MADE EASY

Leading Institute for ESE, GATE & PSUs

ESE 2026 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Civil Engineering

Test-2 : Section A : Highway Engineering + Surveying and Geology [All topics]

Section B : Geo-technical & Foundation Engg. - 1 + Env. Engg. - 1 [Part syllabus]

Name : .....

Roll No :

Test Centres	Student's Signature
Delhi ☑ Bhopal ☐ Jaipur ☐ Pune ☐ Hyderabad ☐	

Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. There are Eight questions divided in TWO sections.
3. Candidate has to attempt FIVE questions in all in English only.
4. Question no. 1 and 5 are compulsory and out of the remaining THREE are to be attempted choosing at least ONE question from each section.
5. Use only black/blue pen.
6. The space limit for every part of the question is specified in this Question Cum Answer Booklet. Candidate should write the answer in the space provided.
7. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
8. There are few rough work sheets at the end of this booklet. Strike off these pages after completion of the examination.

FOR OFFICE USE	
Question No.	Marks Obtained
Section-A	
Q.1	53
Q.2	—
Q.3	40
Q.4	—
Section-B	
Q.5	37
Q.6	50
Q.7	50
Q.8	—
Total Marks Obtained	230

Signature of Evaluator ..... Cross Checked by .....

Good

IMPORTANT INSTRUCTIONS

CANDIDATES SHOULD READ THE UNDERMENTIONED INSTRUCTIONS CAREFULLY. VIOLATION OF ANY OF THE INSTRUCTIONS MAY LEAD TO PENALTY.

DONT'S

1. Do not write your name or registration number anywhere inside this Question-cum-Answer Booklet (QCAB).
2. Do not write anything other than the actual answers to the questions anywhere inside your QCAB.
3. Do not tear off any leaves from your QCAB, if you find any page missing do not fail to notify the supervisor/invigilator.
4. Do not leave behind your QCAB on your table unattended, it should be handed over to the invigilator after conclusion of the exam.

DO'S

1. Read the Instructions on the cover page and strictly follow them.
2. Write your registration number and other particulars, in the space provided on the cover of QCAB.
3. Write legibly and neatly.
4. For rough notes or calculation, the last two blank pages of this booklet should be used. The rough notes should be crossed through afterwards.
5. If you wish to cancel any work, draw your pen through it or write "Cancelled" across it, otherwise it may be evaluated.
6. Handover your QCAB personally to the invigilator before leaving the examination hall.

Section A : Highway Engineering + Surveying and Geology

1 (a) (i) Write the short notes on

1. Prime coat vs tack coat
2. Bitumen emulsion vs Cutback bitumen

(ii) Discuss the requirements of highway drainage system.

[3 + 3 + 6 = 12 marks]

Sol^n

i) Prime coat is a low viscous fluid that is used to fill the voids in the layer. It is used between sub base and base layer.

Tack coat is a high viscous fluid that is used to improve the binding between two layers (generally surface course & Base course).

2

ii) Highway drainage system is required because:-

i) If water remains on the carriageway, there will be difficulty in vehicle movement and chances of skiding and slipping will also increase.

3

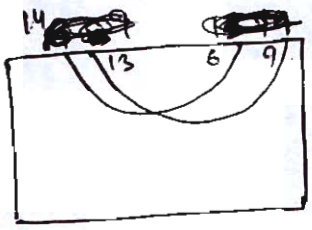
ii) If water is not drained off, then it may penetrate beneath the layers of pavement and that can leads to the failure of our pavement system.

(b) The following observations were made to determine the sensitivity of two bubble tubes. Determine which bubble tube is more sensitive. The distance of the staff from the instrument was 75 m and the length of one division of both the bubble tubes is 2 mm.

Bubble tube	Bubble reading		Staff reading (m)
	L.H.S.	R.H.S.	
A	14	6	1.718
	13	9	1.867
B	16	4	1.735
	15	7	1.888

[12 marks]

For Bubble tube A



∴ Equivalent no. of divisions (n)

$$n = \frac{(14-6)+(13-9)}{2} = 6$$

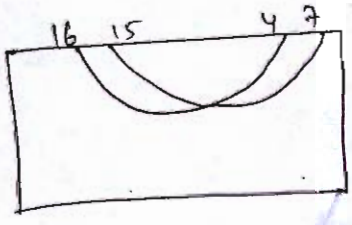
$$S = 1.867 - 1.718 = 0.149.$$

∴ Sensitivity $(\alpha_A) = \frac{S}{nD} \times 206265''$; $D = 75\,m$ ↓ Distance of staff

$$\therefore \alpha_A = \frac{0.149}{6 \times 75} \times 206265'' = 68.296''.$$

Similarly,

For Bubble tube B



∴ Equivalent no. of divisions

$$= \frac{(16-4)+(15-7)}{2}$$

$$= 10$$

$$S = 1.888 - 1.735 = 0.153$$

∴ Sensitivity $(\alpha_B) = \frac{0.153}{10 \times 75} \times 206265'' = 42.078''$.

Here,

$\alpha_A > \alpha_B \Rightarrow$ Bubble tube A has to move by more distance for same divisions as compared to B.

$\therefore$ Sensitivity of B is more than A.

12

Q.1 (c) Calculate the stresses at the interior, edge and corner regions of a cement concrete pavement using Westergaard's stress equations based on the given data.

Design wheel load = 4200 kg

E value of cement concrete = 2.8×10^5 kg/cm^2

Thickness of pavement slab = 20 cm

Poisson's ratio of cement concrete = 0.15

Modulus of subgrade reaction = 10.0 kg/cm^3

Radius of contact area = 14 cm

[12 marks]

Sol^n From Westergaard's stress equation,

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

$l \rightarrow$ Radius of relative stiffness.

$$l = \left[\frac{Eh^3}{12K(1-\mu^2)}\right]^{1/4} \Rightarrow l = \left[\frac{2.8\times10^5 \times 20^3}{12\times10\times(1-0.15^2)}\right]^{1/4} = 66.105\,cm.$$

$b \rightarrow$ Equivalent radius of resisting section.

Here, a (Radius of contact area) $= 14\,cm < 1.724\,h$

$\Rightarrow b = \sqrt{1.6a^2 + h^2} - 0.675h = 13.213\,cm$

$$\therefore S_i = \frac{0.316 \times 4200}{20^2}\left[4\log_{10}\left(\frac{66.105}{13.213}\right) + 1.069\right] = 12.827\ kg/cm^2$$

Similarly,

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

$$= \frac{0.572 \times 4200}{20^2}\left[4\log_{10}\left(\frac{66.105}{13.213}\right) + 0.359\right]$$

$$= 18.954\ kg/cm^2.$$

12

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

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

$$= 16.219\ kg/cm^2$$

Q.1 (d) Using Webster's method, design a two-phase traffic signal with pedestrian crossing for a road intersection. The average normal traffic flow during the design hour on cross roads A and B is 460 PCU per hour and 240 PCU per hour respectively. The corresponding saturation flows on roads A and B are 1300 PCU per hour and 1000 PCU per hour respectively. Assume that the total red time required for pedestrian crossing is 12 seconds and an amber (clearance) time of 2 seconds is to be provided in each phase. Draw the signal phase diagram also.

[12 marks]

Sol^n

Critical flow ratio for Road A $(y_A) = \frac{q_{normal}}{q_{saturation}} = \frac{460}{1300} = 0.3538$

And,

Critical flow ratio for Road B $(y_B) = \frac{240}{1000} = 0.24$

$\Rightarrow Y = y_A + y_B = 0.5938$

∴ From Webster's Method,

Optimum Cycle time $(C_o) = \frac{1.5L+5}{1-Y}$

$L = 2n + R = 2 \times 2 + 12 = 16$ sec ; R → All red time

$\therefore C_o = \frac{1.5 \times 16 + 5}{1 - \frac{460}{1300} - \frac{240}{1000}} = 71.4$ seconds

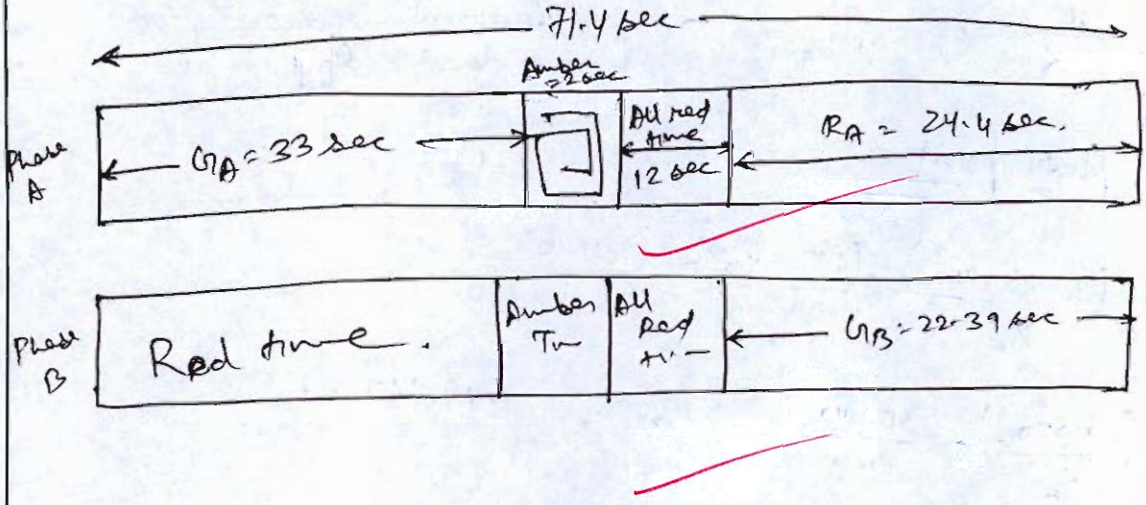
$$\text{Green time}_A = \frac{y_A}{Y}[C_0 - L]$$

$$= \frac{0.3538}{0.5938}[71.4 - 16] = 33 \text{ sec.}$$

$$\text{Green time}_B = \frac{y_B}{Y}[C_0 - L]$$

$$= \frac{0.24}{0.5938}[71.4 - 16] = 22.39 \text{ sec.}$$

12



Q.1 (e) A vertical photograph was taken from a height of 1200 m above the mean sea level with a camera of focal length 30 mm. It contains two points a and b corresponding to ground point A and B respectively. Calculate the horizontal length AB and the average scale along the line *ab* from the following data:

Photo point	Elevation above MSL	Photo co-ordinates	
		x(mm)	y(mm)
a	250	20.5	15.5
b	210	-15.5	-20.5

[12 marks]

Sol^{n} For Vertical photograph,

$$\frac{x}{X} = \frac{y}{Y} = \frac{f}{H - h_{avg}}$$; H → flying height
h_{avg} → Elevation of ground.

∴ For photo point a

$$\frac{(20.5\times10^{-3})}{X_A} = \frac{(15.5\times10^{-3})}{Y_A} = \frac{30\times10^{-3}}{1200-250}$$

$$\Rightarrow \frac{(20.5\times10^{-3})}{X_A} = \frac{30\times10^{-3}}{950} \Rightarrow X_A = 649.167\ m$$

And,

$$\frac{15.5\times10^{-3}}{Y_A} = \frac{30\times10^{-3}}{950} \Rightarrow Y_A = 490.833\ m$$

$$\therefore A \equiv (649.167\ m,\ 490.833\ m).$$

Similarly,

for photo point b $\Rightarrow \frac{-15.5\times10^{-3}}{X_B} = \frac{-20.5\times10^{-3}}{Y_B} = \frac{30\times10^{-3}}{1200-210}$

$$\Rightarrow X_B = -511.5\ m, \quad Y_B = -676.5\ m.$$

$$\therefore B \equiv (-511.5\ m, -676.5\ m).$$

$$\therefore AB = \sqrt{(X_A - X_B)^2 + (Y_A - Y_B)^2} = \sqrt{(649.167+511.5)^2 + (490.833+676.5)^2}$$

$$\Rightarrow AB = 1646.151\ m.$$

∴ Horizontal length (AB) = 1646.151 m.

And, Horizontal length (ab) = $\sqrt{(20.5+15.5)^2+(15.5+20.5)^2}$

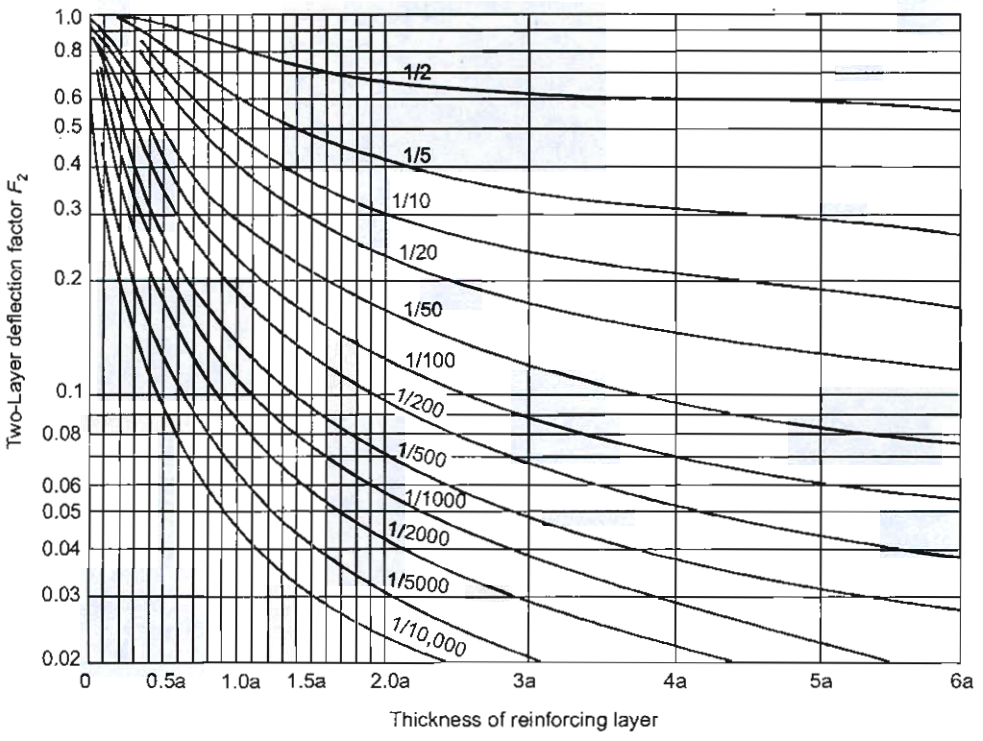
ab = 50.9117 mm.

∴ Scale = $\frac{1646.151}{50.9117 \times 10^{-3}}$ = 32333.452 : 1

∴ 1 m length on map = 32333.452 m distance on horizontal ground.

12

.2 (a) (i) Plate bearing test conducted with 30 cm diameter plate on a soil subgrade yielded a pressure of 1.25 kg/cm^2 at 5 mm deflection. The test carried out over 20 cm base course yielded a pressure of 5 kg/cm^2 at 5 mm deflection. Design the pavement section for wheel load of 4100 kg with a tyre pressure of 6 kg/cm^2 and allowable deflection of 5 mm. Use Burmister's method.



Relationship of F_2 and h in a two - layer system

(ii) Differentiate between Rigid and Flexible Pavement.

[12 + 8 = 20 marks]

2 (b) (i) An expressway having four lanes with a divided carriageway passes through flat terrain. The horizontal curve provided on the expressway has a radius equal to the ruling minimum radius. If the design speed of the expressway is 110 km/h, determine the following elements of the curve:

I. Ruling minimum radius
II. Super elevation
III. Extra widening
IV. Length of the transition curve

(ii) List down the advantages and disadvantages of traffic signals.

(iii) What are the necessary requirements for provision of intersection at grade?

[12 + 4 + 4 = 20 marks]

Q.2 (c) A baseline was measured using a steel tape suspended in catenary under a pull of 155 N at a mean temperature of 15°C. The lengths of the individual tape segments and the corresponding differences in level between the ends of each segment are given below:

Bay/Span	Length (m)	Difference in level (m)
1	29.988	-0.346
2	29.895	+0.214
3	29.838	-0.309
4	29.910	-0.106

The tape was standardized on level ground under a pull of 95 N at a temperature of 18°C. Determine the correct length of the baseline.

The following additional data are provided:

Cross-sectional area of tape = 3.35 mm^2

Mass of tape = 0.025 kg/m

Coefficient of linear expansion = 0.9×10^{-6} per °C

Young's modulus = 14.8×10^4 MN/m^2

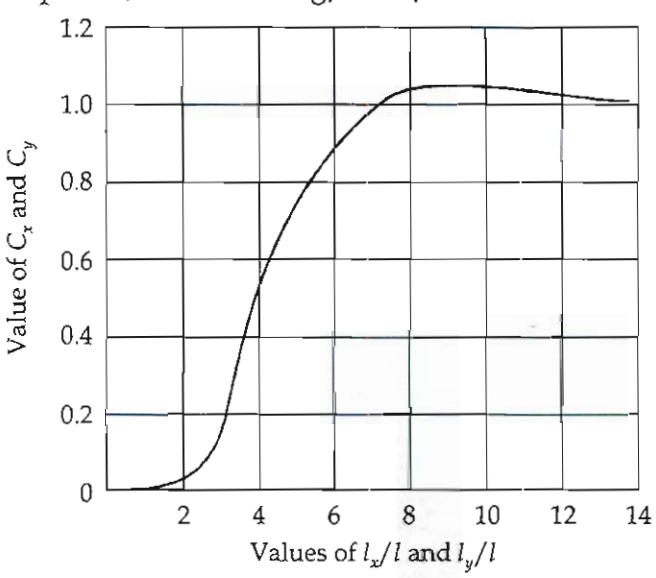
Mean height of the line above M.S.L. = 120 m

Radius of the Earth = 6370 km

[20 marks]

Q.3 (a) (i) Determine the warping stresses at interior, edge and corner region in a 30 cm thick concrete pavement with transverse joints and longitudinal joints at 4.5 m and 3.6 m interval respectively. The modulus of subgrade reaction is 6 kg/cm^3. Assume temperature differential for a day condition to be 12°C and radius of contact area is 15 cm. Additional data for cement concrete pavement is given below:

$\alpha = 10 \times 10^{-6}$ per °C, $E = 3 \times 10^5$ kg/cm^2, $\mu = 0.14$,



Warping Stress Coefficient

(ii) The following staff readings were taken in succession with a level. The instrument was shifted after the fourth and the seventh reading. Enter the data in a page of a level book by rise and fall method. The first reading was taken on a Bench Mark of reduced level 68.235 m.

1.735, 1.625, 1.580, 1.250, 1.115, 2.010, 1.325, 1.055, 1.095, 0.955. Show also the arithmetical check.

[12 + 8 = 20 marks]

n(i) $l_x = 4.5m$, $l_y = 3.6m$

∴ Radius of relative stiffness $(l) = \left[\frac{Eh^3}{12k(1-\mu^2)}\right]^{1/4}$

$\therefore l = \left[\frac{3\times10^5 \times 30^3}{12\times6(1-0.14^2)}\right]^{1/4} = 103.5$ cm.

$\therefore \frac{l_x}{l} = \frac{4.5\times10^2}{103.5} = 4.348$ & $\frac{l_y}{l} = \frac{3.6\times100}{103.5} = 3.478$.

∴ from curve, C_x @ $\frac{l_x}{l} = 4.348 \Rightarrow C_x = 0.62$

and, $C_y = 0.38$.

$\therefore S_{interior} = \frac{EXT}{2}\left[\frac{C_x + \mu C_y}{1-\mu^2}\right]$

$= \frac{3\times10^5\times10^{-5}\times12}{2}\left[\frac{0.62 + 0.14\times0.38}{1-0.14^2}\right]$

$= 12.36$ kg/cm^2

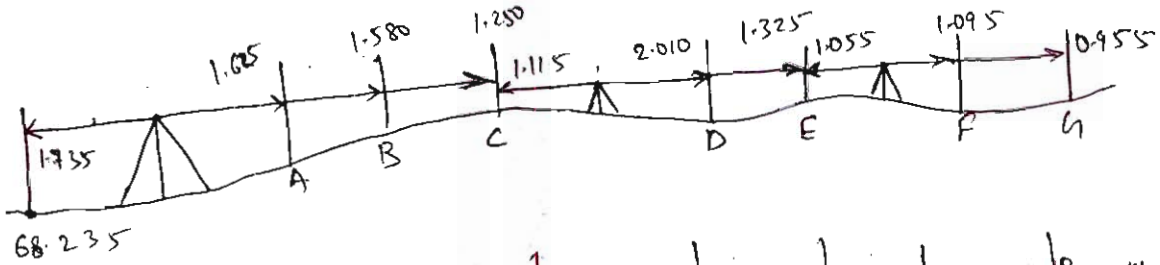
$S_{edge} = \text{Max}^m\begin{cases} C_x EXT/2 \\ C_y EXT/2 \end{cases} = \frac{C_x EXT}{2} = \frac{0.62\times3\times10^5\times10^{-5}\times12}{2}$

$S_{edge} = 11.16$ kg/cm^2

$S_{corner} = \frac{EXT}{2}\left[\frac{C_x + C_y}{3(1+\mu)}\right] = \frac{3\times10^5\times10^{-5}\times12}{2}\left[\frac{0.62+0.38}{3(1-0.14)}\right]$

$= 6.98$ kg/cm^2

(ii) 1.735, 1.625, 1.580, 1.250, 1.115, 2.010, 1.325, 1.055, 1.095, 0.955



Station	BS	IS	FS	Rise (m)	Fall (m)	RL (m)	Remarks
						68.235	BM
BM	1.735						
A		1.625		0.11		68.345	
B		1.580		0.045		68.39	
C	1.115		1.250	0.33		68.72	CP
D		2.010			0.895	67.825	
E	1.055		1.325	0.685		68.51	CP
F		1.095			0.04	68.47	
G			0.955	0.14		68.61	TBM

Rise/Fall = Previous Reading − Current Reading

If +ve → Rise, If −ve → fall.

At A = 1.735 − 1.625 = +0.11

B = 1.625 − 1.580 = +0.045

Similarly, for all stations

Check

Σ Rise = 1.31 , Σ Fall = 0.935

$\therefore \Sigma Rise - \Sigma Fall = 0.375$

And,

Last RL - first RL = 68.61 - 68.235 = 0.375

$\therefore \Sigma Rise - \Sigma Fall = (Last\ RL - first\ RL) = 0.375m$

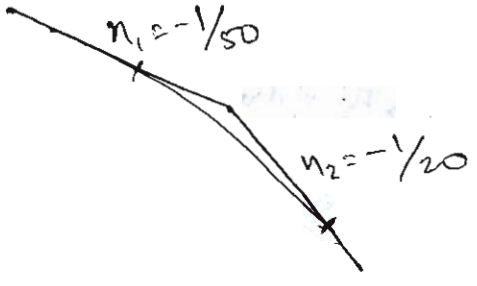
$\Rightarrow$ OK

20

2.3 (b) A two-lane, two-way highway is designed for design speed of 65 km/hr. A vertical curve is to be provided at intersection of downward gradient of 1 in 50 with another downward gradient of 1 in 20. Calculate the length of the vertical curve based on overtaking sight distance and stopping sight distance. The coefficient of longitudinal friction and the acceleration may be taken as 0.35 and 3.6 km/hr/sec respectively.

[20 marks]

Soln



$\Rightarrow$ Summit curve will form.

$\therefore N = |n_2 - n_1|$

$= \left|-\frac{1}{20} + \frac{1}{50}\right| = 0.03$

Now,

SSD as per 65 km/hr : (At 65 km/hr, Assume $t_r = 2.5$ sec).

$$\Rightarrow SSD = 0.278 V t_r + \frac{V^2}{254 f}$$

$$= 0.278 \times 65 \times 2.5 + \frac{65^2}{254 \times 0.35}$$

$$\simeq 92.7 \text{ m}.$$

And,

$$OSD = 0.278 V_B t_r + 0.278 V_B T + 2S + 0.278 V_D T.$$

$V_D = 65$ km/hr.

$V_B = V_D - 16 = 65 - 16 = 49$ km/hr.

Assume $t_r = 2$ sec ; Length of vehicle = 6 sec.

$$T = \sqrt{\frac{4S}{a}} \quad ; \quad S = 0.2 V_B + L = 0.2 \times 49 + 6 = 15.8 \text{ m}.$$

$a = 3.6$ km/h/sec $= 1$ m/s^2

$$\therefore T = \sqrt{\frac{4 \times 15.8}{1}} = 7.95 \text{ sec}.$$

$$\therefore OSD = 0.278 \times 49 \times 2 + 0.278 \times 49 \times 7.95 + (2 \times 15.8) + 0.278 \times 65 \times 7.95$$

$$\therefore OSD = 310.8 \text{ m}$$

i) Length of Curve as per OSD ($S = 310.8$ m)

Let $L_c > OSD$

$$L = \frac{NS^2}{2(\sqrt{H} + \sqrt{h})^2} \quad ; \quad H \rightarrow \text{Ht. of driver's eye} = 1.2 \text{ m}$$
$$h \rightarrow \text{Ht. of obstruction} = 1.2 \text{ m}.$$

$$L = \frac{0.03 \times 310.8^2}{2(\sqrt{1.2} + \sqrt{1.2})^2} = 301.865 \text{ m}.$$

Here, $L_c < OSD$ ⇒ Our assumption is wrong.

Let $L_c < OSD$

$$L_c = 2S - \frac{2(\sqrt{H}+\sqrt{h})^2}{N} = 2\times 310.8 - \frac{9.6}{0.03} = 301.6\,m.$$

∴ Length of curve (301.6m) < OSD (310.8m)

⇒ OK

ii) Length as per SSD ($S = 92.7m$).

Let $L_c > SSD$

$$L = \frac{NS^2}{2(\sqrt{H}+\sqrt{h})^2} \quad ; H = 1.2m,\ h = 0.15m.$$

$$L = \frac{0.03\times 92.7^2}{2(\sqrt{1.2}+\sqrt{0.15})^2} = 58.59\,m < SSD$$

⇒ Our assumption is wrong.

Let, $L_c < SSD$

$$L = 2S - \frac{2(\sqrt{H}+\sqrt{h})^2}{N}$$

20

$$= 2\times 92.7 - \frac{4.4}{0.03} = 38.73m < SSD$$

⇒ OK.

∴ Length of Curve

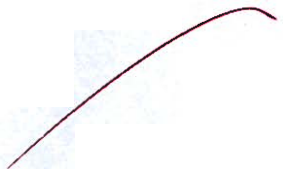
As per OSD ⇒ 301.6m

As per SSD = 38.73m

Q.3 (c) (i) Explain folds and faults and their importance in engineering works.

(ii) Explain the concept of resolution in remote sensing. Describe the different types of resolution and discuss their importance in image interpretation.

[10 + 10 = 20 marks]

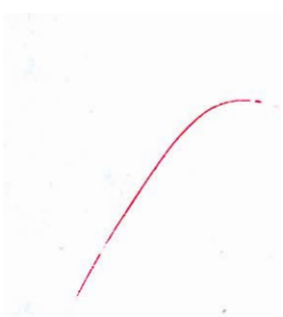


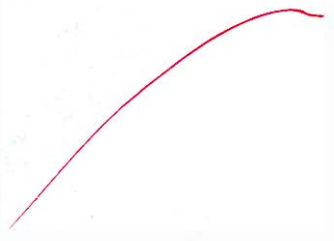
Q.4 (a) (i) Adjust the angular error in the observations (if any) and calculate the bearings of the traverse lines in the following systems if whole circle bearing of the line AB is 30°:

Traverse station	Included angle
A	120°35′00″
B	89°23′40″
C	131°01′00″
D	128°02′20″
E	94°54′40″
F	155°59′20″

(ii) Describe the raster and vector data models in GIS. Compare them with respect to data structure, advantages, and limitations.

[10 + 10 = 20 marks]





4 (b) (i) Discuss the role of joints in rock masses and explain the problems they create in civil engineering works.

(ii) Spot Speed Studies were conducted at a certain stretch of a highway and the consolidated data collected are given below:

Speed Range (kmph)	No. of Vehicles observed
0 – 10	12
10 – 20	35
20 – 30	55
30 – 40	60
40 – 50	140
50 – 60	230
60 – 70	320
70 – 80	95
80 – 90	45
90 – 100	28

Determine:

(i) The upper and lower values of speed limits for regulation of mixed traffic flow.

(ii) The design speed for checking the geometric design elements of the highway.

[10 + 10 = 20 marks]

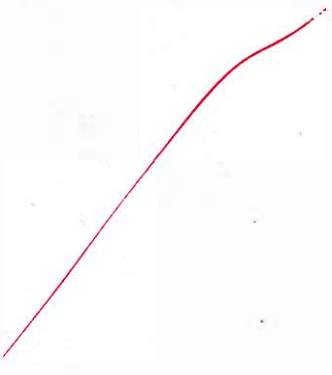
Q.4 (c) A tachometer fitted with an anaclitic lens was set up at station *B* and the following observations were recorded. The value of the multiplying constant is 100.

Station	Station sighted	Bearing	Vertical angle	Staff readings (m)
B	*A*	325°30′	+3°20′	0.750, 1.000, 1.250
	C	55′30′	+2°30′	1.250, 2.000, 2.700

(i) Find the horizontal distance between *A* and *C*.

(ii) Find the difference of level between *A* and *C*.

[20 marks]



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

.5 (a) Describe the triaxial test? State the merits and demerits of Triaxial test?

[12 marks]

Sol^n Triaxial test is a laboratory test that is used to determine the shear strength of soil.

This test is carried out in 2 stages:-

i) Confined stage :- In this stage, a uniform water pressure is applied from all the sides of the soil sample.

The sample made for testing is cylindrical in shape.

ii) Deviator stress stage :- After the completion of 1st stage, deviator stress stage begins in which the axial pressure on the soil is increased systematically till the failure of soil specimen.

5+2

There are various methods of triaxial test :-

i) Consolidated Drained Test :- Pore water pressure is not developed in both stage. Ex:- Sand in both short & longterm.

ii) Consolidated Undrained Test :- Pore water pressure develops in the second stage. Ex:- Sudden drawdown of WT.

iii) Unconsolidated Undrained Test :- Pore water pressure develops in both the stage. Ex:- Clay in short term.

$\therefore \sigma_1 = \sigma_3 \tan^2(45+\Phi/2) + 2C\tan(45+\Phi/2)$

Merits of test :-

i) The failure plane is not predefined, soil can fail from any plane as compared to direct shear test where failure plane is defined.

ii) This test can be performed on all the types of soil.

iii) This test can be performed for all the types of drainage condition in field.

Demerits

i) It is time taking process.

5 (b) A 6 m thick clay layer (e_0 = 1.05, C_c = 0.40, C_α = 0.025) is subjected to an increase in pressure of 75 kPa. The initial effective overburden pressure at the centre of the clay layer is 125 kPa. The clay is underlain by dense gravel and has a coefficient of consolidation c_v = 3.5 m²/year. Calculate the total settlement (in mm) after 20 years, assuming primary consolidation is complete at U = 95%.

[12 marks]

Sol^n

Total primary settlement of clay layer = ΔH (say).

6m Clay $e_0 = 1.05$, $C_c = 0.40$

Dense Gravel.

$\therefore \Delta H = \frac{C_c H_0}{1+e_0} \log\left(\frac{\bar{\sigma}_0 + \Delta\bar{\sigma}}{\bar{\sigma}_0}\right)$

$\bar{\sigma}_0 = 125$ kPa

$\Delta\bar{\sigma} = 75$ kPa.

$\Rightarrow \Delta H = \frac{0.40 \times 6}{1+1.05} \log\left(\frac{125+75}{125}\right) = 0.23897$ m

$= 23.897$ cm

$= 238.97$ mm

6

% age consolidation after 20 years need to be calculated.

$\therefore T_v = \frac{c_v \times t}{d^2}$ (from Terzaghi's eqn.); $d = \frac{6}{2} = 3$m (As double drainage).

$\Rightarrow T_v = 3.5 \times \frac{20}{(3)^2} = 1.944$.

As $T_v > 0.283 \Rightarrow$ Use $1.781 - 0.933 \log(95 - \%U)$.

$\therefore 1.781 - 0.933 \log(95 - \%U) = 1.944$.

$\%U = 94.33\%$.

$\therefore \frac{\Delta h}{\Delta H} = 0.9433 \Rightarrow \Delta h = 238.97 \times 0.9433$

$= 225.42$ mm

Q.5 (c) The BOD of a sewage incubated for 5 days at 20°C is 110 mg/*l*. Calculate the ultimate BOD and one day BOD at 37°C. Assume k_D at 20°C as 0.10 day^{-1}.

[12 marks]

Sol^n

$BOD_5 = BOD_0\left(1 - 10^{-kt}\right)$; $BOD_0 \rightarrow$ Ultimate BOD.

$\Rightarrow 110 = BOD_0\left(1 - 10^{-0.1\times 5}\right)$.

$BOD_0 = 160.872$ mg/l.

As Ultimate BOD is independent of temperature.

∴ Ultimate BOD @ 20°C = Ultimate BOD @ 37°C = 160.872 mg/l

Now,

Reaction rate constant at 37°C.

$K_T = K_{20}(\theta)^{T-20}$; $\theta = 1.047$; $T > 20$ °C

$\Rightarrow K_T = 0.1(1.047)^{17} \Rightarrow K_T = 0.218372$ day^{-1}.

$\therefore$ BOD_1 at 37°C

$\Rightarrow BOD_t = BOD_0 (1 - 10^{-Kt})$

$\Rightarrow BOD_t = 160.872 \left(1 - 10^{-0.21832 \times 1}\right)$

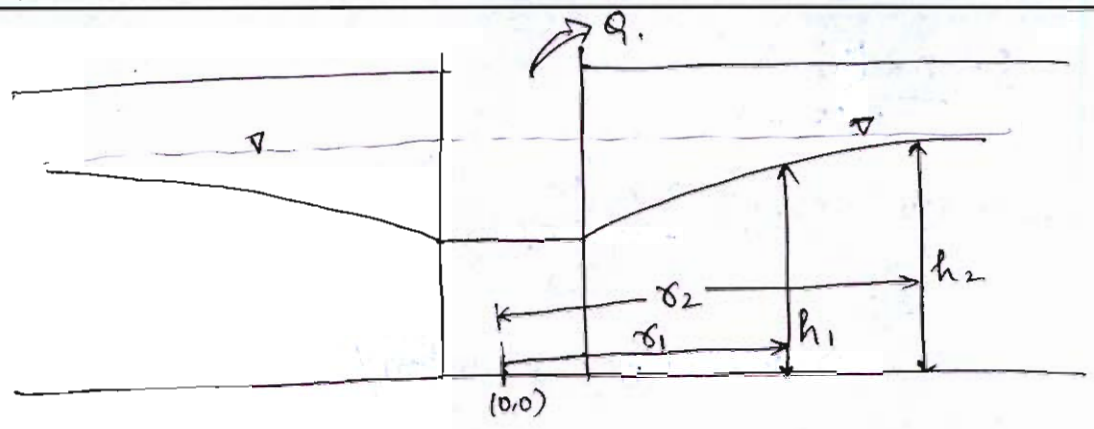
$BOD_{1\,day} = 63.561$ mg/l. 12

.5 (d) Design a septic tank for a colony for the following data:
Population of colony = 100
Sewage produced per capita per day = 120 litres
Dislodging period = 1 year
Length: Width = 4 : 1
Rate of deposited sludge = 30 litres/capita/year
Detention time = 24 hours
Depth of tank = 1.5 m

[12 marks]

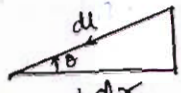
Q.5 (e) Derive an expression for determination of permeability in a well Penetrated fully in a unconfined aquifer. For conducting permeability tests on a well which has an unconfined aquifer, two observation wells *A* and *B* are bored at distances 20 m and 35 m respectively from the centre of the well. When water is pumped at the rate of 7.5 litres per sec, it is observed that the elevations of the watertable above the impervious layer up to which the well is excavated are 12 m and 12.5 m respectively at *A* and *B*. Calculate the permeability of the aquifer.

[12 marks]



From Darcy's law.

$Q = KiA$; $i = \frac{dh}{dL} \simeq \frac{dh}{dr}$ (as θ is small)



$\Rightarrow Q = K \times \frac{dh}{dr} \times A$; Area $= (2\pi r) \cdot h$.

$Q = K \times \frac{dh}{dr} \times 2\pi r h$.

$Q \frac{dr}{r} = 2\pi K h \, dh$.

Integrating both sides

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

$$\Rightarrow Q \left[\ln r\right]_{r_1}^{r_2} = 2\pi K \times \left[\frac{h^2}{2}\right]_{h_1}^{h_2}$$

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

$$\Rightarrow \boxed{Q = \frac{\pi K \left[h_2^2 - h_1^2\right]}{\ln\left(r_2/r_1\right)}}$$

As per question,

$r_1 = 20\,m$, $r_2 = 35\,m$, $Q = 7.5\,lps = 7.5 \times 10^{-3}\,m^3/s$

$h_1 = 12\,m$, $h_2 = 12.5\,m$.

$$\therefore \quad Q = \frac{\pi K (h_2^2 - h_1^2)}{\ln(r_2/r_1)}$$

$$\Rightarrow 7.5 \times 10^{-3}\ m^3/s = \frac{\pi K (12.5^2 - 12^2)}{\ln(35/20)}.$$

$$\Rightarrow K = 1.0906 \times 10^{-4}\ m/sec.$$

$$K = 0.10906\ l/s.$$

12

Q.6 (a) **(i)** With necessary assumptions, derive the expression for permeability of soil for a falling head test.

(ii) A falling head permeability test was performed on a 20 cm long cylindrical sample of silty clay. The diameter of the soil sample was 10.0 cm and the internal diameter of the standpipe was 1.0 cm. During the test, the water level in the standpipe was observed to fall from an initial height of 80 cm to 50 cm in 15 minutes.

Determine:

(a) The coefficient of permeability (k) of the soil in m/day.

(b) The height of the water level in the standpipe after an additional 25 minutes of testing.

(c) The total time required for the water level to drop to 15 cm.

[10 + 4 + 3 + 3 = 20 marks]

Sol^{n} (ii) Co-eff. of permeability $(K) = \frac{2.303\, aL}{At} \log\left(\frac{h_1}{h_2}\right)$.

∴ According to question.

$$\Rightarrow K = \frac{2.303 \times \frac{\pi}{4} \times 1^2 \times 20\ cm}{\frac{\pi}{4} \times 10^2 \times 15 \times 60} \log\left(\frac{80}{50}\right)$$

$$K = 1.04464 \times 10^{-4}\ cm/s = 0.090257\ m/day.$$

b) After additional 25 min,

Now, $t = 15 + 25 = 40$ min

$\therefore$ Equating co-eff. of permeability:

$$\frac{2.303 \times a \times L}{A \times 15} \log\left(\frac{80}{50}\right) = \frac{2.303 \times a \times L}{A \times 40} \log\left(\frac{80}{h_2'}\right).$$

$\Rightarrow h_2' = 22.8439$ cm.

10

$\therefore$ Height of water after additional 25 min = 22.8439 cm

c) Let t be the total time required to drop to 15 cm.

$\Rightarrow$ Equating K

$$\frac{2.303\, aL}{A \times 15} \log\left(\frac{80}{50}\right) = \frac{2.303\, aL}{A\, t} \log\left(\frac{80}{15}\right).$$

$\Rightarrow t = 53.424$ minutes

i) Assumptions for falling head :-

i) Soil is homogeneous & isotropic.

ii) Darcy's law is applicable.

iii) Soil is completely saturated.

∴ From Darcy's law,

$$q = KiA$$

$$\Rightarrow K = \frac{q}{iA} \quad \Rightarrow K = \frac{v \times a}{iA}$$

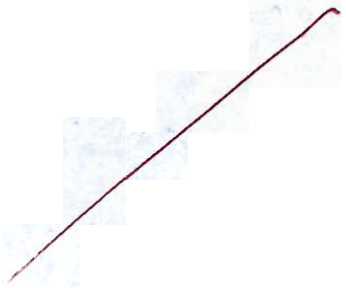
$$\Rightarrow K = \frac{va}{iA}$$; Let L be the length of stand pipe.

$$v = L/t$$

$$\therefore K = \frac{L}{t} \times \frac{a}{iA}$$

$$\therefore K = \frac{La}{At} \ln\left(h_1/h_2\right)$$

$$\therefore K = 2.303 \frac{aL}{At} \log\left(h_1/h_2\right)$$



6 (b) (i) A core sample of undisturbed clay was retrieved from a construction site to assess its consolidation characteristics. To preserve its natural state, the sample was immediately coated with a layer of paraffin wax. In the laboratory, the total mass of the wax-coated specimen was recorded as 725.60 grams, while the mass of the soil specimen alone prior to coating was measured at 715.20 grams. The entire coated assembly was then carefully immersed in a tank, where it was found to displace 395 m*l* of water. A representative portion of the clay was used to determine the moisture content, which was found to be 21.5%. Given that the specific gravity of the soil solids is 2.72 and the specific gravity of the paraffin wax is 0.9, calculate the bulk density, the dry density, the void ratio, and the degree of saturation of the clay sample.

(ii) Determine the effective height of a stack using the following data:

Physical height of stack = 150 m with 1.2 m inside diameter

Wind velocity = 3.0 m/s

Ambient air temperature = 25°C

Barometric pressure = 950 millibars

Stack gas velocity = 14 m/s

Stack gas temperature = 180°C

[10 + 10 = 20 marks]

Sol^n (i) Mass of wax coated specimen = 725.60 gm.

Mass of soil alone = 715.20 gm.

∴ Mass of wax = 725.60 − 715.20 = 10.4 g

∴ Volume of wax = $\frac{\text{Mass of wax}}{S_G \times 1} = \frac{10.4}{0.9} = 11.556\ cm^3$

Volume of displaced water = Volume of wax + Volume of soil

⇒ 395 = 11.556 + V_{soil}

⇒ $V_{soil} = 383.444\ cm^3$.

∴ Bulk density (ρ_b) = $\frac{\text{Mass of soil}}{V_{soil}} = \frac{715.2}{383.444} = 1.8652\ g/cc.$

Given,

Moisture content = 21.5%.

∴ Dry density (ρ_d) = $\frac{\rho_b}{1+w} = \frac{1.8652}{1+0.215} = 1.535\ g/cc.$

Now,

Dry density (ρ_d) = $\frac{G\rho_w}{1+e}$

⇒ $1.535 = \frac{2.72 \times 1}{1+e}$ ⇒ $e = 0.772$

(10)

Now,

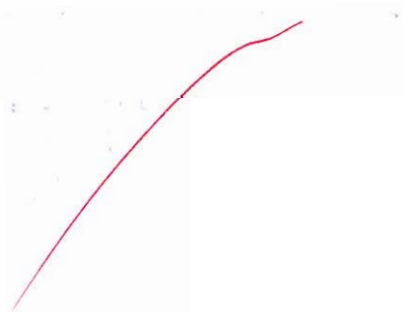
From $wG = eS$.

⇒ $21.5 \times 2.72 = 0.772 \times S$

⇒ $S = 75.75\% = 0.7575$

↓

Degree of saturation



Q.6 (c) (i) A dairy plant processes 1,15,000 kg of milk per day and produces an average of 250 m^3 of wastewater with a BOD of 1200mg/lt. Determine the following:

1. The rate of wastewater flow per 1000 kg of milk received at dairy plant
2. BOD per 1000 kg of milk received.
3. BOD equivalent and hydraulic equivalent of population. Assume 85 g of BOD per person per day and waste water at 350 lts per person per day.

(ii) The per capita water demand of a city is 140 *lpcd*. Estimate the total daily demand of water for this city in the year 2050, given the population of past six decades of this city is as below:

Year	1970	1980	1990	2000	2010	2020
Population (in lacs)	10	15	21	28	34	37

Use incremental method of population forecasting.

[12 + 8 = 20 marks]

Sol^{n} (ii)

Year	Population (in lacs)	Increase in population (x)	Incremental Increase in pop^{n} (y)
1970	10		
1980	15	15-10 = 5	6-5 = 1
1990	21	21-15 = 6	7-6 = 1
2000	28	7	6-7 = -1
2010	34	6	3-6 = -3
2020	37	3.	

Increase in pop^n = $P_n - P_{n-1}$

① Year 1970 ⇒ 15 − 10 = 5 lacs.

∴ Average increase in population ($\bar{x}$) = $\frac{5+6+7+6+3}{5}$

= 5.4 /decade.

Also,

Average incremental increase in pop^n ($\bar{y}$) = $\frac{1+1+(-1)+(-3)}{4}$

= −0.5 /decade.

∴ from incremental method,

$$P_n = P_0 + n\bar{x} + \frac{n(n+1)}{2}\bar{y} \quad ; P_0 \rightarrow \text{Last known Population.}$$

8

$n \rightarrow$ No. of decades from last known pop^n.

∴ Here, n = 2050 − 2020 = 30 years = 3 decades

∴ $P_n = 37 + 3 \times 5.4 + \frac{3 \times 4}{2} \times (-0.5)$

P_{2050} = 50.2 lacs

Per capita water demand = 140 lpcd

∴ Total daily demand in 2050 = $\frac{50.2 \times 10^5 \times 140}{10^3}$ m^3/d

= 702800 m^3/d.

Sol^n i)

In 1,15000 kg milk → Waste water produced is 250 m^3

∴ In 1000 kg of milk received at dairy plant,

wasterwater produced = $\frac{250}{115000}$ = 2.1739 m^3

BOD produced from 115000 kg milk = 1200 mg/l.

∴ BOD produced in 1000 kg = $\frac{1200}{115000} \times 1000$ = 10.4348 mg/l.

BOD equivalent = $\frac{\text{Total BOD produced.}}{\text{BOD per person per day.}}$ (12)

∴ BOD equivalent = $\frac{1200 \times 250 \times 10^3 \text{ mg}}{85 \times 10^3 \text{ mg}}$ = 3529.411

And,

Similarly,

Hydraulic equivalent = $\frac{250 \times 10^3 \text{ l}}{350}$ = 714.285

7 (a) **(i)** With reference to Figure, determine the following:

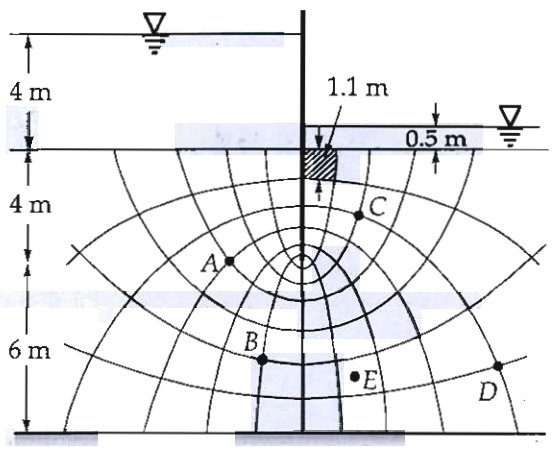
(a) The pressure heads at the points *A* and total head at *E*.

(b) The exit gradient.

(c) Factor of safety against piping.

(d) Quantity of Seepage beneath the per m length of sheet pile.

Given, $G = 2.65$, $e = 0.90$, $k = 0.002$ cm/sec.



[3 + 2 + 2 + 3 = 10 marks]

(ii) A 5 m thick clay layer in the field is underlain by an impermeable rock stratum and overlain by coarse sand. A 25 mm thick undisturbed sample of the same clay was tested in the laboratory with drainage at both top and bottom. The sample reached 60% consolidation in 12 minutes. Determine the time required for the field layer to reach 85% consolidation.

[10 marks]

Sol^n

$\Delta H = 4 - 0.5 = 3.5\ m.$

a) Pressure heads at points A

Total no. of drops = 12 = N

Total flow path = 7

Total head drops till A = 3 → n.

∴ Seepage head at A ⇒ $H - n\Delta h$ → $\Delta h = H/N$.

$= 3.5 - 3 \times \frac{3.5}{12} = 2.625\ m.$

Pressure head at A
$= (H - n\Delta h - DH)$
$= 2.625 - (-4.5)$
$= 7.125\ m$

Total head at A = $3 \times \frac{3.5}{12} = 0.875\ m.$

Total head at E ⇒ $\frac{8+9}{2} = 8.5 \times \frac{3.5}{12} = 2.48.$

b) Exit gradient

$i_{exit} = \frac{\Delta h}{l}$; l → length of last flow path.

$i_{exit} = \frac{3.5/12}{1.1} = 0.265$

c) FOS against piping = $\frac{i_c}{i_{exit}}$; $i_c = \frac{G-1}{1+e} = \frac{2.65-1}{1+0.90} = 0.8684.$

∴ FOS = $\frac{0.8684}{0.265} = 3.277$

d) Quantity of seepage per m length → $Q = KH\frac{N_f}{N_D}$

$\Rightarrow Q = 0.0022 \frac{cm}{sec} \times 10^{-2} \times 3.5 \times \frac{7}{12} = 4.0833 \times 10^{-5}\ m^3/s$/m length of sheet pile.

ii)

Coarse Sand.

Thick clay 5m.

Rock.

For laboratory sample,

Thickness = 25 mm.

& 60% Consolidation in 12 min.

From Terzaghi's Consolidation eqn.

$T_v = \frac{C_v \times t}{d^2}$; $d = \frac{25}{2} = 12.5mm$ (As double drainage)

$\Rightarrow \frac{\pi}{4} \times (0.6)^2 = C_v \times \frac{12}{(12.5 \times 10^{-3})^2}$

$\Rightarrow C_v = \frac{\pi}{4} \times \frac{(0.6)^2 \times (12.5 \times 10^{-3})^2}{12}\ m^2/min.$

$C_v = 3.68155 \times 10^{-6}\ m^2/min$

for field sample,

Drainage is 1 way.

From Terzaghi's eqn.

$T_v = \frac{C_v \times t}{d^2} \Rightarrow 1.781 - 0.933 \log(100 - \%U) = 3.68155 \times 10^{-6} \times \frac{t}{5^2}$

As $\%U = 85\%$.

$\Rightarrow 0.6837 = 3.68155 \times 10^{-6} \times \frac{t}{25}$

$\therefore t = 4642792.134$ Minutes

$t = 8.833$ years.

∴ Time required to reach 85% consolidation is 8.833 years.

20

(b) (i) Explain the concept of break point chlorination in water treatment with a neat diagram.

(ii) The chemical analysis of a water sample gives the following ionic concentrations:

Calcium (Ca^{2+}) = 60 mg/L

Magnesium (Mg^{2+}) = 24 mg/L

Bicarbonate (HCO_3^-) = 183 mg/L

Carbonate (CO_3^{2-}) = 30 mg/L

Chloride (Cl^-) = 71 mg/L

Sulphate (SO_4^{2-}) = 48 mg/L

Assume that hydroxide alkalinity is absent.

(i) Calculate the total alkalinity of the water sample in mg/L as $CaCO_3$.

(ii) Determine the total hardness in mg/L as $CaCO_3$.

(iii) Compute the carbonate hardness and non-carbonate hardness of the water sample in mg/L as $CaCO_3$.

[8 + 12 = 20 marks]

ii) Total alkalinity in water sample is due to the presence of CO_3^{2-}, HCO_3^- & OH^- ions.

As hydroxide alkalinity is absent.

$$\therefore \text{Total equivalents of alkaline species} = \left(\frac{\text{Given wt. of } HCO_3^-}{\text{Eq. wt. of } HCO_3^-} + \frac{\text{Given wt. of } CO_3^{2-}}{\text{Eq. wt of } CO_3^{2-}} \right)$$

$$= \left(\frac{183}{61} + \frac{30}{30} \right) = 4.$$

$$\therefore \text{Total alkalinity as } CaCO_3 = 4 \times \text{Eq. wt. of } CaCO_3 = 4 \times 50 = 200 \text{ mg/l as } CaCO_3$$

Similarly,

Total hardness is due to the presence of multivalent metallic cations.

$$\therefore \text{Total hardness as } CaCO_3 = \left(\frac{\text{Given wt. of } Ca^{2+}}{\text{Eq. wt. of } Ca^{2+}} + \frac{\text{Given wt. of } Mg^{2+}}{\text{Eq. wt. of } Mg^{2+}} \right) \times \text{Eq. wt. of } CaCO_3$$

$$= \left(\frac{60}{20} + \frac{24}{12} \right) \times 50$$

$$= 250 \text{ mg/l as } CaCO_3$$

As we know that,

Carbonate hardness = Minimum {Total hardness, Total Alkalinity}

$= \text{Min}^{m}\{250\ mg/l, 200\ mg/l\}$

$\therefore$ Carbonate Hardness = 200 mg/l as $CaCO_3$.

And,

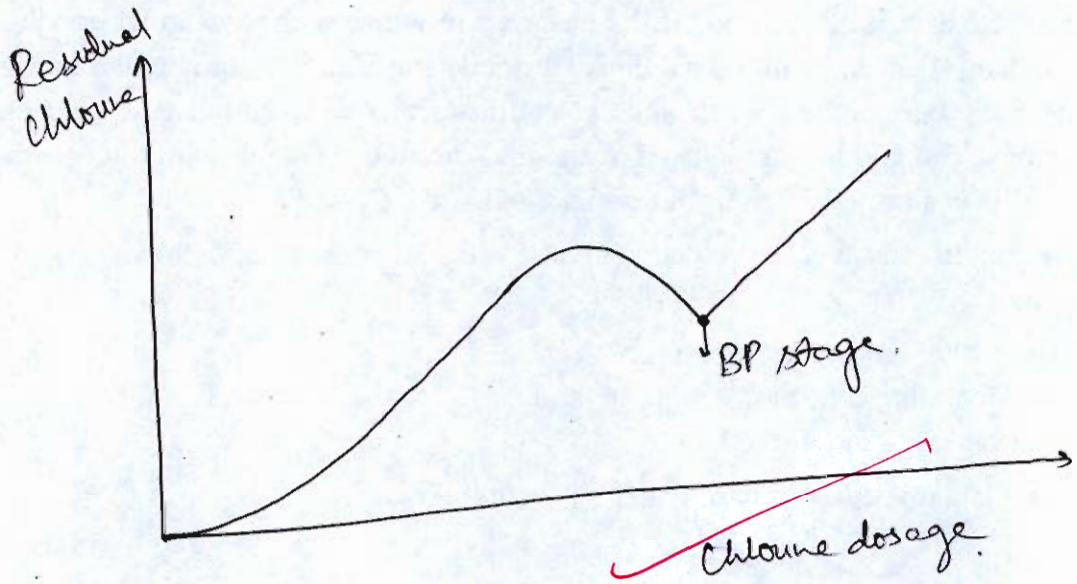
Non-Carbonate Hardness = Total Hardness - Carbonate Hardness

$= 250 - 200$

$= 50\ mg/l$ as $CaCO_3$

12

1) Break Point chlorination



After BP stage, all the chlorine added remains as residual.

After BP stage, foul gases stops coming out.

2

Q.7 (c) (i) Explain the mechanism of Coagulation in reference to water treatment.

(ii) A mechanically mixed flocculation tank having dimensions 32 m × 10 m × 4.8 m is proposed to handle a flow of 80 MLD. The tank is provided with rectangular paddles of size 10 m × 0.35 m, mounted parallel to the tank length on five horizontal rotating shafts. Each shaft rotates at 3 rpm and two paddles are fixed on each shaft in opposite directions. The paddles are located at the mid-depth of the tank with the paddle center line positioned 2.0 m from the shaft axis. Take $C_d = 1.8$

Assuming that the average velocity of water is 0.6 times the paddle tip velocity, determine:

(i) the power required for mixing,
(ii) the detention time of flocculation, and
(iii) the velocity gradient (G).

Take the kinematic viscosity of water 1.0×10^{-6} m^2/s.

[8 + 12 = 20 marks]

Sol^n (ii)

$$\text{Power}(P) = \frac{1}{2} C_D \rho_w A_p (V_r)^3 \quad ; V_r \rightarrow \text{Relative velocity}$$

$$V_r = V_p - V_w = V_p - 0.6V_p = 0.4V_p.$$

$$V_p = \omega r = \frac{2\pi \times 3}{60} \times 2 = 0.6283 \text{ m/s}.$$

$$\therefore \text{Detention time of flocculation} = \frac{V}{Q} = \frac{32 \times 10 \times 4.8}{80 \times 10^6 / 10^3}$$

$$= 0.0192 \text{ days}$$

$$= 0.4608 \text{ hr} = 27.648 \text{ min}$$

$$\therefore \text{Power}(P) = \frac{1}{2} \times 1.8 \times 10^3 \times (10 \times 0.35 \times 5 \times 2) \times (0.4 \times 0.6283)^3$$

$$\therefore P = 500.025 \text{ N m/s}.$$

Velocity gradient (G).

$$G = \sqrt{\frac{P}{\mu V}} \Rightarrow G = \sqrt{\frac{500.025}{10^{-6} \times 10^3 \times 32 \times 10 \times 4.8}}$$

$$G = 18.0426 \text{ s}^{-1}.$$

i) Coagulation is a process in which coagulants are added in water to make flocs in the water and accelerates the settling of solids.

To ensure that the coagulant added is mixed properly in the tank, fast or rapid mixing is produced.

As most of the particles in water are negatively charged, so coagulant should be such that it produces positive charge in the water.

The different mechanisms of coagulation are: 16

1) Ionic layer Compression :- In this method, alternate layer of +ve & -ive ions are ~~found~~ formed.

ii) Adsorption and charge Neutralisation

iii) Sweep Coagulation :- A large floc is formed and when it settles down it sweeps other solids from water.

iv) Interparticle Bridging.

(a) (i) What is the earth pressure at rest? Derive the relationship.

(ii) A 6 m high rigid retaining wall has to retain a backfill of dry, cohesionless soil having the following properties:

$\phi = 30°$, $e = 0.72$, $G = 2.67$, $\mu = 0.35$.

(a) Plot the distribution of lateral earth pressure on the wall at rest.

(b) Determine the magnitude and point of application of the resultant thrust.

(c) Compute the percent change in the lateral thrust if the water table rises from a great depth to the top of the backfill.

[8 + 12 = 20 marks]

Q.8 (b) (i) A square pile group of 16 piles penetrates through a filled-up compressible soil of 3 m depth the pile diameter is 250 mm and pile spacing is 0.75 m the unit cohesion of the material is 18 kN/m^2. Sketch plan and elevation view of the pile group and compute the negative skin friction on the group.
(Take unit weight of soil is 15 kN/m^3 and adhesion factor as 0.4, use uniform cohesion)

(ii) Design a raw water pumping station to draw water from a perennial river for a town with the following data:
Population to be served = 6.0 lakh
Average daily water demand = 160 lpcd
Peak summer demand = 180% of average demand
Pumping hours per day = 12 hours
Normal water level in river = RL 205.00 m
Lowest water level in summer = RL 201.50 m
Water is to be pumped to a treatment plant inlet at RL 220.00 m
Rising main diameter = 1.0 m
Head loss due to friction in rising main during peak summer = 2.8 m
Overall efficiency of pump and motor = 70%
Determine:
(i) Discharge capacity of the pump required during peak summer (m^3/s)
(ii) Horsepower (HP) of the pump required

[10 + 10 = 20 marks]

Q.8 (c) (i) What is the zeolite process of removing hardness. Discuss the advantage and disadvantage of it.

(ii) A water supply system is provided with an ion-exchange softener containing 0.06 m^3 of resin having an ion-exchange capacity of 45 kg/m^3 expressed as $CaCO_3$. The daily water requirement of consumers is 900 litres per day. Chemical analysis of the raw water indicates that it contains 80 mg/L of calcium (Ca^{2+}) and 36 mg/L of magnesium (Mg^{2+}). The consumers require softened water having hardness not exceeding 100 mg/L as $CaCO_3$. Assuming that the ion-exchange resin works with 100% efficiency and that complete saturation of the resin occurs before regeneration, determine

(i) the quantity of water to be bypassed daily and

(ii) the time interval between two successive regenerations interval of the resin.

[8 + 12 = 20 marks]

○○○○

Space for Rough Work

Space for Rough Work

Space for Rough Work

Space for Rough Work

Space for Rough Work