MADE EASY

India's Best Institute for IES, GATE & PSUs

ESE 2023

Main Exam Detailed Solutions

Civil Engineering

PAPER-II

EXAM DATE : 25-06-2023 | 02:00 PM to 05:00 PM

MADE EASY has taken due care in making solutions. If you find any discrepency/error/typo or want to contest the solution given by us, kindly send your suggested answer(s) with detailed explanation(s) at:
info@madeeasy.in

Corporate Office : 44-A/1, Kalu Sarai, Near Hauz Khas Metro Station, New Delhi-110016

Delhi | Hyderabad | Bhopal | Jaipur | Bhubaneswar | Pune | Kolkata

9021300500 www.madeeasy.in

ANALYSIS

Civil Engineering Paper-II
ESE 2023 Main Examination

Sl.	Subjects	Marks
1.	Fluid Mechanics & Hydraulic Machines	44
2.	Engineering Hydrology	32
3.	Water Resource Engineering	20
4.	Environmental Engineering	144
5.	Soil Mechanics & Foundation Engg.	124
6.	Surveying and Geology	52
7.	Transportation Engineering	64
		Total 480

Scroll down for detailed solutions

SECTION : A

Q.1 (a) The annual rainfall of six different raingauge stations of a river basin is 136.70 cm, 102.90 cm, 98.80 cm, 180.30 cm, 82.60 cm and 110.30 cm.
Determine:
(i) The standard error in the estimation of average rainfall of the six raingauge stations.
(ii) The optimum number of raingauge stations in the river basin for a 10% error in the estimation of average rainfall.

[12 marks : 2023]

Solution:

Let, Mean rainfall is represented by $\bar{P}$.

Then, $$\bar{P} = \frac{\Sigma P}{n} \quad \text{where } n \text{ is number of raingauges.}$$

$$= \frac{136.70 + 102.90 + 98.80 + 180.30 + 82.60 + 110.30}{6}$$

$$\Rightarrow \quad \bar{P} = 118.6 \text{ cm}$$

$$\Sigma P^2 = (136.70)^2 + (102.90)^2 + (98.80)^2 + (180.30)^2 + (8260)^2 + (110.30)^2$$

$$= 90533.68 \text{ cm}^2$$

$$\bar{P}^2 = \frac{\Sigma P^2}{n} = \frac{90533.68}{6} = 15088.946 \text{ cm}^2$$

Standard deviation σ is given as

$$\sigma = \sqrt{\frac{n}{n-1} \times \left[\overline{P^2} - (\bar{P})^2\right]}$$

$$\sigma = \sqrt{\frac{6}{(6-1)}\left[15088.946 - (118.6)^2\right]}$$

$$\sigma = 35.037 \text{ cm}$$

Now, the coefficient of variation c_v is given as

$$C_v = \frac{\sigma}{\bar{P}} \times 100$$

$$C_v = \frac{35.037}{118.6} \times 100$$

$$C_v = 29.542\%$$

(i) The standard error in the estimation of average rainfall of the six raingauge stations is given as

$$N = \left(\frac{C_v}{\varepsilon}\right)^2 \quad \text{where } \varepsilon \text{ is the standard error.}$$

$$\varepsilon = \frac{C_v}{\sqrt{N}}$$

$$\varepsilon = \frac{29.542}{\sqrt{6}}$$

$$\varepsilon = 12.06\%$$

Hence, the standard error is 12.06% in the estimation of average rainfall of the six raingauge stations.

(ii) The optimum number of raingauge stations in the river basin for a 10% error in the estimation of average rainfall is given as

$$N = \left(\frac{C_v}{\varepsilon}\right)^2$$

Coefficient of variation, $C_v = 29.542$ [Calcualted above]

Now, $$N = \left(\frac{29.542}{10}\right)^2$$

$$N = 8.72$$

So, total 9 stations will be required to have 10% error in estimation of average rainfall.

End of Solution

Q.1 (b) A 1.3 m wide rectangular channel had 0.35 m depth of water at a certain section of the channel. The flow discharge through the channel is 20 cumecs. Determine whether the hydraulic jump will take place or not. Find the height of jump and loss of energy.

[12 marks : 2023]

Solution:

Given:

Width, $B = 1.3$ m

Depth, $y_1 = 0.35$ m

Discharge, $Q = 2\ m^3/s$

Discharge per unit width, $q = \frac{Q}{B} = \frac{2}{1.3} = 1.538\ m^3/sm$

$q = 1.538\ m^3/s/m$

Now, Froude number, $$Fr_1 = \frac{V}{\sqrt{gy_1}}$$ Where V is velocity in channel.

$$\Rightarrow \quad Fr_1 = \frac{Q}{A\sqrt{gy_1}}$$

$$\Rightarrow \quad Fr_1^2 = \frac{q^2}{gy_1^3} \qquad [\because A = B \cdot y]$$

$$Fr_1^2 = \frac{(1.538)^2}{9.81 \times (0.35)^3} = 5.624$$

$$Fr_1 = 2.37$$

i.e. $Fr_1 > 1$. Hence, flow is supercritical.

Now the sequent depth ratio is given as

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

$$\frac{y_2}{0.35} = \frac{1}{2}\left[-1+\sqrt{1+8\times 5.624}\right]$$

$$y_2 = 1.012 \text{ m}$$

$\therefore$ Sequent depth, $y_2 = 1.012$ m

Now,

$$\text{Froude number (Post jump), } Fr_2^2 = \frac{q^2}{gy_2^3} = \frac{(1.538)^2}{9.81\times(1.012)^3} = 0.233$$

$$Fr_2 = 0.48$$

i.e. $Fr_2 < 1$ hence flow is subcritical.

Thus flow is taking place from supercritical to subcritical hence hydraulic jump will takes place.

$$\text{Height of jump} = y_2 - y_1$$

$$= 1.012 - 0.35 = 0.662 \text{ m}$$

Now, loss of energy, E_L is given as:

$$E_L = \frac{(y_2-y_1)^3}{4y_1 \cdot y_2} = \frac{(1.012-0.35)^3}{4\times(1.012)(0.35)}$$

$$E_L = 0.205 \text{ m}$$

End of Solution

Q.1 (c) Find out the power required to drive the centrifugal pump if it lifts water to a height of 22 m. The overall efficiency of the pump is 70%. The pipe diameter is 10 cm and length is 100 m. It delivers 1500 *l*/min as discharge with the coefficient of friction of pipe as 0.004 and γ as ρg (1000 × 9.81).

[12 marks : 2023]

Solution:

Given: Static head, $H_{stat} = 22$ m

Overall efficiency, $\eta_0 = 0.70$

Diameter of pipe, $D = 0.1$ m

Length of pipe, $L_s + L_d = L = 100$ m

Discharge, $Q = 1500$ L/min

$$= \frac{1.5}{60} \text{ m}^3/\text{s}$$

Friction factor, $f' = 0.004$ $(f = 4f' = 0.016)$

$\because$ Velocity, $V_d = \dfrac{Q}{A}$

$$= \frac{\frac{1.5}{60}}{\frac{\pi}{4}(0.1)^2} = 3.1831 \text{ m/s}$$

$\therefore$ $$\frac{V_d^2}{2g} = 0.5164 \text{ m}$$

Since, $$h_{fs} + h_{fd} = h_f$$

$$= \frac{8Q^2}{\pi^2 g} \cdot \frac{f.L}{D^5}$$

$$= \frac{8\left(\frac{1.5}{60}\right)^2}{\pi^2 g} \frac{(0.016)(100)}{(0.1)^5}$$

$\therefore$ $$h_{fs} + h_{fd} = 8.2627 \text{ m}$$

Now, $$H_{mano} = H_{stat} + h_{fs} + h_{fd} + \frac{V_d^2}{2g}$$

$$= 22 + 8.2627 + 0.5164$$

$$= 30.7791 \text{ m}$$

$\therefore$ Overall efficiency, $$\eta_0 = \frac{H_{mano}}{S.P/\dot{m}g}$$

$\Rightarrow$ $$0.7 = \frac{(10)^3\left(\frac{1.5}{60}\right)(9.81)(30.7791)}{S.P}$$

$\therefore$ $$S.P. = 10.7837 \text{ kW}$$

Hence, power required to drive the pump = 10.7837 kW

End of Solution

Q.1 (d) A PST 15 m long, 6 m wide and 3 m deep treats water for a town with a population of 20,000 supplied with 100 lpcd. The raw water sample indicated suspended solids conc. as 60 ppm. The PST worked with efficiency of 70% SS removal and the average specific gravity of the deposit in PST was 2.6. Compute

(i) Detention Time
(ii) Horizontal Velocity
(iii) Rate of dry solids deposited
(iv) Overflow rate

[12 marks : 2023]

Solution:

Given:

Length of tank, L = 15 m
Width of tank, B = 6 m
Height of tank, H = 3 m
Population of city, P = 20000

Per capita demand, q = 100 lpcd

Suspended solid concentration, SS_0 = 60 mg/L

Efficiency of removal of suspended solid, η = 70%

Specific gravity of deposit, G = 2.6

Now, Average discharge, $Q_{avg} = 20000 \times 100$

$= 2 \times 10^6$ Litre/day

Maximum daily discharge, $Q = 1.8 \times 2 \times 10^6$ Litre/day

$= 3.6 \times 10^6$ Litre/day

So, now, Volume of tank, V = LBH

$= 15 \times 6 \times 3 = 270\ m^3$

(i) So, Detention time, $t_d = \dfrac{\text{Volume of tank}}{\text{Maximum discharge}}$

$$= \frac{270 m^3}{3600 m^3/day}$$

= 0.075 day

= 1.8 hours

(ii) Horizontal velocity, $v_f = \dfrac{Q}{BH}$

$$= \frac{3600 m^3/day}{(6 \times 3) m^2} = 200 \text{ m/day}$$

$= 2.32 \times 10^{-3}$ m/s

= 2.32 mm/sec

(iii) Suspended solids coming in tank = QSS_0

$= 3600\ m^3/day \times 60$ mg/L

= 216 kg/day

Deposits in tank = $QSS_0\eta_0$

$= 216 \times 0.7 = 151.2$ kg/day

(iv) Overflow rate, $V_0 = \dfrac{Q}{BL}$

$$= \frac{3600 m^3/day}{(15 \times 6) m^2}$$

$= 40\ m^3/day/m^2$

End of Solution

Q.1 (e) Discuss the impact of heavy metals in industrial wastewater when disposed into surface water.

With the help of sketches, explain the working principle of the two methods used for removal of heavy metal from industrial wastewater.

[12 marks : 2023]

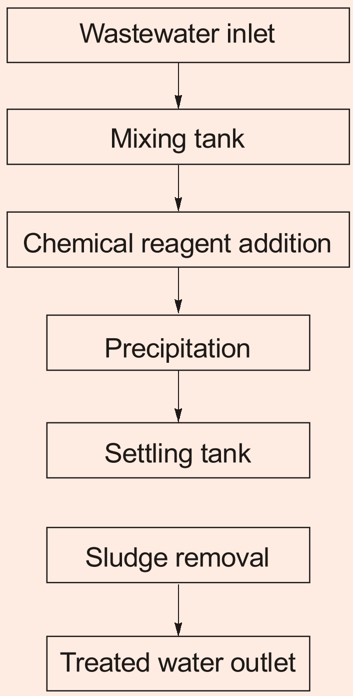
Solution:

The disposal of industrial waste water containing heavy metals into surface water can have significant environmental and human health impacts. Heavy metals, such as, lead, mercury, cadmium, chromium and arsenic are toxic substances that can persist in the environment and accumulate in living organisms, leading to variety of adverse effects.

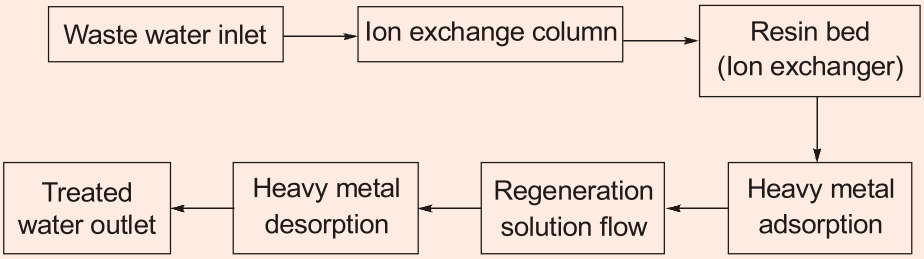
1. Environmental impact:
   - **Water pollution**: Heavy metals can contaminate surface water bodies, leading to water pollution. This contamination can disrupt aquatic ecosystem by affecting the health and survival of aquatic organisms, including fish, amphibians etc.
   - **Bioaccumulation and Biomagnification**: Heavy metals tend to accumulate in the tissues of organisms and can magnify up the food chain through a process called biomagnification. Predatory species at the top of the food chain, including human, can be exposed to high levels of heavy metals through consumption of contaminated organisms.
   - **Eutrophication**: Some heavy metals can contribute to eutrophication, a process in which excess nutrients in water bodies promote the growth of algae. This can lead to oxygen depletion and negatively impact other aquatic organisms.
2. Human Health Impact:
   - **Water Contamination**: Heavy metals in surface water can contaminate drinking water sources, posing a risk to human health. Ingesting or coming into contact with water containing high levels of heavy metals can lead to various health issues including neurological disorder, kidney damage, liver damage etc.
   - **Occupational exposure**: Industrial worker involved in the handling and disposal of wastewater can face direct exposure to heavy metals, increasing the risk of occupational health hazards.

The methods used for the removal of heavy metals from industrial wastewater are: precipitation and ion exchange.

1. **Precipitation method**:
   This method involves the addition of chemical reagent to the wastewater that forms an insoluble precipitate with the heavy metal ions, allowing them to settle and be separated from the water.
   - The industrial water enters the mixing tank through the inlet.
   - A chemical reagent such as lime on sodium hydroxide is added to the wastewater. The reagent reacts with the heavy metal ions, forming insoluble metal hydroxide precipitates.
   - The mixture then flows into a settling tank where the precipitates settle at the bottom due to their increased weight and decreased solubility.
   - The settled precipitates form a sludge which is periodically removed from the bottom of the tank.
   - The treated water, with reduced heavy metal concentrations, is collected and discharged through the treated water outlet.



2. Ion exchange method:
This method involves the use of specially designed resin material that can selectively absorb heavy metal ions from the waste water, replacing them with less harmful ions.



- The industrial wastewater enters the ion exchange column through the inlet.
- Inside the column there is a resin bed having functional groups that attract and bind heavy metal ions.
- As the wastewater flows through the resin bed, heavy metal ions in the water are adsorbed by the resin replacing other less harmful ions.
- After certain period, the resin becomes saturated with heavy metals ion and need regeneration. A regeneration solution such as acid or salt solutionis introduced to the column to desorb the heavy metal ions from the resin.
- The desorbed heavy metal ions, along with the regeneration solution, are collected separately for further treatment or disposal.
- The treated water, with reduced heavy metal concentrations, passes through the resin bed and is collected at the treated water outlet.

End of Solution

Q.2 (a) (i) Define the "dilution method" of flow measurement by sudden injection and constant injection of chemicals in flowing water with diagram and governing equations.

(ii) A Rhodamine dye solution was discharged in a river section at a constant rate. Estimate the discharge if the dye is found to reach an equilibrium of 5 parts per billion (ppb).

Given : Amount of Rhodamine Dye = 25 g/l

Constant rate of flow : 10 cm^3/s

Assume $C_0 = 0$

[10 marks : 2023]

Solution:

(a) (i)

Dilution method: The dilution method of flow measurement, also known as the chemical method depends upon the continuity principle applied to a tracer which is allowed to mix completely with the flow.

Sudden injection method: Consider a tracer in amount of C_1 and introduce it in upstream of river at section 1. Take an another section (2) at downstream which is far away from section (1) such that the complete mixing of tracer takes place. If the stream

also contain some amount of tracer material of concentration C_0 and at section (2) the tracer concentration is C_2, then

$$m_1 = \text{mass of tracer added at section (1)} = V_1C_1$$

Also,
$$m_1 = \text{mass of tracer in river discharge} + \text{mass of tracer in volume 1}$$

$$m_1 = \int_{t_1}^{t_2} Q(C_2 - C_0)dt + \int_{t_1}^{t_2} \frac{V_1(C_2 - C_0)dt}{t_2 - t_1}$$

2nd term on right hand side of above equation is very small, so neglecting it we get

$$V_1C_1 = \int_{t_1}^{t_2} Q(C_2 - C_0)dt$$

$$Q = \frac{V_1C_1}{\int_{t_1}^{t_2} Q(C_2 - C_0)dt}$$

where,
V_1 = volume of tracer
m_1 = discharge of river

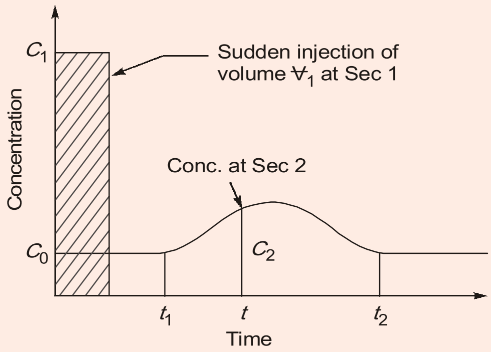


Fig. Injection Method

Constant injection Method : Another way of using the dilution method is to inject the tracer of concentration C_1 injected at section 1 with a constant rate Q_1. If concentration at section 2 is gradually increased from C_0 to C_2, then, by continuity equation for tracer at steady state, we get

$$Q_1C_1 + QC_0 = (Q_1 + Q)C_2$$

$$Q = \frac{Q_1(C_1 - C_2)}{(C_2 - C_0)}$$

This method is known as constant rate injection method or plateau gauging.

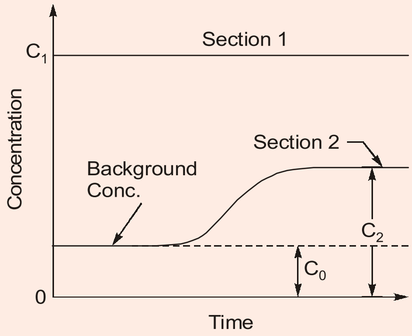


Fig. Constant Rate Injection Method

(ii)

Using constant rate injection method

$$Q = \frac{Q_1(C_1 - C_2)}{C_2 - C_0}$$

$$C_0 = 0 \quad [\because \text{Given}]$$
$$Q_1 = 10 \text{ cm}^3/\text{s} = 10 \times 10^{-6} \text{ m}^3/\text{s}$$
$$C_1 = 25 \text{ g}/l = 25000 \text{ mg}/l = 25000 \text{ ppm}$$
$$C_2 = 5 \text{ ppb} = 5 \times 10^{-3} \text{ ppm}$$

Putting values, we get

$$Q = \frac{10\times10^{-6}\times(25000 - 5\times10^{-3})}{5\times10^{-3} - 0} = 49.99 \text{ m}^3/\text{s} \simeq 50 \text{ m}^3/\text{s}$$

End of Solution

Q.2 (b) A city with population of 5 lakhs is to be supplied water @ 150 lpcd. Using the data given below, determine the storage capacity of the reservoir assuming

(i) Continuous pumping

(ii) Pumping for 9 hours from 6 PM - 3 AM

Also assume fire demand @ 2 lpcd and power breakdown for 2 hours.

0 - 3 AM	:	5% of total
3 - 6 AM	:	5% of total
6 - 9 AM	:	40% of total
9 - 12 PM	:	10% of total
12 - 3 PM	:	5% of total
3 - 6 PM	:	10% of total
6 - 9 PM	:	20% of total
9 - 12 AM	:	5% of total

[20 marks : 2023]

Solution:

Population of city, P = 500000

Per capita supply, q = 150 lpcd

So, total water supplied per day = 75×10^6 litre/day = 75 MLD

(i) When pumping is continuous

$$\text{Water supplied per hour} = \frac{75 \times 10^6 \text{ litre}}{24 \text{hours}} = 3.125 \text{ ML/hour}$$

Water supplied in 3 hours = 3.125 ML/hour × 3 hour
= 9.375 million litres

Now, calculations are done below in table:

Time	Demand (Million litres)	Cumulative demand (Million litres)	Supply (Million litres)	Cumulative supply (Million litres)	Excess demand (Million litres)	Excess Supply (Million litres)
0–3 A.M.	0.05 × 75 = 3.75	3.75	9.375	9.375	Nil	5.625
3–6 A.M.	0.05 × 75 = 3.75	7.5	9.375	18.75	Nil	11.25
6–9 A.M.	0.4 × 75 = 30	37.5	9.375	28.125	9.375	Nil
9–12 A.M.	0.1 × 75 = 7.5	45	9.375	37.5	7.5	Nil
12–3 P.M.	0.05 × 75 = 3.75	48.75	9.375	46.875	1.875	Nil
3–6 P.M.	0.1 × 75 = 7.5	56.25	9.375	56.25	0	0
6–9 P.M.	0.2 × 75 = 15	71.25	9.375	65.625	5.625	Nil
9–12 A.M.	0.05 × 75 = 3.75	75	9.375	75	0	0

From the table, maximum value of excess demand = 9.375 ML

Maximum value of excess supply = 11.25 ML

So, Balancing storage required = 9.375 ML + 11.25 ML
= 20.625 Million litres

Now, fire demand = 2 lpcd × 500000 persons
= 1 million litres per day

$$\text{Breakdown demand} = \frac{75 MLD}{24 \text{hours}} \times 2 \text{hours}$$

= 6.25 million litre per day

Therefore, storage capacity of reservoir.
= (20.625 + 1 + 6.25)ML
= 27.875 Million litres

(ii) When pumping is done for 9 hours

$$\text{Water supplied per hour} = \frac{75 \times 10^6 \text{ litre}}{9 \text{ hours}}$$

$$= \frac{75}{9} \text{Million litre/hour}$$

$$\text{Water supplied in 3 hours} = \frac{75}{9} \frac{ML}{\text{hour}} \times 3 \text{hour}$$

= 25 million litres

Now, calculations are done in table below:

Time	Demand (Million litres)	Cumulative demand (Million litres)	Supply (Million litres)	Cumulative supply (Million litres)	Excess demand (Million litres)	Excess Supply (Million litres)
0−3A.M.	$0.05 \times 75 = 3.75$	3.75	25	25	Nil	21.25
3−6A.M.	$0.05 \times 75 = 3.75$	7.5	0	25	Nil	17.5
6−9A.M.	$0.4 \times 75 = 30$	37.5	0	25	12.5	Nil
9−12A.M.	$0.1 \times 75 = 7.5$	45	0	25	20	Nil
12−3P.M.	$0.05 \times 75 = 3.75$	48.75	0	25	23.75	Nil
3−6P.M.	$0.1 \times 75 = 7.5$	56.25	0	25	31.25	Nil
6−9P.M.	$0.2 \times 75 = 15$	71.25	25	50	21.25	Nil
9−12A.M.	$0.05 \times 75 = 3.75$	75	25	75	0	0

From the table,

Maximum value of excess demand = 31.25 ML

Maximum value of excess supply = 21.25 ML

So, Balancing storage = (31.25 + 21.25) ML = 52.5 ML

Fire demand = 1 million litre per day

Breakdown demand = 6.25 Million litre per day

So, storage capacity of reservoir = 52.5 + 1 + 6.25 = 59.75 million litres

End of Solution

Q.2 (c) Differentiate between Symbiosis and Parasitism relationship. Explaining the working principles of oxidation ponds, discuss the importance of Algal-Bacteria symbiosis relationship in oxidation ponds.

[20 marks : 2023]

Solution:

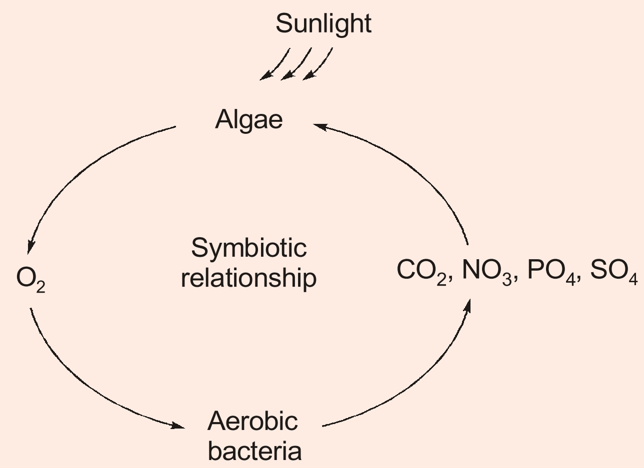
The comparison between symbiosis and parasitism relationships are tabulated below:

Parameter	Symbiosis	Parasitism
Definition	• A close and long term interaction between two species, where at least one species benefits.	• In this type of relationship, one species (parasite) benefits at the expense of another species (host).
Interaction	• Mutualistic, commensalistic or parasitic.	• Predatory or parasitic.
Benefit to host	• Both species can benefit or one species benefits while the other is unaffected.	• The host is harmed or negatively affected.
Dependency	• Both species are dependent on each other for survival or reproduction.	• The parasite is dependent on the host for resources or reproduction. The host is not dependent on the parasite.
Examples	• Lichen (algae and fungi), coral reefs (corals and zooxanthellae), legume plants and nitrogen fixing bacteria.	• Fleas on dogs, ticks on deer, tapeworms in human.
Control	• The interaction is usually well balanced and regulated to prevent over-exploitation or harm to either species.	• The parasite may exert control over the host, often causing harm or disease. The host may evolve defences to minimise the impact of the parasite.

Oxidation ponds, also known as stabilization ponds or waste stabilization ponds are shallow, man-made bodies of water used for wastewater treatment. They rely on the interaction between algae and bacteria to remove pollutants and purify the water.

The key roles of the algae-bacterial symbiosis relationship in oxidation ponds are:

1. **Oxygenation**: Algae photosynthesize and release oxygen, creating an oxygen rich environment that supports the growth of aerobic bacteria. This oxygenation is crucial for the activity of aerobic bacteria, which are responsible for the breakdown of organic matter and the removal of pollutants.
2. **Nutrient cycling**: Algae and bacteria work together to cycle and remove nutrients from the wastewater. Algae take up nitrogen and phosphorus during their growth, reducing their concentration in the water. Bacteria then decompose the organic matter provided by the algae, releasing nutrients that can be reused by the algae. This symbiotic relationship helps to maintain a balanced nutrient cycle and prevent excessive nutrient buildup in the water.
3. **Pollutant removal**: The combined activity of algae and bacteria leads to the degradation and removal of organic compounds, including pollutants and pathogens from the wastewater. Algae provide a source of organic matter for bacterial decomposition, while bacteria break down complex organic molecules into simpler, less harmful forms.
4. **Algae-Bacteria floc formation**: Algae and bacteria contribute to the formation of floc or clumps of organic matter in the oxidation pond. These flocs settle to bottom, facilitating the removal of suspended solids and some pollutants through sedimentation. The floc formation is a result of the mutual interactions between algae and bacteria, enhancing the efficiency of solid removal in the poind.



End of Solution

Q.3 (a) Referring to figure 1, calculate the discharge from the well in steady state condition. The well completely penetrates the confined aquifer.

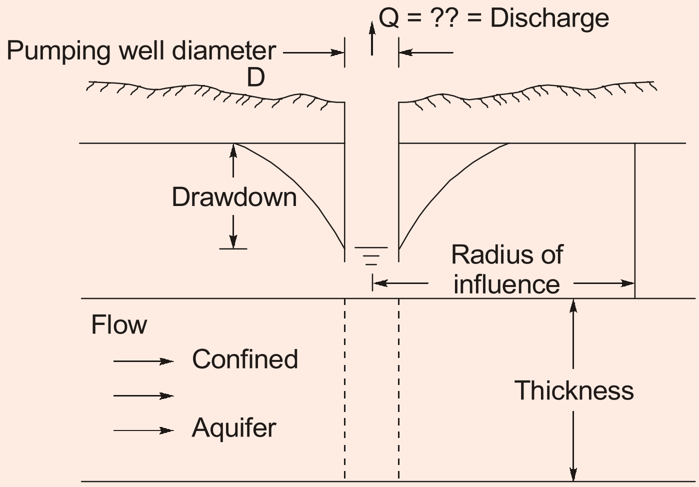


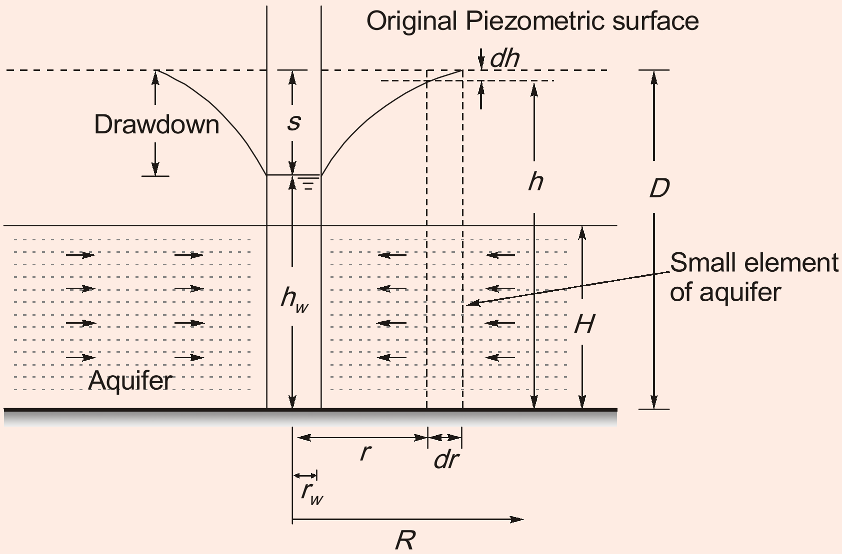
Figure 1

Given:

Diameter of pumping well = 30 cm
Permeability = 45 m/day
Length of the strainer = 20 m
Drawdown = 3.0 m
Radius of influence = 300 m
Discharge = ??

[20 marks : 2023]

Solution:



For small element of aquifer, $Q = kiA$

$$Q = k\frac{dh}{dr}\cdot 2\pi r\cdot H$$

$$\Rightarrow \quad \frac{dr}{r} = \frac{2\pi kH}{Q}dh$$

Integrating between r_w and R, we get

$$\Rightarrow \quad \int_{r_w}^{R}\frac{dr}{r} = \int_{h_w}^{D}\frac{2\pi kH}{Q}dh$$

$$\Rightarrow \quad [\ln r]_{r_w}^{R} = \frac{2\pi kH}{Q}[h]_{h_w}^{D}$$

$$\Rightarrow \quad \ln\left[\frac{R}{l_w}\right] = \frac{2\pi kH}{Q}[D - h_w]$$

$$\therefore \quad Q = \frac{2\pi kHs}{\ln\left[\frac{R}{r_w}\right]} \qquad [D - h_w = \text{drawdown} = s]$$

Now, $r_w = \frac{d_w}{2} = \frac{30}{2} = 15\,\text{cm} = 0.15\,\text{m}$

$k = 45$ m/d $= 5.208 \times 10^{-4}$ m/s

$s = 3$ m

$H = 20$ m

$R = 300$ m

$$\therefore \quad Q = \frac{2\times\pi\times 5.208\times 10^{-4}\times 20\times 3}{\ln\left[\frac{300}{0.15}\right]} = 0.0258 \text{ m}^3\text{/s}$$

So, Discharge from well = 25.8 litre/sec.

End of Solution

Q.3 (b) Find the discharge of water through the pipe, the velocity of venturimeter throat and the pressure 600 cm above the venturimeter using Bernoulli's theorem.

Given:

Diameter of vertical pipe = 15 cm

Venturiimeter throat = 7 cm

Absolute pressure at throat = 1 atm

Pressure at 600 cm below the venturimeter = 5 atm.

[20 marks : 2023]

Solution:

Dia. at venturimeter inlet, $D_1 = 0.15$ m

Dia. at venturimeter throat, $D_2 = 0.07$ m

Pressure at ventrumeter throat, $P_2 = 1$ atm $= 101325$ Pa

Pressure at ventrumeter inlet, $P_1 = (5 \times 101325) - (10^3 \times 9.81 \times 6)$

$= 447765$ Pa

Apply energy equation between section (1) and section (2)

$$\frac{P_1}{\rho g}+\frac{v_1^2}{2g}+z_1 = \frac{P_2}{\rho g}+\frac{v_2^2}{2g}+z_2$$

$$\Rightarrow \quad \left(\frac{P_1}{\rho g}+z_1\right)-\left(\frac{P_2}{\rho g}+z_2\right) = \frac{v_2^2-v_1^2}{2g} \qquad \text{(Apply continuity: } Q = A_1v_1 = A_2v_2)$$

$$\Rightarrow \quad \frac{P_1-P_2}{\rho g}+z_1-z_2 = \frac{1}{2g}\left(\frac{Q^2}{A_2^2}-\frac{Q^2}{A_1^2}\right)$$

(Since $z_1 - z_2$ is not given, So, $z_1 - z_2 = 0$ is considered)

$$\Rightarrow \quad \frac{447765-101325}{(10^3)(9.81)} = \frac{1}{2(9.81)}\frac{Q^2}{A_1^2}\left[\left(\frac{A_1}{A_2}\right)^2-1\right]$$

$$\Rightarrow \quad 692.88\times\left[\frac{\pi}{4}(0.15)^2\right]^2 = Q^2\left[\left(\frac{0.15}{0.07}\right)^4-1\right]$$

$$\therefore \quad Q = 0.103792 \text{ m}^3/\text{s}$$

Now, Velocity at throat, $V_2 = \dfrac{Q}{A_2}$

$$= \frac{0.103792}{\frac{\pi}{4}(0.07)^2}$$

$$\therefore \quad V_2 = 26.97 \text{ m/s}$$

Also, Pressure at 600 cm or 6 m above venturimeter $= P_1 - (10^3 \times 9.81 \times 6)$

$$= 447765 - (10^3 \times 9.81 \times 6)$$

$$= 388905 \text{ Pa}$$

End of Solution

Q.3 (c) With the help of sketches, explain the effect of lapse rate on plume behaviour indicating the possible plume shapes and dispersion conditions.

[20 marks : 2023]

Solution:

Lapse Rate: With the increase in altitude, temperature of normal atmosphere decreases above the earth surface (in troposphere). Thus, the lapse rate is the rate at which temperature changes with height in the atmosphere. This rate will differ from place to place, and from time to time even at the same place.

Types of lapse rate:

(i) Environmental lapse rate: The ELR can be determined by sending up a balloon equipped with a thermometer. The balloon moves through the air, not with it, and the temperature gradient of ambient air, which the rising balloon measures is called the ambient lapse rate, the environmental lapse rate or the prevailing lapse rate.

(ii) Adiabatic lapse rate (ALR): When a parcel of air, which is hotter and lighter than the naturally it tends to rise up, until of course, it reaches to a level at which its own temperature and density becomes equal to that of the surrounding using the law of conservation of energy and gas law.

The three major relative position of ELR line with reference to ALR line are discussed below:

(a) **Super adiabatic lapse rate**: When the ELR is more than the ALR then ambient lapse rate is super adiabatic and the environment is said to unstable.

(b) **Sub-adiabatic lapse rate**: When ELR is less than the ALR then environment set to be stable and this prevailing environmental lapse rate is called the sub-adiabatic lapse rate.

(c) **Neutral**: When ELR equals the ALR and both the lines coincide the environment in such a case is called neutral.

Plume behaviour:

1. **Looping Plume**: Looping plume has wavy character and occurs in super adiabatic environments which produces highly unstable atmosphere, because of rapid mixing.

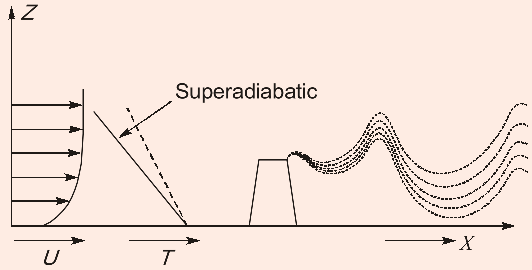


Fig. Looping Plume

2. **Neutral Plume**: Neutral plume is the upward vertical rise of the plume from the stack, which occurs when the ELR is equal to ALR.

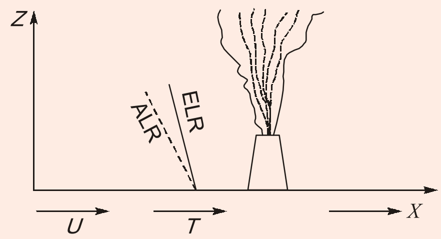


Fig. Neutral Plume

3. **Coning Plume**:
   - Conning plume occurs under sub-adiabatic conditions.
   - The plume dispension is known as coning because the plume makes a cone like shape about the plume line.

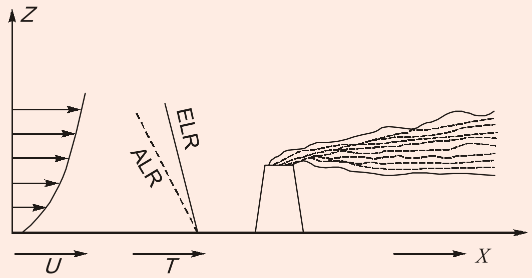


Fig. Conning plume

4. **Fanning plume**: There will be no vertical mixing and the plume will extend horizontally over large distances.

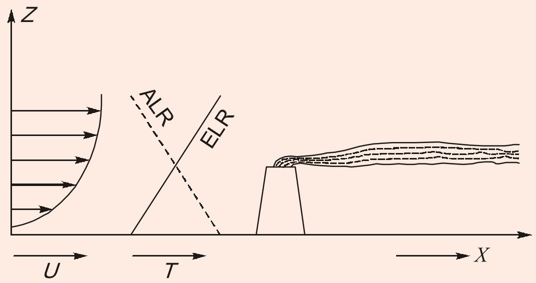


Fig. Fanning plume

5. **Lofting plume**: Where there exists a strong super adiabatic lapse rate above a surface inversion, then the plume is said to be lofting.

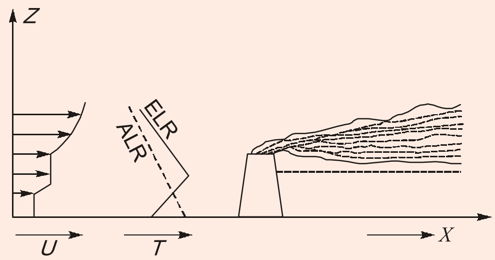


Fig. Lofting plume

6. **Fumigation plume**: When an inversion layer occurs at a short distance above the top of the stack and super adiabatic conditions prevail below the stack, then the plume is said to be fumigation.

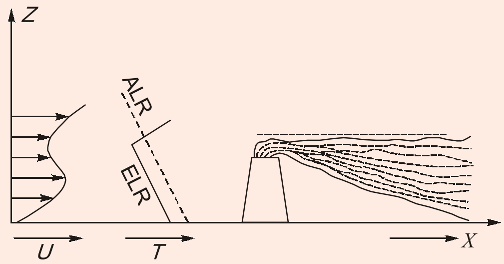


Fig. Fumigating plume

7. **Trapping plume**: When inversion layer occurs above the emission source, as well as below the source, then naturally, the emitted plume will neither go up nor will it go down and would remain confined between the two inversion.

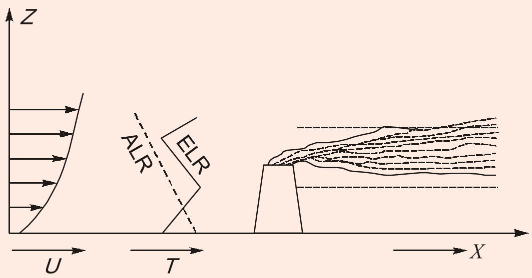


Fig. Trapping plume

End of Solution

Q.4 (a) Calculate (i) total installed capacity of turbo generators, (ii) load factor, (iii) plant factor, and (iv) utilization factor of three generators of a hydel power station, each having a capacity of 10000 kW. The load of the plant varies from 12000 kW to 26000 kW.

[20 marks : 2023]

Solution:

(i) Total installed capacity = Number of generators × capacity of each generator

$$= 3 \times 10000 \text{ kW}$$

$$= 30000 \text{ kW}$$

(ii)
$$\text{Load factor} = \frac{\text{Average load over a Certain period}}{\text{Peak load during that period}}$$

$$= \frac{\frac{(12000+26000)\text{kW}}{2}}{26000\text{kW}} = \frac{19}{26} = 0.73$$

(iii)
$$\text{Plant factor} = \frac{\text{Energy actually produced in time 't'}}{\text{Max.energy that can be produce in time 't'}}$$

$$= \frac{\left(\frac{12000+26000}{2}\right)\times t}{30000\times t} = \frac{19}{30} = 0.63$$

(iv)
$$\text{Utilization factor} = \frac{\text{Maximum power utilised}}{\text{Maximum power available}}$$

$$= \frac{26000}{30000} = 0.87$$

End of Solution

Q.4 (b) The MLSS concentration in an aeration tank of ASP system was 3000 mg/L. Sludge volume was 180 mL after 30 minutes of settling in 1000 mL graduated measuring jar. For the above sample, find

(i) SVI
(ii) SDI
(iii) Return sludge ratio required
(iv) SS conc. in recirculated sludge

[20 marks : 2023]

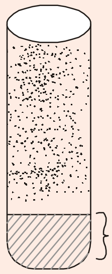
Solution:

Given, MLSS, x = 3000 mg/l

Sludge volume, v = 180 mL (Settled after 30 minutes)

(i) SVI

In 1 litre jar, 3000 mg of suspended solid has occupied 180 mL in SVI jar.



SVI Jar (1 lt)

$$\Rightarrow \quad SVI = \frac{v\,(\text{mL})}{x\,(g)} = \frac{180\,\text{mL}}{3000\,\text{mg}}$$

$$= \frac{180\text{mL}}{3\text{g}} = 60 \text{ mL/g}$$

(ii) Sludge density index $= \frac{100}{SVI} = \frac{100}{60} = 1.67\,\text{g/mL}$

(iii) Return sludge ratio, $R = \frac{Q_R}{Q_0} = \frac{x}{x_u - x}$

where, $x_u = \frac{10^6}{SVI} = \frac{10^6}{60} = 16.67 \times 10^3\,\text{mg}/l$

$\therefore \quad R = \frac{3000}{(16.67-3)\times 10^3} = 0.219$

(iv) S.S concentration in recirculated sludge,

$$x_u = \frac{10^6}{SVI} = \frac{10^6}{60} = 1.67 \times 10^4 \text{ mg/l}$$

End of Solution

Q.4 (c) **Using the data given below, find the moisture content (Wet and dry basis) of the municipal solid waste. Also estimate the as-discarded density. If the compaction is 3, find the size of collection vehicle required for 1000 kg of MSW.**

S.No.	Waste component	Mass(%)	MC(%)	Density (kg/m^3)
1.	Newspaper	15	6	85
2.	Other paper	24	6	85
3.	Cardboard	33	5	50
4.	Glass	4.2	0.5	195
5.	Plastic	0.49	2	65
6.	Aluminium	0.13	0.5	160
7.	Iron	1.18	0.5	320
8.	Non-ferrous	0.35	0.5	160
9.	Yard wastes	17.97	60	105
10.	Food wastes	1.67	60	290
11.	Soil and dust	2.01	8	480

[20 marks : 2023]

Solution:

Moisture content of a solid waste is expressed in two ways:

1. Wet mass method

   In this method, moisture in a sample is expressed as a percentage of wet mass of material.

   So, $\text{moisture content}(\%) = \left(\frac{a-b}{a}\right)\times 100$

   where, a = Initial mass of sample

   b = Mass of sample after drying

2. Dry mass method

   In this method, moisture in a sample is expressed as a percentage of dry mass of material.

   So, $\text{moisture content}(\%) = \left(\frac{a-b}{a}\right)\times 100$

   where, a = Initial mass of sample

   b = Mass of sample after drying

   Now, for the given solid waste sample, calculations are done below in table. Let the mass of given sample is 100 kg.

S.No.	Waste component	Mass(kg)	MC(kg)	Dry mass (kg)	Density (kg/m^3)	Volume(m^3)
1.	Newspaper	15	0.06×15=0.9	14.1	85	0.1765
2.	Other paper	24	0.06×24 = 1.44	22.56	85	0.2824
3.	Cardboard	33	0.05 ×33 = 1.65	31.35	50	0.66
4.	Glass	4.2	0.005 ×4.2 = 0.021	4.179	195	0.0215
5.	Plastic	0.49	0.02 ×0.49 = 0.0098	0.4802	65	0.0075
6.	Aluminium	0.13	0.005 ×0.13 = 0.00065	0.1293	160	0.00081
7.	Iron	1.18	0.005×1.18 = 0.0059	1.1741	320	0.00368
8.	Non-ferrous	0.35	0.005 ×0.35 = 0.00175	0.34825	160	0.00218
9.	Yard wastes	17.97	0.6×17.97 = 10.782	7.188	105	0.1711
10.	Food wastes	1.67	0.6×1.67=1.002	0.668	290	0.00576
11.	Soil and dust	2.01	0.08×2.01 =0.1608	1.8492	480	0.00419
				84.02605		1.3356

NOTE: In table, dry mass is calculated by subtracting moisture from given mass of individual component and volume is calculated by dividing the given mass of component by its density.

So, a = 100 kg

b = 84.02605 kg

So, moisture content (on wet basis) $= \left(\frac{a-b}{a}\right)\times 100$

$$= \left(\frac{100-84.02605}{100}\right)\times 100 \simeq 15.97\%$$

$$\text{Moisture content (on dry basis)} = \left(\frac{a-b}{b}\right)\times 100$$

$$= \left(\frac{100-84.02605}{84.02605}\right)\times 100 = 19.01\%$$

(ii) As-discarded density

Now, volume of 100 kg sample = 1.3356 m^3

So, $$\text{Density} = \frac{\text{Mass}}{\text{Volume}} = \frac{100\,\text{kg}}{1.3356\,\text{m}^3} = 74.87\ \text{kg/m}^3$$

(iii) Size of collection vehicle,

$$\text{Compaction ratio} = \frac{\text{Density of MSW in vehicle}}{\text{As-discarded density of MSW}}$$

$$\Rightarrow \quad 3 = \frac{\text{Density of MSW in vehicle}}{74.87}$$

$$\Rightarrow \quad \text{Density of MSW in vehicle} = 74.87 \times 3 = 224.61\ \text{kg/m}^3$$

$$\text{Now, volume of MSW in vehicle} = \frac{\text{Mass of MSW}}{\text{Density of MSW}}$$

$$= \frac{1000\,\text{kg}}{224.61\,\text{kg/m}^3} = 4.45\ \text{m}^3$$

End of Solution

SECTION : B

Q.5 (a) A 6 m high pier rests on a 2 m × 2 m square footing at 1.5 m depth from the surface at a site having uniform clayey soils. The unconfined compressive strength of the clay is 100 kPa and its bulk unit weight is 20 kN/m^3. The pier carries a vertical load of 80 kN at the centre including its self-weight. A resultant horizontal load of 15 kN also acts on one side of the pier at 1.5 m above the surface. Determine the factor of safety with respect to the pier's net ultimate bearing capacity as per IS 6403 recommendations.

[12 marks : 2023]

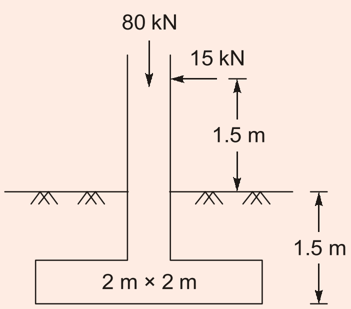
Solution:

Given: Size of footing = 2 m × 2 m

Depth of footing = 1.5 m

Unconfined compressive strength, q_u = 100 kPa

The horizontal load will have the effect of introducing both inclination and eccentricity of loading. The resultant of horizontal load and vertical load will be inclined at an angle α to the vertical.



where, $$\tan\alpha = \frac{\text{Horizontal load}}{\text{Vertical load}} = \frac{15}{80}$$

$\Rightarrow \qquad \alpha = \tan^{-1}\dfrac{15}{80} = 10.62°$

Now, height of horizontal load above the base of footing = 1.5 + 1.5 = 3 m

Eccentricity of the resultant load, e can be calculated as,

$$\frac{e}{3} = \tan\alpha$$

$$e = 3 \times \tan\alpha = 3 \times \tan 10.62° = 0.5625 \text{ m}$$

Now, reduced dimension B' on account of eccentricity of loading is given as

$$B' = B - 2e_x$$
$$= 2 - 2 \times 0.5625 = 0.875 \text{ m}$$

So, Reduced area, $\quad A' = B' \times L$

$$= 0.8752 \times 2 = 1.75 \text{ m}^2$$

Now, as per IS 6403,

for $\quad \phi = 0$

- $N_c = 5.14$
- $N_q = 1$
- $N_\gamma = 0$
- $S_c = \left[1 + 0.2\dfrac{B'}{L}\right] = \left[1 + 0.2 \times \dfrac{0.875}{2}\right] = 1.0875$
- $S_q = 1$
- $d_c = 1 + 0.2\dfrac{D}{B'}\sqrt{N_\phi}$

where, $\quad N_\phi = \tan^2\left(45° + \dfrac{\phi}{2}\right) = \tan^2\left(45° + \dfrac{0°}{2}\right) = 1$

$\therefore \quad d_c = \left[1 + 0.2 \times \dfrac{1.5}{0.875}\right] \times \sqrt{1} = 1.34$

- $d_q = 1$
- $d_\gamma = \left[1 + 0.1 \times \dfrac{D}{B'}\right] = \left[1 + 0.1 \times \dfrac{1.5}{0.875}\right] = 1.17$
- $i_c = i_q = \left(1 - \dfrac{\alpha}{90°}\right)^2 = \left[1 - \dfrac{10.62°}{90°}\right]^2 = 0.78$

Now, net ultimate bearing capacity, $q_{net} = [c\,N_c\,S_c\,d_c\,i_c + q\,(N_q - 1)\,S_q\,d_q\,i_q] \quad [\because N_\gamma = 0]$

$$= 50 \times 5.14 \times 1.0875 \times 1.34 \times 0.78 + 0 \qquad [\because N_q = 1]$$
$$= 292.12 \text{ kN/m}^2$$

So, net ultimate load, $\quad Q_{net} = q_{net} \times A$

$$= 292.12 \times 0.875 \times 2 = 511.21 \text{ kN}$$

$$\text{Factor of safety} = \frac{511.21}{80} = 6.39$$

End of Solution

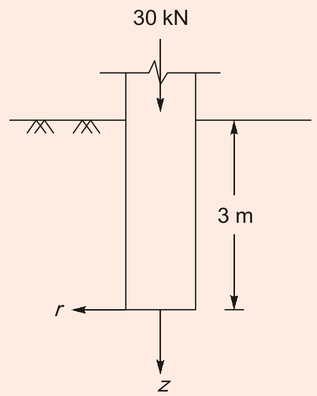
Q.5 (b) An electric power transmission pole is embedded 3 m into the ground. The pole weighs 30 kN and has base diameter of 450 mm. If the pole is assumed to transmit the load as point load in the soil, determine the stress increase at a depth 1 m below the base, and :

(i) Along the centre, and

(ii) 1 m from the centre.

[12 marks : 2023]

Solution:



Given: Diameter of pole = 450 mm

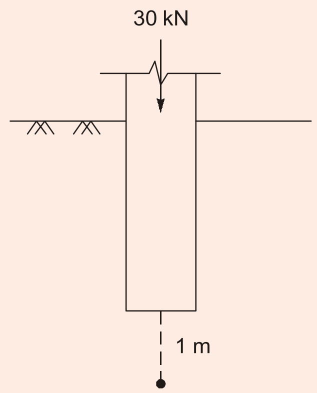
z = 1 m

(i) Stress increase at r = 0 and z = 1 m: As the load is transferred as point load only, so stresses due to side friction is neglected.

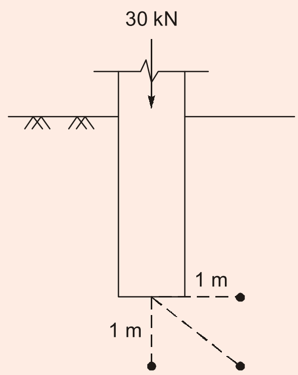
As per Boussinesq's equation,

$$\sigma_z = \frac{3Q}{2\pi z^2}\left[\frac{1}{1+\left(\frac{r^2}{z^2}\right)}\right]^{5/2}$$

$$= \frac{3\times 30}{2\pi \times 1^2} = 14.32 \text{ kN/m}^2$$



(ii) Stress increase at z = 1 m and r = 1 m:



$$\sigma_z = \frac{3 \times 30}{2\pi \times 1^2}\left[\frac{1}{1+\left(\frac{1}{1}\right)^2}\right]^{5/2} = 2.532 \text{ kN/m}^2$$

End of Solution

Q.5 (c) What are the key factors considered in the modernization of railway track with the aim to increase the average speed and capacity of the modernized section?

[12 marks : 2023]

Solution:

The following factors are to be considered for the modernization of railway track with aim to increase average speed and capacity of the section:

(i) Track geometry having proper alignment, appropriate super-elevation, smooth curves.

(ii) Upgrading track structure to accommodate higher speeds and heavy loads using stronger materials for sleepers, rails, ballast etc.

(iii) Focus on optimizing operational practices, such as efficient train scheduling, improved coordination between employee's at all hierarchy levels.

(iv) Implementation of track maintenance by improving regular inspections, timely repairs and the use of modern track inspection techniques.

(v) Electrification of railway track enables faster acceleration, higher speeds and increased capacity.

(vi) Investing funds to upgrade tracks and signalling systems to allow higher speeds and reduce delays.

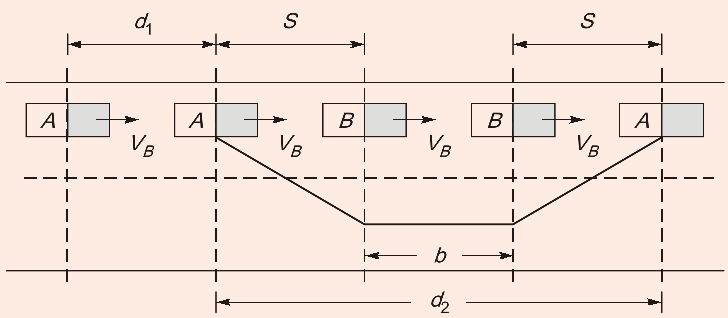
End of Solution

Q.5 (d) A car moving with a speed of 80 kmph has to overtake another car moving at a speed of 64 kmph in the two-lane one-way highway. If the reaction time of the driver is 2.5 s and acceleration of overtaking car is 0.95 m/s^2, calculate the safe overtaking sight distance.

[12 marks : 2023]

Solution:

Given: Two-lane one-way road



Speed of A, V_A = 80 kmph

Speed of B, $V_B = 64$ kmph

Reaction time, $t_R = 2.5$ sec

Acceleration, $a = 0.95$ m/s^2

$$d_1 = 0.278 \times V_B \times t_R$$
$$= 0.278 \times 64 \times 2.5 = 44.48 \text{ sec}$$
$$d_2 = 2s + 0.278 \times V_B \times T$$

where, $s = 0.2 \times V_b + 6$
$$= 0.2 \times 64 + 6 = 18.8 \text{ m}$$

and $$T = \sqrt{\frac{4s}{a}} = \sqrt{\frac{4 \times 18.8}{0.95}} = 8.89 \text{ sec}$$

$\therefore$ $$d_2 = 2 \times 18.8 + 0.278 \times 64 \times 8.89 = 195.8 \text{ m}$$

$\therefore$ $$\text{OSD} = d_1 + d_2$$
$$= 44.48 + 195.8 = 240.28 \text{ m}$$

End of Solution

Q.5 (e) In running fly levels from a benchmark of reduced level 212.40 m, a surveyor took an intermediate sight of 0.420 m with the staff held on a benchmark of reduced level 264.005 m. The sum of Back Sights and Fore Sights from the start to second BM is 75.205 m and 23.450 m, respectively. What is the closing error on the second benchmark? If the distance between the first BM and second BM is 30 km, comment whether the work is satisfactory for ordinary levelling for location and construction survey or not.

[12 marks : 2023]

Solution:

Given: R.L. of B.M.$_1$ = 212.4 m

R.L. of B.M.$_2$ = 264.005 m

Now, Σ Back sight = 75.205

Σ Fore sight = 23.450

Distance between 1 and 2 = 30 km

True R.L of B.M.$_2$ = 264.005

Measured R.L of B.M.$_2$

$$\Sigma BS - \Sigma FS = \text{Last RL} - \text{First RL}$$
$$75.205 - 23.450 = \text{B.M.}_2 - 212.4$$

So, measured R.L. of B.M.$_2$ = 264.155

Now, Closing error = Measured value – True value
$$= 264.155 - 264.505 = 0.15 \text{ m}$$

Permissible error for ordinary levelling = $\pm 0.025\sqrt{d}$ where d is in km
$$= \pm 0.025\sqrt{30} = 0.1369 \text{ m}$$

Since actual error is more than permissible error, work is not satisfactory.

End of Solution

Q.6 (a) (i) An embankment is to be constructed using sandy clay compacted to dry unit weight of 18 kN/m^3. The sandy clay transported to the site from a borrow pit. The bulk unit weight of the sandy clay in the borrow pit is l6 kN/m^3 and its natural water content is 11%. Calculate the volume of sandy clay from the borrow pit required for 1 cubic metre of finished embankment. Assume that the soil swells by 10% due to excavation and during transportation. You can take G_s = 2.7.

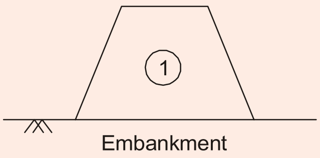
[12 marks : 2023]

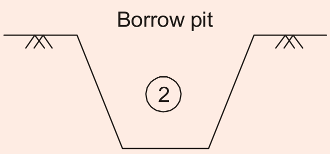
(ii) A 1.2 m thick embankment of loose sand is to be compacted using a Vibratory Roller. If the void ratio decreases from 1.2 to 0.8 due to compaction, calculate the final thickness of the embankment.

[8 marks : 2023]

Solution:

(i)





For Embankment,

Dry unit weight, $(\gamma_d)_1 = 18$ kN/m^3

Total volume, $(V_{total})_1 = 1$ m^3

For Borrow pit,

Bulk unit weight, $(\gamma_{bulk})_2 = 16$ kN/m^3

Water content, $w = 11\%$

Swell $= 10\%$

Now, volume of solids remain same in both the cases.

Dry unit weight in Borrow pit, $(\gamma_{dry})_2 = \dfrac{(\gamma_{bulk})_2}{1+w} = \dfrac{16}{1+0.11} = 14.41$ kN/m^2

and $(\gamma_{dry})_2 = \dfrac{G \cdot \gamma_w}{1+e_2}$ where e_2 is void ratio in Borrow pit

$$14.41 = \frac{2.7 \times 9.81}{1+e_2}$$

$\therefore$ $e_2 = 0.84$

Also $(\gamma_{dry})_1 = \dfrac{G \cdot \gamma_w}{1+e_1}$ where e_1 is void ratio in Embankment

$$18 = \frac{2.7 \times 9.81}{1+e_1}$$

$$e_1 = 0.47$$

Now, $(V_S)_1 = (V_S)_2$

$$\frac{(V_T)_1}{1+e_1} = \frac{(V_T)_2}{1+e_2}$$

$$\frac{1}{1+0.47} = \frac{(V_T)_2}{1+0.84}$$

$$(V_T)_2 = 1.25 \text{ m}^3$$

Volume of soil excavated from Borrow pit = $(V_T)_2 \times$ Swell factor

$$= 1.25 \times 1.1 = 1.375 \text{ m}^3$$

(ii) Given:

Thickness of embankment, $H_o = 1.2$ m

Initial void ratio, $e_o = 1.2$

Final void ratio, $e_f = 0.8$

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

$$\Delta H = \frac{e_o - e_f}{1+e_f} \times 40 = \frac{1.2-0.8}{1+1.2} \times 1 \cdot Q = 0.218 \text{ m}$$

$\therefore$ $$H_{final} = 1.2 - 0.218 = 0.982 \text{ m}$$

End of Solution

Q.6 (b) Soil sample and flow conditions are shown in the following figure:

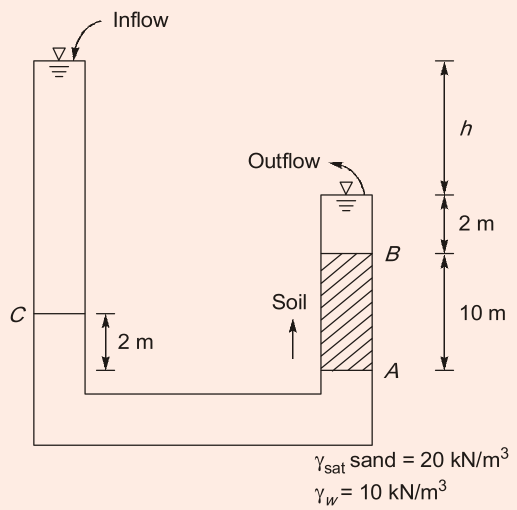


Figure not scale

(i) Find the head, h required to cause quick condition.

(ii) Compute the seepage force per unit volume at quick condition. Use cross-section area of tube as 1 m^2.

(iii) A student accidentally broke the left hand riser tube to the point C at an elevation 2 m above point A. Assuming that the water level is now maintained at C, compute the new hydraulic gradient, effective stress at elevation A and seepage force at elevation A.

[20 marks : 2023]

Solution:

(i) **For quick sand to occur:** Shear strength at A must be zero and for that effective stress at A must be zero.

As upward flow is there, $\bar{\sigma}_A = 0$

$$z \cdot \gamma' - i z \cdot \gamma_w = 0$$

where γ' is submerged unit weight of soil

$$z \cdot (\gamma_{sat} - \gamma_w) = \frac{h}{L} \times z \cdot \gamma_w$$

$$10 \times (20 - 10) = \frac{h}{L} \times 10 \times 10$$

$$h = 10 \text{ m}$$

(ii) **Seepage force per unit volume:**

$$F_S = \frac{\text{Seepage pressure} \times \text{Area}}{\text{Volume}}$$

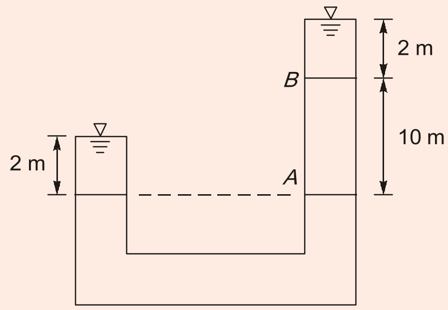
$$= \frac{i \cdot z \cdot \gamma_w \times A}{z \times A}$$

$$= i \cdot \gamma_w$$

$$= \frac{h}{L} \cdot \gamma_w$$

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

(iii)



Now in this condition, downward flow is there.

$$\text{Hydraulic gradient (i)} = \frac{h_L}{L} = \frac{2 + 10 - 2}{10} = 1$$

Effective stresses at A, $\bar{\sigma}_A = z\gamma' + i \cdot z \cdot \gamma_w$

$$\bar{\sigma}_A = 10 \times (20 - 10) + 1 \times 10 \times 10 = 200 \text{ kN/m}^2$$

Seepage force at A, $F_S = (i \cdot z \cdot \gamma_w) \times A$

$$= 1 \times 10 \times 100 \times 1 = 100 \text{ kN}$$

End of Solution

Q.6 (c) (i) Elaborate the various criteria which need to be considered for selection of site of a civilian greenfield airport in the hilly region.

[15 marks : 2023]

(ii) Discuss the essential features of an ideal commercial harbour.

[5 marks : 2023]

Solution:

(i) The key factors for selection of site of a civilian greenfield airport as follows:

(a) Assess to the topography of the hilly region to identify areas with flat or slopy terrains.

(b) To know the accessibility of the site in terms of connectivity to transportation networks including highways, railroads to ensure convenient access for travellers.

(c) Analyze the weather conditions and their patterns as they can significantly impact airport operations. Site chosen should not have high cross winds or heavy precipitation.

(d) Site should have sufficient space to allow constructions for future expansion.

(e) Safety measures should be incorporated into the airports design and operations to ensure well being of all.

(f) To analyze the airports ability to estimate tourism, trade and investment.

(g) Assess the noise impact on nearby residential areas.

(h) Evaluating the feasibility of engineering works on soil.

(i) To check for the longest runway length requirement to accommodate large aircraft.

(j) In India, Biju Patnaik international airport, Bhubaneswar is one of the largest greenfield airport.

(ii) Essential features of an ideal commercial harbour:

(a) A commercial harbour should have deep waterways to ensure safe navigation and accessibility for ships.

(b) The harbour should have proper berthing facilities.

(c) The harbour must have efficient cargo handling facilities.

(d) Harbour is the important transportation hub that facilitate goods movement.

(e) Commercial harbours require customs facilities to process import/export documentation, inspect cargo and collect duties and taxes.

(f) It should be accessible to various transportation networks so as to transport commodities easily and quickly.

End of Solution

Q.7 (a) A simple circular curve is to set out in a National Highway touching the three lines having following details :

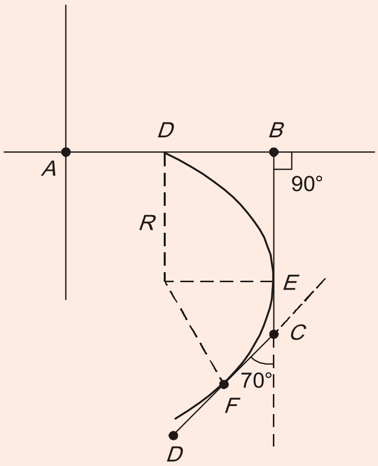
Line	Reduced Bearing	Length (m)
AB	N 90° E	–
BC	S 0° E	170
CD	S 70° W	–

If the chainage of point B is 700 m, calculate the radius of curve and chainage of all the tangent points in the curve.

[20 marks : 2023]

Solution:

In figure, R is radius of given curve



Now, $DB = BE = R\tan\left(\frac{90°}{2}\right)$

$= R$ ...(i)

Also, $EC = CF = R\tan\left(\frac{70°}{2}\right)$

Now, $BC = BE + EC = 170$ m

$R + R\tan 35° = 170$

$= R \approx 100$ m

Now, Tangent length $BD = R = 100$ m

Also, $BE = 100$ m

$$\text{Length of curve from D to F} = \frac{\pi R \times 90°}{180°} = \frac{\pi \times 100 \times 90°}{180°} = 157.08 \text{ m}$$

$$\text{Length of curve from E to F} = \frac{\pi R \times 70°}{180°} = \frac{\pi \times 100 \times 70°}{180°} = 122 \text{ m}$$

Now, chainage of point B = 700 m

So, chainage of point D = Chainage of B – BD

= 700 – 100 = 600 m

Chainage of point E = Chainage of point D + Length of curve from D to E

= 600 + 157.08 = 757.08 m

Chainage of point F = Chainage of point E + Length of curve from E to F

= 757.08 + 122 = 879.08 m

End of Solution

Q.7 (b) (i) A long trench with vertical sides is to be excavated in soft saturated clay deposits ($\phi_u = 0$) to lay a sewage pipeline. If the maximum depth of the trench is 2 m, what should be the approximate undrained cohesion of the clay (C_u) to maintain a minimum safety factor of 3? Assume that the clay has a unit weight of 20 kN/m^3 and that the groundwater table is sufficiently below the excavation depth.

[10 marks : 2023]

(ii) A clay has plastic limit and liquid limit of 18 and 39 percent, respectively. What water content would correspond to its liquidity index of –0.1? Comment on the consistency of this clay.

[10 marks : 2023]

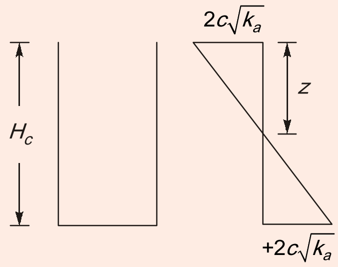
Solution:

Given: Factor of safety (FOS) = 3, Maximum depth of trench (H) = 2 m,

Unit weight of clay (γ) = 20 kN/m^3

(i) At critical depth, total active earth pressure is zero.

At depth z, earth pressure is zero.



$$\Rightarrow \quad k_a \cdot \gamma \cdot z - 2c\sqrt{k_a} = 0$$

$$\Rightarrow \quad z = \frac{2c}{\gamma\sqrt{k_a}}$$

So, Critical depth,
$$H_c = 2z = \frac{4c}{\gamma \cdot \sqrt{k_a}}$$

Since,
$$\text{FOS} = \frac{H_c}{H}$$

$$\Rightarrow \quad H_c = \text{FOS} \times H$$

$$\Rightarrow \quad \text{FOS} \times H = \frac{4c}{\gamma \cdot \sqrt{k_a}}$$

for, $\phi = 0$, $k_a = 1$

$$\Rightarrow \quad 3 \times 2 = \frac{4c}{20 \times 1}$$

So, undrained cohesion, c = 30 kPa

(ii) Given: w_L = 39%, w_P = 18%, $I_L = -0.1$

Let, Natural water content = w_n

Liquidity index,
$$I_L = \frac{w_n - w_P}{w_L - w_P}$$

$$\Rightarrow \quad -0.1 = \frac{w_n - 0.18}{0.39 - 0.18}$$

$$\Rightarrow \quad w_n = 0.159 \text{ or } 15.9\%$$

So, natural water content (w_n) corresponding to ($I_L = -0.1$) is 15.9%

Since, liquidity index (I_L) is less than zero. Hence soil is in semi solid or very hard state of consistency.

End of Solution

Q.7 (c) A prestressed concrete pipe of 0.5 m diameter is driven in medium dense sand up to 10 m depth. The groundwater table level is at 3 m depth below the surface. The properties of the sand are:

Angle of internal friction of sand, ϕ'	30 degrees
Angle of wall friction between pile and sand, δ	20 degrees
Post-driving horizontal earth pressure co-efficient	1
Saturated unit weight of sand	19 kN-m^3
Unit weight of sand above groundwater table	17 kN-m^3

If the unit shaft resistance reaches a limiting value at 15 D, where D is the diameter of the pile, estimate the skin friction resistance of the pile.

[20 marks : 2023]

Solution:

Given: Diameter of pile = 0.5 m

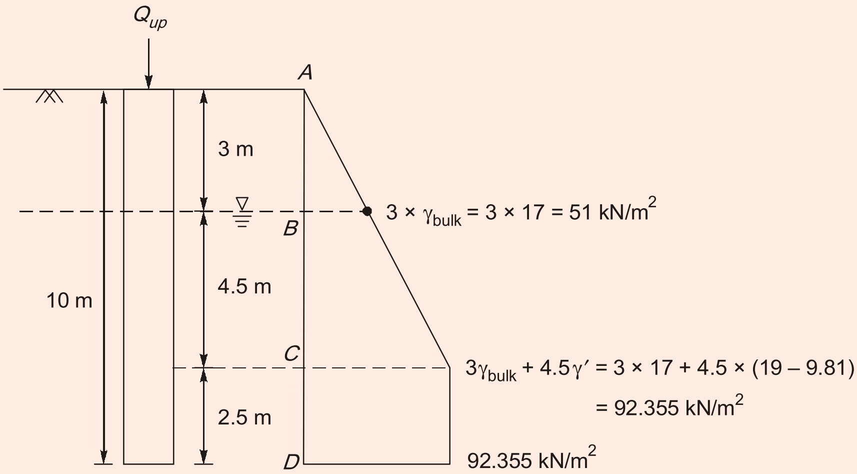
$$\phi' = 30°, \quad \delta = 20°, \quad k = 1$$

$$\gamma_{sat} = 19 \text{ kN/m}^3$$

$$\gamma_{bulk} = 17 \text{ kN/m}^3$$

It is given that maximum value of shaft resistance reaches at critical depth (L_c) of $15D = 15 \times 0.5 = 7.5$ m.

Therefore, effective stresses will be uniform below 7.5 m depth.



As only skin friction is asked,

$$Q_{up} = Q_{Sf_{AB}} + Q_{Sf_{BC}} + Q_{Sf_{CD}}$$

$$\because \quad Q_{Sf_{AB}} = q_{s_1} \cdot A_{s_1}$$

$$q_{s_1} = k[\bar{\sigma}_V]_{avg.} \tan\delta$$

$$= 1 \times \left[\frac{0+51}{2}\right] \times \tan 20°$$

$$= 9.281 \text{ kN/m}^2 \leq 100 \text{ kN/m}^2 \quad \text{(o.k.)}$$

$$\therefore \quad Q_{Sf_{AB}} = q_{s_1} \cdot A_{s_1}$$

$$= 9.281 \times \pi \times 0.5 \times 3 = 43.73 \text{ kN}$$

Also, $$Q_{Sf_{BC}} = q_{s_2} \cdot A_s$$

$$q_{s_2} = 1 \times \left[\frac{51 + 92.355}{2}\right] \times \tan 20° = 26.088 \text{ kN/m}^2$$

$$\therefore \quad Q_{Sf_{BC}} = 26.088 \times \pi \times 0.5 \times 4.5 = 184.4 \text{ kN}$$

Also, $$Q_{Sf_{CD}} = q_{s_3} \cdot A_{s_3}$$

$$q_{s_3} = 1 \times 92.355 \times \tan 20° = 33.61 \text{ kN/m}^2$$

$$\leq 100 \text{ kN/m}^2 \quad \text{(o.k.)}$$

$$\therefore \quad Q_{Sf_{CD}} = 33.61 \times \pi \times 0.5 \times (7 - 0.45) = 132 \text{ kN}$$

$$\therefore \quad \text{Total skin friction} = Q_{Sf_{AB}} + Q_{Sf_{BC}} + Q_{Sf_{CD}}$$

$$= 43.73 + 184.4 + 132 = 132 \text{ kN} = 360.13 \text{ kN}$$

End of Solution

Q.8 (a) (i) A 600 mm diameter pile is installed up to the bottom of a 16 m thick stiff clayey soil. The pile rests on dense gravelly strata. The average undrained shear strength of the clay is 60 kPa ($\phi_u = 0$) and its saturated unit weight is 18 kN/m^3. If the pile has an enlarged base of diameter 1.2 m, determine its ultimate uplift capacity. Assume that the groundwater level is at the ground surface. Ignore the benefit due to the weight of the pile. Take adhesion factor $\alpha = 0.8$ and friction coefficient in uplift $K = 0.5$.

[12 marks : 2023]

(ii) A single-storeyed structure is to be constructed at a site in which construction debris has been dumped down to a depth of 3 m over a period of time. The debris is in loose state and consists of concrete lumps, broken tiles and brickbats mixed with soil. Describe how to proceed to find a solution for design and construction of foundation without basement.

[8 marks : 2023]

Solution:

(i) Given:

$C = 18$ kN/m^3

$\phi = 0$

$\gamma_{sat} = 18$ kN/m^3

Diameter of pile, $d = 600$ mm

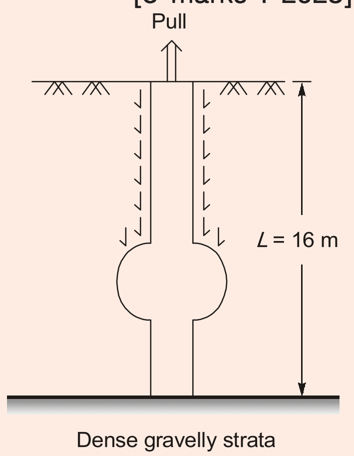
Diameter of bulb, $d_u = 1200$ mm

Adhesion factor, $\alpha = 0.8$

Coefficient of uplift, $K = 0.5$

Pullout capacity $= Q_{eb} + Q_{sf}$

$$= 9 \cdot C \cdot \frac{\pi}{4}\left[d_u^2 - d^2\right] + \alpha C \pi d L$$



$$= 9\times 60\times \frac{\pi}{4}\left[1.2^2 - 0.6^2\right] + 0.8\times 60\times \pi\times 0.6\times 16$$

$$= 1905.569 \text{ kN}$$

$\therefore$ Ultimate uplift capacity = $K \times$ Pull capacity

$$= 0.5 \times 1905.569 = 952.845 \text{ kN}$$

(ii) The filled up soil must be compacted well before undertaking any compaction. Necessary soil filling must be done in order to fill the voids. Concrete blocks may be used to compact the soil sufficiently. After adequate compaction, grade slab may be casted in order to have a firm surface. On this grade slab, singly storey structure can be built. Grade slab may or may not be provided with reinforcement. However, nominal reinforcement will be beneficial. Minimum thickness of this grade slab must be 100 mm. Before laying the grade slab, a layer of bitumen on the soil can be laid.

End of Solution

Q.8 (b) Spot speed study was carried out to redesign the stretch of major district road. The data collected during the study is given below:

Speed range kmph	Frequency of Vehicles		
	Two wheelers	Cars	Others
0 - 10	5	0	0
10 - 20	20	6	4
20 - 30	24	12	4
30 - 40	20	30	5
40 - 50	30	60	30
50 - 60	35	35	30
60 - 70	25	35	15
70 - 80	10	15	10
80 - 90	10	18	2
90 - 100	1	9	0

(i) What is the design speed for redesigning existing MDR?

(ii) What are upper and lower speed limits for mixed traffic?

(iii) What are the different measures to increase the spot speed of vehicles moving on the road?

(iv) Check whether the speed distribution is reasonably normal or not.

[20 marks : 2023]

Solution:

Speed range	Avg. speed	Total number of vehicles	Cumulative number of vehicles	Cumulative frequency (%)
0 - 10	5	5	5	1
10 - 20	15	30	35	7
20 - 30	25	40	75	15
30 - 40	35	55	130	26
40 - 50	45	120	250	50
50 - 60	55	100	350	70
60 - 70	65	75	425	85
70 - 80	75	35	460	92
80 - 90	85	30	490	98
90 - 100	95	10	500	100

(i) Design speed = 98^{th} percentile speed = 85 kmph

(ii) Upper safe limit = 85^{th} percentile speed = 65 kmph

Lower speed limit = 15^{th} percentile speed = 25 kmph

(iii) In order to increase the spot speed of the vehicles, the variation in vehicles class must be reduced and as far as possible, only similar types of vehicles should ply on road thereby avoiding the mixed traffic flow. In the given speed range of 30 kmph to 70 kmph, maximum number of other types of vehicles are there which are occupying significant space on road and thus the number of other types of vehicles must be reduced on the road by providing alternate routes to them.

(iv) Speed distribution is reasonably normal because on either side of the mid-speed (i.e. 50 kmph), roughly equal number of vehicles are there thereby making the speed distribution relatively normal distribution.

End of Solution

Q.8 (c) A straight bridge is set out between two points A and B, whose independent coordinates are given below:

Point	Northing (N)	Easting (E)
A	0	0
B	1200	100

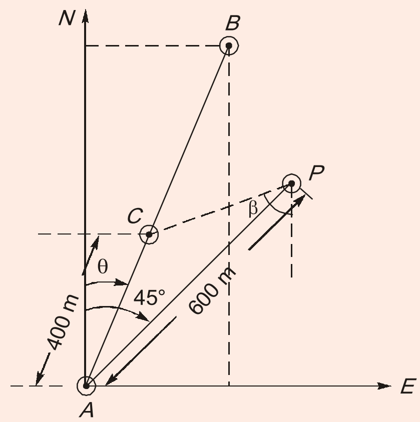
It is required to set out the pillar at point C which is 400 m from point A. It is not possible to set the instrument either at point A or B. To set point C, another point P is selected at a horizontal distance of 600 m from A. Line AP has a bearing of 45°. Calculate:

(i) The independent coordinates of points C and P.

(ii) The length and bearing of line PC.

[20 marks : 2023]

Solution:



In figure, $\tan\theta = \frac{100}{1200} = 4.7636°$

So, Bearing of line AB = 4.7636°

Also, Length of line AB = $\sqrt{1200^2 + 100^2}$

= 1204.16 m

Now, Length of line AP = 600 m

Bearing of line AP = 45°

Now, Latitude of P = 600 cos 45°

= 424.26 m

Departure of P = 600 sin 45°

= 424.26 m

Latitude of C = 400 cos 4.7636°

= 398.62 m

Departure of C = 400 sin 4.7636° = 33.22 m

(i) So, Independent coordinate P = 424.26 N, 424.26 E

So, Independent coordinate C = 398.62 N, 33.22 E

(ii) For line PC

$$\text{Length of line PC} = \sqrt{(424.26 - 398.62)^2 + (424.26 - 33.22)^2}$$

= 291.88 m

As APC is a closed traverse,

So, ΔD = 424.26 – 33.22 = 391.04 m

So, ΔL = 424.26 – 398.62 = 25.64 m

So, $$\beta = \tan^{-1}\left(\frac{\Delta D}{\Delta L}\right) = \tan^{-1}\left(\frac{391.04}{25.64}\right) = 86.26°$$

From the figure, it can be seen that the bearing is S 86.26° W.

So, the bearing is N 86.26° W.

End of Solution

■■■■