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ESE 2019 : Mains Test Series

UPSC ENGINEERING SERVICES EXAMINATION

Civil Engineering

Test-1: Geo-technical & Foundation Engg. + Environmental Engg.

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Student's Signature

Instructions for Candidates

1. Do furnish the appropriate details in the answer sheet (viz. Name & Roll No).
2. Answer must be written in English only.
3. Use only black/blue pen.
4. 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.
5. Any page or portion of the page left blank in the Question Cum Answer Booklet must be clearly struck off.
6. Last two pages of this booklet are provided for rough work. Strike off these two pages after completion of the examination.

FOR OFFICE USE	
Question No.	Marks Obtained
Section-A	
Q.1	53
Q.2	
Q.3	58
Q.4	
Section-B	
Q.5	27
Q.6	14 - 2 = 42
Q.7	39 - 1 = 38
Q.8	
Total Marks Obtained	221 - 3 = 218

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

→ Improve theory writing.

→ Can do better.

⇒ Accuracy is good.

Section A : Geo-technical & Foundation Engineering

Q.1 (a) A core-cutter of diameter 100 mm and height 130 mm having weight 1.5 kg was pushed into embankment under construction and mass of core cutter with soil was found to be 3.865 kg. The soil has water content of 11% and specific gravity of soil is 2.67. Determine the bulk unit weight, dry unit weight and void ratio of soil sample. The unit weight of water is 9.81 kN/m^3.

[12 marks]

Soln

d = Dia = 100 mm

h = height = 130 mm

$W_{c.c} = 1.5$ kg

$W_{c.c} + W_{soil} = 3.865$ kg

$W_{soil} = 3.865 - 1.5 = 2.365$ kg

$\omega(\%) = 11\%$

$G_s = 2.67$

12

Now,

$$\rho_{bulk} = \frac{W_{soil}}{V_{c.c.}}$$

$$\rho_{bulk} = \frac{2.365}{\frac{\pi}{4} \times 0.1^2 \times 0.13} = 2316.31 \text{ kg/m}^3$$

bulk unit wt →

$$\boxed{\gamma_{bulk} = \rho_{bulk} \times g = 22.723 \text{ kN/m}^3}$$

Now,

$$\gamma_{dry} = \frac{\gamma_{bulk}}{1+w} = \frac{22.723}{1.11} =$$

Dry unit wt. →

$$\boxed{\gamma_{dry} = 20.471 \text{ kN/m}^3}$$

Now $\gamma_{dry} = \frac{\gamma_w G_s}{1+e}$

$$20.471 = \frac{9.81 \times 2.67}{1+e}$$

Void ratio

$$\boxed{e = 0.279}$$

Q.1 (b) $\overline{CU}$ tests carried out on a saturated normally consolidated clay showed that $C_u = 0$ and $\phi_u = 15°$. If the pore pressure coefficient A at failure was 0.92, what are the values of c' and ϕ' for the soil?

[12 marks]

Soln

$\overline{CU}$ → $C_u = 0$ $\phi_u = 15°$

Since NC clay saturated, pore pressure coeff. $B = 1$

Let principal stresses (total) be σ_1 and σ_3

So

$$\sigma_1 = \sigma_3 \tan^2\left(45° + \frac{\phi_u}{2}\right) + 2c_u \tan\left(45° + \frac{\phi_u}{2}\right)$$

$c_u = 0$

$\phi_u = 15°$,

$$\boxed{\sigma_1 = \sigma_3 \times 1.698}$$

since test is CU, all pore pressure dissipated during cell pressure application

$$\boxed{\Delta u_c = 0}$$

Now using skemptons A and B, pore pressure developed is

$\Delta u = B \sigma_3 + AB(\sigma_1 - \sigma_3)$

$\Delta u = \sigma_3 + 0.92 \times 1 (\sigma_1 - \sigma_3)$

$\Delta u = \sigma_3 + 0.92 \times (1.698\sigma_3 - \sigma_3)$

$\boxed{\Delta u = 0.642\,\sigma_3}$

Since its an NC clay $\phi =$

$\boxed{C' = 0}$, $\phi' = ?$

12

Now

$\sigma_1' = \sigma_3' \tan^2(45^\circ + \frac{\phi'}{2})$

$\sigma_1 - \Delta u = (\sigma_3 - \Delta u) \tan^2(45^\circ + \phi'/2)$

$1.698\sigma_3 - 1.642\sigma_3 = (\sigma_3 - 0.642)\sigma_3 \tan^2(45^\circ + \phi'/2)$

$1.698\sigma_3 - 0.642\sigma_3 = (\sigma_3 - 0.642)\sigma_3 \tan^2(45^\circ + \phi'/2)$

$1.056\sigma_3 = 0.358\sigma_3 \tan^2(45^\circ + \phi'/2)$

$\boxed{\phi' = 29.58^\circ}$

$\boxed{C' = 0}$

Q.1 (c) Compare the salient features of Standard Penetration Test and Plate Load Test.

[12 marks]

SPT

- A hammer of 65 kg falls freely from 75cm height
- No. of blows for each 150 mm penetration recorded
- No of blows for last 300 mm penetration called as SPT Number 'N'
- Split spoon sampler is used
- 'N' is corrected for overburden press and dilatancy

PLT

- It simulates a foundation
- A plate is kept at level of foundation and load applied using jack to determine settlement of plate
- Load-settlement curve drawn
- Done to obtain bearing capacity of actual foundation

- N' correlated with ϕ, D_r, to obtain imp parameters.

by conducting test on plate

- Also possible to determine allowable pressure corresponding to allowable settlement of foundation.

3

$$\frac{S_f}{S_p} = \left[\frac{B_f\left[B_p + 0.3\right]}{B_p\left(B_f + 0.3\right)}\right]^2$$

→ sand

$$\frac{S_f}{S_p} = \frac{B_f}{B_p}$$

→ clay

Q.1 (d) **(i)** What quantity of cement per m^3 of soil is required for permeation grouting in soil, having void ratio of 0.6, if the grout mix has a water cement ratio of 6 : 1 by weight? Assume that 50% of the void space gets filled with the grout slurry. Take specific gravity of cement as 3.15.

(ii) Grouting is to be carried out in 12 m deep grout holes spaced at 3 m distance center to center for the problem discussed in (i) above. What will be the saving per group hole if 50% cement is replaced by Bentonite, given that the cost of cement is ₹ 250 per kN and that of Bentonite is ₹ 120 per kN? Assume that grout will permeate uniformly around each group hole, the volume soil grouted will be a cylinder of diameter 3 m around each grout hole.

[6 + 6 = 12 marks]

Sol(i)

$e = \frac{V_v}{V_s} = 0.6$, $V_{soil} = 1 m^3$

$V_{solids} = \frac{V_{soil}}{1+e} = 0.625 m^3$

$V_{voids} = 1 - V_{solids} = 0.375 m^3$

Now,
Let weight of cement be W_o
weight of water $6W_o$
volume of this mix of grout
$V = is = \frac{W_o}{3150} + \frac{6W_o}{1000} = 6.317 \times 10^{-3} W_o$ m^3

Now, 50% of voids filled means
voids ~~remains~~ filled $= 0.375 \times 0.5$
voids filled $= 0.1875 m^3$

now
voids filled = Volume of slurry
$0.1875 = 6.317 \times 10^{-3} W_o$

Cement required per m^3 is $W_o = 29.681$ kg

(ii) Volume of soil grouted

$$= \frac{\pi}{4} \times 3^2 \times 12 = 84.823 \ m^3$$

Now,

cement required per m^3 of soil was = 29.681 kg = 0.2912 kN

For 84.823 m^3, weight of cement = 24.698 kN

cost = 250 × 24.698

only cement → cost = 6174.5/-

With Bentonite

$$\text{cost} = \frac{24.698}{2} \times 250 + \frac{24.698}{2} \times 120$$

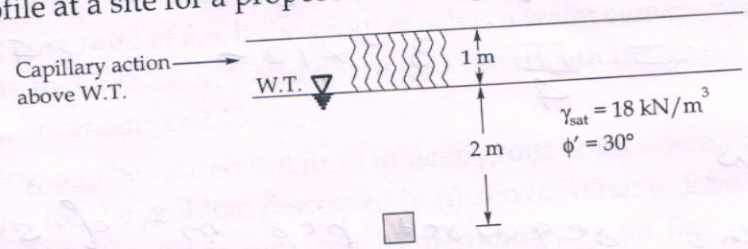
cost = 4569.13/-

Savings = 6174.5 − 4569.13

per grout hole → Savings = 1604.94/-

12

Q.1 (e) The soil profile at a site for a proposed building is shown in figure.



The soil is a homogeneous, poorly graded sand. Determine, the increase in vertical effective stress at which a soil element at a depth of 3 m, under the center of the building will fail if the increase in lateral effective stress is 20% of the increase in vertical effective stress. The coefficient of lateral earth pressure at rest k_0 is 0.5. Assume all stresses are principal stresses.

[12 marks]

Sol⁵

$\phi' = 30°$

Let us find effective lateral and vertical stresses at 3 m depth

σ_1' be vertical eff. stress

σ_3' " lateral "

$\sigma_1' = \gamma_{sat} \times 1 + (\gamma_{sat} - \gamma_w) \times 2$

$\sigma'_{z=3m} = 18 \times 1 + (18 - 9.81) \times 2$

$\sigma'_{z=3m} = 34.38$ kN/m^2

$\sigma'_{3,z=3m} = \sigma_1' k_0$

$k_0 = 1 - \sin\phi = 0.5$

$\sigma'_{3,z=3m} = 17.19$ kN/m^2

Now since its saturated sand

$c' = 0$, $\phi' = 30°$

$\sigma_1' = \sigma_3' \tan^2(45° + \phi/2)$

Let increase in σ_1' be $\Delta\sigma'$

$(24.38 + \Delta\sigma') = (17.19 + 0.20 \times \Delta\sigma') \times \tan^2(45° + 30/2)$

$$24.38 + \Delta\sigma' = (17.19 + 0.20 \times \Delta\sigma')_{\times}^{3}$$

$$\Delta\sigma' - 0.60\sigma' = 51.57 - 24.38$$

$$\Delta\sigma' = \frac{17.19}{0.40} = 42.975 \text{ kN/m}^2$$

Required increase in vertical effective stress = 42.975 kN/m^2

12

Q.2 (a) **(i)** Consider the following options:

(i) Constructing a cofferdam and casting the concrete in situ.

(ii) Floating a prefabricated box caisson and lowering it is to the bearing stratum.

(iii) Sinking a well foundation and plugging it.

Which of the above options would be most appropriate for constructing a 10 m wide foundation on a strong bearing stratum beneath a river bed for the following three cases?

Case A :

Depth of water above bed = 2 m, depth of strong bearing stratum below bed = 2 m.

Case B :

Depth of water above bed = 20 m, depth of strong bearing stratum below bed = 3 m.

Case C :

Depth of water above bed = 10 m, depth of strong bearing stratum below bed = 20 m.

(ii) A new canal is excavated to a depth of 5 m below ground level, through a soil having the following characteristics : $c = 14\ kN/m^2$, $\phi = 15°$, $e = 0.8$ and $G = 2.7$. The slope of banks is 1 in 1. Calculate the factor of safety with respect to cohesion when the canal runs full. If it is suddenly and completely emptied, what will be the factor of safety? [Take, for $i = 45°$, $\phi = 15°$, $s_n = 0.083$ and for $i = 45°$, $\phi = 7.3°$, $s_n = 0.122$]

[10 + 10 marks]

Q.2 (b) (i) What are the differences between reinforced soil walls and nailed soil walls?

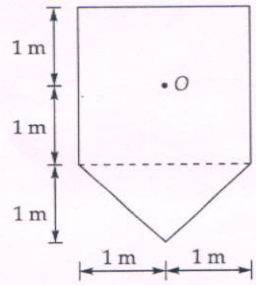
(ii) A foundation trench is to be excavated for a large project in a site. The soil investigation report shows the following details :

Depth from Ground Surface	Type of soil	Index Properties
0 - 8 m	Fine sand	Void ratio = 1.20, Sp.gr. = 2.62
8 - 10 m	Greyish clay	Void ratio = 0.76, Sp.gr. = 2.65
Below 10 m	Coarse sand	--

It is observed that an open excavation is stable up to 5.75 m depth with the existing water table. The excavation is to be made up to 8.5 m depth for which water table is to be lowered. What are the initial and final depths of water table?

[6 + 14 marks]

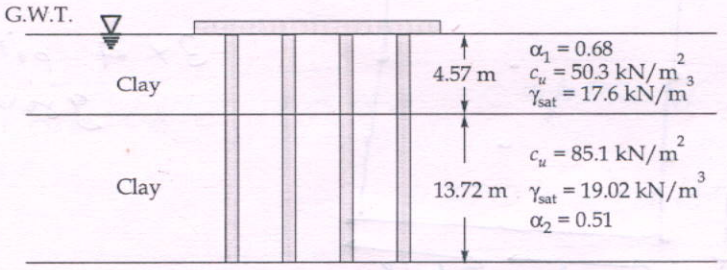
Q.2 (c) **(i)** Compute the vertical stress on a horizontal plane situated at a depth of 2 m below point O in the figure shown below. The area is loaded uniformly to an intensity of 300 kN/m^2. [Use Boussinesq's theory]



(ii) In an unconfined compression test, a sample of clay 100 mm long and 50 mm in diameter fails under a load of 200 N at 10% strain. Calculate the shear resistance of the soil sample by taking into account the effect of change in cross-section of the sample.

[10 + 10 marks]

Q.3 (a) The section of a 3 × 4 group pile in a layered saturated clay is shown in figure.

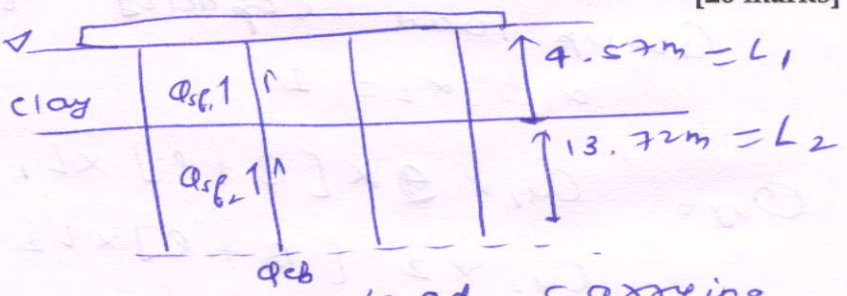


The piles are square in cross-section (356 mm × 356 mm). The center-to-center spacing, d of the piles is 889 mm. Determine the allowable load carrying capacity of the pile group. Use FOS = 4.

[**Note :** Ground water table coincides with the ground surface. For group action of piles take $N_c = 8.57$]

[20 marks]

Solⁿ



Let's find individual load carrying capacity of each pile

$$Q_{up} = Q_{sf_1} + Q_{sf_2} + Q_{eb}$$

$$Q_{up} = \alpha_1 C_{u_1} \times 4 \times b \times L_1 + \alpha_2 C_{u_2} \times 4 \times b \times L_2 + 9 C_{u_2} \times b^2$$

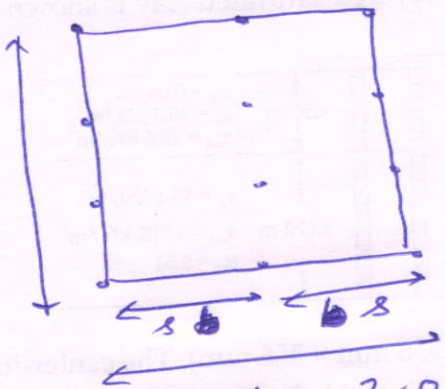
$\alpha_1 = 0.68$ $C_{u_1} = 50.3$ kN/m^2 $L_1 = 4.57$ m

$\alpha_2 = 0.51$ $C_{u_2} = 85.1$ kN/m^2 $L_2 = 13.72$ m

$b = 0.356$ m

$$Q_{up} = 0.68 \times 50.3 \times 4 \times 0.356 \times 4.57 + 0.51 \times 85.1 \times 4 \times 0.356 \times 13.72 + 9 \times 85.1 \times 0.356^2$$

$$Q_{up} = 1167.59 \text{ kN}$$



3×4 pile group

$\ell = 3s + d$

$\ell = 3.023$ m

$2s + d = 2 \times 0.889 + 0.356$

$B = 2.134$ m

Now,

Group load capacity of piles

$\alpha_1 = \alpha_2 = 1$

$$Q_{ug} = C_{u1} \times 9 \times [B + \ell] \times L_1 + C_{u2} \times 2 [B + \ell] \times L_2 + 8.57\, C_{u2} \times B \times \ell$$

$$Q_{ug} = 50.3 \times 2 \times [2.134 + 3.023] \times 4.57 + 85.2 \times 2 [2.134 + 3.023] \times 13.72 + 8.57 \times 85.1 \times 2.134 \times 3.023$$

$$\boxed{Q_{ug} = 19132.2\ kN}$$

Allowable load capacity of piles is

Minimum of $\left\{ \frac{Q_{ug}}{FOS}, \frac{n\, Q_{up}}{FOS} \right\}$

$$= \left\{ \frac{19132.2}{4}, \frac{12 \times 1167.59}{4} \right\}$$

$= \text{Minm.} \{ 4783.05 \text{ kN}, 3502.77 \text{ kN} \}$

Allowable load capacity

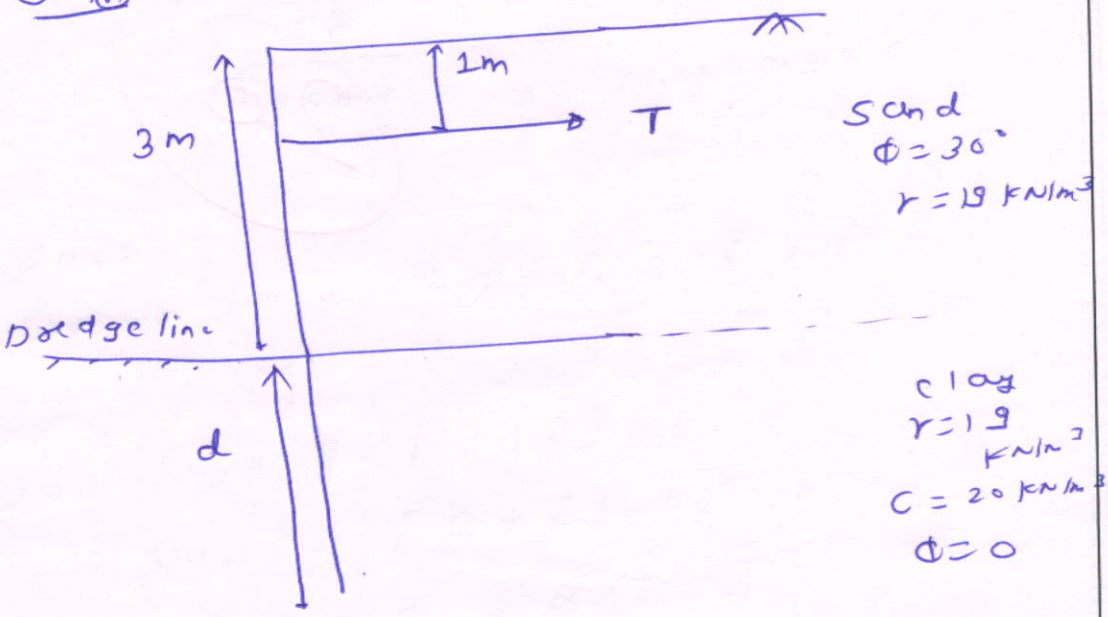
$= 3502.77 \text{ kN}$

20

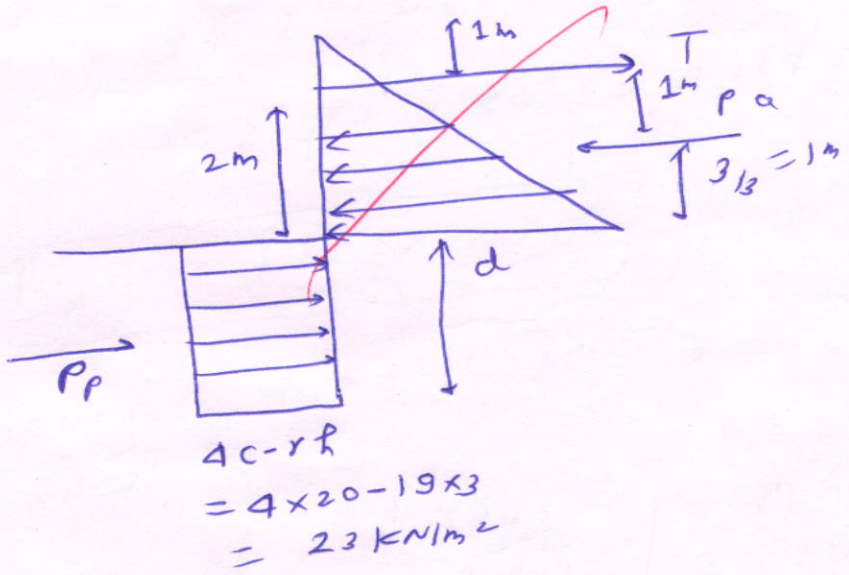
Q.3 (b) An anchored sheet pile supports a sandy back fill of height 3 m having angle of shearing resistance of 30° and unit weight of 19 kN/m^3. The soil below dredge line is clay with a unit weight of 19 kN/m^3, cohesion 20 kN/m^2 and zero angle of internal resistance. The anchor rods are placed 1 m apart and 1 m below the level surface of the backfill. Assuming free earth support, calculate the force in anchor and the depth of sheet pile. Use Rankine's theory for earth pressure.

[20 marks]

Sol^n



Now, free earth support conditions, pressure diagram would be



$\Delta c - \gamma h$

$= 4 \times 20 - 19 \times 3$

$= 23$ KN/m^2

Now For above dredge line

$$K_a = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1}{3}$$

Active earth pressure,

$$P_a = \frac{1}{2} K_a \gamma H^2$$

$H = 3m$

$$P_a = \frac{1}{2} \times \frac{1}{3} \times 19 \times 3^2 = 28.5 \text{ KN/m}$$ length equal,

$$\boxed{P_a = 28.5 \text{ KN/m}}$$

Passive earth pressure, P_p

$$P_p = (4c - \gamma h) \times d$$

$$\boxed{P_p = 23 \times d \text{ KN/m}}$$

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Taking Moments about anchor rod, T

$$\Sigma M = 0$$

$$\Rightarrow P_a \times 1 - P_p \times \left[\frac{d}{2} + 2\right]$$

$$28.5 = 23 \times d \left[\frac{d}{2} + 2\right]$$

$$11.5d^2 + 46d - 28.5 = 0$$

Depth of sheet pile $\boxed{d = 0.545m}$ → This is embedded depth not total

NOW, Force in anchor

$$T = P_a - P_p = 28.5 - 23 \times 0.545$$

Anchor force → $\boxed{T = 15.955 \text{ KN}}$

Increase depth of embedment by 30% $\boxed{d' = 1.3d = 0.71m}$

(3+d)

⇒3.545m

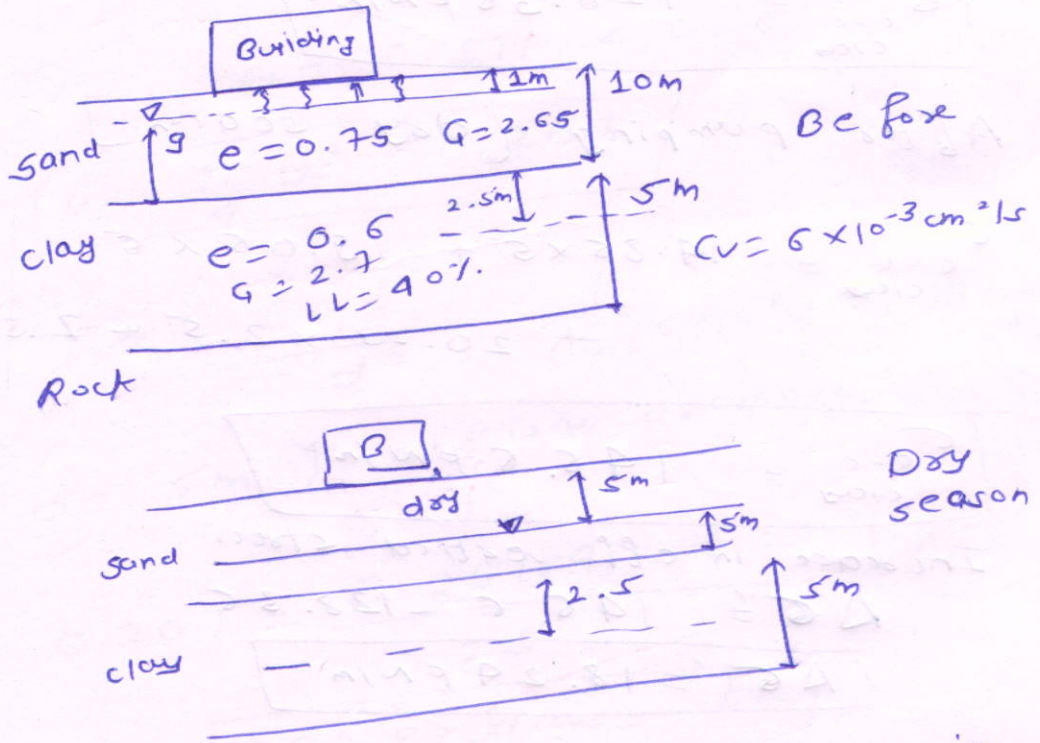
Q.3 (c) A light weight building stands over a 10 m thick stratum of sand. Beneath the sand stratum a clay layer of 5 m thick exists. The clay layer is underlain by a rock stratum. The water table lies at a depth of 1.0 m below ground surface and the sand above the water table is saturated with capillary rise. The sand has a void ratio of 0.75 and sp. gravity 2.65. During dry season, water is pumped out from the sand stratum till the water table is lowered by 4.0 m and sand above water table becomes dry.

Calculate the number of days when the building settles by 25 mm. Ignore settlement during pumping operation.

Take properties of clay : Void ratio = 0.60, Specific gravity = 2.70, Liquid limit = 40%, Coefficient of consolidation = 6×10^{-3} cm^2/s.

[20 marks]

Sol^n



We need to determine increase in eff. vertical stress at centre of clay layer for getting total settlement

sand

$\gamma_{dry} = \frac{\gamma_w G_s}{1+e} = 14.86$ kN/m^3

$\gamma_{sat} = \frac{\gamma_w [G_s + e]}{1+e} = 19.06$ kN/m^3

$\gamma_{sub} = 9.25$ kN/m^3

clay

$\gamma_{sat} = \frac{\gamma_w [G_s + e]}{1+e}$

$= 20.23$ kN/m^3

$\gamma_{sub} = \gamma_{sat} - \gamma_w$

$\gamma_{sub} = 10.42$ kN/m^3

Now

Before, vertical eff. stress at centre of clay layer is

$$\sigma'_{c\text{-}c\ clay} = (\gamma_{sat})_{sand} \times 10 + (\gamma_{sat})_{clay} \times 2.5 - \gamma_w \times 11.5$$

$$\sigma'_{c\text{-}c\ clay} = 19.06 \times 10 + 20.23 \times 2.5 - 9.81 \times 11.5$$

$$\boxed{\sigma'_{c\text{-}c\ clay} = 128.35\ KN/m^2}$$

After pumping [dry season]

$$\sigma'_{c\text{-}c\ clay} = 14.86 \times 5 + 19.06 \times 5 + 20.23 \times 2.5 - 7.5 \times 9.81$$

$$\boxed{\sigma'_{c\text{-}c\ clay} = 146.6\ KN/m^2}$$

Increase in eff. vertical stress

$$\Delta\sigma' = 146.6 - 128.36$$

$$\boxed{\Delta\sigma' = 18.24\ KN/m^2}$$

Clay

$$C_c = 0.009\,[LL-10]$$

$$C_c = 0.009\,[40-10] = 0.27$$

compression index $= C_c = 0.27$

Total settlement $= S_c$

$$S_c = \frac{H\ C_c}{1+e_o} \times \log\left(\frac{\sigma_1' + \Delta\sigma'}{\sigma_1'}\right)$$

$$S_c = \frac{5 \times 0.27}{1.6} \times \log\left(1 + \frac{18.29}{128.36}\right)$$

$$S_c = 48.69 \text{ mm}$$

Now degree of consolidation for 25 mm settlement, $U = \frac{\Delta h}{S_c}$

$$U = \frac{25}{48.69} = 0.51$$

$$U = 0.51 < 0.6$$

$$T_v = \frac{\pi}{4} U^2 = 0.207$$

$$T = \frac{C_v t}{d^2} \qquad t = ?$$

$C_v = 6 \times 10^{-3} \text{ cm}^2/\text{s} = 0.05189 \text{ m}^2/\text{day}$

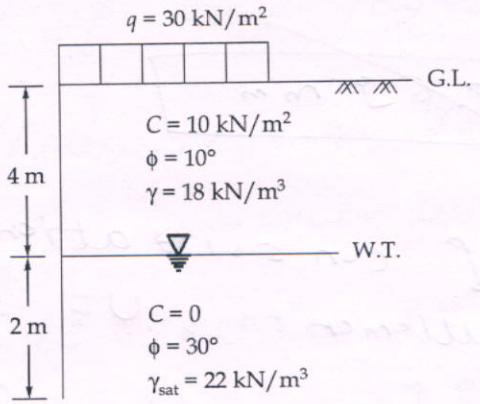
$d = 5\text{m}$ [one way drainage]

20

$$0.207 = \frac{0.05189 \times t}{25}$$

Time required $t = 99.8$ days

Q.4 (a) Calculate the total active earth pressure on the retaining wall 6 m high as shown in the figure. Also calculate the line of action of the lateral force from the base of the wall.



[20 marks]

Q.4 (b) A square mass concrete in footing usually implies raft concrete footing supporting a load of 3250 kN extends from ground level to 3.5 deep into a clay stratum. What will be the size of the footing allowing for a factor of safety of 4? Unit weight of concrete is 25 kN/m^3. Unit weight of soil 21 kN/m^3. Cohesion of soil 0.12 N/mm^2. Adhesion of clay with footing is 25 kN/m^2. The adhesion may be supposed to act over a depth of 2 m from the bottom of the foundation. For $\phi = 0°$, $N_C = 5.7$, $N_q = 1$, $N_\gamma = 0$

[20 marks]

Q.4 (c) **(i)** Draw contact pressure distribution under the following cases:

(a) Rigid footing on cohesionless soil at shallow depth.

(b) Rigid footing on cohesive soil.

(c) Rigid footing on cohesionless soil at deeper depth.

(ii) Find an expression for the unconfined compressive strength q_u in terms of c', ϕ' and A_f (pore pressure parameter at failure). Take parameter $B = 1$ and initial capillary tension = U_c.

[5 + 15 marks]

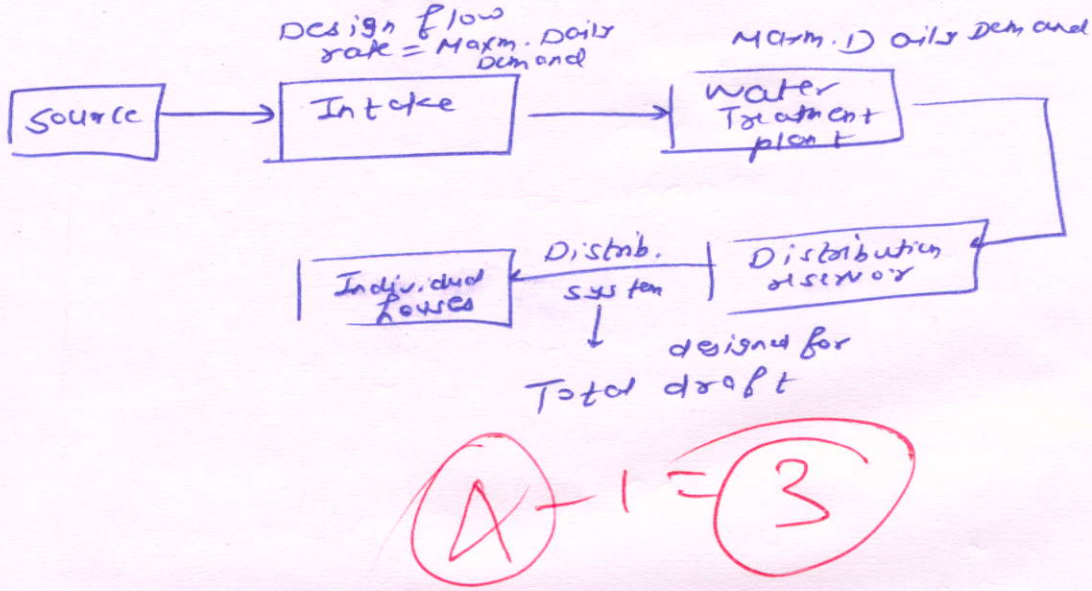
Section B : Environmental Engineering

Q.5 (a) State the salient features of a water supply scheme and also draw a flow chart for the same.

[12 marks]

It includes

- source
- Intake
- water treatment plant
- Distribution reservoir
- Distribution system to each house



4 + 1 = 3

Q.5 (b) Discuss the need of environmental impact assessment. Also discuss the environmental impact of thermal power plants.

[12 marks]

Need for EIA

- to ensure sustainable economic development
- to know like environmental impacts as a result of project before hand
- to identify feasible alternatives to project
- to mitigate likely effects
- to ensure minimum or no harm to environment
- to decide whether project should go ahead

Thermal power plants →

- SO_2
  - causes acid rain
  - respiratory illness
  - corrodes monuments
- Fly ash
  - a PM
  - env. pollutant
  - respiratory distress
  - causes horrines
- use burning of coal & release
  - water slurry
    - Ground water pollution

Air pollution → because of SO_2, NO_x released

Water pollution → water slurry from plants

Noise pollution → Because of generators boilers

soil pollution → fly ash disposal

(4)

Q.5 (c) Estimate the weight of net solids (sludge) produced per day in an activated sludge aeration system in which the influent BOD is reduced from 250 mg/l to 30 mg/l. The flow, Q = 4000 m^3/day; aeration tank volume = 700 m^3 and MLVSS = 3000 mg/l. Assume Y = 0.5, K_d = 0.09/day. Also compute θ_c and F/M.

[12 marks]

Sol⁽ⁿ

$S_0 = 250$ mg/L

$S = 30$ mg/l

$Q = 4000$ m^3/d

$V = 700$ m^3

$X = 3000$ mg/l

$Y = 0.5$ $\quad k_d = 0.09$

Now

$$\frac{1}{\theta_c} = UY - k_d$$

$$\frac{1}{\theta_c} = \frac{Q(S_0 - S)}{VX} \times Y - 0.09$$

$$\frac{1}{\theta_c} = \frac{4000(250-30)}{700 \times 3000} \times 0.5 - 0.09$$

$$\frac{1}{\theta_c} = 0.11952$$

$$\theta_c = 8.366 \text{ days}$$

Sludge produced = wasted sludge

$= Q_w X_u$

$$\theta_c = \frac{VX}{Q_w X_u}$$

$$8.366 = \frac{700 \times 3000 \times 10^{-3}}{Q_w X_u}$$

$Q_w X_u$ = sludge produced = 251.02 kg/day

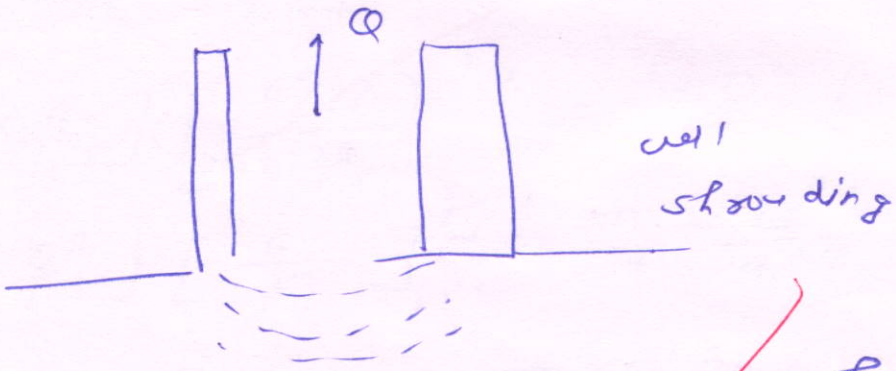
$F/N = \frac{\Phi}{V_x} = \frac{4000 \times 250}{700 \times 3000} = 0.476$

$F/N = 0.476$

7+1 = 8

Q.5 (d) What is shrouding of well? Explain with figure.

[12 marks]

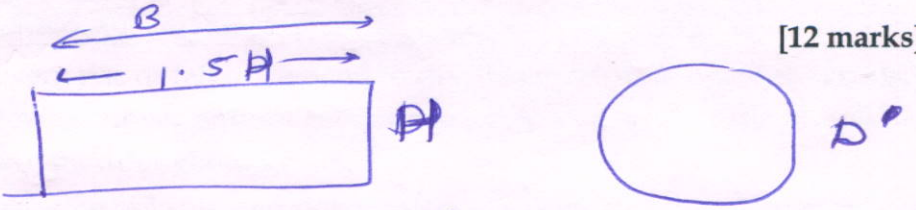


When water being pumped out from well, if the rate of pumping is too high, then upward force because of water flowing up on soil solids will be too high. A time comes when soil solids below well loose its shear strength due to high upward hydraulic gradient and well bottom

heavies. this is called well shadding

Q.5 (e) A rectangular sewer with width 1.5 times its depth is hydraulically equivalent to a circular one. Find the relation between the width of the rectangular sewer and the diameter of the circular sewer.

[12 marks]



Let width be B of tank (rectangular)

$$\text{Depth} = \frac{B}{1.5}$$

For hydraulically equivalency

At full flow $Q_{\text{Rect. tank}} = Q_{\text{circular}}$

As per Manning $Q = \frac{1}{n} A R^{2/3} \sqrt{S_0}$

n = same S_0 = same for both

$$(AR)^{2/3}_{\text{R Tank}} = (AR^{2/3})_{\text{circular}}$$

$$\left[B \times \frac{B}{1.5}\right]\left[\frac{B^2/1.5}{2B + \frac{2B}{1.5}}\right]^{2/3} = \frac{\pi D^2}{4}\left[\frac{D}{4}\right]^{2/3}$$

$$\left[\frac{B^2}{1.5}\right]\left[\frac{B}{5}\right]^{2/3} = \frac{\pi}{4} \times \frac{D^{8/3}}{4^{2/3}}$$

$$\frac{B^{8/3}}{4.386} = \frac{\pi \times D^{8/3}}{4 \times 4^{2/3}}$$

12

$$B = 1.124\, D$$

Width = 1.124 × Dia of sewer

Q.6 (a) (i) Demand of domestic water for a certain city is observed to follow the following pattern :

Time (hr)	0	2	4	6	8	10	12	14	16	18	20	22	24
Demand at the stated time (m^3/s)	0.00	0.10	0.15	0.20	0.50	0.60	0.40	0.30	0.15	0.20	0.25	0.10	0

Assuming uniform rise or fall in demand in the successive time interval, calculate the minimum required capacity of service reservoir, if treated water supply by pumping is constant throughout the day.

(ii) Explain self cleansing velocity and non-scouring velocity and their importance in the design of sewers.

[14 + 6 marks]

Sol^n * All values in m^3

Time	Demand (m^3)	Supply (m^3)	Cumulative Demand (m^3)	Cumulative supply (m^3)	Excess Demand (m^3)	Excess supply (m^3)
0-2	~~720~~ $\frac{720}{2}=360$	1770	360	1770		1410
2-4	~~1080~~ 900	1770	1260	3540		2280
4-6	~~1440~~ 1260	1770	2520	5310		2790
6-8	~~3600~~ 2520	1770	5040	7080		2040
8-10	~~4320~~ 3960	1770	9000	8850	150	
10-12	3600	1770	12600	10620	1980	
12-14	2520	1770	15120	12390	2730	
14-16	1620	1770	16740	14160	2580	
16-18	1260	1770	18000	15930	2070	
18-20	1620	1770	19620	17700	1920	
20-22	1260	1770	20880	19470	1410	
22-24	360	1770	21240	21240	0	

21240 m^3

Capacity = 2730 + 2790

Capacity = 5520 m^3 = 5.52 ML

14

Self cleansing velocity → It is the minimum velocity in sewer at which no solids will get deposited in the sewer. All solids will remain in suspension and will be scoured away.

Importance → At minimum flow in sewer, velocity generated should be greater than self cleansing velocity to avoid deposition of solids in sewer and thus sewer would not get clogged

$$v_{sc} = \sqrt{\frac{8K}{f}} \sqrt{(G_s - 1) g d_p}$$

- K: constant
- f: friction factor
- G_s: specific gravity
- g: gravity $= 9.81 \text{ m/s}^2$
- d_p: particle size

Non-scouring velocity → It is the velocity lesser than the scour velocity. Scour velocity is velocity at which deposited solids will be scoured away in sewer. If some solids get deposited in sewer, then at least once during day velocity greater than non-scour velocity must be generated to scour away deposited solids in sewer to

avoid clogging of sewer

5 - 2 = 3

Q.6 (b) (i) A sample of raw water contains, 200 mg/l alkalinity, 50 mg/l hardness as $CaCl_2$ and 75 mg/l hardness as $MgSO_4$. Compute the quantities of lime and soda required to treat 1 million litres of water. If slaked lime of 85% purity is available in place of pure lime, what will be the required quantity of slaked lime?

(ii) State various disadvantages of Zeolite process of water softening.

[12 + 8 marks]

Sol(n)

Alkalinity = 200 mg/l

Non carbonate Total hardness as $CaCO_3$ $= \left[\frac{50}{\frac{[40+71]}{2}} + \frac{75}{\frac{[24+32+64]}{2}}\right] \times 50$

NCH = 107.55 mg/L

Lime required to remove alkalinity and to convert NCH of $MgSO_4$ into $CaSO_4$

Hydrated lime required to remove alkalinity is x mg/l

$$\frac{200}{50} = \frac{x}{74/2}$$

$$148 = x$$

Now

$$MgSO_4 + Ca(OH)_2 \rightarrow Mg(OH)_2 + CaSO_4$$

moles → $\frac{75}{120}$ $\frac{75}{120}$

hydrated lime required = y

$$y = \frac{75}{120} \times 74 = 46.25 \text{ mg/L}$$

Total hydrated lime required

$= 148 + 46.25$ mg/L

$= 194.25$ mg/L ✗

for 1 MLD $= 194.25$ kg

But purity $= 85\%$

Actual hydrated lime required $= \frac{194.25}{0.85} =$

$= 228.53$ kg

Slaked lime $= \frac{228.53}{74} \times 56 = 172.94$ kg ✗

Soda required is

$\frac{107.55}{50} = \frac{Z}{106/2}$

114 mg/L $= Z$

for 1 MLD $=$ Soda required $= 114$ kg

3

(ii) Disadvantages

- It leaves $NaHCO_3$ in water, causing foaming in boilers
- If Fe, Mn, present, sodium zeolite can't be regenerated process becomes costly
- It is costlier than normal method of softening [Lime-soda process]
- feasible only for water boilers as its uneconomical for water treatment

2

Q.6 (c) A rectangular sedimentation basin is required to handle 10 million litres/day of raw water. A detention basin of width to length ratio of $\frac{1}{3}$ is proposed to trap all particles larger than 0.04 mm in size. Assuming a relative density of 2.65 for the particles and 20°C as the average temperature, compute the basin dimensions. If the depth of tank is 3.5 m, calculate the detention time.

[20 marks]

Sol(c)

Lets find settling velocity of 0.04 mm particles

Assume stokes law to be valid,

$$v_s = \frac{d^2}{18\mu}[\gamma_s - \gamma_\ell]$$

$$v_s = \frac{(0.04 \times 10^{-3})^2}{18 \times 10^{-3}} \times [2650 - 1000] \times 9.8,$$

$$v_{s\,d=0.04mm} = 1.4388 \text{ mm/s}$$

Now $H = 3.5\,m$

Detention time, $t_d = \frac{H}{v_{sett}}$

$$t_d = \frac{3.5}{1.9388 \times 10^{-3}}$$

Detention time $\boxed{t_d = 40.54 \text{ minutes}}$

Surface overflow rate = settling velocity of critical particle

$$SOR = 1.9388 \times 10^{-3}\ m/s$$

$$SOR = 124.31\ m^3/m^2/d$$

$$\frac{Q}{BL} = 124.31$$

Let $B = B \qquad L = 3B$

$Q = 10 \times 10^3\ m^3$

$$\frac{10^4}{3B^2} = 124.31$$

$\boxed{B = 5.18\ m \qquad L = 15.54\ m}$

B: width; L: Length

20

Q.7 (a) The main sanitary sewer is to serve a population of 76000. Calculate the size and slope of the sewer for the following data:

Ratio of maximum flow in sewer to average flow is given by:

$$\frac{Q_{max}}{Q_{avg}} = \frac{18+\sqrt{P}}{4+\sqrt{P}}$$

where 'P' is the population in thousand

Average per capita water supply = 140 lpcd,

Average sewage flow = 80% of water supply.

Manning's roughness coefficient (for concrete sewer) = 0.013. Sewer should run half full while carrying the maximum flow. Velocity in sewer at maximum daily flow = 0.8 m/s.

[20 marks]

Soln

Population $P_{op} = 76000$ $\quad P = 76$

$$\frac{Q_{max}}{Q_{avg}} = \frac{18+\sqrt{76}}{4+\sqrt{76}} = 2.10$$

$$\boxed{Q_{max} = 2.10\, Q_{avg}}$$

$$Q_{average\ sewage} = \frac{140 \times 0.80 \times 76 \times 10^3}{10^6}$$

$$\boxed{Q_{avg} = 8.512\ MLD}$$

$$Q_{max} = 2.1\, Q_{avg} = 17.8752\ MLD$$

$$\boxed{Q_{max} = 0.207\ m^3/s}$$

Now $v = 0.8\ m/s$

As per manning $\boxed{v = \frac{1}{n} R^{2/3} \sqrt{S_0}}$

Now $Q^{max} = \frac{\pi D^2}{8} \times v$

Half Full

$$0.207 = \frac{\pi \times D^2}{8} \times 0.8$$

Diameter $\boxed{D = 0.812\ m}$

$$v = \frac{1}{n} R^{2/3} \sqrt{S_0}$$

$$0.8 = \frac{1}{0.013} \times \left[\frac{D}{4}\right]^{2/3} \sqrt{S_0}$$

Required slope of sewer

$$S_0 = 1 \text{ in } 1103$$

20

Q.7 (b) (i) A river with saturation DO (at 25°C) 8.4 mg/*l* and self purification ratio, (f) 2.4 receives treated wastewater. Find the permissible BOD in the treated wastewater if rate constant k_1 (at 25°C) is 0.1/day (at base 10). The sewage flow is 80 cumecs and the river flow is 1200 cumecs.

(ii) Write a brief note on 'Tropospheric ozone' and 'Stratospheric ozone'?

[14 + 6 marks]

Soln

$(DO)_{sat} = 8.4 \text{ mg/l}$

$f = 2.4$

$Q_s = 80 \text{ m}^3/\text{s}$ $\quad Q_R = 1200 \text{ m}^3/\text{s}$

Critical deficit $= (DO)_{sat} - (DO)_{min}$

Minm. possible D.O. $= 4 \text{ mg/l}$

$D_{cr} = 8.4 - 4 = 4.4 \text{ mg/L}$

$$\left[\frac{L_o}{D_c f}\right]^{f-1} = f\left[1 - (f-1)\frac{D_o}{L_o}\right]$$

$D_o = ?$ $\quad L_o = ?$ $\quad D_c = 4.4 \text{ mg/L}$ $\quad f = 2.4$

$$(DO)_{mix} = \frac{8.4 \times 1200 + 0 \times 80}{1280}$$

$(DO)_{mix} = 7.875$

$(D_o) = (DO)_{sat} - (DO)_{mix}$

initial deficit $D_o = 0.525 \text{ mg/L}$

$$\left[\frac{L_o}{2.9\times 4.9}\right]^{1.4} = 2.4\left[1 - 1.4\times\frac{0.525}{L_o}\right]$$

$$\left[\frac{L_o}{10.56}\right]^{1.4} = 2.4\left[1 - \frac{0.735}{L_o}\right]$$

$$Y = \frac{L_o^{2.9}}{27.11} - 2.4L_o + 1.764 = 0$$

hit & trial put $L_o = 17$ mg/L

$Y = -5.92$

put $L_o = 20 \Rightarrow Y = 2.57$

put ~~$L_o = 18.5$ mg/L~~ $Y = -2.072$

$L_o = 19$ $Y_o \simeq -0.59 \simeq 0$

Adopt $\boxed{L_o = 19 \text{ mg/L}}$

$BOD = L_o\left[1 - 10^{-0.1\times 5}\right]$

$\boxed{(B.O.D)_{mix} = 13 \text{ mg/L}}$

$$13 = \frac{Q_R \times 0 + 80 \times BOD}{128}$$

$\boxed{\left((B.O.D)_{permissible}\right)_{River} = 208 \text{ mg/L}}$

14

Tropospheric ozone

- an atmospheric pollutant
- a green house gas at ground surface
- Causes respiratory distress and irritation in mucuous membrane

Stratospheric ozone

- not pollutant
- beneficial as it absorbs harmful UV rays from sun
- prevents chances of skin cancer, dermatological disorders

3

Q.7 (c) What do you understand by development of well? Describe the various methods used for development of well.

[20 marks]

Development of well → It is done to increase permeability of soil towards well.

- It is done till to pump sand silt free water out from well
- Primarily to have more discharge from well
- Its reverse of flow through well screen

1

Q.8 (a) Pollutant concentration distribution for a continuous single emission source follows Gaussian distribution given as

$$C_{x,y} = \frac{Q}{\pi u \sigma_z \sigma_y} e^{-\frac{1}{2}\left[\frac{H^2}{\sigma_z^2} + \frac{y^2}{\sigma_y^2}\right]}$$

where C = Concentration of pollutant (in gm/m^3)

Q = Pollutant emission rate (in gm/sec)

u = Mean wind velocity (in m/sec)

x and y = downwind and crosswind horizontal distances (in m)

σ_y and σ_z = Plume's standard deviation

H = Effective height of stack

A coal fired thermal power plant burns 6.25 tonnes of coal per hour and discharges the combustion product through a stack having an effective height of 80 m.

The coal has a sulphur content of 4.7% and the wind velocity is 8 m/sec. Determine the ground level concentration at a distance of 2 km downwind at

(i) the centre line of plume.

(ii) a crosswind distance of 0.5 km on either side of the centre line.

Given at x = 2 km, σ_z = 130, σ_y = 220

[20 marks]

Q.8 (b) Design an oxidation pond for treating sewage from a hot climatic residential colony with 5000 persons, contributing sewage @ 120 litres per capita per day. The 5-day BOD of sewage is 300 mg/*l*.

[20 marks]

Q.8 (c) **(i)** What is Vermi-composting? State various steps involved in Vermi-composting.

(ii) State the merits and demerits of incineration method of solid waste disposal.

[12 + 8 marks]