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UPSC ESE 2019

Main Exam Detailed Solutions

Civil Engineering

PAPER-II

EXAM DATE : 30-06-2019 | 2:00 PM to 5:00 PM

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

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Civil Engineering Paper Analysis
ESE 2019 Main Examination

ESE Mains Paper-II

Sl.	Subjects	Marks	Percentage Weightage
1.	Fluid Mechanics & Hydraulic Machines	62	12.91
2.	Engineering Hydrology.	20	4.17
3.	Water Resource Engineering	42	8.75
4.	Environmental Engineering	116	24.17
5.	Soil Mechanics & Foundation Engg.	99	20.63
6.	Surveying and Geology	52	10.83
7.	Highway Engineering	65	13.54
8.	Railway Engineering	12	2.5
9.	Airport, Dock, Harbour & Tunneling Engg.	12	2.5
	Total	**480**	**100.00**

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SECTION 'A'

1. (a) The velocity vector in an incompressive flow is given by

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

(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 Marks]

Solution:

(i) For the given flow field

$$u = 6xt + yz^2$$
$$v = 3t + xy^2$$
$$w = xy - 2xyz - 6tz$$

$\therefore$
$$\frac{\partial u}{\partial x} = 6t$$
$$\frac{\partial v}{\partial y} = 2xy$$
$$\frac{\partial w}{\partial z} = -2xy - 6t$$

For an incompressible flow, continuity equation is given as,

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \qquad \ldots(i)$$

$\therefore$ Substituting values of $\frac{\partial u}{\partial x}, \frac{\partial v}{\partial y}$ & $\frac{\partial w}{\partial z}$ in equation (i)

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

Hence continuity equation is satisfied.

(ii) The acceleration component in x-direction is given as

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

$$\frac{\partial u}{\partial x} = 6t$$
$$\frac{\partial u}{\partial z} = z^2$$
$$\frac{\partial u}{\partial t} = 6x$$

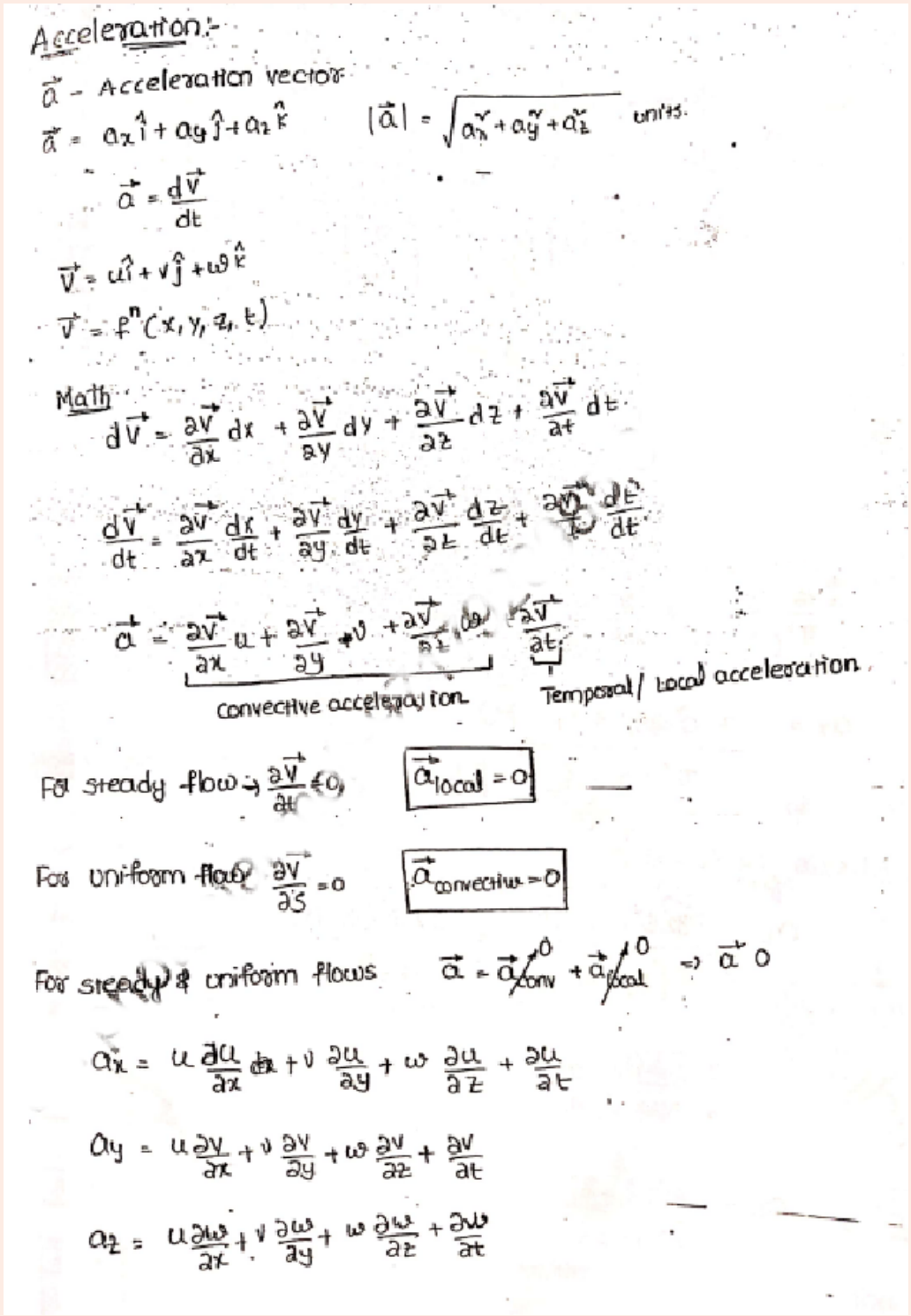
$\therefore$ $a_x = \left(6 \times t + yz^2\right)6t + \left(3t + xy^2\right)z^2 + \left(xy - 2 \times yz - 6tz\right)2yz + 6x$

Value of a_x at point A (1, 1, 1) and t = 1.0 is given as

$a_x = (6 + 1)\cdot 6 + (3 + 1)\cdot 1 + (1 - 2 - 6)\cdot 2 + 6 = 38$ units

MADE EASY Source

- **Rank Improvement Batch Fluid Mechanics workbook:** Q.3 Page 25
- **MADE EASY Classnotes**



End of Solution

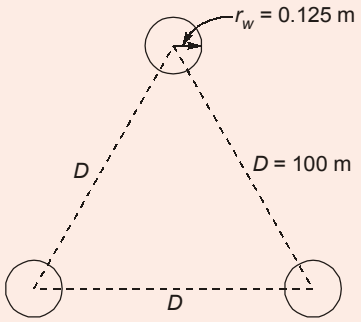
1. (b) Three tube wells of 25 cm, diameter each are located at the three vertices of an equilateral triangle of side 100 m. Each tube well penetrates fully in a confined aquifer of thickness 25 m. Assume the radius of influence for these wells and the coefficient of permeability of the aquifer as 300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

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

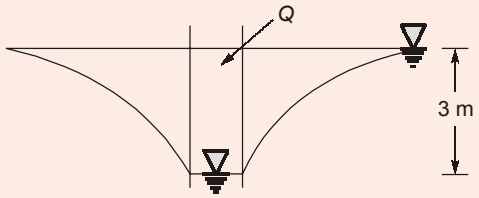
(ii) What will be the percent change in discharge of this well if all the three wells were to pump such that the drawdown is 3 m in all the wells?

[12 Marks]

Solution:



(i) When only one well is pumping



Discharge without interference,

$$Q = \frac{2\pi \times K \times Z \times s}{\ln\left(\frac{R}{r_w}\right)} = \frac{2\pi \times 40 \times 25 \times 3}{\ln\left(\frac{300}{0.125}\right)} = 2421.81\ \text{m}^3/\text{d}$$

(ii) When all three wells are pumping,

When all three wells interfere, discharge through each well would be

$$Q' = \frac{2\pi \times K \times z \times (s)}{\ln\left(\frac{R}{r_w} \times \frac{R^2}{D^2}\right)}$$

$$= \frac{2\pi \times 40 \times 25 \times 3}{\ln\left(\frac{300}{0.125} \times \frac{300^2}{100^2}\right)} = 1888.648\ \text{m}^3/\text{d}$$

Percentage change in discharge=

$$\frac{\text{Discharge without interference} - \text{Discharge with interfence}}{\text{Discharge without interference}} \times 100$$

$$= \frac{2421.8 - 1888.64}{2421.8} \times 100 = 22.01\%$$

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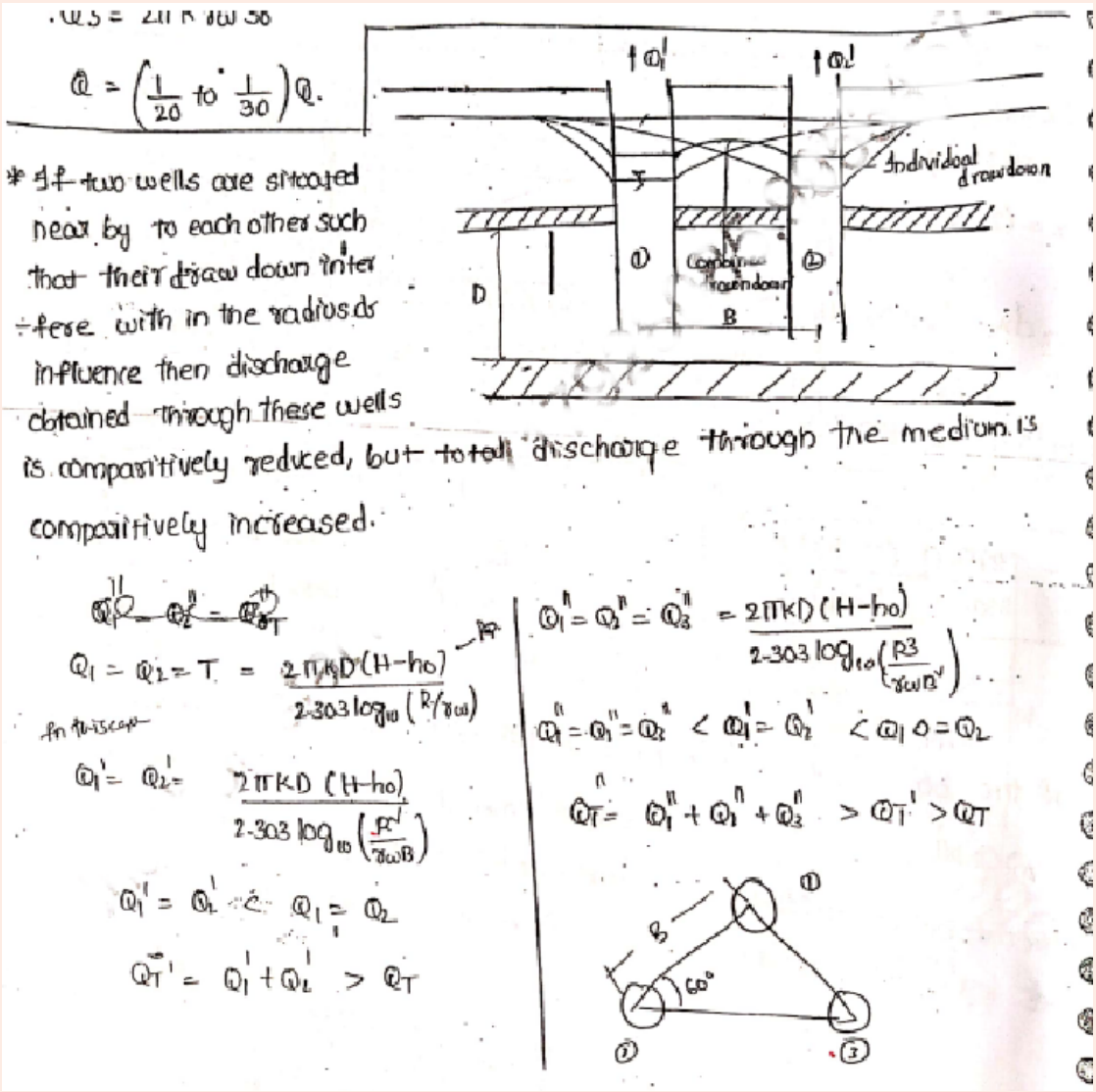
- **ESE 2019 Mains Test Series:** Q.7(c) (i) of Test-2
- **MADE EASY Classnotes**



End of Solution

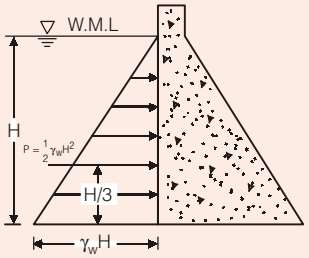
1. (c) Draw the schematic diagram of a gravity dam and indicate the major forces acting on it. Draw the diagram of the uplift force when (i) drain is not provided and (ii) drain is provided.

[12 Marks]

Solution:

Forces Acting on Gravity Dam

(i) Water Pressure



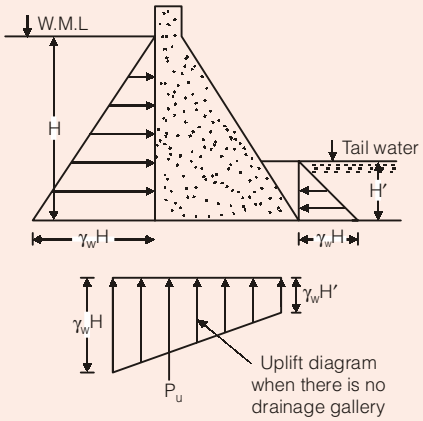
$$P = \frac{1}{2}\gamma_w H^2$$

Acting at $\frac{H}{3}$ from base

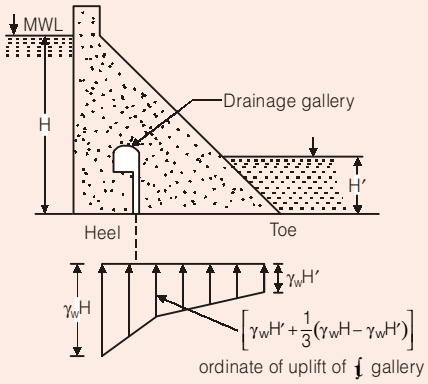
where γ_w = Unit weight of water.

(ii) Uplift Pressure

(a) When Drainage Gallery is not Provided



(b) When Drainage Gallery is Provided



(iii) Earthquake Force

$\alpha_H = 0.1g \text{ to } 0.2g$

$\alpha_v = 0.75\alpha_H$

$\alpha = \beta I \alpha_0$

where, α_H = Horizontal acceleration

α_v = Vertical acceleration

α = Seismic coefficient

β = Soil foundation system factor

I = Importance factor

α_0 = Basic seismic coefficient which depends upon seismic zone of country.

$$F_g = \frac{w}{g}(g \pm \alpha_v)$$

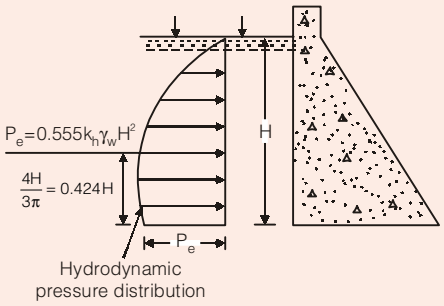
where, F_g = Body force

g = Acceleration due to gravity, +ve for upward & –ve for downward.

(a) Hydrodynamic force

(i) $F_H = \left(\frac{w}{g}\right)\alpha_H$ F_H = Horizontal Inertia force.

(ii) It effect of water pressure due to earthquake distribution of pressure is parabolic.



$P_e = 0.555\alpha\gamma_w H^2$

at 0.424 H from base.

α = 0.1g to 0.2g

(iv) Silt Pressure

$F_{silt} = \frac{1}{2}k_a\gamma_{sub}\cdot h_s^2$

where, h_s = Height of silt from the base.

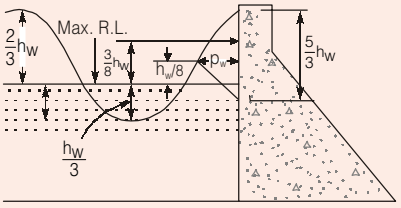
k_a = Coefficient of active earth pressure = $\frac{1-\sin\phi}{1+\sin\phi}$

γ_{sub} = Submerged unit weight.

According to U.S.B.R

$$F_{silt} = \frac{360h_s^2}{2}(kgf)$$

(v) Wave Pressure



$P_w = 2\cdot 4\gamma_w h_w$

Acts at $\frac{h_w}{8}$ from still water level.

where, P_w = Resultant wave pressure.

$F_w = 2\gamma_w h_w^2$ acts at $\frac{3h}{8}$ from still water surface.

where F_w = Total wave force.

$h_w = 0.032\sqrt{VF} + 0.763 - 0.271(F)^{3/4}$ if F < 32 km.

$h_w = 0.032\sqrt{VF}$ when F > 32 km.

where, F = Length of reservoir in km

h_w = Height of wave in meter

V = Wind velocity in km/hr.

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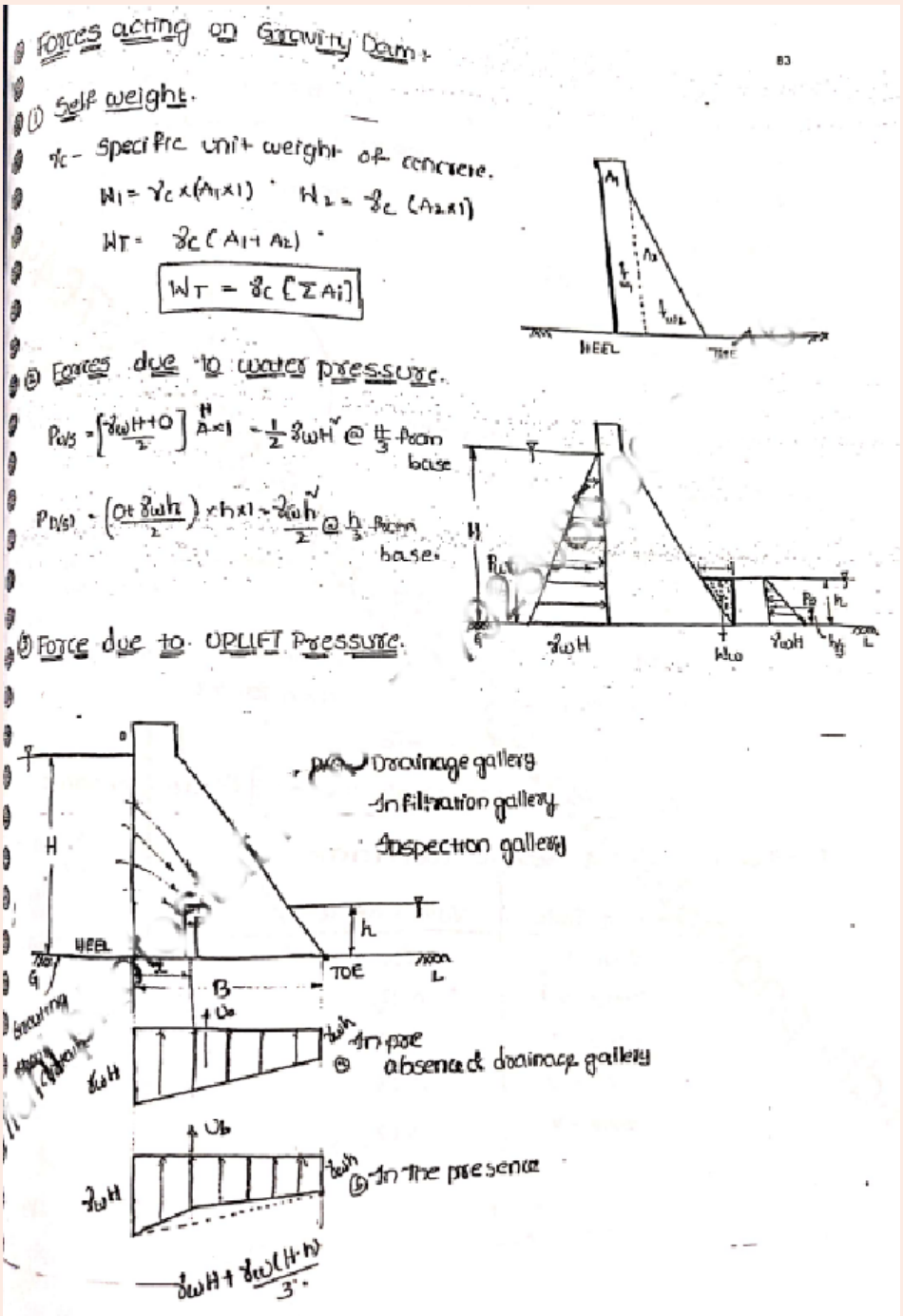
(vi) Self Weight of Dam

$w = \gamma_c V$ where, γ_c = Unit weight of concrete

V = Volume of dam body per unit length

MADE EASY Source

- **MADE EASY Handbook** Irrigation : Page 501, 502 and 503
- **MADE EASY Classnotes**



4) Earthquake forces:

C-centre of earth.
F: Focus & hypocentre of earthquake.
E: Epicentre of the earthquake

As per IS $\boxed{\alpha_h = k\beta}$

Where K = seismic coefficient

and $\boxed{K = \beta I \alpha_0}$

Where β → soil foundation system factor

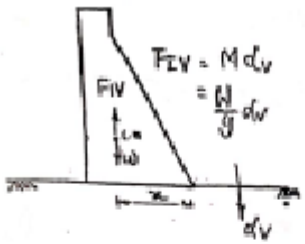
$\boxed{\beta = 1}$ for Gravity dams

and I = importance factor and $\boxed{I = 3}$ for Gravity dams.

Further α_0 : site seismic coefficient.

Seismic Zones	Values of α_0
Zone-I	0.01
Zone-II	0.02
Zone-III	0.04
Zone-IV	0.05
Zone-V	0.08

i) Effect of a_v.



$F_{IV} = M a_v = \frac{W}{g} a_v$

$W' = W - F_{IV}$

$= W - M a_v$

$= W - \frac{W}{g} a_v$

$= W\left(1 - \frac{a_v}{g}\right)$

$\boxed{W_1' = W\left(1 - \frac{a_v}{g}\right)}$

F_{IV} – Inertia force in vertical direction

$\boxed{(M_o)_{IV} = \frac{W}{g} a_v \bar{x}}$

ii) Effect of a_h.

a) Inertia force in Gravity Dam (F_{IH})

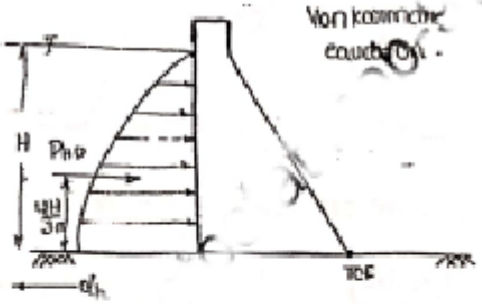
$F_{IH} = M \times a_h$ (⟶)

$= \frac{W}{g} a_h = \frac{W a_h}{g}$ (kg) → W×K

$\boxed{F_{IH} = W \times K}$ kg

(M_o) = (K W) × $\bar{y}$

b) Hydrodynamic pressure force



$\boxed{P_{HD} = 0.555\, K\, \gamma_w H^2}$ ⟶ direction

@ $\frac{4H}{3\pi} = 0.424\,H$

$\beta_1 = 1$, $I = 3$, $a_0 = a_h$

$K = \beta I a_0$ $\quad a_h = Kg$ $\quad a_v = 0.75 a_h$

⑤ Silt pressure:

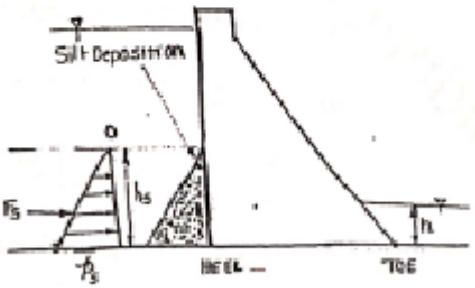
$\boxed{P_s = K_a \gamma_s h_s}$

P_s – Active self pressure at base.

Further

K_a – Active self pressure coeffic

$K_a = \frac{1-\sin\phi}{1+\sin\phi} = \tan^2\left(45 - \frac{\phi}{2}\right)$



Where ϕ - Angle of internal friction of silt

γ_s — Submerged unit weight of silt.

$\gamma_s = \gamma_{sat} - \gamma_w$ γ_{sat} - Saturated unit weight of silt.

and h_s - height of silt deposition.

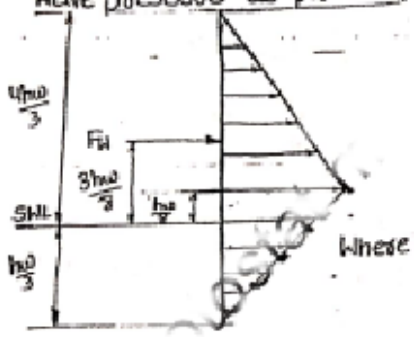
Further $F_s = \left(0 + \frac{p_s}{2}\right) \times (h_s \times 1)$

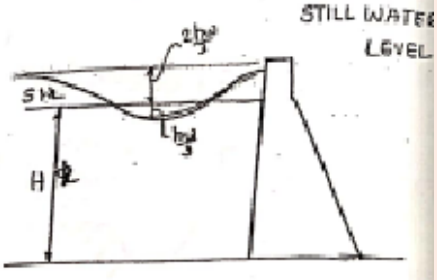
$F_s = \frac{K_a \gamma_s h_s^2}{2}$ @ $\frac{h_s}{3}$ above base.

In the absence of data as per USBR $F_s = \frac{360 h_s^2}{2}$ in kgf

⑥ Wave pressure:-

Wave pressure as per IS.





Where p_w = Max. wave pressure intensity

$p_w = 2.4 \gamma_w h_w$.

Fetch - Max uninterrupted distance

and 'Ha' Im length of gravity dam

$F_w = \left(0 + \frac{p_w}{2}\right) \times \left(\frac{5h_w}{3} \times 1\right) = \frac{2.4 \gamma_w h_w}{2} \times \frac{5h_w}{3}$.

$F_w = 2.0 \gamma_w h_w^2$ @ $H + \frac{3h_w}{8}$ above base.

Where h_w = Height of waves

As per IS $h_w = 0.032 \sqrt{VF}$ m $F \geq 32$ m.

$h_w = 0.032 \sqrt{VF} + 0.763 - 0.271 F^{\frac{1}{4}}$ $F < 32$ km

V = wind velocity F = Fetch (in km)

End of Solution

1. (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 Marks]

Solution:

Year	Population
1971	60000
1991	120000
2011	180000

Saturated population:

$$P_s = \frac{2P_0P_1P_2 - P_1^2(P_0 + P_2)}{P_0P_2 - P_1^2}$$

$$= \frac{2 \times 60000 \times 120000 \times 180000 - (120000)^2(60000 + 180000)}{60000 \times 180000 - 120000^2}$$

$$= 240000$$

$$m = \frac{P_s - P_0}{P_0}$$

$$m = 3$$

$$n = \frac{1}{t_1}\ln\left[\frac{P_0(P_S - P_1)}{P_1(P_S - P_0)}\right]$$

$$= \frac{1}{20}\ln\left[\frac{60000(240000 - 120000)}{120000(240000 - 60000)}\right]$$

$$= -0.0549 \text{ year}^{-1}$$

$$P = \frac{P_S}{1 + m\log_e^{-1}(nt)}$$

$$P = \frac{240000}{1 + 3 \times \log_e^{-1}(-0.0549 \times 60)}$$

$$= 215960.2945$$

$$= 215961$$

MADE EASY Source

- **ESE 2019 Mains Test Series:** Q.5(c) of Test-2
- **Theory Book:** Environmental Engg., 1.7.9, (Page 18)
- **MADE EASY Classnotes**

(66) In two period, each of 25 years, the city is grown from 40,000 to 160000 and then 2.8 lakh. Determine (280000)

(1) saturation population
(2) eqn of logistic curve
(3) expected population after next 15 years

$t = t_0 \quad P_0 = 40,00$
$t = t_1 \quad P_1 = 160000$
$t = t_2 \quad P_2 = 280000$

(i) $$P_S = \frac{2P_0P_1P_2 - P_1^2(P_0+P_2)}{P_0P_2 - P_1^2} = 320000$$

(ii) $$P = \frac{P_S}{1+m\ln^{-1}(nt)}$$

$$m = \frac{P_S - P_0}{P_0} = \frac{320000 - 40000}{40000}$$

$$m = 7$$

$$n = \frac{1}{t_1}\ln\left\{\frac{P_0(P_S - P_1)}{P_1(P_S - P_0)}\right\}$$

$$= \frac{1}{2.5}\ln\left\{\frac{4(32-16)}{16(32-4)}\right\}$$

$$= -0.778.$$

$$P = \frac{P_S}{1+7\ln^{-1}(-0.778t)}$$

(iii) For $t = 6.5$ $\quad (25+25+6.15) = 65$ year $= 6.5$ decades.

$$P_{6.5} = \frac{320000}{1+7\ln^{-1}(-0.778\times 6.5)} = 30635$$

$e^{(-0.778\times 6.5)}$

End of Solution

1. (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 Marks]

Solution:

$$\left[CO_3^{2-}\right] = 110 \text{ mg/}l$$

$$\left[HCO_3^{-}\right] = 80 \text{ mg/}l$$

As $\quad pH = 10$

$\therefore \quad pOH = 4$

$\therefore \quad [OH^-] = 10^{-4} \text{ mol/}l$

$$= 10^{-4} \times 17 \frac{gm}{l} = 1.7 \frac{gm}{l}$$

$$[H^+] = 10^{-10} \text{ mol/}l$$

$$= 10^{-10} \times \frac{1 \times 10^3}{l} \frac{mg}{l}$$

$$= 10^{-7} \frac{mg}{l}$$

$\therefore$ Equivalent weight of $\left[CO_3^{2-}\right] = 30$

Equivalent weight of $\left[HCO_3^{-}\right] = 61$

Equivalent weight of $\left[OH^{-}\right] = 17$

$$\therefore \text{ Total alkalinity in term of } CaCO_3 = \frac{\left[CO_3^{2-}\right]}{\text{Equivalent weight of } \left[CO_3^{2-}\right]} \times \text{equivalent weight of } CaCO_3$$

$$+ \frac{\left[HCO_3^{-}\right]}{\text{Equivalent weight of } \left[HCO_3^{-}\right]} \times \text{equivalent weight of } CaCO_3$$

$$+ \frac{\left[OH^{-}\right]}{\text{Equivalent weight of } \left[OH^{-}\right]} \times \text{equivalent weight of } CaCO_3$$

$$- \frac{\left[H^{+}\right]}{\text{Equivalent weight of } \left[H^{+}\right]} \times \text{equivalent weight of } [H^+]$$

$$= \frac{110}{30} \times 50 + \frac{80}{61} \times 50 + \frac{1.7}{17} \times 50 - \frac{10^{-7}}{1} \times 50$$

$$= 253.907 \text{ mg/}l \text{ as } CaCO_3$$

Approximate alkalinity by ignoring hydroxide ion and hydrogen ion is given as

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

$$= 248.90 \text{ mg/}l \text{ as } CaCO_3$$

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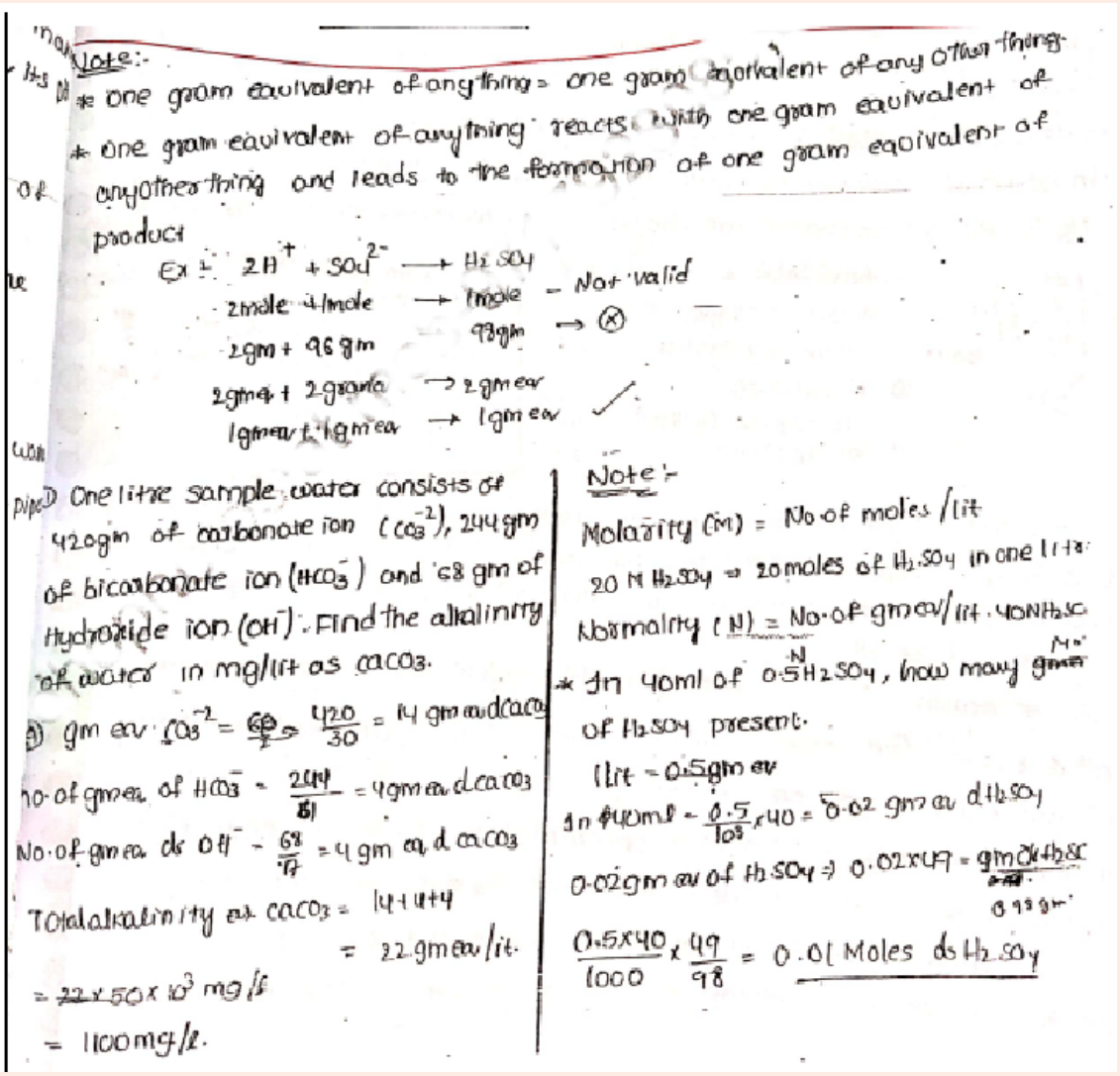
$\therefore$ Percentage error in approximation $= \dfrac{253.907 - 248.907}{253.907} \times 100 = 1.969\%$

MADE EASY Source

- **MADE EASY Classnotes**

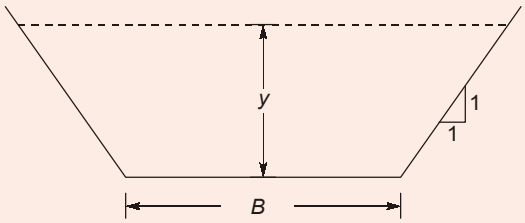


End of Solution

2. (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 Marks]

Solution:



Given data:

$$\text{Discharge} = 50\ m^3/s$$

$$\text{Velocity} = 2\ m/s$$

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

$$n = 0.02$$

We have

$$\text{Discharge} = \text{Velocity} \times \text{Area}$$

$$50 = 2 \times A$$

$\therefore$ $$\text{Area} = 25\ m^2 \quad \text{...(i)}$$

$\therefore$ $$A = \frac{B + B + 2y}{2} \times y$$

$$= (B + y)y$$

$$= (0.8y + y)y$$

$$A = 1.8y^2 \quad \text{...(ii)}$$

$\therefore$ equating (i) and (ii)

$$1.8y^2 = 25$$

$$y = 3.726\ m$$

$$B = 0.8 \times y = 2.9814\ m$$

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

$$R = \frac{A}{P}$$

$$A = 1.8y^2$$

$$P = B + 2 \times \sqrt{y^2 + y^2}$$

$$= 0.8y + 2 \times \sqrt{2}y$$

$$P = 3.628y$$

$\therefore$ $$R = \frac{1.8y^2}{3.628y} = 0.496y$$

$\therefore$ $$2 = \frac{1}{0.02} \times (0.496 \times 3.726)^{2/3} \times S^{1/2}$$

$$S = 7.0548 \times 10^{-4} \text{ i.e. } \frac{1}{1417.46}$$

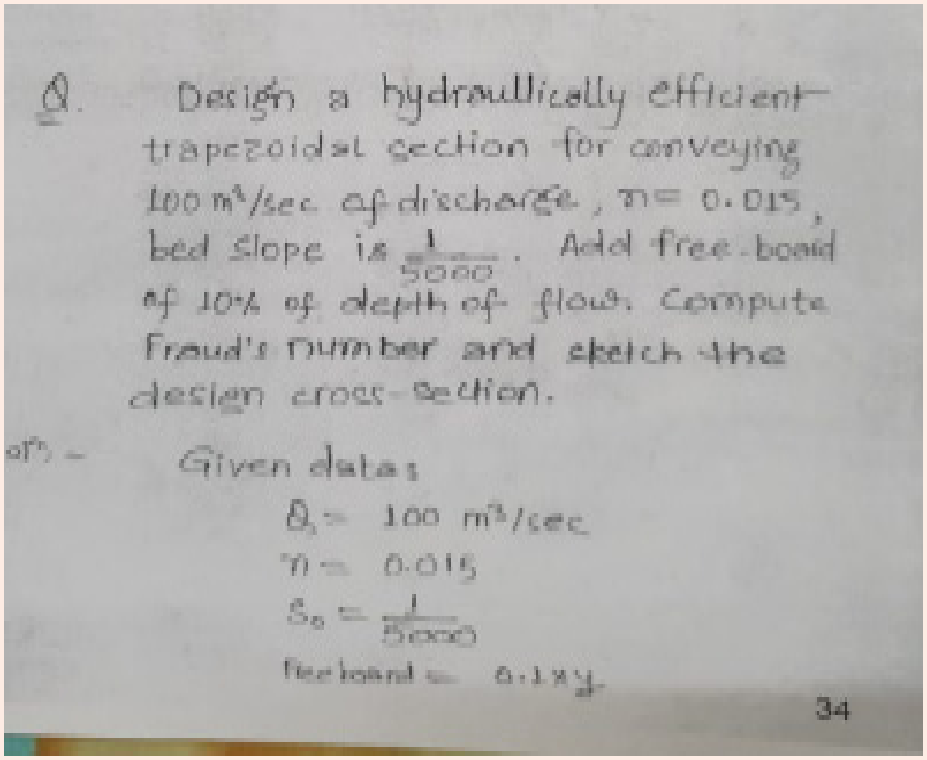
$\therefore$ Bed width = 2.9814 m

Depth of flow = 3.726 m

$$\text{Bed slope} = \frac{1}{1417.46}$$

MADE EASY Source

- **Work Book:** Irrigation : Page 71, Question 69
- **MADE EASY Classnotes**



End of Solution

2. (b) Define a unit hydrograph. Explain two basic assumptions made in the derivation of unit hydrograph. Following are the ordinates 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 Marks]

Solution:

Unit hydrograph : A unit hydrograph is defined as the hydrograph of direct runoff resulting from one unit depth of rainfall excess occurring uniformly over the basin and at a uniform rate for a specific duration.

The basic assumptions of a unit hydrograph are:

(i) **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.

(ii) **Linear Response:** The direct runoff response to the rainfall is assumed to be linear. It means principle of superposition may apply. So that we can find hydrograph of different duration from a given hydrograph.

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

Also, if $x_2(t) = rx_1(t)$

Then $y_2(t) = ry_1(t)$

Hence, this assumption enable the method of superposition to be used to derive DRHs.

Time (h)	Ordinate of 4-h UH (m^3/s)	S-curve addition (m^3/s)	S-curve ordinate (m^3/s) (Col. 2+ Col. 3)	S-curve lagged by 12 h (m^3/s)	(Col. 4 - Col. 5)	$\frac{\text{Col. 6}}{(12/4)}$ = 12-h UH ordinates (m^3/s)
1	2	3	4	5	6	7
0	0	–	0	–	0	0
4	20	0	20	–	20	6.7
8	80	20	100	–	100	33.3
12	130	100	230	0	230	76.7
16	150	230	380	20	360	120.0
20	130	380	510	100	410	136.7
24	90	510	600	230	370	123.3
28	52	600	652	380	272	90.7
32	27	652	679	510	169	56.3
36	15	679	694	600	94	31.3
40	5	694	699	652	47	15.7
44	0	699	699	679	20	6.7
48		699	699	694	5	1.7
52			699	699	0	0

Uses of Unit Hydrographs : The unit hydrograph establish a relationship between *effective rainfall* and *direct runoff* for a catchment. This relationship is very useful in study of the hydrology of a catchment, as

(i) In the development of flood hydrograph for extreme rainfall magnitude

(ii) In extension of flood-flow records based on rainfall records

(iii) In development of flood forecasting and warning system based on rainfall

Limitation of unit hydrograph:

(i) Unit hydrograph assumes uniform distribution of rainfall over the catchment, and the intensity of rainfall is assumed constant for the duration of rainfall excess. In practice these two conditions are never strictly satisfied.

(ii) Unit hydrograph method can not be used for a catchment area greater than 5000 km^2 and less than 2 km^2.

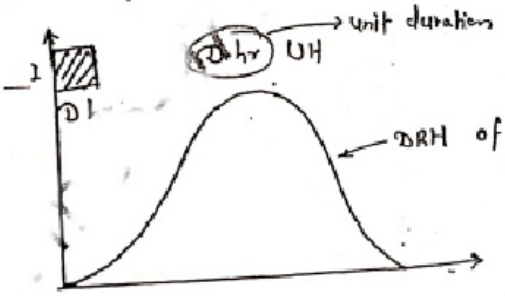
(iii) Precipitation must be from rainfall only. Snow melt runoff can not be satisfactory represented by unit hydrograph.

(iv) The catchment should not have large storage (Ex. tank, pond etc.) which affects the linear relationship between storage and discharge.

MADE EASY Source

- **ESE 2019 Mains Test Series:** Q.8(c) of Test-9 and Q.1(e) Test-7
- **Theory Book:** Hydrology : Example 6.12 (Page No. 147)
- **MADE EASY Classnotes**

Unit Hydrograph :- It is a direct Runoff hydrograph which results in a Runoff depth of 1 cm (this 1 cm may be some other unit value also eg.- 1 mm, 1 inch etc) from a rainfall of some unit duration



A 'D' h. unit hydrograph represents a DRH which results in a runoff depth of 1 cm from a rainfall or storm which lasts for D hrs. This 'D' hr is called as unit duration of this unit hydrograph.

Note. For any particular river or stream infinite no. of unit hydrographs can be obtained.

Theory of unit hydrograph :- This theory was developed by "Sherman" in 1932 and has the following basic assumption -

Time Invariance :- According to this assumption DRH for a given effective rainfall is always same in a catchment irrespective of the time when the rainfall or storm takes place.

Linear Response :- This is a single most important assumption in the theory of unit unit hydrograph. According to this assumption any change in the input is proportionately reflected in the output.

Ques-11

Time	0	4	8	12	16	20	24	28	32	36	40	44
UH	0	20	60	150	120	90	70	50	30	20	10	0

ϕ = 0.25 cm/hr Q_B = 20 m^3/s

$R = P - \phi t$

Time	0	4	8	12
Accumulated	0	5	5.8	8.8
P(cm)	0	5	0.8	3
Runoff	0	4	-0.2	2
		R_1	0	R_3

End of Solution

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

[15 Marks]

(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 Marks]

Solution:

(i) The quantity of water required to be stored in the reservoir for equalising or balancing this variable demand against the constant supply is known as the balancing reservoir or balancing storage or the storage capacity of a balancing reservoir. This storage capacity of balancing reservoirs is worked out with help of hydrographs of inflow and outflow by mass curve method or by analytical tabular solution.

Mass Curve Method

- A mass curve diagram is the plot of accumulated supply or demand versus time.
- The supply is also called as inflow and demand as outflow. First mass curve of supply known as supply line is drawn and over this demand curve is superimposed.
- The amount of balancing storage is determined by adding the maximum ordinates between the demand and supply lines.
- To construct such diagram for a particular water supply project, we have to proceed as follows.

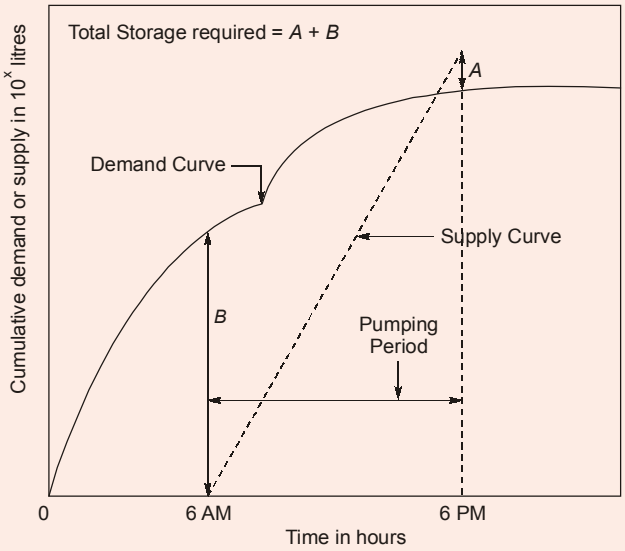
  (a) From the past records, determine the hourly demand (or draft) for all 24 hours for typical days (maximum, average and minimum).

  (b) Calculate and plot the cumulative demand against time and then plot the mass curve of demand.

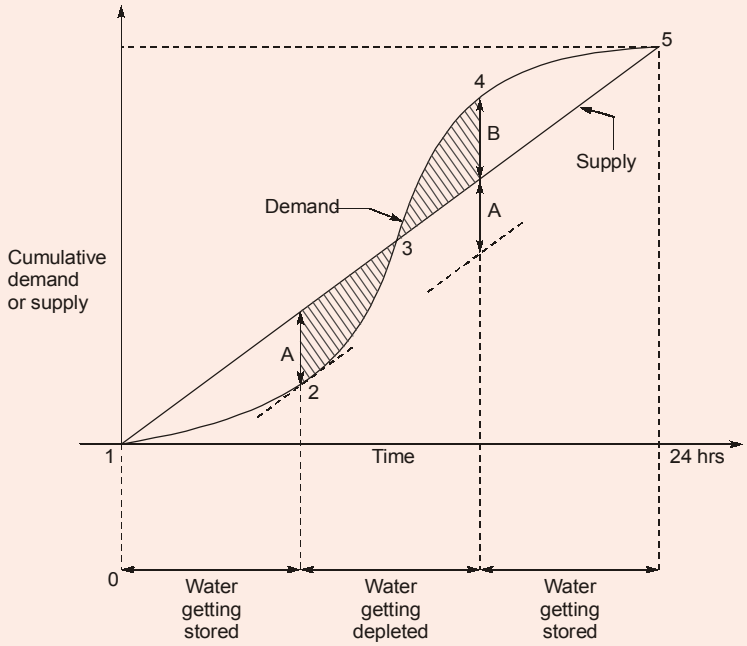
  (c) Draw the cumulative supply also against time, which is a straight line if the supply is constant.

  (d) The storage required is calculated as the sum of the two maximum ordinates between demand and supply lines.

  (e) Repeat the procedures for all the typical days (maximum, average and minimum) and determine the maximum storage required for the worst days.



Limited Hour Supply



Limited Hour Supply

From (2 - 4) → Demand rate > supply rate
→ Water getting depleted
From (4 - 5 - 1 - 2) → Demand rate < supply rate
→ Water getting stored
From (4 - 5) → Accumulation = *B*
From (1 - 2) → Accumulation = *A*

From (2 - 3) $\rightarrow$ Depletion = A

From (3 - 4) $\rightarrow$ Depletion = B

$\Rightarrow$ Maximum water that would be accumulated = $A + B$ (i.e From 4 - 2)

$\Rightarrow$ Maximum water that would be depleted = $A + B$ (i.e From 2 - 4)

(ii) Average sound level is given as

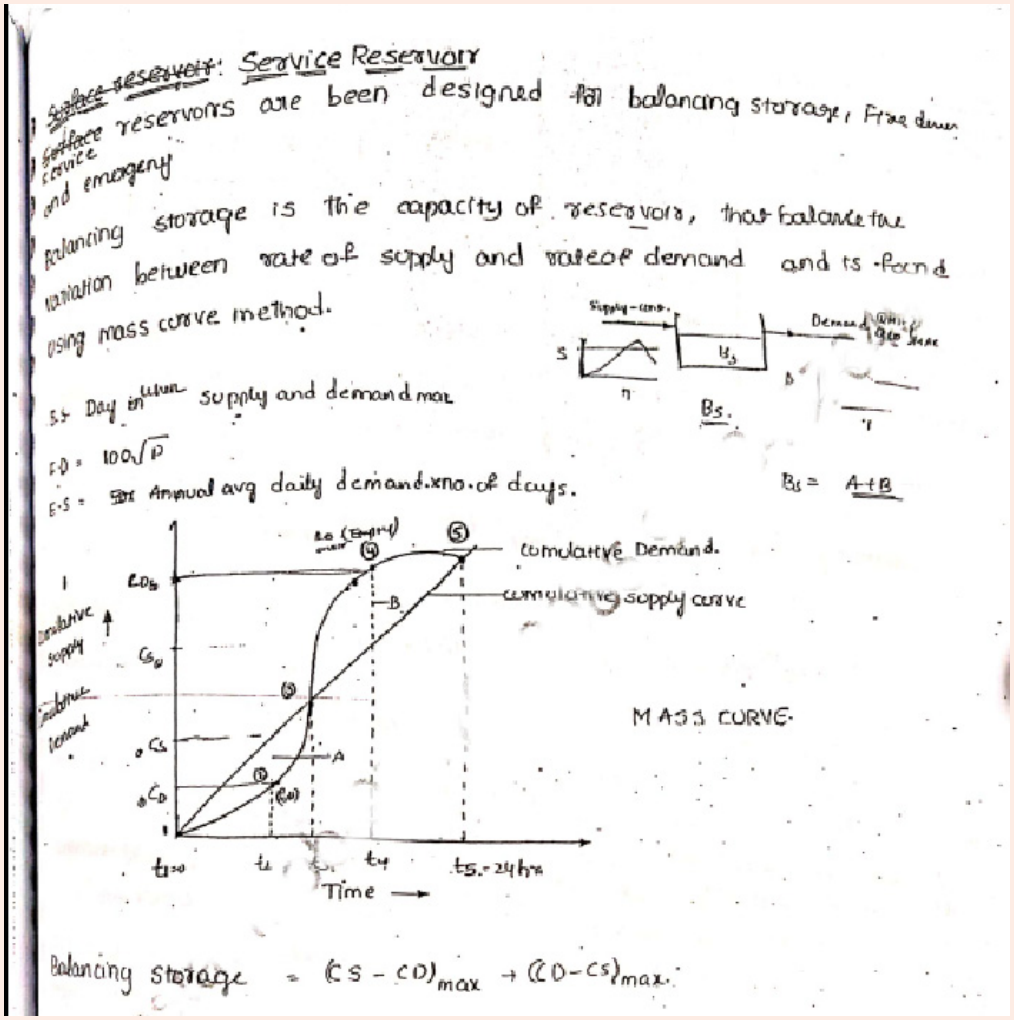
$$\bar{L}_P = 20\log\frac{1}{N}\sum_{n=1}^{N}(10)^{L_n/20}$$

$$= 20\log\frac{1}{4}\left[10^{39/20} + 10^{52/20} + 10^{67/20} + 10^{77/20}\right]$$

$$= 67.78 \text{ dB}$$

MADE EASY Source

- **Theory Book:** 5.15 (Page No. 246 & 247)
- **Rank Improvement Batch :** Environmental Engineering workbook, Q.7 (page 92)
- **MADE EASY Classnotes**



$$L_{avg} = 20\log_{10}\frac{1}{N}\sum_{i=1}^{N} 10^{L_i/20}$$

Average of different sound pressure levels present in the system is not simple arithmatic average and is given by above formula.

Eg. 10DB, 30DB, 40DB, 100DB.

$$L_{avg} = 20\log_{10}\frac{1}{4}\left[10^{10/20} + 10^{30/20} + 10^{40/20} + 10^{100/20}\right] = 87.97\ DB$$

$10^{0.5} + 10^{1.5} + 10^{2} + 10^{5} \simeq 10^{5}$

$$\simeq L_{avg} = 20\log_{10}\frac{1}{4}\left(10^{100/20}\right) = 20\log_{10}\frac{10^5}{4} = 20\log_{10}10^5 + 20\log\frac{1}{4}$$

$$= 20\left[5\log_{10}10^2\right]$$

$= 87.95$ almost equal to Lavg formula

Hence for finding average we can take highest value and calculate the Laverage L.

For a real medium level of noise changes with distance as follows

$$L_1 - 20\log_{10}\frac{d_2}{d_1}$$

End of Solution

3. (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}/sec, Hazen-Williams coefficient of hydraulic capacity of the smooth pipe = 130 and Manning's coefficient = 0.013.

[20 Marks]

Solution:

Diameter of pipe = 2.2 m

Discharge = 3.4 m^3/s

Kinematic viscosity of water at 20°C = 1.004×10^{-6} m^2/sec

$$\text{Area of pile } (A) = \frac{\pi}{4} \times d^2 = 3.799 \text{ m/s i.e. } 3.8 \text{ m/s}$$

$$\text{Velocity } (V) = \frac{Q}{A} = \frac{3.4}{3.8} = 0.894 \text{ m/s}$$

(i) Darcy-weisbach formula

$$h_f = \frac{fLV^2}{2gd}$$

where, F = friction factor which Reynold's number (R_e)

$$R_e = \frac{vd}{\nu} = \frac{0.894 \times 2.2}{1.004 \times 10^{-6}} = 1.958 \times 10^6$$

$$\therefore \quad F = \frac{0.316}{R_e^{1/4}} = 8.447 \times 10^{-3}$$

$$\text{Hydraulic gradient} = \frac{h_f}{L} = \frac{fv^2}{2gd} = \frac{8.44 \times 10^{-3} \times 0.894^2}{2 \times 9.81 \times 2.2}$$

$$\text{i.e.} \quad \frac{h_f}{L} = \frac{1}{6398.88}$$

(ii) Manning's formula

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

$$R = \frac{A}{P} = \frac{\frac{\pi}{4}D^2}{\pi D} = \frac{D}{4} = 0.55 \text{ m}$$

$$\therefore \quad 0.894 = \frac{1}{0.013} \times 0.55^{2/3} \times (S)^{1/2}$$

$$S = \frac{h_f}{L} = 2.9974 \times 10^{-4}$$

$$= \frac{1}{3336.22}$$

(iii) Hazen William's formula

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

$$0.894 = 0.849 \times 130 \times 0.55^{0.63} \times S^{0.54}$$

$$S = 2.6899 \times 10^{-4}$$

$$S = \frac{1}{3717.60}$$

MADE EASY Source

- **MADE EASY Classnotes**

(63) A combined sewer of circular shape is to be designed in a sewerage system for a city of population 1×10^5 in an area of 100 hac. , the mean flow of sewage from the city is 250 l/c/d , the rainfall intensity in the area is 4cm/hour , coefficient of runoff of the area is 0.48 , the ratio of peak to the avg sewage flow is 2 & 'n' is 0.012 Hazen william coefficient is 85 Use manning's & Hazen william eqn & determine the gradient of the sewere to carry the sewage as peak flow with the velocity of 1.2 m/s

Design sanitary sewage discharge $= 2\left[\frac{1\times10^5\times250\times10^{-3}}{86400}\right]$

$= 0.578\ m^3/sec$

Design drainage sewage discharge $= \frac{1}{36} k p_c A$

$= \frac{1}{36}\times0.48\times4\times100$

$= 5.33\ m^3/sec$

Total discharge $= 0.578 + 5.33 = 5.91\ m^3/sec$

Assuming sewer to be running full

$Q = AV$

$5.91 = \frac{\pi D^2}{4}\times1.2 \Rightarrow D = 2.5\ m$

(a) $V = \frac{1}{N} R^{2/3} S^{1/2}$

$1.2 = \frac{1}{0.012}\left(\frac{2.5}{4}\right)^{2/3} S^{1/2}$

$S = \frac{1}{2577}$

(b) $V = 0.85\, CH\, R^{0.63} S^{0.54}$

$1.2 = 0.85\times85\times\left(\frac{2.5}{4}\right)^{0.63} S^{0.54}$

$S = \frac{1}{1142}$

End of Solution

3. (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 and sludge characteristics are as follows:

- Influent SS = 220 mg/L; primary clarifier diameter = 25 mm
- Influent BOD = 250 mg/L; aerator volume = 3000 m^3
- Effluent BOD = 30 mg/L; MLSS in aerator = 3000 m^3/L
- Flow = 20000 m^3/L; 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:

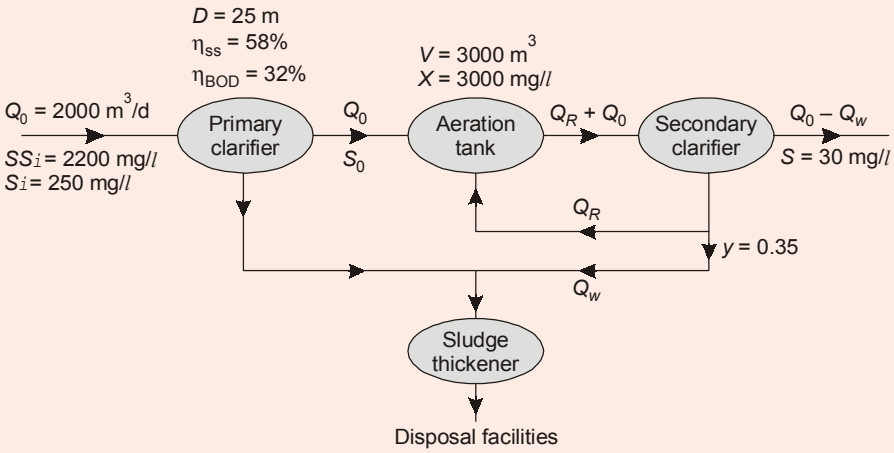
(i) Solids loading in kg/day to the sludge disposal facilities;

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

(iii) percent volume reduction by the thickener.

[20 Marks]

Solution:



(i) Solids entering into PST = $Q_0 SSi$ = 20000 × 220 × 10^{-6} = 4.4 kg/d

Solids settling into PST = $\eta_{SS} Q_0 SSi = 0.58 \times 4.4 = 2.552$ kg/d ...(a)

BOD entering into PST = $Q_0 Si$ = 20000 × 250 × 10^{-6} = 5 kg/d

BOD entering into AT = $(1-\eta_{BOD}) Q_0 Si = Q_0 S_o = (1-0.32)5 = 3.4$ kg/d

BOD leaving from AT = $Q_0 S = 20000 \times 30 \times 10^{-6} = 0.6$ kg/d

BOD removed in AT = (BOD entering – BOD leaving) from AT
= 3.4 – 0.6 = 2.8 kg/d

Biomass in sludge obtained from SST = 0.35 × 2.8 = 0.98 kg/d ...(b)

Total solids entering = Solids from PST (a) + Solids from SST (b) into sludge thickener = 2.552 + 0.98 = 3.532 kg/d

Since there is negligible solids in thickener supernatant solids to sludge disposal facilities = Solids entering into sludge thickener

= 3.532 kg/d

(ii)

$$\frac{F}{M} = \frac{Q_0 S_0}{VX} = \frac{3.4}{3000 \times 3000 \times 10^{-6}} = 0.377 \text{ kg/kg/d}$$

(iii)

$$\text{Volume of sludge entering into thickener} = \left[\begin{bmatrix}\text{Volume of sludge}\\ \text{from PST}\end{bmatrix} + \begin{bmatrix}\text{Volume of Sludge}\\ \text{from SST}\end{bmatrix}\right]$$

For primary sludge

$$\text{Mass of sludge} = \frac{100}{5} \times 2.552 = 51.04 \text{ kg/d}$$

$$\text{Volume of sludge} = \frac{51.04}{10^3} = 0.05104 \text{ m}^3/\text{d} \qquad [\text{Assume } \rho_{\text{sludge}} = 10^3 \text{ kg/m}^3]$$

For secondary sludge

$$\text{Mass of sludge} = \frac{100}{0.75} \times 0.98 = 130.66 \text{ kg/d}$$

$$\text{Volume of sludge} = \frac{130.66}{10^3} = 0.13066 \text{ m}^3/\text{d} \qquad [\text{Assume } \rho_{\text{sludge}} = 10^3 \text{ kg/m}^3]$$

Volume of sludge entering = 0.05104 + 0.13066 = 0.1817 m^3/d into thickener

For thickened sludge

$$\text{Mass of sludge} = \frac{100}{4} \times 3.552 = 88.8 \text{ kg/d}$$

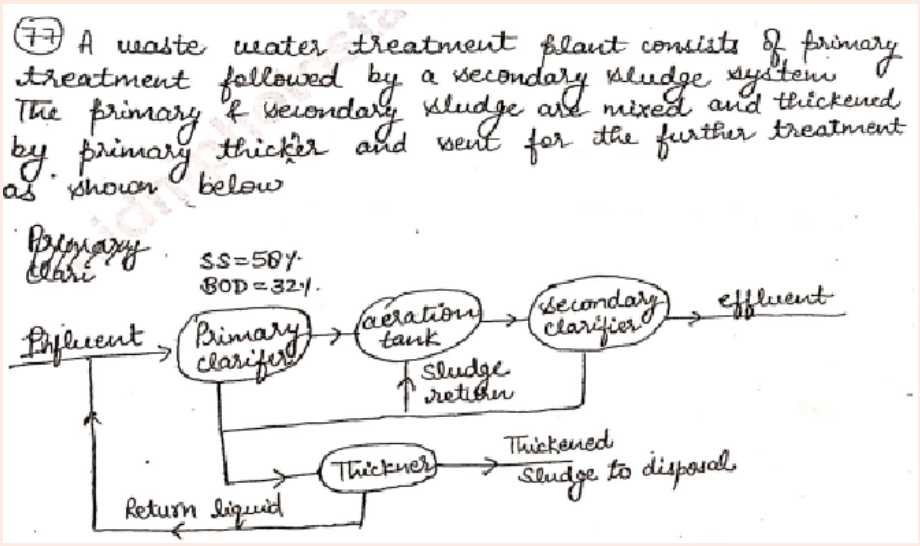
$$\text{Volume of sludge} = \frac{88.8}{10^3} = 0.888 \text{ m}^3/\text{d} \quad [\text{Assume } \rho_{\text{sludge}} = 10^3 \text{ kg/m}^3]$$

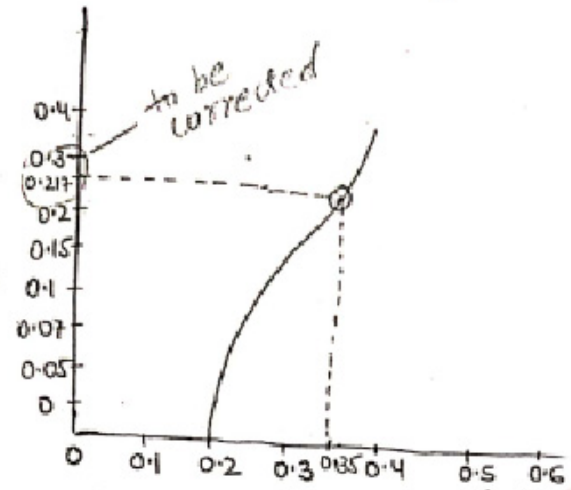
$$\% \text{ Reduction of volume by thickener} = \frac{(0.1817 - 0.0888)}{0.1817} \times 100 = 51.12\%$$

MADE EASY Source

- **MADE EASY Classnotes**

(77) A waste water treatment plant consists of primary treatment followed by a secondary sludge system. The primary & secondary sludge are mixed and thickened by primary thicker and sent for the further treatment as shown below





Determine the –

① solid loading in kg/day to the sludge disposal facility

② The percentage volume reduction by thickner

Waste water		Treatment plant		Sludge	
Influent SS	Influent BOD 300mg/l	Eff. Primary clarifier diameter	25 m	Primary	5% solid
Influent BOD	200 mg/l			Secondary	0.75% solid
Effluent BOD	20 mg/l	Aerator volume	2900 m³	Thicker sludge	4% solid
Flow	90,000 m³/day	MLSS in the aerator	3500 mg/l		

wt fitne solid thickner me aayenge, uthe fir thickner sludge me honge.

wt of the solids in the raw (1°) sludge

$$= 90{,}000 \times 200 \times 10^{-3} \times 10^{-6} \times 0.58$$

$$= 10440 \text{ kg/d}$$

we define as- essen kg of BOD entering into the system

but in graph → kg of BOD consumed so, formula get changed

$$\frac{F}{M} = \frac{Q_0(S_0 - S)}{VX} = \frac{90000 \times 10^3 (0.68 \times 200 - 20) \times 10^{-6}}{2900 \times 3500 \times 10^3 \times 10^{-6}}$$

$$= 1.028$$

$\frac{F}{M} \geq 0.35$

End of Solution

3. (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 Marks]

Solution:

Geometrical Similarity : Geometric similarity exists between the model and the prototype if the ratios of corresponding length dimensions in the model and the prototype are equal. Such a scale ratio is defined as scale ratio.

Length scale ratio : $L_r = \frac{L_m}{L_p} = \frac{b_m}{b_p} = \frac{d_m}{d_p}$ etc

Area scale ratio : $A_r = \frac{A_M}{A_P} = \left(\frac{L_m \times b_m}{L_p \times b_p}\right) = L_r^2$

Volume scale ratio : $V_r = \frac{V_m}{V_p} = \left(\frac{L_m \times b_m \times d_m}{L_p \times b_p \times d_p}\right) = L_r^3$

Kinematic Similarity : Kinematic parameters are velocity, acceleration and discharge. This similarity exists if

(a) At all corresponding points in the model and prototype, the ratio of velocity as well as acceleration are same (both in magnitude and direction).

(b) The path of the corresponding moving particles are geometrically similar.

Time scale ratio : $T_r = \frac{T_m}{T_p}$

Velocity ratio : $V_r = \frac{V_m}{V_p} = \frac{L_r}{T_r}$

Acceleration ratio : $a_r = \frac{a_m}{a_p} = \frac{L_r}{T_r^2}$

Discharge ratio : $Q_r = \frac{Q_m}{Q_p} = \frac{L_r^3}{T_r}$

Dynamic Similarity : For dynamic similarity to exist between model and prototype, identical type of forces (viscous, pressure, elastic, etc.) must be parallel and must bear the same ratio at all corresponding sets of points. Dynamic parameters are force and power.

Force ratio : $\frac{F_m}{F_p} = \rho_r \times Q_r \times a_r = \frac{\rho_r L_r^4}{T_r^2}$

Power ratio : $\frac{P_m}{P_P} = F_r \cdot V_r = \frac{\rho_r L_r^5}{T_r^3}$

Pump A	Pump B
Diameter (D_A) = 50 cm	Diameter (D_B) = ?
Discharge (Q_A) = 0.4 m^3/s	Discharge (Q_B) = 0.3 m^3/s
Head (H_A) = 50 m	Head (H_B) = ?
Speed (N_A) = 600 rpm	Speed (N_B) = 600 rpm

For geometrical, kinematic and dynamic similarity,

$$\left(\frac{Q}{D^3N}\right)_A = \left(\frac{Q}{D^3N}\right)_B$$

$$\frac{0.4}{50^3 \times 600} = \frac{0.3}{(D_B)^3 \times 600}$$

$$D_B = 45.428 \text{ m}$$

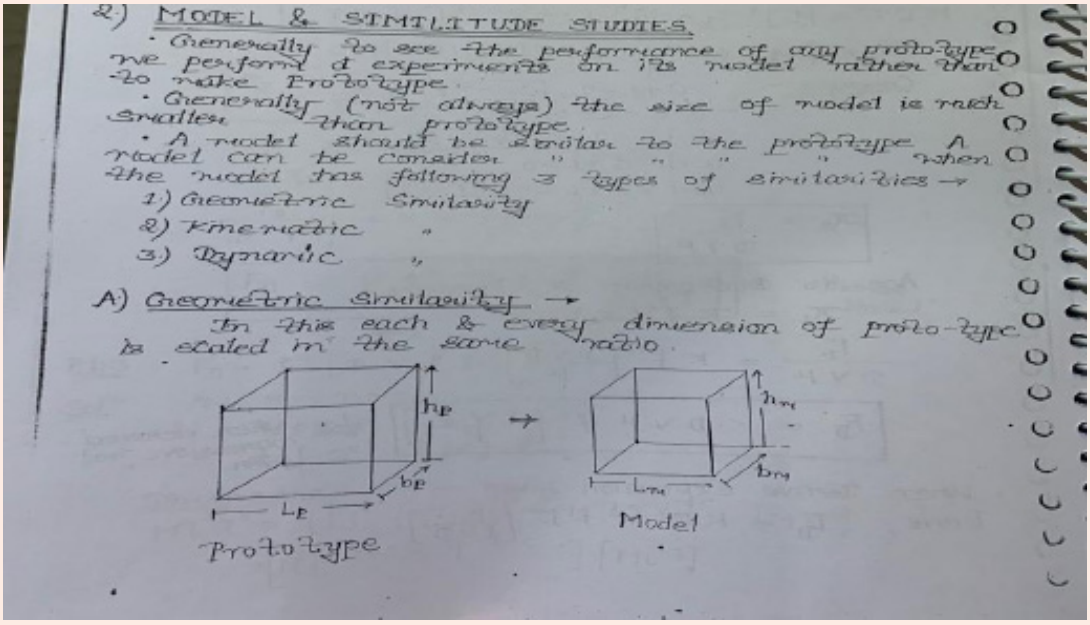
$$\left(\frac{H}{D^2N^2}\right)_A = \left(\frac{H}{D^2N^2}\right)_B$$

$$\frac{H_A}{H_B} = 1.2114$$

$$\therefore \quad H_B = 41.274 \text{ m}$$

MADE EASY Source

- **Theory Book:** Hydraulic machines : Example 18.5 (Page No. 497)
- **MADE EASY Classnotes**



$$\frac{(F_V)_m}{(F_V)_p} = \frac{(F_E)_m}{(F_E)_p} = \frac{(F_G)_m}{(F_G)_p} = \frac{(F_\sigma)_m}{(F_\sigma)_p} = \frac{(F_K)_m}{(F_K)_p} = F_r$$

↓ Force scale ratio

$$F_i = F_V + F_E + F_G + F_\sigma + F_K$$

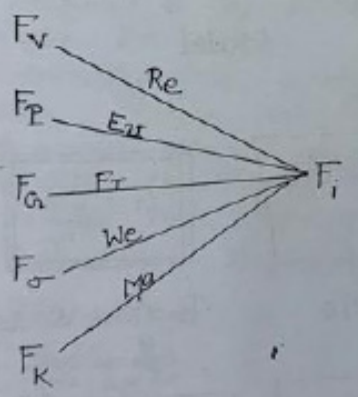
$$(F_i)_m = F_r \cdot (F_i)_p$$

$$\frac{(F_i)_m}{(F_i)_p} = F_r$$

$$\frac{(F_i)_m}{(F_i)_p} = \frac{(F_V)_m}{(F_V)_p} \Rightarrow \frac{(F_i)_m}{(F_V)_m} = \frac{(F_i)_p}{(F_V)_p}$$

$$\boxed{(Re)_m = (Re)_p}$$

In General :



Re ⇒ Reynold's No.
Eu ⇒ Euler No.
F_r ⇒ Froud's No.
We ⇒ Weber No.
Ma ⇒ Mac No.

Scale Analysis :

L ⇒ characteristic dimension

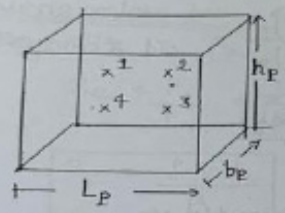
- Inertia Force $[F_i] = ma$
  $\simeq \rho L^3 \frac{V}{T}$ $\left\{V = \frac{L}{T}\right\}$
  $\simeq \rho \cdot L^2 \cdot V^2$
- Viscous Force $[F_V] = \tau A$
  $\simeq \mu \cdot \frac{V}{L} \cdot L^2$
  $\simeq \mu V L$

$$\frac{L_m}{L_p} = \frac{b_m}{b_p} = \frac{h_m}{h_p} = L_r$$

$L_r \Rightarrow$ length scale ratio

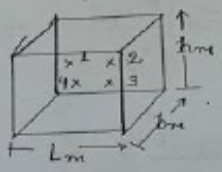
B) Kinematic Similarity →

For kinematic similarity, the ratio of velocity, Acceleration at the corresponding pts of Model & prototype should be same (Both in magnitude & Direction).



Prototype

$\Rightarrow$



Model

$$\frac{(V_1)_m}{(V_1)_p} = \frac{(V_2)_m}{(V_2)_p} = \text{- - - - -} = V_r$$

$V_r \Rightarrow$ Velocity scale Ratio

$$V_r = \frac{L_r}{T_r}$$

T_r = Time scale ratio

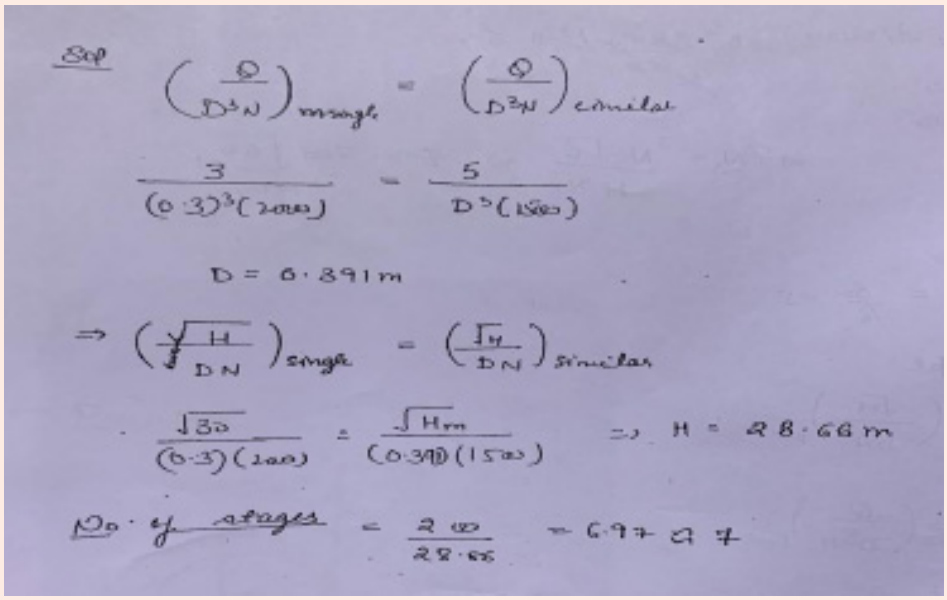
$$\frac{(a_1)_m}{(a_1)_p} = \frac{(a_2)_m}{(a_2)_p} = \text{- - - - -} = a_r$$

$a_r \Rightarrow$ Acceleration scale Ratio

$$a_r = \frac{L_r}{T_r^2} = \frac{V_r}{T_r}$$

C) Dynamic Similarity →

For Dynamic similarity, the ratio of diff^{nt} forces at the corresponding pts. of Model & Prototype should be same.



End of Solution

4. (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 Marks]

Solution:

Initial regime

- If only the bed slope of the channel varies and its wetted perimeter remains unaffected then a condition of non-silting and non scouring may exit which is called initial regime.
- Under initial regime condition Lacey's theory is not valid.

Final regime

- If all the variables such as perimeter, depth, flow are free to vary and can adjust according to the discharge there occurs no effective silting and scouring then such channels are said to have achieved permanent stability and said to be in final regime condition.
- Lacey's design theory is valid for such a regime condition.

Given:

$$Q = 30\ m^3/s,\ f = 1$$

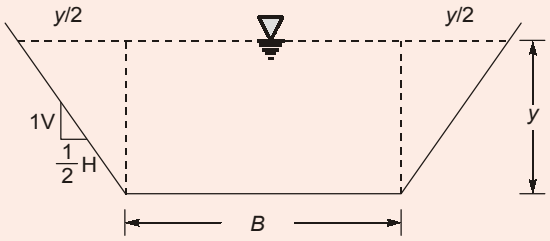
$$V = \left(\frac{Qf^2}{140}\right)^{1/6} = \left(\frac{30 \times 1^2}{140}\right)^{1/6} = 0.77\,m/s$$

$$A = \frac{Q}{V} = \frac{30}{0.77} = 38.96\ m^2$$

$$R = \frac{5}{2}\left(\frac{V^2}{f}\right) = \frac{5}{2}\left(\frac{0.77^2}{1}\right) = 1.48\ m$$

$$P = 4.75\sqrt{Q} = 4.75\sqrt{30} = 26.0168 \text{ m}$$

$$R = \frac{A}{P} = \frac{\frac{1}{2}(2B + y)y}{26.0168}$$



$$\Rightarrow \quad (2B + y)y = 77 \qquad \text{...(i)}$$

$$P = 26.0168 = B + 2y\sqrt{\frac{1}{4} + 1}$$

$$26.0168 = B + 2.236y$$

$$\Rightarrow \quad B = 26.0168 - 2.236y \qquad \text{...(ii)}$$

from equation (i) and (ii),

$$3.472y^2 - 52.03y + 77 = 0$$

$$y = 13.32 \text{ m}, \ 1.66 \text{ m}$$

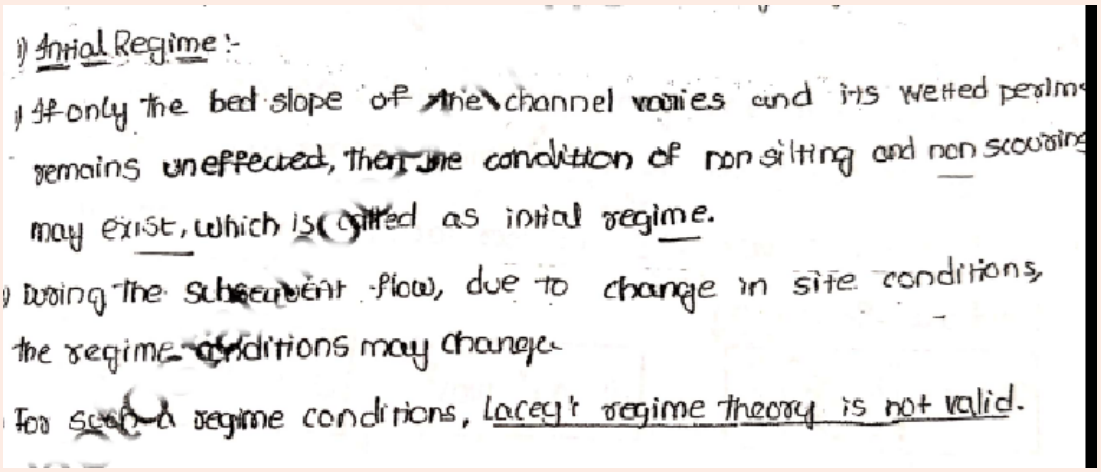
$$B = 22.3 \text{ m}$$

$$S = \frac{f^{5/3}}{3340Q^{1/6}} = \frac{(1)^{5/3}}{3340 \times (30)^{1/6}}$$

$$= \frac{1}{5887.53}$$

MADE EASY Source

- **ESE 2019 Mains Test Series:** Q.4(a) (i) of Test-9
- **Theory Book:** Irrigation : Conventional Q.7 (Page No. 90)
- **MADE EASY Classnotes**


i) Initial Regime :-
If only the bed slope of the channel varies and its wetted perim remains uneffected, then the condition of non silting and non scouring may exist, which is called as initial regime.
ii) During the subsequent flow, due to change in site conditions, the regime conditions may change.
For such a regime conditions, Lacey's regime theory is not valid.

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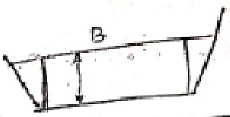
3) Final Regime

① If all the variables such as perimeter, depth of flow, etc are free to vary and can adjust according to the incoming discharge and grade of silt into the alluvial channel. such that there occurs no effective silting and no effective scouring then such chanels are said to have achieved final permanent stability and called to be in final regime condition.

2) Lacey's silt theory is valid and applicable for final Regime condi.

Sol :- ① $V = \left(\frac{Q f^2}{140}\right)^{1/6} = \left(\frac{15 \times 1^2}{140}\right)^{1/6} = 0.689$ m/sec.

② $A = \frac{Q}{V} = 21.76\ m^2$



③ $A = \left(\frac{2B+y}{2}\right)y = 21.76\ m^2$ —①

④ $P = 4.75\sqrt{Q} = 18.396 = B + \frac{y}{2}\sqrt{5}$

$B + 2\sqrt{y^2 + \left(\frac{y}{2}\right)^2}$

$B + \sqrt{4y^2 + y^2} = B + y\sqrt{5}$

$\Rightarrow B + 2.236y$

$B + 2 \times \sqrt{y^2 + \left(\frac{y}{2}\right)^2} = 18.396$

$B + y\sqrt{5} = 18.396 \Rightarrow B = 18.396 - 2.236\,y$ —②

from ① and ②

$(2(18.396 - 2.236y) + y)\,y = 43.52$

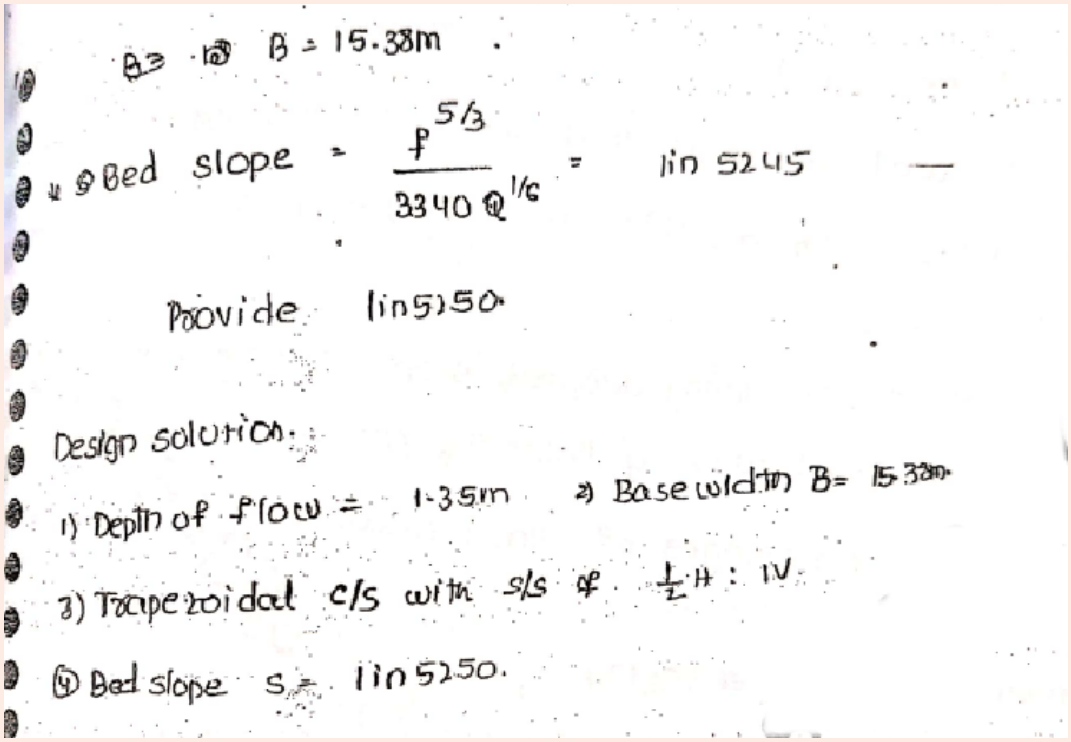
$\Rightarrow 36.792y - 4.472y^2 + y^2 = 43.52$

$\Rightarrow 3.372y^2 - 36.792y + 43.52 = 0$

$y = \frac{+36.792 \pm \sqrt{36.792^2 - 4 \times 43.52 \times 3.372}}{2 \times 3.372} = \frac{36.792 \pm 25.83}{6.744}$

$= 1.35\ m$ or $9.29\ m$

Take $y = 1.35\ m$.



End of Solution

4. (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 Marks]

(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 Froude's number after the jump.

[10 Marks]

Solution:

(i)Field Capacity (F.C.)

- It is the amount of water content held in the soil after excess water gets drained off due to gravity.
- Physically, it can be defined as the bulk water content retained in the soil at particular hydraulic head.
- Field capacity is characterized by measuring water content after wetting a soil profile, covering it (to prevent evaporation) and monitoring the changing soil moisture in the profile.
- When the rate of changing soil moisture is very small, the water content at that point in said to be field capacity.

Field Capacity is expressed in percentage

$$\text{Field Capacity of Soil} = \frac{\text{Weight of maximum amount of moisture held by soil against gravity}}{\text{Unit weight of the dry soil}}$$

- In medium textured soils, field capacity is about 50% of pore volume.
- Soil Moisture tension at field capacity ranges between one-tenth to one-third atmospheres.

Permanent Wilting Point (PWP)

- Water content at which plant is no longer able to extract water from the soil for its growth.
- At permanent wilting point, films of water are held very tightly and hence plant roots are not able to extract sufficient water for their growth.

$$\text{PWP} = \frac{\text{Weight of moisture held by the soil when plants gets permanently wilted}}{\text{Weight of dry soil}}$$

- Soil moisture tension of soil at permanent wilting point is in the range of 7 to 32 atm.

Average moisture content

- Depending upon the depth of irrigation water applied and frequency the average moisture content in the soil may lie between the lower limit wilting point or upper limit field capacity.
- Average moisture content of soil is moisture present in the soil that is available for plant.

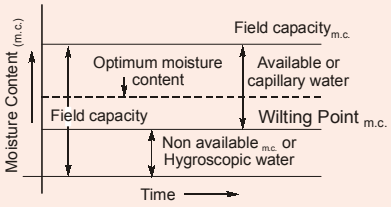
Frequency of irrigation

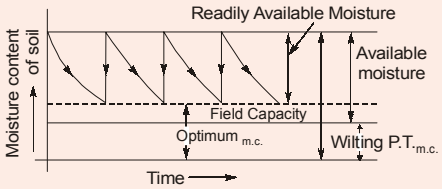
Soil moisture in the root zone varies between field capacity (upper limit) and permanent wilting point (lower limit). When the soil moisture is consumed by plants through their roots, the soil moisture depletes. However, it is not allowed to deplete upto the permanent Wilting point, as it would result in considerable fall in crop yield. The optimum level up to which the soil moisture is allowed to deplete is called optimum moisture content.

The irrigation water should be supplied as soon as the moisture falls upto this optimum falls upto this optimum level, and its quantity should be sufficient enough to bring the moisture content upto its field capacity.

Water will be utilized by the plants after the fresh irrigation dose is given, and the soil moisture will start falling. It is then again recouped by a fresh irrigation dose as soon as the soon as the soil moisture reaches the optimum level.

The time interval between two successive irrigation dose is termed as frequency of irrigation.





Available moisture for the plant = F.C. – ϕ

Readily available moisture for the plant = F.C. – M_O

Here, F.C. = Field capacity

ϕ = Wilting point or wilting coefficients below which plant can't survive.

M_O = Readily available moisture content.

$$\text{Frequency of Irrigation} = \frac{\text{Available/ Readily available moisture depth}}{\text{Consumptive use rate}}$$

(ii) $F_1 = 10.0$ m $E_L = 3.20$ m

The sequent depth ratio $\frac{y_2}{y_1} = \frac{1}{2}\left[-1+\sqrt{1+8F_1^2}\right] = \frac{1}{2}\left(-1+\sqrt{1\times 8\times (10)^2}\right) = 13.651$

$$\text{Energy loss } E_L = \frac{(y_2 - y_1)^3}{4y_1y_2}$$

$$\frac{E_L}{y_1} = \frac{\left(\frac{y_2}{y_1} - 1\right)^3}{4\left(\frac{y_2}{y_1}\right)}$$

$$\therefore \quad \frac{3.20}{y_1} = \frac{(13.651-1)^3}{4\times 13.651} = 37.08$$

- y_1 = depth before the jump = $\frac{3.20}{37.08} = 0.0863$ m

  y_2 = depth after jump = $13.651 \times 0.0863 = 1.178$ m
- $F_1 = \frac{V_1}{\sqrt{g\,y_1}}$

$$10.0 = \frac{V_1}{\sqrt{9.81\times 0.0863}}$$

$V_1 = 9.201$ m/s

Discharge intensity $q = V_1y_1 = 9.201 \times 0.0863$

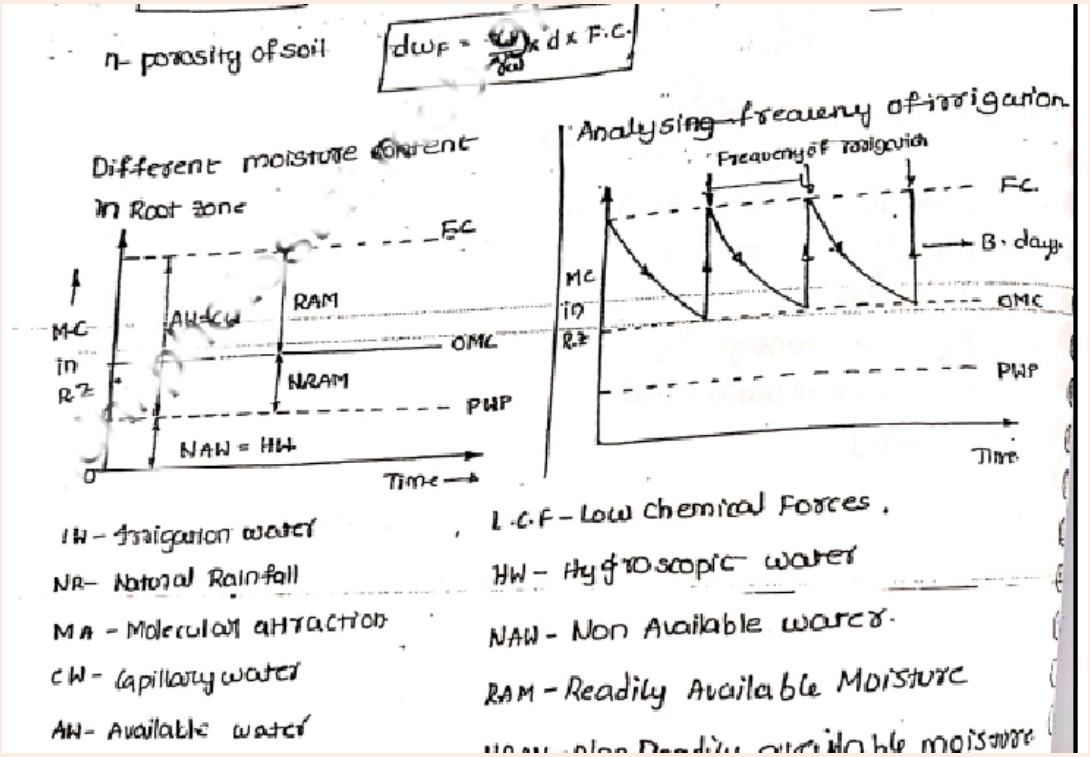
$= 0.7941\ m^3/s/m$

- Froude number after the jump = F_2

$$F_2 = \frac{V_2}{\sqrt{g\,y_2}} = \frac{q}{y_2\sqrt{g\,y_2}} = \frac{0.7941}{1.178\sqrt{9.81\times 1.178}} = 0.1983$$

MADE EASY Source

- **Work Book:** Fluid Mechanics, Q.81 (Page No. 72)
- **MADE EASY Classnotes**



loose chemical forces.

The water which cannot be easily drained under the action of gravity and having its presence in the root zone is calle as field capacity.

The field capacity moisture content further consists of following two parts.

1) First part is that which is attached to soil molecules due to molecular attraction and can be extracted by the roots of plant using capillarity action and is available for the plant growth and is called as available water or capillary water.

2) The other part is that which is attached to the soil molecules by loose chemical forces and cannot be removed by capillarity and therefore is not available for the plant's growth and is called as hygroscopic water & non available water.

5) Permanent Wilting Point PWP.

It is that water content in the root zone below which the plant can no longer extract sufficient water for its growth and the plant permanently wilts up.

Therefore it can be concluded that water which is available for the plant's growth is the difference of FC water and PWP water.

6) Readily Available Moisture:

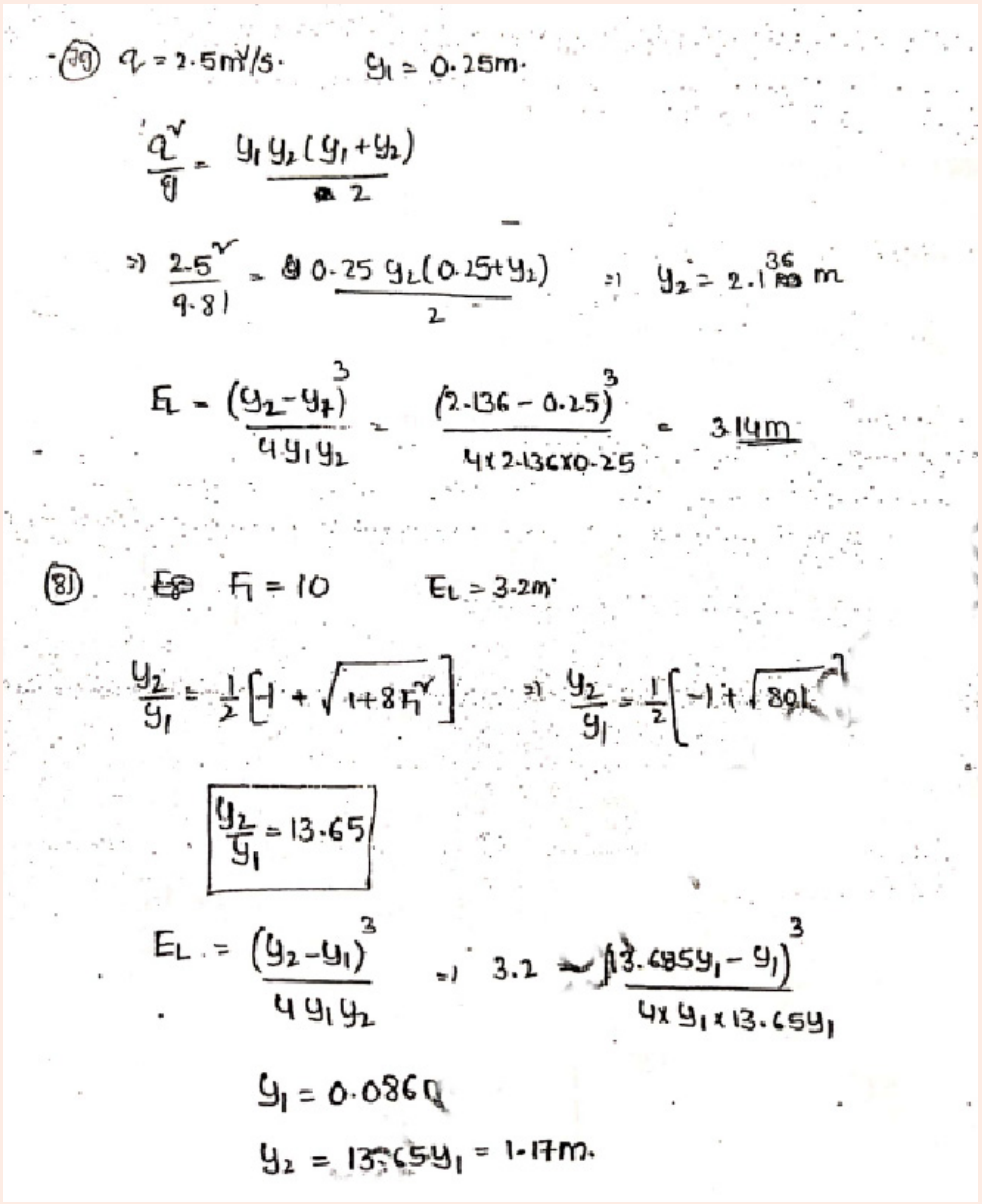
It is that moisture of available water which is most easily extracted by the roots of the plant and is approximately taken as 75-80% of the available moisture.

7) Non Readily Available Moisture

It is that portion of available water which is not so easily available for the plant's growth and if it is extracted by the roots then additional forces have to be applied by the roots, which may reduce the ultimate productivity of crop at the time of harvesting.

8) Optimum Moisture Content:

The optimum level of moisture upto which the soil moisture can be allowed to be depleted in the root zone without any fall in the ultimate crop productivity, represents the CMC.



End of Solution

4. (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 Marks]

(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 Marks]

Solution:

(i) Disposal of Refuse by Composting

- Composting of refuse is a biological method of decomposing solid wastes.
- This decomposition can be affected either under aerobic conditions or under anaerobic condition or both.
- The final end product is a manure, called the compact or humus.
- If the organic materials, excluding plastics, rubber and leather are separated from municipal solid wastes and are subjected to bacterial decomposition, the end product remaining after dissimilatory and assimilatory bacterial activity is humus or compost. The entire process involving both separation and bacterial conversion of the organic solid wastes is known as composting.
- Decomposition of the organic solid wastes may be accomplished either aerobically or anaerobically depending on the availability of oxygen.
- Basically, composting is considered to be an aerobic process, because it involves piling up of refuse and its regular turning, either manually or by mechanical devices, so as to ensure sufficient supply of air and oxygen during its decomposition by bacteria, fungi and other microorganisms, like antinomycetes.
- Initially, the process starts with the mesophilic bacteria, which oxidises the organic matter (in the refuse) to carbon dioxide and liberate heat. The temperature rise about 45°C and at this point, the thermophilic bacteria take over and continue the decomposition. During this phase, the temperature further rises about 60°C which has to be maintained for at least 3 days in order to destroy pathogenic bacteria. This temperature control is crucial, because optimal decomposition occurs between 55 and 60°C, but if the temperature exceeds 60°C, decomposition slows down.
- Complete stabilisation occurs after the compact is allowed to cure for another 2 to 8 weeks. During the active early decomposition phase, the thermophilic bacteria are more active during the curing stage.
- The entire composting, thus gets completed in about 3-4 months time. Volume reductions of the original organic material of up to 50% are achieved under ideal conditions. The finally produced compost usually, has earthy smell and a dark brown colour.
- Moisture content of the compost mass should, however be controlled to ensure optimum aerobic decomposition, because excessive moisture will make it difficult to maintain aerobic conditions, while deficient moisture inhabits biological life. A moisture content of about 55% should be established, so that aerobic biological activity may proceed at an optimum rate.
- Most composting operation involve three basic steps
  1. Preparation of the solid wastes.
  2. Decomposition of the soil wastes
  3. Product preparation and marketing
- Receiving, sorting, separation, size reduction and moisture and nutrient addition are part of the preparation step. Several techniques have been developed to accomplish

the decomposition step. Once the solid wastes have been converted to a humus, they are ready for the third step, product preparing and marketing. This step include fine grinding, blending with various additives, granulation, bagging, storage, shipping and in some case direct marketing.

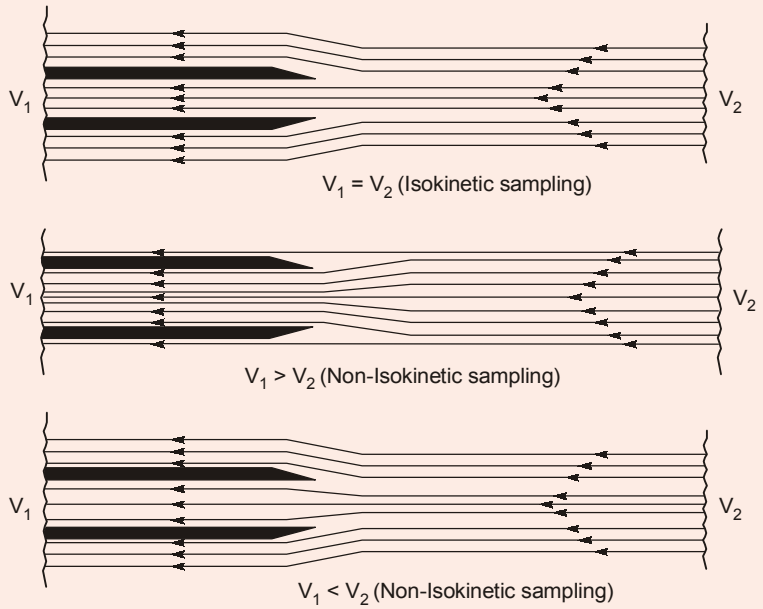
- The principal design consideration associated with the biological decomposition of prepared solid wastes are presented in table below:

Important design considerations for aerobic composting processes	
Item	**Comment**
Particle Size	For optimum results the size of solid wastes should be between 25 and 75 mm (1 and 3 in).
Seeding and Mixing	Composting time can be reduced by seeding with partially decomposed solid wastes to the extent of about 1 to 5 percent by weight. Sewage sludge can also be added to prepared solid wastes. Where sludge is added, the final moisture content is the controlling variable.
Mixing or turning	To prevent drying, caking, and air channeling, material in the process of being composted should be mixed or turned on a regular schedule or as required. Frequency of mixing or turning will depend on the type of composting operation.
Air requirements	Air with at least 50 percent of the initial oxygen concentration remaining should reach all parts of the composting material for optimum results, especially in mechanical systems.
Total Oxygen Requirements	The theoretical quantity of oxygen required can be estimated.
Moisture Content	Moisture content should be in the range between 50 and 60 percent during the composting process. The optimum value appears to be about 55 percent.
Temperature	For best results, temperature should be maintained between 323 and 328 K (50 and 55°C) for the first few days and between 328 and 333 K (55 and 60°C) for the remainder of the active composting period. If temperature goes beyond 339 K (66°C), biological activity is reduced significantly.
Carbon-nitrogen Ratio	Initial carbon-nitrogen ratios (by mass) between 30 and 50 are optimum for aerobic composting. At lower ratios, ammonia is given off. Biological activity is also impeded at lower ratios. At higher ratios, nitrogen may be a limiting nutrient.
pH	To minimize the loss of nitrogen in the form of ammonia gas, pH should not rise above about 8.5.
Control of pathogens	If properly conducted, it is possible to kill all the pathogens, weeds and seeds during the composting process. To do this, the temperature must be maintained between 333 and 343 K (60 and 70°C) for 24 h.

(ii) Isokinetic sampling is a technique used to collect particles in a moving stream which moves at the same velocity in the sampling nozzle as elsewhere in the stream. This can increase the accuracy and reliability of results. It is used for activities like monitoring pollution in factory stacks, taking general air samples in an area of interest, and checking equipment for dust and other concerns.
In an isokinetic sampling procedure, the sampling nozzle is set up to allow the sample stream to enter without changing speed. This reduces the risk of concentrating larger or smaller particles.

If sampling is done other than at isokinetic velocity, then it will cause errors for two reasons. First sampling at greater or less than isokinetic rates tends to cause respectively larger or a smaller volume to be withdraw from the flue gases than

accounted for by the cross-section area of the probe. Also, particles greater than 3.5μ size have sufficient inertia so that particle motion may deviate significantly from the gas flow stream line pattern, Thus, if sampling is not done isokinetically, then we will be unable to obtain representative sample.



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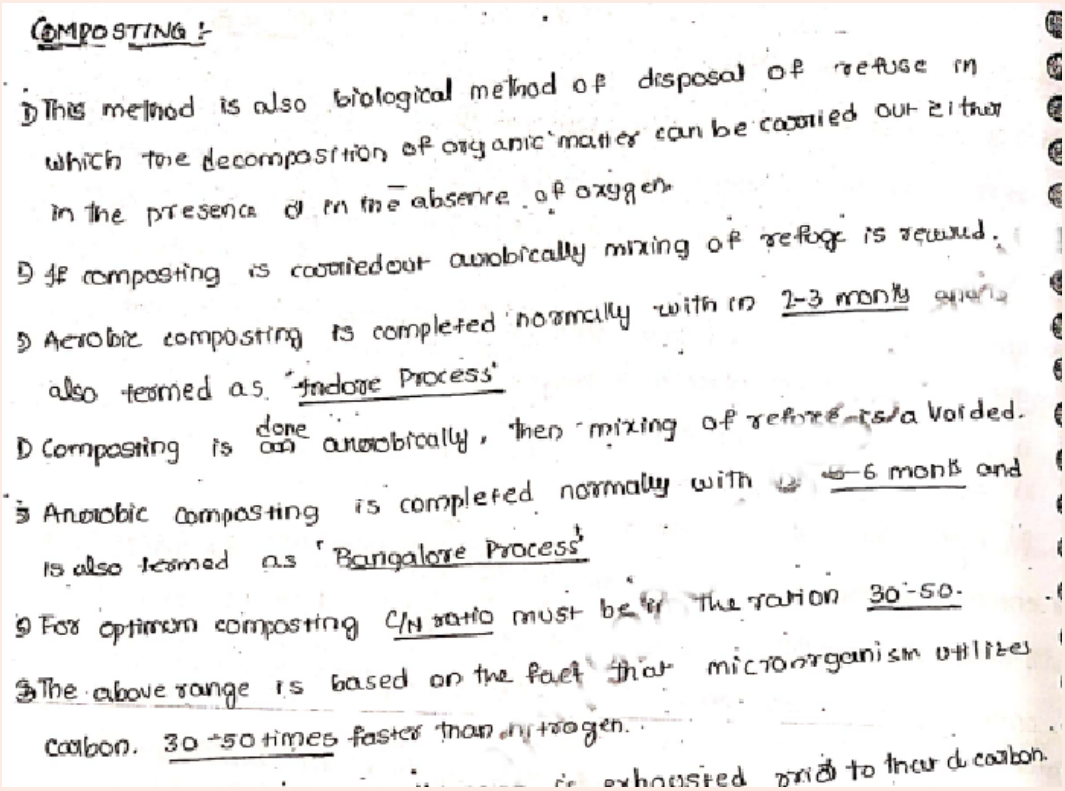

COMPOSTING :-

1) This method is also biological method of disposal of refuse in which the decomposition of organic matter can be carried out either in the presence of in the absence of oxygen.

2) If composting is carried out aerobically mixing of refuse is required.

3) Aerobic composting is completed normally within 2-3 months also termed as "Indore Process"

4) Composting is done anaerobically, then mixing of refuse is avoided.

5) Anaerobic composting is completed normally with 4-6 months and is also termed as "Bangalore Process"

6) For optimum composting C/N ratio must be in the ration 30-50.

7) The above range is based on the fact that microorganism utilizes carbon. 30-50 times faster than nitrogen.

is exhausted and to their carbon.

carbon. 30-50 times faster than nitrogen.

3) If C/N ratio is more Nitrogen is exhausted prior to that of carbon. leaving the growth of microorganisms incomplete and if C/N ratio is less carbon is exhausted prior to that of the nitrogen and the left over nitrogen, it combines with hydrogen and results in formation of ammonium, which is disastrous for Methane-formers. In either of the case composting is left incomplete.

$$\frac{C\ [\text{carbon/Food/Energy}]}{N\ [\text{Nitrogen/Nutrient/Growth}]} = 30/50$$

* Bangalore method is preferred over Indore process because of good sanitary condition.

End of Solution

SECTION 'B'

5. (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 Marks]

Solution:

Given:

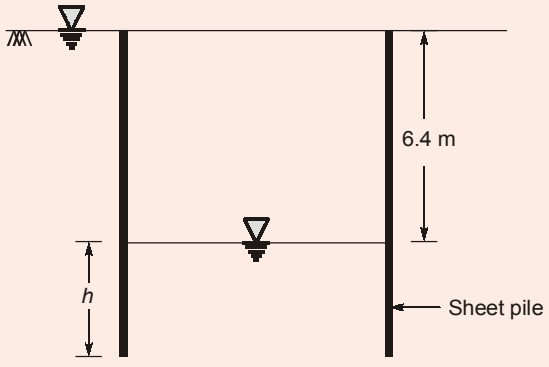
Depth of excavation = 6.4 m

γ_{sat} = 20.3 kN/m^3

FOS = 1.5

G_S = 2.7

γ_W = 9.81 kN/m^3



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$$\because \quad \gamma_{sat} = \frac{G+e}{1+e}\cdot\gamma_w$$

$$\therefore \quad 20.3 = \frac{2.7+e}{1+e}\times 9.81$$

$$\Rightarrow \quad e = 0.5899$$

$$i_{cr} = \frac{G-1}{1+e} = \frac{2.7-1}{1+0.5899} = 1.0692$$

$$i = \frac{i_{cr}}{FOS} = \frac{1.0692}{1.5} = 0.712$$

$$i = \frac{\Delta H}{L} \quad \text{where } \Delta H = 6.4 \text{ m}, \quad L = h$$

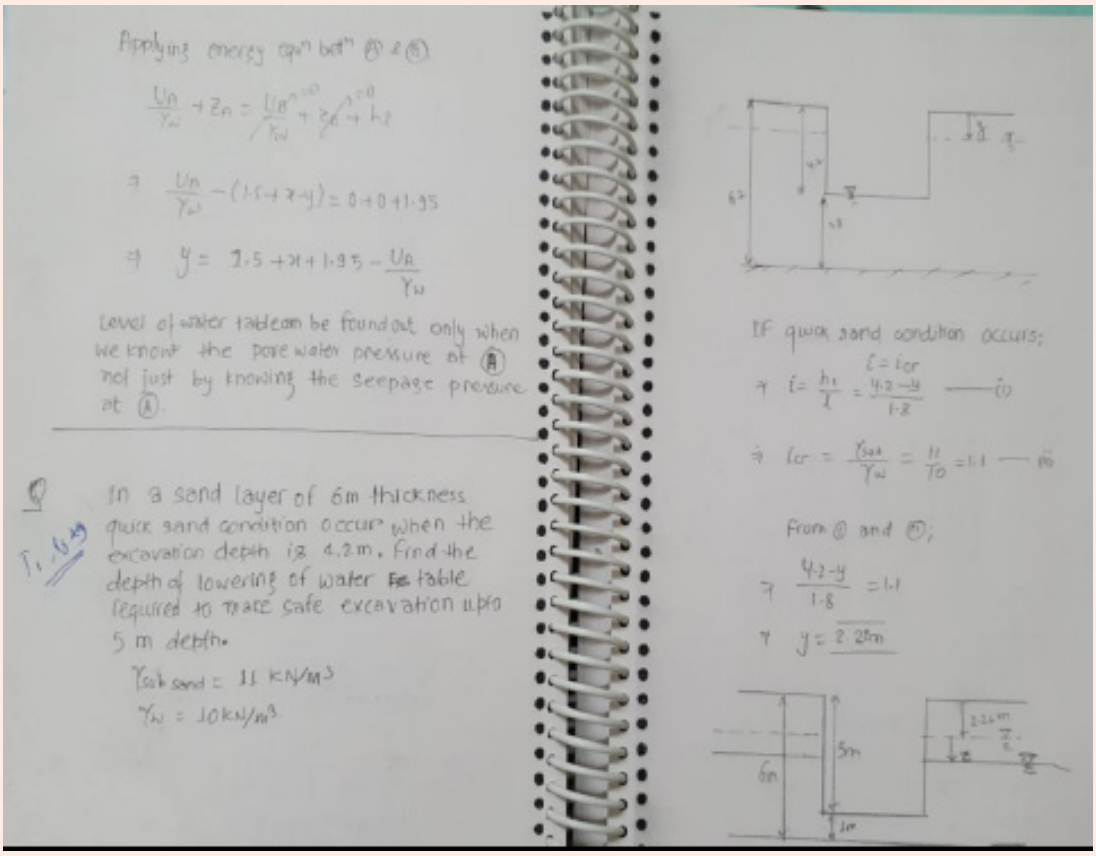
$$\therefore \quad \frac{6.4}{h} = 0.712$$

$$\Rightarrow \quad h = 8.9887 \text{ m}$$

Total length of sheet pile = 6.4 + 8.9887 = 15.3887 m

MADE EASY Source

- **ESE 2019 Mains Test Series:** Q.8(a)(ii) of Test-15
- **MADE EASY Classnotes**



End of Solution

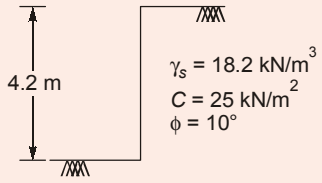
5. (b) An unsupported cut as shown in the figure below was made at a site for which unit weight of soil, γ_s = 18.2 kN/m^3, cohesion, C = 25 kN/m^2 and angle of internal friction, ϕ = 10°. Determine the lateral stress at

(i) the top of the excavation;

(ii) the bottom of the excavation;

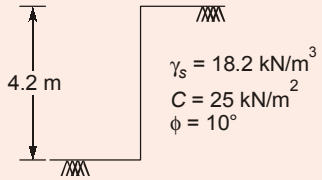
(iii) the maximum depth of potential tension crack for the excavation.

What is the maximum depth up to which the excavation can be carried out safely without any support?



[12 Marks]

Solution:



$$k_a = \tan^2\left(45 - \frac{\phi}{2}\right) = \tan^2(45 - 5) = 0.704$$

(i) At top of the excavation

$$p_a = K_a\gamma_s Z - 2c\sqrt{K_a}$$

$\because$ $Z = 0$ at top

$$p_a = -2 \times 25 \times \sqrt{0.704} = -41.95 \text{ kN/m}^2$$

(ii) At the bottom of excavation (Z = 4.2 m)

$$p_a = 0.704 \times 18.2 \times 4.2 - 2 \times 25 \times \sqrt{0.704}$$
$$= 11.86 \text{ kN/m}^2$$

(iii) Maximum depth of potential tension crack

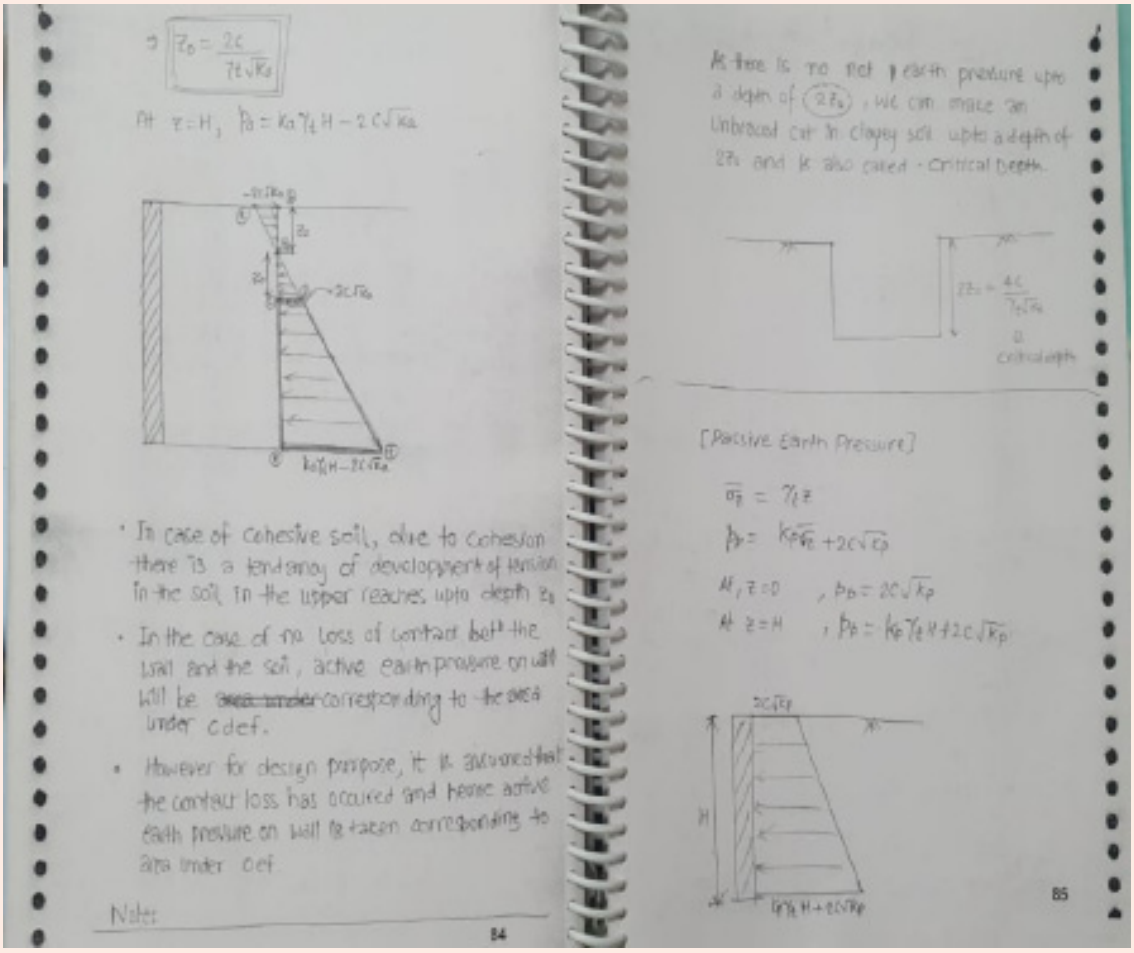
$$0.704 \times 18.2 \times Z - 2 \times 25 \times \sqrt{0.704} = 0$$

$$\Rightarrow \quad Z = \frac{2 \times 25 \times \sqrt{0.704}}{0.704 \times 18.2} = 3.27 \text{ m}$$

Maximum depth up to which the excavation can be carried out safely without any support $2Z$ = 6.54 m.

MADE EASY Source

- **MADE EASY Classnotes**



End of Solution

5. (c) How are runways oriented? Explain the terms 'wind coverage' and 'crosswind' component.

[12 Marks]

Solution:

Runway Orientation

- The orientation of runway depends upon the direction of wind and to some extent area available for development.
- Runway is oriented in the direction of prevailing wind such that the direction of wind is opposite to the direction of landing and take off.
- The head wind provides greater lift force on the wings of aircraft while taking off, thus aircraft rises above the ground earlier i.e. in a shorter length of runway.
- During landing, head wind provides greater drag force so that it comes to hault in a shorter length of runway.

Cross Wind Component

- It is not feasible to obtain the direction of wind along the direction of the center line of runway throughout the year.
- If the direction of wind is at an angle to runway centre line, then its components.
- The normal component to movement of aircrafts is called cross wind component. It interrupts safe landing and take-off operations.
-

Type of Aircraft	Permissible limit of cross wind component
Small aircraft	15 kmph (10 mph)
Medium aircraft traffic	25 kmph (15 mph)
Big aircraft	35 kmph (23 mph)

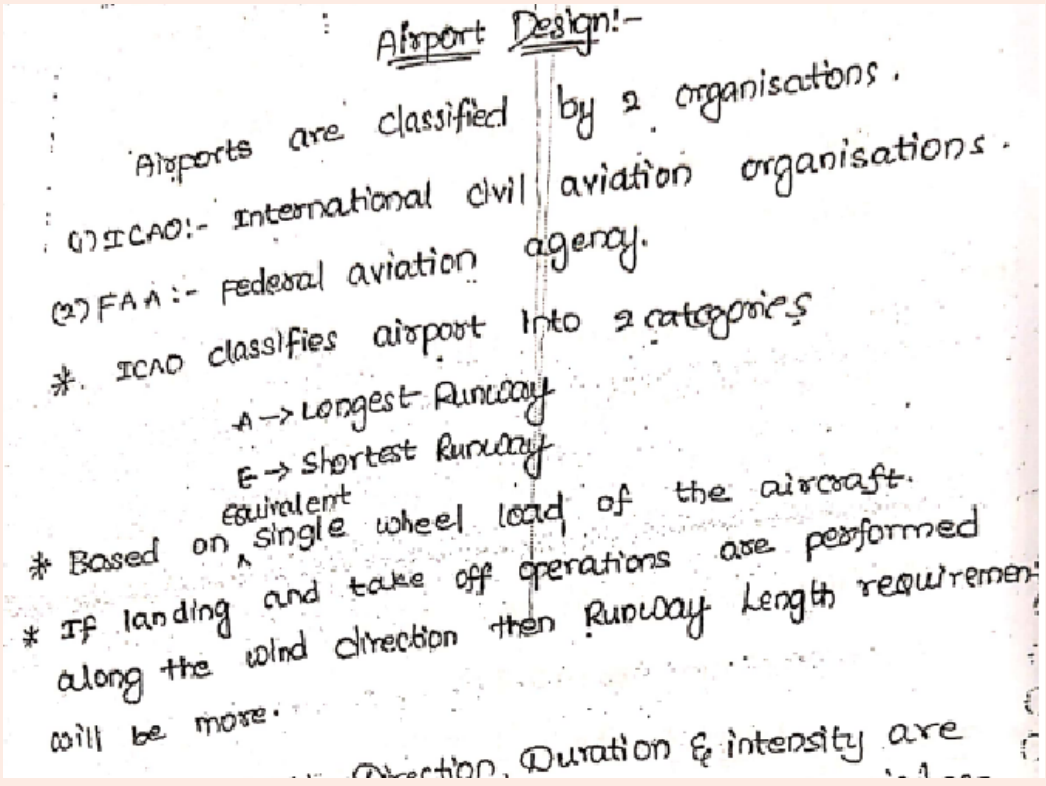
- Centre line of the runway should not make an angle with the wind direction exceeding 30°.

Wind Coverage

- The percentage of time in a year during which cross wind component is within the permissible limit is called wind coverage or usability factor of airport.
- According to FAA, runway handling mixed air traffic is planned such that minimum wind coverage is 95%.
- For busy airport, wind coverage may be increased to 98-100%.

MADE EASY Source

- **Theory Book:** Airport (Page No. 113, 114)
- **MADE EASY Classnotes**


Airport Design:-

Airports are classified by 2 organisations.

(1) ICAO:- International civil aviation organisations.

(2) FAA:- Federal aviation agency.

*. ICAO classifies airport into 2 categories

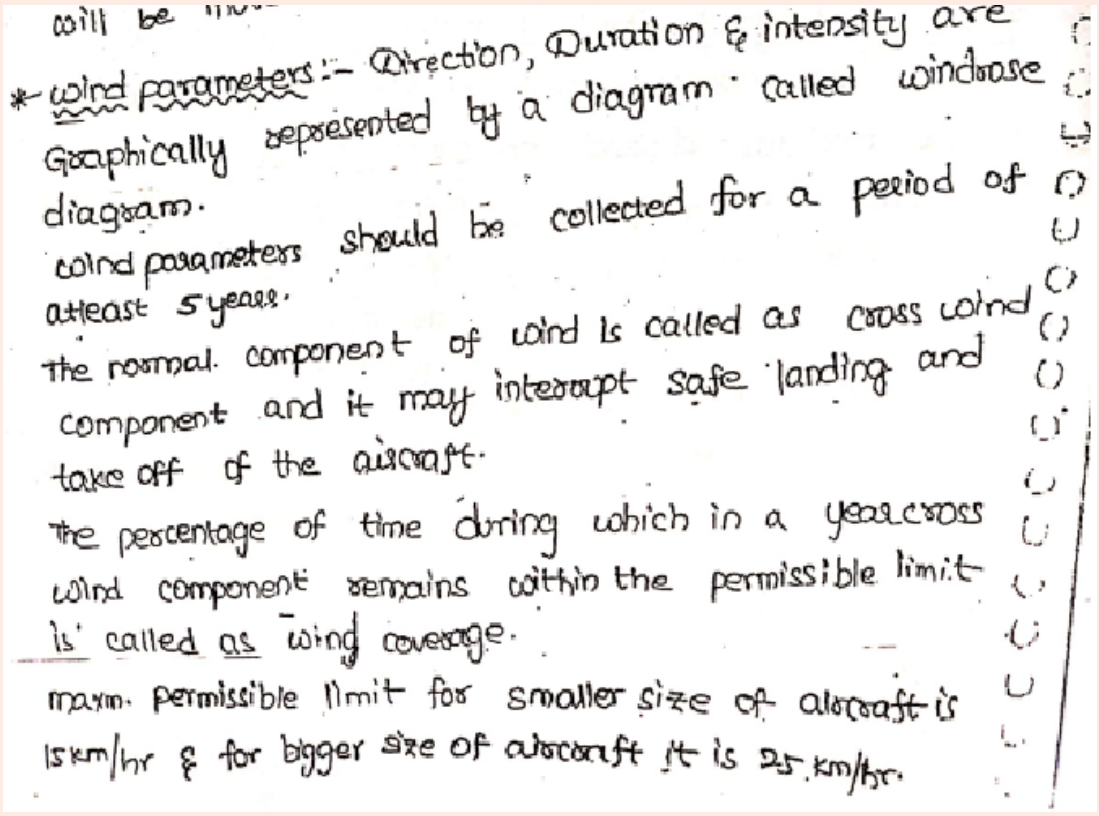
A -> Longest Runway

E -> Shortest Runway

* Based on single wheel load of the aircraft. equivalent

* If landing and take off operations are performed along the wind direction then Runway Length requirement will be more.

Direction, Duration & intensity are


will be
* wind parameters :- Direction, Duration & intensity are Graphically represented by a diagram called windrose diagram.
wind parameters should be collected for a period of atleast 5 years.
the normal component of wind is called as cross wind component and it may interrupt safe landing and take off of the aircraft.
the percentage of time during which in a year cross wind component remains within the permissible limit is called as wind coverage.
maxm. permissible limit for smaller size of aircraft is 15 km/hr & for bigger size of aircraft it is 25 km/hr.

End of Solution

5. (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 Marks]

Solution:

Given Degree of curve = 6°

V = 50 kmph

$$e_a = \frac{GV^2}{127R} = \frac{1\times 50^2}{127\times R}$$

$$R = \frac{1720}{6} = 286.67 \text{ m}$$

$$e_a = \frac{1\times 50^2}{127\times 286.67} = 0.0686 \text{ m} = 6.87 \text{ cm}$$

∵ For speed < 100 kmph, for MG limit of cant deficiency is equal to 5.1 cm.

$$e_{th} = e_a + e_d$$
$$= 6.87 + 5.1 = 11.97 \text{ cm} = 0.1197 \text{ m}$$

Now, $e_{th} = \frac{GV_{max}^2}{127R}$

$$0.1197 = \frac{1 \times V_{max}^2}{127 \times 286.67}$$

$\Rightarrow$ $V_{max} = 66.01$ kmph

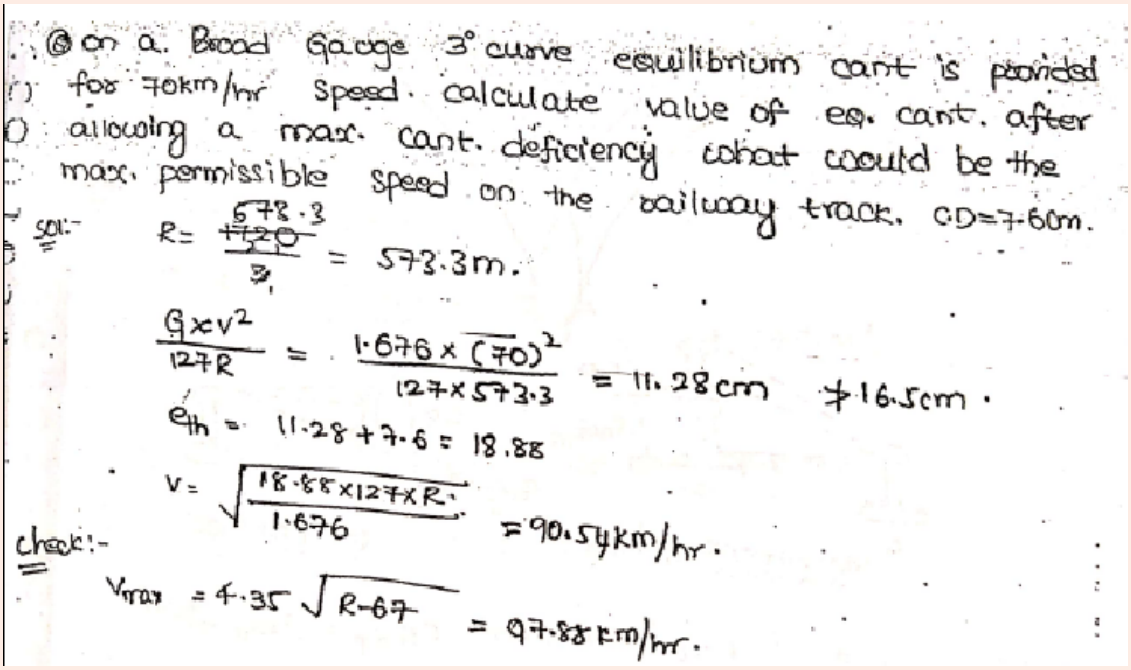
By Martin's formula, $V_{max} = 4.35\sqrt{(R-67)}$

$$V_{max} = 4.35\sqrt{(286.67-67)} = 64.47 \text{ kmph}$$

So, maximum permissible speed = 64.47 kmph $\simeq$ 64 kmph

MADE EASY Source

- **Theory Book:** Railway Q.9.2 (Page No. 84)
- **MADE EASY Classnotes**



End of Solution

5. (e) (i) What is repetition method in theodolite surveying? What are different instrumental errors which can be eliminated by the repetition method?

[6 Marks]

(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 720 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 Marks]

Solution:

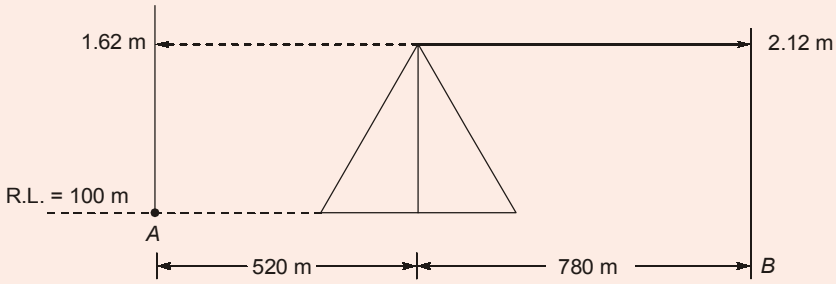
(i) Methods of Repetition:

This method is used to measure horizontal angle to a finer degree of accuracy obtainable with the least count of Vernier.

Following errors are eliminated by this method:

1. **Errors due to eccentricity** of Vernier's and centers are eliminated by taking both Vernier readings.
2. **Error due to adjustment** of line of collimation and the trunnion axis are eliminated by taking both face readings.
3. **Error due to accurate graduations** are eliminated by taking the readings at different parts of the circle.

(ii)



Given : RL of A = 100.00 m

Correct staff reading at station A = $1.62 - 0.0673\ (0.52)^2$

Correct staff reading at station B = $2.12 - 0.0673 \times 0.78^2 = 2.079$ m

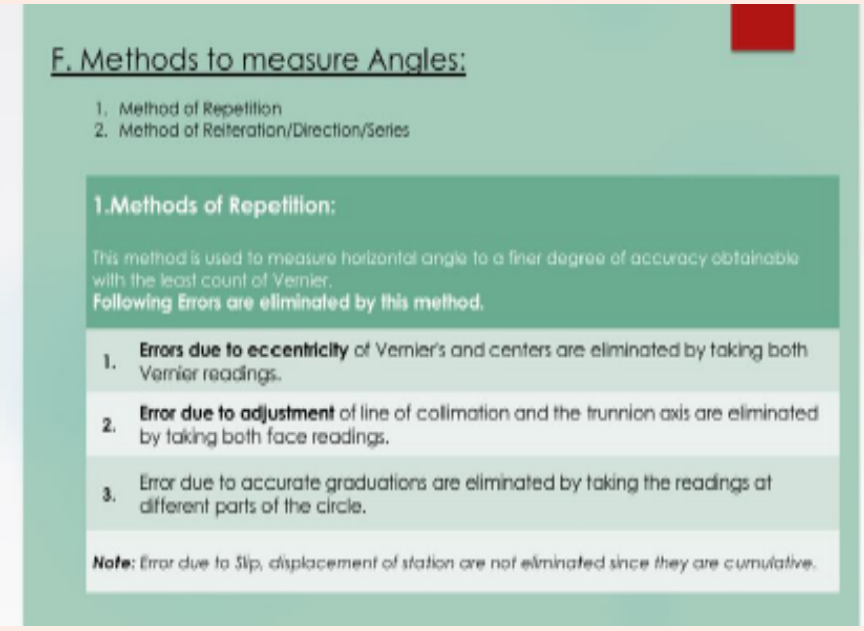
Difference in elevation between A and B

$$\Delta h = 2.079 - 1.6018 = 0.4772 \text{ m}$$

R.L. of $B = 100 - 0.4772 = 99.52$ m

MADE EASY Source

- **MADE EASY Classnotes**


F. Methods to measure Angles:

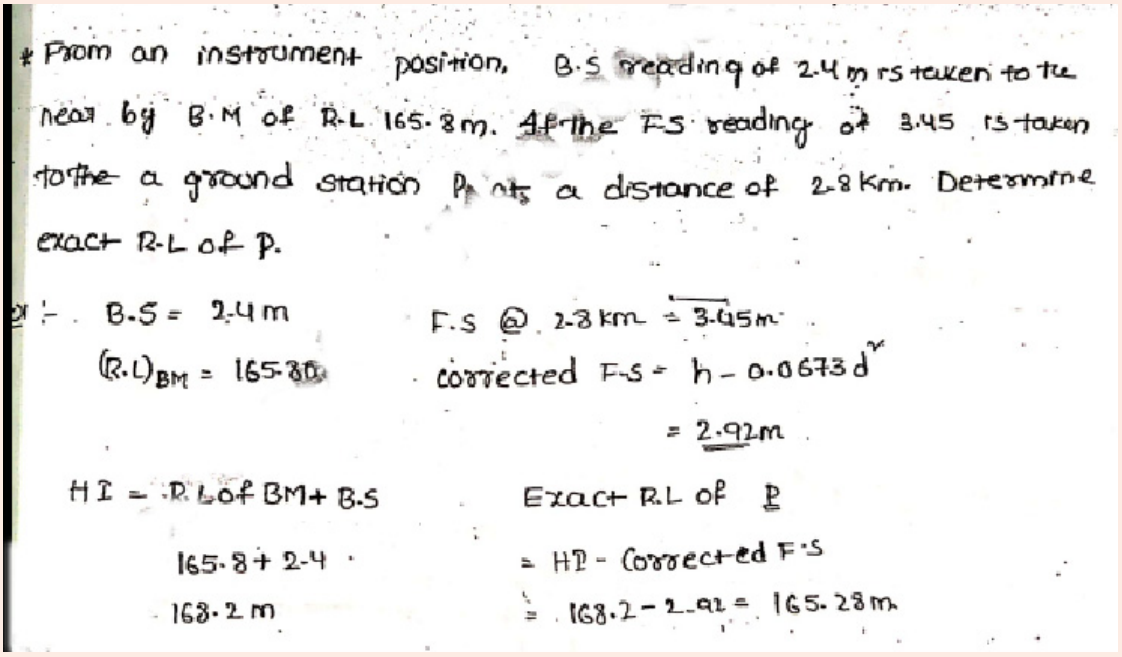
1. Method of Repetition
2. Method of Reiteration/Direction/Series

1.Methods of Repetition:

This method is used to measure horizontal angle to a finer degree of accuracy obtainable with the least count of Vernier.
Following Errors are eliminated by this method.

1. **Errors due to eccentricity** of Vernier's and centers are eliminated by taking both Vernier readings.
2. **Error due to adjustment** of line of collimation and the trunnion axis are eliminated by taking both face readings.
3. Error due to accurate graduations are eliminated by taking the readings at different parts of the circle.

Note: *Error due to Slip, displacement of station are not eliminated since they are cumulative.*


From an instrument position, B.S reading of 2.4 m is taken to the near by B.M of R.L 165.8 m. If the F.S reading of 3.45 is taken to the a ground station P at a distance of 2.8 km. Determine exact R.L of P.

∴ B.S = 2.4 m
$(R.L)_{BM}$ = 165.80
F.S @ 2.8 km = 3.45 m
corrected F.S = $h - 0.0673 d^2$
= 2.92 m
HI = R.L of BM + B.S
165.8 + 2.4
168.2 m
Exact R.L of P
= HI - Corrected F.S
= 168.2 - 2.92 = 165.28 m

End of Solution

6. (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 Marks]

Solution:

Given: Liquid limit = 60%

Plastic limit = 36%

As per IS classification I_P of A-line = 0.73 (LL – 20)

= 0.73 (60 – 20)

= 29.2%

Now, I_P of soil = 60 – 36 = 24%

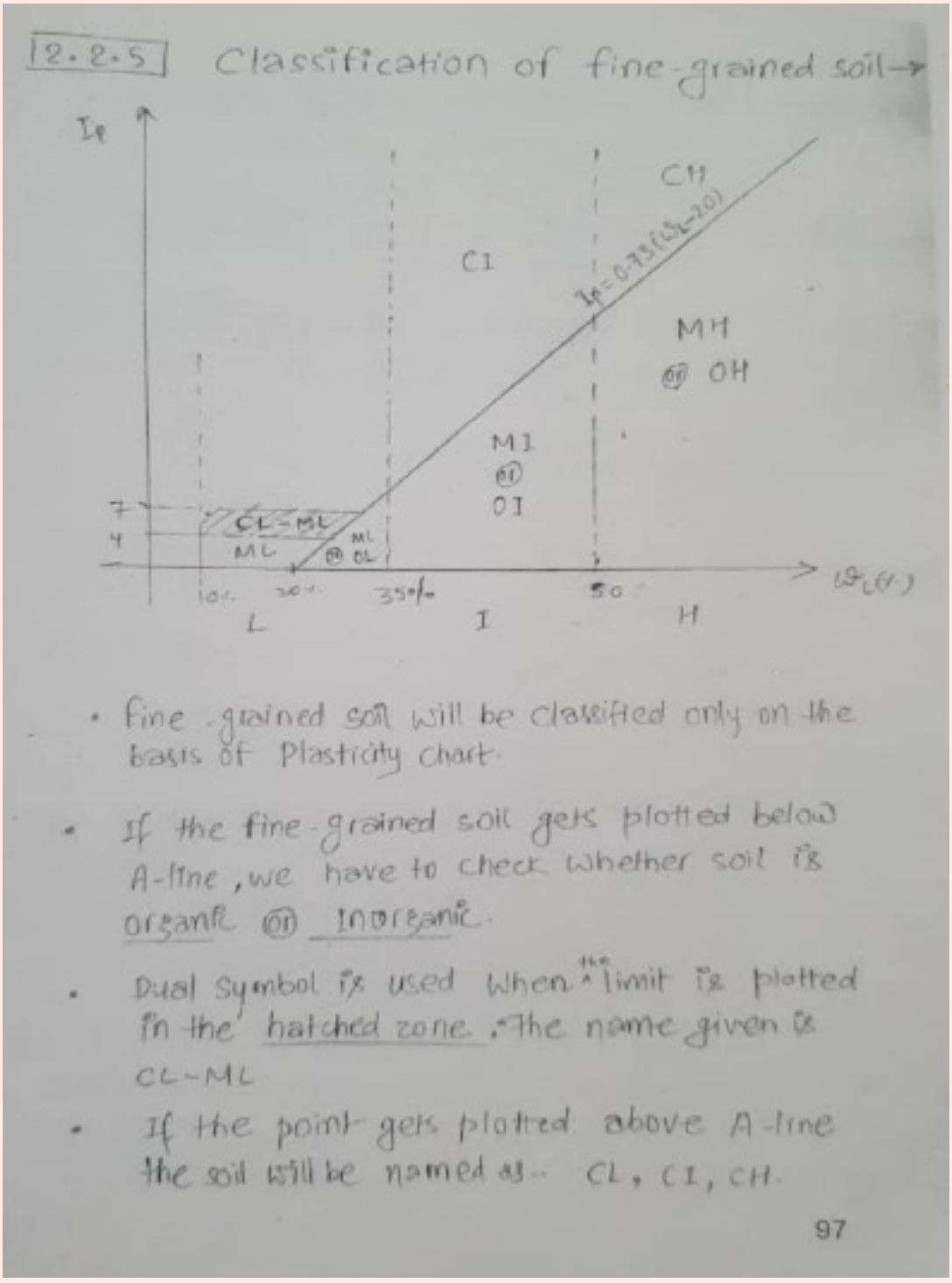
$\because$ I_P of A-line > I_P of soil

Therefore, the soil will lie below A-line. Also LL > 50%, therefore soil should be highly plastic (highly compressible).

So soil type is MH or OH.

MADE EASY Source

- **Theory Book:** Soil Mechanics Example 3.6 : (Page No. 83)
- **MADE EASY Classnotes**

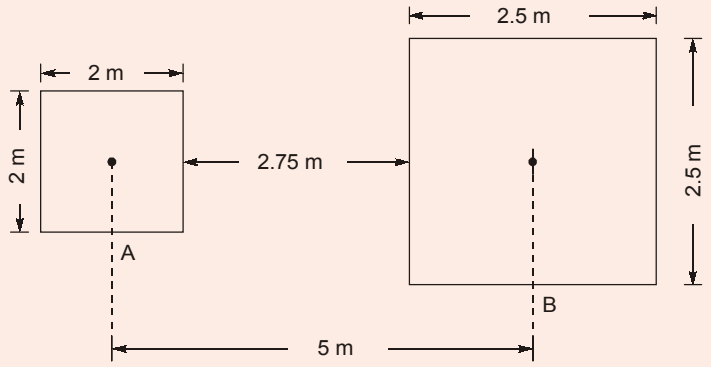


End of Solution

6. (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 × 2 m 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 Marks]

Solution:



Contact pressure = 250 kPa (given) equal for both the footings.

(i) Vertical stress at 2 m vertically below 2 m × 2 m

Footing as per Boussinesq's point load formula.

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

$$= \left[\frac{3\times 250\times 2^2}{2\pi(2)^2}\left(\frac{1}{1+0^2}\right)^{5/2}\right]_A + \left[\frac{3\times 250\times 2.5^2}{2\pi(2)^2}\left(\frac{1}{1+\left(\frac{5}{2}\right)^2}\right)^{5/2}\right]_B$$

$\therefore$ $\sigma_z = 119.366 + 186.5096\ (7.0657 \times 10^{-3})$

$= 120.683\ \text{kN/m}^2$

(ii) Vertical stress at 2 m vertically below 2.5 m × 2.5 m

Footing as per Boussinesq's point load formula

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

$$= \left[\frac{3\times 250\times 2.5^2}{2\pi(2)^2}\left(\frac{1}{1+0^2}\right)^{5/2}\right]_B + \left[\frac{3\times 250\times 2^2}{2\pi(2)^2}\left(\frac{1}{1+\left(\frac{5}{2}\right)^2}\right)^{5/2}\right]_A$$

$\therefore$ $\sigma_z = 186.5096 + 119.366\ (7.0657 \times 10^{-3})$

$= 187.353\ \text{kN/m}^2$

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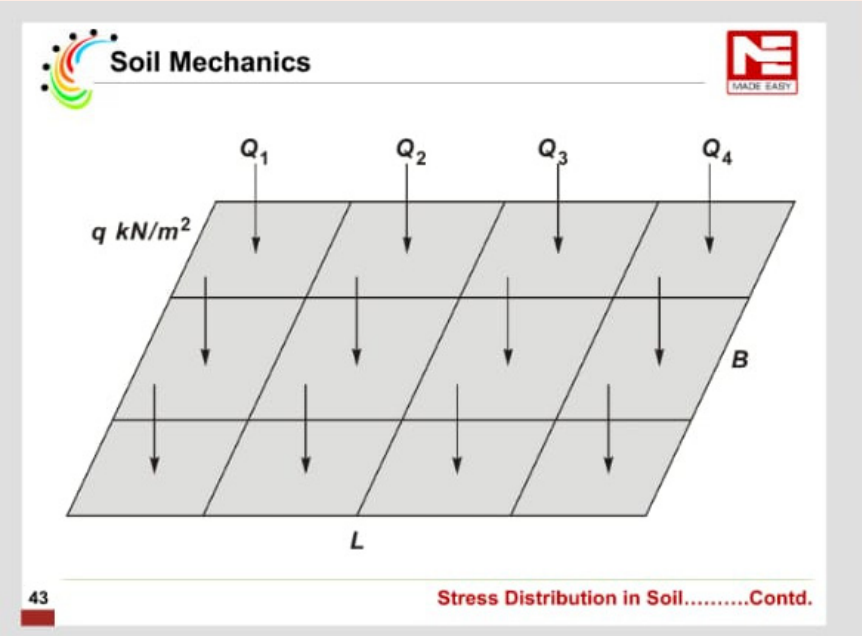
(iii) Mid point between the footings

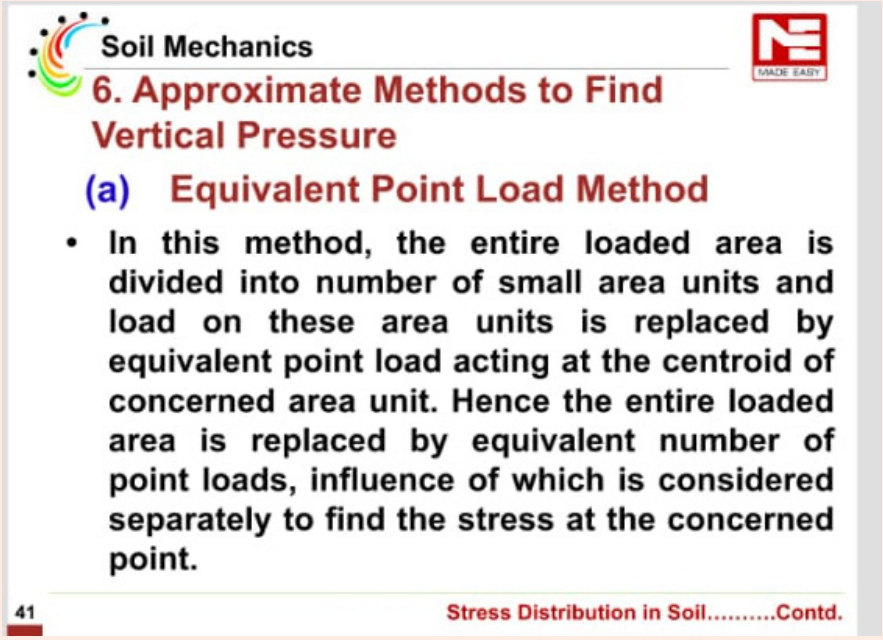
$$\sigma_z = \left[\frac{3\times 250\times 2\times 2}{2\pi\times(2)^2}\times\left(\frac{1}{1+\left(\frac{2.5}{2}\right)^2}\right)^{5/2}\right]_A + \left[\frac{3\times 250\times 2.5\times 2.5}{2\pi\times(2)^2}\times\left(\frac{1}{1+\left(\frac{2.5}{2}\right)^2}\right)^{5/2}\right]_B$$

σ_z = (119.366 × 0.095) + (186.581 × 0.095) = 29.064 kN/m^2

MADE EASY Source

- **ESE 2019 Mains Test Series:** Q.2(c) (i) of Test-1
- **MADE EASY Classnotes**





End of Solution

6. (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 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:

$\phi°$	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	23.27	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

[20 Marks]

Solution:

Given: diameter of plate = 0.3 m

load = 3.5 kN

For plate load test, $q = 0.3\gamma BN\gamma$

$$\frac{3.5}{\frac{\pi}{4}(0.3)^2} = 0.3 \times 19.2 \times 0.3 \times N_\gamma$$

$\therefore$ $N_\gamma = 28.65$

For $N_\gamma = 28.65$

The values of N_q and N_c can be found from the table

$$N_q = 25.52 + \frac{28.65 - 27.49}{36.96 - 27.49} \times (36.51 - 28.52)$$

$$N_q = 29.498$$

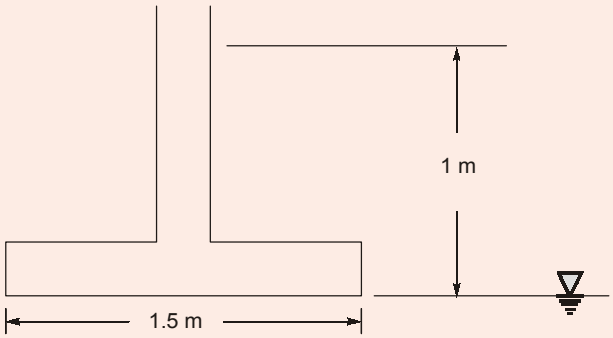
$$N_c = 44.04 + \frac{28.65 - 27.49}{36.96 - 27.49} \times (52.64 - 44.04)$$

$$N_C = 45.09$$

Now,

$$q_u = 1.3CN_C + qN_q + 0.4\gamma' BN_\gamma$$

For sand, $c = 0$



$$q_u = 1 \times 19.2 \times 29.498 + 0.4 \times (19.2 - 9.81) \times 1.5 \times 28.65$$

$$q_u = 727.7757 \text{ kN/m}^2$$

$$q_{nu} = 727.7757 - 1 \times 19.2 = 708.57 \text{ kN/m}^2$$

Assuming FOS = 3

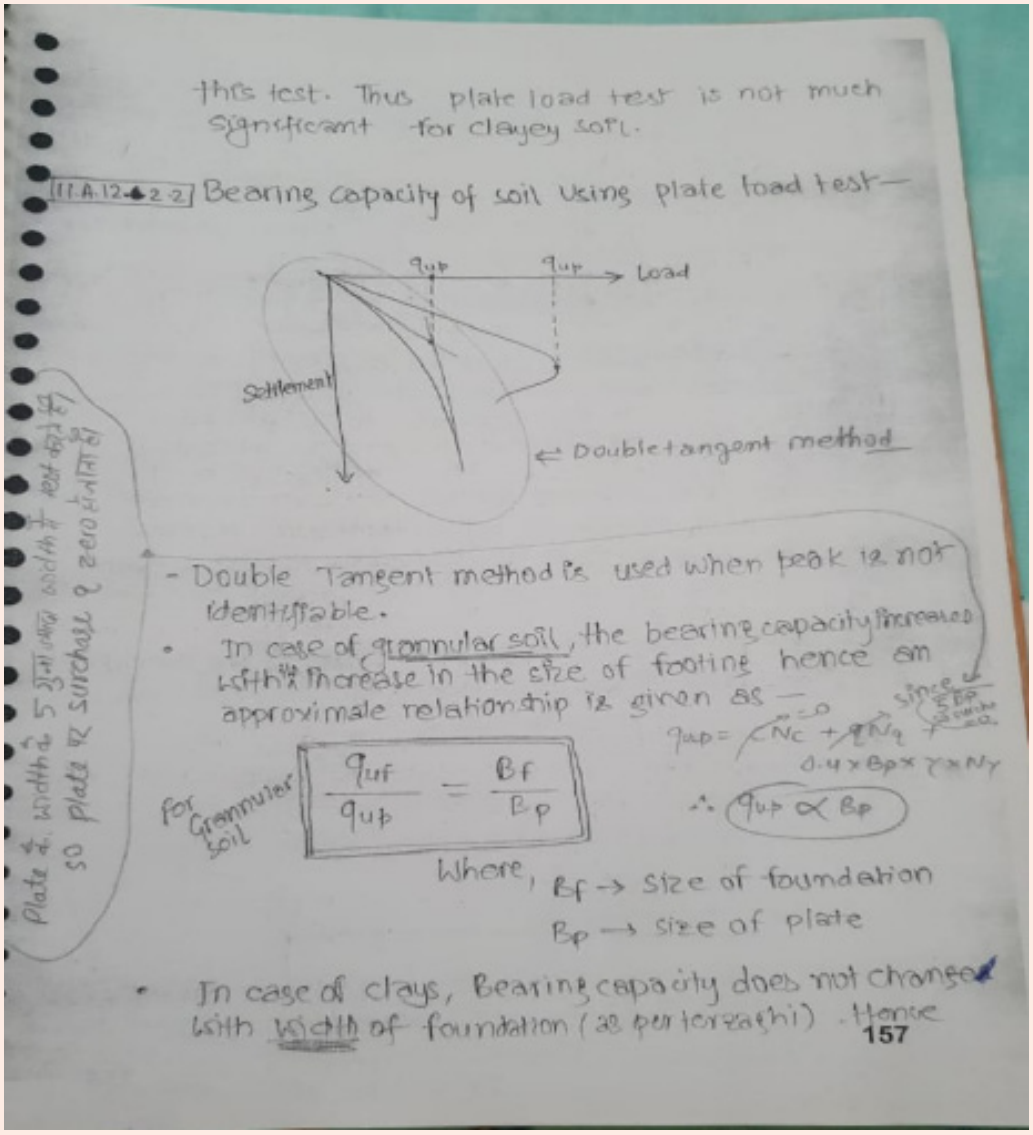
$$q_{ns} = \frac{705.57}{3} \text{kN/m}^2$$

$$q_s = \frac{705.57}{3} + 1 \times 19.2 = 255.39 \text{ kN/m}^2$$

So, the allowable bearing capacity of the footing = 255.39 kN/m^2

MADE EASY Source

- **MADE EASY Classnotes**



End of Solution

6. (d) Write down the construction steps for Water Bound Macadam road. Also compare WBM construction with WMM construction.

[20 Marks]

Solution:

The construction of WBM roads may be divided into following steps:

(i) **Preparation of foundation for receiving the WBM course:** The foundation layer i.e. subgrade, subbase or base course is prepared to required grade and camber. On existing road surfaces, the depressions and pot holes are filled and corrugations are removed by scarifying and reshaping the surface to the required grade and camber.

(ii) Provision of Lateral Confinement: It may be done by constructing the shoulders to advance to a thickness equal to that of compacted *WBM* layer.

(iii) Spreading of Coarse Aggregate: The coarse aggregates are spread uniformly to proper profile to even thickness upon the prepared foundation.

(iv) Rolling: Rolling is started from the edges and then gradually shifted towards the centreline of the road.

(v) 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.

(vi) Sprinkling and Grouting: After screeching, the surface is sprinkled with water, swept and rolled.

(vii) Application of Binding Material

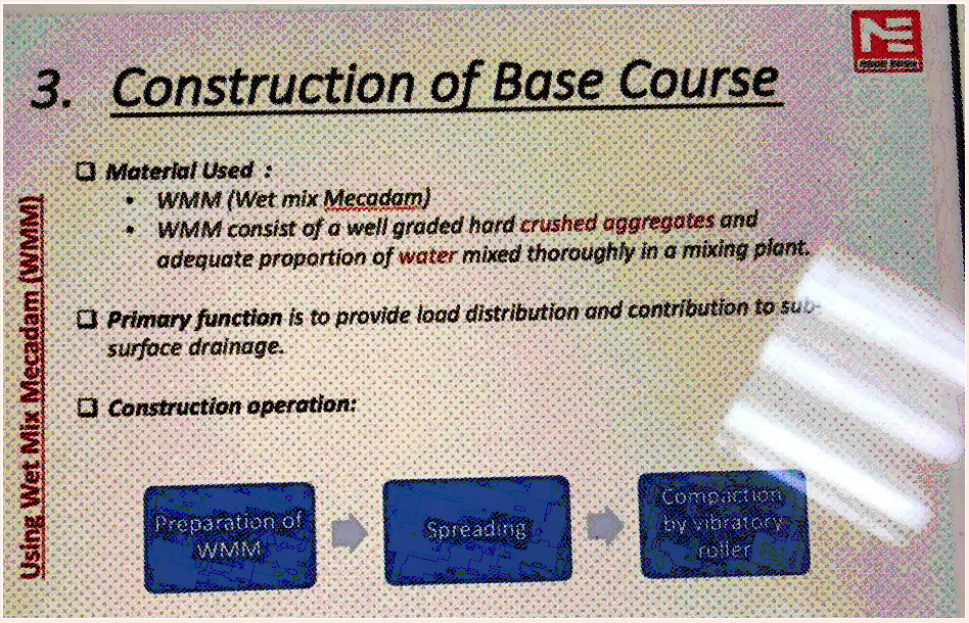
(viii) Setting and Drying

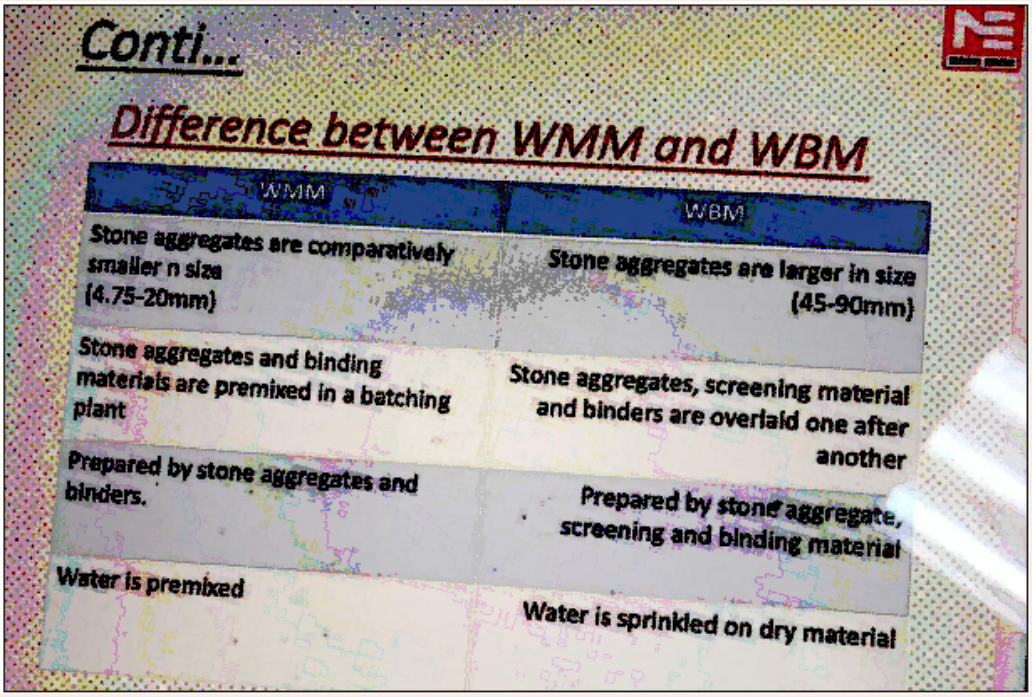
Difference between WMM and WBM

Wet Mix Macadam (WMM)	Water Bound Macadam (WBM)
Stone aggregates are comparatively smaller in size (4.75-20 mm)	Stone aggregate are larger in size (45-90 mm)
Stone aggregates and binding materials are premixed in a batching plant	Stone aggregates, screening material and binders are overlaid one after another
Prepared by stone aggregates and binders	Prepared by stone aggregate, screening and binding material
Water is premixed	Water is sprinkled on dry material

MADE EASY Source

- **Theory Book:** Highway Engineering (Page No. 218)
- **MADE EASY Class PPT**





End of Solution

7. (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-centre 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 up to 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 Marks]

Solution:

Given:

Slab thickness (h) = 25 cm

Poisson's ratio of concrete (μ) = 0.15

Modulus of subgrade reaction (k) = 8 kg/cm^3

Center to center spacing of dowel bars (δ) = 30 cm

Load to be transferred by joint is 50% of the wheel load (P)

Distance upto which dowel bars are effective = 1.0 × radius of relative stiffness

Also, modulus of elasticity of cement concrete (E) = 3×10^5 kg/cm^2

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

$$l = \left[\frac{3\times 10}{12k\left(1-\mu^2\right)}\right]^{1/4} = 84.069 \text{ cm}$$

$\therefore$ Distance upto which dowel bars are effective = 84.069 cm

$$\text{Load capacity} = 1+\frac{(1\times l-\delta)}{1\times l}+\frac{(1\times l-2\delta)}{1\times l}+\frac{(1\times l-3\delta)}{1\times l}+\ldots$$

[As long as numerator is positive]

$$\therefore \quad \text{Load capacity} = 1+\frac{(84.069-30)}{84.069}+\frac{(84.069-60)}{84.069} = 1.929$$

Maximum load carried by single dowel

$$P_s = \frac{0.5\times P}{1.929} = \frac{0.5\times 4100}{1.929} = 1062.73 \text{ kg}$$

MADE EASY Source

- **ESE 2019 Mains Test Series:** Q.2(b) of Test-2

End of Solution

7. (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 300 mm, 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 Marks]

Solution:

Given:

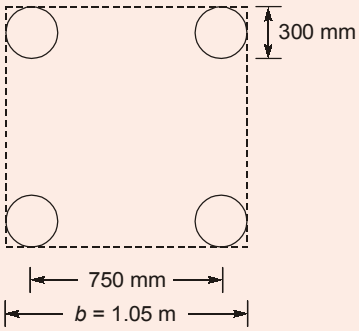
$\gamma = 20.2$ kN/m^3

Unconfined compressive strength = 200 kPa

Diameter of pile = 0.3 m

Length = 12 m

$\alpha = 0.6$



(i) Load capacity on individual pile failure

$$Q_{us} = q_s \cdot A_s + q_b \cdot A_b$$

$$q_s = \alpha \bar{c} = 0.6\times\frac{200}{2} = 60 \text{ kN/m}^2$$

$$A_s = \pi dL = \pi\times 0.3\times 12 = 11.3097 \text{ m}^2$$

q_bA_b term is neglected as the piles are friction piles.

$$Q_{us} = 60 \times 11.3097 = 678.24 \text{ kN}$$

$$Q_{us\ Total} = n \cdot Q_s = 4 \times 678.24 = 2712.96 \text{ kN}$$

$$Q_{an} = \frac{Q_{us,total}}{FOS} = \frac{2712.96}{2} = 1356.48 \text{ kN}$$

(ii) Load capacity of the group based on the block failure.

$$Q_{ug} = q_sA_s$$

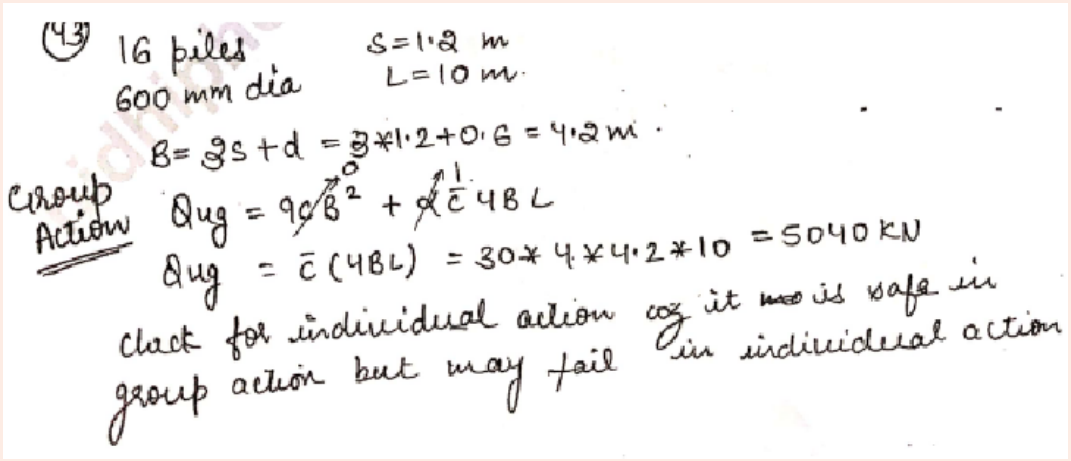
$$Q_{ag} = \frac{q_sAs}{FOS} = \frac{100 \times 4 \times 1.05 \times 12}{3} = 1680 \text{ kN}$$

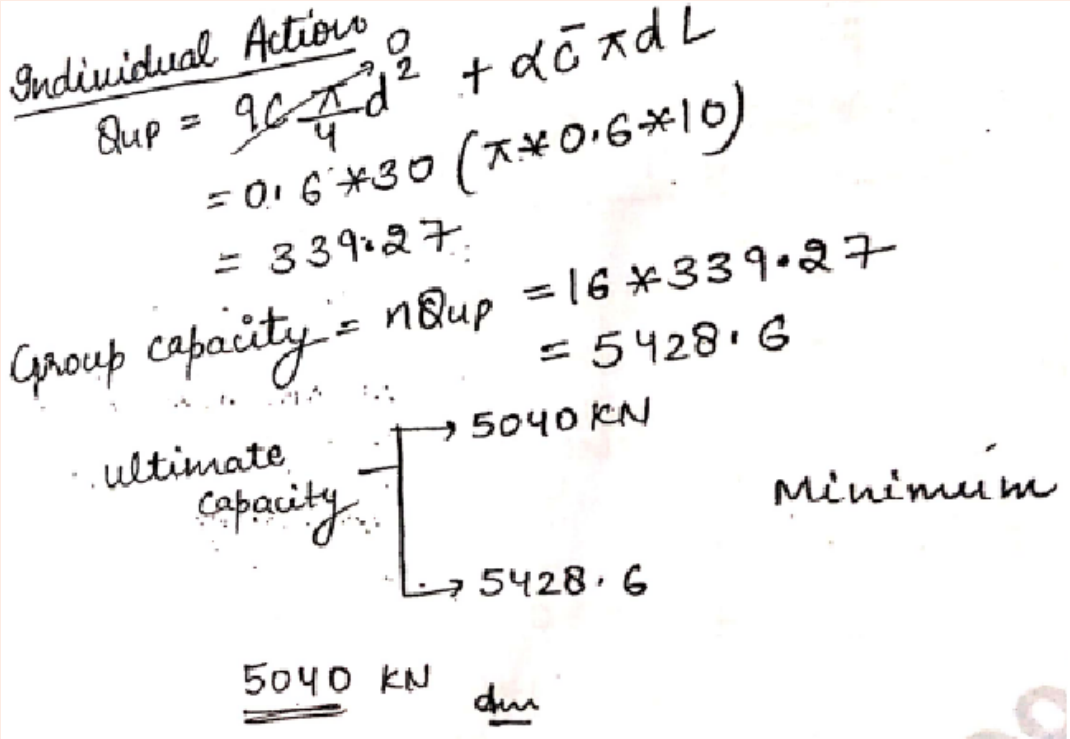
(iii) Design load capacity (Q_{safe}) = Minimum of (Q_{an}, Q_{ag})

= 1356.48 kN

MADE EASY Source

- **ESE 2019 Mains Test Series:** Q.3(a) of Test-1
- **MADE EASY Classnotes**





End of Solution

7. (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 coordinate of points A, B, C and D. Assume line AD in north direction.

[20 Marks]

Solution:

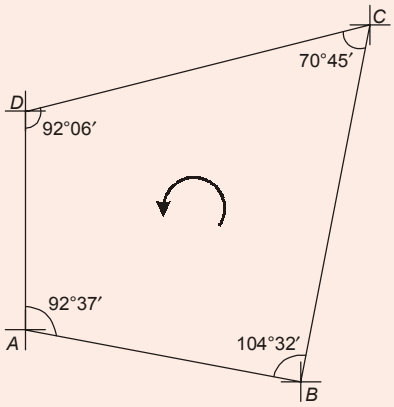
$$\text{Sum of internal angles} = \angle A + \angle B + \angle C + \angle D$$
$$= 92°38' + 104°33' + 92°38' + 104°33'$$
$$= 360°04'$$
$$\text{Error} = 360°04' - 360° = 0°04'$$
$$\text{Correction} = -0°04'$$
$$\text{Correction per angle} = \frac{-0°04'}{4} = -0.01'$$

$\therefore$ Correct interior angles, $\angle A = 92°38' - 0°01' = 92°37'$

$\angle B = 104°33' - 0°01' = 104°32'$

$\angle C = 70°46' - 0°01' = 70°45'$

$\angle D = 92°07' - 0°01' = 92°06'$



FB of AB = 92°37′

FB of BC = 104°32′ + 2°37′ – 90°

= 17°09′

FB of CD = 17°09′ + 70°45′ – 180°

= 267°54′

FB of DA = 180°

Line	Length (L′) (in m)	Fore bearing	Latitude (L)	Correction	Corrected latitude	Departure (D)	Correction	Correction departure
AB	27.15	92°37′	–1.239	–0.054	–1.293	27.1216	–0.09218	27.029
BC	52.16	17°09′	49.84	–0.104	49.736	15.3806	–0.17709	15.203
CD	41.96	267°54′	–1.537	–0.083	–1.62	–41.9318	–0.14246	–42.074
DA	46.73	180°	–46.73	–0.093	–46.823	0	–0.15865	–0.15865
	$\Sigma L' = 168$ m		$\Sigma L = 0.334$	$\Sigma C = 0.334$		$\Sigma D = 0.5704$	$\Sigma C' = -0.5704$	

$$e_x = \Sigma D = 0.5704$$

$$e_y = \Sigma L = 0.334$$

$$\text{Closing error} = \sqrt{(0.5704)^2 + (0.334)^2} = 0.661$$

$$\theta = \tan^{-1}\left(\left|\frac{e_x}{e_y}\right|\right) = 59.65°$$

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- **MADE EASY Classnotes**

Que. For a closed traverse, following readings were taken. Find the closing error and correct the bearings by
(a) Bowditch Method (b) Transit method

(a) Bowditch Method

Line	Length	Bearing	Latitude	Departure	Correction for Latitude	Correction for Departure	Corrected Value Latitude	Corrected Value Departure
PQ	85	40°	+65.114	+54.637	-1.530	-4.010	+63.583	+50.626
QR	230	60°	+115.00	+199.186	-4.141	-10.851	+110.858	+188.335
RS	160	160°	-150.361	+54.723	-2.881	-7.548	-153.232	+47.175
ST	150	220°	-114.910	-96.418	-2.701	-7.077	-117.607	-103.495
TP	200	300°	+100.00	-173.205	-3.601	-9.426	+96.399	-182.641
0	$\Sigma = 825$	Σ	$e_L = 14.356$ (+)	$e_D = 38.923$ (+)	-14.856	38.923	$\Sigma L = 0$	$\Sigma D = 0$

Closing Error $= e = \sqrt{e_L^2 + e_D^2}$

$= \sqrt{14.856^2 + 38.923^2}$

$= 41.661$ m

$\theta = \tan^{-1}\left(\frac{e_D}{e_L}\right)$

$= \tan^{-1}\left(\frac{38.923}{14.856}\right)$

$= 69°108°$

$C_{L_1} = -\left[\frac{l_1}{\Sigma l} \times e_L\right] = -\left(\frac{85}{825} \times 14.856\right)$

$= -1.530$

Corrected Latitude $= L_1 + C_{L_1}$

$= 65.114 + -1.530 = +63.583$

$C_{D_1} = -\left[\frac{l_1}{\Sigma l} \times e_L\right] = -\left(\frac{85}{825} \times 38.923\right)$

$= -4.010$

Corrected Departure $= D_1 + C_{D_1}$

$= 54.637 - 4.010$

$= +50.626$

End of Solution

8. (a) (i) What is spectral reflectance curve (spectral signature) in remote sensing? Explain any four applications of remote sensing in civil engineering?

[10 Marks]

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

[10 Marks]

Solution:

(i) Electromagnetic energy incident on the surface features are partially reflected, absorbed or transmitted through it. The fractions that are reflected absorbed or transmitted vary with material type and the condition of the feature. It also varies with the wavelength of the incident energy. Majority of the remote sensing systems operate in the region in which the surface features mostly reflect the incident energy. The reflectance characteristics of the surface features are represented using spectral reflectance curves.

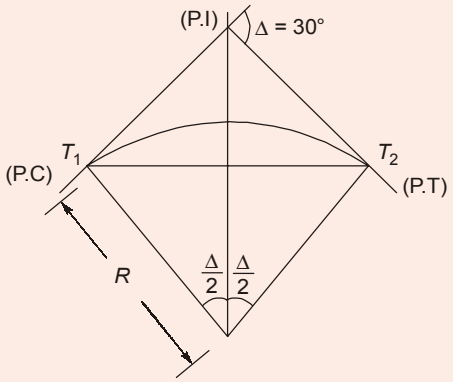
Applications of Remote Sensing In Civil Engineering

1. **Agriculture**
   - (i) Early season estimation of total cropped area
   - (ii) Monitoring crop condition using crop growth profile.
   - (iii) Identification of crops and their coverage estimation in multi-cropped regions.
   - (iv) Crop yield modelling
   - (v) Cropping system/crop rotation studies
   - (vi) Command area management
   - (vii) Detection of moisture stress in crops and quantification of its effect on crop yield
   - (viii) Detection of crop violations
   - (ix) Zoom cultivation–desertification
2. **Land use and soils**
   - (i) Mapping land use/cover (level-III) at 1 : 25000 scale or better
   - (ii) Change detection
   - (iii) Identification of degraded lands/erosion prone areas
   - (iv) Soil categorization
3. **Geology**
   - (i) Lithological and structural mapping
   - (ii) Geomorphological mapping
   - (iii) Ground water exploration
   - (iv) Engineering geological
   - (v) Geo-environmental studies
   - (vi) Drainage analysis
   - (vii) Mineral exploration
   - (viii) Coal fire mapping
   - (ix) Oil field detection

4. Urban Land use

(i) Urban land use level IV mapping
(ii) Updating of urban transport network
(iii) Monitoring urban sprawl
(iv) Identification of unauthorised structures

(ii)



R = 30 chains = 30 × 20 = 600 m

Chainage of point of tangency,

T_2 = 300 chains = 300 × 20 = 6000 m

Also, chainage of T_2 = Chainage of T_1 + Length of curve (L_C)

$$L = 2\pi R \times \left(\frac{\Delta}{360^\circ}\right) = \frac{2 \times \pi \times 600 \times 30^\circ}{360^\circ} = 314.159 \text{ m}$$

∴ Chainage of T_1 = 6000 – 314.159 = 5685.84 m

Chainage of point intersection (PI)

= Chainage of T_1 + Tangent length (T)

$$= 5685.84 + R\tan\frac{\Delta}{2}$$

$$= 5685.84 + 600\tan\left(\frac{30}{2}\right)$$

= 5685.84 + 160.77 = 5846.609 m

Now, revised radius of curve R′ = 45 × 20 = 900 m

$$\text{Chainage of } T_1 = R'\tan\frac{\Delta}{2} = 5846.609 - 900\tan\left(\frac{30}{2}\right)$$

= 5846.609 – 241.154 = 5605.454 m

∴ Chainage of T_2 = Chainage of $T_1 + 2\pi R' \times \left(\frac{\Delta}{360}\right)$

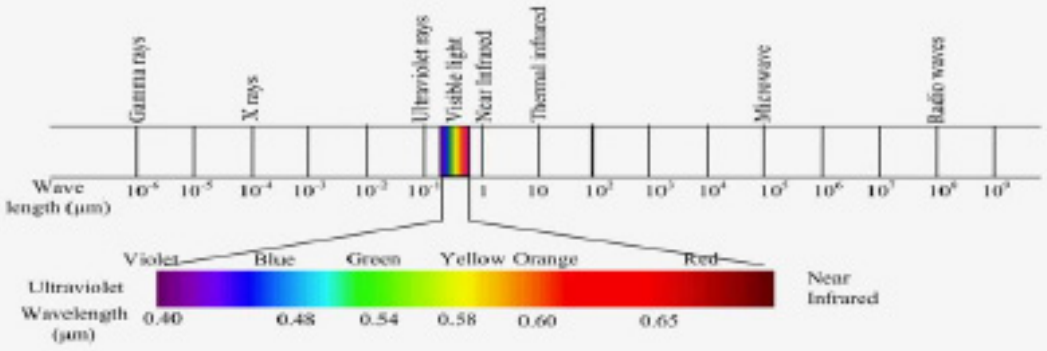
$$\Rightarrow \quad 5605.454 + 2\pi \times 900 \times \left(\frac{30}{360}\right) = 6076.692 \text{ m}$$

$$\text{Length of long chord } (T_1T_2) = 2R'\sin\frac{\Delta}{2} = 2 \times 900 \times \sin\left(\frac{30}{2}\right) = 465.874 \text{ m}$$

MADE EASY Source

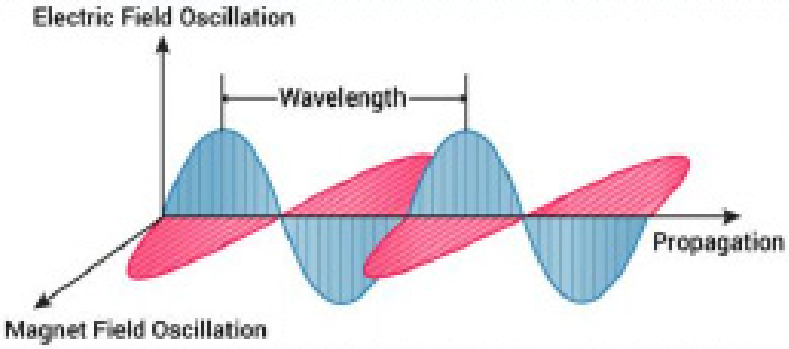
- **ESE 2019 Mains Test Series:** Q.6(a) of Test-11
- **Theory Book:** Surveying (Page No. 282, 283)
- **MADE EASY Classnotes & PPT**

- Distribution of the continuum of energy can be plotted as a function of wavelength (or frequency) and is known as the EMR spectrum.
- In Remote sensing terminology, electromagnetic energy is generally expressed in terms of wavelength, λ.



EMR

- Electromagnetic energy or electromagnetic radiation (EMR) is the energy propagated in the form of an advancing interaction between electric and magnetic fields.
- It travels with the velocity of light. Visible light, ultraviolet rays, infrared rays, heat, radio waves, X-rays all are different forms of electro-magnetic energy.

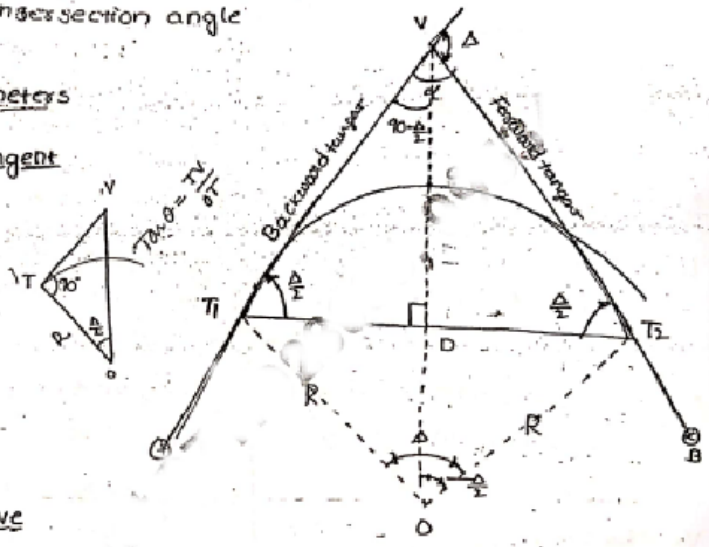


Let A- Starting point, B- end point

T_1- Point of curve. T_2- Point of tangency

V – Point of intersection Δ- Angle of deflection

α - Intersection angle



Basic Parameters

1) Length of tangent

$T_1V = VT_2$

$\boxed{T_1V = R\tan\frac{\Delta}{2}}$

2) Length of curve

$\boxed{l = \frac{2\pi R}{360} \times \Delta}$

3) Length of longest chord

$T_1T_2 = T_1D + DT_2$

$T_1T_2 = 2R\sin\frac{\Delta}{2}$

4) Mid ordinate

$CD = OC - OD$

$= R - R\cos\frac{\Delta}{2}$

$\boxed{CD = R\left(1-\cos\frac{\Delta}{2}\right)}$

$\boxed{CD = R\,\text{Versine}\frac{\Delta}{2}}$

5) Apex/External distance:

$VC = OV - OV$

$= R\sec\frac{\Delta}{2} - R$

$VC = R\left(\sec\frac{\Delta}{2} - 1\right)$

$\sec\frac{\Delta}{2} = \frac{OV}{R}$

$OV = R\sec\frac{\Delta}{2}$

Chainage:-

Chainage at T_1 = Chainage at V – Length of tangent.

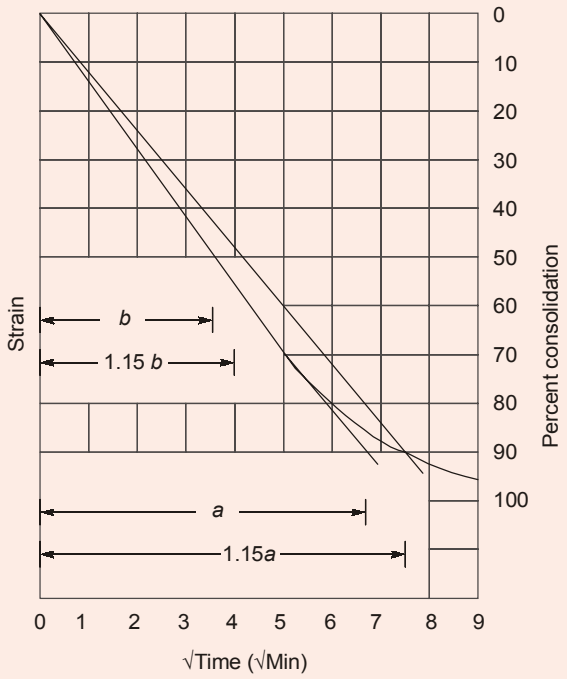
Chainage at T_2 = Chainage at T_1 + length of curve

End of Solution

8. (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

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

$$T = 1.781 - 0.9331 \log (100 - U\%),\ U \le 60\%$$



[15 Marks]

Solution:

Given : Thickness of clay layer = 30 mm

$$T_{90} = 1.781 - 0.933 \log (100 - 90) = 0.848$$

From the graph

$$\sqrt{t_{90}} = 7.5$$

$$t_{90} = 56.25 \text{ min}$$

$$0.848 = \frac{C_V \times t_{90}}{H^2}$$

$$\left(H = \frac{30}{2} = 15 \text{ mm as double drainage condition is given}\right)$$

$$\Rightarrow \quad \frac{0.848 \times 15^2}{56.25} = C_V$$

$$C_V = 3.392 \text{ mm}^2/\text{min} = 4.88 \times 10^{-3} \text{ m}^3/\text{day}$$

Now, $$T_{50} = \frac{\pi}{4}\left(\frac{50}{100}\right)^2 = 0.196$$

$$0.196 = \frac{C_V \times t}{H^2}$$

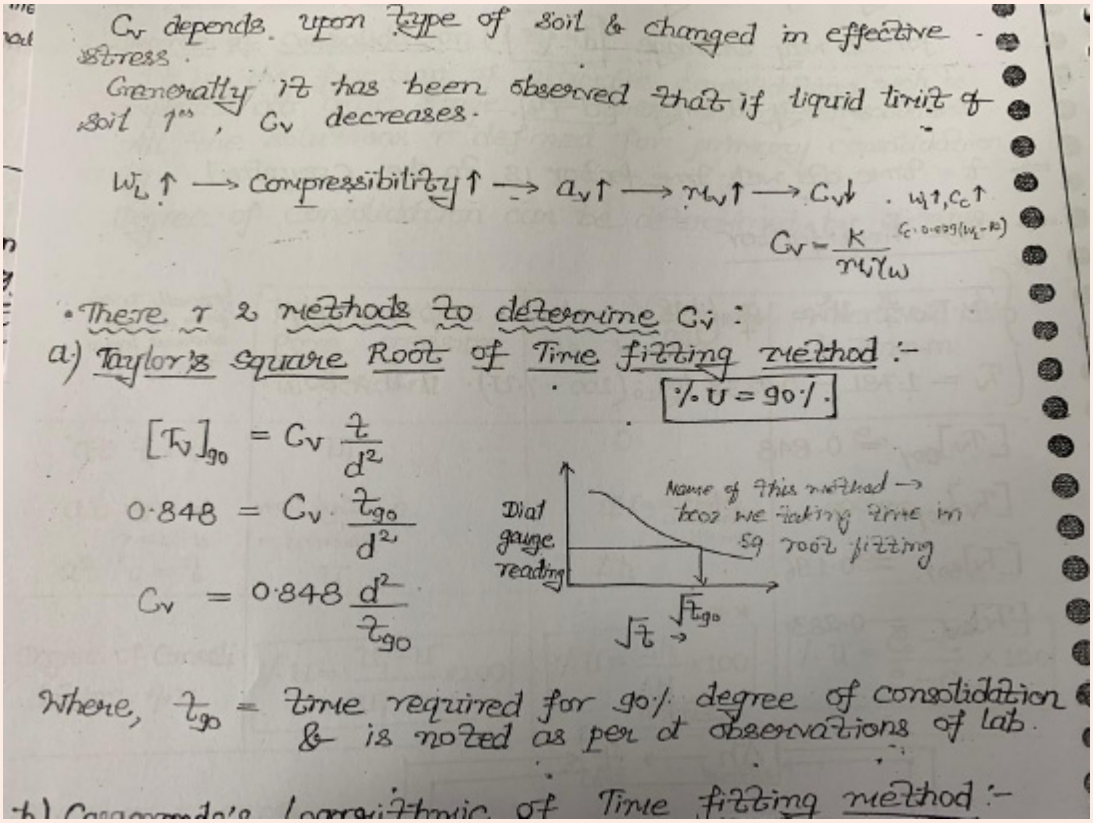
(Here, H = 2.5 m, One way drainage is given)

$\therefore$ $$0.196 = \frac{4.88 \times 10^{-3}}{2.5^2}$$

$$t = \frac{4.88 \times 10^{-3} \times t}{2.5^2} = 251.02 \text{ days}$$

MADE EASY Source

- **MADE EASY Classnotes**



End of Solution

8. (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 Marks]

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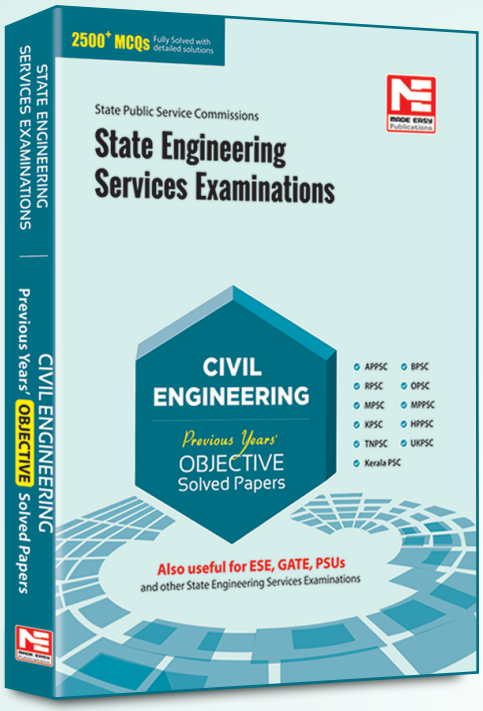

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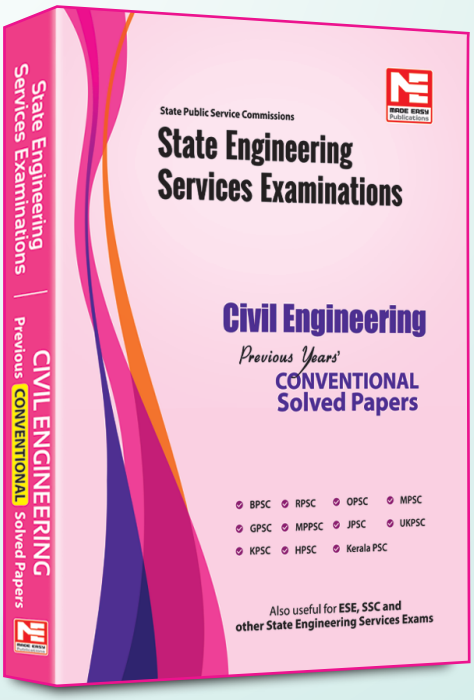

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Solution:

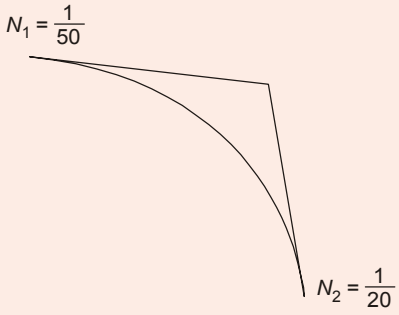
$$N_1 = -\frac{1}{50}$$

$$N_2 = -\frac{1}{20}$$

Deviation angle, $N = N_1 - N_2$

$$= -\frac{1}{50} - \left(-\frac{1}{20}\right)$$

$$N = \frac{3}{100}$$



Design speed (v) = 80 kmph = 22.22 m/s

(I) Stopping sight distance (SSD) calculation:

$$\text{SSD} = vt + \frac{v^2}{2gfb}, \text{ [Consider brake efficiency } b = 100\%]$$

Coefficient of longitudinal friction, $f = 0.35$

Assume reaction time = 2.5 seconds

$$\therefore \quad \text{SSD} = 22.22 \times 2.5 + \frac{(22.22)^2}{2 \times 9.81 \times 0.35} = 127.448 \text{ m}$$

(II) Overtaking sight distance (OSD) calculation:

Since speed of overtaken vehicle V_b is not given,

$$\therefore \quad V_b = (V - 4.5) \text{ m/s} = 17.72 \text{ m/s}$$

OSD for two lane, two-way highway = $d_1 + d_2$

$$d_1 = V_b \times t_r$$

[Assume, reaction time of driver, $t_r = 2$ sec]

$$\therefore \quad d_1 = 17.72 \times 2 = 35.44 \text{ m}$$

$$d_2 = b + 2s,$$

where $S = 0.7V_b + 6$

$$\therefore \quad S = 0.7 \times 17.72 + 6 = 18.404 \text{ m}$$

Also, $b = V_b \times T$, where $T = \sqrt{\frac{4S}{a}}$

$a = 3.6$ km/hr/sec (given)

$$\therefore \quad T = \sqrt{\frac{4 \times 18.404}{3.6 \times \frac{5}{18}}} = 8.5799 \text{ sec}$$

$$\therefore \quad b = 17.72 \times 8.5799 = 152.037 \text{ m}$$

$$\therefore \quad d_2 = b + 2s = 152.037 + 2 \times 18.404 = 188.845 \text{ m}$$

$$d_3 = vT = 22.22 \times 8.5799 = 190.645 \text{ mm}$$

Hence, OSD $= d_1 + d_2 + d_3$

$= 35.44 + 188.845 + 190.645$

$= 414.93 \text{ m} \simeq 415 \text{ m}$

Case 1 : Assume (L_C > SSD)

$$L_C = \frac{NS^2}{4.4} = \frac{\left(\frac{3}{100}\right) \times 127.448^2}{4.4}$$

$$= 110.747 \text{ m} < 127.448 \text{ m}$$

Hence, our assumption is wrong.

$\therefore$ L_C < SSD

$$L_C = 2S - \frac{4.4}{N} = 2 \times 127.448 - \frac{4.4}{\left(\frac{3}{100}\right)}$$

Length of vertical curve based on SSD;

$$L_C = 108.23 \text{ m}$$

Case 2 :

Assume, (L_C > OSD)

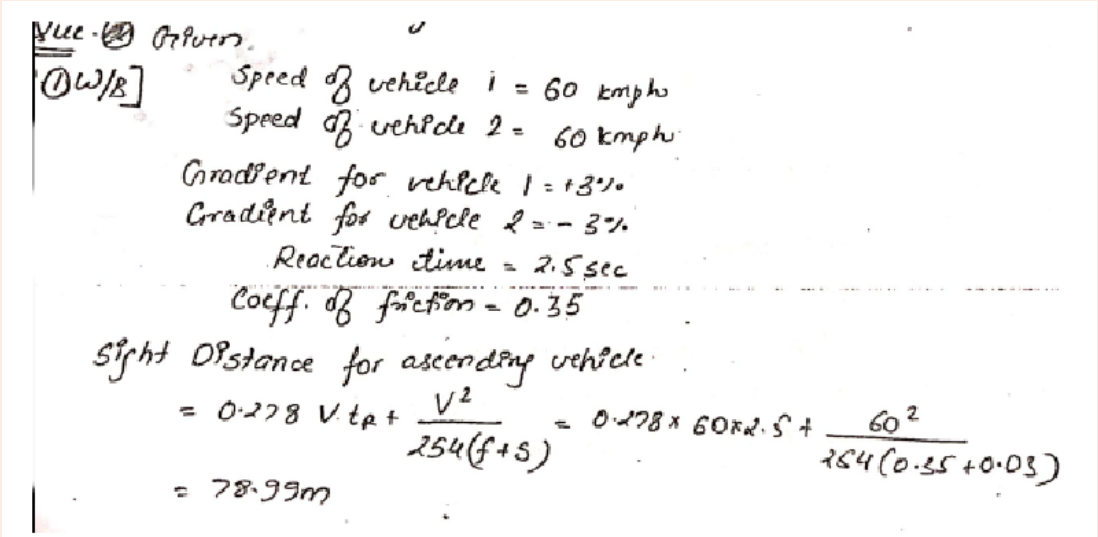
$$L_C = \frac{NS^2}{9.6} = \frac{\left(\frac{3}{100}\right) \times 415^2}{9.6} = 538.20 \text{ m}$$

Hence, our assumption is correct.

Length of vertical curve based on OSD = 538.20 m

MADE EASY Source

- **Theory Book:** Highway Engineering (Geometric Design) 3.4 and 3.9.1
- **MADE EASY Classnotes**


Vue-(2) Option
(1) (W/B)
Speed of vehicle 1 = 60 kmph
Speed of vehicle 2 = 60 kmph
Gradient for vehicle 1 = +3%
Gradient for vehicle 2 = −3%
Reaction time = 2.5 sec
Coeff. of friction = 0.35
Sight Distance for ascending vehicle
$= 0.278\, V t_R + \frac{V^2}{254(f+S)} = 0.278 \times 60 \times 2.5 + \frac{60^2}{254(0.35+0.03)}$
$= 78.99 m$

Soln Given $V_A = V_C$ = Design Speed = 85 kmph

Acceleration = 1.2 m/sec²

To find : OSD

Assume : l = 6m

Now, $V_B = 85 - 16 = 69$ kmph

Space Headway, $S = 0.2V_B + 6 = 0.2 \times 69 + 6 = 19.8$ m

Overtaking time, $T = \sqrt{\frac{4S}{a}} = \sqrt{\frac{4 \times 19.8}{1.2}} = 8.12$ sec

$OSD = (0.278 \times V_B \times t_e) + (2S + 0.278 V_B t_e T) + (0.278 V_C T)$

$= [0.278 \times 69 \times 2] + [2 \times 19.8 + 0.278 \times 69 \times 8.12] + [0.278 \times 85 \times 8.12]$

$= 425.55$ m ≈ Adopt 430 m

Que (7) SSD = S = 180 m

$n_1 = +\frac{1}{50}$, $n_2 = -\frac{1}{30}$

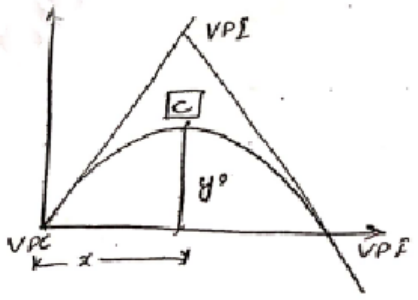
Change in gradient, $N = |n_1 + n_2| = \frac{1}{50} + \frac{1}{30} = \frac{4}{75}$

Assume, $L_S > SSD$

$L_S = \frac{NS^2}{4.4} = \frac{4/75 \times 180^2}{4.4} = 392.72$ m > SSD (i.e. 180m)

Assumption was correct

(8)



At VPI, $x = \frac{1}{2} \cdot L_S$

$y' = \left(\frac{-N}{2L_S}\right)x^2 + n_1 x$

y' @ $x = \frac{L_S}{2}$ $= \frac{-N}{2L_S} \cdot \frac{L_S^2}{4} + n_1 \frac{L_S}{2}$

$= -\frac{NL_S}{8} + \frac{n_1 L_S}{2}$

Que. (8) $n_1 = +\frac{1}{100}$

$n_2 = -\frac{1}{120}$

$V = 80$ kmph

$OSD = S = 470m$

Assuming $L_S > OSD$

$$L = \frac{NS^2}{9.6} = \frac{(1/100 + 1/120) \times 470^2}{9.6}$$

$$= 421.85 \not> 470m \ (L_S)$$

Now, $L_C < OSD$

$$L = 2S - \frac{9.6}{N} = 2 \times 470 - \frac{9.6}{(1/100 + 1/120)} = 416.36m$$

End of Solution