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ESE – 2019
(MAINS)

Questions with Detailed Solutions

CIVIL ENGINEERING

PAPER – II

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CIVIL ENGINEERING

ESE _MAINS_2019_PAPER – II

PAPER REVIEW

Except few questions from Geotechnical remaining questions in the paper can be easily attempted. Particularly in this paper selection of questions plays a vital role in securing a good score. For example Section-A is relatively easy than Section-B, so choosing 3 questions from Section-A will fetch you a big advantage.

SUBJECT WISE REVIEW

SUBJECT(S)	LEVEL	Marks
SECTION-A		
Fluid Mechanics	Moderate	62
Hydraulic Machines	Moderate	20
Environmental Engineering	Moderate	84
Hydrology	Moderate	32
Irrigation	Easy	42
SECTION-B	**LEVEL**	**Marks**
Geotechnical Engineering	Hard	99
Surveying	Moderate	52
Highway Engineering	Moderate	65
Airport Engineering & Railway Engineering	Easy	24

Subject Experts,
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SECTION-A

01(a). The velocity vector in an incompressible flow is given by

$V = (6xt + yz^2)i + (3t + xy^2)j + (xy - 2xyz - 6tz)k$

(i) Verify whether the continuity equation is satisfied.

(ii) Determine the acceleration in x direction at point A (1, 1, 1) and t = 1.0 [12 M]

01(a).

Sol: (i) $u = 6\,xt + yz^2$

$v = 3t + xy^2$

$w = xy - 2\,xyz - 6tz$

$$\frac{\partial u}{\partial x} = 6 \times 1 \times t + 0 = 6t$$

$$\frac{\partial v}{\partial y} = 0 + x.(2y) = 2xy$$

$$\frac{\partial w}{\partial z} = 0 - 2xy.1 - 6t = -2xy - 6t$$

Condition of continuity equation for 3- D. Incompressible fluid flow.

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0$$

$(+6t) + (2xy) + (-2xy-6t) = 0$

Yes, the given velocity vector satisfied the condition of continuity equation

(ii) Acceleration (a_x) at (1, 1, 1) and t = 1.0 sec

$a_x = a_{local} + a_{convective}$

$$a_{local} = \frac{\partial u}{\partial t} = \frac{\partial}{\partial t}\left(6xt + yz^2\right) = (6x \times 1 + 0) = 6\,x$$

$= 6 \times 1 = 6$ units (m/sec^2)

$$a_{convective} = u.\frac{\partial u}{\partial x} + v.\frac{\partial u}{\partial y} + w.\frac{\partial u}{\partial z}$$

$$= \left(6xt + yz^2\right).\frac{\partial}{\partial x}\left(6xt + yz^2\right) + \left(3t + xy^2\right)\frac{\partial}{\partial y}\left(6xt + yz^2\right) + (xy - 2xyz - 6tz).\ \frac{\partial}{\partial z}\left(6xt + yz^2\right)$$

$= (6xt + yz^2\,(6t) + (3t + xy^2)\,(z^2) + (xy - 2xyz - 6tz)\,(2yz)$

At (x, y, z) = (1, 1, 1) and t = 1.0

$a_{conv} = (6 \times 1 \times 1 + (1)(1)^2)(6 \times 1) + (3 \times 1 + 1 \times 1^2)(1^2) + (1 \times 1 - 2 \times 1 \times 1 \times 1 - 6 \times 1 \times 1)(2 \times 1 \times 1)$

$a_{conv} = (7)(6) + (4)(1) + (-7)(2)$

$a_{conv} = (42) + (4) + (-14)$

$a_{conv} = 32$ units (m/sec²)

Total acceleration in x direction

$a_x = a_{local} + a_{conv}$

$= 6 + 32$

$= 38$ units (m/sec²)

01(b). Three tube wells of 25 cm diameter each are located at the three vertices of an equilateral triangle of side 100 m. Each tube well penetrates fully in a confined aquifer of thickness 25 m. Assume the radius of influence for these wells and the coefficient of permeability of the aquifer as 300 m and 40 m/day respectively.

(i) Calculate the discharge when only one well is pumping with a drawdown of 3 m

(ii) What will be the percent change in discharge of this well if all the three wells were to pump such that the drawdown is 3 m in all the wells?

[12 M]

01(b).

Sol: Diameter = 25 cm

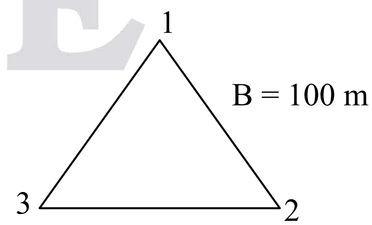
$r_w = 12.5$ cm = 0.125 m

b = 25 m (thickness of confined aquifer)

R = 300 m

K = 40 m/day

(i) Q = ? $S_w = 3$ m T = kb



$$Q = \frac{2\pi T S_W}{\ell n\left(\frac{R}{\gamma_w}\right)}$$

$$Q = \frac{2 \times \pi \times 40 \times 25 \times 3}{\ell n\left(\frac{300}{0.125}\right)} = \frac{2 \times \pi \times 40 \times 25 \times 3}{7.783}$$

$Q = 2421.88$ m³/day

(ii) Draw down in all the wells is 3 m

$$Q_1 = Q_2 = Q_3 = \frac{2\pi kb \times S_w}{\ell n\left[\dfrac{R^3}{\gamma_w \times B^2}\right]}$$

$$Q_1 = Q_2 = Q_3 = \frac{2\times\pi\times40\times25\times3}{\ell n\left[\dfrac{300^3}{0.125\times100^2}\right]} = \frac{2\times\pi\times40\times25\times3}{9.98}$$

$Q_1 = Q_2 = Q_3 = 1888.733\ m^3/\ day$

% decrease in discharge

$$= \frac{2421.88 - 1888.733}{2421.88}\times100$$

$$= 22.01\%$$

01(c). Draw the schematic diagram of a gravity dam and indicate the major forces acting on it. Draw the diagram of the uplift force when (i) drain is not provided and (ii) drain is provided. [12 M]

01(c).

Sol: Gravity dam

4 major forces & 2 minor forces are generally considered.

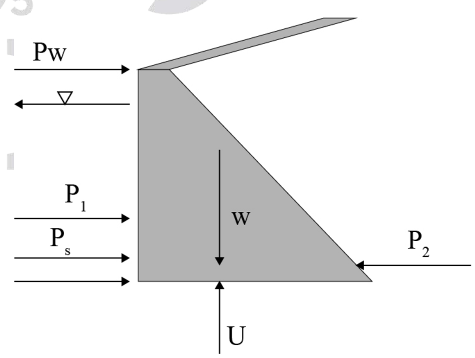
Major forces:

P_1 : U/S hydrostatic force

P_2 : D/S hydrostatic force

W : Self weight of dam

U : Uplift force



Minor forces:

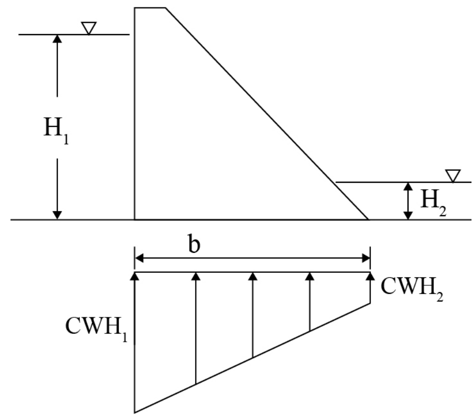
P_S : Silt pressure force

P_W : Wave pressure force

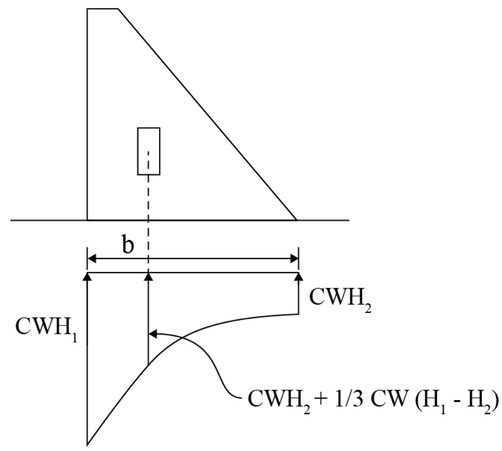
In seismic zones 3 & 4, seismic force also will be considered.

Uplift force:

(i) When drain is not provided



(ii) When drain is provided:



01(d). A city has the following recorded population:

Year 1971 : 60000

Year 1991 : 120000

Year 2011 : 180000

Estimate (i) the saturation population and (ii) expected population in the year 2031 by logistic curve method.

[12 M]

01(d).

Sol: $P_o = 60,000$ $t_o = 0$

$P_1 = 1,20,000$ $t_1 = 20$

$P_2 = 1,80,000$ $t_2 = 40$

(i) The saturation population calculated by using equation

$$P_s = \frac{2P_oP_1P_2 - P_1^2(P_o + P_2)}{P_oP_2 - P_1^2}$$

$$= \frac{(2\times 6\times 12\times 18) - 12^2(6+18)}{6\times 18 - (12)^2}\times\frac{10^{12}}{10^8}$$

$$= \left(\frac{2592 - 3456}{108 - 144}\right)\times 10^4$$

$P_s = 2,40,000$

$$m = \frac{P_s - P_o}{P_o}$$

$$= \frac{2,40,000 - 60,000}{60,000} = 3$$

$$n = \frac{2.3}{t_1}\log_{10}\frac{P_o(P_s - P_1)}{P_1(P_s - P_o)}$$

$$= \frac{2.3}{20}\log_{10}\left(\frac{60,000(2,40,000 - 1,20,000)}{1,20,000(2,40,000 - 60,000)}\right)$$

$= 0.115 \log_{10}(0.33)$

$= -0.055$

(ii) Population in 2031 by logistic curve method

$$P = \frac{P_s}{1 + m\,e^{nt}}$$

$$P = \frac{2,40,000}{1 + 3e^{(-0.055\times 60)}}$$

$= 2,16,089.77$

ESE / GATE / PSUs 2020 – 2021
ADMISSIONS OPEN

GATE + PSUs – 2020

Regular Batches @ **Dilsukhnagar**	**08th & 22nd July, 05th & 20th August 2019**
Regular Batch @ **Kukatpally**	**01st July 2019**
Regular Batches @ **Pune**	**01st & 15th July 2019**
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Regular Batch @ **Bengaluru**	**08th July 2019**

ESE + GATE + PSUs – 2020

Regular Batch @ **Dilsukhnagar**	**08th July 2019**
Regular Batch @ **Pune**	**01st July 2019**

GATE + PSUs – 2021

Morning Batches @ **Abids**	**12th July & 10th August 2019**
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Morning & Evening Batches @ **Kukatpally**	**12th July & 10th August 2019**
Weekend Batches @ **Pune**	**6th July & 17th August 2019**
Weekend Batch @ **Chennai**	**6th July 2019**
Weekend Batch @ **Bengaluru**	**3rd August 2019**
Weekend Batch @ **Vijayawada**	**7th July 2019**
Weekend Batch @ **Tirupati**	**13th July 2019**
Weekend Batch @ **Vizag**	**20th July 2019**

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IES GENERAL STUDIES BATCH

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GENCO / TRANSO / DISCOMS BATCH

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01(e). A water contains 110 mg/L carbonate ion and 80 mg/L bicarbonate ion at a pH of 10. Calculate the alkalinity exactly at 25°C. Approximate the alkalinity by ignoring hydroxide and hydrogen ion. What is the percentage error in approximation? [12 M]

01(e).

Sol: Given

$CO_3^{2-} = 110$ mg/l

$HCO_3^- = 80$ mg/l

pH = 10

pOH = 14 – 10 = 4

$OH^- = 10^{-4}$ mol/lit

$= 10^{-4} \times (16 + 1) \times 1000$ mg/l

$= 1.7$ mg/l

$$\text{Total alkalinity} = CO_3^{2-} \times \frac{50}{30} + HCO_3^- \times \frac{50}{61} + OH^- \times \frac{50}{17}$$

$$= 110 \times \frac{50}{30} + 80 \times \frac{50}{61} + 1.7 \times \frac{50}{17}$$

= 253.9 mg/l as $CaCO_3$

Neglecting H^+ & OH^-

$$\text{Total alkalinity} = CO_3^{2-} \times \frac{50}{30} + HCO_3^- \times \frac{50}{61}$$

$$= 110 \times \frac{50}{30} + 80 \times \frac{50}{61}$$

= 248.9 mg/l as $CaCO_3$

$$\% \text{ error} = \frac{253.9 - 248.9}{253.9} \times 100$$

= 1.969%

02(a). A trapezoidal channel is to be designed to convey a discharge of 50 m^3/sec at a velocity of 2 m/sec. The bed width to depth ratio is 0.8. The side slopes are 1H : 1V. Calculate the bed width, depth of flow and bed slope of the channel. Assume Manning's coefficient, n = 0.02. [20 M]

02(a).

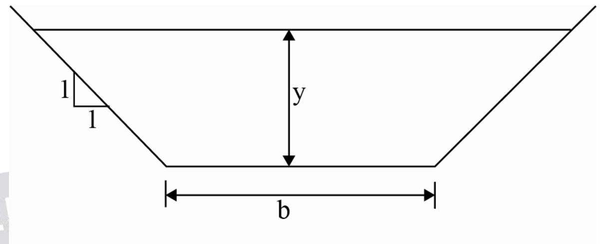
Sol: Given

$Q = 50\ m^3/s$

$V = 2\ m/s$

Manning's coefficient, $n = 0.02$

$\frac{b}{y} = 0.8$



Area, $A = (b + my)\,y$

$= \left(\frac{b}{y} + m\right) y^2$

$= (0.8 + 1)\,y^2$

$= 1.8\,y^2$

Wetted perimeter, $P = b + 2y\sqrt{1+m^2}$

$= \left(\frac{b}{y} + 2\sqrt{1+m^2}\right) y$

$= \left(0.8 + 2\sqrt{1+1}\right) y$

$= 3.628\,y$

Hydraulic radius, $R = \frac{A}{P} = \frac{1.8y^2}{3.628y} = 0.496\,y$

We have, $Q = AV$

$\Rightarrow 50 = 1.8\,y^2 \times 2$

$\Rightarrow y^2 = 13.89$

$\Rightarrow y = 3.727\ m$

$\because \frac{b}{y} = 0.8$

$b = 0.8 \times 3.727 \Rightarrow \boxed{b = 2.981\ m}$

$\because R = 0.496\, y$

$= 0.496 \times 3.727$

$\Rightarrow \boxed{R = 1.849\text{ m}}$

We have

$$V = \frac{1}{n}R^{2/3}S^{1/2}$$

$$2 = \frac{1}{0.02}(1.849)^{2/3}S^{1/2}$$

$$\Rightarrow S^{1/2} = \frac{2\times 0.02}{(1.849)^{2/3}} = \frac{0.04}{1.506} = 0.0266$$

$$\Rightarrow S = 0.00071$$

$$\Rightarrow \boxed{S = \frac{1}{1408}}$$

02(b). Define a unit hydrograph. Explain two basic assumptions made in the derivation of unit hydrograph. Following are the ordinate of a 4-hr unit hydrograph. Using this, derive the ordinates of a 12-hr unit hydrograph (do not plot the graph)

Time (hr)	**0**	**4**	**8**	**12**	**16**	**20**	**24**	**28**	**32**	**36**	**40**	**44**
Ordinate of 4-hr UH	**0**	**20**	**80**	**130**	**150**	**130**	**90**	**52**	**27**	**15**	**05**	**0**

What are the uses and limitations of unit hydrograph? [20 M]

02(b).

Sol: A unit hydrograph is defined as the hydrograph of direct runoff resulting from one unit depth (1 cm) of rainfall excess occurring uniformly over the basin and at is uniform rate for a specified duration (D hours)

Basic assumptions in unit hydrograph:

1. **Time invariance:**

   The direct-runoff response to a given effective rainfall in a catchment is time invariant.

   This implies that the DRH for a given effective rainfall in a catchment is always the same irrespective of when it occurs.

2. **Linear Response**

   The direct runoff response to the rainfall excess is assumed to be linear.

   Linear response means that if an input is $x_1(t)$ cause an output $y_1(t)$ and an input $x_2(t)$ causes an output $y_2(t)$, then an input $x_1(t) + x_2(t)$ gives an output $y_1(t) + y_2(t)$.

Uses and Limitations of Unit Hydrograph

Uses:

- Development of flood hydrograph for extreme rainfall magnitudes for use in the design of hydraulic structure.
- Extension of flood-flow records based on rainfall records.
- Development of flood forecasting and warning system based on rainfall.

Limitations:

- Upper limit for UH use is 5000 km^2 (area)
- Lower limit for UH use is 200 ha (area)
- Precipitation must be rainfall only
- Snow-melt runoff cannot be satisfactory represented by UH
- Catchment should not have unusually large storages in the form of tanks, ponds, etc.
- If the precipitation is decidedly non-uniform, UH cannot be expected to give good results.

Each UH lags by 4 hours from previous one

Time	**4 hr UH**	**4 hr UH**	**4 hr UH**	**DRH**	**Ordinate of 4 hr UH =** $\frac{\text{Ordinate of DRH}}{R = 3\text{cm}} \times 1\text{cm}$
0	0	-	-	0	0
4	20	0	-	20	6.67
8	80	20	0	100	33.33
12	130	80	20	230	76.67
16	150	130	80	360	120
20	130	150	130	410	**136.67**
24	90	130	150	370	123.33
28	52	90	130	272	90.67
32	27	52	90	169	56.33
36	15	27	52	94	31.33
40	5	15	27	47	15.67
44	0	5	15	20	6.67
		0	5	5	1.67
			0	0	0

Application:

Unit hydrograph is used to derive direct runoff hydrograph for a catchment due to a given storm by selecting an appropriate UH.

02(c).

(i) How will you estimate the total storage capacity of a distribution reservoir? Support your answer with suitable sketches and formulae. [15 M]

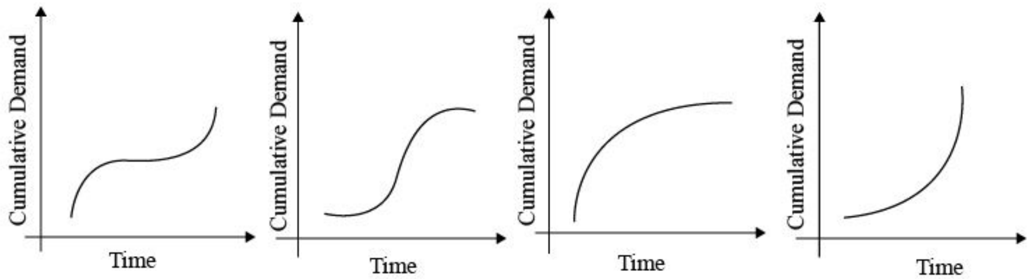
02(c). (i)

Sol: Total Storage capacity of distribution reservoir = Balancing storage capacity + Fire storage + Breakdown (or) Repair storage

Balancing storage capacity of reservoir is fixed by plotting mass curve of supply demand.

Mass curve is a plot between cumulative supply and cumulative demand and time.

These are different demand patterns.

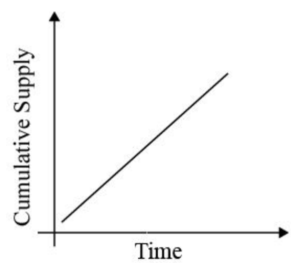


There are two types of supply patterns

(i) Continuous supply

(ii) Intermittent supply

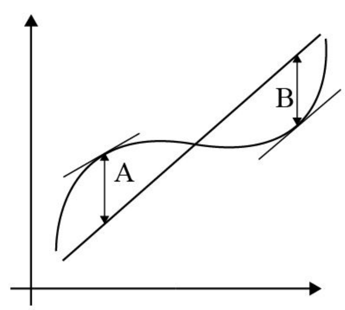
For continuous supply



Note: For intermittent system time at which water supply is made must be mentioned.

By superimposing cumulative supply v/s time plot over cumulative demand v/s time then mass curve of supply & demand is determined.

Ex:



Find the maximum difference between supply & demand by drawing tangents to the pack of demand curve.

Then the balancing storage Capacity of reservoir = A + B

A : Maximum deficit

B : Maximum surplus

Note: In addition to this 2 to 3 % extra space is provided for fire storage & breakdown (or) repair storage to arrive at total storage capacity of distribution reservoir.

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CIVIL ENGINEERING

REGULAR BATCH: 15th July 2019

FREE ORIENTATION SESSION & DEMO CLASS

06th July 2019, 10am TO 1pm @ PUNE

02(c).

(ii) Compute the average sound pressure level from the following sound pressure readings:

(1) 39 dBA (2) 52 dBA (3) 67 dBA (4) 77 Dba [5 M]

02(c). (ii)

Sol: Given 39 dB, 52dB, 67dB, 77 dB

Average sound pressure = $\bar{L} = 20\log_{10}\left(\frac{1}{N}\sum_{i=1}^{4}10^{\frac{L_i}{20}}\right)$

$$\sum_{i=1}^{4}10^{\frac{Li}{20}} = 10^{\frac{39}{20}} + 10^{\frac{52}{20}} + 10^{\frac{67}{20}} + 10^{\frac{77}{20}}$$

$= 9805.41$

$$\bar{L} = 20\log_{10}\left(\frac{1}{4}(9805.41)\right)$$

$= 20\log_{10}(2451.35)$

$\bar{L} = 67.78$ dB

03(a). Estimate the hydraulic gradient in a 2.2 m diameter smooth concrete pipe carrying a discharge of 3.4 cumecs at 20°C temperature by using (i) Darcy-Weisbach formula, (ii) Manning's formula and (iii) Hazen-Williams formula. The kinematic viscosity of water at 20°C = 1.004 × 10^{-6} m²/sec. Hazen-Williams coefficient of hydraulic capacity of the smooth pipe = 130 and Manning's coefficient = 0.013.

[20 M]

03(a).

Sol: Diameter of smooth pipe (D) = 2.2 m

Discharge of water through the pipe (Q) = 3.4 m^3/sec

Kinematic viscosity of water (ν) = 1.004×10^{-6} m^2/sec

Hazen-Williams coefficient (C) = 130 (unitless)

Mannings coefficient, n = 0.013

Hydraulic gradient = ?

Hydraulic gradient is a vector gradient between two (or) more hydraulic head measurements over the length of the pipe flow.

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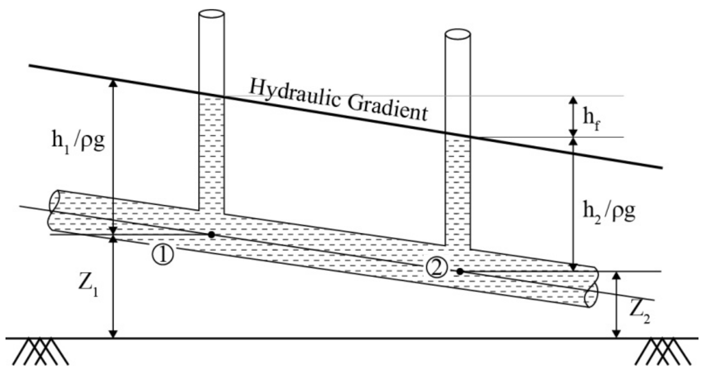

Hydraulic gradient is a dimensionless quantity (i)

$$= \frac{dh}{d\ell} = \frac{h_2 - h_1}{\text{length of pipe between two points(1)and(2)}}$$

For the given case, the pipe is to be taken as horizontal, since elevations are not mentioned, Hence $z_1 = z_2$.

(i) Hydraulic gradient using **Darcy – Weisbach formula**:

loss of head between (1) and (2) according to Darcy – Weisbach formula,

$$h_f = \frac{f.\ell.V^2}{2gD} = \frac{f\ell Q^2}{12.1D^5}$$

$$\therefore \qquad i = \frac{h_f}{\ell} = \frac{\Delta h}{\ell} = \frac{f.Q^2}{12.1D^5}$$

Where f = friction coefficient which depends on Reynolds number of pipe (since pipe is smooth)

$$Re = \text{Reynolds number} = \frac{\rho.V.D}{\mu} = \frac{V.D}{\nu}$$

$$= \frac{Q}{A}.\frac{D}{\nu} \qquad \left(\because A = \frac{\pi}{4}D^2\right)$$

$$= \frac{4Q}{\pi.D.\nu} = \frac{4\times 3.4}{\pi\times 2.2\times 1.004\times 10^{-6}} = 1.96\times 10^6 > 2000$$

for smooth turbulent flow

$$f = \frac{0.316}{Re^{1/4}} \text{ ---------- (1)}$$

$$f = \frac{0.316}{\left(1.96\times10^{6}\right)^{0.25}}$$

$= 0.00844$

But the above formula is valid only for Re < 10^5,

For Re > 10^5 we have,

$$\frac{1}{\sqrt{f}} = 2.0\log_{10}\left(\text{Re}\sqrt{f}\right) - 0.8$$

$$\Rightarrow \frac{1}{\sqrt{f}} - 2.0\log_{10}\left(\text{Re}\sqrt{f}\right) + 0.8 = 0 \text{ ---------- (2)}$$

Substituting the value of *f* we got from equation (1) in equation (2) we get

$$\text{L.H.S} = \frac{1}{\sqrt{0.00844}} - 2\log_{10}\left(1.96\times10^{6}\times\sqrt{0.00844}\right) - 0.8$$

$= 10.88 - 2 \times \log_{10}(180064) - 0.8$

$= 10.88 - 2 \times 5.255 - 0.8$

$= 10.88 - 10.51 - 0.8$

$= 10.88 - 9.71 = 1.17 \neq 0$ (R.H.S)

Adjusting *f* value to *f* = 0.008

We get

$$\text{L.H.S} = \frac{1}{\sqrt{0.008}} - 2\log_{10}\left(1.96\times10^{6}\sqrt{0.008}\right) - 0.8$$

$= 11.18 - 2\times 5.24 - 0.8$

$= -0.1 \approx 0$ (R.H.S)

So taking f = 0.08

$$\frac{h_f}{L} = \frac{fQ^2}{12.1\, D^5}$$

$$= \frac{0.008\times3.4^2}{12.1\times2.2^5}$$

$= 1.48 \times 10^{-4} = 0.00015$

Hydraulic gradient using Darcy – Weisbach formula, $\boxed{\frac{h_f}{L} = 0.00015}$

(ii) Hydraulic gradient using **Manning's formula**:

Hydraulic radius, $R = \frac{D}{4} = \frac{2.2}{4}$

$$Q = \frac{A.(R)^{2/3} S^{1/2}}{n}$$

$$3.4 = \frac{\frac{\pi}{4}(2.2)^2 \times \left(\frac{2.2}{4}\right)^{2/3} .S^{1/2}}{0.013}$$

$S = 3 \times 10^{-4} = 0.0003$

Hydraulic gradient using Manning's formula:

$\boxed{S = \frac{h_f}{L} = 0.0003}$

(iii) **Hazen –Williams formula :** It is an empirical relationship relates the flow of water in a pipe with pipe physical properties and pressure drop caused by friction.

$V = 0.849\ C\ R^{0.63}\ S^{0.54}$

$$\Rightarrow \frac{Q}{A} = 0.849\ C R^{0.63} S^{0.54} \qquad \left(\because V = \frac{Q}{A}\right)$$

$$\Rightarrow \frac{3.4}{\frac{\pi}{4} \times 2.2^2} = 0.849 \times 130 \times \left(\frac{2.2}{4}\right)^{0.63} S^{0.54}$$

$$\Rightarrow S^{0.54} = \frac{4 \times 3.4}{\pi \times 2.2^2 \times 0.849 \times 130} \times \left(\frac{4}{2.2}\right)^{0.63}$$

$\Rightarrow S^{0.54} = 0.01181$

$\Rightarrow S = 0.000269$

$\therefore$ Hydraulic gradient by Hazen Williams formula, $\boxed{S = \frac{h_f}{L} = 0.000269}$

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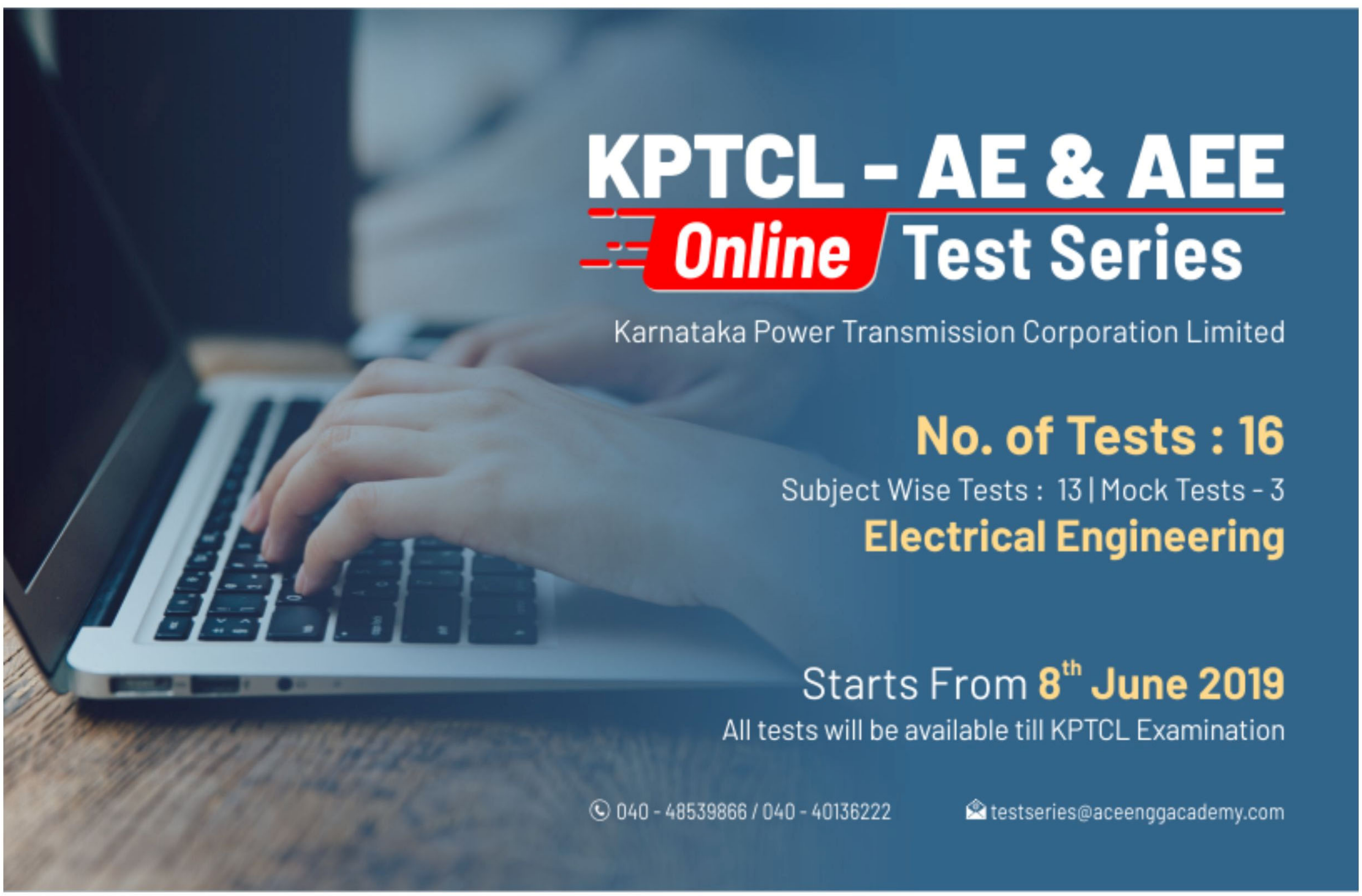


03(b). A wastewater treatment plant consists of primary treatment clarifier followed by an activated sludge treatment unit. The primary and secondary sludge are mixed, thickened in a gravity thickener and sent to further treatment. Wastewater, treatment plant sludge characteristics are as follows:

- **Influent SS = 220 mg/L; primary clarifier diameter = 25 m**
- **Influent BOD = 250 mg/L; aerator volume = 3000 m^3**
- **Effluent BOD = 30 mg/L; MLSS in aerator = 3000 mg/L**
- **Flow = 20000 m^3/day; solids in thickener supernatant = negligible**
- **Primary sludge = 5% solids; secondary sludge = 0.75% solids and thickened sludge = 4% solids**
- **Efficiency of primary clarifier for SS and BOD removal are 58% and 32% respectively.**
- **Biomass conversion factor in aerator = 0.35**

Determine

(i) Solids loading in kg/day to the sludge disposal facilities;

(ii) $\frac{F}{M}$ ratio in aerator;

(iii) Percent volume reduction by the thickener. **[20 M]**

03(b).

Sol: Given:

$(SS)_i = 220$ mg/l $y_i = 250$ mg/l $y_e = 30$ mg/l

$X = 3000$ mg/l $Q = 20000$ m^3/day

Primary sludge : 5% solids ⇒ m.c = 100 – 5 = 95%

Secondary sludge : 0.75 % solids ⇒ m.c = 100 – 0.75 =99.25%

Thickened sludge : 4% solids ⇒ m.c = 100 – 4 = 96%

$\eta_{pc} = 58\%$, BOD removal $\eta_{pe} = 32\%$, Y = 0.35

Mass of solids removed @ pc $(M_P) = Q \times (SS)_i \times \eta_{pc}$

$$= 20 \times 220 \times \frac{58}{100}$$

$$= 2552 \text{ kg/day}$$

Volume of primary sludge (V_p) = $\dfrac{M_P}{\rho_w \times \%\,\text{solids}}$

$$= \frac{2552}{1000 \times \frac{5}{100}}$$

$(V_p) = 51.04\ m^3/\text{day}$

BOD applied to aeration tank = $250 - \dfrac{32}{100} \times 250$

= 170 mg/l

BOD consumed in aeration tank (BOD removed) = 170 – 30 = 140 mg/l

Total BOD removed = Q × BOD removed = 20 × 140 = 2800 kg/day

Mass of secondary solids (M_s) = Y × Total BOD removed

= 0.35 × 2800 = 980 kg/day

(i) Solids loading to sludge disposal facilities = 2552 + 980 = 3532 kg/day

(ii) $\dfrac{F}{M} = \dfrac{Q(y_i - y_e)}{VX}$

$$= \frac{20{,}000 \times [170 - 30]}{3000 \times 3000} = 0.311/\text{day}$$

Volume of secondary sludge (V_s) = $\dfrac{M_s}{1000 \times \frac{0.75}{100}}$

$$= \frac{980}{1000 \times \frac{0.75}{100}} = 130.67\ m^3/\text{day}$$

Volume of sludge = $V_p + V_s$ = 51.04 + 130.66 = 181.70 m^3/day

Volume of thickened sludge= $\dfrac{3532}{1000 \times \frac{4}{100}} = 88.3\ m^3/\text{day}$

(iii) % volume reduction = $\dfrac{181.7 - 88.3}{181.7} \times 100 = 51.4\%$

03(c). Explain geometric similarity, kinematic similarity and dynamic similarity. Two homologous pumps are to run at the same speed of 600 r.p.m. Pump A has an impeller of 50 cm diameter and discharges 0.4 m^3/sec of water under a head of 50 m. Determine the size of pump B and its net head if it is to discharge 0.3 m^3/sec. [20 M]

03(c)

Sol: In model studies of turbomachines and dimensional analysis, all the corresponding π-terms must be equated to satisfy the following conditions:

(i) Geometric similarity (ii) Kinematic similarity (iii) Dynamic similarity

(i) Geometric similarity:

A model and prototype are geometrically similar if and only if all body dimensions in all three coordinates have the same linear-scale ratio. i.e same shape and all the linear dimensions of the model and prototype related to corresponding dimensions or the prototype by a constant scale factor.

(ii) Kinematic similarity:

The motions of two systems are kinematically similar if homogeneously lie at same points at same times Ex: Velocities at corresponding points are in the same direction (i.e same streamline patterns) and are related in magnitude by a constant scale factor.

(iii) Dynamic similarity:

When two flows have force distributions such that identical types of forces are parallel and are related in magnitude by a constant scale factor at all corresponding points, then the flows are dynamically similar. For a model and prototype, the dynamic similarity exists, when both of them have same length scale ratio and force-scale (or) mass-scale ratio.

Given data:

$N_A = N_B = 600$ rpm

$D_A = 0.5$m

$Q_A = 0.4$ m^3/sec

$H_A = 50$ m

$D_B = ?$

$H_B = ?$

$Q_B = 0.3\ m^3/sec$

Head coefficient : $\dfrac{N.D}{\sqrt{H}}$

$$\frac{N_A D_A}{\sqrt{H_A}} = \frac{N_B . D_B}{\sqrt{H_B}}$$

$$\frac{0.5}{\sqrt{50}} = \frac{D_B}{\sqrt{H_B}} \rightarrow (1)$$

Flow or discharge coefficient $\dfrac{Q}{N.D^3}$

$$\frac{Q_A}{N_A D_A^3} = \frac{Q_B}{N_B D_B^3}$$

$$\frac{0.4}{(0.5)^3} = \frac{0.3}{(D_B)^3}$$

$\therefore D_B = 0.4543$ m

From Equation (1)

$$\frac{0.5}{\sqrt{50}} = \frac{0.4543}{\sqrt{H_B}}$$

$\therefore H_B = 41.28$ m

04(a). Explain the terms 'initial regime' and 'final regime' as explained in Lacey's regime theory of stable channels. Design a stable channel for carrying a discharge of 30 m^3/sec using Lacey's method assuming a silt factor equal to 1.0. [20 M]

04(a).

Sol: Initial Regime:

It is the fist stage of regime attained by a channel after it has been put into service.

Initial regime is attained by a channel only by the variation of bed slope and depth.

If a channel is excavated with some what smaller width and flatter bed slope, then as the flow takes place in the channel, the bed slope of the channel is increased due to deposition of silt on the bed of the channel, so that an increased velocity of flow is developed which allows the given discharge to flow through the channel of smaller width. With the increase in the bed slope of the depth may also vary. However, the width of the channel remains invariable because the sides of the channels are usually cohesive and hence they resist erosion. The channel thus has a given discharge, silt grade, silt charge & width, and only by varying bed slope and depth it attains stability which is termed as initial regime.

Final Regime:

It is the ultimate stage of regime attained by a channel when in addition to bed slope and depth the width of the channel has also been suitably adjusted. For the channel considered earlier due to continuous action of water the resistance of sides is ultimately overcome and a condition is developed when the channel may adjust its width, depth and bed slope so that a stable channel is obtained. The stability so attained by a channel is termed as final regime or true regime.

Design:

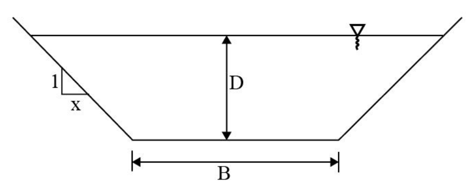
Given: $Q = 30\ m^3/s$; $f = 1.0$

i. Velocity $V = \left(\frac{Qf^2}{140}\right)^{1/6} = 0.774\ m/s$

ii. Area $A = \frac{Q}{V} = \frac{30}{0.774} = 38.78\ m^2$

iii. Perimeter, $P = 4.75\sqrt{Q} = 4.75\sqrt{30} = 26.02\ m$

iv. Assume side slopes $\frac{1}{2}H : 1\ V$ $\quad x = 0.5$



v. $A = (B + x\,D)\,D$

$38.78 = (B + 0.5\,D)\,D$

$38.78 = BD + 0.5\,D^2 \rightarrow (1)$

vi. $P = B + 2\,D\,\sqrt{1+x^2}$

$P = B + 2\,D\,\sqrt{1+0.5^2}$

$26.02 = B + 2.236\,D \rightarrow (2)$

Solve (1) & (2) $B = 22.474\ m$

$D = 1.66\ m$

vii. $R = \frac{A}{P} = \frac{(B+0.5D)D}{B+2D\sqrt{1+0.5^2}} = 1.477 \approx 1.48$

viii. $R = \frac{5}{2}\times\frac{V^2}{f} = \frac{5}{2}\times\frac{(0.774)^2}{1} = 1.488 \approx 1.48$

Hence checked.

ix. Bed slope $S = \frac{f^{5/3}}{3340Q^{1/6}}$

$$= \frac{1^{5/3}}{3340\,(30)^{1/6}} = \frac{1}{5887.5} \approx \frac{1}{5900}$$

Hence B = 22.47 cm, D = 1.66 m, $S = \frac{1}{5900}$

04(b).

(i) Define field capacity, permanent wilting point and average moisture content. Explain how these will be useful in deciding the frequency of irrigation. (A schematic diagram showing less and more frequent irrigation is to be drawn for clarity). [3 + 4 + 3 = 10 M]

4(b). (i)

Sol: Field capacity:

It is the moisture content of the soil at which all vegetative needs of plant are achieved. It is the safest maximum moisture content of the soil.

We should not supply water to a field beyond the field capacity of soil.

Permanent wilting point:

It is the moisture content of the soil at which at the minimum plant can survive, without external water supply. If we do not provide external water even atleast PWP the plant will die.

Average moisture content:

Also called optimum moisture content of the soil. It is the safest minimum moisture content of the soil, at which external water supply should be made to achieve healthy growth of crop. At this moisture content, SMT value is least i.e. $\frac{1}{3}$ to $\frac{1}{6}$ atmospheric pressure.

Frequency of Irrigation:

$$f = \frac{d_w}{C_u}$$

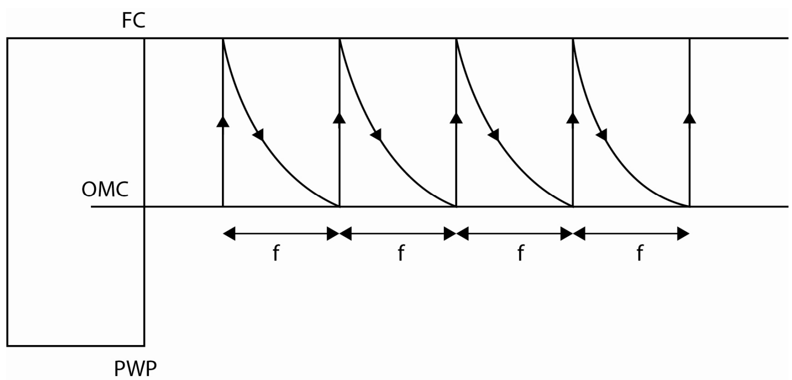
$$= \frac{Sd[FC - OMC]}{C_u}$$

$$= \left(\frac{100 - x}{100}\right)\left(\frac{FC - PWP}{C_u}\right)Sd$$

S : Specific gravity of soil

d : Root zone depth of soil

x : % moisture content of available moisture below which crop growth will not be healthy



Frequency of irrigation: It is the time interval between two consecutive watering given to field

f depends on

(1) Specific gravity

(2) Type of soil

(3) Type of crop

(4) Stage of growth of crop

(5) Consumptive use

04(b). (ii)

In a hydraulic jump occurring in a horizontal channel, the Froude's number before the jump is 10.0 and energy loss is 3.2 m. Estimate sequent depths, discharge intensity and Frounde's number after the jump. [10 M]

04(b). (ii)

Sol: Given

Froude's member before jump, $Fr_1 = 10$

Energy loss, $\Delta E = 3.2$ m

We have

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

$$= \frac{1}{2}\left(-1+\sqrt{1+8\times 10^2}\right)$$

$$= \frac{1}{2}\left(-1+\sqrt{801}\right)$$

$$= \frac{1}{2}(27.30) = 13.65$$

$\Rightarrow y_2 = 13.65\ y_1$

We have

$$\Delta E = \frac{(y_2 - y_1)^3}{4y_1y_2} = \frac{(13.65y_1 - y_1)^3}{4\times y_1\times 13.65y_1} = \frac{12.65^3\times y_1^3}{4\times 13.65\times y_1^2}$$

$$\Rightarrow\ 3.2 = \frac{12.65^3}{4\times 13.65}y_1$$

$$\Rightarrow y_1 = \frac{3.2\times 4\times 13.65}{12.65^3}$$

$y_1 = 0.086$ m

$\because$ we have $\frac{y_2}{y_1} = 13.65$ $\quad y_2 = 13.65 \times 0.086 = 1.178$ m

$\therefore$ sequent depth are

$y_1 = 0.086$ m
$y_2 = 1.178$ m

we have

$$\frac{2q^2}{g} = y_1y_2(y_1 + y_2)$$

$\Rightarrow \quad \frac{2 \times q^2}{9.81} = 0.086 \times 1.178(0.086 + 1.178)$

$\Rightarrow \quad q^2 = 0.628$

$\Rightarrow$ Discharge intensity, $q = 0.792\ m^3/s/m$

We have

$$\frac{y_1}{y_2} = \frac{1}{2}\left(-1 + \sqrt{1 + 8Fr_2^2}\right)$$

$$\frac{0.086}{1.178} = \frac{1}{2}\left(-1 + \sqrt{1 + 8Fr_2^2}\right)$$

$\Rightarrow \quad -1 + \sqrt{1 + 8Fr_2^2} = 0.146$

$\Rightarrow \quad \sqrt{1 + 8Fr_2^2} = 1.146$

$\Rightarrow \quad 1 + 8Fr_2^2 = 1.313$

$\Rightarrow \quad 8Fr_2^2 = 0.313$

$\Rightarrow \quad Fr_2^2 = 0.039$

$\Rightarrow$ Froude's number after jump, s$Fr_2 = 0.198$

04(c). (i)

Explain in detail the various process parameters required to control the aerobic composting of solid waste. Discuss the relevance of each parameter also. [10 M]

04(c). (i)

Sol: Process parameter required to control the aerobic composting

(a) Particle size → For optimum results size of solid waste should be between 25 to 75 mm

(b) Seeding & mixing → Composting lime is reduced by seeding with partially decomposed solid waste.

(c) Mixing & turning → To prevent drying, caking and air channelling material in the process being composted should be mixed (or) turned at regular schedule.

(d) Air requirements → Air containing at least 50 % of initial oxygen should reach all parts of compositing material for optimum results.

(e) Moisture content → Moisture content should be in the range of 50 to 60 percent during composting process

(f) Temperature → For best results temperature = 50 to 55°C for few days and temperature 55°C to 60°C for remaining days.

(g) Carbon to nitrogen ratio → Should be between 30 to 50 for optimum aerobic composting

(h) pH → To minimize the loss of nitrogen in the form of ammonium gas pH ≥ 8.5.

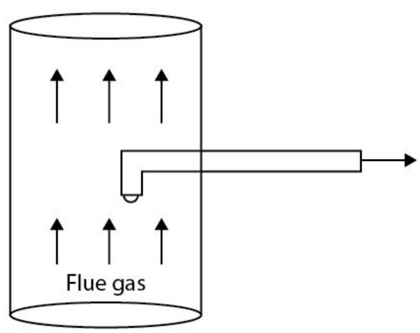
04(c).

(ii) Discuss the isokinetic sampling process of flue gas stack sampling and explain with the help of diagram, how the results will be affected if the sampling is not done isokinetically. [10 M]

04(c). (ii)

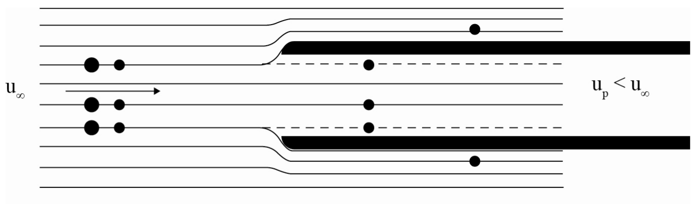
Sol: Isokinetic Sampling:

It is one type of sampling (or) technique such that particles are captured that pass through a defined area for a defined path without disturbing other paths.



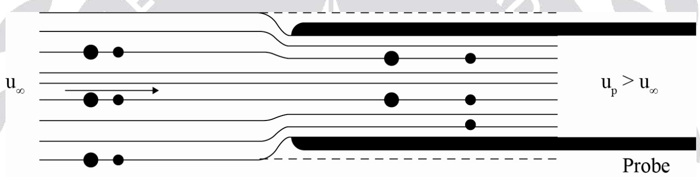
In this technique, a sample is drawn into the probe such that the conditions at the tip of the probe are the same as those in the free gas stream at the sampling point. The static pressure at the tip of the probe must be equal to the static pressure in the free stream at the same cross section. This implies that when the two pressures are equalized then the corresponding velocities must be equal.

If a gas velocity (u_p), less than the free stream velocity (u_∞), is maintained inside the probe, then the gas flow pattern at the tip of the probe may be represented as shown figure. In this case the static pressure at the tip of the probe is greater than the free stream static pressure at the same cross section.



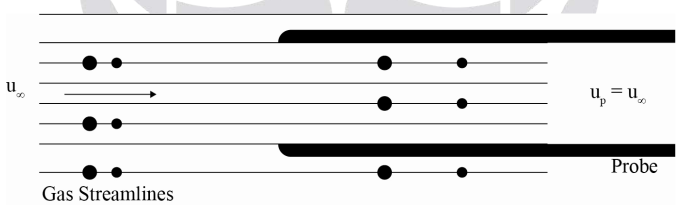
(Sub - Isokinetic)

If the sampling velocity (u_p) is greater than the free stream velocity (u_∞), then the flow pattern may look somewhat like that represented in figure below, the static pressure at the tip of the probe is less than the free stream pressure, and too much gas will be sampled in proportion to the probe area.



(Super - Isokinetic)

Only when the sampling velocity is equal to the free stream velocity, the pressure become equal and true isokinetic conditions are attained. Under isokinetic conditions the flow pattern in front of the probe is not disturbed as shown in figure.



(Isokinetic)

Depending on the particle composition and sizes in the gas stream depends upon how much effect there will be on the final pollutant mass rate from the stack.

If Isokinetic sampling is not done:

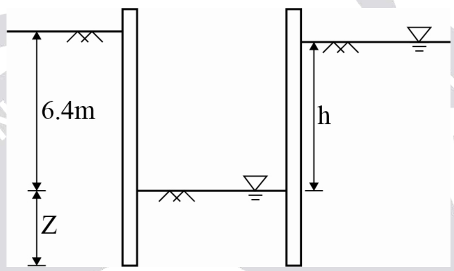
Small particles (< 1 microns) tend to follow the stream lines of the gas stream, little effect on pollutant mass rate if they collected. Where as large particles (> 5 microns) are also present along with them, they tend to move in their own inertial direction, so we consequently have too many large particles for the small volume sampled.

SECTION-B

05(a). A pit of 6.4 m deep is to be excavated in a fine sand stratum completely saturated up to the ground surface. The saturated unit weight of the sand was obtained as 20.3 kN/m^3. To stabilize the bottom of the excavation (prevent boiling), it was decided to drive steel sheet piles to act as cutoff walls that encircle the excavation. Determine the total length of sheet pile wall to provide a factor of safety of 1.5 against sand boiling. Assume specific gravity of soil, G_s = 2.7 and unit weight of water, γ_w = 9.81 kN/m^3. [12 M]

05(a).

Sol:



Given

$\gamma_{sat} = 20.3$ kN/m^3, $G_s = 2.7$, $\gamma_w = 9.81$ kN/m^3

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

$$20.3 = 9.81\left[\frac{2.7 + e}{1+e}\right]$$

$2.07 + 2.07e = 2.7 + e$

$1.07\ e = 0.63$

$e = 0.589$

Critical hydraulic gradient, $i_c = \dfrac{G_s - 1}{1+e}$

$$= \frac{2.7-1}{1+0.589} = 1.07$$

Factor of Safety against boiling, $F = \dfrac{i_c}{i}$

Safe gradient, $i = \dfrac{i_c}{F} = \dfrac{1.07}{1.5} = 0.713$

$$i = \frac{h}{z}$$

$$0.713 = \frac{6.4}{z}$$

$$\therefore\ z = 8.98\text{ m}$$

Total depth of sheet pile required = 6.4 + z = 6.4 + 8.98 = 15.376 m

Say 15.4 m

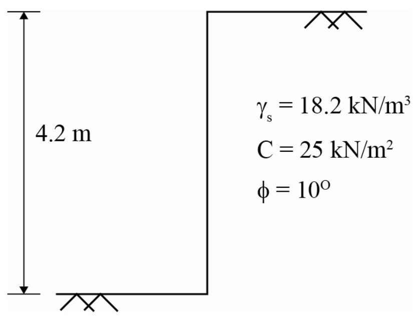
05(b). An unsupported cut as shown in the figure below was made at a site for which unit weight of soil, γ_s = 18.2 kN/m^3, cohesion, C = 25 kN/m^2 and angle of internal friction, ϕ = 10^o. Determine the lateral stress at –

(i) the top of the excavation;

(ii) the bottom of the excavation

(iii) the maximum depth of potential tension crack for the excavation. What is the maximum depth up to which the excavation can be carried out safely without any support?

[12 M]



05(b). Given :

Sol: γ = 18.2 kN/m^3, C = 25 kN/m^2, ϕ = 10^o

Coefficient of active earth pressure

$$k_a = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1-0.174}{1+0.174} = 0.704$$

The lateral stress induced is active earth pressure

(i) At top, active pressure, $p_a = k_a\,\sigma_v - 2C\sqrt{k_a}$

$$= 0 - 2\times 25\sqrt{0.704}$$

$$= -\,41.95\text{ kN/m}^2$$

(ii) At bottom:

$\sigma_v = \gamma H = 18.2 \times 4.2 = 76.44$

$p_a = k_a \sigma_v - 2C\sqrt{k_a}$

$= 0.704 \times 76.44 - 2 \times 25\sqrt{0.704} = 11.86$

(iii) Maximum depth of tension crack, $Z_c = \dfrac{2C}{\gamma\sqrt{k_a}}$

$= \dfrac{2 \times 25}{18.2\sqrt{0.704}}$

$= 3.274$ m

Maximum depth upto which the excavation can be carried out safety without any lateral support,

$H_c = 2Z_c = 2 \times 3.274 = 6.55$ m

05(c). How are runways oriented? Explain the terms 'wind coverage' and 'crosswind component'. [12 M]

05(c).

Sol: Runway orientation:

The number and orientation of the runways play an important role in the overall arrangement of various components of an airport. The number of runways will depend on the volume of air traffic while its orientation will depend on the direction of the wind and sometimes on the extent area available for the airport development.

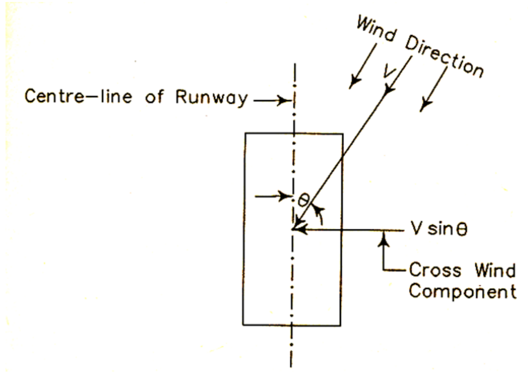
Preliminary information required:

It is necessary to collect the following data before deciding the orientation of the runway:

1) maps of the area in the vicinity of the airport showing contours at suitable intervals; and
2) records of direction, force and duration of the wind in the vicinity and fog characteristics of the area for as long a period as possible.

Cross wind component:

It is not possible to get the direction of opposite wind parallel to the centre – line of the runway length everyday or throughout the year. For some period of the year at least, the wind may blow making some angle θ with the direction of the centre – line of the runway length as shown in figure:



Cross wind component

If V kmph is the velocity of the inclined opposing wind, its component, Vsinθ which is normal to the centre – line of the runway length is called the cross wind component. If this component is in excess, it will interrupt the safe landing and take off operations. The orientation of the runway should therefore be such that this component is kept to a minimum. For light and medium weight aircrafts, the cross wind component should not exceed 25 kmph.

Wind coverage:
Wind coverage or usability factor of airport is the percentage of time in a year during which the cross wind component remains within the limit or runway system is not restricted because of excessive cross wind.

Based on the type of airport and the selected cross wind component ,we have to look at the maximum percentage of time in a year for which the cross wind component will remain below that value and that is what is the wind coverage being defined. A single runway or a set of parallel runways cannot be oriented to provide the required wind coverage of 95% as defined by ICAO, FAA. Then, one or more than one runways needs to be provided in that case and the combined value of those two or more runways will come out as more than 95%. So, that is the value which needs to be provided while selecting the orientation of the runways. ICAO and FAA recommends minimum wind coverage of 95%.

05(d). Calculate equilibrium cant on an MG curve of 6 degree for an average speed of 50 km/hr. Also find out the maximum permissible speed after allowing maximum cant deficiency.

[12 M]

05(d)

Sol: **Given:** Degree of curve for Meter Gauge (MG) = 6^o

Average speed = 50 km/hr

(i) Equilibrium superelevation 'e' = $\dfrac{GV^2}{127R}$

V = Average speed = 50 km/hr

G = Gauge distance = 1 m for MG

$\therefore$ R = Radius of curve = $\dfrac{1720}{D} = \dfrac{1720}{6} = 286.67$ m

$$e = \frac{1 \times 50^2}{127 \times 286.67}$$

= 0.06866 m

= 6.866 cm

Maximum permissible cant for MG track = 10 cm > 6.866 cm, Hence ok

(ii) Maximum permissible cant deficiency for MG track = 50 mm

$\therefore$ Cant that can be provided for maximum permissible speed = 6.866 + 5

= 11.866 cm

$$e = \frac{GV^2}{127R}$$

$$\Rightarrow \frac{11.866}{100} = \frac{1 \times V_{max}^2}{127 \times 286.67}$$

$\Rightarrow V_{max} = 65.727$ km/hr

Maximum permissible speed from martins formula

$= 4.35\sqrt{R - 67}$

$= 4.35\sqrt{286.67 - 67}$

= 64.47 km/hr

$\therefore$ Maximum permissible speed = 64.47 km/hr

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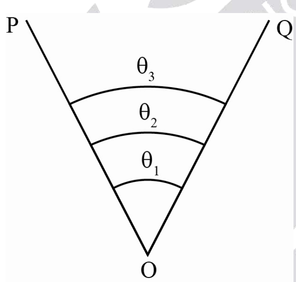
05(e).

(i) What is repetition method in theodolite surveying? What are different instrumental errors which can be eliminated by the repetition method? [6 M]

05(e).(i)

Sol: The method of repetition is used to measure a horizontal angle to a finer degree of accuracy than that obtainable with the least count of the vernier. By this method, an angle is measured two or more times by allowing the vernier to remain clamped each time at the end of each measurement instead of setting into back at zero when sighting at the previous station. Thus an angle reading is mechanically added several times depending upon the number of repetitions. The average horizontal angle is then obtained by dividing the final reading by the number of repetitions.



$$\angle POQ = \frac{\theta_3}{3} = \frac{\text{Final reading}}{\text{No. of repetitions}}$$

Any number of repetitions may be made however three repetitions with the telescope normal and three with the telescope normal and three with the telescope inverted are quite sufficient for any thing except very precise work.

The following instrumental errors can be eliminated by the repetition method.

(1) Errors due to eccentricity of verniers and centres are eliminated by taking both vernier readings.

(2) Errors due to in adjustments of line of collimation and the trunnion axis are eliminated by taking both face readings.

(3) The errors due to inaccurate graduations are eliminated by taking the readings at different parts of the circle.

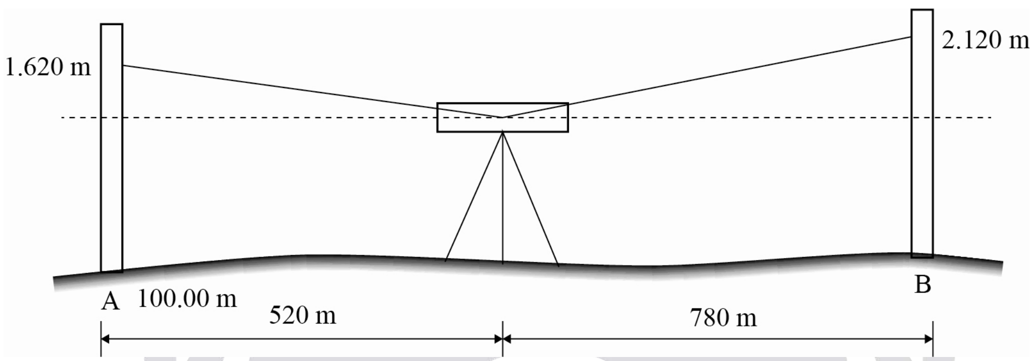
(4) Errors due to inaccurate bisection of the object eccentric centering etc may be to some extent counter balanced in different observations.

05(e).

(ii) A level was set up between two stations A and B. The distance of level from station A was 520 m and the reading on the staff held at A was 1.620 m. The distance of level from station B was 780 m and the reading on the staff held at B was 2.120 m. The reduced level (RL) of point A was 100.000 m. What is the RL of point B? Assume that there is no error in the instrument. [6 M]

05(e). (ii)

Sol:



Correct staff reading on 'A' = $1.620 - 0.06735 \times (0.52)^2$

$= 1.602$ m

Correct staff reading on 'B' = $2.120 - 0.06735 \times (0.78)^2$

$= 2.079$ m

$\therefore$ T.R.L Difference between A & B = $2.079 - 1.602 = 0.477$ m, 'B' @ lower level than 'A'

$\therefore$ RL of B = $100 - 0.477 = 99.523$ m

06(a). Liquid limit (LL) and plastic limit (PL) tests were carried out on a soil sample as per Indian Standard method. The values were 60% and 36% respectively for LL and PL. What is the type of soil based on the above test data as per Indian Standard Classification System? Justify your answer. [10 M]

06(a).

Sol: Given

LL = 60% , PL = 36%

Plasticity index, PI = LL – PL = 60 – 36 = 24

PI of A – line = 0.73 (LL – 20)

= 0.73(60 – 20) = 29.2

Therefore, the PI of soil plots below the A line

Hence it is silty soil

Since LL is > 50 %, it is highly compressible

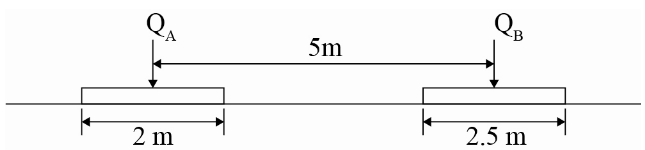
As per IS soil classification system, the soil is highly compressible silt, MH

06(b). Two square footings with equal contact pressure of 250 kPa are at 5 m apart (centre – to – centre). The size of the one footing (A) is 2 m × 2m and the other one (B) is 2.5 m × 2.5 m. Determine the vertical stress at 2 m vertically below (i) the footing (A), (ii) the footing (B) and (iii) the midpoint between the footings. Use Boussinesq's point load formula.

[10 M]

06(b).

Sol:



Equivalent concentrated load on footing A is $Q_A = A.q$

$$Q_A = 2^2 \times 250 = 1000 \text{ kN}$$

Equivalent concentrated load on footing B is $Q_B = A.q$

$$Q_B = 2.5^2 \times 250 = 1562.5 \text{ kN}$$

Vertical stress at 2 m vertically below the footing A:

$\sigma_Z = \sigma_{ZA} + \sigma_{ZB}$

$$= \frac{Q_A}{Z^2} \times \frac{3}{2\pi} + \frac{Q_B}{Z^2} \times \frac{3}{2\pi}\left[\frac{1}{1+\left(\frac{r}{Z}\right)^2}\right]^{5/2}$$

$$= \frac{1000}{2^2} \times \frac{3}{2\pi} + \frac{1562.5}{2^2} \times \frac{3}{2\pi}\left[\frac{1}{1+\left(\frac{5}{2}\right)^2}\right]^{5/2}$$

$= 119.43 + 1.318$

$= 120.74 \text{ kN/m}^2$

(ii) Vertical stress at 2 m vertically below the footing B

$\sigma_Z = \sigma_{ZA} + \sigma_{ZB}$

$$= \frac{Q_A}{Z^2} \times \frac{3}{2\pi}\left[\frac{1}{1+\left(\frac{r}{Z}\right)^2}\right]^{5/2} + \frac{Q_B}{Z^2} \times \frac{3}{2\pi}$$

$$= \frac{1000}{2^2} \times \frac{3}{2\pi}\left[\frac{1}{1+\left(\frac{5}{2}\right)^2}\right]^{5/2} + \frac{1562.5}{2^2} \times \frac{3}{2\pi}$$

$= 0.844 + 186.6$

$= 187.45\ kN/m^2$

(iii) Vertical stress at 2 m below the midpoint between the two footings

$\sigma_Z = \sigma_{ZA} + \sigma_{ZB}$

$$= \frac{Q_A}{Z^2} \times \frac{3}{2\pi}\left[\frac{1}{1+\left(\frac{r}{Z}\right)^2}\right]^{5/2} + \frac{Q_B}{Z^2} \times \frac{3}{2\pi}\left[\frac{1}{1+\left(\frac{r}{Z}\right)^2}\right]^{5/2}$$

$$= \frac{1000}{2^2} \times \frac{3}{2\pi}\left[\frac{1}{1+\left(\frac{2.5}{2}\right)^2}\right]^{5/2} + \frac{1562.5}{2^2} \times \frac{3}{2\pi}\left[\frac{1}{1+\left(\frac{2.5}{2}\right)^2}\right]^{5/2}$$

$$= \frac{1000}{2^2} \times 0.04545 + \frac{1562.5}{2^2} \times 0.04545$$

$= 29.12\ kN/m^2$

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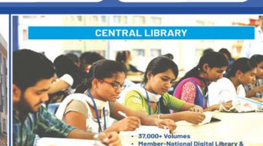

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06(c). A plate bearing test with a 0.3 m diameter plate was carried out on a thick deposit of sand. The shearing failure of the plate was occurred when a load of 3.5 kN was applied. The unit weight of the sand was 19.2 kN/m^3 and water table was found to be at a depth of 1.0 m below the ground surface. If a square foundation of size 1.5 m × 1.5 m is planned in the same sand deposit but placed at a depth of 1.0 m below the ground surface, what will be the allowable bearing capacity of the footing? Assume saturated unit weight of sand also as 19.2 kN/m^3 and unit weight of water as 9.81 kN/m^3. The chart given below may be used:

[20 M]

ϕ^o	N_c	N_q	N_γ
0	5.70	1.00	0.00
2	6.30	1.22	0.18
4	6.97	1.49	0.38
6	7.73	1.81	0.62
8	8.60	2.21	0.91
10	9.61	2.69	1.25
12	10.76	3.29	1.70
14	12.11	4.02	2.23
16	13.68	4.92	2.94
18	15.52	6.04	3.87
20	17.69	7.44	4.97
22	20.27	9.19	6.61
24	23.36	11.40	8.58
26	27.09	14.21	11.35
28	31.61	17.81	15.15
30	37.16	22.46	19.73
32	44.04	28.52	27.49
34	52.64	36.51	36.96
36	63.53	47.16	51.70
38	77.50	61.55	73.47
40	95.67	81.27	100.39
42	119.67	108.75	165.69
44	151.95	147.74	248.29
46	196.22	204.20	426.96
48	258.29	287.86	742.61
50	347.52	415.16	1153.15

06(c).

Sol: Plate diameter = 0.3 m

Failure load = 3.5 kN

$\therefore$ Failure stress = $\dfrac{\text{Load}}{\text{Area}} = \dfrac{3.5}{\frac{\pi}{4}\times 0.3^2} = 49.54\ \text{kN/m}^2$

$\therefore$ Ultimate bearing capacity, $q_u = 49.54\ \text{kN/m}^2$

Using Terzaghi's equation

$q_u = 1.3CN_C + \gamma\, D_f\, N_q + 0.3\gamma\, B\, N_\gamma$

For sand, C= 0

Here test was done on the soil deposit $\therefore$ Depth, $D_f = 0$

$\therefore\ q_u = 0.3\ \gamma\ B\ N_\gamma$

where B = diameter

$49.54 = 0.3 \times 19.2 \times 0.3 \times N_\gamma$

$N_\gamma = 28.67$

From the given table, for N_γ of 28.67, the corresponding ϕ - value is:

$$= 32^o + \frac{(34-32)}{(36.96-27.49)} \times (28.67 - 27.49)$$

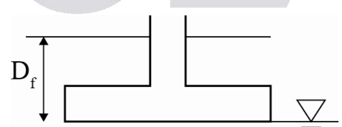
$$= 32^o + \frac{2\times 1.18}{9.47} = 32.25^o \ \text{(by interpolation)}$$

Say 32^o

For $\phi = 32^o$, $N_q = 28.52$, $N_\gamma = 27.49$

Square foundation:

B = 1.5 m, depth D_f = 1 m



$\gamma' = \gamma_{sat} - \gamma_w$

$= 19.2 - 9.81$

$= 9.39\ \text{kN/m}^3$

Gross ultimate bearing capacity, $q_u = 1.3\ CN_c + \gamma\ D_f\ N_q + 0.4\ \gamma'\ B\ N_\gamma$

(W.T. is at footing level)

$= 0 + 19.2 \times 1 \times 28.52 + 0.4 \times 9.39 \times 1.5 \times 27.49$

$= 702.46\ \text{kN/m}^2$

Net ultimate bearing capacity, $q_{nu} = q_u - \gamma D_f$

$$= 702.46 - 19.2 \times 1 = 683.26 \text{ kN/m}^2$$

Net allowable bearing capacity of the footing, $q_{ns} = \frac{q_{nu}}{F}$

Assume a Factor of safety of 3

$$\therefore q_{ns} = \frac{683.26}{3} = 227.75 \text{ kN/m}^2$$

Gross allowable bearing capacity, $q_s = q_{ns} + \gamma D_f$

$$= 227.75 + 19.2 \times 1 = 246.95 \text{ kN/m}^2$$

06(d). Write down the construction steps for Water Bound Macadam road. Also compare WBM construction with WMM construction. [20 M]

06(d).

Sol: Construction steps for Water Bound Macadam roads

Step 1: Preparation of Foundation for Receiving the WBM Course

The foundation for receiving the new layer of WBM may be either the subgrade or sub-base or base course. This foundation layer is prepared to the required grade and camber and the dust and either loose materials are cleaned.

Step 2: Provision of Lateral Confinement

Lateral confinement is to be provided before starting WBM construction. This may be done by constructing the shoulders to advance, to a thickness equal to that of the compacted WBM layer and by trimming the inner sides vertically.

Step 3: Spreading of Coarse Aggregates

The coarse aggregates are spread uniformly to proper profile to even thickness upon the prepared foundation and checked by templates.

Step 4: Rolling

After spreading the coarse aggregates properly, compaction is done by a three wheeled power roller of capacity 6 to 10 tonnes or alternatively by an equivalent vibratory roller the weight of the roller depends on the type of coarse aggregates.

Rolling is started from the edges, the roller being run forward and backward until the edges are compacted. The run of the roller is then gradually shifted towards the centre lien of the road, uniformly overlapping each preceding rear wheel track by one half width.

On superelevated portions of the road, rolling is commerced from the inner or lower edge and progressed gradually towards the outer or upper edge of the pavement.

Step 5: Application of Screenings

After the coarse aggregates are rolled adequately, the dry screenings are applied gradually over the surface to fill the interstices in three or more applications. Dry rolling is continued as the screenings are being spread and brooming carried out.

Step 6: Sprinkling and Grouting

After the application of screenings, the surface is sprinkled with water, swept and rolled. Wet screenings are swept into the voids using hand brooms. Additional screenings are applied and rolled till the coarse aggregates are well bonded and firmly set.

Step 7: Application of Binding Material

After the application of screening and rolling, binding material is applied at a uniform and slow rate at two or more successive thin layers. After each application of binding material, the surface is copiously sprinkled with water and wet slurry swept with brooms to fill the voids. This is followed by rolling with a 6 to 10 tonnes roller and water is applied to the wheels to wash down the binding materials that sticks to the roller. When crushable type screenings like moorum or gravel are used, there is no need to apply binding materials, except in the surfacing course.

Step 8: Setting and Drying

After final compaction, the WBM course is allowed to set over-night. On the next day the 'hungry' spots are located and are filled with screenings or binding material,. Lightly sprinkled with water if necessary and rolled. No traffic is allowed till the WBM layer set and dries out. In the case of WBM base coarse, the layer is allowed to dry completely without permitting traffic to ply and then the bituminous surfacing is laid Limited construction traffic may be permitted to ply over the WBM layer taking proper care not to damage the layer.

Step 6: On superelevated portions of the road, rolling is commenced from the inner or lower edge and progressed gradually towards the outer or upper edge of the pavement.

Step 7: After the coarse aggregates are rolled adequately, the dry screenings are applied gradually over the surface to fill the interstices

The difference between WBM (Water Bound Macadam) and WMM (Wet mix macadam) construction is as follows:

S.No.	WBM construction	WMM construction
1	Materials used for WBM construction are stone aggregates, screenings and binder material.	Materials used for WBM construction are stone aggregates and binder material only.
2	The size of aggregates used is 45mm to 90mm.	The size of aggregates used is 4.75mm to 20mm
3	Broken stones, crushed slag, over burnt bricks and any other natural occurring aggregates can be used	In this properly crushed and graded aggregates are used.
4	In this, stone aggregates, screenings and binders are laid one after another in layers.	In WMM, aggregates and binders are premixed in the batching plants in suitable proportions and then brought to the site for overlaying and compacting.
5	Spreading of coarse aggregates is done by templates or motor graders, and, and compacted using 6 to 10tn roller	Mix is spread by a self propelled paver finisher, and in case of multi-layer construction bottom layer is spread using motor graders.
6	Complete drying of WBM roads takes approximately one month.	The WMM roads gets dry sooner and can be opened for traffic within less time
7	During drying, Limited construction traffic may be permitted taking proper care.	During setting, construction traffic is also not permitted.
8	Since naturally natural occurring aggregates can be used and is directly laid, WBM is cheaper.	Since aggregates are to be broken down and remixing is required, WMM is costlier

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07(a). A rigid pavement of 25 cm thickness of M40 grade of concrete is supported over a subgrade having modulus of subgrade reaction as 8.0 kg/cm^3. If dowel bars are placed at centre-to-center spacing of 30 cm, calculate the maximum load carried by a single dowel which is just below the wheel. Assume wheel load as 4100 kg, participation of dowel bars in load distribution upto 1.0 × radius of relative stiffness and load to be transferred by joint as 50%. Poisson's ratio of the concrete may be taken as 0.15. [20 M]

07(a).

Sol: **Given** h = 25 cm Spacing, S = 30 cm

M40 concrete

k = 8 kg/cm^3 $E = 5000\sqrt{40} = 31622.7\text{ MPa} = 316227\text{ kg/cm}^2$

Maximum load taken by dowel bar which is just below wheel load, W = 4100 kg

Participation of dowel bar = 1 ×*l*

Load transferred by joint 50%

μ = 0.15

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

$$\ell = \left[\frac{316227\times 25^3}{12\times 8(1-0.15^2)}\right]^{1/4} = 85\text{ cm}$$

Load transfer capacity of dowel bar

Effective distance of transfer = 1 × *l* = 85 cm

$$\text{Actual capacity} = 1+\frac{85-30}{85}+\frac{85-60}{85}$$

$$= 1+ 0.64 + 0.29 = 1.93$$

$$\text{Load carrying capacity} = \frac{0.5\times W}{\text{actual capacity}}$$

$$= \frac{0.5\times 4100}{1.93} = 1062.17\text{ kg}$$

07(b). A pile group consists of four friction piles in cohesive soil. The unit weight and unconfined compressive strength of the soil are respectively 20.2 kN/m^3 and 200 kPa. The diameter of each pile is 300mm, length is 12.0 m and centre-to-centre spacing between the piles is 750 mm. Assuming an adhesion factor of 0.6, determine (i) load capacity of the group based on the individual pile failure, (ii) load capacity of the group based on the block failure and (iii) design load capacity of the group. Assume a factor of safety of 2.0 for individual pile failure and 3 for block failure. [20 M]

07(b).

Sol: Unconfined compressive strength, q_{uc} = 200 kPa

$$\text{Cohesion, } C = \frac{q_{uc}}{2} = \frac{200}{2} = 100 \text{ kPa}$$

(i) Ultimate group load capacity based on the individual pile failure, Q_{gi}

$Q_{gi} = n\,[A_P\, C_p\, N_c + A_s.\, \alpha\, .\, C]$

For friction piles, End bearing is negligible

$$Q_{gi} = n[A_s \alpha C]$$

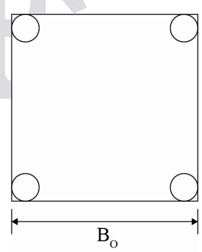
$$= 4\,[\,\pi\, D.\, L.\, \alpha.C]$$

$$= 4\,[\pi \times 0.3 \times 12 \times 0.6 \times 100]$$

$$= 2713 \text{ kN}$$

$$\text{Safe capacity} = \frac{Q_{gi}}{F} = \frac{2713}{2} = 1356.5 \text{ kN}$$

(ii) Ultimate group capacity based on block failure, Q_{gb}



$B_o = S + D$

$= 750 + 300$

$= 1050 \text{ mm} = 1.05 \text{ m}$

$Q_{gb} = A_{gs}\, C$ for friction piles

$= 4.\, B_o.\, L.\, C$

$= 4 \times 1.05 \times 12 \times 100 = 5040 \text{ kN}$

$$\text{Safe capacity} = \frac{Q_{gb}}{F} = \frac{5040}{3} = 1680 \text{ kN}$$

(iii) Design load capacity = smaller of the above two loads = 1356.5 kN

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Type of Batch	Timings	Date	Duration	Venue
Weekend Batch	6 to 8 hours of classes Sat: 10am to 7pm & Sun 8am to 6pm	13th July 2019	4 to 5 Months	@ Pune

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07(c). The following internal angles and length of sides are observed for a closed traverse ABCDA (in anti-clockwise direction):

Angle	Observed value	Side	Measured length (m)
DAB	92°38'	AB	27.15
ABC	104°33'	BC	52.16
BCD	70°46'	CD	41.96
CDA	92°07'	DA	46.73

Adjust the internal angles for closing error. Also adjust the traverse by Bowditch method and calculate the consecutive coordinates of points A, B, C and D. Assume line AD in north direction. [20 M]

07(c).

Sol: The sum of integer angles = $(2x – 4)90^o$

$x = 4$, $\Rightarrow (2(4) – 4)\ 90^o$

$\Rightarrow 360^o$

$\angle A + \angle B + \angle C + \angle D = 360^o\ 4'$

Error = $360^o\ 4' – 360^o$

= 4'

$\therefore$ Correction = – 4'

Correction angle = – 4' / 4 = – 1'

Corrected $\angle DAB = 92^o\ 38' – 1' = 92.37'$

Corrected $\angle ABC = 104^o 33' – 1' = 104.32'$

Corrected $\angle BCD = 70^o 46' – 1' = 70^o 45'$

Correct $\angle CDA = 92^o 7' – 1' = 92.6'$

For Bearing of AB = $92^o\ 37'$

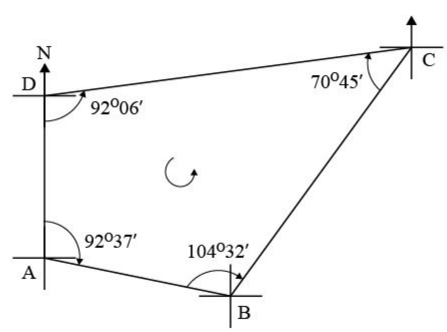
$BB_{AB} = 92^o\ 37' + 180^o$

$= 272^o\ 37'$

$BB_{AB} + \angle B + FB_{BC}$

$BB_{BC} = 272^o 37' – 104^o\ 32'$

$= 377^o 9'\ (–360^o)$



$= 17^o\ 9'$

$BB_{BC} = 17^o\ 9'$

$FB_{CD} = BB_{BC} + \angle C$

$= 267^o\ 54'$

$BB_{CD} = 87^o\ 54'$

$FB_{DA} = BB_{CD} + \angle D$

$= 180^o$

$\therefore$ Checked

Line	l(n)	FB	L	D	Correction L	Correction D	Corrected Lat	Corrected Dep
AB	27.15	$92^o37'$	– 1239	27.122	– 0.054	– 0.093	– 1.293	27.029
BC	52.16	$17^o9'$	49.841	15.381	– 0.104	– 0.178	49.737	15.203
CD	41.96	$267^o54'$	– 1.538	– 41.931	– 0.083	– 0.143	– 1.621	– 42.074
DA	46.73	180^o	– 46.73	0	– 0.093	– 0.159	– 46.823	– 0.159
Σl=168 m		ΣL=0.334	ΣD=0.573					

$\Sigma L \neq 0 \quad \Sigma D \neq 0$

$\therefore$ Closing error is present

Bowditch's Rule:

$$C_L = -\Sigma L \times \frac{\ell}{P}; \quad C_D = -\Sigma D \times \frac{\ell}{P}$$

Latitude

1. $C_{AB} = -0.334 \times \dfrac{29.15}{168}$

$= -0.054$

2. $C_{BC} = -0.104$
3. $C_{CD} = -0.083$
4. $C_{DA} = -0.093$

Departure

1. $C_{AB} = -0.573 \times \frac{27.15}{168} = -0.093$

2. $C_{BC} = -0.178$

3. $C_{CD} = -0.143$

4. $C_{DA} = -0.159$

Consecutive co-ordinates:

A. (0, 0)

B. (– 1.293, 27.029)

C. (49.737, 15.203)

D. (– 1.621, – 42.074)

08(a).

(i) What is spectral reflectance curve (spectral signature) in remote sensing? Explain any four applications of remote sensing in civil engineering. [10 M]

08(a). (i)

Spectral Reflectance signature:

Electromagnetic Spectrum: Spectral Signatures:

All objects on the surface of earth has spectral signatures. A spectral signature of an object or a ground surface feature is a set of values for the reflectance or radiance of the feature each values corresponding to the reflectance (or) radiance arranged over a different and well defined wavelength interval.

Spectral signature is distinct set of distinguishable characteristics. The response of ground surface interval to incident radiation is reflectance and the energy emitted by all object as a function of their temperature. A structure is their emittance. The reflectance of emittance determine the signature. The knowledge of spectral signature is essential for exploring the potential of remote-sensing technique. This knowledge enables to identify of classify objects. It is also required for interpretation of all remotely sensed data, whether the interpretation is carried-out visually (or) digitally. Evaluation of spectral signature implies a basic understanding of interaction of EM – radiations with various earth surface-object.

When radiation is incident on a surface, it is reflected, absorbed, scattered or transmitted. All the processes are strongly related to wavelength of incident reflection, as well as the atomic and molecular structure of the material. In view of these facts one can identify the material constituting the object from a spectral plot, Multi-band photograph or any other recovered which shows enough details of its spectral reflection, absorption, scattering or transmission properties.

Applications of Remote Sensing:

Remote Sensing pervaded almost all types of modern human activity. Its applications are not restricted to surveying and engineering but found in various fields.

(i) *Environmental applications:* for weather prediction, pollution control and management, profiling the atmospheric conditions like pressure, temperature, content of water vapour, measurement of wind velocity etc.

(ii) *Mineral exploration:* Locating and detailing mineral wealth and providing basic geological data.

(iii) *Agricultural applications:* for assessing land use and land cover, forestry of monitor the extent and type of vegetation cover, its state of health, mapping soil types, forecasting crop yield, erosion of soil etc.

(iv) *Applications in disaster control and management:* for detection of earthquakes, land slides, volcanic eruptions, floods and assessing the extent of damage suffered due to these causes etc.

(v) *Archaeological applications:* for recognizing pre-historic sites of civilization etc.

(vi) *Military applications:* to monitor movement of vehicles military formations and assessing the terrain.

(vii) *Hydrological applications:* for assessing water resources, forecasting run-off etc.

08(a).

(ii) A simple circular curve of radius 30 chain length has been set out to connect two tangents with external deflection angle of 30^o. The chainage of point of tangency is 300 chains. On further inspection, it is proposed to alter the radius of curve to 45 chain length. Calculate the chainage of point of curve and point of tangency for revised curve. Also calculate the length of long chord for revised curve. (Chain length = 20 m) [10 M]

08(a). (ii)

Sol: R = 30 chains Ch_I = 300chains [Chain = 20 m]

$\Delta = 30^o$

$$Ch_{T_1} = Ch_I - R\tan\left(\frac{\Delta}{2}\right)$$

$$= 300 \text{ chains} - 30\tan\left(\frac{4}{2}\right) \text{ chains}$$

$$= 5839.23 \text{ m}$$

$$\text{Length of curve} = R\Delta^o \times \frac{\pi}{180^o}$$

$$= 30 \times 30^o \times \frac{\pi}{180^o} = 314.159 \text{ m}$$

$$Ch_{T_2} = Ch_{T_1} + \ell$$

$$= 5839.23 + 314.159 = 6153.389 \text{ M}$$

$$\text{Length of long chord} = 2R\sin\left(\frac{\Delta}{2}\right)$$

$$= 2 \times (30 \times 20)\sin\left(\frac{30^o}{2}\right) = 310.583 \text{ m}$$

Revised curve:

R = 45 chains

= 900 m

$$Ch_{T_1} = Ch_I - R\tan\left(\frac{\Delta}{2}\right)$$

$$= 6000 - 900\tan\left(\frac{30^o}{2}\right) = 5858.846 \text{ m}$$

$$Ch_{T_2} = Ch_{T_1} + \ell$$

$$= 5758.846 + \left(900 \times 30^o \times \frac{\pi}{180^o}\right) = 6230.085 \text{ m}$$

$$\text{Long chord h} = 2R\sin\left(\frac{\Delta}{2}\right) = 465.874 \text{ m}$$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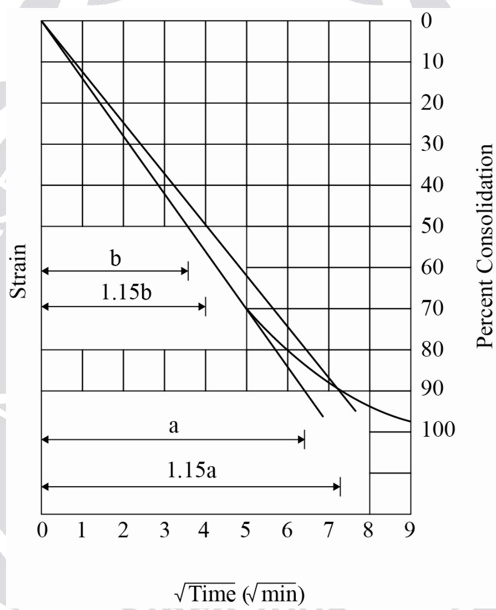
08(b). The figure given below represents time-consolidation relationship for a 30 mm thick clay sample subjected to a given pressure range under double drainage condition. Determine the coefficient of consolidation, C_V, for the clay sample. How long will it take (in days) to reach 50% consolidation for the same soil if it was 2.5 m thick and drained in one direction only? Given

$$T = \frac{\pi}{4}\left(\frac{U\%}{100}\right)^2, \; U \le 60\%$$

T = 1.781 – 0.933 log (100 – U%), U > 60% **[15 M]**



08(b).

Sol: For double drainage, the drainage path, $d = \frac{H}{2} = \frac{30}{2} = 15$ mm

[The abscissa corresponding to 1.15 a shown in the figure represents time for 90% consolidation]

$\therefore$ From the graph given, for 90% degree of consolidation, $\sqrt{t_{90}} = 7.5$

$\therefore t_{90} = 56.25$ min

$T = 1.781 - 0.933 \log_{10} [100 - U\%]$

$T_{90} = 1.781 - 0.933 \log_{10} [100 - 90] = 0.848$

$$T_{90} = \frac{C_V . t_{90}}{d^2}$$

$$0.848 = \frac{C_V \times 56.25}{(15)^2}$$

$\therefore$ Coefficient of consolidation, $C_V = 3.392\ \text{mm}^2/\text{min}$

Field clay:

Thickness, H = 2.5 m

For one-way drainage, drainage path, d = H = 2.5 m = 2500 mm

$$T_{50} = \frac{\pi}{4}\left[\frac{50}{100}\right]^2 = 0.19625$$

$$T_{50} = \frac{C_V t_{50}}{d^2}$$

$$\therefore\ t_{50} = \frac{T_{50}.d^2}{C_V} = \frac{0.19625 \times 2500^2}{3.392} = 361604.5\ \text{min}$$

$$= 251.11\ \text{days}$$

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08(c). A two-lane, two-way highway is designed for design speed of 80 km/hr. A vertical curve is to be provided at intersection of downward gradient of 1 in 50 with another downward gradient of 1 in 20. Calculate the length of the vertical curve fulfilling the requirement of stopping sight distance and overtaking sight distance. The coefficient of longitudinal friction and the acceleration may be taken as 0.35 and 3.6 km/hr/sec respectively. [25 M]

08(c).

Sol: Given 2-lane 2-way

Design speed, V = 80 kmph

$\nu = 22.22$ m/s

Acceleration, $a = 3.6 \text{ kmph/sec} = \frac{3.6}{3.6} = 1 \text{ m/sec}^2$

Coefficient of longitudinal friction, f = 0.35

Calculation of SSD

$$SSD = \nu t + \frac{\nu^2}{2gf}\text{ ; let } t = 2.5 \text{ sec (reaction time)}$$

$$SSD = 22.22 \times 2.5 + \frac{22.22^2}{2 \times 9.81 \times 0.35}$$

$$= 55.55 + 71.9 = 127.45 \text{ m}$$

Calculation of OSD

Let speed of overtaking vehicle, $v_A = 22.22$ m/s (design speed)

Let speed of opposite vehicle, $v_c = 22.22$ m/s

Let speed of overtaken, vehicle, $v_B = v_A - 4.5 = 17.72$ m/s

Let spacing between over taking & over taken vehicles,

$$s = 0.7\, v_B + l\text{ ; Let } l = 6.1 \text{ m}$$

$$= 0.7 \times 17.72 + 6.1 = 18.504 \text{ m}$$

Overtaking time, $T = \sqrt{\frac{4s}{a}} = \sqrt{\frac{4 \times 18.504}{1}} = 8.6 \text{ sec}$

$OSD = (v_B t) + (v_B T + 2s) + (v_c T)$

Let t = 2sec (reaction time)

= (17.72 × 2) + (17.72 × 8.6 + 2 × 18.504) + (22.22 × 8.6)

= 35.44 + 189.4 + 191.092

∴ OSD = 415.93 m

Given gradients, $N_1 = \frac{1}{50} = 2\%$ (downward)

$N_2 = \frac{1}{20} = 5\%$ (downward)

Net deflection angle, $N = (N_1) - (N_2)$

$N = (-2\%) - (-5\%) = +3\% = 0.03\%$

∵ Net deflection angle is positive; the curve formed is summit curve

Length of summit curve

(i) Based on SSD (S = 127.45 m)

Let S< l (l > S); $l = \frac{NS^2}{4.4} = \frac{0.03 \times 127.45^2}{4.4}$ f

L = 110.75 m < S

Assumption is wrong

Let S > l (l < S), $l = 2S - \frac{4.4}{N}$

$= 2 \times 127.45 - \frac{4.4}{0.03}$

l = 108.23 m < S

(ii) Based on OSD (S = 415.93 m)

Let S < l (l >S); $l = \frac{NS^2}{9.6} = \frac{0.03 \times 415.93^2}{9.6}$

l = 540.62 m > S

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