ESE Mains 2023

Civil Engineering

Questions & Solutions

PAPER-2

ESE CE Paper 2 : Marks Distribution					
S.NO.	Subjects	Difficulty Level 2023	2023 Marks	2022 Marks	2021 Marks
1	Fluid Mechanics	Easy	20	59	76
2	Open Channel flow	Easy	12	10	10
3	Hydraulic Machines	Easy	32	20	20
4	Geotechnical Engineering	Moderate	124	86	104
5	Highway Engineering	Moderate	32	52	52
6	Railway, Airport and Tunnelling	Tough	32	42	52
7	Environmental Engineering	Easy	124	109	84
8	Surveying	Moderate	52	60	52
9	Irrigation Engineering	-	-	20	0
10	Engineering Hydrology	Easy	52	22	30
Total		Moderate	480	480	480

CIVIL ENGINEERING

Paper-2

SECTION-'A'

1.(a) The annual rainfall of six different rain gauge 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 the average rainfall of the six rain gauge stations.

(ii) The optimum number of rain gauge stations in the river basin for a 10% error in the estimation of average rainfall.

[12 Marks]

Sol. **(i) Calculation of standard error**

Given the annual rainfall of six rain gauge stations is.

P_1 = 136.70 cm $\qquad$ P_4 = 180.30 cm

P_2 = 102.90 cm $\qquad$ P_5 = 82.60 cm

P_3 = 98.80 cm $\qquad$ P_6 = 110.30 cm

So,

The average of six rainfall data

$$\bar{P} = \frac{P_1 + P_2 + P_3 + P_4 + P_5 + P_6}{6}$$

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

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

And,

Standard Deviation

$$\sigma_{n-1} = \sqrt{\frac{\left(P_1 - \bar{P}\right)^2 + \left(P_2 - \bar{P}\right)^2 + \left(P_3 - \bar{P}\right)^2 + \left(P_4 - \bar{P}\right)^2 + \left(P_5 - \bar{P}\right)^2 + \left(P_6 - \bar{P}\right)^2}{n-1}}$$

$$= \sqrt{\frac{(136.70 - 118.6)^2 (102.9 - 118.6)^2 + (98.80 - 118.6)^2 + (180.30 - 118.6)^2 + (82.60 - 118.6)^2 + (110.30 - 118.6)^2}{6-1}}$$

$$= \sqrt{\frac{(18.1)^2 + (15.7)^2 + (19.8)^2 + (61.7)^2 + (36)^2 + (8.3)^2}{5}}$$

$$\sigma_{n-1} = 35.0368$$

So,

Coefficient of variation (C_v)

$$C_V = \frac{\sigma_{n-1}}{\bar{P}} \times 100$$

$$= \frac{35.0368}{118.6} \times 100 = 29.542\%$$

We know the number of stations required (N)

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

Where C_v = Coefficient of variation

ε = Standard error in the estimation

$$6 = \left(\frac{C_V}{\varepsilon}\right)^2$$

$$6 = \left(\frac{29.542}{\varepsilon}\right)^2$$

ε = 12.06%

So, the standard error in the estimation of the average rainfall of the six rain gauge stations = 12.06%

(ii) The optimum number of rain gauge stations in the river basin for a 10% error

The optimum number of stations required (N)

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

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

= 8.727

The optimum number of rain gauge stations $\simeq$ 9

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 2.0 cumecs. Determine whether the hydraulic jump will take place or not. Find the height of jump and loss of energy.

[12 Marks]

Sol. B = 1.3 m

y_1 = 0.35 m

Q = 2 m^3/s

$$q = \frac{Q}{B} = \frac{2}{1.3} = 1.538 m^3 / s / m$$

$$y_c = \left(\frac{q^2}{g}\right)^{1/3} = \left[\frac{(1.538)^2}{9.81}\right]^{1/3}$$

= 0.622 m

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

$$= \frac{Q}{A\sqrt{gy_1}}$$

$$\frac{Q}{By_1\sqrt{gy_1}}$$

$$Fr_1 = \frac{q}{y_1\sqrt{gy_1}}$$

$$Fr_1^2 = \frac{q^2}{gy_1^3} = \frac{(1.538)^2}{9.81 \times (0.35)^3}$$

$$Fr_1^2 = 5.6239$$

$= 5.624$

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

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

$y_2 = 1.012$ m

Hydraulic jump will take place as flow takes place from supercritical depth (y = 0.35 m) to subcritical depth (y = 1.012 m)

Height of hydraulic jump

$= y_2 — y_1$

$= 1.012 — 0.35$

$= 0.662$ m

Energy of hydraulic jump $= \frac{(y_2 - y_1)^3}{4y_1y_2}$

$$= \frac{(1.012 - 0.35)^3}{4 \times 0.35 \times 1.012}$$

$= 0.2047$ m

$= 0.205$ m

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 x 9.81).

[12 Marks]

Sol. Discharge = 1500 l/min = 0.025 m^3/sec

Height = $H_s = h_s + h_d = 22$ m

Diameter = $D = d_s = d_d = 10$cm = 0.1 m

Length = $L = L_s + L_D = 100$ m

Overall efficiency = η_o = 70% = 0.7

Coefficient of friction, f = 0.004

$$\text{Velocity of water in pipe} = V = \frac{0.025}{\frac{\pi}{4} \times 0.1^2}$$

V = 3.18 m/sec

$$\text{Frictional head loss} = H_f = \frac{4fLV^2}{2gd}$$

$$H_f = \frac{4 \times 0.004 \times 100 \times 3.18^2}{2 \times 9.81 \times 0.1}$$

H_f = 8.25 m

Using the following equation we get the manometric head as

$$H_m = (h_s + h_d) + (h_{f_s} + h_{f_d}) + \frac{V_d^2}{2g}$$

$$= 22 + 8.25 + \frac{3.18^2}{2 \times 9.81} = 30.77\text{m}$$

We know,

$$\eta_o = \frac{\left(\frac{WH_m}{1000}\right)}{S.P} = \frac{\rho g Q H_m}{1000 \times SP}$$

$$SP = \frac{\rho g Q H_m}{1000 \times \eta_o} = \frac{1000 \times 9.81 \times 0.025 \times 30.77}{1000 \times 0.7}$$

Shaft Power = 10.78 kW

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

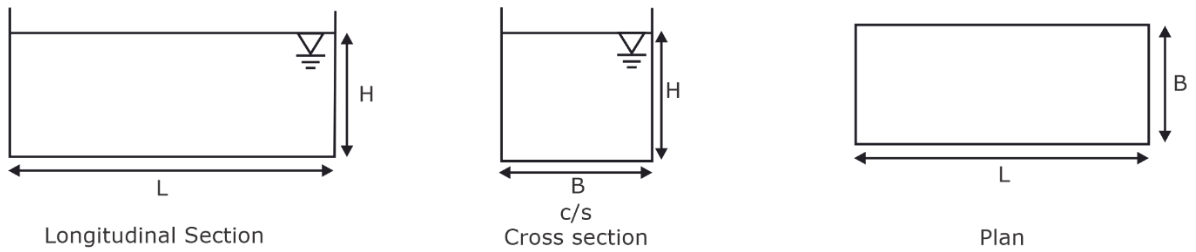
(ii) Horizontal Velocity

(ii) Rate of dry solids deposited

(iv) Overflow rate

[12 Marks]

Sol.



Given population p = 20,000

Per capita water demand x = 100 lpcd

Annual average daily demand = p.x

$$= 20{,}000 \times 100 \frac{l}{c-d} \times 10^{-3} m^3$$

= 2000 m^3/d

(i) Detention time $(Dt) = \frac{V}{Q} = \frac{L \times B \times H}{Q}$

$$= \frac{15m \times 6m \times 3m}{2000m^3 / d} \times 24hrs$$

= 3.24 hrs

(ii) Horizontal velocity $V_f = \frac{Q}{\text{cross section area}}$

$$= \frac{Q}{BH}$$

$$= \frac{2000m^3 / d}{6m \times 3m}$$

$$= \frac{2000m^3}{18m^2 \times 24} \frac{m}{hr}$$

= 4.629 m/hr

= 4.63 m/hr

(iii) Rate of solids deposited = Suspended solids removal efficiency × Total weight of solids per day

$$= 0.70 \times 2 \times 10^6 \frac{l}{d} \times 60 \frac{mg}{l} \times 10^{-6} kg$$

= 84 kg/d

(iv) Overflow rate $V_o = \frac{\text{Discharge}}{\text{Plan area}} = \frac{Q}{BL} = \frac{2000m^3 / d}{6 \times 15m^2} = 22.22\, m / d$

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]

Sol. The disposal of industrial wastewater containing heavy metals into surface water can have significant environmental and health impacts. Heavy metals are metallic elements with high atomic weights and densities, such as lead, mercury, cadmium, chromium, and arsenic. These metals are often used in industrial processes and can be present in wastewater as byproducts or contaminants.

When heavy metal-laden wastewater is discharged into surface water bodies, several detrimental effects can occur:

Environmental Contamination: Heavy metals can accumulate in sediments and disrupt the ecological balance of aquatic ecosystems. They can persist in the environment for a long time, leading to bioaccumulation in plants and animals. This bioaccumulation can result in toxic metals entering the food chain, affecting not only aquatic organisms but also humans who consume contaminated fish or other aquatic organisms.

Water Quality Degradation: Heavy metals can contaminate surface water, leading to a decline in water quality. Elevated levels of heavy metals can alter the pH, turbidity, and oxygen levels of water, affecting the survival and reproduction of aquatic species. These metals can also interfere with nutrient cycling and biological processes, leading to ecosystem imbalances.

Human Health Risks: Heavy metals are toxic to humans, and exposure to contaminated water can pose severe health risks. Drinking water contaminated with heavy metals can lead to various health problems, including damage to the nervous system, liver and kidney damage, respiratory issues, and even certain types of cancer. Vulnerable populations, such as children and pregnant women, are particularly at risk.

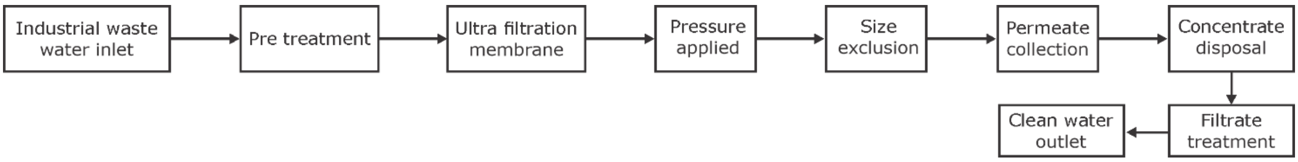
Soil Contamination: Heavy metals can infiltrate into the soil through runoff or by direct absorption from contaminated water, leading to soil pollution. This contamination can have detrimental effects on agriculture, as plants can take up heavy metals, potentially entering the food chain and posing health risks to humans and animals.

The two methods used for the removal of heavy metals from industrial wastewater are Ultrafiltration and Photocatalysis.

1. ULTRAFILTRATION

Ultrafiltration is a membrane filtration process that utilizes a semi-permeable membrane to separate and remove suspended solids, colloids, and high molecular weight substances from a liquid, such as industrial wastewater. The process works based on the principle of size exclusion, where the membrane acts as a barrier, allowing smaller molecules and solvents to pass through while retaining larger particles.

Here is a block diagram illustrating the working principle of ultrafiltration for the removal of heavy metals from industrial wastewater:



Industrial Wastewater Inlet: The contaminated wastewater containing heavy metals is introduced into the ultrafiltration system through an inlet.

Pre-Treatment: Before entering the ultrafiltration unit, the wastewater undergoes pre-treatment to remove large particles, debris, and any coarse solids. This step helps protect the ultrafiltration membrane from fouling and clogging.

Ultrafiltration Membrane: The pre-treated wastewater is then directed to the ultrafiltration membrane module. This module consists of numerous hollow fibers or flat-sheet membranes, which are selectively permeable to molecules based on their size.

Pressure Applied: To facilitate the separation process, pressure is applied to the wastewater. This pressure helps to overcome the resistance of the membrane and promotes the flow of water through the membrane while retaining the larger particles, including heavy metals.

Size Exclusion: As the pressurized wastewater passes through the ultrafiltration membrane, particles and molecules above a certain size threshold, typically in the range of 0.01 to 0.1 micrometers, are retained by the membrane. These particles include suspended solids, colloids, and high molecular weight substances, including heavy metal ions.

Permeate Collection: The permeate, which is the filtrate that passes through the membrane, is collected separately. It consists of purified water and smaller dissolved substances that have passed through the membrane, while heavy metals and larger contaminants are left behind.

Concentrate Disposal: The retained particles, including heavy metals, accumulate as a concentrated stream on the feed side of the membrane. This concentrate, also known as retentate, requires proper disposal or further treatment, depending on the specific regulations and requirements for heavy metal removal.

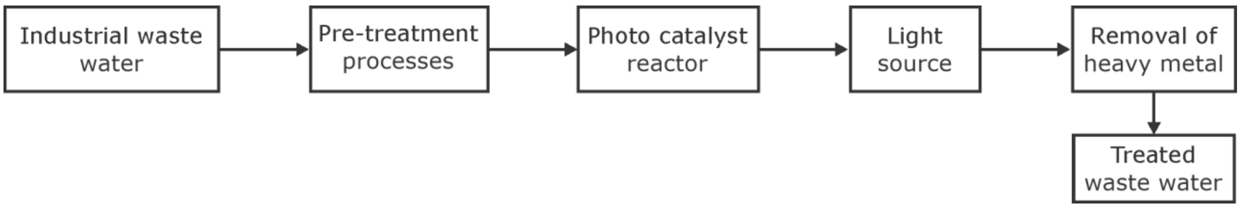
Filtrate Treatment: The collected permeate or filtrate can undergo additional treatment steps, such as pH adjustment or chemical precipitation, to further remove any residual heavy metals or other contaminants, if necessary.

Clean Water Outlet: The purified water, having undergone ultrafiltration and subsequent treatment steps, is discharged as clean water from the system.

2. PHOTOCATALYSIS

Photocatalysis is a process that utilizes a photocatalyst to facilitate the degradation or removal of pollutants, such as heavy metals, from wastewater. The principle of photocatalysis involves the use of light energy to activate the photocatalyst, which then generates reactive species that can break down the contaminants.

Here's a block diagram illustrating the working principle of photocatalysis for the removal of heavy metals from industrial wastewater:



Industrial Wastewater: This is the initial source of wastewater containing heavy metal pollutants.

Pre-Treatment Processes: The wastewater undergoes pre-treatment processes, which may include physical, chemical, or biological methods to remove larger particles, suspended solids, and organic matter.

Photocatalyst Reactor: The pre-treated wastewater is then introduced into a photocatalyst reactor. The reactor contains a suitable photocatalyst material, such as titanium dioxide (TiO2), which is capable of absorbing light energy.

Light Source: A light source, typically UV lamps or sunlight, provides the necessary energy to activate the photocatalyst. The light source emits photons with sufficient energy to excite the electrons in the photocatalyst material.

Removal of Heavy Metals: When the photocatalyst is activated by light, it generates electron-hole pairs. These highly reactive species can initiate various chemical reactions, including the breakdown of heavy metal pollutants into less harmful forms. The reactive species may oxidize the heavy metals or form complexes with them, facilitating their removal from the wastewater.

Treated Wastewater: After the photocatalysis process, the treated wastewater undergoes further treatment or filtration to remove any residual particles or by-products.

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

[10 Marks]

Sol. The dilution method is one of the methods for stream flow measurement. Stream discharge is determined based on how much of the tracer is diluted by the flowing water. Suitable tracers have the following characteristics:

- They readily dissolve in water at ordinary temperatures.
- They are absent in the stream or present at very low concentrations.
- They are not decomposed in the stream and are not retained or absorbed in significant quantities by plants, sediments, or other organisms.
- They can be detected in extremely low concentrations.
- They are harmless to the environment.

Theory of the Tracer Dilution Method

In tracer dilution methods, a tracer is injected into a stream and subject to dilution by the stream. The stream discharge can be determined from the rate of injection, the concentration of the tracer in the injection solution, and the downstream concentrations.

There are two primary methods for discharge determination:

1. **The constant rate injection method and**
2. **The sudden injection method.**

1. The constant rate injection method

- In the constant rate injection method, the tracer solution is introduced to the stream at a constant flow rate over a period sufficiently long to achieve a constant concentration of the tracer in the streamflow and at the downstream sampling locations.
- The instantaneous injection of a slug of tracer solution is the basis of the sudden injection method.
- The determination of the total mass of the tracer at a sampling cross-section determines, indirectly, the stream discharge. Also, if the cross-sectional area of the stream or conduit is constant, the sudden injection method may also be used to determine the velocity of flow.

A constant rate injection system is illustrated in Figure below (a), provided the tracer is introduced into the stream for a sufficiently long period of time, the concentration variation at a downstream cross-section will resemble a concentration-time curve similar to Figure (b). The stream discharge can be computed using the equation given below.

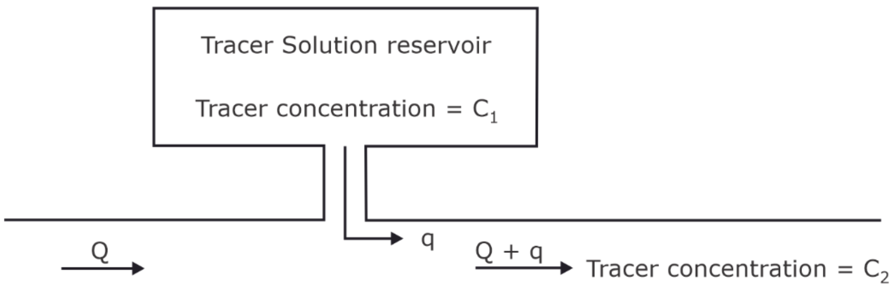


Figure (a). Constant rate tracer injection system.

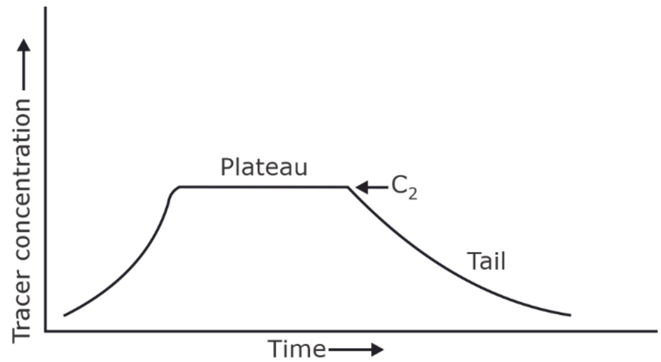


Figure (b). Typical concentration curve with constant tracer injection.

Conservation of mass requires that the following mass balance is satisfied within the stream.

$$QC_b + qC_1 = (Q + q)\,C_2$$

This equation can be rearranged to solve for the discharge.

$$\boxed{Q = \left[\frac{C_1 - C_2}{C_2 - C_b}\right] q}$$

Where

Q = Total stream discharge

q = Injected tracer flow rate

C_b = Background tracer concentration

C_1 = Injected tracer concentration

C_2 = Steady downstream tracer concentration

2. Sudden Injection Method

The instantaneous injection of a slug of tracer solution produced a downstream concentration-time curve similar to Figure (c). The stream discharge can be computed using the equation given below.

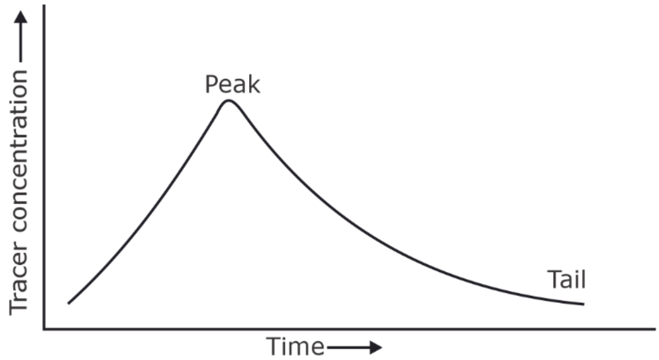


Figure (c). Typical concentration curve with sudden tracer injection.

Conservation of mass requires that the following mass balance is satisfied within the stream.

$$\boxed{Q = \frac{V_1 C_1}{\int_0^{\infty} (C - C_b)\,dt}}$$

Where;

Q= total stream discharge

V_1 = volume of the injected tracer

C_1 = injected tracer concentration

C = downstream tracer concentration at any given time

C_b = background tracer concentration

t = time

The integral expression is the total area beneath the concentration-time curve. The integral can be approximated by the summation,

$$\int_0^{\infty} (C - C_b)\,dt \cong \sum_{i=1}^{N} \frac{(C_i - C_b)(t_{i+1} - t_{i-1})}{2}$$

Where

i = sequence number of a sample

N = total number of samples

C_i = tracer concentration of sample i

t_i = time of sample i

2.(a) **(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).

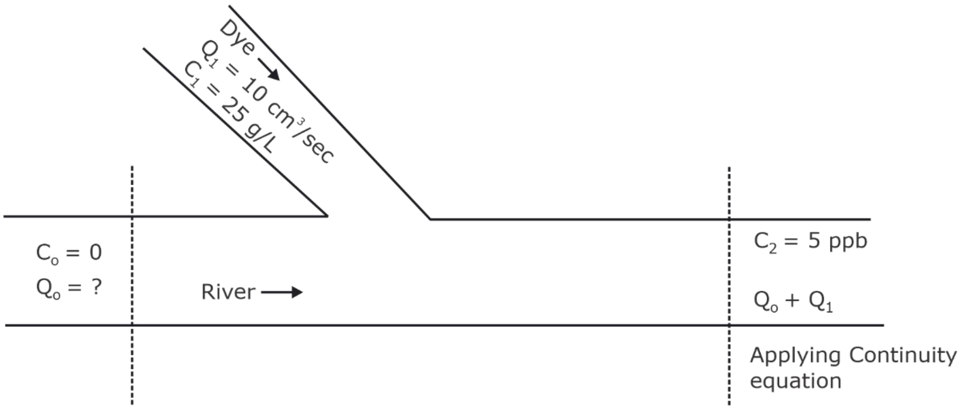
Given: Amount of Rhodamine Dye = 25 g/l

Constant rate of flow: 10 cm^3/s

Assume C_o, = 0.

[10 Marks]

Sol.



1 ppm = 10^3 ppb = 1 mg/L

C_2 = 5 ppb = 5 × 10^{-6} g/L

So,

$Q_oC_o + Q_1C_1 = (Q_o + Q_1)\ C_2$

$$0 + 10\frac{cm^3}{sec} \times 25\frac{gm}{L} = (Q_o + 10)\frac{cm^2}{sec} \times 5 \times 10^{-6}\ \frac{gm}{L}$$

The discharge of the river

Q_o = 50 × 106 cm^3/sec = 50 m^3/sec.

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]

Sol. Total daily supply= Rate of supply × Population

= 150 × 5× 10^5 L/day= 75 MLD

i. Continuous pumping:

Time	Demand (MLD)	Cumulative demand (CD) in MLD	Supply in MLD	Cumulative supply (CS) in MLD	Excess supply CS — CD	Excess demand CD — CS
0 — 3 AM	3.75	3.75	9.375	9.375	5.625	0
3 — 6 AM	3.75	7.5	9.375	18.75	11.25	0
6 — 9 AM	30	37.5	9.375	28.125	—	9.375
9 — 12 PM	7.5	45	9.375	37.5	—	7.5
12 — 3 PM	3.75	48.75	9.375	46.875	—	1.875
3 — 6 PM	7.5	56.25	9.375	56.25	0	0
6 — 9PM	15	71.25	9.375	65.625	5.625	5.625
9 — 12 PM	3.75	75	9.375	75	0	0

Demand= Supply= 75 MLD

75 ML/24 hour= 3.125 ML/hour

So,

For 3 hours supply, demand= 3×3.125= 9.375 ML

From the table above,

Maximum Excess supply= 11.25 MLD

Maximum Excess demand= 9.375 MLD

So,

Balancing storage= 9.375+ 11.25= 20.625 MLD

Fire demand= 2 lpcd= 2×5×10^5= 1 MLD

Breakdown storage for 2 hours= 3.125×2=6.25 MLD

So,

Total storage capacity of reservoir=

= Balancing storage+ Fire demand+ Breakdown storage

= 20.625+ 1+ 6.25= 27.875 MLD

ii. Pumping for 9 hours from 6 PM to 3 AM

Time	Demand (MLD)	Cumulative demand (CD) in MLD	Supply in MLD	Cumulative supply (CS) in MLD	Excess supply CS — CD	Excess demand CD — CS
0 — 3 AM	3.75	3.75	25	25	21.25	0
3 — 6 AM	3.75	7.5	—	25	17.5	0
6 — 9 AM	30	37.5	—	25	—	12.5
9 — 12 PM	7.5	45	—	25	—	20
12 — 3 PM	3.75	48.75	—	25	—	23.75
3 — 6 PM	7.5	56.25	—	25	—	31.25
6 — 9PM	15	71.25	25	50	—	21.25
9 — 12 PM	3.75	75	25	75	0	0

Demand= supply

75 ML is to be supplied in 9 hours i.e., from 6 PM to 3 AM

9 hrs — 75 ML

$$3\text{hrs} - 75 \times \frac{3}{9} = 25\text{mL / d}$$

Total balancing storage = maximum accumulation + maximum depletion

$|CS - CD|_{max} + |CD - CS|_{max}$

= 21.25+ 31.25

= 52.5 MLD

Breakdown storage for 2 hrs = $\frac{75}{24} \times 2 = 6.25\,\text{ml / d}$

Fire demand = $2 \times 5 \times 10^5$ = 1 MLD

Hence, Total storage required = Balancing storage + breakdown storage + fire demand

= 52.5 + 6.25 + 1

= 59.75 MLD

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]

Sol. Symbiosis is a close relationship between two species in which usually both get benefits from each other. Both species are called symbionts. Lichens, mycorrhizae, aphids, and ants where aphids provide ants with honeydew and ants protect them from predators.

Parasitism is a relationship between two species in which one of them benefitted and the other species is harmed. The species which is benefitted is called the parasite, and the species which is harmed is called the host. Example: Lice on the human head, Puccinia on wheat causing black rust disease, and helminths in the intestine of their hosts.

WORKING PRINCIPLE OF OXIDATION POND

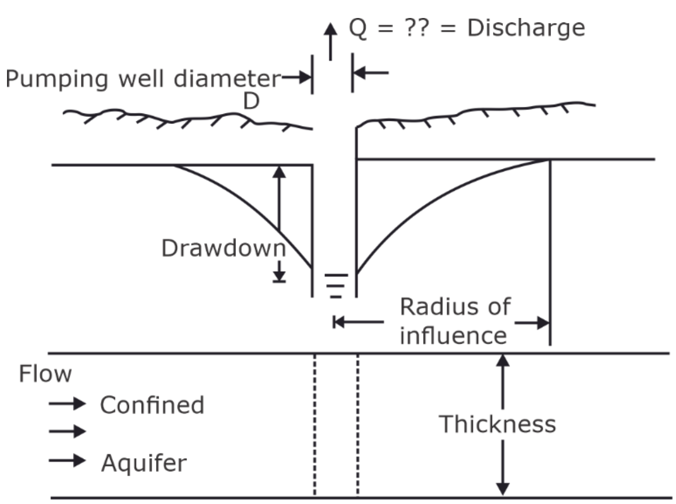
Oxidation pond is in the form of long earthen channel which has comparatively large detention time, during which microorganisms carry out decomposition of organic matter in suspension. In this pond a special relationship exists between aerobic microorganisms and algae in the aerobic zone. i.e., oxygen released by algae during photosynthesis is utilized by microorganisms to carry out decomposition of organic matter resulting in biomass which again reverts as nutrient for algae. This type of relationship also exists between aerobics and anaerobic microorganisms, in the bottom zone. Gases released by anaerobic microorganisms during decomposition rise to surface and to be used as food by aerobic microorganisms and biomass formed by aerobic microorganisms settles down to bottom layer to act as a nutrient for anaerobic microorganisms. Such mutual relationships are termed symbiotic relationships. In actual terms, oxidation pond is facultative process (practically). Oxidation pond is also known as stabilisation pond and symbiotic pond. Oxidation pond/ Stabilization Pond may be classified as aerobic, an aerobic or facultative depending upon mechanism of purification.

Importance of algal-bacteria symbiosis relationship in oxidation ponds–

The sewage which is applied to the oxidation pond is being stabilized by both aerobic and anaerobic reaction in different depths of the pond to a certain depth from the top. Aerobic microorganisms carry out decomposition of dissolved organic matter where oxygen to these microorganisms is being supplied through algal photosynthesis. The end products after aerobic decomposition are carbonates and sulphates. These end products are utilized by anaerobic microorganisms which finally results in the formation of methane.

Mass originating from raw waste and microbial synthesis in the aerobic layer and dissolved and suspended organics in the bottom layers undergo stabilization through conversion to CH_4 which escapes the pond in the form of bubble. Each kg of BOD ultimate is stabilized to 0.25 kg or 0.35 m^3 of CH_4.

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



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]

Sol. The given aquifer is confined.

Diameter of main well (D)= 30 cm

So,

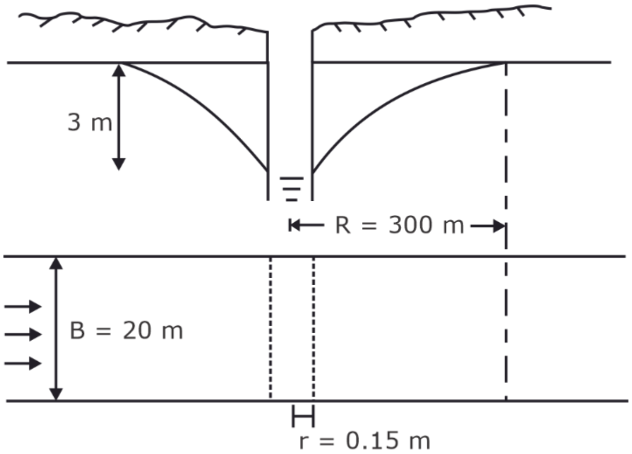
Radius of the well (r) = 0.15 m

Permeability (K) = 45 m/d

Length of strainer (B) = 20 m

Drawdown (S) = (H — h) = 3m

The radius of influence (R) = 300 m



The discharge (Q) for the confined aquifer is given as

$$Q = \frac{2\pi KB(H-h)}{2.303\log_{10}\left(\frac{R}{r}\right)}$$

$$Q = \frac{2\pi \times 45\frac{m}{d} \times 20 \times 3}{2.303\log_{10}\left(\frac{300}{0.15}\right)}$$

$$= 2231.517\frac{m^3}{d}$$

= 0.0258 m^3/s

Q = 25.827 l/s

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

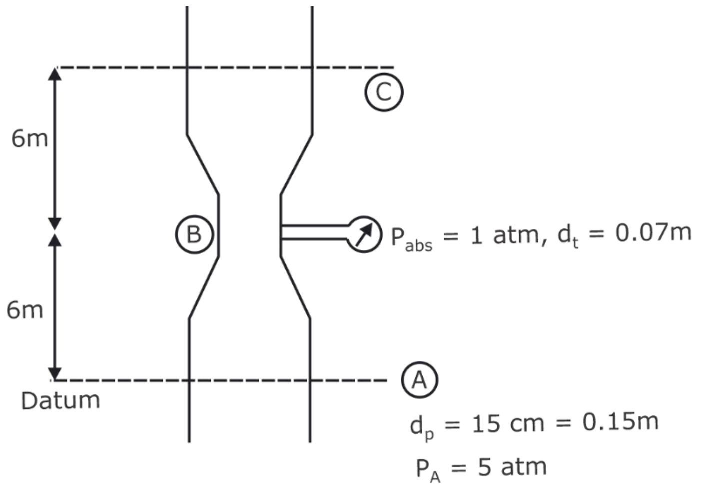
Venturimeter throat = 7 cm

Absolute pressure at throat = 1 atm

Pressure at 600 cm below the venturimeter = 5 atm

[20 Marks]

Sol.



Applying Bernoulli's equation at A and B

$$\frac{P_A}{\rho g} + Z_A + \frac{V_A^2}{2g} = \frac{P_B}{\rho g} + Z_B + \frac{V_B^2}{2g}$$

$Z_A = 0$, $Z_B = 6$m

$$\frac{P_A - P_B}{\rho g} - 6 = \frac{V_B^2 - V_A^2}{2g}$$

$$\frac{(5-1)\times 101.325}{9.81} - 6 = \frac{Q^2}{2g}\left[\frac{1}{A_B^2} - \frac{1}{A_A^2}\right]$$

$$35.315 = \frac{Q^2}{2\times 9.81}\left[\frac{1}{\frac{\pi^2}{16}(0.07)^4} - \frac{1}{\frac{\pi^2}{16}(0.15)^4}\right]$$

$Q = 0.1038\ m^3/sec$

$$\text{Velocity at throat} = \frac{Q}{\frac{\pi}{4}d_t^2} = \frac{0.1038\times 4}{\pi\times 0.07^2}$$

$V_t = 26.97$ m/sec

Now, applying Bernoulli's equation at A and C

$$\frac{P_A}{\rho g} + Z_A + \frac{V_A^2}{2g} = \frac{P_C}{\rho g} + Z_C + \frac{V_C^2}{2g}$$

$$P_C = P_A - 12\rho g = 5atm - \frac{12 \times 9.81}{101.325} \quad (V_A = V_C)$$

$\therefore \quad P_C = 3.838$ atm.

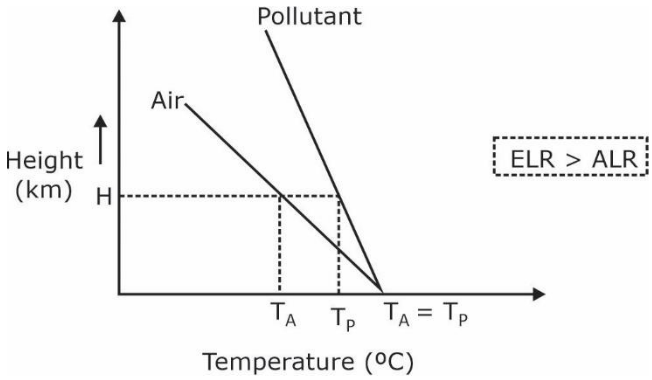
3.(c) With the help of sketches, explain the effect of lapse rate on plume behavior indicating the possible plume shapes and dispersion conditions.

[20 Marks]

Sol. In the troposphere, the temperature of the air decreases with increase in the altitude. The rate of change of temperature with respect to height is called lapse rate. Depending upon the relative magnitude of ELR and ALR different types of environments are being defined-

Unstable environment/Super Adiabatic environment

It is type of environment in which rate of decrease of temperature with height for air (ELR) is more than that of pollutant (ALR). Due to this, rapid mixing of pollutants takes place when released in this environment. In such a case the rising parcel of air will always remain warmer than the surrounding air and hence keep on rising in the atmosphere, and a descending parcel of heavier air will keep falling onto the earth's surface.

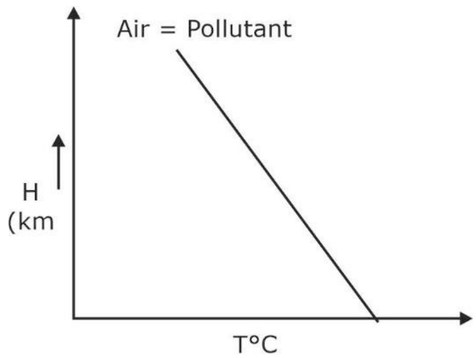


Stable or Sub-adiabatic environment

It is the type of environment in which the rate of decrease of temperature for air (ELR) is less than that of pollutant (ALR). This prevailing environmental lapse rate in such cases is called as sub-adiabatic lapse rate and the environment is called as the sub-adiabatic environment.

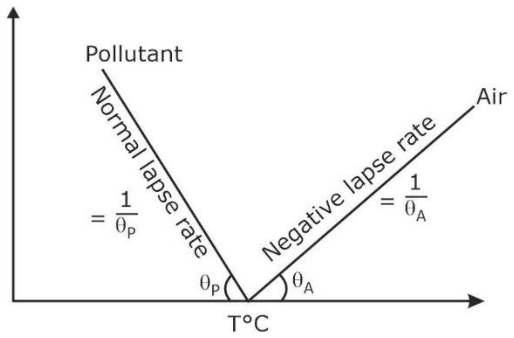
Neutral environment

It is the type of environment in which ELR = ALR



Inversion/Negative lapse

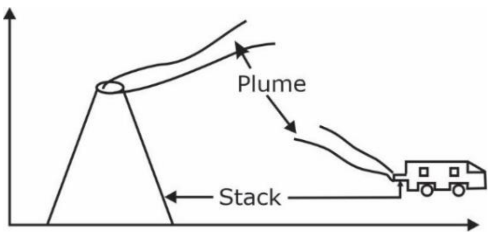
It is an unusual case in which temperature of environment increases with increase in height in troposphere instead of decreasing**.** The rate of increase of temp with height in this case is termed as negative lapse rate. In this case, warmer air lies over the colder air parcel (Pollutant) below.



The effect of lapse rate on plume behavior are as follows:

TYPES OF PLUMES

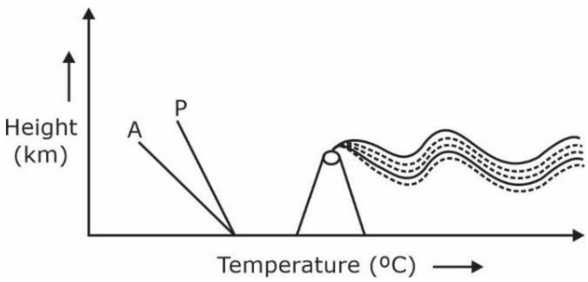
- Gases released into the atmosphere are termed as "Plumes," and the source of their origin is termed "STACK."
- The following types of plumes may be observed depending on the prevailing environmental conditions.



Plume & Stack

Looping plume

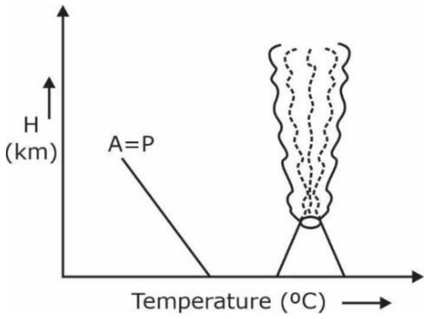
- This plume is formed in an unstable environment where ELR > ALR.
- Because of the rapid mixing of the pollutant, in this case, loops are formed, and wave character is observed. Hence, it is termed a looping plume. Therefore, it requires more stack height.
- During the high degree of turbulence, plume dispersion would be rapid.
- Higher concentrations near the ground may occur due to the turbulence before the dispersion is finally completed.



Looping Plume

Neutral Plume

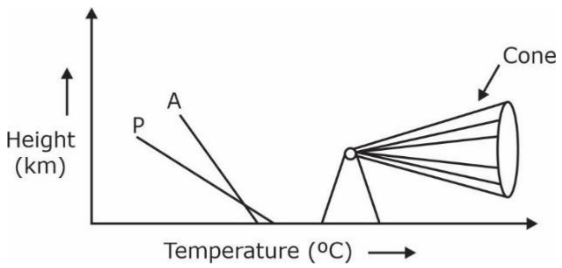
- It is a type of plume formed in neutral environments where ELR = ALR.
- It is characterized by the vertical rise of the pollutant from the stack.
- The upward lifting of the plume will continue till air density becomes similar to that of the plume itself.



Neutral Plume

Coning Plume

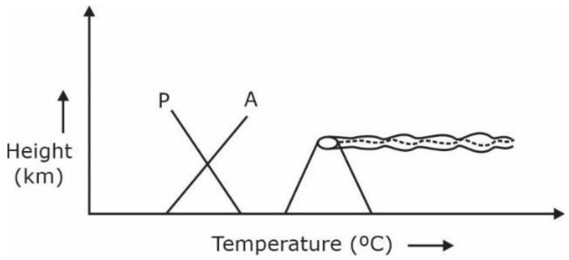
- This plume is observed in a stable environment with a neutral lapse rate and wind velocity greater than 32 km/hr.
- It is observed when cloud cover blocks solar radiation by day and terrestrial radiation by night.
- It appears like a cone in shape and hence is termed a coning plume, i.e., it has limited vertical mixing, increasing the chances of pollution.



Coning Plume

Fanning Plume

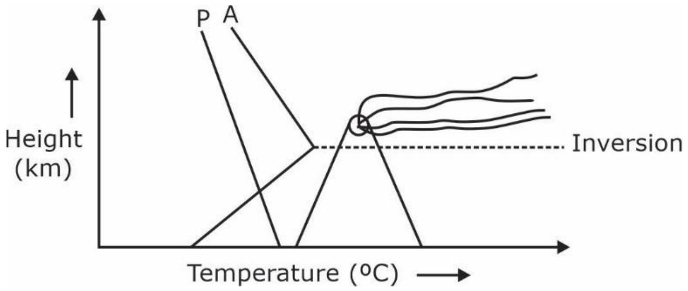
- This plume is observed in extreme inversion conditions with negative lapse rates.
- This plume is characterized by horizontal spread into the atmosphere due to a limited tendency to rise vertically.
- In this case, the height of the stack is properly designed to avoid interference with life.



Fanning Plume

Lofting Plume

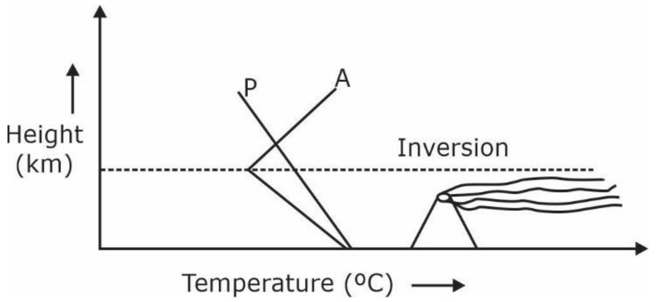
- This plume is found where a strong super adiabatic lapse rate exists over a surface inversion.
- This plume has minimum downward mixing due to the presence of inversion below it.
- It is the best condition for the dispersion of pollutants.



Lofting Plume

Fumigating Plume

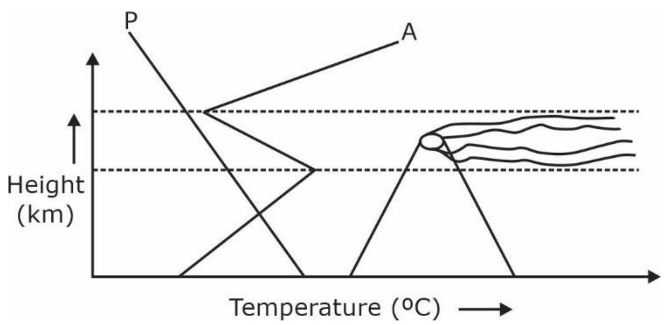
- When the inversion layer occurs at a short distance above the top of the stack, and the super adiabatic condition is present below it, it forms Fumigating plume.
- In such a case, the pollutant cannot escape above the top of the stack because of the inversion layer over it; hence continues to interface with the life in the biosphere.
- It is the worst condition for the dispersion of pollutants.



Fumigating Plume

Trapping plume

- When the inversion layer exists above and below the super adiabatic environment, i.e., the plume is caused between two inversion layers; it forms a trapping plume.
- It is considered a bad dispersion condition, as it cannot go above a certain height.



Trapping Plume

4.(a) Calculate (i) total installed capacity of turbo generators, (ii) load factor, (ii) 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]

Sol. **(i) Total installed capacity of turbo generators:**

The total installed capacity of the turbo generators is the sum of the capacities of all the generators. In this case, there are three generators, each having a capacity of 10,000 kW.

Total installed capacity = 3 × 10,000 kW = 30,000 kW

(ii) Load factor:

Load factor is a measure of the utilization of the installed capacity over a specific period. It is calculated as the average load divided by the maximum load during that period.

$$\text{Average load } = \frac{(12000\text{kW} + 26000\text{kW})}{2} = 19000\text{kW}$$

$$\text{Load factor } = \frac{(\text{Average load})}{(\text{Maximum load})} \times 100$$

$$= \frac{(19000\text{kW})}{(26000\text{kW})} \times 100$$

≈ 73.08%

(iii) Plant factor:

Plant factor is a measure of the actual generation compared to the maximum possible generation of the plant. It is calculated as the average load divided by the installed capacity.

$$\text{Plant factor } = \frac{(\text{Average load})}{(\text{Total installed capacity})} \times 100$$

$$= \frac{(19000\text{kW})}{(30000\text{kW})} \times 100$$

≈ 63.33%

(iv) Utilization factor:

It is the ratio of maximum demand on the power station to the rated capacity of the power station.

$$\text{Utilization factor } = \frac{(\text{Maximum Demand})}{(\text{Plant capacity})} \times 100$$

$$= \frac{(26000\,\text{kW})}{(30000\,\text{kW})} \times 100$$

≈ 86.66%

Therefore:

(i) The total installed capacity of the turbo generators is 30,000 kW.

(ii) The load factor is approximately 73.08%.

(iii) The plant factor is approximately 63.33%.

(iv) The utilization factor is approximately 86.66%.

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

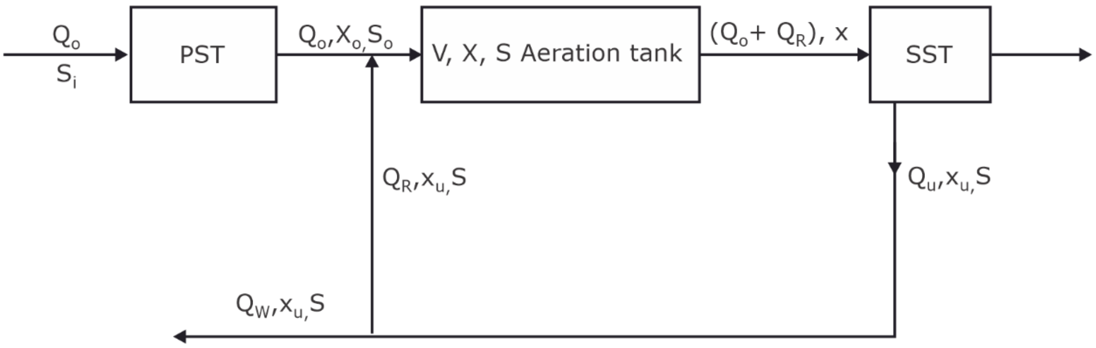
(ii) SDI

(iii) Return sludge ratio required

(iv) SS conc. in recirculated sludge

[20 Marks]

Sol.



X = MLSS = 3000 mg/L

(i) $\text{SVI} = \frac{V(\text{ml}/\text{L})}{X(\text{mg}/\text{L})} \times 10^3$

$= \frac{180}{3000} \times 10^3$

= 60 ml/gm

(ii) SDI

$\text{SDI} = \frac{100}{60} = 1.67\text{gm}/\text{ml}$

(iii) $\text{Xu} = \frac{1}{\text{SVI}}\left(\frac{\text{gm}}{\text{ml}}\right) \times 10^3 \left(\frac{\text{mg}}{\text{gm}}\right) \times 10^{-3} (\text{l}/\text{ml})$

$\text{xu} = \frac{10^6}{\text{SVI}} \text{mg}/\text{L}$

$= \frac{10^6}{60} \text{mg}/\text{L}$

= 16666.67 mg/L

So, $R = \frac{Q_R}{Q_o} = \frac{x}{x_u - x}$

$= \frac{3000}{16666.67 - 3000}$

= 0.2195

(iv) SS concentration in recirculated sludge= 16666.67 mg/l

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/m³)
1.	Newspaper	15	6	85
2.	Other Paper	24	6	85
3.	Carboard	33	5	50
4.	Glass	4.2	0.5	195
5.	Plastic	0.49	2	65
6.	Aluminum	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]

Sol. **Calculating moisture content on wet and dry basis**

Waste component	Mass (%)	MC (%)	Density kg/m³	Dry mass (%)	Volume = Mass/density
Newspaper	15	6	85	14.01	0.1765
Other paper	24	6	85	22.56	0.2823
Cardboard	33	5	50	31.35	0.660
Glass	4.2	0.5	195	4.179	0.0215
Plastic	0.49	2	65	0.4802	0.0075
Aluminum	0.13	0.5	160	0.1293	0.00081
Iron	1.18	0.5	320	1.1741	0.00368
Non-ferrous	0.35	0.5	160	0.3482	0.00218
Yard waste	17.97	60	105	7.188	0.1711
Food waste	1.67	60	290	0.668	0.00575
Soil and dust	2.01	8	480	1.8492	0.00418
	$\Sigma W = 100$			$W_d = 83.936$	V = 1.3355

Dry mass (%) calculation for Newspaper:

For newspaper, moisture content is 6%.

So,

94% is the dry content.

Mass (%) of newspaper= 15% (given)

Hence, Dry mass (%) for newspaper = 15 × 0.94 = 14.01%

Similarly,

dry mass (%) can be calculated for all other waste components.

Now, Wet moisture content = $\frac{\text{Total mass—dry mass}}{\text{Total mass}}$

$$= \frac{\Sigma w - wd}{\Sigma w}$$

$$= \left(\frac{100 - 83.936}{100}\right) \times 100$$

= 16.064%

Now,

$$\text{Moisture content of MSW on dry basis} = \frac{\text{Total mass} - \text{dry mass}}{\text{Total dry mass}}$$

$$= \left(\frac{100-83.936}{83.936}\right) \times 100$$

= 19.138%

Now,

$$\text{As-discarded density} = \frac{w}{v} = \frac{100}{1.3355}$$

= 74.878 kg/m^3

Now,

Calculation of size of collection vehicle (V)

Since,

Compaction ratio = 3 (given)

So,

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

Hence, Density of MSW in vehicle = 3 × 74.878 kg/m^3 = 224.634 kg/m^3

As, the Mass of MSW = 1000 kg

So,

$$\text{Density of MSW in vehicle} = \frac{\text{Mass of MSW in vehicle}}{\text{Volume of vehicle}}$$

$$\text{Volume of collection vehicle} = \frac{1000\,\text{Kg}}{3 \times 74.878\,\text{Kg/m}^3}$$

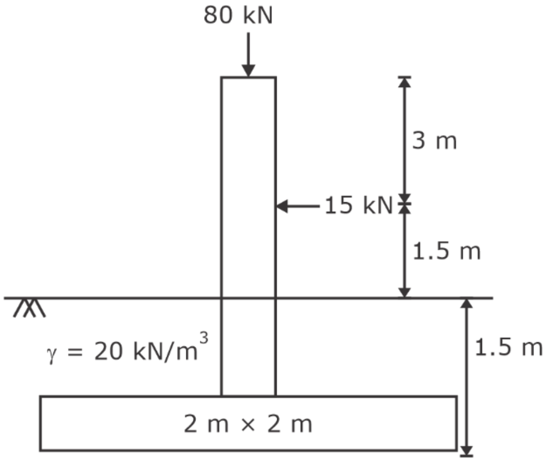
Volume of collection vehicle = 4.452 m^3

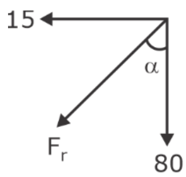
SECTION-'B'

5.(a) A 6 m high pier rests on a 2 m x 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]

Sol.

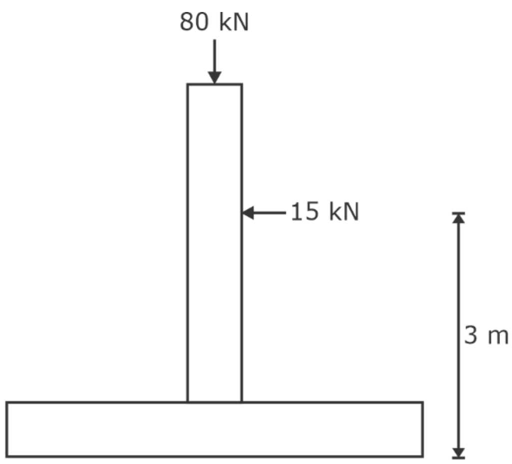




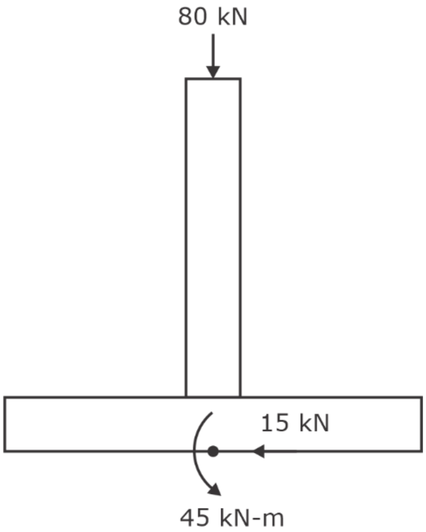
Resultant force

$$F_r = \sqrt{80^2 + 15^2} = 81.39 \text{ kN}$$

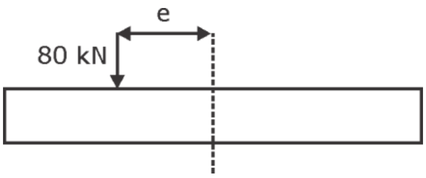
$$\tan\alpha = \frac{15}{80} \Rightarrow \alpha = 10.62°$$



Equivalent loading to the given loading condition will be as shown below–

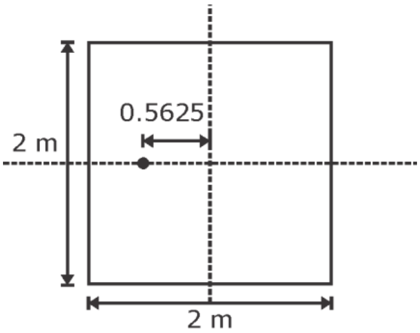


For the moment (45 kN–m) consider the load 80 kN acting at an eccentricity ‘e’.

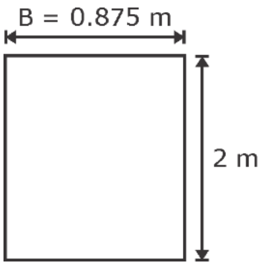


$80 \times e = 45$

$\Rightarrow e = 0.5625$ m



Plan



Reduced dimension

$B = 2 - 2 \times 0.5625$

$= 0.875$ m

Reduced area = B × L = 0.875 × 2 = 1.75 m^2

As per IS 6403

For $\varphi = 0$ (since it is clay)

$N_C = 5.14$, $N_q = 1$, $N_\gamma = 0$

$$S_C = \left[1 + \frac{0.2B}{L}\right] = 1.0875$$

$S_q = 1$

$$d_c = 1 + 0.2\frac{D}{B}\sqrt{N_\phi}$$

$$N_\phi = \tan^2\left(45 + \frac{\phi}{2}\right) = \tan^2(45 + 0) = 1$$

$$d_c = 1 + 0.2 \times \frac{1.5}{0.875}\sqrt{1} = 1.34$$

$$i_c = \left(1 - \frac{\alpha}{90^\circ}\right)^2 = \left(1 - \frac{10.62}{90}\right)^2 = 0.78$$

Unconfined compressive strength = 100 kPa

$$\Rightarrow \text{Cohesion, } C = \frac{100}{2} = 50\,\text{kPa}$$

Net ultimate bearing capacity

$q_{net} = C\, N_C\, S_C\, d_C\, i_C + q(N_q - 1)\, S_q\, d_q\, i_q$ ($N_\gamma = 0$)

$= C\, N_C\, S_C\, d_C\, i_C + 0$ ($N_q = 1$)

$= 50 \times 5.14 \times 1.0875 \times 1.34 \times 0.78$

$= 292.12$ kN/m^2

Net ultimate load = $q_{net} \times A$

$= 292.12 \times 0.875 \times 2$

$= 511.21$ kN

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

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 depth 1 m below the base, and:

(i) Along the centre, and

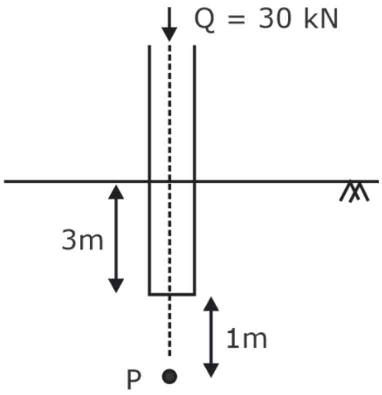
(ii) 1m from the centre.

[12 Marks]

Sol. As mentioned in the question, the load is assumed as point load.

$Q = 30$ kN

(i) Stress increase at a depth 1m below the base of the pole along the centre.



z = 1 m, r = 0 m

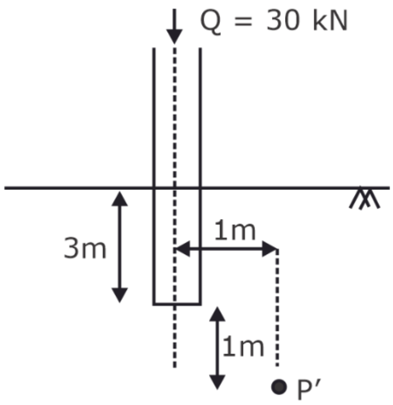
Using Boussinesq's equation, stress increase at point P

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

$$= \frac{3\times 30}{2\pi \times 1^2}\left[\frac{1}{1+0}\right]^{5/2}$$

= 14.32 kN/m^2

(ii) Stress increase at a depth 1m below the base of pole and 1m from centre.



z = 1 m, r = 1 m

Using Boussinesq's equation, stress increase at point P'

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

$$= \frac{3\times 30}{2\pi \times 1^2}\left[\frac{1}{1+\frac{1^2}{1^2}}\right]^{5/2}$$

= 2.53 kN/m^2

Note – We can also use Westergaard's equation. Even though Westergaard's equation will give more realistic results, for the given r and z values of soil, the stress value given by Boussinesq's equation will be more and hence, it will give a more conservative result.

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]

Sol. The modernization of railway tracks with the aim to increase average speed and capacity involves various key factors. Here are some of the important considerations:

Track Alignment and Geometry: Improving track alignment and geometry is crucial for achieving higher speeds. This involves straightening curves, reducing gradients, and ensuring smooth transitions between sections. It helps trains maintain higher speeds and reduces wear and tear on the rolling stock.

Track Structure: Upgrading the track structure involves replacing old and worn-out components with modern materials that provide better stability, durability, and load-bearing capacity. This includes the use of high-quality rails, sleepers, ballast, and fastening systems.

Signalling and Train Control Systems: Implementing advanced signaling and train control systems, such as positive train control (PTC) or European Train Control System (ETCS), can enhance safety and increase capacity. These systems enable closer train spacing, more efficient braking and acceleration, and reduce the risk of collisions.

Electrification: Electrifying the railway track eliminates the reliance on fossil fuels, reduces operating costs, and enables faster acceleration and higher speeds. It involves installing overhead catenary wires or a third rail system to provide electric power to trains.

Level Crossings and Grade Separation: Modernization projects often involve eliminating level crossings or replacing them with grade-separated crossings. This reduces the chances of accidents and minimizes disruptions to train operations.

Advanced Train Technologies: Introducing modern train technologies, such as high-speed trains or maglev (magnetic levitation) systems, can significantly increase average speeds and capacity. These trains are designed for faster acceleration, reduced air resistance, and smoother rides.

Capacity Enhancements: Increasing capacity often involves adding additional tracks, constructing passing loops, or building new sections of railway lines. These measures enable more trains to operate simultaneously and allow for better segregation of fast and slow-moving trains.

Maintenance and Monitoring Systems: Implementing advanced maintenance and monitoring systems, including track condition monitoring, predictive maintenance, and automated inspection tools, helps ensure the safe and reliable operation of the modernized track. These systems enable proactive maintenance interventions and reduce downtime.

Integration with Digital Technologies: Integrating the modernized track with digital technologies, such as real-time train tracking, data analytics, and predictive modelling, can optimize train scheduling, maintenance planning, and overall system performance. These technologies enable operators to make data-driven decisions and respond effectively to disruptions.

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]

Sol. Velocity of overtaking car, v_b = 64 km/h

$OSD = d_1 + d_2$

$d_1 = 0.278\ v_b t = 0.278 \times 64 \times 2.5$

$d_1 = 44.48$ m

$S = 0.7\ (0.278\ v_b) + 6$

$S = 0.7 \times 0.278 \times 64 + 6 = 18.45$ m

$$T = \sqrt{\frac{4S}{a}} = \sqrt{\frac{4 \times 18.45}{0.95}} = 8.89\,\text{sec}$$

$d_2 = 2S + 0.278\ v_b T$

$d_2 = 2 \times 18.45 + 0.278 \times 64 \times 8.89$

$d_2 = 195.1$ m

Road	**O.S.D.**
1 way	$d_1 + d_2$
2 way	$d_1 + d_2 + d_3$

OSD = 44.48 + 195.1 = 239.58 m

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]

Sol. Arithmetic check

$\Sigma BS - \Sigma FS$ = Last RL − First RL

Note: But as per question last reading is given as IS & if we want to apply check between BM_1 & BM_2 the reading 0.420 should be taken as FS.

$\Sigma BS = 75.205$ m

$\Sigma FS = 23.450 + 0.42 = 23.870$ m

$\Sigma BS - \Sigma FS = 51.335$ m (measured value)

Last BM − first BM = 264.005 − 212.40 = 51.605 m (true value)

Error = MV − TV= -0.27 m

Permissible error = $\pm 24\sqrt{K}$

For k= 30 km

$e = \pm 24\sqrt{30}$

$e = \pm 131.4534\,mm = \pm 0.1314534$ m

Our error (0.27m) > Permissible error (0.1314m)

$\therefore$ Work is not satisfactory.

6.(a) **(i)** An embankment is to be constructed using clay compacted to dry unit weight of 18 kN/m^3. The sandy clay has to be transported to the site from a borrow pit. The bulk unit weight of the sandy clay in the borrow pit is 16 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]

Sol. **For embankment**

Volume of finished embankment = 1 m^3

Dry unit weight of embankment, γ_d = 18 kN/m^3

$$\gamma_d = \frac{\text{weight of solids}(W_s)}{\text{Volume of embankment}}$$

$$18 = \frac{W_s}{1} \Rightarrow W_s = 18kN$$

For Borrow-pit

Since, weight of solid will remain constant,

Weight of solids for burrow pit, W_s = 18 kN

Bulk unit weight of burrow pit, γ_b = 16 kN/m^3

Natural water content, w = 11%

Specific gravity, G_s = 2.7

Dry unit weight of burrow pit,

$$\gamma_d = \frac{\gamma_b}{1+w} \Rightarrow \gamma_d = \frac{16}{1+0.11} = 14.41kN/m^3$$

Let volume of burrow pit without considering swelling = V

$$\gamma_d = \frac{W_s}{V} \Rightarrow 14.41 = \frac{18}{V}$$

V = 1.249 m^3

Since there is 10% swelling due to excavation and during transportation.

Required volume of sandy clay from burrow pit

= 1.1 × 1.249

= 1.374 m^3

6.(a) (ii) A 1.2 m thick embankment of loose 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]

Sol. Initial thickness of embankment, H_o = 1.2m

Initial void ratio, e_o = 1.2

Final void ratio, e_f = 0.8

Let the change in thickness of embankment be ΔH

Assuming 1-D compression

$$\frac{\Delta H}{H_0} = \frac{\Delta e}{1+e_0}$$

$$\Rightarrow \frac{\Delta H}{1.2} = \frac{1.2-0.8}{1+1.2}$$

$$\Delta H = \frac{0.4 \times 1.2}{2.2}$$

= 0.218 m

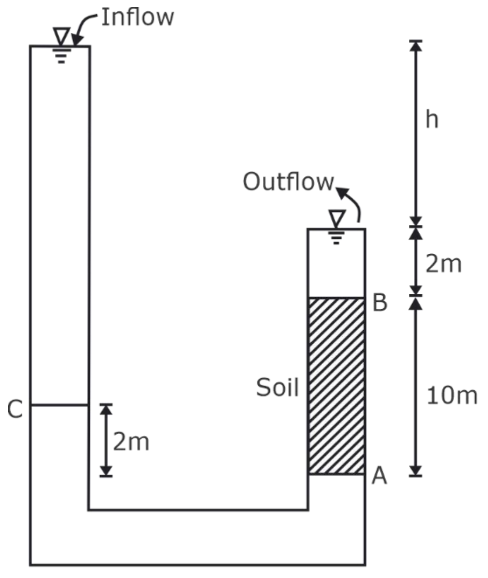
Let final thickness of embankment be H_f

$H_f = H_o - \Delta H$

= 1.2 — 0.218

= 0.982 m

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



γ_{sat} of sand = 20 kN/m^3

γ_w = 10 kN/m^3

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

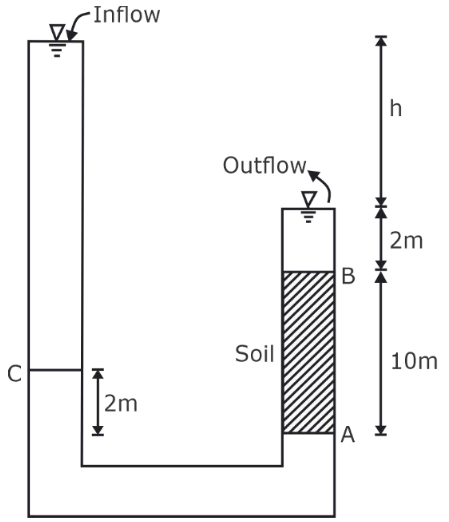
(ii) Compute the seepage force per unit volume at quick condition.

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]

Sol.



(i) Head required to cause quick sand condition

$\bar{\sigma}_{net}$ at $A = 0$ [For quick sand condition]

$\gamma_{sub} z - iz\gamma_w = 0$

$(\gamma_{sat} - \gamma_w) z - \frac{h}{L} Z\gamma_w = 0$

$(20 - 10)10 = \frac{h}{10}.10.10$

h = 10 m

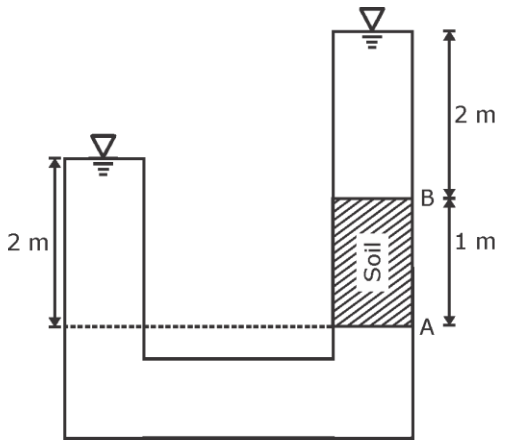
(ii) Seepage force per unit volume (f_s)

$f_s = i\gamma_w = \frac{h}{L}\gamma_w$

$= \frac{10}{10} \times 10$ (Assume same head as quick sand condition)

$f_s = 10\ kN/m^3$

(iii)



Flow will be downwards

$$i = \frac{h_L}{L} = \frac{10}{10} = 1$$

$$\bar{\sigma}_A = \gamma_{sub} z + iz\gamma_w$$

$= 10 \times (20 - 10) + 1 \times 10 \times 10 = 200$ kN/m^2

Seepage force at A = $h_L \gamma_w A$

$= 10 \times 10 \times 1$

$= 100$ kN

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]

Sol. **Topography and Terrain:** The topography of the hilly region plays a significant role in site selection. The airport site should have a relatively flat terrain with minimal slopes to facilitate runway construction and aircraft operations. Steep slopes, excessive undulations, or rocky terrain may make construction difficult and restrict expansion options.

Accessibility: The site should have good connectivity and accessibility to the surrounding region. It should be located close to major cities or population centers to ensure ease of travel for passengers. Proximity to existing road networks and availability of transportation infrastructure is crucial for convenient access to the airport.

Weather Conditions: The hilly region may experience adverse weather conditions such as fog, high winds, or heavy precipitation. It is important to consider the local climate and weather patterns when selecting the site. Factors such as wind direction, average visibility, and precipitation levels should be studied to assess the impact on flight operations.

Safety: Safety is a critical factor in airport site selection. The site should be away from high-risk areas prone to natural disasters such as landslides, avalanches, or seismic activity. It is essential to conduct a thorough geotechnical and geological assessment to ensure stability and minimize the risk of hazards.

Environmental Impact: The selection process should consider the environmental impact of the airport on the surrounding ecosystem. Environmental studies should be conducted to assess the potential impact on flora, fauna, water bodies, and air quality. Mitigation measures such as noise reduction, wildlife conservation, and wastewater treatment should be incorporated into the design and planning of the airport.

Land Availability and Acquisition: Sufficient land availability is crucial for airport development and future expansion. The site should offer ample land for runway length, taxiways, aprons, terminal buildings, parking facilities, and other airport infrastructure. Acquiring the necessary land should be feasible without significant legal, social, or environmental conflicts.

Obstacle Limitation: The presence of tall structures or natural obstacles, such as mountains or hills, near the airport site can pose challenges to aircraft operations. A thorough obstacle limitation study should be conducted to ensure the approach and departure paths are free from obstructions.

Infrastructure and Utilities: The availability of essential infrastructure and utilities is important for the successful operation of the airport. Adequate water supply, power supply, sewage systems, and telecommunication networks should be readily accessible to the site. If these utilities are not readily available, the cost and feasibility of establishing them should be evaluated.

Future Growth and Expansion: The airport site should have potential for future growth and expansion to accommodate increasing air traffic demand. Sufficient land should be available for runway extensions, the addition of new terminals or facilities, and the construction of cargo or maintenance areas. A master plan for the airport should be developed to ensure long-term scalability.

Economic Viability: The economic feasibility and potential for the airport to stimulate local and regional development should be assessed. The site should have the capacity to attract airlines, support tourism, and stimulate economic activities in the surrounding areas. A comprehensive economic impact analysis should be conducted to evaluate the potential benefits and returns on investment.

By considering these criteria, an informed decision can be made regarding the selection of a suitable site for a civilian greenfield airport in a hilly region.

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

[5 Marks]

Sol. Essential features of an ideal commercial harbors

In general, any harbor should have following features.

1. Channel should have sufficient depth for draft of vessels.
2. Bottom of harbors should have secured anchorage to hold ships against strong winds.
3. Land masses or breakwater must be provided to protect from strong waves.
4. Entrance width should be optimum, keeping in mind the entry of various ships at the same time restrict transfer of wave energy in case of storms.

In addition, for commercial harbors following requirements should be met.

1. Storage sheds for cargo
2. Repair facility
3. Long and large quays for fast and easy loading/unloading.
4. Sufficient accommodation of commercial marines.

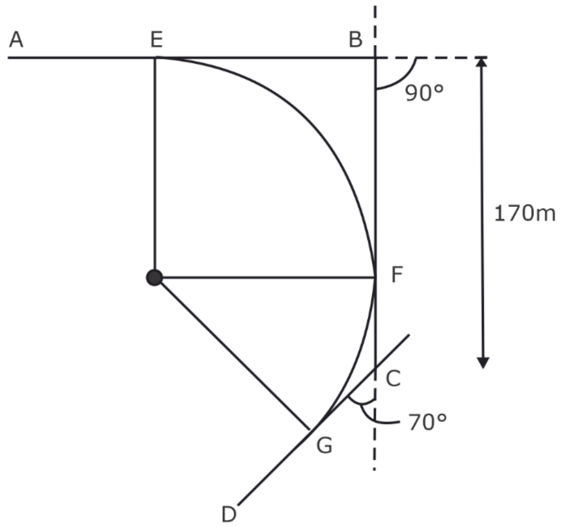
7.(a) A simple circular curve is to set out in a National Highway touching the three lines having following details:

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]

Sol. Assuming CF = x



For curve E to F, FB is the tangent length

$$\therefore \ EB = BF = R\tan\left(\frac{90}{2}\right)$$

or R tan 45° = (170 — x) ...(i)

For curve F to G, CF is the tangent length

$$CF = R\tan\left(\frac{70}{2}\right)$$

$$x = R\tan\left(\frac{70}{2}\right) \qquad \text{...(ii)}$$

Equating x from both equation

170 — R tan 45° = R tan 35°

R= 100 m

Now, Length of curve $EF = \frac{\pi R\Delta}{180} = \frac{\pi \times 100 \times 90}{180} = 157.08$ m

Also, Length of curve E to G = $\frac{\pi \times R \times 70^\circ}{180} = 122.17$ m

Chainage of tangent point E = 700 — 100 = 600 m

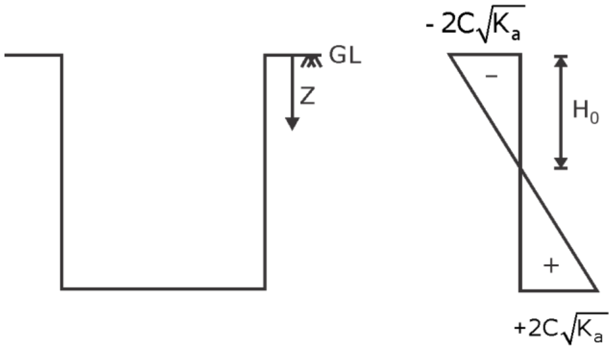
Chainage tangent point F = 600 + 157.08 = 757.08 m

Chainage of tangent point G = 757.08 + 122.17 = 879.25 m

7.(b) **(i)** A long trench with vertical sides is to be excavated in soft saturated clay deposits ($\varphi_u = 0$) 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]

Sol.



From the pressure diagram, it is clear that active earth pressure is negative upto certain depth and becomes zero at H_0

$$\sigma_H = K_a\gamma z - 2C\sqrt{K_a}$$

$$0 = K_a\gamma H_0 - 2C\sqrt{K_a}$$

$$H_0 = \frac{2C}{\gamma\sqrt{K_a}}$$

At z = $2H_0$ when positive and negative region of earth pressure diagram will be equal, then net pressure will be zero. Till this depth, excavation in cohesive soil can stand without support.

So, the critical height, $H_C = 2H_0$

$$H_C = \frac{4C}{\gamma\sqrt{K_a}}$$

For $\varphi = 0°$

$$K_a = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1-\sin 0}{1+\sin 0} = 1$$

Factor of safety is given as

$$FOS = \frac{H_C}{H}$$

$$3 = \frac{H_C}{2} \Rightarrow H_C = 6$$

$$\frac{4C}{\gamma\sqrt{K_a}} = 6 \Rightarrow \frac{4C}{20\sqrt{1}} = 6$$

$\Rightarrow$ C = 30 kPa

7.(b) **(ii)** A 10 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]

Sol. Plastic limit, w_P = 18%

Liquid limit, w_L = 39%

Liquidity index, I_L = – 0.1

Let natural water content be W_n

$$I_L = \frac{w_n - w_P}{w_L - w_P}$$

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

w_n = 0.159 = 15.9%

Since, $w_n < w_P \rightarrow$ Soil is in semi–solid stage.

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 degree
Angle of wall friction between pile and sand, δ	20 degree
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]

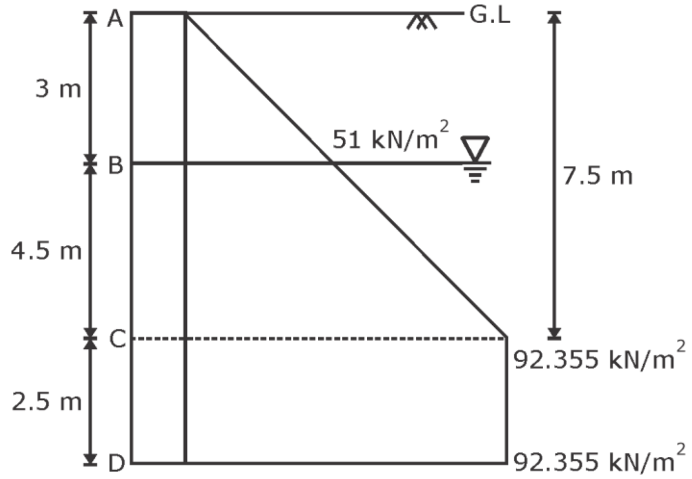
Sol. Given:

Diameter of pile = 0.5 m

$\varphi = 30°$, $\delta = 20°$, k = 1

γ_{sat} = 19 kN/m^3

γ_{bulk} = 17 kN/m^3



Effective stress at A = 0

Effective stress at B = $\gamma_{bulk} \times 3$ = 17 × 3 = 51 kN/m^2

Effective stress at C = $\gamma_{bulk} \times 3 + \gamma_{sub} \times 4.5$

= 17 × 3 + (19 – 9.81) × 4.5

= 92.355 kN/m^2

Since, the limiting value of shaft resistance reaches at critical depth of 15D = 15 × 0.5 = 7.5m.

So, effective stress will be uniform below 7.5 m depth.

Skin friction resistance,

$Q_F = q_F \times A_S$

A_S is the surface area of pile

$q_F = k\bar{\sigma}_{av} \tan\delta$

Total $Q_F = Q_{FAB} + Q_{FBC} + Q_{CFD}$

$$= 1\tan 20\left[\frac{0+51}{2}\right]\times\pi\times0.5\times3 + 1\tan 20\left[\frac{51+92.355}{2}\right]\times\pi\times0.5\times4.5$$

$$+ 1\tan 20\times92.355\times\pi\times0.5\times2.5$$

= 360.15 kN

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 (ϕ_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 α = 0.8 and friction coefficient in uplift K = 0.5.

[12 Marks]

Sol. γ_{sat} = 18 kN/m^3

γ_w = 9.81 kN/m^3

Shear strength = C + σ tan φ

C + σ tan φ = 60

C + σ tan 0 = 60

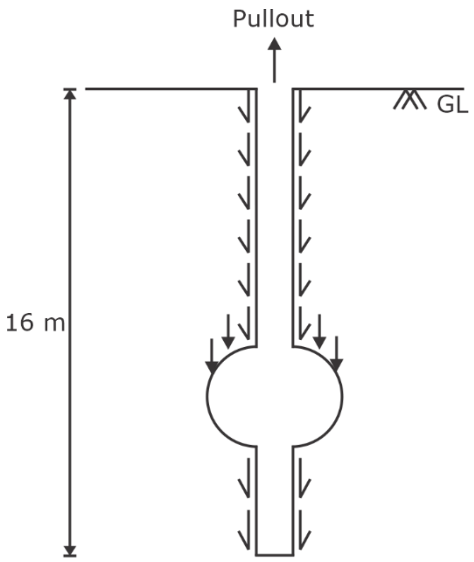
C = 60 kPa

While pulling out the pile, 3 factors will provide resistance

(a) Friction

(b) End bearing at enlarged portion

(c) Weight (assumed to be zero as given in question)



Pullout capacity = friction + end bearing

$$= \alpha C\pi DL + CN_C\text{Area}$$

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

= 1904.724 kN

Assuming efficiency of 100%, the ultimate pullout capacity = 1904.724 kN

8.(a) **(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]

Sol. Shallow foundation will be used as load due to single storey would be less.

- As the particles that are dumped in the site are larger, soil will be compacted by vibratory roller.

- Even before compaction to make soil stronger, so that bearing capacity can be increased, we should add suitable soil also.
- A slab foundation can be laid with reinforcement as per design load.

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	Other
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]

Sol.

Speed (km/hr)	Average (km/hr)	Frequency			Total Frequency	% frequency	Cumulative frequency
		2-wheeler	Car	Other			
0—10	5	5	0	0	5	1	1
10—20	15	20	6	4	30	6	7
20—30	25	24	12	4	40	8	15
30—40	35	20	30	5	55	11	26
40—50	45	30	60	30	120	24	50
50—60	55	35	35	30	100	20	70
60—70	65	25	35	15	75	15	85
70—80	75	10	15	10	35	7	92
80—90	85	10	18	2	30	6	98
90—100	95	1	9	0	10	2	100

(i) Design speed corresponding to 98th percentile speed

$$V_{98} = 85 \text{ kmph}$$

(ii) Lower speed limit corresponds to 15th percentile speed

$$V_{15} = 25 \text{ kmph}$$

Upper speed limit corresponds to 85th percentile speed

$$V_{85} = 65 \text{ kmph}$$

(iii) There are several measures that can be implemented to increase the spot speed of vehicles moving on the road. Here are some common strategies:

Road Infrastructure Improvements: Enhancing the quality of the road infrastructure can help increase spot speed. This includes widening lanes, improving road surface conditions, and minimizing road hazards. Upgrading intersections with traffic signals or roundabouts can also facilitate smoother traffic flow.

Traffic Signal Synchronization: Coordinating traffic signals along a road or a network of roads can minimize delays and improve the efficiency of traffic flow. Synchronized signals aim to reduce the number of stops and starts, allowing vehicles to maintain a higher average speed.

Intelligent Transportation Systems (ITS): Implementing ITS technologies can improve spot speeds. These include traffic monitoring cameras, dynamic message signs, and variable speed limit systems that provide real-time information to drivers, enabling them to make informed decisions and adjust their speed accordingly.

Access Management: Properly managing access points to roads can minimize conflicts and disruptions. This involves strategically locating entrances, exits, and driveways, as well as restricting direct access to high-speed roadways, such as using ramps or grade separations.

Speed Limit Adjustments: Evaluating and adjusting speed limits based on engineering studies and prevailing traffic conditions can optimize spot speeds. Setting appropriate speed limits that align with road characteristics and traffic patterns helps maintain a smoother traffic flow.

Enforcement and Education: Strict enforcement of traffic laws, especially regarding speeding, can encourage drivers to comply with speed limits and reduce the likelihood of excessive speeds. Educational campaigns and driver awareness programs can also promote responsible driving behavior and increase awareness of the importance of adhering to speed limits.

Public Transportation and Carpooling: Encouraging the use of public transportation and carpooling can reduce the number of vehicles on the road, thereby decreasing congestion and improving spot speeds for those who still need to drive.

(iv) Mean speed, $u_{avg} = \dfrac{\sum(\text{Frequency} \times \text{Speed})}{\sum \text{Frequency}} = \dfrac{25300}{500} = 50.6 \text{ kmph}$

Standard deviation $\sigma = \sqrt{\dfrac{\Sigma f\left(u - u_{avg}\right)^2}{n-1}}$

$$\sigma = \sqrt{\frac{185320}{500 - 1}}$$

σ = 19.27 kmph

For speed distribution to be normal, σ should be approximately half the difference between 85th percentile speed and 15th percentile speed.

$$\frac{V_{85} - V_{15}}{2} = 20 \text{ kmph}$$

Hence the distribution is reasonably normal.

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°.

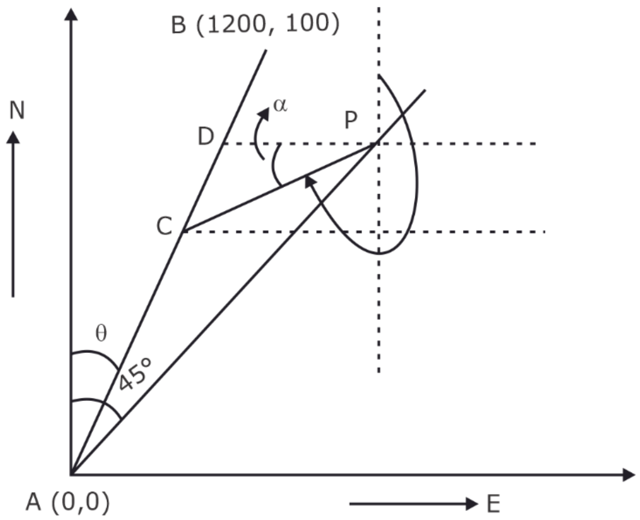
Calculate:

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

(ii) The length and bearing of line PC.

[20 Marks]

Sol.



The independent co-ordinates of points A & B are shown in the diagram.

L_{AC} = Length of line AC

L_{Ap} = Length of line AP

L_{AC} = 400 m

L_{AP} = 600 m

θ_{AP} = Bearing of line AP

θ_{AP} = 45°

(i) Calculate of independent co-ordinate of C & P

For point P

Northing of P = L_{AP} cos 45= 600 cos 45° = 424.264 m

Easting of P = L_{AP} sin 45= 600 sin 45° = 424.264 m

Co-ordinate of P is (424.264 m, 424.264 m)

Since Point C lies on the line AB, hence

θ = bearing of line AB = Bearing of line AC

$$\tan\theta = \frac{100}{1200}$$

θ = 4.76°

Northing of C = L_{AC} cos 4.76°= 400 cos 4.76 = 398.618

Easting of C = L_{AC} sin 4.76°= 400 sin 4.76 = 33.213 m

Co-ordinate of C is (398.618 m, 33.213 m)

(ii) Calculate of length and bearing of line PC

If L_{PC} is length of line PC then

$$L_{PC} = \sqrt{(424.264 - 398.618)^2 + (424.264 - 33213)^2} = 391.891 \text{ m}$$

Let ∠DPC = α

$$\tan\alpha = \frac{424.264 - 398.681}{424.264 - 33.213}$$

α = 3.743°

Bearing of line PC = 270° — 3.743°= 266.256°

The length of PC is 391.891 m and bearing of line PC is 266.256°

****

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