$

(iii) Extra widening required

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

where, l = wheel base = 6 m (assumed)

$\Rightarrow$ $E_W = \frac{4 \times 6^2}{2 \times 433.07} + \frac{110}{9.5 \times \sqrt{433.07}}$

$\Rightarrow$ $E_W = 0.72$ m

(iv) Length of the transition curve

(a) Based on rate of change of centrifugal accelerate

$$L_{s1} = \frac{v^3}{RC}$$

$$C = \frac{80}{75 + v}, 0.5 < c < 0.8$$

$C = \frac{80}{75 + 110} = 0.43 \text{ m/sec}^3$ Take ($C = 0.5 \text{ m/sec}^3$)

$\Rightarrow$ $L_{s1} = \frac{\left(110 \times \frac{5}{18}\right)^3}{433.07 \times 0.5}$

$\Rightarrow$ $L_{s1} = 131.75$ m

(b) Based on rate of introduction of super elevation

$$L_{s2} = \frac{Ne(w+w_e)}{2} \quad \text{For flat terrain}$$

$$\Rightarrow \quad L_{s2} = \frac{150 \times 0.07 \times (14 + 0.72)}{2} \quad N = 150$$

$$\Rightarrow \quad L_{s2} = 77.28 \text{ m} \quad \text{For four lane road}$$

w = width of pavement
= 3.5 × 4 = 14 m

(c) Empirical method by IRC

$$Ls_3 = \frac{2.7V^2}{R} = \frac{2.7 \times 110^2}{433.07} = 75.44 \text{ m}$$

$$L_s = \text{Max of } (L_{s1}, L_{s2}, L_{s3}) = 131.75 \text{ m}$$

2. (b) (ii) Solution:

Advantages of traffic signals:

1. Traffic signals provide orderly movement of traffic and increase the traffic handling capacity at most of the intersections at grade.
2. They reduce chances of accidents.
3. They aid pedestrians to cross the roads safely at signalised intersections.
4. They allow the crossing of heavy traffic with safety.
5. When properly synchronised, they aid in good speed along the major road traffic.
6. Automatic traffic signal is quite economical as compared to manual control.

Disadvantages of traffic signals:

1. Traffic signals increase the possibility of rear end collision.
2. Improperly designed traffic signals lead to violation of traffic signals.
3. Failure of electric power supply to traffic signals often creates chaos at intersections.

2. (b) (iii) Solution:

Basic requirements of intersection at grade:

1. At the intersection area, the conflict area must be small.
2. The relative speed of the vehicles and angle of approach of vehicles must be small.
3. Adequate visibility must be there at intersection for the approaching vehicles.
4. Geometric design of elements like radius and width of the pavement must be properly designed.

5. At the intersection area, proper signs must be provided on the approaching leg to warn the drivers.
6. Proper lighting must be there at intersections in night.
7. There should not be sudden change of path at the intersection area.

2. (c) Solution:

Given: Standardisation data

$$P_o = 95 \text{ N}$$
$$T_o = 18\ °\text{C on ground}$$

Measureded under–

$$P_m = 155 \text{ N}$$
$$T_m = 15\ °\text{C}$$

on sloped ground (From given table)

$$\text{Total measurement} = 29.988 + 28.895 + 29.838 + 29.910$$
$$= 119.631 \text{ m}$$

(a) Pull correction

$$C_p = \frac{(P_m - P_o)L}{AE} = \frac{(155-95)\times 119.631}{3.35\times 14.8\times 10^4} = 0.0145 \text{ m}$$

(b) Temperature correction,

$$C_t = L\,\alpha\,(T_m - T_o) = 119.631 \times 0.9 \times 10^{-6} \times (15 - 18)$$
$$= -0.0003 \text{ m}$$

(c) Sag correction is to be applied for each individual catenary measurement.

$$C_{Sag} = \Sigma\left[-\frac{w^2 l_o^3}{24P_m^2}\right]$$

where, w = weight of tape per unit length

$$= 0.025 \times 9.81 \text{ N/m} = 0.24525 \text{ N/m}$$

$$\Rightarrow \quad C_{Sag} = \frac{w^2}{24P_m^2}\left[l_1^3 + l_2^3 + l_3^3 + l_4^3\right]$$

$$\Rightarrow \quad C_{Sag} = \frac{-(0.24525)^2}{24\times 155^2}\left[29.998^3 + 29.895^3 + 29.838^3 + 29.910^3\right]$$

$$\Rightarrow \quad C_{Sag} = -0.0112 \text{ m}$$

(d) Slope curréction

$$C_s = -\frac{h^2}{2L}$$

$$\Rightarrow \quad C_s = -\frac{1}{2}\left[\frac{0.346^2}{29.988}+\frac{0.214^2}{29.895}+\frac{0.309^2}{29.838}+\frac{0.106^2}{29.910}\right]$$

$$\Rightarrow \quad C_s = -0.0045 \text{ m}$$

(e) M.S.L correction

$$C_{msl} = -\frac{Lh}{R_e} = -\frac{119.631\times 120}{6370\times 10^3} = -0.0022 \text{ m}$$

Total correction = Sum of all above corrections

= + 0.0145 – 0.0003 – 0.0112 – 0.0045 – 0.0022

= – 0.0037 m

Corrected length = 119.631 – 0.0037

= 119.6273 m

3. (a) (i) Solution:

Given: h = 30 cm

L_x = 4.5 m

L_y = 3.6 m

K = 6 kg/cm^3

temperature differential, t = 12 °C

a = 15 cm

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

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

μ = 0.14

Radius of relative stiffness,

$$l = \left[\frac{Eh^3}{12K(1-\mu^2)}\right]^{1/4} = \left[\frac{3\times 10^5\times 30^3}{12\times 6\times(1-0.14^2)}\right]^{1/4}$$

$$l = 103.50 \text{ cm}$$

$$\therefore \quad \frac{l_x}{l} = \frac{4.5\times 100\ cm}{103.50\ cm} = 4.35$$

$$\therefore \quad \frac{l_y}{l} = \frac{3.6\times 100}{103.50} = 3.48$$

Warping stress at interior region:

$$\sigma_i = \frac{E\alpha t}{2}\left[\frac{C_x + \mu C_y}{1-\mu^2}\right]$$

$$\Rightarrow \quad \sigma_i = \frac{3\times10^5 \times 10\times10^{-6}\times12}{2}\left[\frac{0.62+0.14\times0.4}{1-0.14^2}\right]$$

$$\Rightarrow \quad \sigma_i = 12.41 \text{ kg/cm}^2$$

Warping stress at edge, $\sigma_e = \text{Max of}\left(\frac{C_x E\alpha t}{2}, \frac{C_y E\alpha t}{2}\right) \quad (\because \; C_x > C_y)$

$$\Rightarrow \quad \sigma_e = \frac{C_x E\alpha t}{2} = \frac{0.62\times3\times10^5\times10\times10^{-6}\times12}{2}$$

$$\Rightarrow \quad \sigma_e = 11.16 \text{ kg/cm}^2$$

Warping stress at corner, $\sigma_c = \frac{E\alpha t}{3(1-\mu)}\sqrt{\frac{a}{l}} = \frac{3\times10^5\times10\times10^{-6}\times12}{3\times(1-0.14)}\times\sqrt{\frac{15}{103.50}}$

$$\Rightarrow \quad \sigma_c = 5.312 \text{ kg/cm}^2$$

3. (a) (ii) Solution:

B.S.	*I.S.*	*F.S.*	Rise	Fall	*R.L.*	Remarks
1.735					68.235	A. Bench mark
	1.625		0.110		68.345	B
	1.580		0.045		68.390	C
1.115		1.250	0.330		68.720	D. Change point
	2.010			0.895	67.825	E
1.055		1.325	0.685		68.510	F. Change point
	1.095			0.040	68.470	G
	1.110			0.015	68.455	H
		0.955	0.155		68.610	I. End point

Arithmetical Check

$$\Sigma \text{ B. S.} - \Sigma \text{ F. S.} = 3.905 - 3.530 = 0.375 \text{ m}$$

$$\Sigma \text{ Rise} - \Sigma \text{ Fall} = 1.325 - 0.950 = 0.375 \text{ m}$$

$$\text{Last R.L.} - \text{First R.L.} = 68.610 - 68.235 = 0.375 \text{ m}$$

3. (b) Solution:

Given: Two lane two way highway

$$\text{Design speed} = 65 \text{ kmph} = 65 \times \frac{5}{18} = 18.056 \text{ m/sec}$$

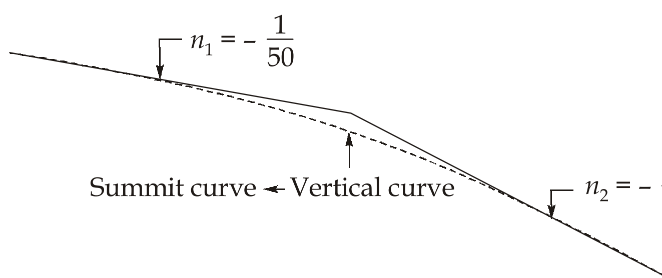
$$n_1 = \frac{-1}{50}$$

$$n_2 = \frac{-1}{20}$$

$$N = |n_1 - n_2| = \left|\frac{-1}{50} - \left(\frac{-1}{20}\right)\right| = 0.03$$

$$f = 0.35$$

$$a = 3.6 \text{ km/hr/sec} = \frac{3.6 \times 1000}{60 \times 60} = 1 \text{ m/sec}^2$$



Stopping light distance (SSD)

$$SSD = vt + \frac{v^2}{2gf}$$

Take reaction time $t = 2.5$ sec

$$SSD = 18.056 \times 2.5 + \frac{18.056^2}{2 \times 9.81 \times 0.35}$$

$$= 92.61 \text{ m}$$

Overtaking light distance

OSD per two lane two way traffic

$$OSD = d_1 + d_2 + d_3$$

$\because$ $d_1 = v_b t$

Where, v_b = speed of slow moving vehicle

$$= (v_d - 4.5) \text{ m/sec}$$

$$= 18.056 - 4.5 = 13.556 \text{ m/sec}$$

$t = 2.0$ sec (as per IRC for OSD)

$\therefore \quad d_1 = 13.556 \times 2.0 = 27.112$ m

$d_2 = 2s + b$

Where, $s = 0.7\,v_b + 6 = 0.7 \times 13.556 + 6 = 15.489$ m

$b = v_b \times t$

and $T = \sqrt{\dfrac{4s}{a}} = \sqrt{\dfrac{4 \times 15.489}{1}} = 7.87$ sec

$\therefore \quad d_2 = 2 \times 15.489 + 13.556 \times 7.87$

$d_2 = 137.66$ m

Now $d_3 = v_d \times T = 18.056 \times 7.87 = 142.10$ m

$\therefore \quad OSD = 27.112 + 137.66 + 142.10 = 306.872$ m

Length of vertical curve based on SSD

Case 1: Assume $L_s > SSD$

$$L_s = \frac{NS^2}{4.4} = \frac{0.03 \times 92.61^2}{4.4} = 58.48 \text{ m} < SSD$$

(Assumption is wrong)

Assume: $L_s < SSD$

$$\therefore \quad L_s = 2S - \frac{4.4}{N}$$

$$L_s = 2 \times 92.61 - \frac{4.4}{0.03} = 38.55 \text{ m} > \text{SSD}$$

(Assumption is correct)

Length of vertical curve based on OSD

Case1: Assume $L_s > OSD$

$$L_s = \frac{NS^2}{9.6} = \frac{0.03 \times 306.872^2}{9.6}$$

$$L_s = 294.28 \text{ m} < \text{OSD}$$

(Assumption is wrong)

Assume ($L_s < OSD$) $\quad L_s = 2S - \dfrac{9.6}{N} = 2 \times 306.872 - \dfrac{9.6}{0.03}$

$$L_s = 293.744 \text{ m} < \text{OSD}$$

(Assumption is correct)

3. (c) (i) Solution:

- **Folds:** Folds are bends or warping in rock layers caused due to compressional forces acting within the Earth's crust. When rocks are subjected to stress beyond their elastic limit, they undergo plastic deformation resulting in folding. Common types of folds include anticlines (upward arching folds), synclines (downward trough-like folds), monoclines, and overturned folds. Folds indicate zones of weakness and influence the attitude of rock strata, which is important in planning engineering structures.
- **Faults:** Faults are fractures or cracks in the Earth's crust along which relative movement of rock blocks has occurred due to tectonic forces. Depending on the nature of movement, faults are classified as normal faults, reverse (thrust) faults, and strike-slip faults. Fault zones generally contain crushed and fractured rocks, making them weak and unstable. These zones often act as pathways for groundwater movement and may be associated with seismic activity.
- **Significance in Engineering Works:** The presence of folds and faults greatly affects engineering projects such as dams, tunnels, bridges, and foundations. Folded rock strata may cause uneven load distribution and instability in foundations. Fault zones are structurally weak and may lead to seepage, settlement, or failure of structures. In dam construction, faults can cause excessive leakage, while in tunnels they may lead to roof collapse or water ingress. Therefore, identification and detailed geological investigation of folds and faults are essential for safe design and construction of engineering works.

3. (c) (ii) Solution:

Types of Resolution and Their Importance in Image Interpretation

Spatial Resolution: Spatial resolution is the size of the smallest ground area represented by one pixel in an image. High spatial resolution images (small pixel size) allow clear identification of small features like narrow roads and buildings, whereas low spatial resolution images are suitable for large-area studies such as regional land use.

Spectral Resolution: Spectral resolution refers to the ability of a sensor to record data in different wavelength bands of the electromagnetic spectrum. Sensors with high spectral resolution can distinguish between objects that appear similar visually, such as different types of vegetation or soil, thereby improving classification accuracy.

Temporal Resolution: Temporal resolution is the frequency with which a sensor revisits the same area on the Earth's surface. High temporal resolution is important for monitoring changes over time, such as crop growth, floods, forest fires, and urban expansion

Radiometric Resolution: Radiometric resolution indicates the sensor's ability to detect slight differences in energy reflected or emitted from objects. Higher radiometric resolution allows better discrimination between features with similar reflectance values, improving image contrast and interpretation.

Importance in Image Interpretation: The combined effect of spatial, spectral, temporal, and radiometric resolutions determines the effectiveness of image interpretation. Proper selection of resolution helps in accurate identification, classification, and analysis of surface features, making remote sensing data reliable for applications in civil engineering, environmental studies, agriculture, and resource management.

4. (a) (i) Solution:

Adjustment of angular error

The sum of the internal angles of a polygon having a sides is $(2n - 4)\ 90°$, therefore for six sides polygon

$$\Sigma \text{ Internal angles} = (2 \times 6 - 4) \times 90° = 720°$$

$$\Sigma \text{ Observed internal angles} = 120°35'00'' + 89°23'40'' + 131°01'00'' + 128°02'20'' + 94°54'40'' + 155°59'20'' = 719°56'00''$$

$$\text{Total error} = 719°56'00'' - 720° = -4'$$

$$\text{Total correction} = 4' \text{ or } 240''$$

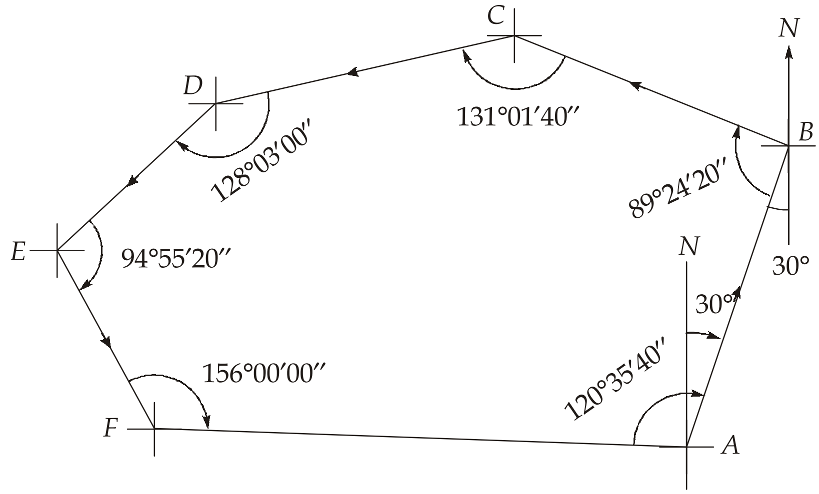
Since the error is of some magnitude, it implies that the work is of relatively low order, therefore, the correction may be applied equally to each angle assuming that the conditions were constant at the time of observation and the angles were measured with the same precision.

Hence the correction to each angle $= \dfrac{240'}{6} = 40''$.

The corrected included angles are given in the following table:

Traverse station	Included angle	Correction	Adjusted value
A	120°35′00″	+ 40″	120°35′40″
B	89°23′40″	+ 40″	89°24′20″
C	131°01′00″	+ 40″	131°01′40″
D	128°02′20″	+ 40″	128°03′00″
E	94°54′40″	+ 40″	94°55′20″
F	155°59′20″	+ 40″	156°00′00″
Sum	719°56′00″	+ 240″	720°00′00″

Based on corrected included angle, following diagram may be prepared.



Bearing of traverse line

FB of line AB = 30° (given)

BB of line AB = 180° + 30° = 210°

FB of line BC = BB of line AB + included angle at B

= 210° + 89°24'20''

= 299°24'20''

BB of line BC = 299° 24'20'' – 180° = 119°24'20''

FB of line CD = BB of line BC + included angle at C

= 119°24'20'' + 131° 01'40''

= 250°26'0''

BB of line CD = 250°26'00'' – 180°

= 70°26'00''

FB of line DE = 70°26'00'' + 128°03'00'

= 198°29'00''

BB of line DE = 198°29'00'' – 180° = 18°29'00''

FB of line EF = 18°29'00'' + 94°55'20''

= 113°24'20''

BB of line EF = 113°24'20'' + 180° = 293°24'20''

FB of line FA = (293°24'20'' + 156°) – 360°

= 89°24'20''

BB of line FA = 89°24'20'' + 180° = 269°24'20''

FB of line AB = (269°24'20'' + 120°35'40'') – 360°

= 30° (checked) Ok

4. (a) (ii) Solution:

Raster Data Model

The raster data model represents geographic features as a grid of uniform-sized cells (pixels), where each cell holds a value representing an attribute such as elevation, land use, or temperature. The position of each cell is defined by its row and column in the grid. Raster data is commonly used for continuous data and is well suited for remote sensing images and surface modeling.

Advantages:

(i) Simple data structure and easy to understand

(ii) Efficient for representing continuous phenomena

(iii) Well suited for spatial analysis and overlay operations

(iv) Compatible with satellite imagery and scanned maps

Limitations:

(i) Requires large storage space for high-resolution data

(ii) Less accurate representation of boundaries

(iii) Spatial resolution depends on cell size

(iv) Not ideal for representing discrete features like roads or boundaries

Vector Data Model

The vector data model represents geographic features using points, lines, and polygons. Points represent features such as wells or towers, lines represent roads and rivers, and polygons represent areas such as lakes or land parcels. Each feature is defined by precise coordinates and is linked to attribute data stored in tables.

Advantages:

(i) High positional accuracy and clear representation of boundaries

(ii) Requires less storage compared to raster for discrete features

(iii) Suitable for network analysis and cadastral mapping

(iv) Easy to edit and update

Limitations:

(i) Complex data structure

(ii) Overlay and spatial analysis are compositionally intensive

(iii) Not suitable for continuous data

(iv) Conversion from raster may lead to data loss

4. (b) (i) Solution:

Role of Joints in Rock Masses and Problems Created in Civil Engineering Works

Joints are natural fractures in rocks along which no visible displacement has occurred. They play a significant role in determining the behavior of rock masses and greatly influence the design and performance of civil engineering structures.

Role of Joints in Rock Masses:

Joints divide a rock mass into blocks and control its strength, permeability, and deformability. The orientation, spacing, and continuity of joints govern how the rock mass responds to loads and excavations. Closely spaced joints reduce the overall strength of the rock mass, while well-developed joint systems increase permeability and facilitate groundwater movement. Joints also influence weathering processes, as water and air penetrate through them, accelerating rock disintegration.

Problems Created in Civil Engineering Works:

In dam construction, joints act as seepage paths leading to leakage and uplift pressure, which may threaten stability. In tunnel construction, joints can cause roof falls, sidewall failures, and excessive groundwater inflow, increasing the need for support and drainage. For slopes and hill roads, joints dipping outwards may trigger landslides and rock falls. In foundation works, joints reduce bearing capacity and may lead to uneven settlement. Thus, joints often create instability, seepage, and construction difficulties.

Therefore, detailed study of joints and their characteristics is essential in engineering geology to design appropriate support, drainage, and treatment measures for safe and economical civil engineering works.

4. (b) (ii) Solution:

Speed Range (kmph)	Average Speed (kmph)	No. of Vehicles	Cumulative No. of Vehicles	Cumulative Percentage (%)
0-10	5	12	12	1.18
10-20	15	35	47	4.61
20-30	25	55	102	10.00
30-40	35	60	162	15.88
40-50	45	140	302	29.61
50-60	55	230	532	52.16
60-70	65	320	852	83.53
70-80	75	95	947	92.84
80-90	85	45	992	97.25
90-100	95	28	1020	100.00

Based on data provided, following table may be prepared, cumulative% is calculated as

$$= \frac{\text{Cumulative number of vehicles}}{\text{Total number vehicles}}$$

$$\text{for first row, cumulative\%} = \frac{12}{1020} \times 100 = 1.18\%$$

Similarly for others

(a) Upper speed limit: 85th percentile speed by linear interpolation between (83.53% and 92.84%)

$$v_{85} = 65 + \frac{(75-65)}{(92.84-83.53)} \times (85-83.53) = 66.58 \text{ kmph}$$

$$\text{Lower speed limit} = 15^{th} \text{ percentile speed}$$

$$v_{15} = 25 + \frac{(35-25)}{(15.88-10)} \times (15-10) = 33.50 \text{ kmph}$$

(b) Design speed = 98th percentile speed

$$v_{98} = 85 + \frac{(95-85)}{(100-97.25)} \times (98-97.25) = 87.73 \text{ kmph}$$

4. (c) (i) Solution:

Given: Tacheometer fitted with anallactic lens,

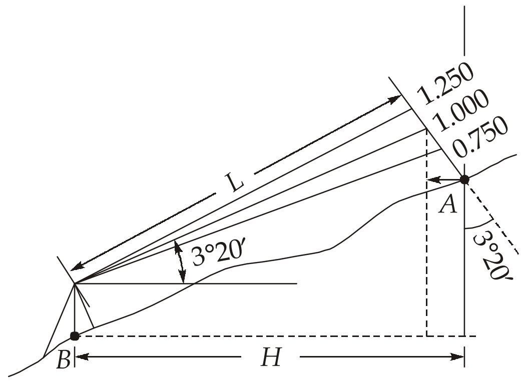
$$C = 0, K = 100$$

Since difference between staff readings is constant

$$0.250 \begin{cases} \left.\begin{matrix} 0.750 \\ 1.000 \end{matrix}\right\} 0.250 \\ 1.250 \end{cases} \Rightarrow \text{Staff held perpendicular to line of sight}$$

$$0.750 \begin{cases} \left.\begin{matrix} 1.250 \\ 2.000 \end{matrix}\right\} 0.750 \\ 2.750 \end{cases} \Rightarrow \text{Staff held perpendicular to line of sight}$$

For $B \rightarrow A$:



$$L = KS + C = 100\,(1.250 - 0.75) = 50 \text{ m}$$

$$H_{AB} = L\cos\theta + S_2 \sin\theta$$

$$H_{AB} = 50\cos 3°20' + 1.00 \times \sin 3°20'$$

$$H_{AB} = 49.973 \text{ m}$$

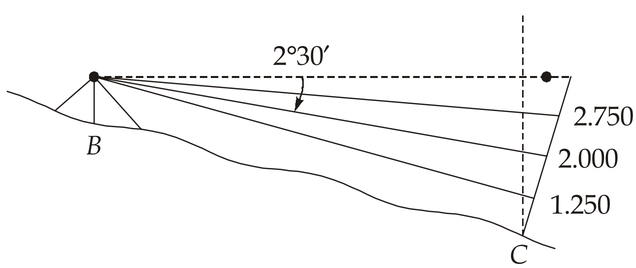
Assuming the *RL* of height of instrument is 100 m

$$RL_A = HI_{RL} + L\sin\theta - S_2\cos\theta$$

$\Rightarrow$ $$KL_A = 100 + 50\sin 3'20' - 1\cos 3°20'$$

$\Rightarrow$ $$KL_A = 101.909 \text{ m}$$

For $B \rightarrow C$



$$L = KS + C = 100\,(2.750 - 1.25) + 0 = 150 \text{ m}$$

$$H_{BC} = L\cos\theta - S_2\sin\theta$$

$$H_{BC} = 150\cos 2°30' - 2.00\sin 2°30'$$

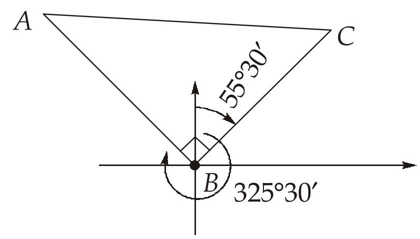
$$H_{BC} = 149.769 \text{ m}$$

$$RL_C = (HI)_{RL} - L\sin\theta - S_2\cos\theta$$

$$= 100 - 150\sin 2°30' - 2.00\cos 2°30'$$

$$= 91.459 \text{ m}$$

(a) Distance AC



$$\angle_B = 360° - 325°30' + 55°30' = 90°$$

$$\therefore \quad AC = \sqrt{BA^2 + BC^2} = \sqrt{H_{BA}^2 + H_{BC}^2}$$

$$= \sqrt{49.973^2 + 149.769^2}$$

$$= 157.886 \text{ m}$$

(b) Difference in level between A and C

$$= 101.909 - 91.459$$

$$= 10.45 \text{ m (A is at higher level than C)}$$

Section B : Geo-tech & Found. Engg. - 1 + Environmental Engg. - 1

5. (a) Solution:

The triaxial test is a laboratory test used to determine the mechanical properties of soil, such as shear strength, cohesion (c), and angle of internal friction (ϕ), under controlled stress conditions. It is one of the most versatile and widely used tests in geotechnical engineering.

Principle of the Test

A cylindrical soil sample is encased in a rubber membrane and subjected to:

1. Confining pressure (σ_3) applied by water or oil in a pressure chamber.
2. Axial load (σ_1) applied along the vertical axis until failure occurs.

During the test, the difference in stress ($\sigma_1 - \sigma_3$) is measured, which represents the deviator stress causing shear failure.

Types of Triaxial Test

The triaxial test can be classified based on drainage conditions and stress application:

1. Based on Drainage:
   - Unconsolidated Undrained (UU):
     - Soil is not allowed to consolidate, and the test is conducted quickly.
     - Measures total stress shear strength.

- Consolidated Undrained (*CU*):
  - Sample is consolidated under confining pressure first, then sheared without drainage.
  - Measures pore pressure changes and effective stress parameters.
- Consolidated Drained (CD):
  - Sample is allowed to drain during loading, so excess pore pressure does not develop.
  - Measures effective stress shear strength.

Merits and demerits of triaxial test

The triaxial test has the following merits and demerits.

Merits.

1. There is complete control over the drainage conditions. Tests can be easily conducted for all three types of drainage conditions.
2. Pore pressure changes and the volumetric changes can be measured directly.
3. The stress distribution on the failure plane is uniform.
4. The specimen is free to fail on the weakest plane.
5. The state of stress at all intermediate stages upto failure is known. The Mohr circle can be drawn at any stage of shear.
6. The test is suitable for accurate research work. The apparatus is adaptable to special requirements such as extension test and tests for different stress paths.

Demerits

1. The apparatus is elaborate, costly and bulky.
2. The drained test takes a longer period as compared with that in a direct shear test.
3. The strain condition in the specimen are not uniform due to frictional restraint produced by the loading cap and the pedestal disc. This leads to the formation of the dead zones at each end of the specimen.

   The non-uniform distribution of stresses can be largely eliminated by lubrication of end surfaces. However, non-uniform distribution of stresses has practically no effect on the measured strength if length/diameter ratio is equal to or more than 2.0.
4. It is not possible to determine the cross-sectional area of the specimen accurately at large strains, as the assumption that the specimen remains cylindrical does not hold good.
5. The test simulates only axis-symmetrical problems. In the field, the problem is generally 3-dimensional. A general test in which all the three stresses are varied would be more useful.
6. The consolidation of the specimen in the test is isotropic; whereas in the field, the consolidation is generally anisotropic..

5. (b) Solution:

To find the total settlement after 20 years, we need to account for both primary consolidation settlement and secondary compression settlement.

Primary Consolidation Settlement (S_c)

First, we calculate the ultimate primary consolidation settlement using the given parameters:

$$\text{Thickness of clay layer } (H) = 6 \text{ m}$$
$$\text{Initial void ratio } (e_0) = 1.05$$
$$\text{Compression index } (C_c) = 0.40$$
$$\text{Initial effective pressure } (\sigma'_0) = 125 \text{ kPa}$$
$$\text{Increase in pressure } (\Delta\sigma) = 75 \text{ kPa}$$

The formula for ultimate settlement is:

$$S_c = \frac{C_c \times H}{1+e_0} \times \log_{10}\left(\frac{\sigma'_0 + \Delta\sigma}{\sigma'_0}\right)$$

Substituting the values:

$$S_c = \frac{0.40 \times 6}{1+1.05} \times \log_{10}\left(\frac{125+75}{125}\right)$$

$$\Rightarrow \quad S_c = \frac{2.4}{2.05} \times \log_{10}(1.6)$$

$$\Rightarrow \quad S_c = 0.239 \text{ m} = 239 \text{ mm}$$

Time Required for Primary Consolidation (t_p)

We are told primary consolidation is complete at $U = 95\%$. For $U > 60\%$, the time factor (T_v) is:

$$T_v = 1.781 - 0.933 \times \log_{10}(100 - U)$$

$$\Rightarrow \quad T_v = 1.781 - 0.933 \times \log_{10}(100 - 95)$$

$$\Rightarrow \quad T_v = 1.781 - 0.933 \times \log_{10}(5) = 1.129$$

The drainage path (d) for double drainage is $H/2 = 6/2 = 3$ m. Using $c_v = 3.5\ \text{m}^2/\text{year}$:

$$t_p = \frac{T_v \times d^2}{c_v} = \frac{1.129 \times 3^2}{3.5}$$

$$t_p \approx 2.903 \text{ years}$$

Since, t = 20 years is greater than t_p, the primary consolidation is fully finished, and secondary compression has been occurring for (20 – 2.903) years.

Secondary Compression Settlement (S_s)

The void ratio at the end of primary consolidation (e_p) is:

$$e_p = e_0 - \Delta_e = e_0 - \left[\frac{S_c \times (1+e_o)}{H}\right]$$

$$\Rightarrow \quad e_p = 1.05 - \left[\frac{0.239 \times 2.05}{6}\right] \approx 0.968$$

Now, calculate secondary settlement using $C_\alpha = 0.025$:

$$S_s = \frac{C_\alpha \times H}{1+e_p} \times \log_{10}\left(\frac{t}{t_p}\right)$$

$$\Rightarrow \quad S_s = \frac{0.025 \times 6}{1+0.968} \times \log_{10}\left(\frac{20}{2.903}\right)$$

$$\Rightarrow \quad S_s = 0.064 \text{ m} = 64 \text{ mm}$$

The total settlement after 20 years is the sum of primary and secondary settlements:

$$S_{\text{total}} = S_c + S_s$$

$$\Rightarrow \quad S_{\text{total}} = 239 + 64$$

$$\Rightarrow \quad S_{\text{total}} = 303 \text{ mm}$$

5. (c) Solution:

$$\text{5 days 20°C BOD} = 110 \text{ mg}/l \text{ (Given)}$$

BOD at 20°C at 5 days is given by

$$\text{(BOD)} = L_t = L_o\left[1-(10)^{-k_D t}\right]$$

Using,

$$L_t = 110 \text{ mg}/l$$

$$(k_D)_{20°C} = 0.10 \text{ day}^{-1}$$

$$\therefore \quad 110 = L_o\,[1 - (10)^{-0.1\times5}]$$

$$\Rightarrow \quad L_o = \frac{110}{\left[1-(10)^{-0.1\times5}\right]} = 160.87 \text{ mg}/l$$

Now, calculate k_D at 37°C

$$(k_D)_{T°C} = (k_D)_{20°C}\,[1.047]^{T-20}$$

$$\Rightarrow \quad (k_D)_{37°C} = 0.10[1.047]^{37-20}$$

$$= 0.218 \text{ day}^{-1}$$

Now, calculate (BOD) at 37°C after 1 day

$$L_t = L_o\left[1-(10)^{-k_D t}\right]$$

Using, $L_o = 160.87$ mg/l

$(k_D)_{37°C} = 0.218$ day^{-1}

$t = 1$ day

$\therefore$ $(BOD)_{37°C\text{-}1\ day} = 160.87 \times [1 - (10)^{-0.218\times1}]$

$= 63.49$ mg/l

$\therefore$ $(BOD)_{at\ 37°C}$ after 1 day $= 63.49$ mg/l

5. (d) Solution:

Quantity of sewage produced =100 × 120 = 12000 l/day

Quantity of sewage produced during detention period

$$= 12000 \times \frac{24}{24} = 12000 \text{ litres}$$

Now, given the rate of deposited sludge is 30 litres/ capita/year

Period of cleaning = 1 year

$\therefore$ The volume of sludge deposited

= 30 × 100 × 1 = 3000 litre

$\therefore$ Total required capacity of tank = Capacity for sewage + Capacity for sludge

= 12000 + 3000 = 15000 litre = 15 m^3

Given depth of tank = 1.5 m

$$\text{Surface area of tank} = \frac{15}{1.5} = 10 \text{ m}^2$$

Ratio of length to width = 4 : 1

$\therefore$ $4B^2 = 10$

$$\Rightarrow \quad B = \sqrt{\frac{10}{4}} = 1.58 \text{ m} \simeq 1.6 \text{ m}$$

Length of tank = $4B$ = 4 × 1.58 = 6.32 m $\simeq$ 6.4 m

Thus, dimension of the septic tank will be 6.4 m × 1.6 m × 1.5 m

Provide 0.5 m as free board

$\therefore$ Use tank of size 6.4 m × 1.6 m × 2 m

5. (e) Solution:

Permeability of an Unconfined Aquifer (Fully Penetrating Well)

Derivation of Expression

Consider a well fully penetrating an unconfined aquifer resting on an impervious stratum. Let water be pumped at a steady discharge Q, producing a steady radial flow towards the well.

At any radial distance r from the centre of the well, let the height of the water table above the impervious layer be h.

For steady radial flow through a cylindrical surface of radius r and thickness h:

$$\text{Area of flow} = 2\pi rh$$

Using Darcy's law,

$$Q = k \times (\text{hydraulic gradient}) \times (\text{area of flow})$$

$$Q = k\left(\frac{dh}{dr}\right)(2\pi rh)$$

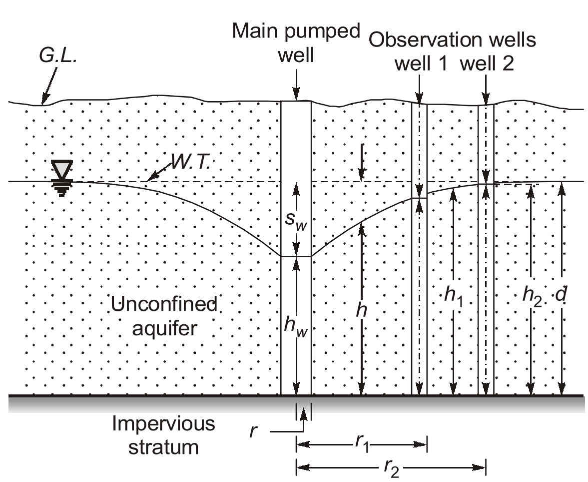
$$\Rightarrow \qquad Q = 2\pi krh\frac{dh}{dr}$$

Rearranging,

$$\frac{Q}{2\pi k} = rh\frac{dh}{dr}$$

Integrating between two observation wells:

- At $r = r_1$, water table height $= h_1$
- At $r = r_2$, water table height $= h_2$



$$\int_{h_1}^{h_2} h\,dh = \frac{Q}{2\pi k}\int_{r_1}^{r_2}\frac{dr}{r}$$

$$\frac{h_2^2 - h_1^2}{2} = \frac{Q}{2\pi k}\ln\left(\frac{r_2}{r_1}\right)$$

Rearranging

$$k = \frac{Q\ln\left(\frac{r_2}{r_1}\right)}{\pi\left(h_2^2 - h_1^2\right)}$$

This is the required expression for permeability of an unconfined aquifer using two observation wells.

Given:

Pumping rate,

$$Q = 7.5 \text{ L/s} = 0.0075 \text{ m}^3\text{/s}$$

Distance of observation well A,

$$r_1 = 20 \text{ m}, h_1 = 12 \text{ m}$$

Distance of observation well B,

$$r_2 = 35 \text{ m}, h_2 = 12.5 \text{ m}$$

Substitute into the formula

$$k = \frac{0.0075\ln\left(\frac{35}{20}\right)}{\pi\left(12.5^2 - 12^2\right)}$$

$$= 1.09 \times 10^{-4} \text{ m/s}$$

Convert to m/day

$$k = 1.09 \times 10^{-4} \times 86400 \approx 9.418 \text{ m/day}$$

6. (a) (i) Solution:

Falling Head Permeability Test

Assumptions

The soil is fully saturated and homogeneous and flow through the soil is laminar and follows Darcy's law.

Derivation

Let:

a = cross-sectional area of standpipe

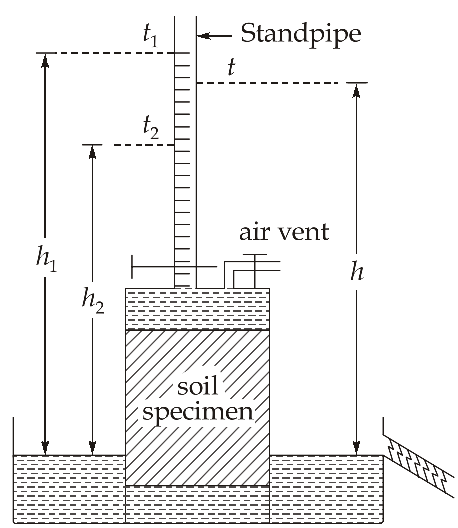
A = cross-sectional area of soil specimen

L = length of soil specimen

h = head of water at time t

k = coefficient of permeability

t = time taken for head to fall



According to Darcy's law, the rate of flow through the soil sample is:

$$Q = k\frac{h}{L}A$$

The rate of decrease of water in the standpipe is:

$$Q = -a\frac{dh}{dt}$$

(The negative sign indicates that head decreases with time.)

Equating both expressions:

$$k \times A \times \frac{h}{L} = -a\frac{dh}{dt}$$

$$\Rightarrow \quad \frac{dh}{h} = \frac{-kA}{aL}dt$$

Integrating between limits:

- At $t = 0$, head = h_1
- At $t = t$, head = h_2

$$\Rightarrow \quad \int_{h_3}^{h_2}\frac{dh}{h} = -\frac{kA}{aL}\int_0^1$$

$$\Rightarrow \quad \ln\left(\frac{h_2}{h_1}\right) = -\frac{kA}{aL}t$$

$$\Rightarrow \quad k = \frac{aL}{At}\ln\left(\frac{h_1}{h_2}\right) = \frac{2.303\,aL}{At}\log_{10}\left(\frac{h_1}{h_2}\right)$$

Where,

h_1 = initial head

h_2 = final head

t = time taken for head to fall from h_1 to h_2

6. (a) (ii) Solution:

Given:

Length of sample (L) = 20 cm

Area of stand-pipe, $a = \frac{\pi}{4}\times(1.0)^2 = 0.7854\ \text{cm}^2$

Area of soil sample, $A = \frac{\pi}{4}\times(10.0)^2 = 78.54\ \text{cm}^2$

Initial head h_1 = 80 cm

Final head h_2 = 50 cm

Time interval t = 15 min

The falling head permeability equation is:

$$k = 2.303\frac{aL}{At}\log_{10}\left(\frac{h_1}{h_2}\right)$$

$$\Rightarrow \quad k = 2.303 \times \frac{0.7854 \times 20}{78.54 \times 15} \times \log_{10}\left(\frac{80}{50}\right)$$

$$\Rightarrow \quad k = 2.303 \times 0.01333 \times 0.2041$$

$$\Rightarrow \quad k = 0.00627 \text{ cm/min}$$

$$k = 0.00626 \times \frac{60 \times 24}{100} = 0.0901 \text{ m/day}$$

(b) Water Level After an Additional 25 Minutes

Total elapsed time:

$$t_{total} = 15 + 25 = 40 \text{ min}$$

Using:

$$\frac{1}{t}\log_{10}\left(\frac{h_1}{h}\right) = C$$

From first 15 minutes:

$$C = \frac{1}{15}\log_{10}\left(\frac{80}{50}\right) = 0.0136$$

For $t = 40$ min:

$$0.0136 = \frac{1}{40}\log_{10}\left(\frac{80}{h_3}\right)$$

$$\Rightarrow \quad \log_{10}\left(\frac{80}{h_3}\right) = 0.544$$

$$\Rightarrow \quad \frac{80}{h_3} = 10^{0.544} = 3.50$$

$$\Rightarrow \quad h_3 = \frac{80}{3.50} = 22.86 \text{ cm}$$

(c) Time Required for Water Level to Drop to 15 cm

$$t_{final} = \frac{1}{C}\log_{10}\left(\frac{h_1}{h_{final}}\right)$$

$$\Rightarrow \quad t_{final} = \frac{1}{0.0136}\log_{10}\left(\frac{80}{15}\right)$$

$$\Rightarrow \quad t_{final} = 73.53 \times 0.727$$

$$\Rightarrow \quad t_{final} = 53.46 \text{ minutes}$$

6. (b) (i) Solution:

Given:

Mass of soil (M_s) = 715.20 g

Mass of soil + wax (M_{total}) = 725.60 g

Volume of water displaced (V_{total}) = 395 ml = 395 cm^3

Moisture content (w) =21.5% = 0.215

Specific gravity of soil solids (G_s) = 2.72

Specific gravity of paraffin wax (G_{wax}) = 0.90

Determine Volume of the Soil Sample

First, find the volume of wax and subtract it from the total volume.

Mass of wax (M_{wax}):

$$M_{wax} = 725.60 - 715.20 = 10.40 \text{ g}$$

Volume of wax (V_{wax}):

$$V_{wax} = \frac{M_{wax}}{G_{wax} \times \rho_w} = \frac{10.40}{0.9 \times 1} = 11.556 \text{ cm}^3$$

Volume of soil (V):

$$V = V_{total} - V_{wax} = 395 - 11.556 = 383.444 \text{ cm}^3$$

Density and Void Ratio

Using the soil mass 715.20 g and volume 383.444 cm^3:

- Bulk density (ρ_b):

$$\rho_b = \frac{M_s}{V} = \frac{715.20}{383.444} = 1.865 \text{ g/cm}^3$$

- Dry density (ρ_d):

$$\rho_d = \frac{\rho_b}{1+w} = \frac{1.865}{1+0.215} = 1.535 \text{ g/cm}^3$$

- Void ratio (e):

  Using the relation

$$\rho_d = \frac{G_s \cdot \rho_w}{1+e}$$

$$\Rightarrow \quad 1 + e = \frac{G_s \cdot \rho_w}{\rho_d} = \frac{2.72 \times 1}{1.535}$$

$$\Rightarrow \quad e = 1.772 - 1 = 0.772$$

Calculate Degree of Saturation (S)

Using the relation $Se = wG_s$

$$S = \frac{w \cdot G_s}{e} = \frac{0.215 \times 2.72}{0.772} = 0.758$$

Degree of Saturation of Soil Sample, S = 75.8%

6. (b) (ii) Solution:

Given data (symbolised):

$$h = 150 \text{ m}$$
$$D = 1.2 \text{ m}$$
$$u = 3.0 \text{ m/s}$$
$$T_a = 25 + 273 = 298 \text{ K}$$
$$P = 950 \text{ millibars}$$
$$v_s = 14 \text{ m/s}$$
$$T_s = 180° \text{ C} + 273 = 453 \text{ K}$$

Using the standard Holland's equation for plume rise:

$$\Delta h = \frac{v_s D}{u}\left[1.5 + 2.68 \times 10^{-3} PD\left(\frac{T_s - T_a}{T_s}\right)\right]$$

$$\Rightarrow \quad \Delta h = \frac{14 \times 1.2}{3.0}\left[1.5 + 2.68 \times 10^{-3} \times 950 \times 1.2\left(\frac{453 - 298}{453}\right)\right]$$

$$\Rightarrow \quad \Delta h = 14.25 \text{ m}$$

Effective Height of Stack

$$H = h + \Delta h$$

$$\Rightarrow \quad H = 150 + 14.25 = 164.25 \text{ m}$$

6. (c) (i) Solution:

1. Quantity of milk received per day = 1,15,000 kg

   Quantity of wastewater produced per day = 250 m^3

   $\therefore$ Wastewater flow per 1000 kg of milk = $\frac{250}{115000} \times 1000 = 2.174 \text{ m}^3$

2. BOD of waste water = 1200 mg/lt

$$= 1200 \times 10^3 \text{ mg/m}^3$$

$$= \frac{1200 \times 10^3}{10^3} \text{g/m}^3$$

$$= \frac{1200 \times 10^3}{10^3 \times 10^3} \text{kg/m}^3 = 1.2 \text{ kg/m}^3$$

Now 1000 kg. of milk received≡ 2.174 m^3 of waste water flow

∴ BOD per 1000 kg of milk = 1.2 × 2.174

= 2.6008 kg

≃ 2.61 kg

3. Total BOD of 250 m^3 of waste water per day

= 250 × 1.2

= 300 kg

BOD of domestic wastewater per person per day = 85 g

= 0.085 kg

∴ Population equivalent = $\frac{300}{0.085} = 3529.4$

≃ 3529 persons (BOD equivalent)

Total waste water produced per day = 250 m^3

= 250 × 10^3 lt

Domestic waste water produced per day per person = 350 lt

∴ Population equivalent = $\frac{250 \times 10^3}{350}$ = 714.3 ≃ 714 (Hydraulic equivalent)

6. (c) (ii) Solution:

Year	Population (in lacs)	Increase in population	Incremental Increase in population
1970	10		
1980	15	5	
1990	21	6	1
2000	28	7	1
2010	34	6	–1
2020	37	3	–3
	Total	27	–2
		$\bar{x} = \frac{27}{5} = 5.4$	$\bar{y} = \frac{-2}{4} = -0.5$

Now, $$P_n = P_0 + n\bar{x} + \frac{n(n+1)}{2}\bar{y}$$

From 2020 to 2050, total number of decades is 3 i.e. n = 3

∴ $$P_{2050} = P_{2020} + n\bar{x} + \frac{n(n+1)}{2}\bar{y}$$

$$= 37 + 3 \times 5.4 + \frac{3(3+1)}{2}(0.5)$$

$$= 37 + 16.2 + 3$$

$$= 56.2 \text{ lacs}$$

$\therefore$ Water required in the year 2050 = $56.2 \times 10^5 \times 140\ lt/\text{day}$

$$= 786.8 \times 10^6\ lt/\text{day}$$

$$= 786.8 \text{ MLD}$$

7. (a) (i) Solution:

Given: $G = 2.65$

$e = 0.90$

$K = 2 \times 10^{-3}$ cm/sec

Seepage head H = 4 – 0.5 = 3.5 m

Number of flow channels N_f = No. of flow line – 1

= 8 – 1 = 7

Number of equipotential drops, $N_d = 12$

Head loss per equipotential drop, $\Delta h = \frac{\Delta H}{N_d} = \frac{3.5}{12} = 0.2917$ m

(a) Total head at point A = 14 – 3 × 0.2917

= 13.125 m

Pressure head at A = 13.125 – datum head at A

= 13.125 – 6 = 7.125 m

and total head (piezometric head) at point E

= 14 – 7.5 × 0.2917

= 11.812 m

(b) Exit gradient

$$i_e = \frac{\Delta h}{\Delta L} = \frac{0.2917}{1.1} = 0.265$$

(c) Critical exit gradient

$$i_{cr} = \frac{(G-1)}{(1+e)} = \frac{2.65-1}{1+0.90} = 0.868$$

$$\text{(FOS) against piping} = \frac{i_{cr}}{i_e} = \frac{0.868}{0.265} = 3.28 \quad \text{(ok)}$$

(d) Quantity of seepage per m length of wall,

$$q = KH\frac{N_f}{N_d}$$

$$\Rightarrow \qquad q = \frac{2\times10^{-3}}{100}\times3.5\times\frac{7}{12}$$

$$\Rightarrow \qquad q = 4.083 \times 10^{-5}\ \text{m}^3/\text{s/m}$$

7. (a) (ii) Solution:

Given Data:

Parameter	**Lab**	**Field**
Thickness, *H*	0.025 m	5 m
Drainage	Double (top & bottom)	Single (top only)
Time for 60% consolidation	12 min	?
Target degree of consolidation	60%	85%

Lab sample (double drainage):

Drainage path length, $d_{\text{lab}} = \frac{H_{\text{lab}}}{2} = \frac{0.025}{2} = 0.0125\ \text{m}$

Field layer (single drainage):

$$d_{\text{field}} = H_{\text{field}} = 5\ \text{m}$$

For lab, U_{lab} = 60% (Taylor's formula for double drainage):

$$T_{60} = \frac{\pi}{4}\left(\frac{U}{100}\right)^2$$

$$\Rightarrow \qquad T_{60} = \frac{\pi}{4}(0.6)^2 = \frac{\pi}{4}\times0.36 = 0.283$$

For field, U_{field} = 85% (logarithmic formula for $U > 60\%$):

$$T_{85} = 1.781 - 0.933 \log_{10}(100 - U)$$

$$\Rightarrow \qquad T_{85} = 1.781 - 0.933 \log_{10}(15)$$

$$\Rightarrow \qquad T_{85} = 1.781 - 0.933 \times 1.176 = 1.781 - 1.097 = 0.684$$

Coefficient of Consolidation (C_v) from lab data

$$C_v = \frac{T_{60} \times d_{lab}^2}{t_{60,\,lab}}$$

$$\Rightarrow \quad C_v = \frac{0.283 \times (0.0125)^2}{12}$$

$$\Rightarrow \quad C_v = \frac{0.283 \times 0.00015625}{12} \approx 3.685 \times 10^{-6}\ \text{m}^2/\text{min}$$

Time for 85% Consolidation in Field

$$t_{85,\,field} = \frac{T_{85} \times d_{field}^2}{C_v} = \frac{0.684 \times 5^2}{3.685 \times 10^{-6}}$$

$$\Rightarrow \quad t_{85,\,field} = \frac{0.684 \times 25}{3.685 \times 10^{-6}}$$

$$\Rightarrow \quad t_{85,\,field} = \frac{17.1}{3.685 \times 10^{-6}} = 4{,}640{,}434\ \text{min}$$

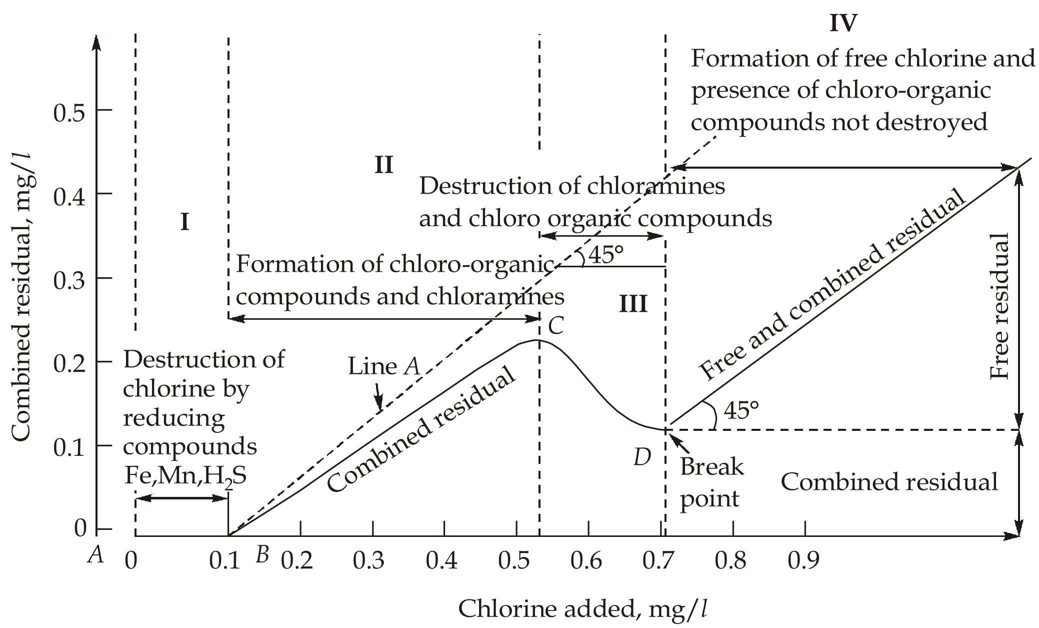
$$\Rightarrow \quad t_{85,\,field} = \frac{4{,}640{,}434}{60 \times 24} = 3222.5\ \text{days} = 8.829\ \text{years}$$

7. (b) (i) Solution:

Break-point Chlorination: Break point chlorination is a term which indicates the chlorine demand of water. In fact, it represents, that much dose of chlorination, beyond which any further addition of chlorine will equally appear as free residual chlorine.

When chlorine is added to the water, it first of all, generally reacts with the ammonia present in the water, so as to form chloramines.

These chloramines are measured as combined residual chlorine in D.P.D. test in the same manner as does free chlorine. Therefore, the D.P.D. tests will indicate the quantum of total residual chlorine, "combined" as well as "free". Hence, if chlorine is slowly added to the water, and the residual is tested, it will be found that the residual chlorine increases initially with the addition of chlorine. (However, some chlorine is consumed for killing bacteria, and thus the amount of residual chlorine shall be slightly less than that added, as shown by the curve AB in figure below.



Chlorine Reaction in Water

If the addition of chlorine is continued beyond the point *B*, the organic matter present in water starts getting oxidised, and therefore, the residual chlorine content suddenly falls down, as shown by the curve *BC*.

The point *C* is the point beyond which any further addition of chlorine will appear equally as free chicrine, since chlorine demand is fully satisfied. This point *C* is called the 'break point', as any chlorine that is added to water beyond this point, appears as free residual chlorine. The additional chlorine beyond break point is called break point chlorination.

7. (b) (ii) Solution:

Given:
$$Ca^{2+} = 60 \text{ mg/L}$$
$$Mg^{2+} = 24 \text{ mg/L}$$
$$HCO^{-}_3 = 183 \text{ mg/L}$$
$$CO_3^{2-} = 30 \text{ mg/L}$$

(i) Equivalent weight of:
$$HCO^{-}_3 = 61$$
$$CO^{2-}_3 = 30$$

$$\therefore \quad HCO_3^{-} \text{ alkalinity} = 183 \times \frac{50}{61} = 150 \text{ mg/L as } CaCO_3$$

$$\text{and} \quad CO_3^{2-} \text{ alkalinity} = 30 \times \frac{50}{30} = 50 \text{ mg/L as } CaCO_3$$

$\therefore$ Total Alkalinity = 150 + 50 = 200 mg/L as $CaCO_3$

(ii) Total Hardness

Equivalent weight of Ca^{2+} = 20 mg/meq.

$$\text{Calcium hardness} = 60 \times \frac{50}{20} = 150 \text{ mg/L}$$

Equivalent weight of Mg^{2+} = 12 mg/meq.

$$\text{Magnesium hardness} = 24 \times \frac{50}{12} = 100 \text{ mg/L}$$

Total Hardness:

$$TH = 150 + 100 = 250 \text{ mg/L as } CaCO_3$$

(iii) Carbonate & Non-Carbonate Hardness

Rule:

- Carbonate hardness = Minimum [Total hardness, Total alkalinity]
- Non- Carbonate hardness = $TH - CH$

Carbonate hardness:

$$CH = \text{Min } (250, 200) = 200 \text{ mg/L as } CaCO_3$$

Non-carbonate hardness:

$$NCH = 250 - 200 = 50 \text{ mg/L as } CaCO_3$$

7. (c) (i) Solution:

Mechanism of Coagulation (Water Treatment): Coagulation is the process of destabilization finely divided and colloidal particles present in water so that they can aggregate and be removed by sedimentation and filtration. The mechanism of coagulation mainly involves the following steps:

1. **Compression of Electrical Double Layer:** Colloidal particles in water usually carry a negative surface charge, leading to mutual repulsion and stability of suspension. When a coagulant (like alum or ferric chloride) is added, it releases positively charged ions that reduce the thickness of the electrical double layer surrounding the particles. The reduction in repulsive forces enables aggregation.
2. **Charge Neutralization:** The positive ions produced by the hydrolysis of coagulants neutralize the negative charge on colloidal particles. Once the surface charge is sufficiently reduced or neutralized, the particles lose stability and can collide and stick together due to van der Waals forces, forming micro-flocs.

3. **Enmeshment in Precipitate (Sweep Coagulation):** At higher coagulant dosages, bulky gelatinous precipitates such as Al(OH) or Fe(OH) are formed. Colloidal and fine suspended particles get trapped or "swept" within these precipitates as they settle. This is the dominant mechanism in conventional water treatment plants.
4. **Adsorption and Inter-Particle Bridging:** In the presence of polymer coagulants or coagulant aids, long-chain molecules adsorb on the surface of multiple particles simultaneously, forming bridges between them. This results in the formation of larger, stronger flocs that settle rapidly.
5. **Floc Growth during Flocculation:** After destabilization, gentle mixing during flocculation promotes particle collisions and floc enlargement without breaking them. The formed flocs gain sufficient size and weight to be removed by sedimentation or filtration.

7. (c) (ii) Solution:

Given Data

Tank dimensions = 32 m × 10 m × 4.8 m

Flow rate, $Q = 80\ MLD = \dfrac{80 \times 10^6 \times 10^{-3}}{86400} = 0.926\ \text{m}^3/\text{s}$

Paddle dimensions = 10 m × 0.35 m

Rotational speed, N = 3 rpm

Number of shafts = 5

Paddles per shaft = 2

Total number of paddles, n = 10

Distance of paddle centre from shaft axis, r = 2.0 m

Coefficient of drag, C_d = 1.8

Kinematic viscosity of water, $\nu = 1.0 \times 10^{-6}\ \text{m}^2/\text{s}$

Density of water, $\rho = 1000\ \text{kg/m}^3$

(i) Power Required for Mixing

Paddle tip velocity

$$v_p = \omega r = \frac{2\pi r N}{60} \qquad \left(\because \quad \omega = \frac{2\pi N}{60}\right)$$

$$\Rightarrow \quad v_p = \frac{2 \times \pi \times 2.0 \times 3}{60}$$

$$\Rightarrow \quad v_p = 0.628\ \text{m/s}$$

Relative velocity between paddle and water

$$\text{Average water velocity} = 0.6\, v_p$$

$$v_r = v_p - 0.6\, v_p = 0.4\, v_p$$

$$\text{Relative velocity, } v_r = 0.4 \times 0.628 = 0.2512 \text{ m/s}$$

Total paddle area

$$\text{Area of one paddle} = 10 \times 0.35 = 3.5 \text{m}^2$$

$$\text{Total paddle area, } A = 10 \times 3.5 = 35 \text{ m}^2$$

Power required,

$$P = F \times v_r = C_d \times \frac{1}{2}\rho A v_r^2 \times v_r$$

$$\Rightarrow \quad P = \frac{1}{2} C_d \rho A v_r^3$$

$$\Rightarrow \quad P = \frac{1}{2} \times 1.8 \times 1000 \times 35 \times (0.2512)^3$$

$$\Rightarrow \quad P = 499.3\, W \simeq 0.5 \text{ kW}$$

(ii) Detention Time of Flocculation

Volume of tank, $V = 32 \times 10 \times 4.8$

$$\Rightarrow \quad V = 1536 \text{ m}^3$$

Detention time,

$$t = \frac{V}{Q} = \frac{1536}{0.926}$$

$$\Rightarrow \quad t = 1658.7\, s = 27.65 \text{ min}$$

(iii) Velocity Gradient (G)

Dynamic viscosity

$$G = \sqrt{\frac{P}{\mu V}}$$

$$\Rightarrow \quad G = \sqrt{\frac{499.3}{1.0 \times 10^{-3} \times 1536}}$$

$$\Rightarrow \quad G = 18.03\, s^{-1}$$

8. **(a) (i) Solution:**

Earth pressure at rest is the lateral pressure exerted by soil when it is in its natural, undisturbed condition and no lateral deformation (strain) is permitted.

In other words, when a retaining wall or any supporting structure does not move either towards or away from the backfill, i.e. remains stationary. The soil mass does not undergo lateral strain ($\varepsilon_x = 0$).

The lateral stress developed under this condition is called earth pressure at rest.

It is represented by:

$$\sigma_h = K_0 \sigma_v$$

Where:

σ_h = horizontal stress

σ_v = vertical stress

K_0 = coefficient of earth pressure at rest

For normally consolidated soils:

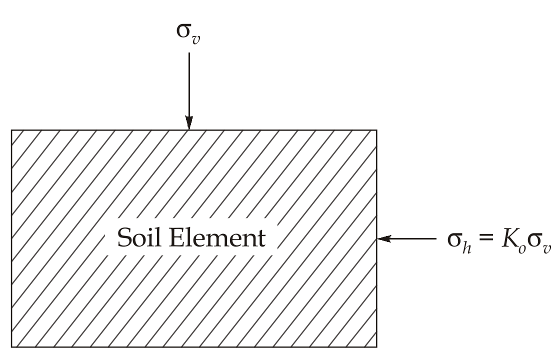
$$\Rightarrow \quad K_0 = \frac{\mu}{1-\mu}$$

Thus, earth pressure at rest corresponds to the condition where the soil mass is laterally confined and neither expands nor contracts sideways.

Though soil is not a perfectly elastic material, but for the purpose of analysis we can make following assumptions.

- Soil mass is homogeneous, isotropic and semi-infinite.
- Elastic modulus E and Poisson's ratio is constant through the depth.

For plain strain condition we can write.



$$\varepsilon_x = \frac{1}{E}[\sigma_x - \mu(\sigma_y + \sigma_z)]$$

$$\varepsilon_x = 0 \ (\therefore \ \text{Earth pressure at rest})$$

$\because$ $$\sigma_x = \sigma_z = \sigma_h$$

Hence,

$$\sigma_h - \mu(\sigma_v + \sigma_h) = 0$$

$\Rightarrow$ $$\sigma_h(1 - \mu) = \mu\sigma_v$$

$\Rightarrow$ $$\sigma_h = \left(\frac{\mu}{1-\mu}\right)\sigma_v$$

$\Rightarrow$ $$K_o\sigma_v = \left(\frac{\mu}{1-\mu}\right)\sigma_v$$

$$K_o = \left(\frac{\mu}{1-\mu}\right)$$

8. (a) (ii) Solution:

Given:

Height of the wall (H) = 6 m

Angle of internal friction (ϕ) = 30°

Void ratio (e) = 0.72

Specific gravity (G) = 2.67

Poisson's ratio (μ) = 0.35

Unit weight of water (μ) = 9.81 kN/m^3

1. Earth Pressure Coefficient and Unit Weight

Using the Poisson's ratio approach for the at-rest earth pressure coefficient (K_0):

$$K_0 = \frac{\mu}{1-\mu} = \frac{0.35}{1-0.35} = \frac{0.35}{0.65} = 0.538$$

Dry unit weight of soil (γ_d):

$$\gamma_d = \frac{G \times \gamma_w}{1+e} = \frac{2.67 \times 9.81}{1+0.72} = 15.228 \text{ kN/m}^3$$

(i) Lateral Earth Pressure Distribution

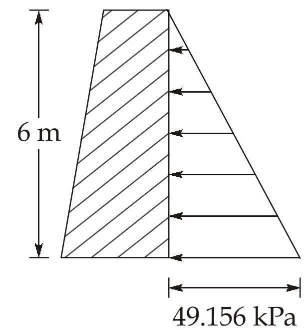
The lateral pressure increases linearly with depth (z):

At z = 0: $$p_0 = 0$$

At z = 6m:

$$p_h = K_0 \times \gamma_d \times H = 0.538 \times 15.228 \times 6 = 49.156 \text{ kN/m}^2$$

The distribution is triangular, as shown in the plot below.



(ii) Magnitude and Point of Application of Resultant Thrust per m length

Magnitude of resultant thrust (P_0):

$$P_0 = \frac{1}{2} \times K_0 \times \gamma_d \times H^2$$

$$P_0 = \frac{1}{2} \times 0.538 \times 15.228 \times 6^2 = 147.468 \text{ kN/m}$$

Point of application:

The resultant acts at a height of $H/3$ from the base of the wall.

$$\text{Point of application} = \frac{6}{3} = 2 \text{ m from the base}$$

(iii) Percent Change in Lateral Thrust (Water Table at Top)

Saturated unit weight (γ_{sat}):

$$\gamma_{sat} = \frac{(G+e) \times \gamma_w}{1+e} = \frac{(2.67+0.72) \times 9.81}{1+0.72} = 19.335 \text{ kN/m}^3$$

Submerged unit weight (γ'):

$$\gamma' = \gamma_{sat} - \gamma_w = 19.335 - 9.81 = 9.525 \text{ kN/m}^3$$

Total thrust (P_{total}) consists of submerged earth pressure and hydrostatic water pressure:

$$P_{total} = \left(\frac{1}{2} \times K_0 \times \gamma' \times H^2\right) + \left(\frac{1}{2} \times \gamma_w \times H^2\right)$$

$$\Rightarrow \quad P_{total} = \left(\frac{1}{2} \times 0.538 \times 9.525 \times 6^2\right) + \left(\frac{1}{2} \times 9.81 \times 6^2\right)$$

$$\Rightarrow \quad P_{total} = 268.82 \text{ kN/m}$$

Percent change in thrust:

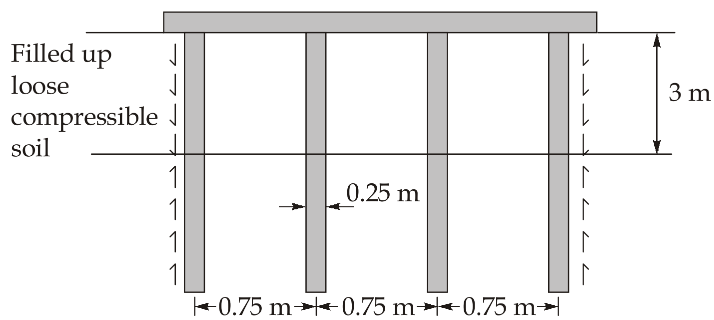
$$\text{Percent Change} = \frac{P_{total} - P_0}{P_0} \times 100$$

$$= \frac{268.82 - 147.468}{147.468} \times 100$$

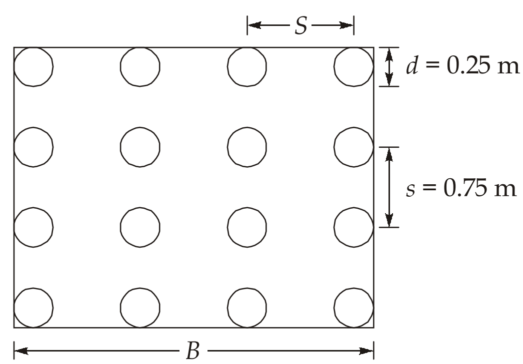
$$= 82.29\%$$

8. (b) (i) Solution:

The plan and section of the given pile group of 16 piles is shown in figure below.



(Elevation view)



(Plan view)

Size of pile group,

$$B = 3S + d$$

$$= 3 \times 0.75 + 0.25 = 2.5 \text{ m}$$

Negative skin friction for the pile group for the given cohesive soil is taken as the maximum of the following two cases:

Based on individual pile action:

$$Q_{nfg} = Q_{nf} \times 16$$

$$\Rightarrow \quad Q_{nfg} = \alpha \cdot \bar{C}_u (\pi d) \cdot L_c \times 16$$

$$\Rightarrow \quad Q_{nfg} = 0.4 \times 18 \times \pi \times 0.25 \times 3 \times 16$$

$$\Rightarrow \quad Q_{nfg} = 271.44 \text{ kN} \quad \text{...(i)}$$

Based on block failure of pile group:

$$Q_{nfg} = \bar{C}_u (4B) \cdot L_c + \gamma A L_c$$

$$\Rightarrow \quad Q_{nfg} = 18 \times 4 \times 2.5 \times 3 + 15 \times (2.5 \times 2.5) \times 3$$

$$\Rightarrow \quad Q_{nfg} = 821.25 \text{ kN} \quad \text{...(ii)}$$

$$\text{Negative skin friction} = \max \begin{cases} 271.44 \text{ kN} \\ 821.25 \text{ kN} \end{cases} = 821.25 \text{ kN} \quad \textbf{Ans.}$$

8. (b) (ii) Solution:

The population to be served is 6.0 lakh. With an average water demand of 160 litres per capita per day, the average daily water demand is

$$Q_{\text{avg}} = 6.0 \times 10^5 \times 160 = 96{,}000{,}000 \; L/\text{day} = 96{,}000 \text{ m}^3/\text{day}$$

During peak summer, the demand is 180% of the average. Hence,

$$Q_{\text{summer}} = 1.8 \times 96{,}000 = 172{,}800 \text{ m}^3/\text{day}$$

Since pumping is done for 12 hours per day, the discharge capacity of the pump required during peak summer is

$$Q = \frac{172800}{12} = 14400 \text{ m}^3/\text{hr}$$

$$Q = \frac{14400}{3600} = 4.0 \text{ m}^3/\text{s}$$

The total head against which the pump works is calculated using the lowest summer water level. The static head is

$$H_s = 220.00 - 201.50 = 18.5 \text{ m}$$

The friction loss in the rising main during peak summer is given as 2.8 m. Therefore, the total head on the pump is

$$H = 18.5 + 2.8 = 21.3 \text{ m}$$

The power required is computed using the relation

$$P = \frac{\rho g Q H}{\eta}$$

Substituting ρ = 1000 kg/m^3, g = 9.81 m/s^2, Q = 4.0 m^3/s, H = 21.3 m and overall efficiency η = 0.70,

$$P = \frac{1000 \times 9.81 \times 4.0 \times 21.3}{0.70} = 1.19 \times 10^6 \text{ Watts}$$

Converting this into horsepower,

$$HP = \frac{1.19 \times 10^6}{746} \approx 1600 \text{ HP}$$

Hence, the pump required for peak summer conditions should have a discharge capacity of about 4.0 m^3/s and a power of approximately 1600 HP.

8. (c) (i) Solution:

Zeolite or Base-Exchange or Cation-Exchange Process for Removing Hardness. Zeolites are the natural salts or clays, which are hydrated silicates of sodium and aluminium, having the general formula as $Na_2O\ Al_2O_3x.\ SiO_3y.\ H_2O$. The usual value of x is generally ≥ 2 or more, and that of y of ranging amounts. Naturally occurring zeolite like substances can also be manufactured synthetically, and they are known as ion-exchange resins. The zeolites or Resins have the property of exchanging their cations; and hence, during softening operation, the sodium ions of the zeolite get replaced by the calcium and magnesium ions present in hard waters. The chemical reactions which may be involved are given in the following equation, where Z stands for the complex zeolite radical.

$$\underset{\text{Sod. zeolite or active zeolite}}{Na_2Z} + \underset{\text{Cal. or Mg. salt}}{\left.\begin{matrix} Ca \\ Mg \end{matrix}\right\} \begin{matrix} (HCO_3)_2 \\ SO_4 \\ Cl_2 \end{matrix}} \longrightarrow \underset{\text{Sod. salts which don't cause hardness}}{Na_2 \left\{ \begin{matrix} (HCO_3)_2 \\ SO_4 \\ Cl_2 \end{matrix}\right.} + \underset{\text{Ca or Mg zeolite i.e. exchanged or used zeolite}}{\left.\begin{matrix} Ca \\ Mg \end{matrix}\right\} Z}$$

The calcium and magnesium zeolite can be regenerated into active sodium zeolite by treating it with 5–10 per cent solution of sodium chloride. The exchange reactions that take place during regeneration can be represented as:

$$\underset{\text{Used zeolite}}{\left.\begin{matrix} Ca \\ Mg \end{matrix}\right\} Z} + \underset{\text{Sod. chloride solution}}{2NaCl} \longrightarrow \underset{\text{Regenerated zeolite}}{Na_2Z} + \left.\begin{matrix} Ca \\ Mg \end{matrix}\right\} Cl_2$$

The advantages and disadvantages of this method are given below:

Advantages

(i) Water of zero hardness can be obtained, and hence, useful for specific uses in textile industries, boilers, etc.

(ii) The plant is compact, automatic and easy to operate.

(iii) No sludge is formed, and hence, there is no problem of sludge disposal.

(iv) The RMO (Running, maintenance and operation) cost is relatively low.

(v) It also removes ferrous iron and manganese from water.

(vi) Can treat water of varying quality.

(vii) There is no problem of incrustation of pipes of the distribution system, as is there in the lime soda process.

Disadvantages

(i) This process is not suitable for treating highly turbid waters, because the suspended impurities get deposited around the zeolite particles, and thus causing obstruction to the working of the zeolite.

(ii) The process leaves sodium bicarbonate in water, which causes priming and foaming in industrial or boiler feed waters.

(iii) The zeolite process is costlier and unsuitable for treating waters containing iron and manganese. This is because of the fact that the iron zeolite or manganese zeolite formed during the chemical reactions, cannot be regenerated into sodium zeolite. The zeolite is thus wasted, although the iron and manganese are removed from the water.

8. (c) (ii) Solution:

Total Hardness of Raw Water:

The total hardness of raw water is calculated by converting the concentrations of calcium and magnesium ions into their equivalent hardness as $CaCO_3$.

Total Hardness of raw water

$$H_{raw} = TH = \left(\frac{80}{20} + \frac{36}{12}\right) \times 50$$

$$H_{raw} = 350 \text{ mg/L as } CaCO_3$$

(i) Quantity of Water to be Bypassed per Day

Given:

Total daily water requirement, Q = 900 L/day

Required mixed water hardness, H_{mixed} = 100 mg/L

Hardness of treated (resin) water = 0 mg/L

Let Q_b = quantity of raw water bypassed (L/day)

Hardness Balance Equation

$$Q_b \times H_{raw} + (Q - Q_b) \times 0 = Q \times H_{mixed}$$

$$Q_b \times 350 = 900 \times 100$$

$$Q_b = \frac{90000}{350}$$

$$Q_b = 257.14 \text{ L/day}$$

(ii) Time Interval Between Regenerations

Total Exchange Capacity of Resin

$$\text{Resin volume} = 0.06 \text{ m}^3$$

$$\text{Exchange capacity} = 45 \text{ kg/m}^3$$

$$\text{Total capacity} = 0.06 \times 45$$

$$= 2.7 \text{ kg as } CaCO_3$$

$$= 2{,}700{,}000 \text{ mg as } CaCO_3$$

Water Treated by Resin per Day

$$Q_{\text{treated}} = Q - Q_b$$

$$Q_{\text{treated}} = 900 - 257.14$$

$$Q_{\text{treated}} = 642.86 \text{ L/day}$$

Hardness Removed per Day

$$\text{Daily hardness removal} = Q_{\text{treated}} \times H_{\text{raw}}$$

$$= 642.86 \times 350$$

$$= 225{,}001 \text{ mg/day}$$

Regeneration Interval

$$T = \frac{\text{Total exchange capacity}}{\text{Daily hardness removal}}$$

$$T = \frac{2700000}{225001}$$

$$T = 12 \text{ days}$$