# SYLLABUS FOR CIVIL ENGINEERING

## ENGINEERING MATHEMATICS:

→ Linear Algebra
→ Calculus
→ Differential equation
→ Complex Variables
→ Probability and Statistics.
→ Numerical Method

## STRUCTURAL ENGINEERING:

→ Mechanics
→ structural Analysis
→ Concrete structures
→ Steel structures.

## GEOTECHNICAL ENGINEERING:

→ Soil Mechanics.
→ Foundation Engineering

## WATER RESOURCE ENGINEERING:

→ Fluid Mechanics and Hydraulics
→ Hydrology
→ Irrigation

## ENVIRONMENTAL ENGINEERING:

→ water Requirements
→ Air pollution
→ Municipal solid Wastes
→ Noise pollution.

# STRUCTURAL ENGINEERING

→ MECHANICS

→ STRUCTURAL ANALYSIS

→ CONCRETE STRUCTURES

→ STEEL STRUCTURES

# GEOTECHINAL ENGINEERING

→ SOIL MECHANICS

→ FOUNDATION ENGINEERING

# SOIL MECHANICS

- → Origin of soil
- → Soil classification
- → Three-phase system
- → Fundamental definitions, Relationship and inter relationships.
- → Permeability and seepage
- → Effective stress principle
- → Consolidation
- → Compaction
- → Shear strength.

# FOUNDATION ENGINEERING

→ Sub surface investigation

* Scope
* Drilling bore holes
* Sampling
* Penetration Tests
* Plate Load Test

→ Earth pressure theories

* Effects of water table
* Layered soils.

→ Stability of slopes

* Infinite | slope
* Finite slope.

→ Foundation types

* Foundation design
* Requirements

→ Shallow foundation

* Bearing capacity
* Effect of shape, water table and other factors

→ Stress distribution

→ Settlement analysis in sands and clay

→ Negative skin friction.

* Disintegration of rocks is called weathering
* Weathering consistitues soil.
* Types of weathering → Physical weathering, Chemical weathering.

Physical weathering:

* Occurs due to physical effects like temperature, abrasion, wedging action of ice, penetration of plants root.
* No change in chemical composition
* It produces coarse grained and non-cohesive soil.

Ex: sand, gravel etc.,

chemical weathering:

* Due to chemical actions (oxidation, hydration, carbonation, leaching etc.,]
* original rock minerals are converted into clay minerals.
* The resulting soil is of cohesive natu

Ex: clay, slit.

* Based on rate of transportation, there are 2 types of soil.

1.) Residual soil [Rate of weathering > Rate of transportation]

2.) Transported soil (Rate of weathering < Rate of transportation

* Residual soil (shallow depth)

* Sources of transportation are.

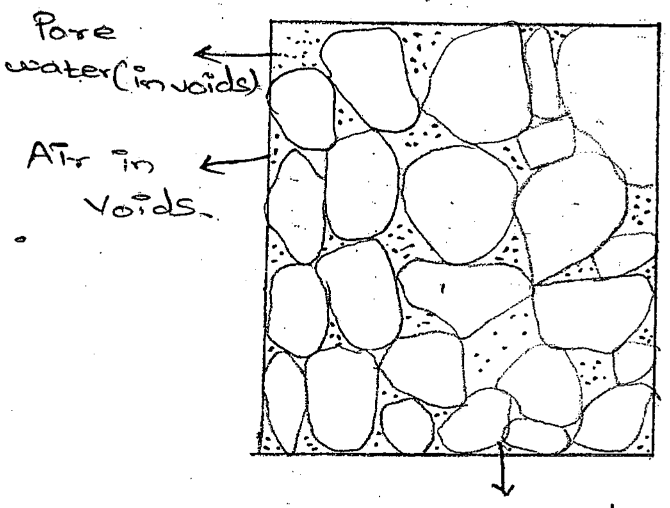
(a) water
(b) Air
(c) gravity.
(d) Ice

| Source of Transportation | Type of Soil |
|---|---|
| (i) water | |
| (a) River | Alluvial soil |
| (b) Lake | Lacustrine. |
| (c) Sea | Marl (or) Marine |
| (ii) Wind | Aeolin, Dune, Loess. |
| (iii) Ice | Drift, glacial drift (or) fill. |
| (iv) Gravity | Colluvial (or) Talus |

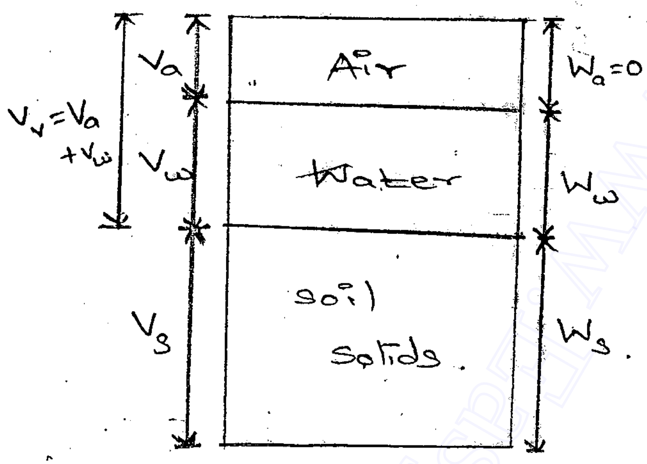
* The soil formed by the decomposition of vegetation under excess water is called cumulose (Peat & Muck) (organic soil)

* The soil from volcanic origin.

Ex: Tuff, Bentonite (highly porus soil, high swelling and shrinkage).

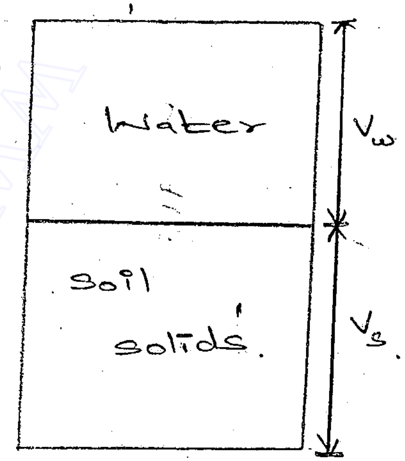



soil solids.
(or)
soil particles
(or)
soil grains.



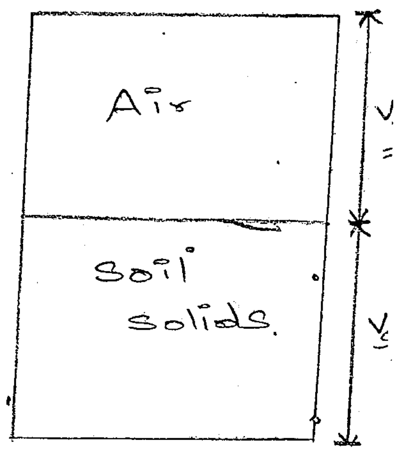

3 phase diagram
(Bulk condition)
(Partially saturated Condition)

$$\boxed{V = V_a + V_w + V_s}$$




2 phase diagram
(fully saturated condition)
(100% saturation)
Rainy season.

$$\boxed{V = V_w + V_s}$$




2 phase diagram.
(fully dried condition);

$$V = V_v + V_s$$

$$\boxed{V = V_a + V_s}$$

 (4)

* Black cotton soil also subjected to high swelling and shrinkage due to minerals.

ex: Montmorillonite.

* Under reamed piles are suitable for black cotton soil.

* Varved clay:

→ It contains alternate layers of clay and silt.

Varved clay (Lacustrine deposit).

* Loam - Mixture of sand, silt and clay approximately in equal proportion.

* Moorum - gravel + Red clay.

* Sequence of geological cycle for the formation of soil is:-

weathering → Transportation → Deposition → upheaval

Based on the size the soils are classified as follows:

| | Type of Soil | size |
|---|---|---|
| 1.) | clay | < 2 μ |
| 2.) | silt | 2μ - 75μ |
| 3.) | fine sand | 75μ - 425μ |
| 4.) | Medium Sand | 425μ - 2mm |
| 5.) | Coarse sand | 2mm - 4.75mm |
| 6.) | Fine gravel | 4.75mm - 20mm |
| 7.) | Coarse gravel | 20mm - 80mm |
| 8.) | cobble | 80mm - 300mm |
| 9.) | Boulder | > 300mm |

Symbols:

$V_s$ - Volume of soil solids

$V_w$ - Volume of water

$V_a$ - volume of air.

$V_v$ - Volume of voids.

$= V_a + V_w$ (Bulk condition)

$= V_w + 0$. (fully saturated condition)

$= V_a + 0$. (fully dried condition).

$V$ = Total volume of soil mass

$= (V_v + V_s)$.

$V = V_s + \underbrace{V_a + V_w}_{V_v}$ (Bulk).

$V = V_s + V_w$ (fully saturated).

$V = V_s + V_a$ (fully dried).

$W_s$ - weight of soil solids.

$W_w$ - weight of water (in voids)

$W_a$ - weight of air in voids. ($\Omega$ - 0)

$W = W_a + W_w + W_s$.

$W = W_w + W_s$ (Bulk)

$W = W_w + W_s$ (fully saturated)

$W = W_s$ (fully dried)

Important Terms:



(i) Void ratio (e):

$$e = \frac{V_v}{V_s}$$

$$e > 0$$

$$V_v \neq 0.$$

for Bentonite $e = 5$.

$$\frac{V_v}{V_s} = 5.$$

$$\boxed{V_v = 5V_s.}$$

Cubical array:

* If spherical soil grains are arranged in a cubical array then the maximum possible void ratio is 0.91.

* If spherical soil grains are arranged in a face centred arrangement having inclination 45° then the minimum possible void ratio is 0.35.

* void ratio is maximum for bentonite. (e = 5)

(ii) Porosity (n)

$$n = \frac{V_v}{V} \times 100\%$$

$$\boxed{0 < n < 1}$$

$$n = \frac{V_v}{V} = \frac{V_v}{V_v + V_s} = \frac{1}{\frac{V_v + V_s}{V_v}}$$

$$= \frac{1}{1 + \frac{1}{e}} = \frac{e}{1+e}.$$

$$\boxed{n = \frac{e}{1+e}}$$

$$e = \frac{V_v}{V_s} = \frac{V_v}{V - V_v}$$

$$= \frac{1}{\frac{V}{V_v} - \frac{V_v}{V_v}} = \frac{1}{\frac{1}{n} - 1}$$

$$\boxed{e = \frac{n}{1-n}}$$

(iii) Degree of saturation:

$$S_r = \frac{V_w}{V_v} \times 100\%$$

$$\boxed{0 \leq S_r \leq 1}$$

(iv) Air content $(a_c)$:

$$a_c = \frac{V_a}{V_v} \times 100\%$$

$$\boxed{0 \leq a_c \leq 1}$$

$$a_c = \frac{V_a}{V_v}$$

$$= \frac{V_v - V_w}{V_v}$$

$$\boxed{a_c = 1 - S_r}$$

(v) Percentage of air voids $(\eta_a)$:

$$\eta_a = \frac{V_a}{V} \times 100$$

$$\boxed{0 \leq \eta_a \leq 100\%}$$

$$\eta_a = \frac{V_a \times V_v}{V \times V_v}$$

$$\boxed{\begin{aligned} \eta_a &= a_c \times n \\ \eta_a &= (1 - S_r)\left(\frac{e}{1+e}\right) \end{aligned}}$$

(vi) Water ~~Content~~ (or) Moisture Content (w):

$$w = \frac{W_w}{W_s} \times 100\%$$

$$\boxed{0 \leq w}$$

$$\gamma_{bulk} = \frac{W}{V} = \frac{W_s + W_w}{V_s + V_w + V_a}.$$

$$\gamma_{sat} = \frac{W_{sat}}{V} = \frac{W_s + W_w}{V_s + V_w}.$$

For fully saturated condition $\gamma_{sat} = \gamma_b$

$$\gamma_{dry} = \frac{W_{dry}}{V} = \frac{W_s}{V_s + V_a}.$$

$$\gamma_{sub} = \frac{W_{sub}}{V}$$

$W_{sub}$ = $W_{sat}$ − weight of water displaced.

= $W_{sat} - \gamma_w \times V_w$ (displaced)

$$\gamma_{sub} = \frac{W_{sat}}{V} - \frac{\gamma_w \times V}{V}.$$

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

$$\gamma_s' = \frac{W_s}{V_s}. \qquad \gamma_d = \frac{W_s}{V}.$$

$$\gamma_s \neq \gamma_d$$

$$\gamma_w = \frac{W_w}{V_w}.$$

$$\gamma_w = 9.81 \ kN/m^3.$$

$$\gamma_s > \gamma_{sat} > \gamma_{bulk} > \gamma_d > \gamma_{sub}$$

Specific gravity of soil solids $(G_s)$:

$$G_s = \frac{\gamma_s}{\gamma_w} = \frac{W_s}{W_w}$$

$G_s = 2.65$ sand

$G_s = 2.7$ clay.

Mass specific gravity (or) specific gravity of soil mass (or) Bulk specific gravity:

$$G_m = \frac{\gamma_{bulk}}{\gamma_w}$$

Relative Density.

$$R.D = \frac{e_{max} - e}{e_{max} - e_{min}}.$$

R.D indicates relative compactness of soil

It is applicable for cohesionless soil (i.e) (sand gravel).

$e_{max}$ - loose state.

$e_{min}$ - Dense state.

| R·D | Nature |
|---|---|
| 0 – 15% | Very loose |
| 15 – 35% | Loose |
| 35% – 65% | Medium |
| 65% – 85% | Dense |
| 85% – 100% | Very dense. |

Functional Relation:

1.) $e = \frac{n}{1-n}$.

2.) $n = \frac{e}{1+e}$.

3.) $a_c = 1 - S_r$.

4.) $\eta_a = a_c \times n = (1-S_r) \times \left(\frac{e}{1+e}\right)$.

5.) $\gamma_d = \frac{G_s}{(1+e)} \gamma_w$.

6.) $\gamma_{bulk} = \gamma_d (1+w)$

$= \frac{G_s}{(1+e)} \gamma_w (1+w)$.

7.) $\gamma_{sat} = \frac{(G_s+e)}{(1+e)} \gamma_w$.

8.) $\gamma_{sub} = \frac{(G_s-1)}{1+e} \gamma_w$.

9.) $G_s \times w = e \times S_r$.

10.) critical hydraulic gradient.

$$\gamma_{sub} = \frac{(G_s - 1)}{(1+e)} \gamma_w$$

$$\frac{\gamma_{sub}}{\gamma_w} = \frac{(G_s - 1)}{(1+e)}$$

$$\boxed{i_c = \frac{(G_s - 1)}{1+e}}$$

11.) Actual hydraulic gradient ($i_a$).

$$i_a = \frac{\Delta H}{L_{seep}} = \frac{H_1 - H_2}{L_{seep}}$$

If $i_a \geq i_c$ sand boiling will occur.

$i_c > i_a$ sand boiling will not occu

1.) Given:

$w = 22.22\%$ $G_s = 2.7$ $S_r = 1$

$\gamma_{sat} = ?$

$$G_s \times w = S_r \times e$$

$$e = 2.7 \times 0.2222$$

$$\boxed{e = 0.5994}$$

$$\gamma_{sat} = \left(\frac{G_s + e}{1+e}\right) \gamma_w$$

$$= \frac{(2.7 + 0.5994)}{(1 + 0.5994)} \times 10$$

$$\boxed{\gamma_{sat} = 20.63 \text{ kN/m}^3}$$

2.) Given :





$$\frac{\gamma_{sat}}{\gamma_d} = 1.25 \qquad G_s = 2.65$$

$e = ?$

$$\frac{\dfrac{(G_s+e)\times\gamma_w}{\cancel{(1+e)}}}{\dfrac{G_s\times\cancel{\gamma_w}}{\cancel{(1+e)}}} = 1.25$$

$$\frac{G_s+e}{G_s} = 1.25$$

$$e = (1.25\times2.65) - 2.65$$

$$\boxed{e = 0.6625}$$

3.) Given :

$\gamma_{sat} = 22\ kN/m^3$ $\qquad w = 10\%$

$S_r = 1$ $\qquad \gamma_d = ?$

$$\gamma_{sat} = \frac{(G_s+e)}{(1+e)}\times\gamma_w$$

$$\boxed{\gamma_{sat} = \gamma_{bulk} = 22\ kN/m^3}$$

$$\gamma_{bulk} = \gamma_d\,(1+w)$$

$$\gamma_d = \frac{\gamma_{bulk}}{1+w}$$

$$= \frac{22}{1+0.1}$$

$$\boxed{\gamma_d = 20\ kN/m^3}$$

4.) Given :

$\omega = 20\%$. $G_s = 2.67$ $\gamma_w = 10\ kN/m^3$.

$S_r = 1$.

$G_s \times w = S_r \times e$.

$e = 2.67 \times 0.2$.

$\boxed{e = 0.534.}$

$\gamma_{sat} = \dfrac{G_s + e}{1+e} \times \gamma_w$.

$= \dfrac{2.67 + 0.534}{1 + 0.534} \times 10$.

$\boxed{\gamma_{sat} = 20.886\ kN/m^3.}$

5.) Given: dry soil.

$W = 120\ g$ $V = 80\ ml$ $= 80\ cm^3$.

$e = \frac{V_v}{V_s} = \frac{V - V_s}{V_s}$

$G_s = 2.8$. $e = ?$

$\gamma_d = \dfrac{W}{V} = \dfrac{120}{80} \times 9.81 = 14.715\ kN/m^3$.

$\gamma_d = \dfrac{G_s \times \gamma_w}{1+e}$.

$1+e = \dfrac{27.468}{14.715}$.

$\boxed{e = 0.86.}$

6.) Given:

$G_s = 2.7$ $e = 0.945$ $S_r = 1$. $\omega = ?$

$G_s\ \omega = e\ S_r$.

$\omega = \dfrac{0.945}{2.7}$.

$\boxed{\omega = 35\%.}$

7.) Embankment

Borrow Pit.

$e = 0.85.$

$V = 10^5 \ m^3.$

$e = 0.7.$

$$e = \frac{V_v}{V_s}$$

$$e = \frac{V - V_s}{V_s}.$$

$$0.7 = \frac{V}{V_s} - 1$$

$$\frac{V}{V_s} = 1.7.$$

$$V_s = \frac{10^5}{1.7}$$

$$V_s = 58823.52941 \ m^3.$$

$$e = \frac{V_v}{V_s}.$$

$$e \times V_s = V - V_s.$$

$$V = (0.85 \times 58.823 \times 10^3) + 58.823 \times 10^3.$$

$$\boxed{V = 108.82 \times 10^3 \ m^3.}$$

8.) Given:

$e = 0.45 \quad e_{max} = 0.9 \quad e_{min} = 0.4$

$$R.D = \frac{e_{max} - e}{e_{max} - e_{min}}.$$

$$= \frac{0.9 - 0.45}{0.9 - 0.4}.$$

$$\boxed{R.D = 90\%}$$

9.) Given:

$w = 400\%$. $S_r = 1$. $G_s = 2.1$.

$e = G_s \times w$.

$= 2.1 \times 4$.

$\boxed{e = 8.4}$

$\gamma_{sat} = \dfrac{G_s + e}{1+e} \times \gamma_w$.

$= \dfrac{(2.1 + 8.4)}{(1+8.4)} \times 9.81$

$\boxed{\gamma_{sat} = 10.96 \text{ kN/m}^3}$

1. A masonary dam is found on a pervious sand having $n = 45\%$. $G_s = 2.65$. Determine max. permissi upward gradient if F.O.S = 3.

Given:

$$e = \frac{n}{1-n} = \frac{0.45}{1-0.45} = 0.818$$

$$\text{Hydraulic gradient} = \frac{G_s - 1}{1+e}$$

$$= \frac{2.65-1}{1+e}$$

$$= 0.9075$$

$$\left.\begin{array}{l}\text{Permissible hydraulic} \\ \text{gradient}\end{array}\right\} = \frac{0.9075}{3}$$

$$= 0.3025$$

2. The soil is compacted in an embankment @ a $\rho_{bulk} = 2.15\ Mg/m^3$

$w = 12\%$ ; $G_{specific} = 2.65$.

Estimate: $g/cm^3$

(i) $\rho_{dry}$. (ii) $e$

(iii) Degree of saturation

(iv) Air content

(v) % of air void.

(vi) $\eta$.

(vii) $\gamma_{sub}$.

$= S_r$

$= w$

(i) $\gamma_d = \dfrac{G_s \cdot \gamma_w}{1+e}$

$= \dfrac{2.65 \times 1}{1+}$

$\gamma_{bulk} = \gamma_d (1+w)$

$= \gamma_d (1+0.12)$

$\therefore \gamma_d = \dfrac{2.15}{1.12}$

$\boxed{\gamma_d = 1.9196\ g/cm^3}$ $18.83\ kN/m^3$

$\gamma_d = \dfrac{G_s \gamma_w}{1+e}$

$1.9196 = \dfrac{2.65 \times 1}{1+e}$

$e = \left(\dfrac{2.65}{1.9196}\right) - 1$

$\boxed{e = 0.38}$

3.) Determine the quantity of earth to be borrowed to construct a road having Top width = 12m and h = 3m. side slope 1:1. soils

$\gamma_{bulk}$ = 17 kN/m³. (undisturbed soil).

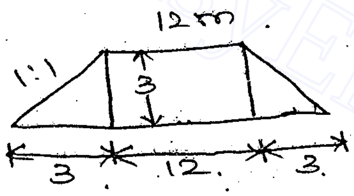
$\gamma_{bulk}$ = 16 kN/m³ (Re moulded soil);

$\omega$ = 10% (undisturbed soil)

$\omega$ = 15%. (re moulded soil)

Take Gs = 2.68. Also determine extra quantity of water to be added in the embankment. Consider unit length of road.

Embankment




$\gamma_{bulk}$ = 16 kN/m³.

$\omega$ = 15%.

Gs = 2.68

Borrow pit

$\gamma_{bulk}$ = 17 kN/m

$\omega$ = 10%.

Gs = 2.68.

$$\text{Volume} = \frac{h}{2}(a+b)\times l$$

$$= \frac{3}{2}(12+18)\times 1$$

$$= \frac{3\times \cancel{30}^{15}}{\cancel{2}}\times 1$$

$$V = 45\ m^3.$$

$$\gamma_{bulk} = \frac{W}{V}$$

$$W = 16\times 45$$

$$\boxed{W = 720\ kN}$$

W

1) The soil sample is coated with wax and total weight is 230 gm. The weight of wax is 30 gm. coated sample is immersed in water and volume of water displaced 150 cm³. The specific gravity of wax and soil solid are 0.78 and 2.65 respectively. Determine void ratio, $\eta$, $S_r$, $\eta_a$, $\gamma_d$, $\gamma_{bulk}$, $\gamma_{sat}$, additional volume of water to make the soil saturated.

Take $W_d$ of soil mass = 185 gm.

Given:

$W_{total} = 230$ gm. $W_{soil\ solids} = 200$ gm

$W_{wax} = 30$ gm. $V_{displace} = 150$ cm³

$W_w = 200 - 185 = 15$ gm.

$G_{wax} = 0.78$ $G_s = 2.65$. $W_d = 185$

$V_{wax} = 30x$.

$V_{displace} = V_{wax} + V_{soil\ mass}$.

$\rho_{wax} = 0.78 \times 1$

$= 0.78$ g/cm³.

$V_{wax} = \frac{W_{wax}}{\rho_{wax}} = \frac{30}{0.78} = 38.46$ cm³

$\boxed{V_{soil\ mass} = 111.54 \text{ cm}^3}$

$$\gamma_{bulk} = \frac{W}{V} = \frac{200}{111.54} = 1.79 \ g/cm^3$$
$$= 16.27 \ kN/m^3$$

$$\gamma_{bulk} = \gamma_d (1+w) \qquad \gamma_d = \frac{W_s}{V} = \frac{185}{111.54} = 1.66 \ g/cm^3$$

$$w = \frac{W_w}{W_s} = \frac{15 \times 100}{185} = 8.1\%$$

$$e = \frac{V_v}{V_s} \qquad \rho_{s} = 2.65$$

$$\rho_s = \frac{W_s}{V_s}$$
$$= V_d = \frac{185}{2.65} =$$

$$\gamma_d = \frac{G_s \gamma_w \cancel{(1+w)}}{1+e}$$

$$1.66 = \frac{2.65}{1+e} \times 1$$

$$1+e = 1.5963$$

$$\boxed{e = 0.596}$$

$$e = \frac{n}{1-n} \qquad n = \frac{e}{1+e}$$
$$n = 0.3735$$

$$G_s w = e S_r$$

$$S_r = \frac{G_s \times w}{e}$$
$$= \frac{2.65 \times 0.081}{0.5961}$$

$$\boxed{S_r = 0.36} \qquad a_c = 1 - S_r$$
$$= 0.64$$

$$n_a = a_c \times n$$
$$= 0.64 \times 0.3735$$
$$n = 0.239 \simeq 0.24$$

$$\gamma_{sat} = \frac{(G_s + e)}{1+e} \times \gamma_w$$

$$= \frac{(2.65 + 0.596)}{1+0.596} \times 9.81$$

$$\gamma_{sat} = 19.95 \text{ kN/m}^3$$

$$\eta_a = \frac{V_a}{V}$$

$$V_a = 111.54 \times 0.24$$

$$V_a = 26.7696 \text{ cm}^3$$

Extra volume of water to be added to make ~~the~~ soil mass fully saturated

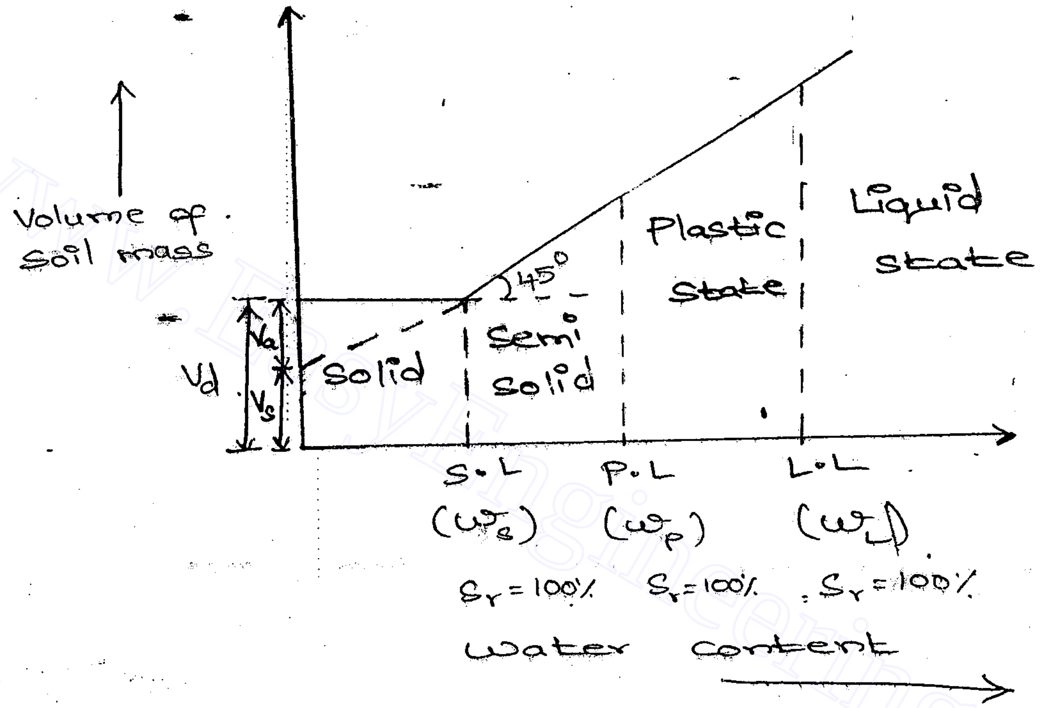
3/7/2015

# CONSISTENCY OF SOILS:

* The term consistency denotes the degree of firmness.
* The consistency of soil indicates the relative ease by which the soil mass can be deformed.
* The term consistency represent the state of soil. Such as
  * Liquid
  * very soft
  * Soft
  * stiff
  * Very stiff
  * Semi solid
  * solid.
* The term consistency mainly mean for fine grained soil. (<425µ
* The consistency is governed by the change of water content of soil
* The term consistency has been developed by Atterberg in 1911.
* consistency of soil is expressed in
  1. Atterberg's limit (L.L, P.L, S.L)
  2. Unconfined compressive strength of clay.

* The term plasticity of the soil represents the property of the soil due to which it can be deformed without rupture and without change in volume.

Atterberg's Graphical Representation of Consistency:




S.L < P.L < L.L (Ascending order)

L.L > P.L > S.L. (Descending order)

* Arbitrary limit of water content b/w two successive physical state of soil mass is called Atterberg limit.

# SOIL MECHANICS

## Liquid Limit (L.L (or) $W_L$):

* It is an arbitary limit between liquid and plastic state of fully saturated soil mass.

* It is the minimum water content of fully saturated soil mass on which the soil is in liquid state having very low shear strength. which is measurable.

* It is a minimum water content of fully saturated soil mass on which the soil can flow. for half an inch under 25 blows. (i.e. at which the standard groove is closed)

* The liquid limit is determined in the lab by casagrande apparatus.

* There are 2 standard grooves made in the soil sample.

| | Bottom width | Top width | Height |
|---|---|---|---|
| (a) Casagrande Groove | 2mm | 11mm | 8mm |
| (b) ASTM Groove | 2mm | 13.6mm | 10mm |

* Casagrande Liquid Limit Test:

Casagrande Liquid Limit Test :



* Fine grained soil in dry state passing through IS 425 μ sieze is taken into account.
* The dry mass is about 120 gm.
* A certain amount of water say 15 - 20% is added to the dry soil
* The soil paste is placed in a bras cup
* A standard groove is made in the soil paste.
* The brass cup is lifted (1 cm) and dropped on the rubber pad.
* The No. of. blows ($N_1$) is noted at which the groove is closed for the corresponding water content ($\omega_1$)
* The volume of the water content is changed and the test is repeated for various trials.

(a) $N_1$ , $\omega_1$

(b) $N_2$ , $\omega_2$

(c) $N_3$ , $\omega_3$.

(d) $N_4$ , $\omega_4$.

* A graph is plotted between. No. of. blows (log scale) on x-axis, and corresponding water content on y-axis.
* The plotted graph is known as Flow curve (straight line).

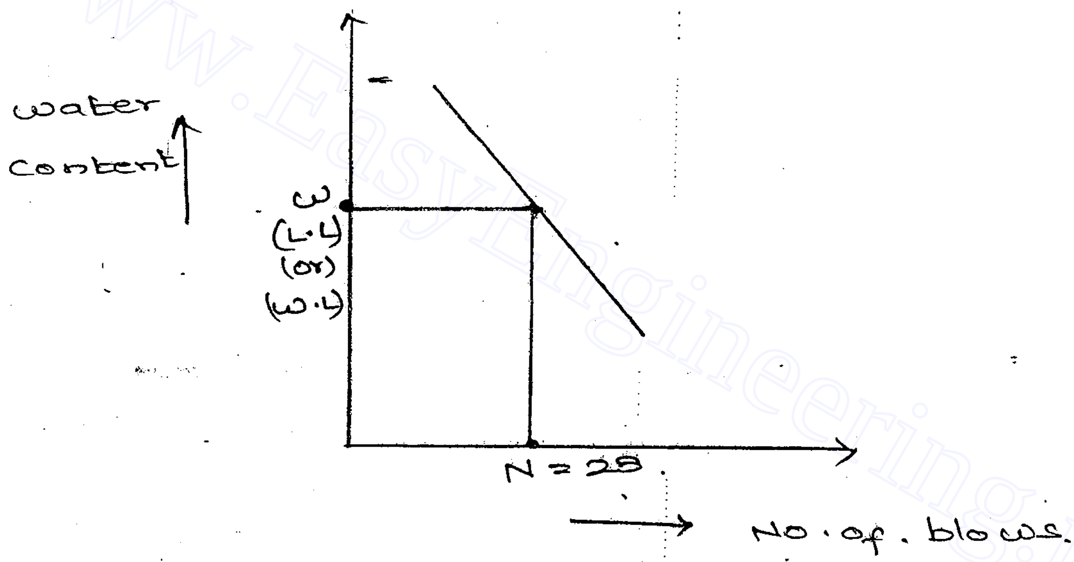
* The water content corresponding to 25 blows in the graph is called as liquid Limit.

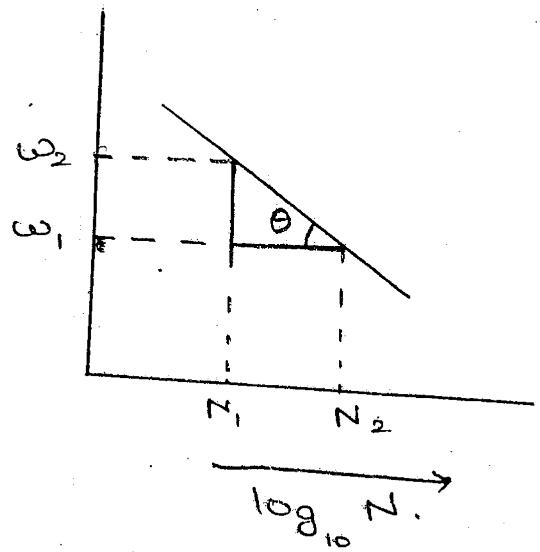
* The slope of the flow curve is known as Flow Index ($I_f$)

* Flow index is the measurement of shear strength of soil.

* If the flow index is high, shear strength is low.

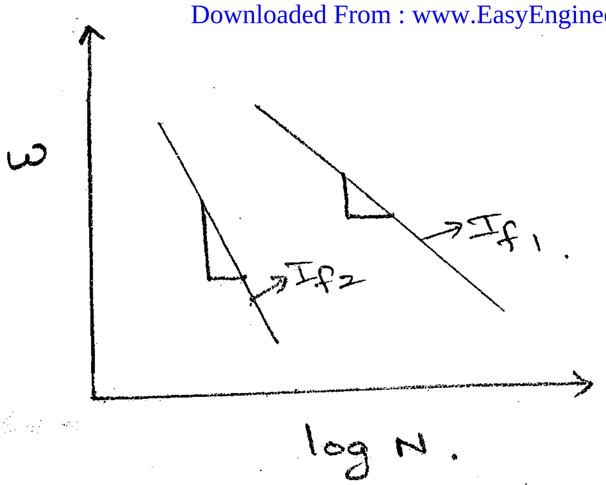
$$\text{shear strength} \propto \frac{1}{I_f}.$$




$$\tan\theta = \frac{\omega_2 - \omega_1}{\log N_2 - \log N_1}$$

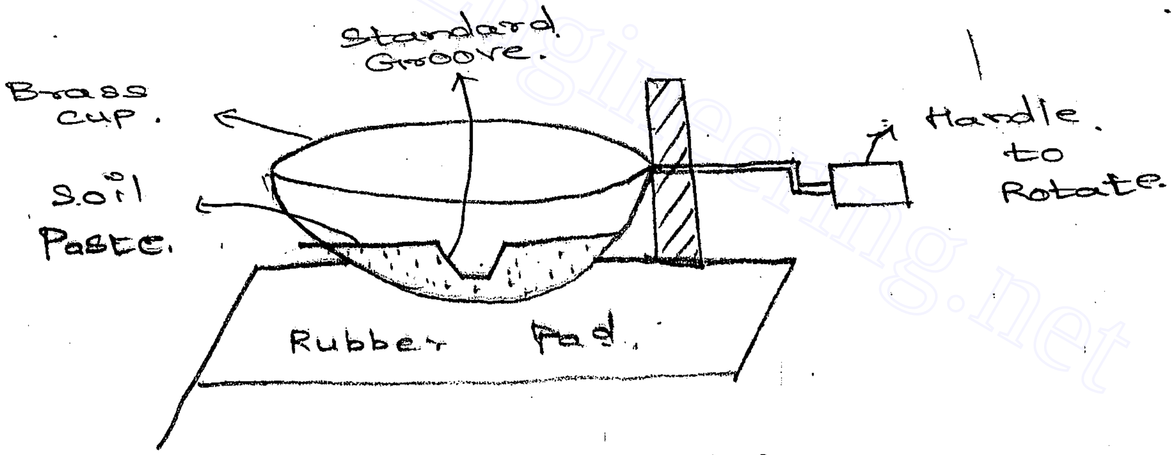
$$\boxed{I_f = \frac{\omega_2 - \omega_1}{\log(N_2/N_1)}}$$




$I_{f_2} > I_{f_1}$.

Shear strength 2 < Shear Strength 1

* There are 3 methods to determ L.L in lab.
  - (a) Casagrande liquid limit Test.
  - (b) one point method
  - (c) static cone penetrometer method.




PLASTIC LIMIT : (P.L (or) $w_p$)

* P.L is an arbitorty limit b/w plastic and semi-solid state.
* P.L is the water content fully saturated soil mass on whic a thread of 3 mm diameter of soil starts crumbling. while rolling into threac

SHRINKAGE LIMIT : (S.L (or) $W_s$)



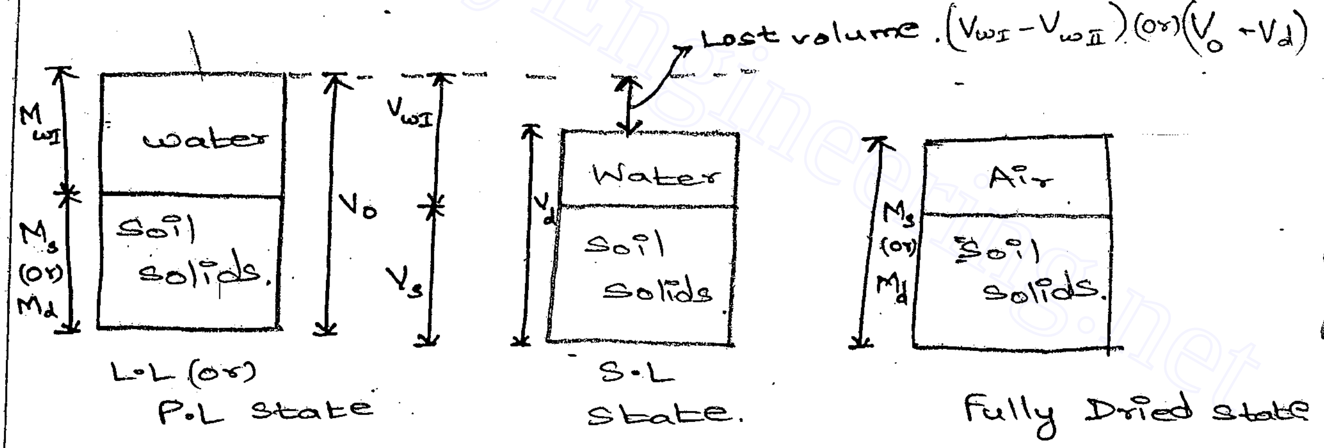


* It is an arbitary limit b/w semi-solid and soil state of the saturated soil mass.

* It is the lowest level of 100% saturation. (if water is less than S.L then the soil becomes is not in fully saturated condition ie, $S_r \neq 100\%$.)

* It is maximum water content of the saturated soil mass below which the volume of soil mass does not change, even though the degree of saturation is lowered.

* shrinkage limit is determined with the help of observational data




$$\rho_w = \frac{M_{water\ lost}}{V_{water\ lost}}$$

$$M_{water\ Lost} = \rho_w \times V_{water\ lost}$$

$$\boxed{M_{(water\ lost)} = \rho_w \times (V_o - V_d)}$$

Mass of water content in L.L (or) P.L

$$\boxed{M_{w_I} = M_o - M_d}$$

Mass of water in S.L:

$$M_{w_{II}} = M_{w_I} - M_{\text{water lost}}$$

$$= (M_o - M_d) - \rho_w (V_o - V_d)$$

$$\text{water content} = \frac{M_w}{M_s \text{(or)} M_d}$$

$$\text{Shrinkage Limit} = \frac{(M_o - M_d) - \rho_w (V_o - V_d)}{M_d}$$

$$= \frac{M_o - M_d}{M_d} - \frac{\rho_w (V_o - V_d)}{M_d}$$

$$\boxed{\text{Shrinkage Limit} = \text{L.L (or) P.L} - \frac{\rho_w (V_o - V_d)}{M_d}}$$

$V_o$ - Total volume of soil.

$V_d$ - Volum of soil solids.

$M_d$ - Mass of soil solids.

## Degree of shrinkage (D.S):

$$D.S = \frac{V_o - V_d}{V_o} \times 100\%$$

| | Degree of shrinkage | Quality of soil |
|---|---|---|
| 1.) | $< 5$ | Good. |
| 2.) | $5 - 10$. | Moderate. |
| 3.) | $10 - 15$. | Medium |
| 4.) | $> 15$. | Very poor (Black cotton). |

## Shrinkage Ratio (S.R):

$$S.R = \frac{\gamma_d}{\gamma_w} \text{ (or) } G_m.$$

$$S.R = \frac{\left(\frac{V_o - V_d}{V_d}\right)}{(L.L \text{ (or) } P.L) - S.L}$$

$$S.R = \frac{\frac{V_o - V_d}{V_d}}{(L.L \text{ or } P.L) - (L.L \text{ or } P.L) + \frac{\rho_w (V_o - V_d)}{M_d}}$$

$$= \frac{V_o - V_d}{V_d} \times \frac{M_d}{\rho_w (V_o - V_d)}$$

$$= \left(\frac{M_d}{V_d}\right) / \rho_w.$$

$$= \rho_d / \rho_w.$$

## Indices:

### (i) Plasticity Index ($I_p$)

$$I_p = L.L - P.L$$

(or)

$$I_p = w_L - w_P.$$

| $I_p$ | Degree of plasticity. |
|---|---|
| $-ve$ | Non plastic. |
| $< 7\%$ | Low plastic. |
| $7 - 17\%$ | Medium plastic. |
| $> 17\%$ | Highly plastic. |

Thixotrophy:

It is defined as the property of soil due to which it regains the part of the original strength while reorienting its grain in presence of adsorbed water without change of water content in disturbed (remoulded) condition.

* It plays an important role during pile driving.

4/8/2015

5

# SOIL MECHANICS

## Sensitivity:

It is the ratio of unconfined compressive strength of clay in the undisturbed condition to the unconfined compressive strength of clay in remoulded condition.

Unconfined compressive strength of clay is the ultimate load on soil per unit c/s area without any lateral support.

$$\boxed{S_t = \frac{q_u\,(\text{undisturbed})}{q_u\,(\text{disturbed})}}$$

| $S_t$ | Nature |
|---|---|
| 1 – 4 | Normal |
| 4 – 8 | Medium sensitive. |
| 8 – 16 | Extra sensitive |
| >16 | Quick condition. |

Stroke's

## Storke's Law: (wet Mechanical Analysis)

$V_s = \frac{gD^2(G_s-1)}{18\nu}$ $\quad \nu = \frac{\mu}{\rho}$

$= \frac{gD^2(G_s-1)}{18\,\mu/\rho}$

$= \frac{\rho g D^2 (G_s-1)}{18\mu}$

$\therefore V_s = \frac{\gamma D^2 (G_s-1)}{18\mu}$

* In India, the smallest sieve size is 75 μm.
* If the size of soil particle is less than 75 μm than sieve analysis is not possible.
* In such case stroke's law is adopted.
* According to Mr. G.G. stroke the soil particles are of spherical shape, equal specific gravity and have independent velocities.
* According to him the constant velocity of falling soil grain in infinite depth of liquid is known as terminal velocit (settling velocity)

According to stroke's Law,

$V_s \propto D^2$ ; $V_s \propto (\gamma_s - \gamma_w)$ ; $V_s \propto \frac{1}{\mu}$

$$V_s \propto \frac{D^2(\gamma_s-\gamma_w)}{\mu}$$

$$V_s = \frac{1}{18}\,\frac{D^2(\gamma_s-\gamma_w)}{\mu}$$

$G_s = \frac{\gamma_s}{\gamma_w}$

$$V_s = \frac{1}{18}\,\frac{D^2(G_s\gamma_w-\gamma_w)}{\mu}$$

$$\boxed{V_s = \frac{1}{18}\,\frac{D^2\gamma_w(G_s-1)}{\mu}}$$

$\gamma_w = \rho_w \times g$

$$= \frac{1}{18}\,\frac{D^2\rho_w g(G_s-1)}{\mu}$$

$$\boxed{V_s = \frac{1}{18}\,\frac{D^2 g(G_s-1)}{\nu}}$$

$$\boxed{\nu = \frac{\mu}{\rho}}$$

D - Dia of spherical particle (m (or) mm)

g - acceleration due to gravity. ($m/s^2$)

$G_s$ - Specific gravity of soil solids

$\mu$ - Dynamic viscosity. (Pa.s (or) $\frac{Ns}{m^2}$ (or) Poise)

$\nu$ - kinematic viscosity. ($\frac{m^2}{s}$ (or) $\frac{cm^2}{s}$ (or) stoke)

Toughness Index:

$$I_t = \frac{I_p}{I_f} = \frac{L.L - P.L}{\frac{(\omega_1 - \omega_2)}{\log(N_2/N_1)}}$$

$I_t \to 0-3$ (clay soil)

$I_t < 1$ (soil particle can be crushed @ P.L)

1. Determine S.L with the help of following data:

(i) Mass of shrinkage dish $M_d$ = 10 gm.

(ii) Combined Mass of soil sample and dish = 40 gm

(iii) Combined Mass of dry soil and dish } = 32 gm.

(iv) Volume of the dish $V_0$ = 18 cm³

(v) Volume of dry soil $V_d$ = 15 cm³.

$$S.L = (L.L \text{ or } P.L) - \frac{\rho_w (V_0 - V_d)}{M_d}$$

$$= \frac{M_0 - M_d}{M_d} - \frac{\rho_w (V_0 - V_d)}{M_d}$$

$$= \left(\frac{30 - 22}{22}\right) - \frac{1(18 - 15)}{22}$$

$$\boxed{S.L = 0.227} \qquad \boxed{S.L = 22.72}$$

2.) Determine the time required to settle a particle having size ~~d~~ = 0.01mm for a depth H = 1m of water Take $G_s = 2.65$ and $\mu = 0.1$ Poise.

$$V_s = \frac{D^2 (G_s - 1)\gamma_w}{18 \cdot \mu}$$

$$\frac{H}{\text{time}} = \frac{(0.01 \times 10^{-3})^2 (2.65-1) \times 9.81 \times 1[illegible]}{18 \times 0.01}$$

$$\frac{H}{\text{time}} = 8.9925 \times 10^{-6} \text{ m/s}$$

~~time = 0.1112 s.~~

~~time = 4.287 × 10^-6 hr.~~

$$\text{time} = \frac{1}{8.9925 \times 10^{-6}}$$

$$= 111203.7809$$

$$\boxed{\text{time} = 30.89 \text{ hr.}}$$

3.) Determine activity number if L.L = 50%

P.L = 30 %  % finer less than $2\mu$ is 50%

$$A_c = \frac{L.L - P.L}{\%\ \text{of less than } 2\mu}$$

$$= \frac{50 - 30}{50}$$

$A_c = 0.4$   (Inactive)

4.) Determine ~~consistency~~ $I_p$ of soil if L.L = 60%

P.L = 35%.

$I_p = 60 - 35$

$\boxed{I_p = 25\%.}$   Highly plastic

5.) Determine toughness index $(I_t)$ if L.L = 60%

P.L = 40%.  $N_1 = 20 \rightarrow \omega_1 = 65\%$.

$N_2 = 30 \rightarrow \omega_2 = 58\%$.

$$I_t = \frac{(20/100)}{\frac{(\omega_2 - \omega_1)}{\log\left(\frac{30}{20}\right)}} = \frac{(20/100)}{\frac{-(65 - 58)}{\log\left(\frac{30}{20}\right)}}$$

$$\boxed{I_t = 0.5031.}$$

Comes under clay and it is crushable at P.L.

(iii) Consistency Index: $(I_c)$:



$$\boxed{I_c = 1 - I_L}$$

$$I_c = 1 - \frac{(\omega_n - P.L)}{L.L - P.L}$$

$$= \frac{L.L - P.\cancel{L} - \omega_n + \cancel{P.L}}{L.L - P.L}$$

$$I_c = \frac{L.L - \omega_n}{L.L - P.L} = \frac{L.L - \omega_n}{I_p}.$$

| $I_c$ | solid ~~state~~. |
|---|---|
| $-ve$ | Liquid state. |
| 0 | very stiff. |
| 1 | stiff |
| >1 | semi solid (or) solid state. |

(iv) Activity Number:

According to Mr. skempton the behaviour of soil regarding swelling and shrinkage is dependent of $I_p$ and and quantity of colloidal particle. (i.e. < 2 μm)

$$A_c = \frac{I_p}{\% \text{ finer than } 2\mu.}$$

| $A_c$ | Nature of Soil. |
|---|---|
| < 0.75. | Inactive |
| 0.75 – 1.25 | Normal |
| ≥ 1.25. | Active. |

(ii) Liquidity Index ($I_L$):

$$I_L = \frac{w_n - w_p}{I_p} = \frac{w_n - w_p}{L.L - P.L}$$

case (i): $w_n > L.L$

$$= \frac{>L.L - P.L}{L.L - P.L}$$

$I_L > 1$ (Liquid state)

case (ii) $w_n = L.L.$

$$I_L = \frac{L.L - P.L}{L.L - P.L.}$$

$I_L = 1.$ (very soft)

case (iii) $w_n = P.L.$

$$I_L = \frac{P.L - P.L}{L.L - P.L} = 0.$$

$I_L = 0$ (soil in stiff condition)

case (iv): $w_n < P.L.$

$$I_L = \frac{<P.L - P.L}{L.L - P.L.}$$

$I_L = -ve$ (semi solid (or) solid)

$G_s \times w = S_r \cdot e$.

$2.65 \times 0.12 = S_r \cdot (0.38)$

$S_r = 0.8368$

$\boxed{S_r = 83.68\%}$

$a_c = 1 - S_r$.

$= 1 - 0.8368$

$\boxed{a_c = 0.163}$

$\eta_a = a_c \times n$.

$= 0.163 \times 0.2753$

$\boxed{\eta_a = 4.49\%}$

$n = \frac{e}{1+e} = \left(\frac{0.38}{1+0.38}\right) = 0.2753$.

$\boxed{n = 0.2753}$

$\gamma_{sub} = \frac{(G_s - 1)\gamma_w}{1+e}$.

$= \frac{(2.65 - 1) \times 9.81}{1 + 0.38}$.

$\boxed{\gamma_{sub} = \gamma_{sub} = 11.73 \text{ kN/m}^3}$.

Consistency:





| $I_c$ | $I_L$ | Consistency. |
|---|---|---|
| >1 | <0 | very stiff (solid) |
| 1–0.75 | 0–0.25 | stiff |
| 0.75–0.5 | 0.25–0.5 | Medium soft |
| 0.5–0.25 | 0.5–0.75 | soft |
| 0.25–0 | 0.75–1 | very soft |
| <0 | >1 | Liquid state. |

Note:

* As the particle size decreases liquid limit, plastic limit and plasticity Index increases.
* If silt is added to clay both L.L and P.L decreases. $I_p$ also decreases.

Shrinkage Index:

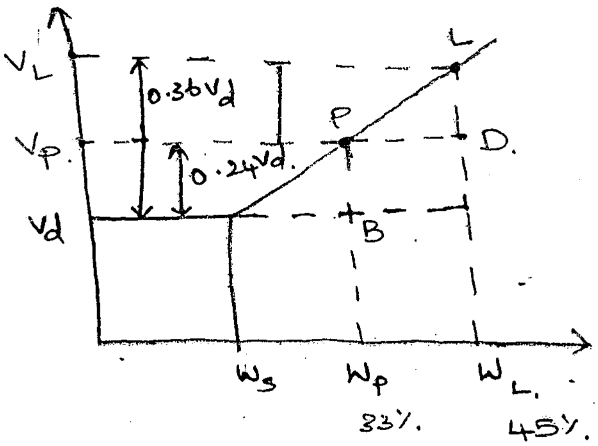
$$\boxed{S.I = P.L - S.L}$$

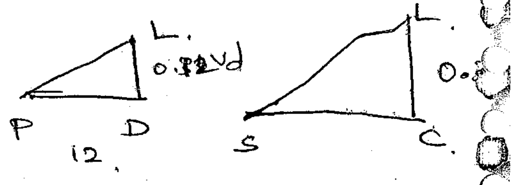
1\. The P.L = 33% and L.L = 45%. The ~~percentage~~ volume change L.L to Dry state is 36% of dry volume. similarly the % volume change from P.L to dry state is 24% of dry volume.

(a) S.L — a) 12% (b) 17% (c) 28% (d) 9%

(b) S.R (shrinkage Ratio) (a) 1.3 (b) 1.2 (c) 1.1 (d) 1

$$S.R = \frac{\left(\frac{V_0 - V_d}{V_d}\right)}{\underset{\text{or } P}{L.L} - S.L} = \frac{0.36}{0.45 - 0.09} = \frac{0.36}{0.36} = 1$$




By 111$^{rl}$ triangle property

$$\frac{LD}{LC} = \frac{PD}{SC}$$

$$SC = \frac{PD}{LD} \times LC$$

$$= \frac{12}{0.12V_d} \times 0.36V_d$$

$$S_c = 36\%$$

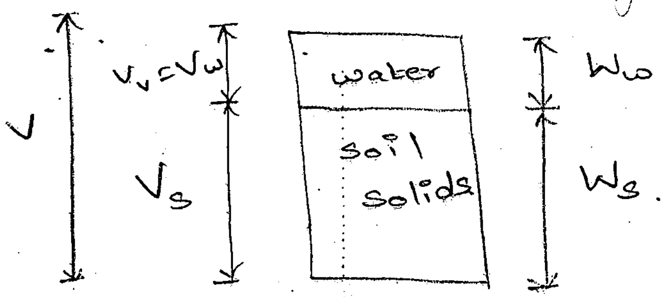
$$S.L = 45 - 36 = 9\%$$

$$S.R = \frac{\left(\frac{V_o - V_d}{V_d}\right)}{L.L - S.L} = \frac{\left(\frac{0.36V_d}{V_d}\right)}{\left(\frac{45 - 9}{100}\right)}$$

$$\boxed{S.R = 1}$$

## Shrinkage Limit:

Shrinkage limit can be determined as follows.




S.L = water content

$$w = \frac{W_w}{W_s}.$$

$$S.L = \frac{W_w}{W_s}.$$

$$S.L = \frac{\gamma_w \times V_w}{W_s}.$$

$$= \frac{\gamma_w \times (V - V_s)}{W_s}.$$

$$= \gamma_w \left[ \frac{1}{(W_s/V)} - \frac{1}{W_s/V_s} \right]$$

$$= \frac{\gamma_w}{\gamma_d} - \frac{\gamma_w}{\gamma_s}.$$

$$\boxed{S.L = \left[ \frac{1}{G_m} - \frac{1}{G_s} \right]}$$

$$S.L = \frac{1}{(\gamma_d/\gamma_w)} - \frac{1}{G_s}.$$

$$= \frac{\gamma_w}{\gamma_d} - \frac{1}{G_s}.$$

$$= \frac{\gamma_w}{\frac{G_s \gamma_w}{1+e}} - \frac{1}{G_s}.$$

$$= \frac{1+e}{G_s} - \frac{1}{G_s}.$$

$$\boxed{S.L = \frac{e}{G_s}.}$$

$G_s w = S_r e$

2.) $G_m = 1.88$ full saturated specimen of clay



having $w = 40\%$. on oven drying.

$G_m = 1.74$.

(a) $G_{clay}$ (a) 1.95 (b) 2.67 (c) 2.9 (d) None of the above

(b) S.L (shrinkage Limit):

(c) S.R (Shrinkage Ratio):

Solution:

(a) $G_s w = eS_r$.

$G_s \times 0.4 = e \times 1$

$e = 0.4 G_s$.

$$G_m = \frac{\gamma_{sat}}{\gamma_w} = \frac{\left(\frac{G_s+e}{1+e}\right)\gamma_w}{\gamma_w}.$$

$$1.88 = \frac{G_s + 0.4G_s}{1+0.4G_s}.$$

$1.88(1+0.4G_s) = 1.4G_s$.

$1.88 = 0.648 G_s$.

$\boxed{G_s = 2.9}$

(b) $S.L = \frac{1}{G_m} - \frac{1}{G_s} = \frac{1}{1.74} - \frac{1}{2.9}$.

$S.L = 0.2298$.

$S.L = 22.98\%$

(c) $S.R = G_m = \frac{\gamma_d}{\gamma_w} = 1.74$.

## Grain Size Distribution:





* According to Mr. Hazen the degree of soil regarding its compactness and mixture like poorly graded or well graded can be determined using uniformity co-efficient (Cu).

* According to him the grain size distribution curve can be plotted and then uniformity co-efficient and co-efficient of curvature (Cc) can be determined

Steps:

1. A no. of standard sieves are arranged in descending order (coarser to finer) from top to bottom. (50mm @ top. 75 μm @ bottom)

2. Above 500gm of soil in dry condition is placed on the topmost sieve

3. Sieves are shaken. and then the quantity (M) of soil retained on each sieve are determined.

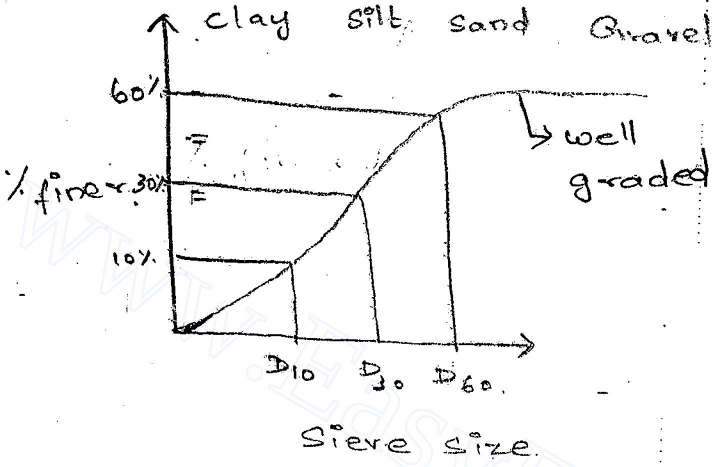
4. The percentage retained on each sieve is determined individually. $(M/\Sigma M)$

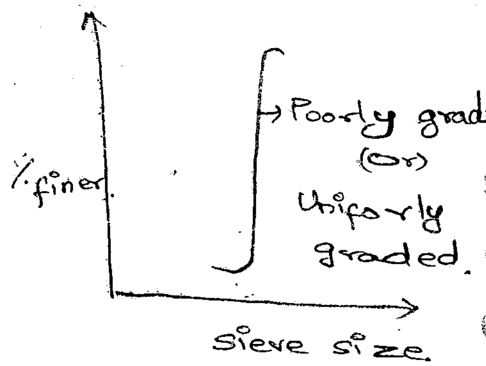
5. The cummulative percentage retained on each sieve is determined which nothing but the sum of % retained on each sieve (coarser will be retained)

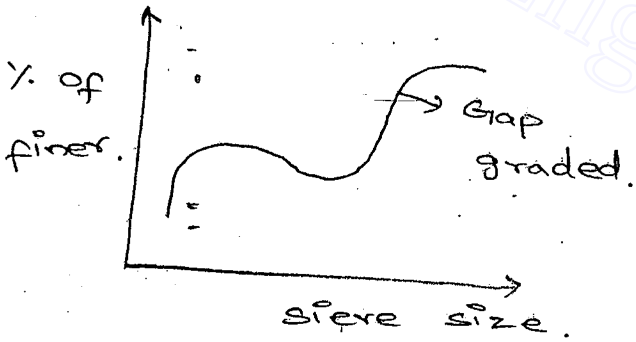
6. The percentage of finer passing through each sieve is calculated.

% finer = 100 − cummulative % retained on a particular sieve.

7.) A graph is plotted in b/w % finer and sieve corresponding sieve size as shown in figure below.




Uniformity co-efficient $(C_u) = \dfrac{D_{60}}{D_{10}}$.

$C_u > 4$ well graded gravel.

$C_u > 6$ well graded sand.

Co-efficient of Curvature $(C_c) = \dfrac{D_{30}^2}{D_{60} \times D_{10}}$.

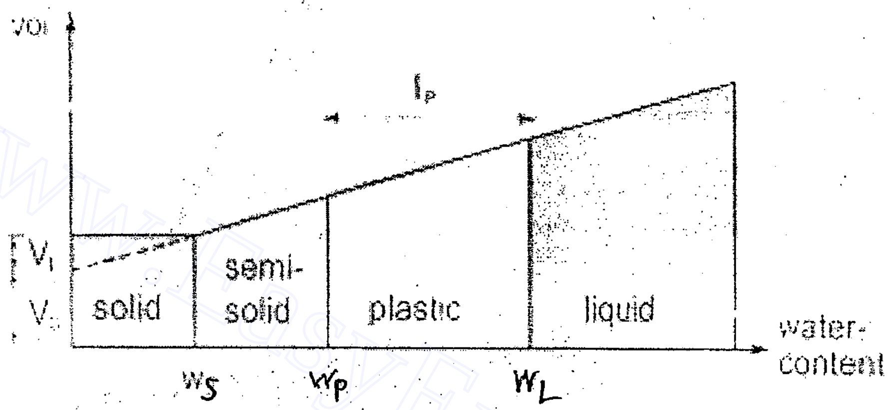
$C_c \rightarrow 1$ to 3 (soil is well graded)

## CONSISTENCY OF SOIL :

✓ The term consistency denotes the degree of firmness.

✓ It represents the different physical states such as

- Liquid state
- Very soft
- Soft
- Stiff
- Very stiff
- Semi solid or solid




✓ The term consistency is mainly meant for fine grained soils (less than 425 micron)

✓ It has been developed by Mr. Atterberg in 1911.

✓ Consistency of soil is expressed in

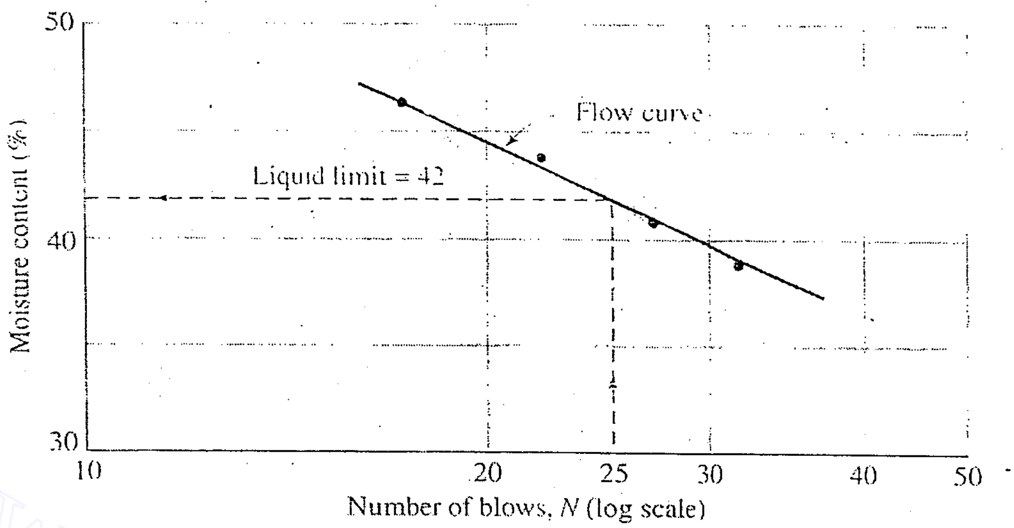
- Atterberg Limit
- Unconfined compressive strength of clay

✓ Atterberg limits :

- Liquid limit (LL)
- Plastic Limit (PL)
- Shrinkage Limit (SL)

## LIQUID LIMIT :

- It is the min. water content of fully saturated soil mass on which the soil is in liquid state having very low shear strength which is measurable.




| | BOTTOM WIDTH | TOP WIDTH | DEPTH |
|---|---|---|---|
| CASAGRANDE GROOVE | 2mm | 11mm | 8mm |
| ASTM GROOVE | 2mm | 13.6mm | 10mm |

✓ There are three methods to determine LL in the lab :

- Casagrande L.L method
- One point Method
- Static cone penetrometer method (IS 2720 – 1970)

## CASAGRANDE METHOD PROCEDURE :

- Fine grained solid (dry state) passing through IS 425 micron sieve is taken into account
- The dry mass is about 120 gm
- A certain amount of water (say about 10 to 15 ) is added to dry soil

- The casagrande cup is lifted (1cm) and dropped on the rubber pad
- The number of blows is counted till the groove is closed ($N_1$)
- The water content of the soil mass is determined accurately (Say $w_1$)
- The volume of the water content is changed and the test is repeated
- A number of test results are obtained.
- A graph is plotted in between number of blow (log scale) on x axis and corresponding water content on y axis (ordinate)
- The graph such plotted is known as Flow curve (st. line)
- The water content corresponding to 25 blows on the flow curve is known as liquid limit (LL)
- The slope of the flow curve is known as flow index ($I_f$)
- Flow index is measured by shear strength of soil
- If flow index is higher, shear strength will be lesser

✓ In one point method, only one trial is conducted using casagrande apparatus and then by mathematical relations.

- Liquid limit (LL) = w $\left[\frac{N}{25}\right]^{0.1}$
- $W_l = w_l \left[\frac{N1}{25}\right]^{0.1}$

✓ In static cone penetrometer method, the water content corresponding to 25mm penetration of cone is called liquid limit.

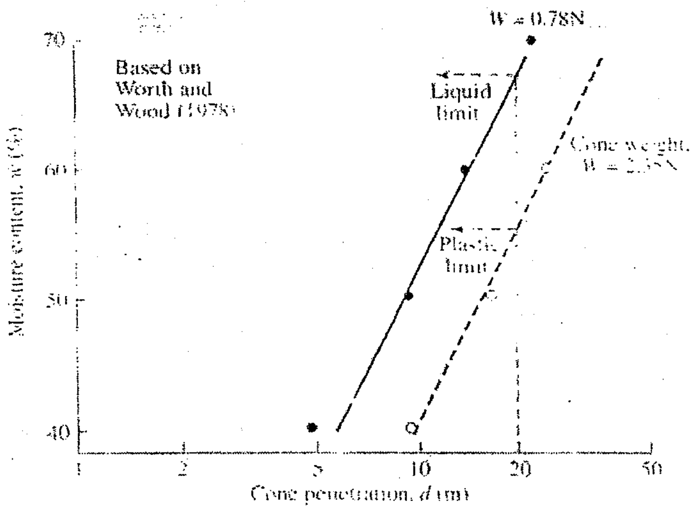
- Liquid limit (LL) = w $\left[\frac{N}{25}\right]^{0.1}$

## PLASTIC LIMIT :

- It is the water content of fully saturated soil mass on which a thread of 3mm diameter of soil starts crumbling while rolling in to thread.

➢ The size of the soil grain is less than 425 micron

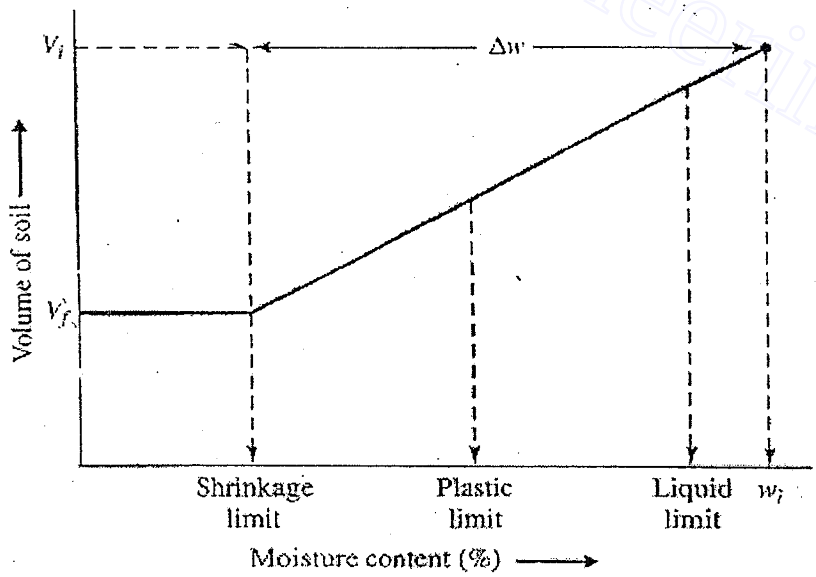



**SHRINKAGE LIMIT :**

➢ It is an arbitrary limit between semi solid and solid state of the saturated soil mass.

➢ It is the lowest level of full saturation.

➢ It is the max. water content of the saturated soil mass below which the volume of soil mass does not change even though water content of saturation is lowered.



## FORMULAS :

$V_O \rightarrow$ Intial volume of soil mass

$V_d \rightarrow$ ~~Final~~ volume of soil mass Dried

1. DEGREE OF SHRINKAGE :

$$D.S = \frac{V_O - V_d}{V_O} \times 100\%$$

| D.S | Quality of Soil |
|---|---|
| < 5 | Good |
| 5 – 10 | Moderate |
| 10 – 15 | Poor |
| > 15 | V. poor |

2. SHRINKAGE RATIO :

$$S.R = \frac{\frac{V_O - V_d}{V_O}}{(L.L\ (or)\ P.L) - S.L}$$

3. PLASTIC INDEX :

$$I_P = L.L - P.L$$

| $I_P$ | Degree of Plasticity |
|---|---|
| -ve | Non plastic |
| < 7 | Low plastic |
| 7 to 17 | Medium plastic |
| > 17 | Highly plastic |

4. LIQUIDITY INDEX :

$$I_L = \frac{w_n - W_P}{w_L - W_P} \times 100\%$$

5. CONSISTENCY INDEX :

$$I_C = \frac{w_L - W_n}{I_P}$$

| $I_C$ | $I_L$ | Consistency |
|---|---|---|
| > 1 | 0 | V. stiff |
| 1 – 0.75 | 0 – 0.25 | Stiff |
| 0.75 - 0.5 | 0.25 – 0.5 | Medium soft |
| 0.5 – 0.25 | 0.5 – 0.75 | Soft |
| 0.25 – 0 | 0.75 - 1 | Very soft |
| < 0 | > 1 | Liquid state |

6. TOUGNESS INDEX :

$$I_T = \frac{I_P}{I_f}$$

| $I_T$ | Soil type |
|---|---|
| 0 – 3 | For general soil |
| < 0 | Crushable / fryable soil at plastic limit |

7. ACTIVITY NUMBER :

$$A_C = \frac{I_P}{\%\,Finer\ than\ 2\ micron}$$

| $I_P$ | Nature of soil |
|---|---|
| < 0.75 | Inactive |
| 0.75 – 1.25 | Normal |
| > 1.25 | Active |

## TOTAL STRESS, PORE WATER PRESSURE AND EFFECTIVE STRESS

**1) Total Stress :**

Total stress (σ) = Total load per unit area.

Total stress is due to

(a) Self weight of soil and

(b) Over burden on the soil

$$\sigma = \frac{Total\ load}{area}$$

$$= \frac{\gamma\ x\ volume}{area} + q$$

$\sigma = \gamma h + q$

where q is the surcharge load.

If there is no surcharge, then

$\sigma = \gamma h$

Unit : kPa ($kN/m^2$)

Dimension : $ML^{-1}T^{-2}$

**2) Neutral pressure (or) pore pressure (u) :**

(a) The pressure transmitted through the pore fluid

(b) $u = h_w \times \gamma_w$ (i.e) u = Pressure head x unit weight of water

**3) Effective stress (σ') :**

(a) It is equal to the total vertical reaction force transmitted at the points of contact of soil grains divided by the total area, including that occupied by water.

(b) In other words, it is the pressure transmitted from particle to particle through their points of contact through soil mass.

(c) It is also called 'Inter granular pressure'

Significance : The decrease in void ratio and mobilization of shear strength of soil depend on effective stress only.

**4) Relationship among (σ , σ' and u) :**

$\sigma' = \sigma - u$

effective stress = total stress – neutral stress

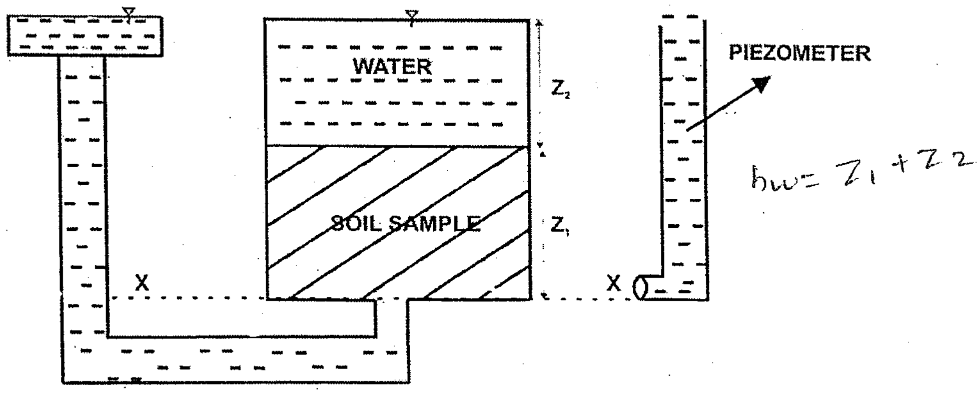
5) The ~~difference~~ eff pressure increases due to downward seepage flow (Flow from top to bottom) and the increase in effective pressure is equal to $iz\,\gamma_w$

6) The effective pressure reduces or decreases due to upward seepage flow (Flow from bottom to top) and reduction in effective pressure is $iz\,\gamma_w$

$$i_{cr} = \frac{\Delta H}{L_{seepage}\ (z)}$$

## EFFECT OF SEEPAGE IN EFFECTIVE STRESS :

### 1) IF NO SEEPAGE :




Effective Stress at section XX

$\sigma'_{XX} = \gamma_1 Z_1 + \gamma_2 Z_2 - \gamma_w h_w$

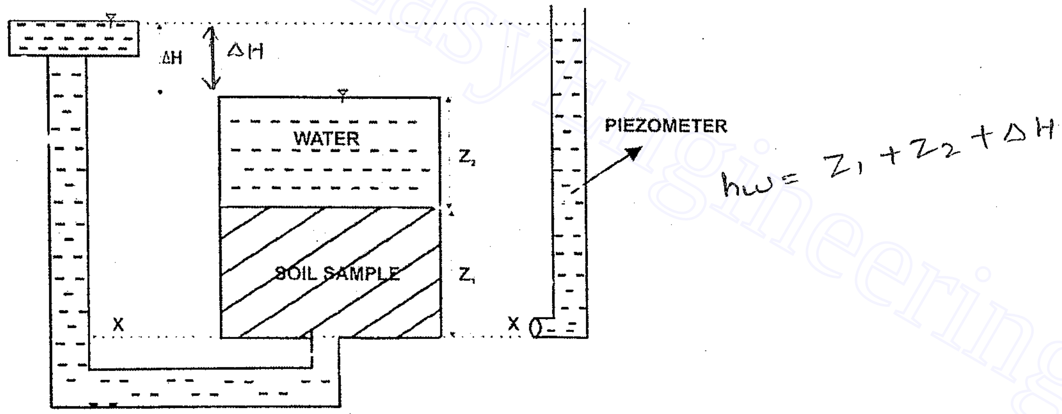
$\sigma'_{XX} = \gamma_{sat} Z_1 + \gamma_w Z_2 - \gamma_w (Z_1 + Z_2)$

$= \gamma_{sat} Z_1 - \gamma_w Z_1$

$= (\gamma_{sat} - \gamma_w) Z_1$

$\sigma'_{XX} = \gamma_{sub} Z_1$

### 2) IF THERE IS UPWARD SEEPAGE :




Effective Stress at section XX

$\sigma'_{XX} = \gamma_1 Z_1 + \gamma_2 Z_2 - \gamma_w h_w$

$\sigma'_{XX} = \gamma_1 Z_1 + \gamma_2 Z_2 - \gamma_w (Z_1 + Z_2 + \Delta H)$

$\sigma'_{XX} = \gamma_{sat} Z_1 + \gamma_w Z_2 - \gamma_w (Z_1 + Z_2 + \Delta H)$

$= (\gamma_{sub} Z_1) - \gamma_w \Delta H$

*where* $\gamma_w \Delta H$ can be rewritten as, $\gamma_w \frac{\Delta H}{Z_1} \times Z_1$

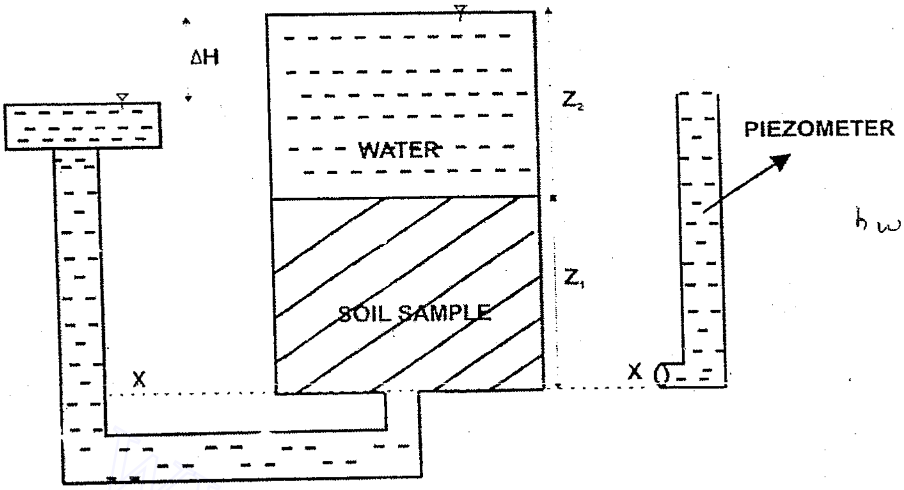
Which can be written as, $\gamma_w \times i \times Z_1$

Where, i is the hydraulic gradient and $Z_1$ is the length of the seepage.

Then, $\sigma'_{xx} = (\gamma_{sub} Z_1) - \gamma_w \times i \times Z_1$

Note : If there is upward seepage, then there is a chance for sand boiling when the upward seepage force is equal to the downward weight of the soil.

### 3) IF THERE IS DOWNWARD SEEPAGE :




$h_w = Z_1 + Z_2 - \Delta H$

Effective Stress at section XX

$\sigma'_{XX} = \gamma_1 Z_1 + \gamma_2 Z_2 - \gamma_w h_w$

$\sigma'_{XX} = \gamma_{sat} Z_1 + \gamma_w Z_2 - \gamma_w (Z_1 + Z_2 - \Delta H)$

$\sigma'_{XX} = \gamma_{sat} Z_1 + \gamma_w Z_2 - \gamma_w (Z_1 + Z_2 - \Delta H)$

$= \gamma_{sub} Z_1 + \gamma_w Z_1$

$= (\gamma_{sub} Z_1) + \gamma_w \Delta H$

*where* $\gamma_w \Delta H$ can be rewritten as, $\gamma_w \frac{\Delta H}{Z_1} x\ Z_1$

Which can be written as, $\gamma_w\, x\, i\ x\ Z_1$

Where, i is the hydraulic gradient and $Z_1$ is the length of the seepage.

Then, $\sigma'_{xx} = (\gamma_{sub} Z_1) + \gamma_w\, x\, i\ x\ Z_1$

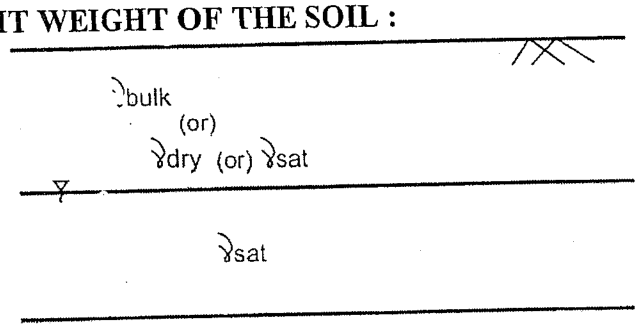
Note : If there is seepage flow then it will affect the effective stress.

$\sigma = (\gamma_{sub} Z_1) \pm \gamma_w\, x\, i\ x\ Z_1$

" – " upward Seepage

" + " Downward Seepage

### UNIT WEIGHT OF THE SOIL :

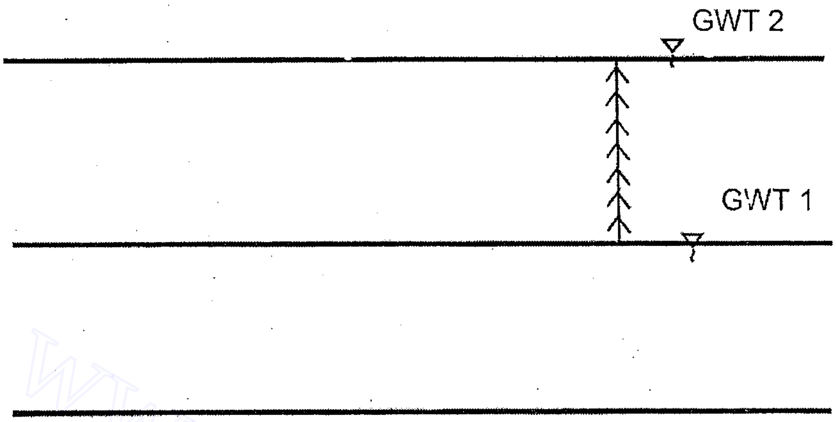



If there is capillary rise, then soil above W.T will be γsat.

- Soil above G.W.T will be in bulk state or dry state
- If the soil above G.W.T is in fully saturated condition (Due to capillary rise) the soil is considered to be fully saturated.
- Soil below G.W.T will be always in saturated condition.

## EFFECT OF WATER TABLE IN EFFECTIVE STRESS CALCULATION :

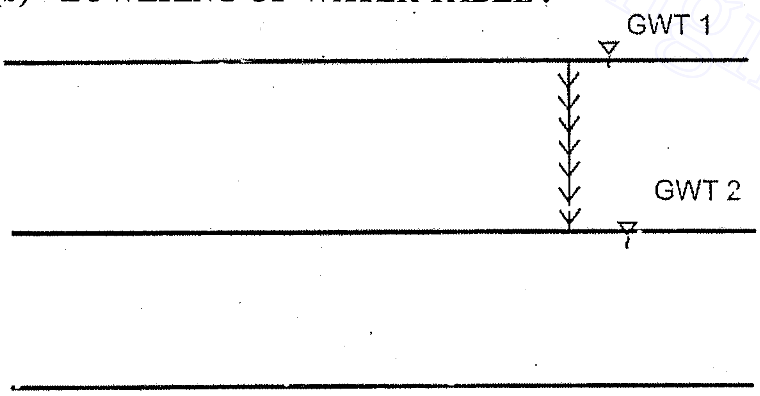
### (a) RISE OF WATER TABLE :




- Due to the rise of water table, the soil above the G.W.T ~~also~~ will become ~~fully saturated~~ Sub-merged soil.
- As $\gamma_{sat} > \gamma_{dry}$ or $\gamma_{bulk}$ effective stress ~~increases~~ decreases.

$\gamma_{sat} > \gamma_{bulk} > \gamma_{dry} > \gamma_{sub}$.

### (b) LOWERING OF WATER TABLE :



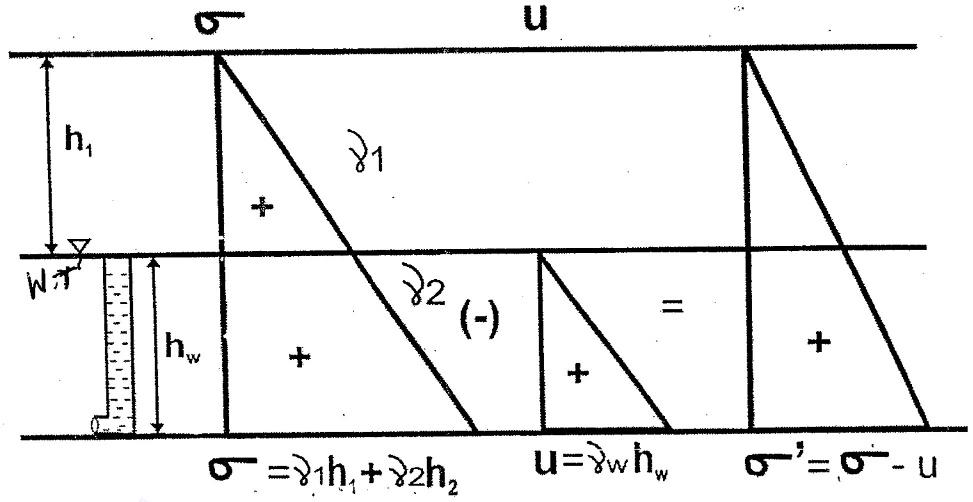

- Effective stress ~~decreases~~ Increases.



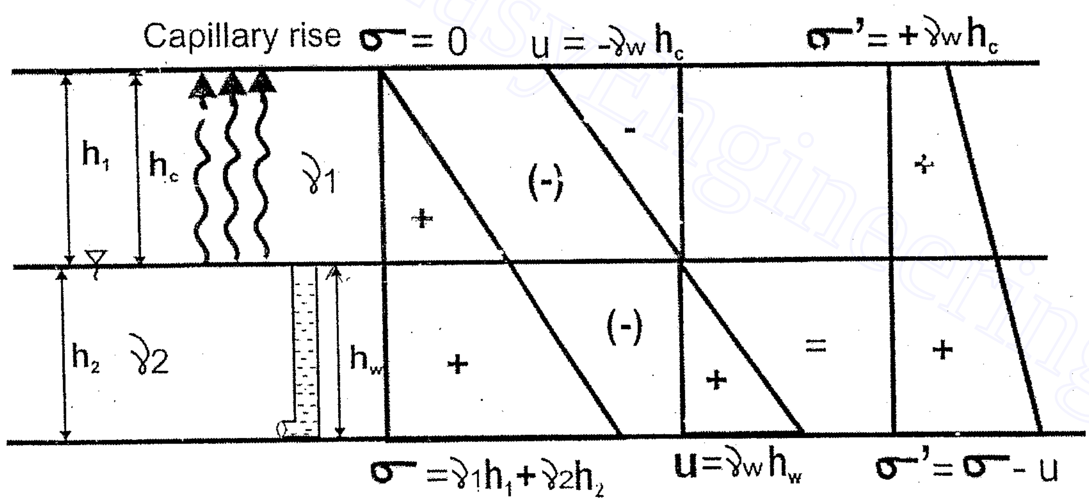
$\sigma'$ will be zero at the interface of clay & sand.

**STRESS DIAGRAM :**

**(a) WITHOUT CAPILLARY RISE :**




**(b) WITH CAPILLARY RISE :**




Note : Pore water pressure is positive below ground water table and negative above ground water table due to capillary rise.

Fluid Mechanics:





## PRESSURE MEASUREMENT:

1) The Pressure or pressure intensity is the force exerted per unit area. Its symbol is (p).

$$p = \frac{F}{A} = \frac{W}{A} = \frac{\gamma \, x \, V}{A} = \frac{\gamma \, x \, A \, x \, h}{A}$$

$$\boxed{p = \gamma h}$$

where γ is the unit weight of the fluid

$\gamma_{liq} = S_{liq} \gamma_w$ ⇒ $\gamma_{liq} = S_{liq} \times \gamma_w$

S is the specific gravity of fluid

$\gamma_w$ is the unit weight of water (generally 10 kN/m$^3$)

**Units of Pressure Intensity :**

$\frac{M L T^{-2}}{L^2}$ kN/m$^2$

∴ $M L^{-1} T^{-2}$

- ✓ N/m$^2$ (Pascal) S.I
- ✓ kgf/m$^2$ (Metric gravity system)
- ✓ Dyne/cm$^2$ (Absolute metric system)

**Dimension :**

- ✓ $ML^{-1}T^{-2}$

**Notes :**

- ✓ 1 Pascal = 1N/m$^2$
- ✓ 1 Mega pascal = $10^6$N/m$^2$ = 1N/mm$^2$
- ✓ 1 bar = $10^5$N/m$^2$ ☆ TNPSC
- ✓ 1 kilopascal = $10^3$N/m$^2$
- ✓ 1mm of Hg (p) = γh

$S_{mercury} = 13.6$

$= S \gamma_w \times h$

$\rho_w = 1$ g/cc (or) 1000 kg/m$^3$

$= 13.6 \times 9810 \times \frac{1}{1000}$ m

$= 133.416$ N/m$^2$ i.e.) 0.133 kN/m$^2$

- ✓ 10.3m of water (p) = γh

$S_{water} = 1$

$= S \gamma_w \times h$

$= \cancel{13.6}\ 1 \times 9810 \times 10.3$

13/8/2015



# TOTAL STRESS, EFFECTIVE STRESS AND PORE WATER PRESSURE

## Total Pressure ($\sigma$):

It is defined as total weight of soil load, water load and surcharge load if any, per unit surface area.

$$\sigma = \frac{\text{Wt of soil}}{\text{Area}} + q \quad \text{kPa.}$$

$$= \frac{\gamma \times \text{volume of soil}}{A} + q$$

$$= \frac{\gamma \times \cancel{A} \times h}{\cancel{A}} + q.$$

$$\boxed{\sigma = \gamma h + q}$$

Unit – kPa.

## Effective Stress ($\sigma'$):

The pressure transmitted from grain to grain of soil mass @ the point of contact @ the given section. In the soil mass is called as effective pressure (or) Inter granular pressure.

$$\sigma' = \sigma - U_w.$$

$$\sigma' = (\gamma_1 h_1 + \gamma_2 h_2 + \dots) - \gamma_w h_w$$

Note:



## Pore water Pressure

The pressure exerted by pore water in the voids on the soil grain is called Pore water pressure (neutral pressure)

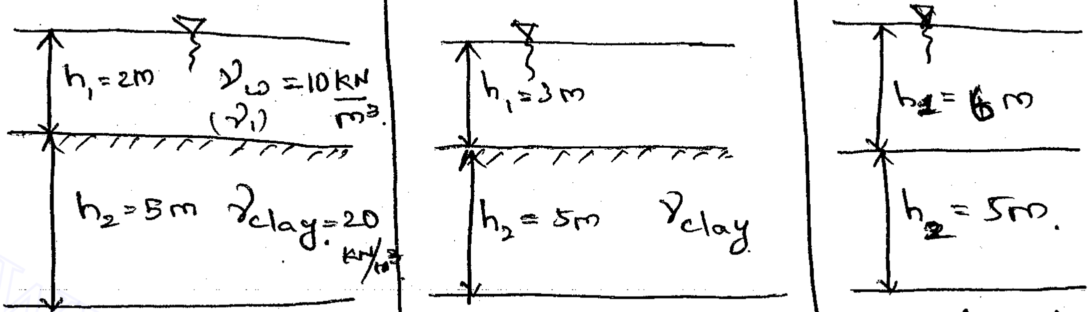
$$U_w = \gamma_w h_w$$

Note:
It's value may become negative due to capillary rise and its value is zero @ water table and positive below water table.

# Total stress, Effective stress & Pore water Pressure.

## Effective stress in Pond:

Sep | Oct | Nov.




**Sep:**

$\sigma = (10 \times 2) + (5 \times 20)$

$= 120\ kN/m^2$

$U_\omega = 10 \times 7$

$= 70\, kN/m^2$

$\sigma' = 120 - 70 = 50\, kN/m^2$

**Oct:**

$\sigma = (10 \times 3) + (5 \times 20)$

$= 130\ kN/m^2$

$U_\omega = 10 \times 8 = 80\, kN/m^2$

$\sigma' = 130 - 80 = 50\, kN/m^2$

**Nov:**

$\sigma = (10 \times 6) + (5 \times 20)$

$= 160\ kN/m^2$

$U_\omega = 10 \times 11 = 110\ kN/$

$\sigma' = 160 - 110 = 50\, kN/$

**Note:**

* Effective stress in a pond at a certain depth below the bed will not change eventhough the water level in the pond varies.

* But total stress is subjected to change with the increase or decrease of water level in the pond.

1.) Given Data:

$F.C = 20\%$

$P.W.P = 10\%$

$d_{w\,R.A.M} = 50\%\ d_{w\,A.M}$.

$\gamma_d = 1500\ kgf/m^3$

$= 1500 \times 9.81\ N/m^3$.

$$d_{w\,A.M} = \frac{\gamma_d}{\gamma_w} \times D_{root} \times (F.C - P.W.P)$$

$$= \frac{1500 \times 9.81}{9.81 \times 10^3} \times 1 \times (0.2 - 0.1)$$

$d_{w\,A.M} = 0.150\ m. = 150\ mm.$

$$d_{w\,R.A.M} = \frac{50}{100} \times 150$$

$$\boxed{d_{w\,R.A.M} = 75\ mm}$$

$N.I.R = 75 - 25 = 50mm$

2.) Given:

$Q = 10\ m^3/s$. $A = 32\ Ha = 32 \times 10^4\ m^2$.

Time of discharge = 4 hours.

water to be stored in root zone = 0.3.

$$\text{water supplied in the field} = \frac{10 \times 4 \times 60 \times 60}{32 \times 10^4}$$

$= 0.45$

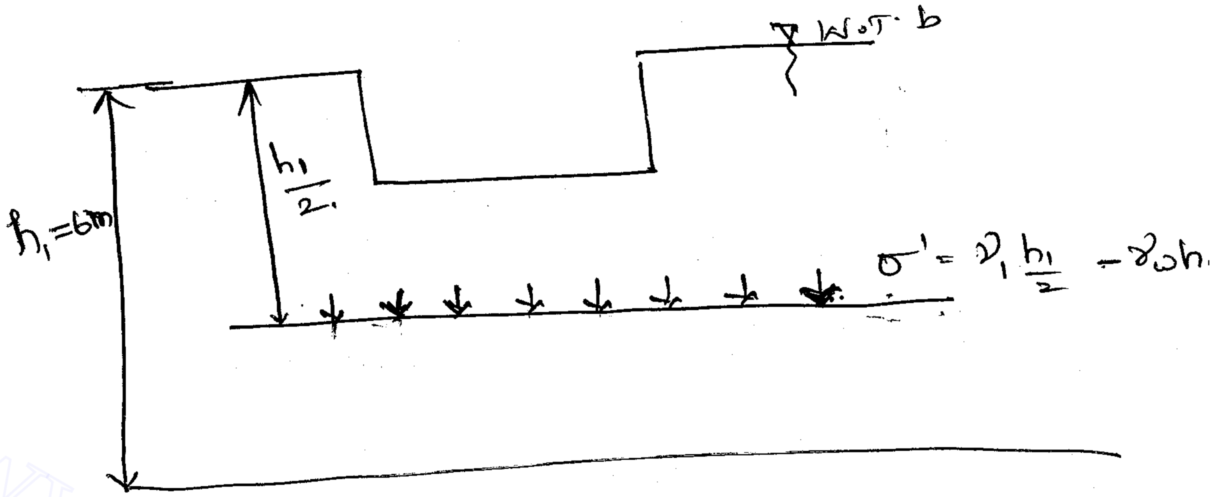
$$\eta_a = \frac{\text{water stored in root zone}}{\text{water supplied in field}} \times 100$$

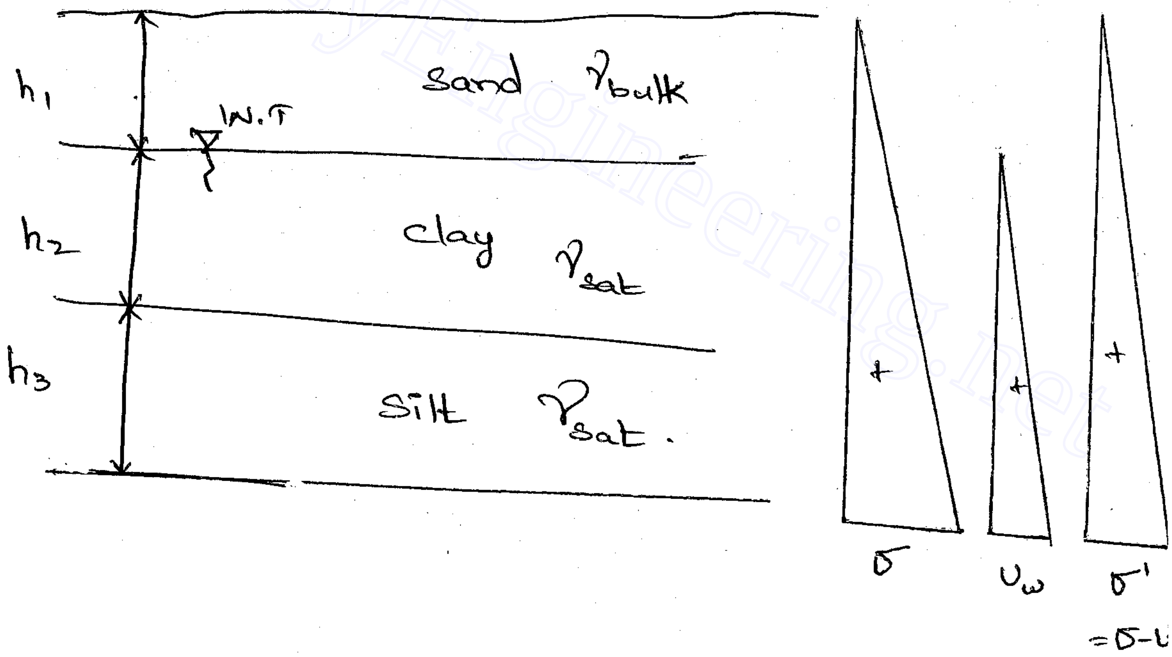
$$= \frac{0.3}{0.45} \times 100$$

$$\boxed{\eta_a = 66.67\%}$$

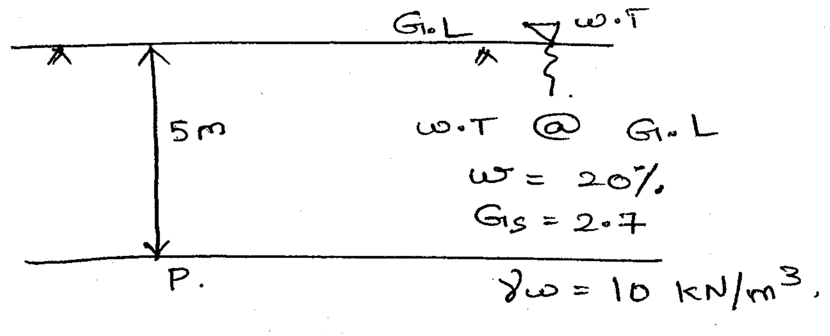
Note:

* In consolidation problem of clay, effective stress is always calculated in the middle depth of clay section.



10) Ground condition at a site are shown in the figure below




Soil is in fully saturated condition.

$\therefore \quad S_r = 1.$

$e\, S_r = w\, G_s.$

$e \times 1 = \frac{20}{100} \times 2.7.$

$\boxed{e = 0.54}$

$\gamma_{sat} = \left(\frac{G_s + e}{1+e}\right) \times \gamma_w.$

$= \left(\frac{2.7 + 0.54}{1 + 0.54}\right) \times 10.$

$\boxed{\gamma_{sat} = 21\ kN/m^3.}$

Total stress $\Big\}\ \sigma = \gamma_{sat} \times h.$

$= 21 \times 5.$

$\boxed{\sigma = 105\ kN/m^2}$

Pore water Pressure, $u_w = \gamma_w \times h_w.$

$= 10 \times 5.$

$\boxed{U_w = 50\ kN/m^2}$

Effective stress, $\sigma' = \sigma - U_w$

$= 105 - 50$

$\boxed{\sigma' = 55\ kN/m^2}$

$e\, S_r = w\, G_s$

$e = 0.2 \times 2.7$

$e = 0.54$

$$\gamma_{sat} = \left(\frac{G_s + e}{1+e}\right) \gamma_w$$

$$= \left(\frac{2.7 + 0.54}{1+0.54}\right) \times 10$$

$= 21.038$

$= 21\ kN/m^3$

$\sigma = (\gamma_{sat} \times h_1) + \gamma_w \times h_w$

$= (21 \times 5) + (10 \times 5)$

$= 105\ kN/m^2$

$U_w = \gamma_w \times h_w = 10 \times 5 = 50\ kN/m^2$

$\sigma' = \sigma - U_w$

$= 105 - 50$

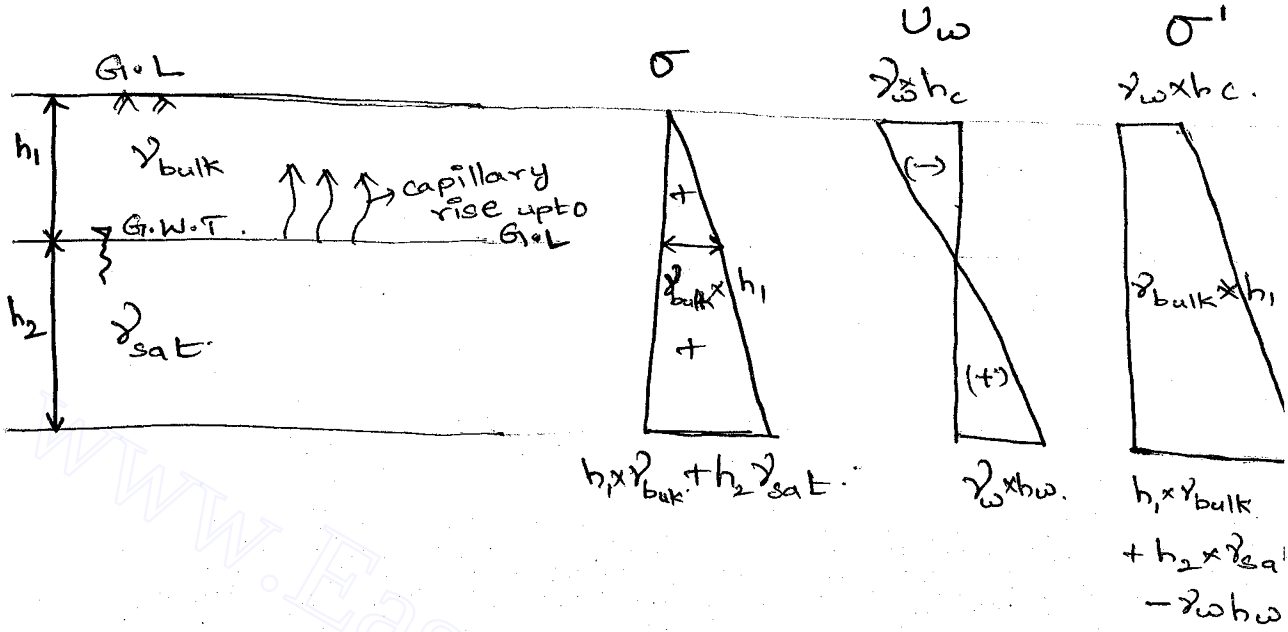
$= 55\ kN/m^2$

10/9/2015

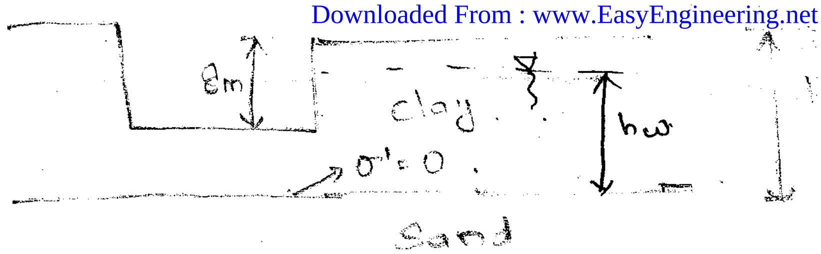


Soil Mechanics

TOTAL STRESS, EFFECTIVE STRESS & PORE WATER PRESSURE




1. A large excavation was made in a stratum of stiff clay with a saturated unit weight of 18.64 kN/m³. When the depth of excavation reached 8m the excavation ~~field~~ failed as a mixture of sand and water rushed in. Subsequent boring indicated that clay was under lined by a bed of sand with its top surface @ a bed of 12.5m. To what height water have risen above the stratum of sand into a drill hole before the excavation of excavation was started.




$$\sigma' = \sigma - U_w$$

$$0 = (18.64 \times 4.5) - (9.81 \times h_w)$$

$$h_w = \frac{83.88}{9.81}$$

$$\boxed{h_w = 8.55\,m}$$

2. A clay layer having thickness 12m lies on a layer of sand. A large open trench is made in the clay and as soon as the excavation reached 7m the bed rose. Determine the position of W.T below G.L if $\gamma_{sat} = 20\ kN/m^3$.

$$\sigma' = (\gamma_{sat} \times 5) - (9.81 \times h_w)$$

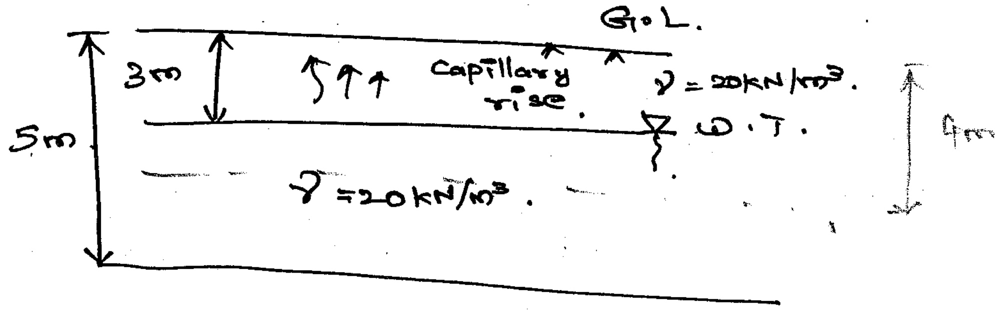
$$0 = (20 \times 5) - (9.81 \times h_w)$$

$$h_w = \frac{100}{9.81}$$

$h_w = 10.1936\,m$ (from sand layer.)

$h_w = 1.806\,m$. from G.L.

3. Determine $\sigma'$ @ 2m & below G.L as shown in the figure below. Also determine change in effective pressure if the W.T is lowered down by 1m.




$\sigma'$ @ 2m:

$$\sigma' = (20\times2) + (9.81\times1)$$
$$= 49.81 \ kN/m^2.$$

$$\sigma' \text{ @ } 5m = (20\times5) - (9.81\times2)$$
$$= 80.38 \ kN/m^2.$$

After G.W.T. lowering.

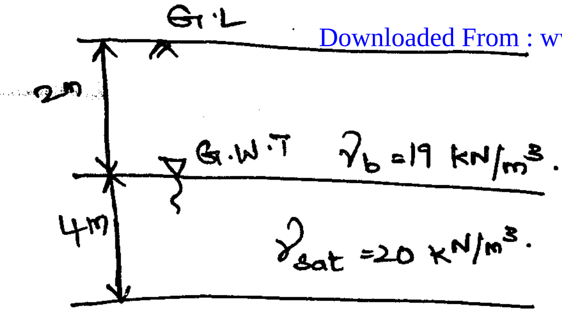
$\sigma'$ @ 2m.

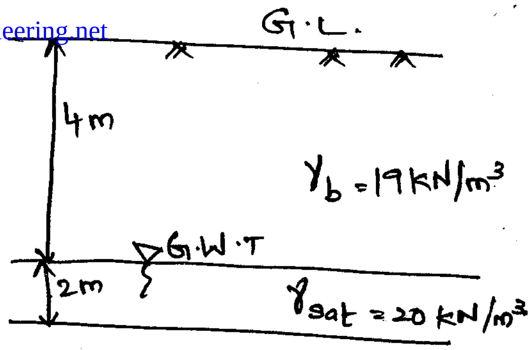
$$\sigma' = (20\times2) + (9.81\times2)$$
$$= 59.62 \ kN/m^2$$
$$= 9.81 \ kN/m^2 \uparrow$$

$$\sigma' \text{ @ } 5m = (20\times5) - (9.81\times1)$$
$$= 90.19 \ kN/m^2.$$

Change in $\sigma' = 90.19 - 80.38$.
$$= 9.81 \ kN/m^2. \uparrow.$$

4.)




$\sigma' = (2 \times 19) + (4 \times 20) - (9.81 \times 4)$

$\sigma' = 78.76$ kPa.

$\sigma' = (4 \times 19) + (2 \times 20) - (9.81 \times 2)$

$= 96.38$ kPa.

Inference :

* when the W.T increase ~~ab~~ from the initial condition effective stress decrease

* when W.T decrease below its initial position effective stress will increases.

Reason :

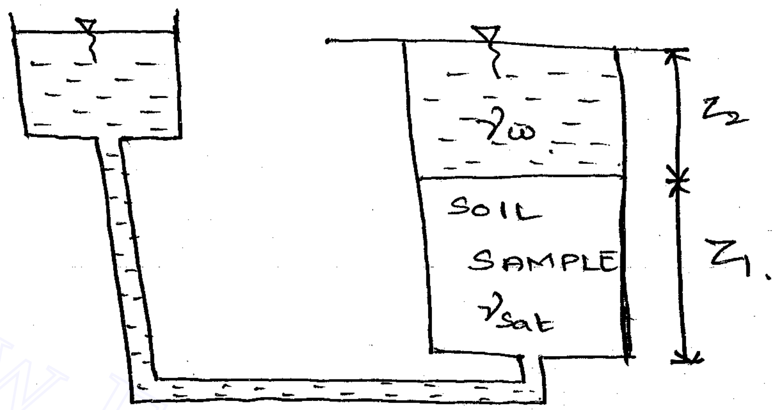
when W.T increase from the initial position the ~~as~~ depth of $\gamma_{sub}$ increase and $\gamma_{bulk}$ decrease.

when W.T decreases from the initial position, the depth of $\gamma_{sub}$ decreas. $\gamma_{bulk}$ (or) $\gamma_d$ increase. $(\gamma_{sub} < \gamma_d < \gamma_{bulk})$

* while finding ~~Q~~ $\sigma'$ the soil below ground water table is in sumberged condition.

# ANALYSIS OF SEEPAGE AND EFFECTIVE STRESS:

a) When there is no seepage:




$$\sigma' = \sigma - U_\omega.$$

$$\sigma = (\gamma_\omega \times Z_2) + (\gamma_{sat} \times Z_1)$$

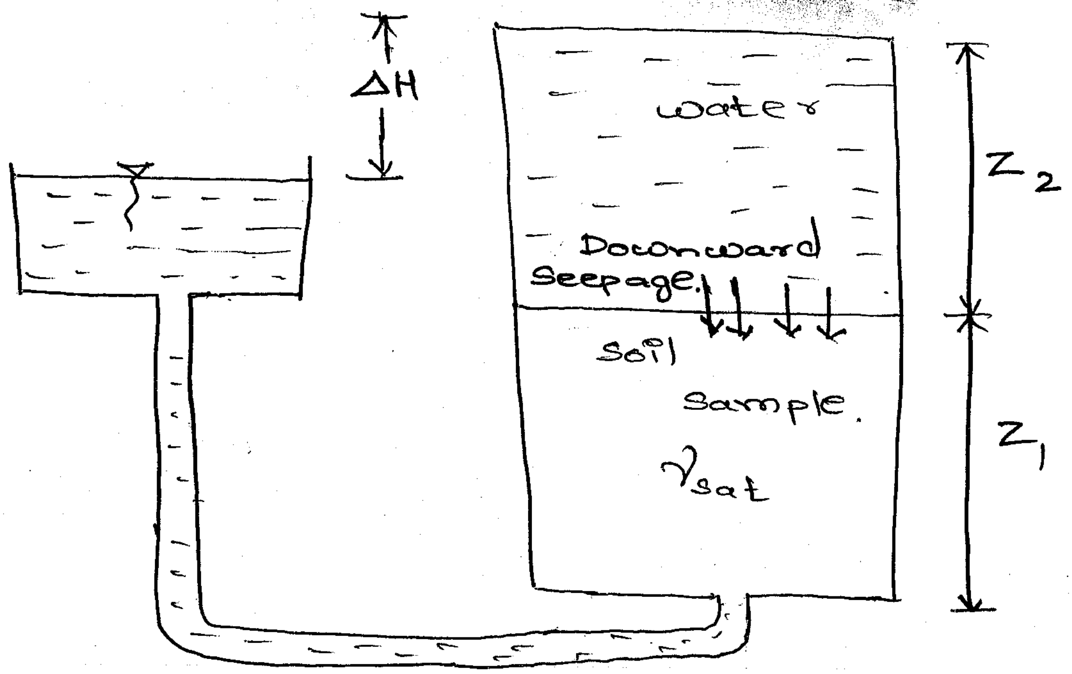
$$U_\omega = \gamma_\omega (Z_2 + Z_1).$$

$$\sigma' = \gamma_\omega \times \cancel{Z_2} + \gamma_{sat} \times Z_1 - \gamma_\omega \cancel{Z_2} - \gamma_\omega Z_1.$$

$$= \gamma_{sat} \times Z_1 - \gamma_\omega Z_1$$

$$\boxed{\begin{aligned} \sigma' &= (\gamma_{sat} - \gamma_\omega) \times Z_1 \\ \sigma' &= \gamma_{sub} \times Z_1. \end{aligned}}$$

(b) when there is a downward seepage.


$$\sigma' = \sigma - U_\omega.$$

$$\sigma = (\gamma_\omega \times Z_2) + (\gamma_{sat} \times Z_1).$$

$$U_\omega = \gamma_\omega \times (Z_2 + Z_1 - \Delta H).$$

$$\sigma' = \cancel{\gamma_\omega Z_2} + \gamma_{sat} Z_1 - \cancel{\gamma_\omega Z_2} - \gamma_\omega Z_1 + \gamma_\omega \Delta H$$

$$= (\gamma_{sat} - \gamma_\omega) Z_1 + \gamma_\omega \Delta H.$$

$$= \gamma_{sub} \times Z_1 + \gamma_\omega \times Z_1 \times \frac{\Delta H}{Z_1}$$

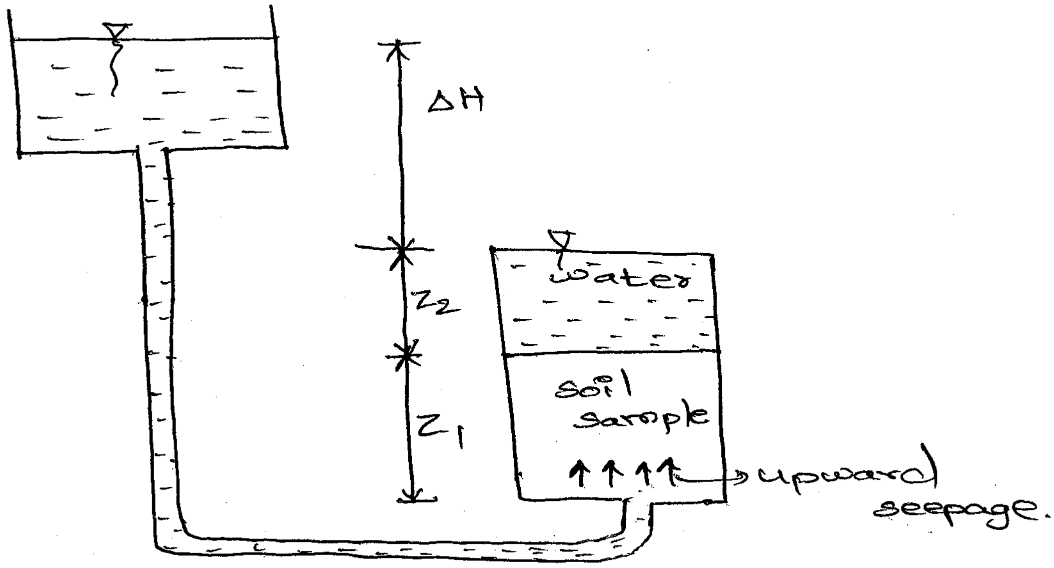
$$= \gamma_{sub} \times Z_1 + \gamma_\omega \times Z_1 \times i$$

$$\boxed{\sigma' = \gamma_{sub} Z_1 + i \gamma_\omega Z_1}$$

Effective stress increases.

c) water is in upward seepage.






$$\sigma' = \sigma - U_\omega$$

$$\sigma = (\gamma_\omega \times Z_2) + (\gamma_{sat} \times Z_1)$$

$$U_\omega = \gamma_\omega (Z_2 + Z_1 + \Delta H).$$

$$\sigma' = \gamma_\omega \cancel{Z_2} + \gamma_{sat} Z_1 - \gamma_\omega \cancel{Z_2} - \gamma_\omega Z_1 - \gamma_\omega \Delta H$$

$$= (\gamma_{sat} - \gamma_\omega) Z_1 - \gamma_\omega \frac{\Delta H \times Z_1}{Z_1}$$

$$\boxed{\sigma' = \gamma_{sub} Z_1 - i \gamma_\omega Z_1}$$

$$\boxed{\frac{\Delta H}{Z_1} = i}$$

decrease in effective stress.

* Due to upward seepage effective stress decreases.

* Due to downward seepage $\sigma'$ increases

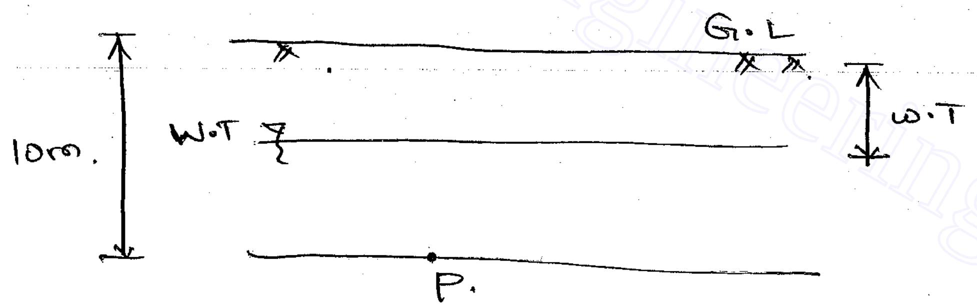
* If there is a seepage flow in a soil mass the effective stress will increase or decrease by $i z \gamma_w$.
(Downward seepage) (upward seepage)

Z – length of seepage

i – hydraulic gradient

$$\boxed{i = \frac{\Delta H}{Z \text{ (or) } L}}$$

1. The W.T is 5m below G.L and unit weight of soil $19 kN/m^3$ every where due to capillary rise. If the W.T rises to the ground level determine the change in effective stress @ a point P as shown in the fig. below.




W.T @ 5 m.

$$\sigma' = (19 \times 10) - (9.81 \times 5)$$
$$= 140.95 \ kN/m^2$$

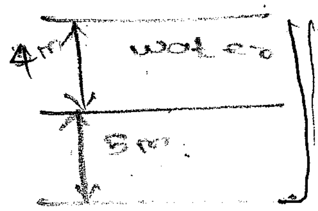
W.T @ G.L.

$$\sigma' = (19 \times 10) - (9.81 \times 10)$$
$$= 91.9 \ kN/m^2$$

Change in pressure = $49.05 \ kN/m^2$ (↓)

2. Determine the effective pressure at a depth of 5m below the bed of a river where the water level in the river is 4m in July 5m in August, 3m in September. Take $\gamma_{sat} = 20\ kN/m^3$. $\gamma_w = 10\ kN/m^3$.

<u>Given:</u>




$$\sigma' = \sigma - U_w$$

$$= (4 \times 10) + (5 \times 20) - (9 \times 10)$$

$$\sigma' = 50\ kN/m^2$$

$\sigma = (5 \times 20)$
$+ (10 \times 3)$
$- (9.81 \times$

$$\sigma' = \sigma - U_w$$

$$= (5 \times 10) + (5 \times 20) - (10 \times 10)$$

$$= 50\ kN/m^2$$

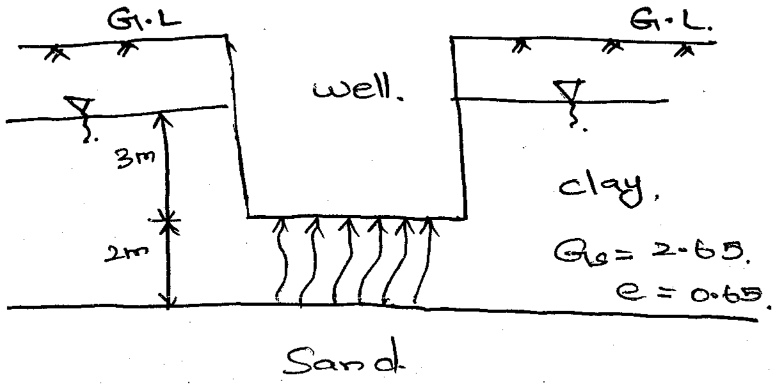
$$\sigma' = \sigma - U_w$$

$$= (3 \times 10) + (5 \times 20) - (8 \times 10)$$

$$\sigma' = 50\ kN/m^2$$

$$\boxed{\sigma' = 50\ kN/m^2}$$

1. A well is being pumped out as shown in the figure below determine whethere sand boiling will occur or not. Also suggest its remedy. If sand boiling occur




$L_{seep}$ is from sand layer.

$\Delta H$: chang in water level w.r.t G.W.T.

$$i_c = \frac{G_s - 1}{1+e} = \frac{2.65}{1+0.65} = 1$$

$$i_a = \frac{\Delta H}{L_{seep}} = \frac{3}{2} = 1.5$$

$i_a > i_c$ $\therefore$ Sand boiling will occur.

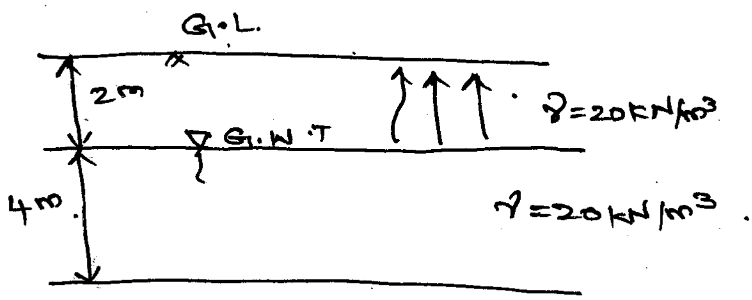
In order to avoid sand boiling

→ water in well can be raised above 1m. from the bottom of well.

→ ~~A~~ The ground water table can be lowered down. ~~kept~~ above 1m from existing w.T.

2) Determine the effective pressure at

the G.L and @ 6m from the G.L for the given figure. Also draw the stress diagram




$\sigma'$ @ G.L. $= \gamma_w h_c = 9.81 \times 2$

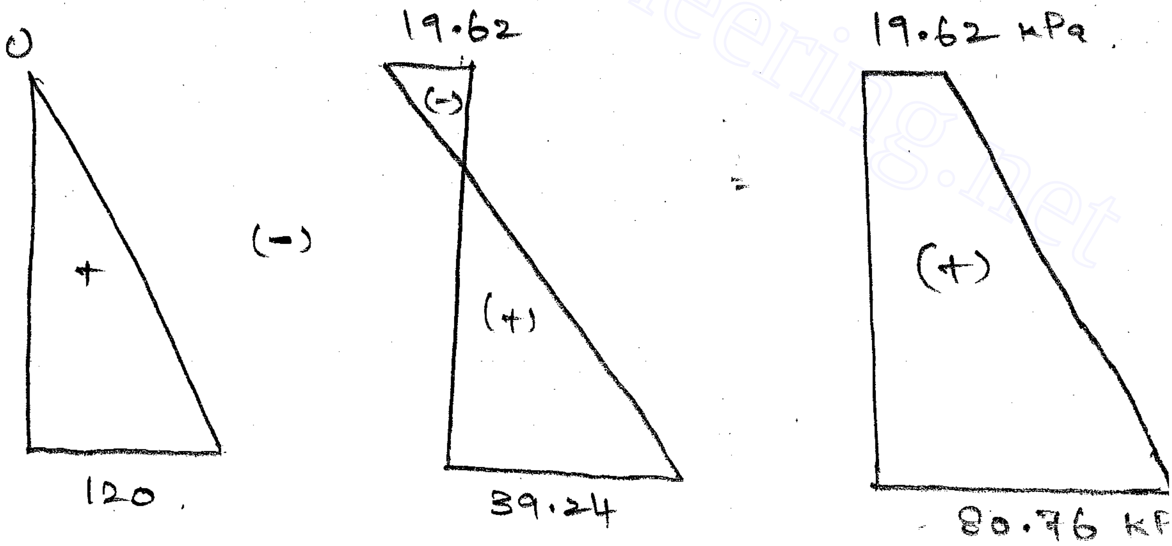
$= 19.62$ KPa.

$\sigma'$ @ 6m $= \sigma - U_w$.

$= (20 \times 6) - (9.81 \times 4)$

$= 120 - 39.24$

$= 80.76$ KPa



B · BIWIN —



# TERZAGHI INSTITUTE

## STRESS DISTRIBUTION

### INTRODUCTION :

Stress distribution at a certain depth due to externally applied load on the ground surface can be determined with the help of following theories.

(a) Boussinesq's theory

(b) Westergat theory (For stratified soil)

(c) Newmark's chart (For irregular shaped footing)

(d) 2:1 Method (~~For~~ approximate method)

### BOUSSINESQ'S THEORY :

1. **Boussinesq's Equation :**

Boussinesq's theory is widely adopted because of its conservative value (higher value than any other method)

**Assumptions made by Boussinesq in the derivation of this theory:**

Soil is homogenous, isotropic, semi infinite, elastic medium, weight less and the load is a point load acting on the ground surface.

2. **Homogenous :**

A material is said to be homogenous if it has identical properties at different points, in identical directions.

3. **Isotropic :**

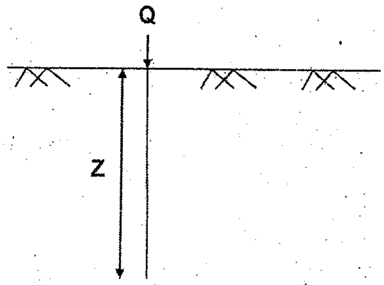
A material is said to be isotropic when it has identical elastic properties in all directions at a point.

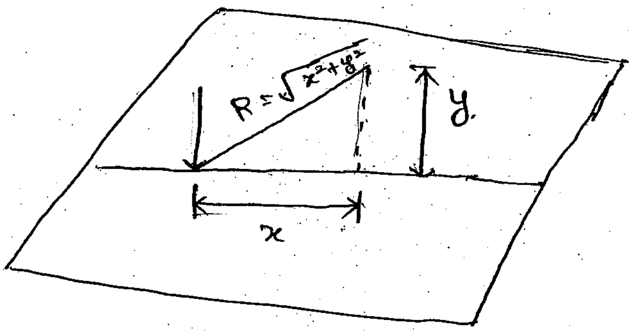
4. **Semi infinite :**

A material is said to be semi infinite if it extends infinite in all directions below a horizontal surface.

## 5. Vertical stress ($\sigma_z$) : (Boussinesq's Theory)

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




Where,

Z = vertical distance of the point below the load, m.

Q = point load KN.

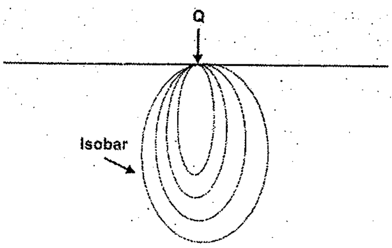
r = radial distance of the point = $\sqrt{x^2+y^2}$ = Rr

- Radial shear stress, $\tau_{rz} = \sigma_z(r/z)$
- Note : When r = 0, $K_B = 3/2\pi = 0.478$ $\Rightarrow \sigma_z = 0.478\left(\frac{Q}{Z^2}\right)$
- Theoretically, $\sigma_z$ is zero only at an infinite distance.

## 6. Isobar :

It is a curve or contour connecting all points below the ground surface of equal vertical stress. It is a spatial curved surface. The zone within a soil mass bounded by an isobar of given vertical pressure intensity is called "Pressure bulb".

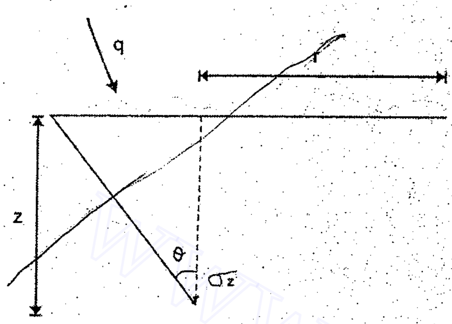
The pressure in the soil inside an isobar is greater than the pressure present on that isobar.



**Note** : Boussinesq theory is best suited to shallow foundations.

7. **Vertical stress due to circular loaded area :** (circular footing).

$\sigma_z$ at a depth 'z' on the vertical axis passing through centre of a uniformly loaded circular area of radius 'a'.

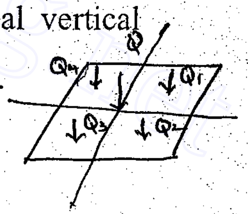



q – Pressure intensity @ the base of the footing kN/m².

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

or $\sigma_z = q\,[1 - \cos^3\theta]$

8. According to Boussinesq, the depth factor must be checked (i.e) if Z/B ≥ 3, then the formula can be applied directly. If the depth factor is not satisfied, then the footing must be split into a number of segments such that if Z/B ≥ 3. Then ~~only~~ the vertical stresses shall be determined by considering each segment individually and the final vertical stress is equal to sum of all vertical stresses due to the load on segmental areas.




$$\sigma = \sigma_1 + \sigma_2 + \sigma_3 + \sigma_4$$

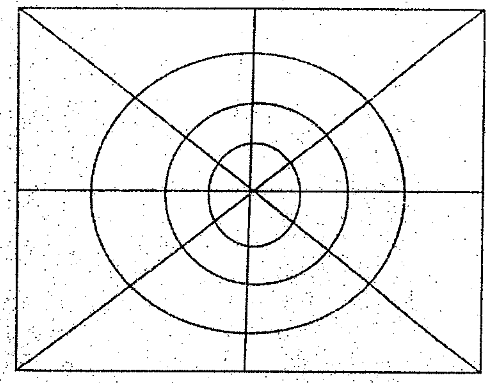
**NEWMARK'S INFLUENCE CHART :**

(a) To find vertical stress below the loaded area of any shape (irregular shaped footing)

(b) The point may lie with in or outside the loaded areas

(c) Each area unit causes equal vertical stress at the centre of the chart.

(d) The Newmark's chart is based on Boussinesq's theory.



$I_f = \frac{1}{10} \times \frac{1}{20} = 0.005$

$\boxed{I_f = \frac{1}{20 \times 10} = 0.005}$

$\sigma_z = I.\ n.\ q$

I = influence coefficient

n = number of sectors or area units occupied by footing

q = intensity of loading (KN/$m^2$ or Kg/$m^2$)

**WESTERGA~~R~~D'S THEORY :**

**Assumptions :** Elastic medium of semi in finite extent but containing numerous, closely spaced horizontal sheets of negligible thickness of an infinite rigid material which permits only downward deformation as a whole without allowing it to undergo any lateral strain. Westergaard's theory is suitable for stratified soils or sedimentary soils, varved clays.

$\sigma_z$ (Vertical stress) at a point is given by,

$$\sigma_z = \frac{Q}{z^2} I_W$$

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

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

**Case (i) :**

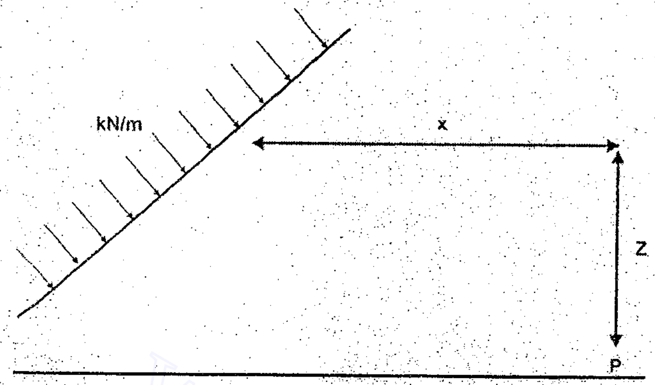
**Vertical stress below circular footing :**

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

if $\sigma_z <$ S.B.C (design is safe) but if $\sigma_z >$ S.B.C (design is not safe, change the dimensions)

**Case (ii) :**

**Vertical stress under line load (Railway line) :**

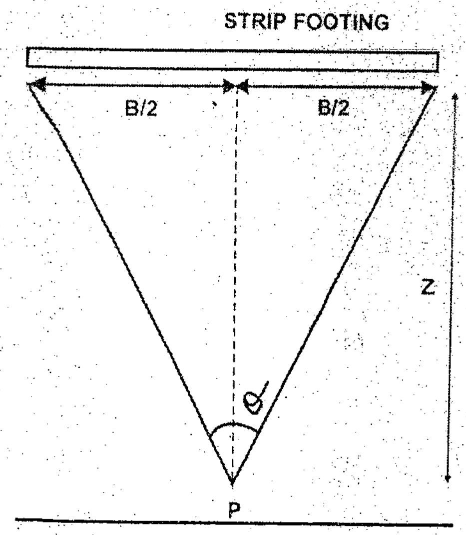



$$\sigma_z = \frac{q}{Z}\frac{2}{\pi}\left[\frac{1}{\left(1+\left(\frac{x}{z}\right)^2\right)^2}\right]$$

**Case (iii) :**

**Vertical stress below strip footing :**

**Exactly below :**

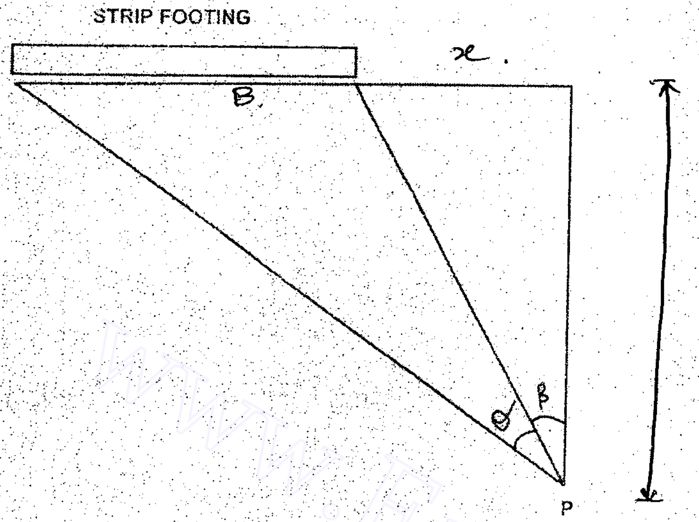



$$\sigma z = \frac{q}{\pi}\left[\theta + \sin\theta\right]$$

**Case (iv) :**

**Vertical stress below strip footing :**

**Away from footing :**




$$\sigma_z = \frac{q}{\pi}[(\theta + sin\theta)\cos\,(\theta + 2\beta)]$$

**Fenske's Chart** is used to find the vertical stress based on Westergaard's equation.

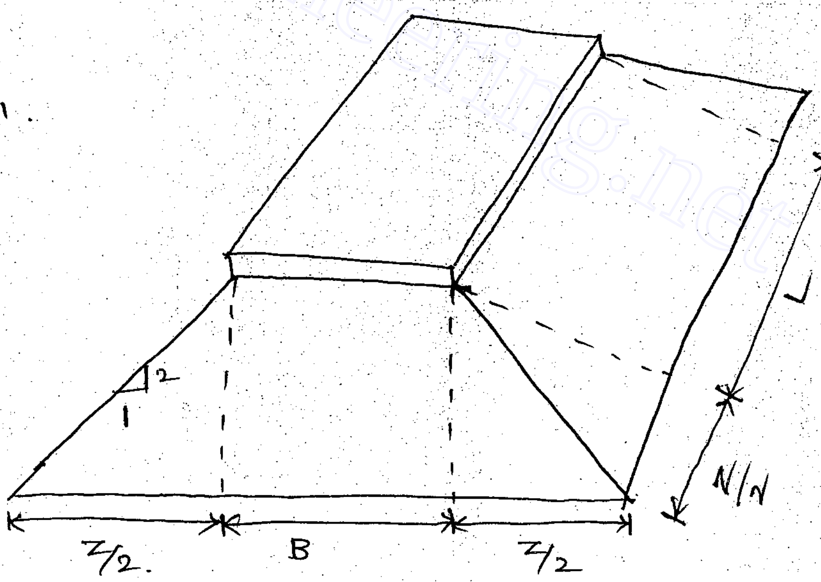
H.

**2 : 1 METHOD :**

$$\sigma_z = \frac{Q}{(B+Z)(L+Z)} = \frac{Q}{B' \times L'}.$$

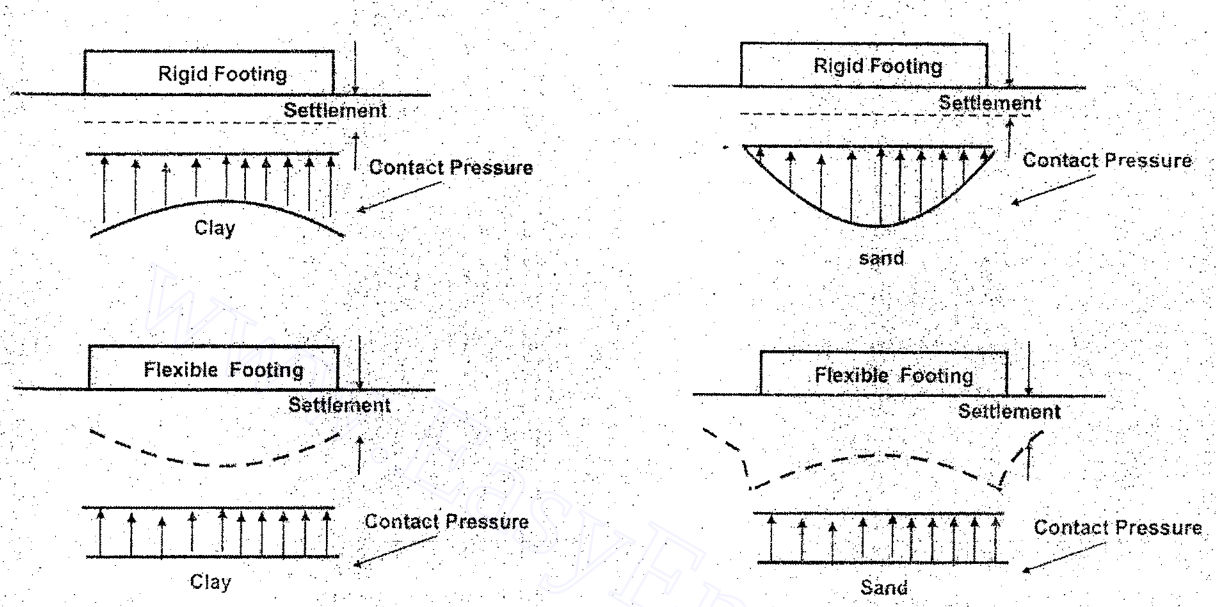
$$\frac{1}{2} = \frac{x}{z}.$$

$$\boxed{x = \frac{z}{2}}$$



## CONTACT PRESSURE :

It is the pressure exerted by foundation soil on the under side of the footing. It depends upon elastic properties of the soil and footing.




Vertical stress below the corner of a uniformly loaded rectangular area (Newmark's Method).

$m = L/z$

$n = B/z$

The parameters 'm' and 'n' are interchangeable

Vertical stress at the corner is given by $\sigma_z = I.\ q$

Where I is and influence coefficient depends on parameters 'm' and 'n'.

The I value can be read from tables or curves developed by New mark.

Line Load $= \frac{q}{z} \times \frac{2}{\pi} \left[ \frac{1}{1+(r/z)^2} \right]^2$

Circular footing $= q \left[ 1 - \left( \frac{1}{1+\left(\frac{r}{z}\right)^2} \right)^{3/2} \right]$

$= q [1 - \cos^3 \theta]$

Strip footing $= q(\theta + \sin\theta)$

Newmark's Chart $= I \times q$ $= 0.005$

2:1 Method $= \frac{Q}{(L+z)(B+z)}$

Stress distribution: Stress @ certain "depth" due to externally applied load

Boussinesq's assumption

* Homogeneous
* Elastic
* Isotropic
* Weightless
* point load acting on ground surface

Westergaard
Assumption

Approximate Method

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

$r = \sqrt{x^2+y^2}$

* Radial stress
* when $\sigma_z = 0$ @ $z = \infty$

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

Irregularly shaped footing

Based on Boussinesq's theory

* $\sigma_z = I \times q \times n$

$q$ - kPa

$n$ - no. of sectors

Circular:

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

$= q [1 - \cos^3\theta]$

Line load:

$\sigma_z = \frac{q}{z} \frac{2}{\pi} \times \left[ \frac{1}{1+(x/z)^2} \right]^2$

Strip footing:

$= \frac{q}{\pi} (\theta + \sin\theta)$

$= \frac{q}{\pi} (\theta + \sin\theta) \cos(\ldots)$

$\frac{Q}{(L+z) \times (B+z)}$

Pressure of ... Resistance.

03/10/2015





1. A circular water tank having circular raft as foundation. and is subjected to a total load of 10000 kN. Radius of the raft is 6m. The S.B.C of the soil at a depth of 4m. below the base is 100kPa Determine whether the foundation size is adequate are not.

$$\sigma_z = q\left[1 - \frac{1}{1+\left(\frac{r}{z}\right)^2}\right]^{3/2} \qquad q = \frac{10000}{\frac{\pi \times 12^2}{4}}$$

$= \cancel{353.68\,k}$

$q = 88.42\ \frac{kN}{m^2}$

$$= 88.42\times10^3\left[1 - \left[\frac{1}{1+\left(\frac{6}{4}\right)^2}\right]^{3/2}\right]$$

$= 73.32\ N/m^2$.

$= 73.33\ kPa. < 100 kPa. (S.B.C)$

size is adequate.

2. Determine the vertical stress under the centre of the footing at a depth of 8m. The size of the footing is 3m × 3m and the intensity of Load is 150 KPa. Use Boussinesq Theory.



$Kpa = 10^3\ N/m^2$

$Kpa = kN/m^2$

Given:

$Z = 8m$ Footing size $= 3 \times 3\ m$.

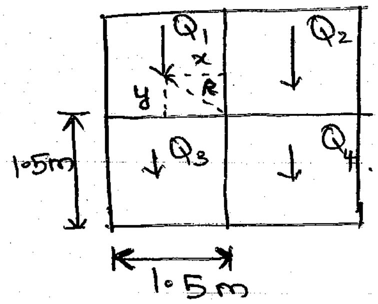
Load intensity $= 150 \times 10^3\ N/m^2$.

Load $= 150 \times 10^3 \times 3 \times 3$.

$\boxed{Q;\ \text{Load} = 1350\ kN.}$

$\frac{Z}{B} = \frac{8}{3} = 2.67 < 3$

∴ we have to split the area




$\frac{Z}{B} = \frac{8}{1.5} = 5.33 > 3.$

$\sigma_{z_1} = \sigma_{z_2} = \sigma_{z_3} = \sigma_{z_4}$.

$r = \sqrt{x^2+y^2} = \sqrt{(0.75)^2+(0.75)^2} = 1.06\ m$.

$Q_1 = \frac{Q}{4} = \frac{1350 \times 10^3}{4} = 337.5\ kN.$

$$\sigma_{z_1} = \frac{Q_1}{Z^2}\ \frac{3}{2\pi} \left[\frac{1}{1+\left(\frac{r}{z}\right)^2}\right]^{5/2}$$

$$= \frac{337.5 \times 10^3}{(8)^2} \times \frac{3}{2\pi} \left[\frac{1}{1+\left(\frac{1.06}{8}\right)^2}\right]^{5/2}$$

$\boxed{\sigma_{z_1} = 2.410\ KPa}$

$\sigma_z = 4 \times \sigma_{z_1}$

$= 4 \times 2.41$

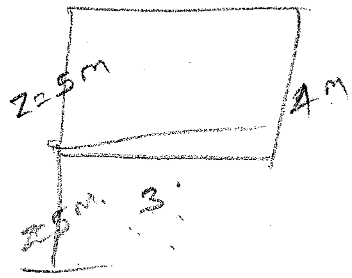
$\boxed{\sigma_z = 9.64\ KPa}$

3/10/2015

# SOIL MECHANICS

1. A rectangular footing having size 3m×4m is subjected to a load of 100 kPa. Determine the vertical stress at a depth of 5m Below the ground level Adopt 2:1 Method

$$Q = 100 \times 3 \times 4 = 1200 \text{ kN}.$$




$$\sigma_z = \boxed{\frac{Q}{(L+z)*(B+z)}}$$

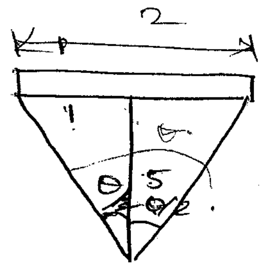
$$= \frac{1200 \times 10^3}{(3+5) \times (4+5)}$$

$$\boxed{\sigma_z = \cancel{70.59}\ 16.67 \text{ kPa}.}$$

$$\boxed{\sigma_z = 16.67 \text{ kPa}}$$

2) A strip footing having a size of 2m. is subjected to a load of 150kPa. Determine the vertical stress below the centre of footing and at a distance 3m from the edge. Find the stress below the base at 5m.

Solution:




$$\frac{\theta}{2} = 11.309 \quad \theta = 22.618 \quad \cancel{5.6545}$$

$$= 0.197 \text{ radian}.$$

$$= \cancel{0.0986} = 0.3947$$

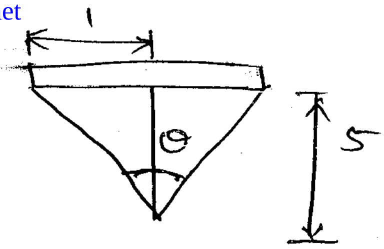
$$\sigma_z = \frac{q}{\pi}(\theta + \sin\theta)$$

$$= \frac{150}{\pi}((0.197)2 + \sin 2(11.309))$$

$$\boxed{\sigma_z = 18.77 \text{ kPa}.} \qquad \cancel{\sigma_z = 26.415}$$

$$\boxed{\sigma_z = 37.19 \text{ kPa}}$$

2.) solution :




$$\frac{\theta}{2} = \tan^{-1}\left(\frac{1}{5}\right).$$

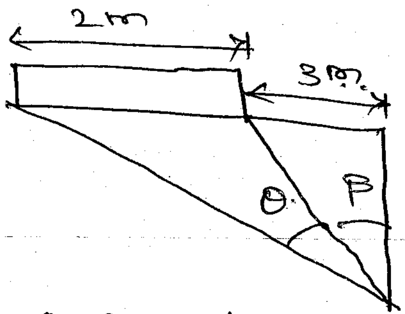
$$\theta = 22.61^\circ.$$

$$\theta = 0.394 \text{ radian}$$

$$\sigma_z = \frac{q}{\pi}(\theta + \sin\theta)$$

$$= \frac{150}{\pi}\left[0.394 + \sin 22.61\right].$$

$$\boxed{\sigma_z = 37.17 \text{ kPa}}$$




$$\theta + \beta = \tan^{-1}\left(\frac{5}{5}\right) = 45^\circ.$$

$$\beta = \tan^{-1}\left(\frac{3}{5}\right) = 30.96^\circ.$$

$$\theta = 14.04^\circ = 0.245 \text{ radian.}$$

$$\sigma_z = \frac{q}{\pi}\left[\theta + \sin\theta \times \cos(\theta + 2\beta)\right]$$

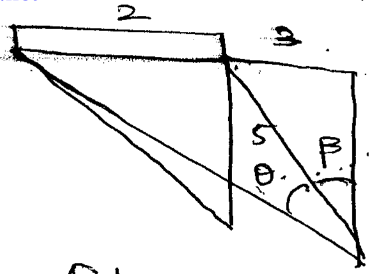
$$= \frac{150}{\pi}\left[0.245 + \sin 14.04 \times \cos(14.04 + 2(30.96))\right]$$

$$\boxed{\sigma_z = 14.507 \text{ kPa}}$$

$\theta + \beta = 45^\circ$.

$\beta = 30.96$.

$\theta = 14.04^\circ$.




θ+

$$\sigma_z = \frac{q}{\pi}\left[(\theta + \sin\theta)\cos(\theta + 2\beta)\right]$$

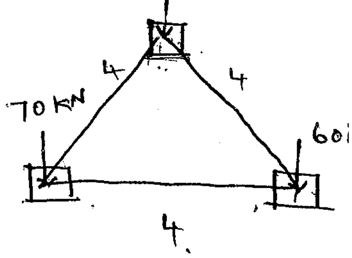
$$= \frac{150}{\pi}\left[(0.245 + (\sin 14.04)\cos(14.04 + 2(30.\right.$$

$\boxed{\sigma_z = 12.81\ kPa}$ $\boxed{\sigma_z = 14.507\ kPa}$

$$\boxed{\sigma_z = \frac{q}{\pi}\left[\theta + (\sin\theta \times \cos(\theta + 2\beta)\right]}$$

3.) 3 columns are placed at the corners of a equilateral triangle. Having side 4m each. the columns carry loads of 100 kN, 70 kN and 60 kN. Determine the maximum possible vertical stress under one column @ a depth of 5m below the base (Boussinesq Theory:

$\frac{z}{B} = \frac{5}{4} = k > 3$.




Stress under 60 kN.

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

$$\sigma_z = \sigma_{z100} + \sigma_{z60} + \sigma_{z70}.$$

$$= \left[0.478 \times \frac{60}{5^2}\right] + \frac{70 + 100}{5^2} \times \frac{3}{2\pi}\left[\frac{1}{1 + \left(\frac{4}{5}\right)^2}\right]^{5/2}$$

$= 1.1472 + 0.942 =$ ~~2.62 kPa~~.

$= 2.089$.

$$\sigma_z = \frac{0.478 \times 100}{5^2} + \frac{(70+60)}{5^2} \times \frac{3}{2\pi}\left[\frac{1}{1+\left(\frac{4}{5}\right)^2}\right]^{5/2}$$

$$= 1.912 + 0.721.$$

$$\boxed{\sigma_{z_{100}} = 2.633\,kPa}$$

$$\sigma_z = \frac{0.478 \times 70}{5^2} + \frac{(100+60)}{5^2} \times \frac{3}{2\pi}\left[\frac{1}{1+\left(\frac{4}{5}\right)^2}\right]^{5/2}$$

$$= 1.3384 + 0.887$$

$$\boxed{\sigma_{z_{70}} = 2.225\,kPa}$$

$\therefore$ Maximum stress is under 100kN.

Loaded column.

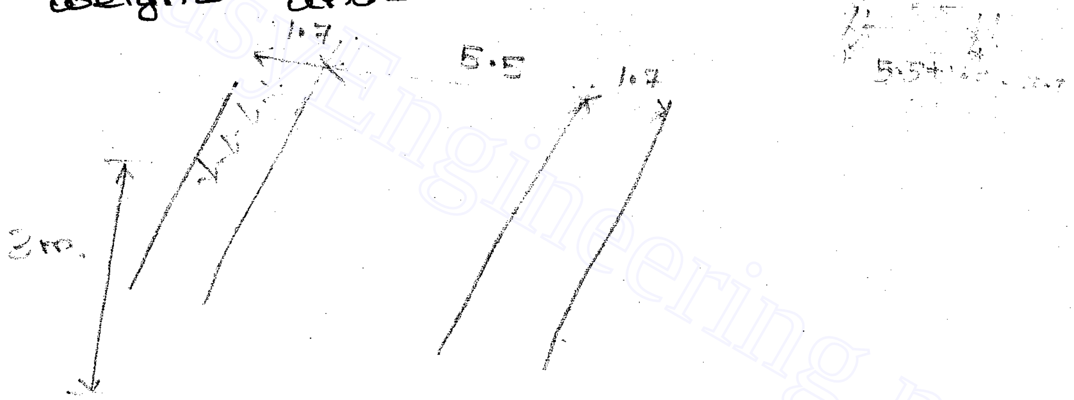
4.) Two railway lines are running parallel at a clear distance of 5.5m. The gauges 1.7m. $q = 100$ kN/m. and 80 kN/m respectively

Determine
(a) Max. vertical stress under the centre of 1 railway track @ a depth of 3m below the base.

(b) Vertical stress @ the midway of 2 tracks.

(c) Increment in vertical stress under max. loaded track and if a crane weighing 40kN is placed @ the mid way of the two tracks.

(d) Max. Vertical stress including crane weight under one track.




Case (i) :

$$\sigma_z = \sigma_{z_1} + \sigma_{z_2}$$

$$= \frac{q}{z} \times \frac{2}{\pi}\left(\frac{1}{1+\left(\frac{0}{z}\right)^2}\right)^2 + \frac{q}{z} \times \frac{2}{\pi}\left[\frac{1}{\left(1+\left(\frac{r}{z}\right)^2\right)^2}\right]$$

$$= \frac{100}{3} \times \frac{2}{\pi}\left\{\ \right\} + \frac{80}{3} \times \frac{2}{\pi}\left[\frac{1}{\left(1+\left(\frac{7.2}{3}\right)^2\right)^2}\right]$$

$$= 21.22 + 0.371$$

$$\boxed{\sigma_z = 21.59 \text{ kPa}}$$

case (ii) :

$$\sigma_z = \sigma_{z1} + \sigma_{z1}$$

$$= \frac{2(100+80)}{3\times\pi} \times \left[\frac{1}{\left(1+\left(\frac{3.6}{3}\right)^2\right)^2}\right]$$

$$\sigma_z = 3.3 \text{ kPa.}$$

$$\boxed{\sigma_z = 6.42 \text{ kPa.}}$$

case (iii)

$$\Delta\sigma_z = \frac{40}{3^2} \times \frac{3}{2\pi} \times \left[\frac{1}{1+\left(\frac{3.6}{3}\right)^2}\right]^{5/2}.$$

$$\boxed{\Delta\sigma_{z\,crane} = 0.23 \text{ kPa.}}$$

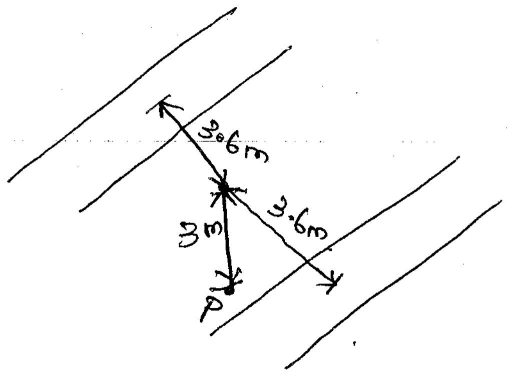
case (iv).

$$\sigma_z = \sigma_{z1} + \sigma_{z2} + \Delta\sigma_{z\,crane}$$

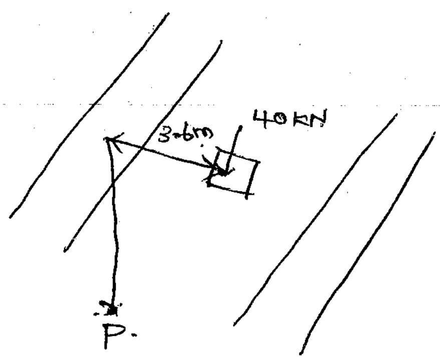
$$= 21.59 + 0.23.$$

$$\boxed{\sigma_z = 21.82 \text{ kPa.}}$$

case (ii)




case (iii)



27/10/2015





Finished.

# FLOW NETS.

* The path traced by a fluid particle is called. through a saturated soil mass is called flow line (or) phreatic line (or) seepage line ~~or~~

* The line joining points of equal piezometric head is called equipotential line.

* Flow Net:

Flow net is a network of flow lines and equipotential lines crossing each other orthogonally (90°).

It is a graphical representation of seepage flow and loss of head of seepage water through the soil mass.

* Properties of Flow Net:

1. Flow lines are curved lines.
2. Equipotential lines are curved lines.
3. Flow lines and equipotential lines intersect @ 90°.
4. Two seepage lines ~~are~~ (or) flow lines form a flow channel.
5. The seepage quantity through each flow channel are the same. (or) equal.

Flow Line (or) phreatic (or) Seepage Line:

Path traced by fluid particle through Saturated soil mass.

Equipotential Line:

Line joining points of equal peizometric head

Flow Nets:

Graphical representation of flow lines or equipotential line.

Properties:

1. Flow lines and Equipotential lines are curved lines.
2. No two flow lines (or) equipotential line start at the same point.
3) No two flow lines (or) equipotential lines intersect each other.
4) A flow line and equipotential line intersect each other @ 90°.
5) 2 Seepage line form a flow channel
6) 2 equipotential line form a equipotential drop.
7) 2 two flow line and equipotential line which is intersect to form a feild approximately square
8) Seepage quantity through each flow channel is constant.
9) Head loss b/w 2 or more equipotential ~~line~~ drop will be same.
10) Shape factor $= \frac{N_f}{N_d}$.

shape factor independent of permeability

6) No ~~two~~ flow lines start from a same point and never intersect (2 flow line) each other.

7.) Two equipotential lines do not start ~~som~~ from the same point.

8.) Space b/w two equipotential lines is called equipotential drops.

9.) The head loss b/w ~~two~~ (or) more equipotential drops ~~offt~~ will be the same.

10.) Two flow lines and two equipotential line intersects to form a field which is approximately a square where ~~4~~ a circle can be drawn with 4 tangent ~~to~~.

11.) The ratio of No. of flow lines ($N_f$) to the No. of potentials drops ($N_d$) is called shape factor.

$$\boxed{\text{shape factor} = \frac{N_f}{N_d}}$$

It is independent of permeability of soil.

Purpose :

To find

→ seepage quantity

→ seepage pressure.

→ uplift pressure.

→ exit gradient

Seepage Discharge.

$$q = kiA$$

$$q = \sqrt{k_x k_y}\ H_{net}\ \frac{N_f}{N_d}$$

$$k_{mean} = \sqrt{k_x k_y} \qquad i = \frac{\Delta H}{L}$$

$$\Delta H \text{ in one potential drop} = \frac{H_{net}}{N_d}$$

## Purpose of Flow Net:



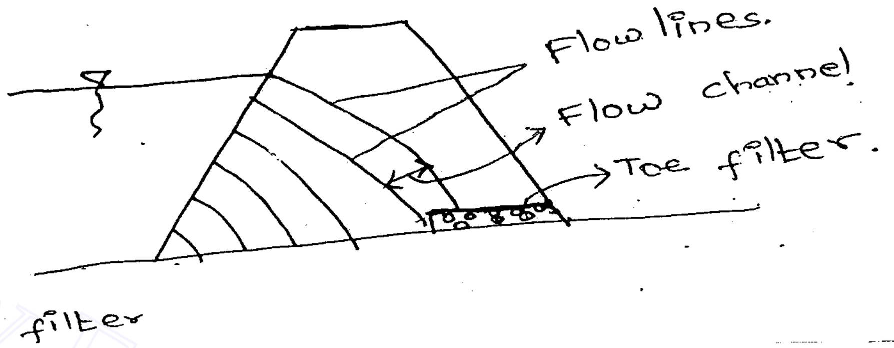
(i) To find seepage quantity.

(ii) To find seepage pressure.

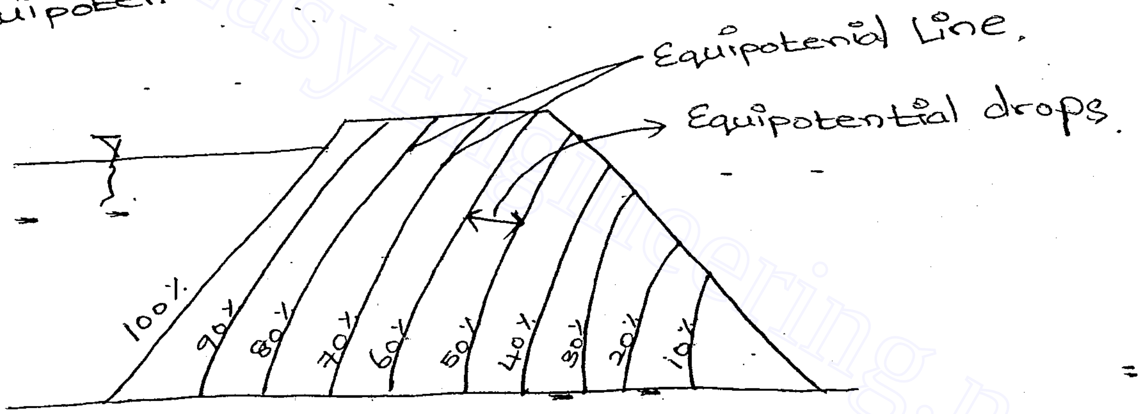
(iii) To find uplift pressure.

(iv) To find exit gradient.

### ① seepage (or) Flow line:



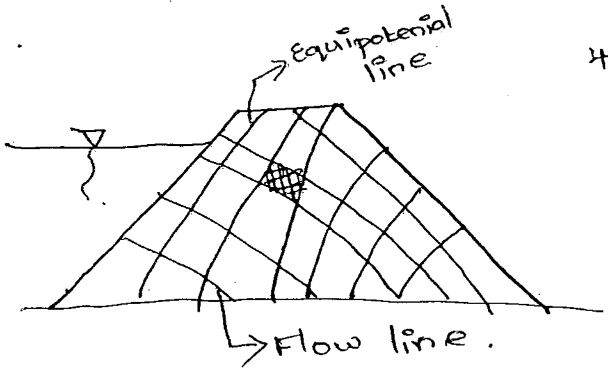

### ② Equipotential Lines.



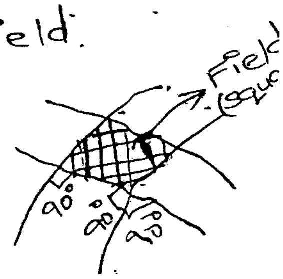

* Energy loss ~~through~~ through each potential drops are same.

* upstream face of an Earthen dam is an equipotential line.

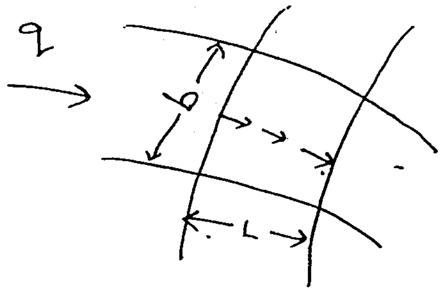
### 3.) Flow Net.




### 4.) Field.



Expression For Quantity Of Seepage Through A Flow ~~channel~~ Field :




According to Darcy's law, discharge in a field (flow channel) is given by,

$$q = k i A$$

$$\boxed{K_{mean} = \sqrt{k_x \times k_y}}$$

$$\boxed{i = \frac{\Delta h}{L}}$$

A = b x unit ~~length~~ depth.

$= b \times 1$

$$\boxed{A = b}$$

$$q = \sqrt{k_x \times k_y} \times \frac{\Delta h}{L} \times b$$

Total head lost = $H_{net}$.

Head lost in 1 $N_d$ = $\frac{H_{net}}{N_d}$.

$$q = \sqrt{k_x \times k_y} \times \frac{H_{net}}{N_d} \times \frac{b}{L}$$

$$\boxed{b = L}$$

$$q = \sqrt{k_x \times k_y} \; \frac{H_{net}}{N_d}$$

Total seepage for $N_f$ = $q \times N_f$.

$$\boxed{q = \sqrt{k_x \times k_y} \; H_{net} \times \frac{N_f}{N_d}}$$

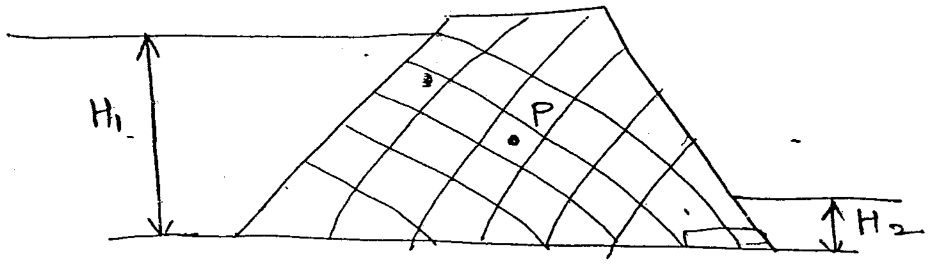
20/12/2015 .

SOIL MECHANICS.



FLOW NET.

## UPLIFT PRESSURE (OR) PORE WATER PRESSURE




$$H_{net} = H_1 - H_2.$$

For No. of. drops $= N_d$ , Head lost $= H_{net}$

For No. of. drop $= 1$ Head lost $= \frac{H_{net}}{N_d}$

For $N_d = N_d'$ Head lost $= \frac{H_{net}}{N_d} \times N_d'$

By Bernoulli's Equation.

$$E_{net} = \frac{P}{\gamma} + \cancel{\frac{V^2}{2g}} + Z$$

$$E_{net} = \frac{P}{\gamma} + Z.$$

$$\frac{P}{\gamma} = E_{net} - Z.$$

$$E_{net} = \left(\begin{matrix}\text{Total Head} \\ \text{or} \\ \text{Energy}\end{matrix}\right) - \left(\begin{matrix}\text{Energy} \\ \text{lost upto} \\ \text{P}\end{matrix}\right)$$

$$= H_{net} - H_{net}\frac{N_d'}{N_d}.$$

$$\boxed{E_{net} = H_{net}\left[1 - \frac{N_d'}{N_d}\right]}$$

$$\frac{P}{\gamma} = H_{net}\left(1 - \frac{N_d'}{N_d}\right) - Z.$$

$$\boxed{P = \gamma_w\left[H_{net}\left(1 - \frac{N_d'}{N_d}\right) - (\pm Z)\right]}$$

Z = +ve above base

"Z" below the base = −ve

30/12/2015




# FLOWNETS.

1. An earthen dam having total h = 30m and F.B = 2m. is subjected to seepage and seepage analysis gives the following results. $N_f = 4$ $N_d = 15$. The hydraulic conductivity in horizontal direction $k_H = 4 \times 10^{-7}$ cm/s and in vertical direction $k_V = 1 \times 10^{-7}$ cm/s. Determine the seepage quantity per unit length of dam and the pore water pressure @ a point above 5m above base @ 2.5th No. of drop.

Solution:

$$q = \sqrt{k_H k_V} \times H_{net} \frac{N_f}{N_d}$$

$$= \sqrt{(4 \times 10^{-9} \times 1 \times 10^{-9})} \times 28 \times \frac{4}{15}$$

$$= 1.493 \times 10^{-8} \; m^3/s/m$$

$$\boxed{q = 1.49 \times 10^{-4} \; cm^3/s/m}$$

$$q = 1.49 \times 10^{-4} \times 100 \; cm^3/s/cm$$

$$\boxed{q = 0.0149 \; cm^3/s/cm}$$

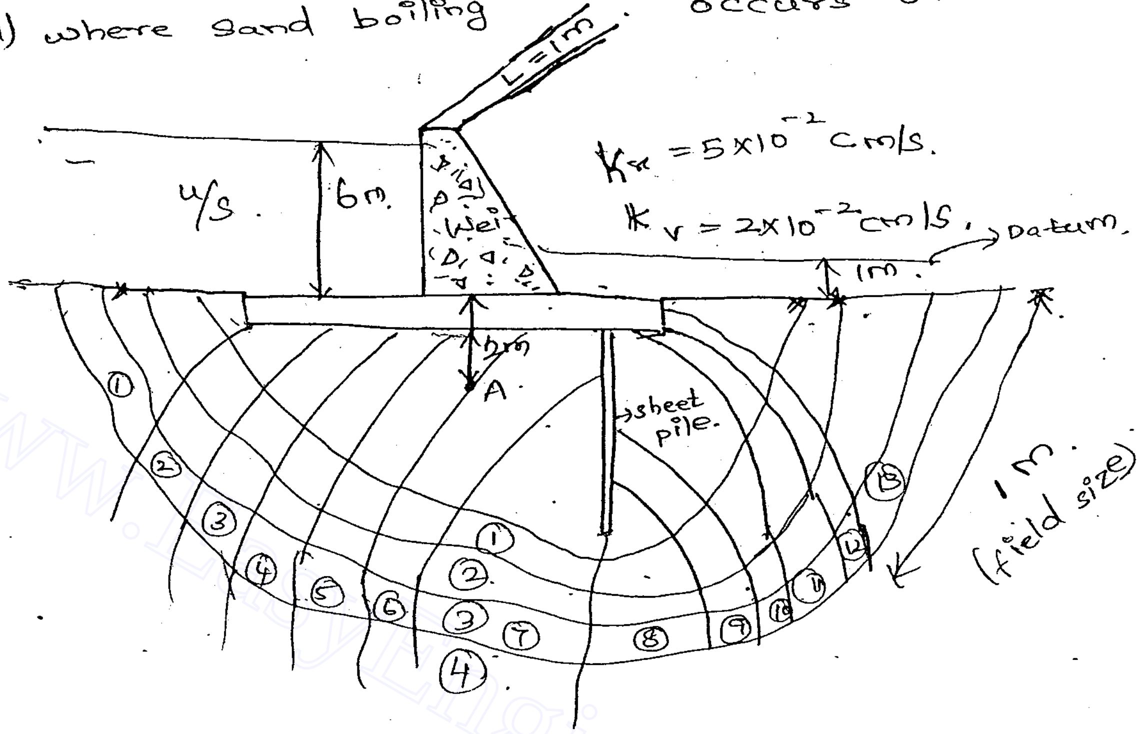
2. The flow net below the base of a weir or barrage is shown in the following figure. Determine

a) Seepage quantity

(b) Exit gradient

(c) uplift pressure @ point A.

(d) where sand boiling occurs or not.




$N_f = 4 \quad N_d = 13.$

$$q = \sqrt{k_H \times k_V} \times H_{net} \times \frac{N_f}{N_d}$$

$$= \sqrt{5\times10^{-2} \times 2\times10^{-2}} \times (6-1)\times100 \times \frac{4}{13}$$

$$\boxed{q = 4.86 \ cm^3/s/m}$$

(c) $P = \gamma_w \left[\left(H_{net}\left(1-\frac{N_d'}{N_d}\right)\right) - (-z)\right]$

$= 9.81\left[5\left(1-\frac{5}{13}\right) + 3\right]$

$\boxed{P = 49.80 \ kPa}$ $\boxed{P = 59.61 \ kPa}$

(b) $i_a = \dfrac{\Delta H}{L_{seepage}}$ Hnet in one drop =

$= \dfrac{\left(\dfrac{H_{net}}{N_d}\right)}{\text{size of one equipotential drop}}$ $\left(\cancel{H_{net}}\ \left(H_{net}\ \text{in one drop}\right)\right.$

$= \dfrac{\left(\dfrac{5}{13}\right)}{1}$

$\boxed{i_a = 0.385}$

(c) $i_c = \left(\dfrac{G_s - 1}{1+e}\right)$

For sand $G_s = 2.65$. $e = 0.65$

$= \left(\dfrac{2.65 - 1}{1+0.65}\right)$

$i_c = 1$.

$i_c > i_a$

Sand boiling will not occur.

Note:

Z must be taken upto the water level in d/s

# TERZAGHI INSTITUTE

## SOIL MECHANICS

## PERMEABILITY AND CAPILLARITY

**PERMEABILITY :**

1) Permeability is the ability of soil mass (porous medium) to permit water to pass through it.
2) Permeability is also known as Hydraulic conductivity.
3) Importance of permeability :
   In the determination of :
   (a) Consolidation
   (b) Seepage through Earthern dams, Canals and below hydraulic structures.
   (c) Yield from an aquifer.
4) Permeability is highest for Gravel and lowest for clay.
5) **Darcy law (1856) :**

   $\boxed{V = ki}$

   c/s area(A) x V = k. i. A

   $\boxed{Q = k\,i\,A}$

   Where, Q is the seepage discharge

   $i = \frac{\Delta h}{L}$ (Hydraulic gradient)

   A = c/s area of soil sample

   V = Avg. velocity (or) Superficial velocity (or) Darcy Velocity (or) Apparent velocity (by consider c/s area)

   k = coefficient of permeability (or) permeability (or) hydraulic conductivity

   Unit is cm/sec
6) **Factors affecting Permeability :**

   (i) Particle size of the soil grain :

   $k \propto D^2$

   $k = CD_{10}^2$

   Where, C = 100 (Acc. to Hazen)

   $D_{10}$ = effective size

   Unit = cm/s

   (ii) Void ratio :

   When e increases, then k increases

   $k \propto \frac{e^3}{1+e}$

   % Change of k = $\frac{k_2 - k_1}{k_1}$ x 100%

   (iii) Unit weight of water :

   $k \propto \gamma_w$

   $k = c\,\gamma_w$

$\frac{k_1}{k_2} = \frac{\gamma_{w1}}{\gamma_{w2}}$

(iv) Viscosity of water ($\mu$)

k α (1/ μ)

$\frac{k_1}{k_2} = \frac{\mu_2}{\mu_1}$

*if* μ and γ are given then,

$k = C \times \frac{\gamma w}{\mu}$

$\frac{k_2 - k_1}{k_1} \times 100\%$

$= \frac{\frac{\gamma w_2}{\mu_2} - \frac{\gamma w_1}{\mu_1}}{\frac{\gamma w_1}{\mu_1}} \times 100$

(v) Temperature of water :

If temperature increases then viscosity decreases and hence k increases

(vi) Degree of Saturation : $S_r$

k α $S_r^3$

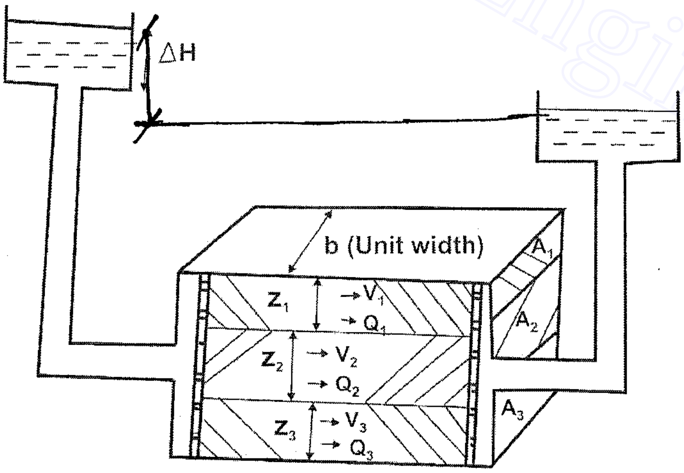
(vii) Presence of entrapped air : Decreases k

(viii) Adsorbed Water :

Void ratio is reduced hence k decreases

(ix) Stratification of soil and flow pattern :

**Case (i) : Seepage flow parallel to bedding plane :**




a) $i_1 = i_2 = i_3 = \frac{\Delta h}{L}$

b) $Q = Q_1 + Q_2 + Q_3$

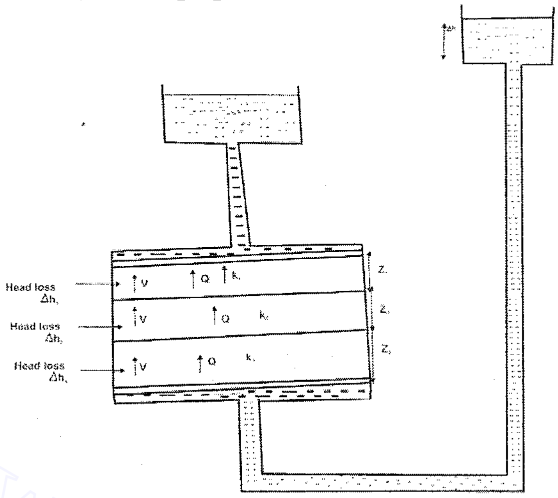
$kiA = k_1 i_1 a + k_2 i_2 a + k_3 i_3 a$

$kA = k_1A_1 + k_2A_2 + k_3A_3$

$k[b \times Z_{total}] = k_1[b \times Z_1] + k_2[b \times Z_2] + k_3[b \times Z_3]$

$\boxed{k = \frac{k_1Z_1 + k_2Z_2 + k_3Z_3}{Z_1 + Z_2 + Z_3}}$

**Case (ii) : Seepage flow perpendicular to bedding plane :**




a) By law of continuity : $Q = Q_1 \pm Q_2 \pm Q_3$

A is same hence V is same

$V = V_1 + V_2 + V_3$

b) $\boxed{\Delta h = \Delta h_1 + \Delta h_2 + \Delta h_3}$

On applying Darcy law,

$V = k \, x(\frac{\Delta h}{z})$

$\Delta h = \left(\frac{VZ}{k}\right)$

$\frac{VZ}{k} = \frac{V_1 Z_1}{K_1} + \frac{V_2 Z_2}{K_2} + \frac{V_3 Z_3}{K_3}$

$$\frac{Z}{K} = \frac{Z_1}{K_1} + \frac{Z_2}{K_2} + \frac{Z_3}{K_3}$$

$\boxed{k_v = \frac{Z}{\frac{Z_1}{K_1} + \frac{Z_2}{K_2} + \frac{Z_3}{K_3}}}$ $(Z = Z_1 + Z_2 + Z_3)$

$\boxed{k_H > k_V}$

(x) $K_{equivalent} = \sqrt{k_H \, x \, k_v}$

7) **Limitations :**

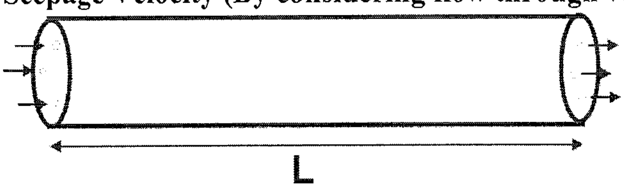
(a) Soil must be fully saturated and homogeneous

(b) Flow must be laminar [$R_e = \frac{\rho V d}{\mu} \leq 1$]

V α i [Should not be > 1]

(c) If flow turbulent $V \, \alpha \, i^{4/7}$ so Darcy law is invalid

8) **Seepage Velocity (By considering flow through voids only)**





$V_s$ = seepage velocity

$V_s = \dfrac{Length\ of\ flow}{Flow\ time}$

$\boxed{V_s = k_p \times i}$ (where $k_p$ is coefficient of percolation)

$\boxed{k_p > k}$

Q1(Discharge through c/s area) = Q2(Discharge through Voids only)

$A_{c/s} \times V_{darcy} = A_{void} \times V_{seepage}$

$V_s = \dfrac{A_{c/s} \times V_{Darcy}}{A_{void}} = \dfrac{A_{c/s} \times L}{A_{void} \times L} \times V_{darcy}$

$V_s = \dfrac{V}{V_v} \times V_{darcy} = \dfrac{V_{Darcy}}{n}$

$V_s = \dfrac{V_{Darcy}}{\frac{e}{1+e}} = \dfrac{V_{Darcy}\,(1+e)}{e}$

$V_s > V_D$

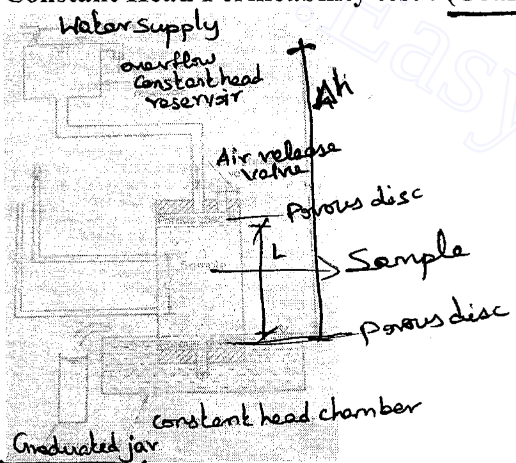
9) **Determination of Permeability (Hydraulic Conductivity)**

(a) Constant head permeability test

(b) Falling head permeability test

(c) Field test (Pumping out test)

10) **Constant Head Permeability test : (Coarse Grained Soil)**




$\boxed{K = \dfrac{V_w L}{H A t}}$

Where, H is the constant head

A is the c/s area of sample $[(\pi/4)d^2]$

L is the length of soil sample

$V_w$ is volume of seepage water collected in time 't'

11) **Variable Head Permeability test : (Fine Grained Soil)** (or) falling head

$K = \dfrac{a\,L\ln\left(\frac{h_1}{h_2}\right)}{A(t_2 - t_1)}$ (or) $K = \dfrac{2.303\,a\,L\log\left(\frac{h_1}{h_2}\right)}{A(t_2 - t_1)}$

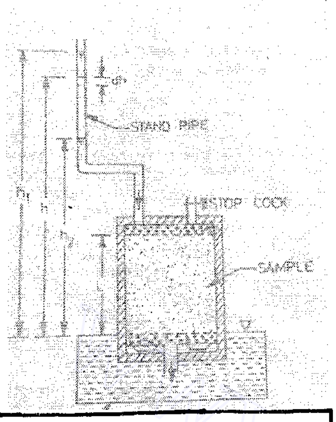
Where, a is the area of stand pipe $[(\pi/4)d^2]$ $d \to$ dia of stand pipe

A is the c/s area of soil sample $[(\pi/4)D^2]$ $D \to$ dia of soil sample

L is the length of soil sample

$h_1$ is head at time $(t_1)$

$h_2$ is head at time $(t_2)$




$$\boxed{\text{If } (t_2 - t_1) = (t_3 - t_2)}$$

Then $k_{1\text{-}2} = k_{2\text{-}3}$

$$\frac{a\,L\log\left(\frac{h_1}{h_2}\right)}{A(t_2-t_1)} = \frac{a\,L\log\left(\frac{h_2}{h_3}\right)}{A(t_2-t_3)}$$

$$\ln\left(\frac{h_1}{h_2}\right) = \ln\left(\frac{h_2}{h_3}\right)$$

$$\left(\frac{h_1}{h_2}\right) = \left(\frac{h_2}{h_3}\right)$$

$$h_2^2 = h_1 \times h_3$$

$$\boxed{h_2 = \sqrt{h_1\, x\, h_3}}$$

12) **Capillarity :**

$$h_c = \frac{4\,\sigma\cos\theta}{(S\,\gamma_w)d}$$

where, $\sigma$ = surface tension (N/m)

$\theta$ = Contact angle

S = Specific gravity of liquid

d = dia. Of soil pore (m), D = dia. Of soil grain

if d is not given,

w.k.t, $e = \frac{v_v}{V_s} = \frac{\frac{\pi}{6}d^3}{\frac{\pi}{6}D^3}$

$$e = \frac{d^3}{D^3}$$

$$d = e^{1/3} D$$

# ENVIRONMENTAL

# ENGINEERING

# WATER REQUIREMENTS



- → Quality standards
- → Basic unit processes and operatio[ns] for water Treatment
- → Drinking water standards
- → water Requirements
- → Basic unit operations and unit processes for surface water treatm[ent]
- → Distribution Of water
- → Sewage and Sewage Treatment
- → Quantity and characteristics of waste water.
- → Primary, Secondary and Tertiary treatment of waste water
- → sludge disposal
- → Effluent discharge standards.
- → Domestic waste water treatme[nt]
- → Quantity and characteristics of Domestic waste water.
- → Primary and secondary treatment Unit operation and unit processes of domestic waste water.
- → sludge Disposal.

# MUNICIPAL SOLID WASTES



→ Characteristics

→ Generation

→ collection and transportation of Solid wastes

→ Engineered systems for solid wast management [Reuse / Recycle, energy recovery, treatment and disposal]

# NOISE POLLUTION

→ Impacts of Noise

→ Permissible limits of Noise polluti

→ Measurement of noise pollution

→ Control of noise pollution.

# AIR POLLUTION



→ Types of pollutants

→ Their Sources and impacts

→ Air pollution Meteorology

→ Air pollution Control

→ Air quality standards and limits.

# ENVIRONMENTAL

# ENGINEERING

# WATER REQUIREMENTS

→ Quality standards

→ Basic unit processes and operatio. for water Treatment

→ Drinking water standards

→ water Requirements

→ Basic unit operations and unit processes for surface water treatm

→ Distribution Of water

→ Sewage and Sewage Treatment

→ Quantity and characteristics of waste water.

→ Primary, Secondary and Tertiary treatment of waste water

→ Sludge disposal

→ Effluent discharge standards.

→ Domestic waste water treatmen

→ Quantity and characteristics of Domestic waste water.

→ Primary and secondary treatment Unit operation and unit processes of domestic waste water.

→ sludge Disposal.

0|7|2015

(1)

# ENVIRONMENTAL ENGINEERING.

## Treatment Of Municipal Water :

1.) Screening

2.) Plain sedimentation (Type - I settling tan

3.) sedimentation aided with coagulation (Type - II settling Tank)

4.) Filtration

5.) Dis infection

6.) Aeration

7.) softening.

8.) Desalination.

9.) Miscellenous Treatment such as fluoridation etc.,

## Screening:

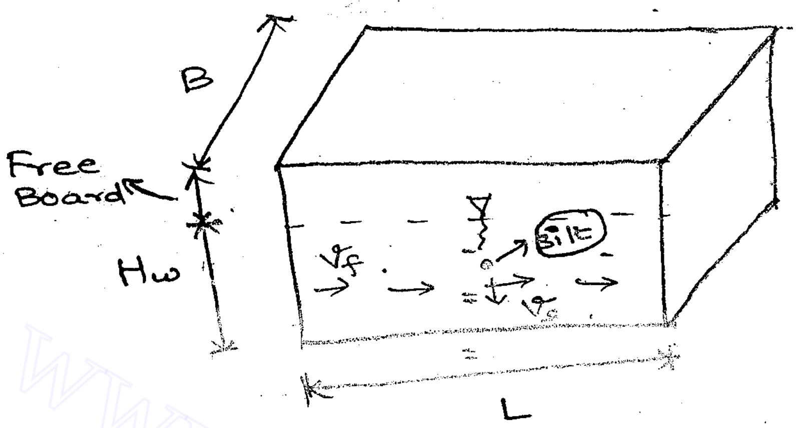
Types.

- Coarse screen (0.8 m/s)
- Fine screen.

* In fine screens c/c distance of steel bars are kept less than 1cm. and hence it is subjected to
* frequent clogging.
* Nowadays it is obsolete.
* c/c distance of 2cm - 10cm of steel bars are used in Coarse screens. and the coarse screens are kept @ an angle of 45° to 60°. to reduce the flow velocit

of the water into the plain sedimentation tank.

Plain Sedimentation Tank: (Type - I settling Tank):




$v_f$ - flow velocity
$v_s$ - settling velocity
$H_w$ - Height of water in Type-I tank
B - width of the tank
L - Length of tank

* The flow velocity in a plain sedimentation is 0.3m/min.
* Detention time is 4 - 8 hrs.
* Surface Loading (or) overflow rate is 500 - 750 lit/hr/m² of plan area.

$$\left.\begin{array}{l}\text{Surface Loading (or)} \\ \text{overflow rate } (v_0)\end{array}\right\} = \frac{Q}{L \times B}$$

settling velocity, $v_s = \frac{Q}{L \times B}$.

* Flow velocity, $v_f = \frac{Q}{B \times H_w}$

settling velocity by Stoke's Law :

$$\boxed{V_s = \frac{D^2 (G_s - 1)\gamma_w}{18 \times \mu}}$$

$$= \frac{D^2 (G_s - 1) \times \rho_w \times g}{18 \times \mu}$$

$$= \frac{D^2 (G_s - 1) \times g}{18 \times \mu/\rho_w}$$

$\frac{Ns}{m^2} \times \frac{1}{\frac{N s^2}{m^4}}$ , $\frac{m^2}{s}$

$$\boxed{V_s = \frac{D^2 (G_s - 1) g}{18 \times \nu}}$$

$V_s$ - settling velocity

$D$ - Dia of silt.

$G_s$ - specific gravity of silt.

$g$ - acceleration due to gravity.

$\mu$ - Viscosity $(Ns/m)$

$\nu$ - kinematic viscosity.

$$V_s = 418 D^2 (G_s - 1)\left[\frac{3T + 70}{100}\right].$$

$$\left.\begin{matrix}\text{Efficiency of sedimentation} \\ (\eta)\end{matrix}\right\} = \frac{V_s}{V_o} \times 100\%$$

$V_o$ - surface loading.

Volume of Rectangular tank = $L \times B \times H_w$.

Volume of circular (or) cylinde.

$$= 0.011 D^3 + \frac{\pi}{4} \times D^2 \times H_w$$

10) A sedimentation tank is designed for an overflow rate of 20 $m^3/day/m^2$ and it is designed to remove the silt particles of size D = 0.01 mm. with the $G_s = 2.65$. Take $\nu = 0.01\ cm^2/s$. Find $\eta$ of sediment removal:

Given:

$$V_o = 20\ m^3/day/m^2.$$

$$= \frac{20}{24 \times 60 \times 60}\ m^3/s/m^2.$$

$$V_s = \frac{D^2 (G_s - 1)\, g}{18\, \nu}$$

$$= \frac{(0.01 \times 10^{-3})^2 (2.65 - 1) \times 9.81}{18 \times 0.01 \times 10^{-4}}$$

$$V_s = 8.9925 \times 10^{-5}\ m/s.$$

$$\eta = \frac{V_s}{V_o} \times 100.$$

$$= \frac{8.9925 \times 10^{-5}}{\frac{20}{24 \times 60 \times 60}} \times 100.$$

$$\eta = \cancel{0.29975}\%.$$

$$\boxed{\eta = 38.85\%}$$

2.) A sedimentation tank of $W = 6m$ $L = 15r$ $0.8 m/s$.

$H_w = 3m$ is treating $Q = 2 MLD$ of wate

(a) surface overflow rate $\underline{925.926}$, lit/hr/hr

(b) Detetion time $\underline{1.08}$ hrs.

(c) Mass of sludge deposited if con. 60ppm $\eta = 70\%$ $G_{bulk} =$

Given:

$$Q = 2 \times 10^6 \text{ lit/day}.$$

$$Q = \frac{10^6}{12} \text{ lit/hr} = \frac{10^3}{12} m^3/hr.$$

$$\text{Surface overflow rate} = \frac{Q}{L \times B}$$

$$= \frac{\frac{10^6}{12}}{15 \times 6}$$

$$= 925.926 \text{ lit/hr/m}^2$$

$$\text{Discharge Surface overflow rate} = \frac{\text{discharge volume}}{\text{Detention time}}$$

$$\text{Detention time} = \frac{6 \times 15 \times 3}{\left(\frac{10^3}{12}\right)}$$

$$= \cancel{1.08 \text{ hr}}$$

$$= 3.24 \text{ hr}$$

$$V = Q \times t$$

$$V = 6 \times 15 \times 3$$

$$G_{bulk} = \frac{\rho_{silt}}{\rho_w}$$

$$\rho_{silt} = 2 \times 1000 = 2000 \text{ kg/m}^3.$$

$$V_{silt} = 6 \times 15 \times 3 \times \frac{60}{10^6}$$

$$= 0.0162 \ m^3.$$

$$M = \rho \times V$$

$$= 2000 \times 0.0162$$

$$M_{silt} = 32.4 \text{ kg}.$$

$$\text{Settled mass} = 32.4 \times \frac{70}{100} = \underline{\underline{22.68 \text{ kg}}}.$$

3) A rectangular sedimentation tank is treating Q = 1.8 MLD of raw water with detention period = 4 hrs.

(a) Volume of the tank required $\underline{300\ m^3}$

(b) If allowable overflow rate is 500 lit/hr/$m^2$ and L : B = 4 : 1 then the length required $\underline{24.5\ m}$

$\frac{m/s}{h}$

a) $Q = \frac{V}{T}$

$Q = 1.8 \times 10^6\ l/day$

$= \frac{1.8 \times 10^3}{24}\ \frac{m^3}{hr}$

$V = Q \times T$

$= \frac{1.8 \times 10^3}{24} \times 4$

$\boxed{V = 300\ m^3}$

(b) $L = 4B$

Over flow rate = 500 lit/hr/$m^2$

$V_o = \frac{Q}{L \times B}$

$4B^2 = \frac{\frac{1.8 \times 10^6}{24}}{500}$

$B = 6.123$

$\boxed{L = 24.5\ m}$

21/7/2015  Environmental Engineering. (7)

1.) Determine $v_s$, if $V_0 = 700$ lit/hr/m² & % settlement $\eta = 60\%$. m/s.

$$V_0 = \frac{700}{1000} \text{ m/hr}$$

$$= \frac{700}{1000 \times 60 \times 60}.$$

$$v_s = \eta V_0.$$

$$= \frac{0.6 \times 700}{1000 \times 60 \times 60}.$$

$$\boxed{\begin{aligned} v &= 1.167 \times 10^{-4} \text{ m/s.} \\ v_s &= 0.01167 \text{ cm/s} \end{aligned}}$$

2.) Determine Mass of the sediment settled on the floor of Type - I settling Tank if Q = 3MLD. and concentration is 60 ppm. Take $G_{s\,bulk} = 1.9$ Assume 100% settlement $t = 6$ hr.

Given:

$Q = 3 \times 10^6$ lit/day. $\eta = 100\%$.

Amount of particles = 60 ppm. mg/lit. $t = 6$ hr.

$G_{bulk} = 1.9$ 60 mg/lit.

$$Q = \frac{V}{t}.$$

$$V = Q \times t.$$

$$= \frac{3 \times 10^6}{24} \cancel{\text{kg}} \times 6.$$

$$\boxed{V = 750,000 \text{ lit}}$$

$V_{silt} = 750,000 \times \frac{60}{10^6}$.

$= 45000000$ mg.

$V_{silt} = 45$ ~~kg~~ lit

$$\boxed{V_{silt} = 45 \text{ lit}}$$

20/7 Find:
(2) Qty of sludge deposited if the concentration ... and the % settled is 70%. Take $G_{bulk} = 2$.

$$G_m = \frac{\rho_{silt}}{\rho_w}$$

$$1.9 \times 1000 = \rho_{silt}$$

$$\rho_{silt} = 1900 \ kg/m^3$$

$$\rho_{silt} = \frac{Mass}{Volume}$$

$$1900 = \frac{Mass}{0.045}$$

$$Mass = 1900 \times 0.045$$

$$\boxed{Mass = 85.5 \ kg}$$

3.) Design a Type - I settling tank to treat Q = 12 MLD raw water. If t = 6 hr & $V_f$ = 0.3 m/min. Assume $V_0$ = 600 lit/hr/m$^2$.

$$V_f = \frac{Q}{L \times H_w}$$

$$V = Q \times t$$

$$= \frac{12 \times 10^6}{24} \times 10^{-3} \times 6$$

$$V = 3000 \ m^3$$

$$\boxed{H_w = 3.6 \ m}$$

$$\boxed{L = 108 \ m}$$

$$Q = \frac{V}{t}$$

$$V = Q \times t$$

$$V_0 = \frac{Q}{L \times B}$$

$$L \times B = Q / V_0$$

$$600 = \frac{\frac{12 \times 10^6}{24}}{L \times B}$$

$$L \times B = 833.33 \ m^2$$

$$V_f = \frac{Q}{B \times H_w}$$

$$B \times H_w = \frac{\frac{12 \times 10^6}{24 \times 60}}{0.3}$$

$$\boxed{B = 7.716 \ m}$$

4.) A circular tank having $D = 25m$, $H_w = 2.5m$ is used for treating 26,000 $m^3/day$ of raw water. There are 2 tanks of same dimension. Determine detention time & $V_o$ & weir loading.

Given:

$$Q = 26{,}000 \ m^3/day.$$

$$Q_b \text{ in one tank} = \frac{26000}{2}$$

$$= 13{,}000 \ m^3/day.$$

$$t = \frac{V}{Q}.$$

$$V = 0.11\, D^3 + \frac{\pi}{4} \times D^2 \times H_w$$

$$= 0.011 \times 25^3 + \left(\frac{\pi}{4} \times 25^2 \times 2.5\right)$$

$$V = \cancel{2945.935}\ 1399.059 \ m^3.$$

$$\text{Detention time} = \frac{V}{Q}.$$

$$= \frac{\cancel{2945.935}\ 1399.059}{\frac{13{,}000}{24}}.$$

$$= \cancel{5.438 \text{ hrs}}.$$

$$\boxed{\text{Detention time} = 2.582 \text{ hrs}}$$

$$\cancel{V_o = \frac{Q}{\frac{\pi \times D^2}{4}}}$$

(ii) $$V_o = \frac{Q}{\text{Surface Area}} = \frac{Q}{\frac{V}{H_w}}.$$

$$= \frac{\frac{13{,}000}{24}}{\left(\frac{1399.059}{2.5}\right)}$$

$$= 0.9679 \ m^3/hr/m^2.$$

$$\boxed{V_o = 23.229 \ m^3/day/m^2}$$

(iii) weir loading $= \dfrac{Q}{\pi \times D}$

$$= \frac{\frac{13000}{24}}{\pi \times 25} \quad m^3/s$$

$$= 6.8967 \; m^3/hr/m$$

$$\boxed{\text{weir loading} = 165.521 \; m^3/day/m}$$

3/8/2015







## SEDIMENTATION AIDED WITH COAGULATION.

## (TYPE - II SETTLING TANK).

* In case of plain sedimentation tank, fine particles like mud and colloidal particle do not settle down by gravity.
* Therefore it is necessary to make them larger in size to settle down.
* Generally chemicals called coagulants are added to water coming from Type - I settling tank show that the chemicals produce floc (or) gel which attracts colloidal particles to make them large in size and hence they easily settle down on the floor of Type - II settling tank.
* The most commonly used coagulant is : Alum ($Al_2(SO_4)_3 \cdot 18H_2O$)
* (Aluminium sulphate)
* Alum reacts with the alkali ($Ca(HCO_3)_2$ - calcium bi carbonate,
  $CaCO_3$ - Calcium carbonate
  $CaO$ - Lime) and not with the water.
* If alkali is not present in the water then we have to add lime.

* Alum reacts with the alkali and produces Aluminium hydroxide as floc, Calcium sulphate and carbondioxide

* $CaSO_4$ - imparts permanent hardness to the water and

$CO_2$ - corrodes the pipe line.

## Advantages Of Using Alum:

* It produces relatively clear water
* It also removes colour
* It is easy to handle.
* Recently Alum can be seperated from the colloidal particles after collecting the sludge from the bottom of ~~Type~~ ~~settling~~ tank
* It is cheap.

* → The dose of alum is 85 mg/lit for turbid water. and 5 mg/lit for relatively clear water.

→ In general the dose of alum is about 17 mg/lit.

$$Al_2(SO_4)_3 \cdot 18H_2O + 3Ca(HCO_3)_2$$

Aluminium sulphate (Alum) — Calcium bicarbonate (Alkali)

$$\rightarrow 3CaSO_4 + 2Al(OH)_3 + 6CO_2 + 18H_2O$$

$CaSO_4$ (Permanent hardness); $Al(OH)_3$ (Floc); $CO_2$ corrodes the pipeline; $H_2O$ water.

$$3\,Ca(HCO_3)_2 = 3\,CaCO_3 + 3\,CO_2 + 3H_2O.$$

$$= 3CaO + 6CO_2 + 3H_2O.$$

ENVIRONMENTAL ENGINEERING

$$Al_2(SO_4)_3 \cdot 18H_2O + 3Ca(HCO_3)_2 \longrightarrow 3CaSO_4 + 2Al(OH)_3 + 6CO_2 + 18H_2O$$

Al – 27
S – 32
O – 16.
H – 1
Ca – 40.
C – 12.

$Al_2(SO_4)_3 \cdot 18H_2O$

$= (2\times27) + 3(32+4(16)) + 18((2\times1)+16)$

$= \underline{\underline{666}}$

$3\,Ca(HCO_3)_2$.

$= 3\left[40 + 2(1+40+3(16))\right]$

$= \underline{\underline{486}}$.

$3\,CaSO_4 = 3\left[40+32+64\right]$.

$= 408$.

$2\,Al(OH)_3 = 2\left[27+3(16+1)\right]$

$= 156$

$6\,CO_2 = 6\left[12+2(16)\right]$

$= 264$.

$18H_2O = 18(2(1)+16)$.

$= 324$.

$3\ CaCO_3 = 3(40+12+3(16))$

$= \underline{\underline{300}}$.

$3\ CaO = 3\ (40+16)$.

$= \underline{\underline{168}}$.

1) Determine quantity of alkali $(Ca(HCO_3)_2)$ kg/d to be added to 10MLD of water if the dose is 15 ppm. Also determine the quantity of lime.

Solution:

Alum dose. = 15 mg/lit.

For 10 MLD of water.

$= 10 \times 10^6 \times 15$.

$= 150 \times 10^6$ mg/day

1 mg of alum produces $= \frac{486}{666}$ mg of $Ca(HCO_3)_2$

Qty of $Ca(HCO_3)_2$ required. $= \frac{486}{666} \times 150 \times 10^6$ mg/day.

$= 109.459$ kg/day.

Qty of CaO required $= \frac{109.459 \times 168}{486}$

$= 37.838$ kg/day.

2.) Determine total qty of sludge produced per day while treating 15 MLD of water. Take dose of alum = 10 ppm and $G_s = 2.3$.

Solution:

1 mg of Alum contains $= \frac{156}{666}$ parts of $2Al(OH)_3$

$$10 \text{ ppm} = \frac{10 \times 156}{666} \text{ mg/lit}$$

$$15 \text{ MLD} = 15 \times 10^6 \times \frac{10 \times 156}{666}$$

$$= 35.135 \times 10^6 \text{ mg/day}$$

weight of $2Al(OH)_3$ $= 35.135 \times 10^3$ g/day.

$$G_s = \frac{\gamma_s}{\gamma_w}$$

$\gamma_w = 9.81$

$$2.3 = \frac{\gamma_s}{\gamma_w}$$

$$\gamma_s = 2.3 \times 1$$

$$\frac{W}{V} = 2.3$$

$$V = \frac{35.135 \times 10^3}{2.3}$$

$$V = 15276.14 \text{ cm}^3$$

$$V = 0.0152 \text{ m}^3/\text{day}$$

$$\boxed{V = 15.2 \text{ lit/day}}$$

3.) a) Determine ~~total~~ quantity of hardness produce during ~~treatment~~ of 15ML of water where dose of alum is 17ppm.

(b) In the above question determin volume of sludge produces if the suspended solid is 35 ppm and remaining turbitity after coagulatio is 10 ppm. Take $G_s = 2.9$.

Solution:

1 mg of alum produce $= \frac{408}{666}$ mg of $CaSO_4$

15 MLD and 17ppm of alum produce $\Big\} = 15 \times 10^6 \times 17 \times \frac{408}{666}$

$\doteq 156.216$ kg/day

Amount of sludge settled $= 35 - 10$

$= 25$ ppm mg/lit

Amount of sludge settled $= \underset{mg/lit}{25} \times \underset{lit/day}{15 \times 10^6}$

$\doteq 375$ kg/day

Amount of $2Al(OH)_3$ setteled $= \frac{156}{666} \times 17 \times 15 \times 10^6$

$= 59.73$ kg/day.

$G_m = \frac{\rho_s}{\rho_w}$

$2.9 \times 1000 = M/V_s$

$V_s = \frac{375 + 59.73}{1000 \times 2.9}$

$V_s = 0.149906 \; m^3/day$

$V_s = 149.9$ lit/day.

4) Determine Qty of alum required to treat 15MLD of water and also determine amount of $CO_2$ evolved if dose of alum is 17 ppm.

kg/day

225 kg/day.

101.08 kg/day.



Qty of alum $= 17 \times 15 \times 10^6$.

$= 255$ kg/day.

Qty of $CO_2$ produced $= \frac{264}{666} \times 17 \times 15 \times 10^6$

$= 101.08$ kg/day.

5) A type-II settling tank clarifies 50MLD. Dosage of alum is 16 mg/lit. If the raw water is having an alkalinity of 5 mg/lit. of $CaCO_3$, Determine the Qty of filter alum and quick lime (CaO) (containing 87% CaO) required per tons per year for the plant.

Solution:

alkalinity needed $= \frac{486}{666} \times 16$.

$\frac{300}{666} \times 16$.

$= 11.67$ mg/lit

$CaCO_3$ Alkalinity to be added $= 11.67 - 5$.

$CaCO_3$ to be added. $= 6.6756$ mg/li

$= \frac{6.6756 \times 168}{486}$

CaO =

CaO required $= 2.307$ mg/li

Amout of CaO actually to be added $\}$ = $\frac{2.307}{0.87}$

= 2.607 mg/lit

Total Qty of CaO needed = $\frac{2.607 \times 50 \times 10^6}{10^6}$

= 130.37 kg/day

= 47.585 ton/year

Qty of alum required = 16 × 50

= 800 kg/day.

= 292 ton/year.

$CaCO_3$ required = $\frac{300}{666} \times 16$.

= 7.207 mg/lit.

Excess $CaCO_3$ to be added $\}$ = 7.207 − 5.

= 2.207 mg/lit

CaO to be added = $\frac{168}{300} \times 2.207$.

= 1.236 mg/lit.

Total CaO to be added = $\left(\frac{1.236}{0.87}\right) \times 50$

Total CaO to be added = 25.928 ton/year

# AIR POLLUTION

→ Types of pollutants

→ Their sources and impacts

→ Air pollution Meteorology

→ Air pollution Control

→ Air quality standards and limits.

15/10/2015





# ENVIRONMENTAL ENGINEERING

1.

Types of sedimentation Tank.

* Intermittent Tank : ( Quiescent tank)

Water is completely brought to res

* Continous flow Tank :

Flow velocity of water is reduced. sufficient length of travel.

* Over flow rate (or) Surface Loading for Coagulation tank is 1000 – 1250 lit/hr/m$^2$

* By decreasing the overflow rate very fine particles are also gets settled. Therefore in order to increase the efficiency overflow rate should be reduced.

* Depth doesn't have any effect on the efficiency of sedimentation tank.

* Detention time for coagulation tank is ~~to~~ 2 to 4 hrs.

* Chlorinate copperas (Ferric sulphate):

Copperas (Ferrous sulphate + lime).

* optimum alum dosage may be determined by Jar Test.

* Flocculation - agglomeration.

* Filters:

Mechanism of filtration:

1. Mechanical ~~static~~ straining.
2. Sedimentation and Adsorption.
3. Biological metabolism.
4. Electrolytic changes.

1. Mechanical straining:

The particles of suspended matter that are larger in size than the size of the voids, are arrested and removed by the action of mechanical straining.

2. Sedimentation and adsorption:

The interstices (voids) between the sand grains act as a ~~in~~ minute sedimentation tank in which particles will settle and adhere to the sides of sand grains. Also the colloidal particles held in the voids and on the surface act as a gelatinous material, and attracts the other fine particles.

3. Biological Metabolism:

The bacteria which are caught in the voids of the sand grains utilize organic impurities present in water and convert them into harmless compounds by complex bio chemical reaction.

The harmless compounds so formed are deposited at the surface of the sand in the form of a layer which contains a zoological. ~~ge~~ jelly in which the biological activities are at their highest; This layer is called the schmutzdecke. (Dirty skin) This layer farther helps in ~~absorbing~~ absorbing and straining out the impurities.

4. Electrolytic Action:

Some of the sand grains of filter are charged with electricity of some polarity, hence when the particles of suspended and dissolved matter having electricity of opposite polarity when coming to contact with such sand grains they neutralize each other and results in changing chemical characteristic of water.

# FILTRATION

1. Filtration is a process of water treatment where the water is passed through a bed of porous medium like sand layer to remove turbidity, colour, very ~~very~~ fine colloidal matter and especially pathogenic bacteria.
2. Filtration is generally adopted after Coagulation.
3. There are three types of filter :
   (a) Slow sand filter
   (b) Rapid gravity filter
   (c) Pressure filter
   (d) Combination of rapid gravity and pressure filter is called Rapid sand filter.
4. Slow sand filter was developed by Mr. Simpson in (U.K) 1829
5. Slow sand filter can remove turbidity upto 50mg/lit ~~only~~.
6. Slow sand filter has very high efficiency of bacterial removal about 98 to 99%
7. The filtration rate is very low, 100 to 200 lit/hr/$m^2$
8. Slow sand filter is suitable only for small town, under ~~un~~developed country, industrial use.
9. Rapid gravity filter was developed by Mr.Fuller (U.S.A) and improved by Mr.Wallace and Morrell.
10. Rapid gravity filter can remove turbidity upto 35mg/lit only.
11. The efficiency of Rapid gravity filter is lower than that of slow sand filter.
12. According to Mr.Wallace, the approximate number of filter unit in a plant may be given by the relation,

$$\boxed{n = 1.22\sqrt{MLD}}$$

13. The head loss during seepage of water through sand (Rapid sand) is 2.5m and the negative pressure head (or) suction head is 1.5m.
14. The size of filter unit is based on maximum daily demand (1.8 times of average daily demand)

$$Q_{max} = 1.8\ Q_{avg}$$

15.The surface area of filter unit is determined by Interpolation,

$$\text{Surface area} = \frac{\text{Max daily demand}}{\text{Rate of filtration}}$$

$$\text{Surface Area} = \frac{Q_{Max}}{\text{Rate of filtration}}$$

$$\text{Surface area} = \frac{1.8\,[\text{Population x average daily demand per head}](\frac{lit}{day})}{\text{Rate of filtration (lit/day/sq.m)}}$$

$m^2$.

16.Comparison between Rapid sand filter and slow sand filter

| ITEM | SLOW SAND FILTER | RAPID GRAVITY FILTER |
|---|---|---|
| Filter sand size | 0.2mm to 0.4mm | 0.35 to 0.55 |
| Uniformity coefficient of sand, $C_u = \frac{D_{60}}{D_{10}}$ | 1.8 to 2.5 | 1.2 to 1.8 |
| Size of each unit | 100 to 2000 $m^2$ [30 x 60m] | 10 to 80 $m^2$ [3 x 8m] |
| Pretreatment requirement | Coagulation is not at all required but plain sedimentation may be adopted. | Coagulation and plain sedimentation is compulsory. |
| Economy | High initial cost of land and material but low operation and maintenance cost | Low initial cost but higher operational & maintenance cost, cheaper than slow sand. |
| Flexibility | Not flexible for meeting variation in demand | Quite flexible |
| Suitability | Small town, village, industry, hotter place, now a days it became obsolete. | Widely used for public water supply system and major town |
| Quantity of wash water | Very small quantity (0.2 to | Larger amount, 1-5% of |

| | | |
|---|---|---|
| | 0.6% of total water filtered) | total water filtered |
| Period of cleaning | 1 – 3 month interval | 1 – 3 days interval |
| Post treatment | Slight disinfection | Disinfection is must |
| Base material | The gravel supports the sand, the size of the gravel is 3mm to 65 mm and the depth of base is 30cm to 75cm | Size of gravel is 3mm to 40mm and depth is 60cm to 90 cm |
| Loss of head | 0.8m to 1.2m (Initial loss 10cm) | 2.5 to 3.5m (initial loss is 30cm) |
| Method of cleaning | Scrapping and removing the top 1.5cm to 3cm thickness | Backwash and agitating |
| Construction process | Simple method | Complicated |
| Supervision | No skilled supervision | Requires skilled supervision |
| Under drainage system | To remove filtered water only | To remove filter and backwash |

17.Pressure filter :

(a) It is a small rapid gravity filter placed in a closed vessel where pressure applied on water is very high [300 to 700kPa] (30 to 70m head of water).

(b) The rate of filtration is 2 to 5 times of Rapid gravity filter i.e6000 to 15000 lit/hr/$m^2$ but its efficiency is less than rapid gravity filter.

(c) The diameter of the closed vessel is 1.5 to 3m and the length may vary from 3.5 to 8m.

22/9/2015




# FILTRATION:

1. Determine the size of each filter unit where 6 filter units are used keeping 1 as stand by. use following dagta

(a) Population = 60,000
(b) Per captia demand = 160 lit/head/day.
(c) Rate of filtration = 150 lit/hr/m².
(d) L = 2B.
(e) $Q_{max} = 1.8 \times Q_{avg}$.

$Q_{avg} = 60000 \times 160$.
$= 96,00,000$ lit/day.
$= 4,00,000$ lit/hr.

$Q_{max} = 1.8 \times 4,00,000$
$= 7,20,000$ lit/hr.

Surface area $= \frac{720,000}{150}$.
$= 4800 m^2$

Area of one unit $= \frac{4800}{5}$
$= 960 m^2$

surface area = 960.
$L \times B = 960$.
$2B^2 = 960$.
$B = \cancel{6n928}\ 21.9 \simeq \cancel{7}\ 22$.

$\boxed{\cancel{B = 7m} \quad \cancel{L = 14m}}$ $\boxed{B = 22m \quad L = 44m}$

Ashwin · M
S-R-R.



# TERZAGHI INSTITUTE

## ENVIRONMENTAL ENGINEERING

### DISINFECTION (PURIFICATION OF WATER)

1. Disinfection is a process of purification of water which is very essential to kill pathogenic bacteria coming out from filter bed (after filtration).
   During filtration all pathogenic bacteria are not killed and hence it is very essential to disinfect the water coming from filtration process before supplying to the public distribution system.

2. There are following minor methods of disinfection :
   (a) Boiling of water
   (b) Treatment with excess lime
   (c) Treatment with potassium permanganate ~~KMnO~~ $KMnO_4$.
   (d) Treatment with ozone
   (e) Treatment with bromine and iodine
   (f) Treatment with silver electrolyte
   (g) Treatment with ultra violet ray (UV ray)

3. The major method of disinfection is chlorination which is used widely all over the world.

4. Chlorination is the best method of disinfection due to the following reasons.
   (a) It is cheap
   (b) It is reliable
   (c) It is easy to measure
   (d) It has capacity to control or protect recontamination of water supply in future
   (e) The supply of drinking water will be safe for a long duration
   (f) It is not unstable like ozone
   (g) It is easily mixed with water without any costly equipment

5. The chlorine mixed with water reacts with water only when the $P_H$ value is more than 5

6. During chemical reaction b/n water and chlorine, hypochlorous acid (Hocl) takes place along with Hcl. The Hypochlorous acid is the most destructive agent to kill bacteria. It is 80 times more destructive than Hypochlorite ion. ($OCl^-$)

   Hocl
   $HOCl^-$

7. Hypochlorous acid gets dissociated when the $P_H$ value of water increases from 7 and hence for effective chlorination the $P_H$ value of water is kept slightly less than 7 (5 – 7).

   5 – 7 – 8

8. If the $P_H$ value of water is more than 8 (then Hocl is dissociated) in to $H^+$ and $OCl^-$ where $OCl^-$ is called hypochlorite ion which is not so destructive as HoCl.

9. The free chlorine in water indicates about mixture or presence of chlorine gas ($Cl_2$), Hocl and OCl.

10. The dose of chlorine is dependent on the source of water and it is determined experimentally in the lab.

11. The dose of chlorine is the total quantity of chlorine given to water such that the residual chlorine after ten minutes of mixing shall not be less than 0.2 mg/lit (p.p.m)

12. If the chlorine is added to the water, it reacts with in organic substance present in water like iron, manganese to form chlorides and hence the residual becomes nil.

13. If the chlorination is continued then all bacterias present in water are killed and the graph rises at an angle less than $45^0$ where the residual chlorine is less than dose of chlorine.

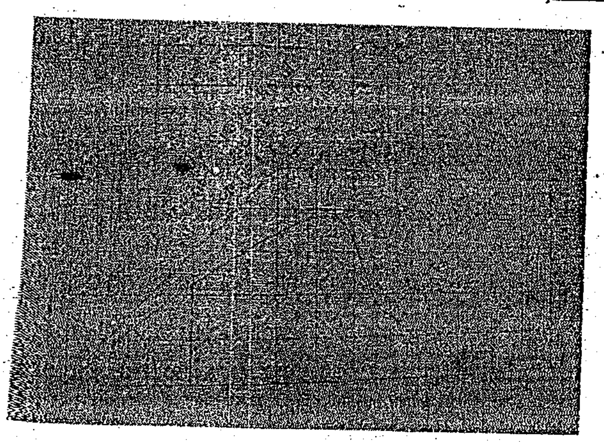
14. If the chlorination is further continued then the organic matters gets oxidixed and hence the graph falls down suddenly where residual chlorine is very very less than the dose of chlorine.

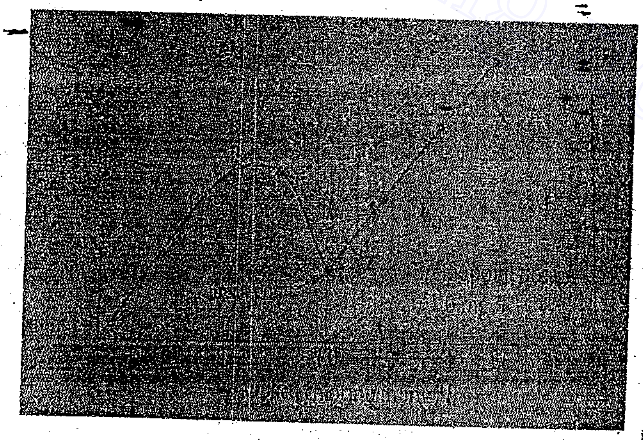
15. After chlorination of organic matter, the supply of chlorine appears as free chlorine and at that point of chlorination the type of chlorination is called Break point chlorination where the supply of chlorine is not consumed at all and hence appears as free chlorine.

16. The dose of chlorine is determined at the breakpoint only, before it, it is not safe.

17. The residual chlorine is generally adopted at break point chlorination.

18. The chlorine demand is equal to
Dose of chlorine – residual chlorine (free chlorine)
Demand = dose (Supply) – residual chlorine (Free chlorine)

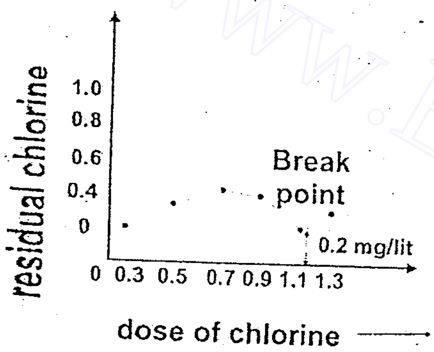




NUMERICALS :

1) Determine dose of chlorine at breakpoint and demand of chlorine. Also determine chlorine demand at dose of 1.3 ppm.

| Sample | Chlorine dose (ppm) | Residual chloride after 10 mins contact (ppm) |
|---|---|---|
| 1 | 0.3 | 0.19 |
| 2 | 0.5 | 0.36 |
| 3 | 0.7 | 0.5 |
| 4 | 0.9 | 0.48 |
| 5 | 1.1 | 0.2 |
| 6 | 1.3 | 0.4 |
| 7 | 1.5 | 0.6 |
| 8 | 1.7 | 0.8 |




Dose of break point = 1.1 mg/lit

Residual chlorine = 0.2 ppm

Demand = 1.1 – 0.2

= 0.9 mg/lit

Demand at 1.3ppm = dose – residual

= 1.3 – 0.4

= 0.9 mg/lit

Note : After breakpoint demand will never change.

2) Determine the quantity of bleaching powder required to treat the water to serve a population of 25000 at a demand of 160 l/head/day. Assume bleaching powder contains 30% of chlorine. Take chlorine dose 0.4 ppm. Consider 1 year duration.

**Solution :** 0.4 mg/l

Total quantity of water = population x demand per head

= 25000 x 160 lit/day

= $4 \times 10^6$ lit/day

Dose of chlorine = 0.4 mg/lit

So, to treat 1 litre of water, quantity of chlorine required is 0.4 m

To treat $4 \times 10^6$ lit/day of water, qty. of chlorine is,

$= (0.4 \times 4 \times 10^6) / (1000 \times 1000)$

$= 1.6$ kg/day

$= 1.6 \times 365$ kg/yr

$= 584$ kg/yr

So, 30 kg of chlorine is contained by 100 kg of bleaching powder.

Hence, 1 kg of chlorine contained by 100 kg of bleaching powder = 100/30

584 kg/yr of chlorine contained by 100kg of bleaching powder,

$= (100/30) \times 584 = 1946.67$ kg/yr

$= 1.946$ ton /yr

**IMPORTANT NOTES :**

- $Cl_2 + H_20 = HoCl + Hcl$ ($P_h > 5, P_h < 7$)
- $HoCl = H^+ + OCl^-$ ($Ph > 8$)

3) Determine the dose and demand of chlorine in ppm if total chlorine supplied is 8 kg/day and total quantity water is 20,000 $m^3$/day. The residual chlorine 10 minutes is 0.2 ppm.

**Solution :**

$$\text{Dosage} = \frac{\textit{quantity of chlorine}}{\textit{quantity of water}} = \frac{80 \times 1000 \times 1000}{20000 \times 1000} = 0.4 \text{ ppm}$$

Demand at 1.3ppm = dose – residual

$= 0.4 - 0.2$

$= 0.2$ ppm

**TYPES OF CHLORINATION :**

(a) Plain chlorination
(b) Pre chlorination
(c) Post chlorination or chlorination
(d) Double chlorination (pre and post chlorination)
(e) Break point chlrination
(f) Super chlorination
(g) Dechlorination

**A) PLAIN CHLORINATION :**

It indicates about only the chlorine treatment and no other treatment given to the raw water. It helps in removing bacteria, organic matter and colour from the water. The quantity of chlorine required is about 0.5 mg/lit (ppm) or more

**B) PRE CHLORINATION :**

It is the process of applying chlorine to the water before filtration or before sedimentation – coagulation. It helps in removing taste, odour, algae. The dose of chlorine should be such that the residual should be about 0.1 to 0.5 ppm. The normal dose is 5 to 10 ppm.

**C) POST CHLORINATION :**

It is also called chlorination which is adopted after filtration. The dose of chlorine should be such that the residual chlorine is 0.2 mg/lit.

**D) DOUBLE CHLORINATION :**

The pre chlorination and post chlorination are generally used in double chlorination.

**E) BREAK POINT CHLORINATION :** (Residual chlorine – 0.2 mg/lit)

It is a term which gives an idea of the extent of chlorine added to water which is determined from the graph plotted between dose of chlorine on x axis and residual chlorine on y axis.

**F) SUPER CHLORINATION :**

It is a term which indicates the addition of chlorine of excessive amount of chlorine to the water during epidermic or in highly polluted water. In this case the residual chlorine is very high (1 to 2 ppm) and the dose is about 5 to 15 ppm

**G) DE CHLORINATION :**

It is generally required to remove excess chlorine from water such that the residual chlorine is 0.2 mg/lit. Generally sulphur di oxide, activated carbon, sodium bi sulphate, ammonia and sodium thio sulphate are used for dechlorination.

**MINOR METHODS OF DISINFECTION :**

**a) Boiling of water :**

The bacteria present in water can be destroyed by boiling it for a long itme but it is not at all used for disinfecting public supply.

**b) Treatment with excess lime :**

Lime is generally used for softening the water. It kills the bacteria if excess lime is added to the water i.e 14 to 43 mg/lit of excess lime is required to remove bacteria about 99 – 100% but the $P_h$ value of water increases. The $P_h$ value of water becomes 9.5.

**c) Treatment with ozone :**

Ozone gas is a faintly blue gas and it is an excellent disinfectant but it is unstable. The dose of ozone is about 2 – 3 ppm so that the residual ozone is 0.1 ppm after a contact of 10 mins. The residual ozone is tested by orthotolidine. In India, ozone is used in Chandigarh.

**d) Treatment with Iodine and Bromine :**

The quantity of Iodine and Bromine is about 8ppm but they are not used for trating large quantity of water for public supply. It may be used for private plants, army troops, swimming pools.

**e) Treatment with ultra violet rays :**

Ultra violet rays are invisible light having wavelength 1000 to 4000 microns. They are basically found in sunlight and they can be produced by electric current passing through mercury in quantity bulb. UV rays are highly effective in killing bacterias but water should be less turbid and colour less. It is very costly and hence unsuitable for public water supply. It may be used for treatment of water in hospital, minor factories and swimming pool.

Quartz

**f) Treatment with potassium permanganate :**

It is used for disinfecting well water in villages. The quantity of $KMnO_4$ is about 0.1 mg/lit. The contact period is 4 to 6 hours. And the normal dose is about 1 – 2 mg/lit. It can remove about 98% bacteria. Therefore it is not recommended for public water supply, it is mainly used for rural areas.

**g) Treatment with Silver :**

In this method metallic silver, iron are introduced in the water and a direct current of 1.5 volt is supplied. The contact period is about 10 mins to three hours. But it is very costly and hence not adopted for treating public supply.

Notes :

1) Quantity of free chlorine to kill virus :

| Types of virus | Qty. of free chlorine after 30mins contact |
|---|---|
| Polio | 0.1 mg/lit |
| Hepatitis | 0.4 mg/lit |
| Ameobic dysentry | 3 mg/lit |
| T.B | 3 mg/lit |
| Coxsaickie | 2.1 mg/lit to 138 mg/lit |

2) The commercial name of hypochlorite is HTH (High test hypochlorite) (ccl)

3) The chemical name of bleaching powder is chlorinated lime or calcium oxy chlroite ($Caocl_2$)

4) Bleaching powder contains chlorine about 30% but calcium hypochlrite contains 60 to 70% of chlorine.

5) Sometimes chloramine is used as disinfectant which is formed by the reaction between ammonia and chlorine.

6) Sometimes chlorine di oxide gas ($ClO_2$) is used as disinfectant which is 2.5 times stronger than chlorine.

**TEST OF CHLORINE :**

The amount of residual chorine left in the chlorinated water can be experimentally determined by using any of the following test.

DPD TEST

**1) DPD TEST : (Diethy phenylene diamine)** DPD

It is widely used in modern age generally 10ml of water is taken as sample and DPD is used to detect the presence of chlorine. It has been developed by BDH (British Drug House)

**2) STARTCH IODINE TEST :**

In this test, 5ml of starch is mixed with 10ml of potassium iodine and with the help of titration method the presence of chlorine is determined. It is very costly and laborian therefore it is not used for public supply.

**3) CHLOROTEX TEST :**

It has been developed by British drug house where 5ml of chlorotene mixed with 50ml of water if the colour developed is pink the the residual chlorine will be 0.2 ppm but if it is white in colour, then there is no chlorine at all. If it is blue in colour then residual chlorine is more than or equal to 1 ppm.

**4) ORTHOTOLIDINE :**

In this test 10ml of water is mixed with 0.1ml of orthotolidine and if the colour is yellow then the chlorine is present.

# TRANSPORTATION ENGINEERING

## HIGHWAY PLANNING:

→ Geometric Design Of Highway

→ Testing and specification of paving materials

→ Design of Flexible and Rigid Pavements

## TRAFFIC ENGINEERING:

→ Traffic characteristics

→ Theory of Traffic Flow

→ Intersection Design

→ Traffic signs and signal design

→ Highway Capacity

# TRANSPORTATION ENGINEERING

## HIGHWAY PLANNING:

→ Geometric Design Of Highway

→ Testing and specification of paving materials

→ Design of Flexible and Rigid Pavements

## TRAFFIC ENGINEERING:

→ Traffic characteristics

→ Theory of Traffic Flow

→ Intersection Design

→ Traffic signs and signal design

→ Highway Capacity.

# MUNICIPAL SOLID WASTES

→ Characteristics

→ Generation

→ collection and transportation of Solid wastes

→ Engineered systems for solid waste management [Reuse/Recycle, Energy recovery, treatment and disposal]

# NOISE POLLUTION

→ Impacts of Noise

→ Permissible limits of Noise pollution

→ Measurement of noise pollution

→ Control of noise pollution.

T. SIDDHARTH

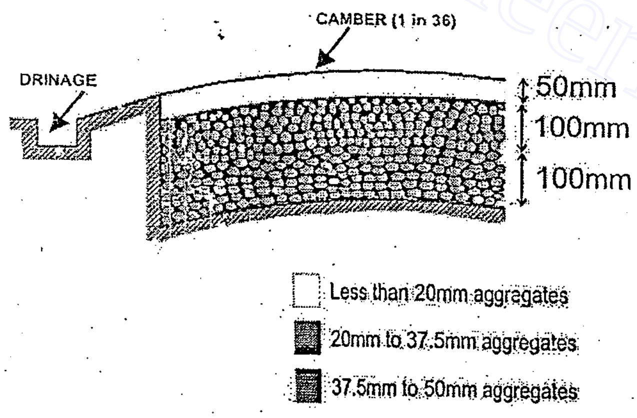
# TERZAGHI INSTITUTE

## TRANSPORTATION

Railway – 1 Degree of freedom

### DEVELOPMENT AND PLANNING OF HIGHWAY:

1) Highway is a mode of transportation having two degrees of freedom.
2) The road density is the length of road in km per 100 $km^2$ area.
3) The highest road density in the world is Japan (296 km per 100 $km^2$ area) and the second highest road density of the world is Netherland. The lowest road density is Afganisthan.
4) **Mr. JOHN MACADAM (1827) :**
   i. He is called as Father of Modern Roadway.
   ii. He was surveyor general of London (U.K).
   iii. He suggested not to use large boulder.
   iv. He suggested to use only 25cm thickness of pavement in three different layers as shown in figure.
   v. According to him the cross slope (Camber) should be 1 in 36 to drain of rain water.




JOHN MACADAM PAVEMENT

5) **JAYAKAR COMMITTEE :**

i. In India, the development of road was investigated under the chairmanship of Mr. Jayakar (1927)

ii. Mr. Jayakar suggested to setup CRF (Central Road Fund) and IRC (Indian Road Congress)

| ACTS | YEAR |
|---|---|
| Central Road Fund – CRF | 1929 |
| Indian Road Congress – IRC | 1934 |
| Central Road Research Institute CRRI | 1950 |
| Motor Vehicle's Act | 1939 |

6) **20 YEAR ROAD DEVELOPMENT PLAN :**

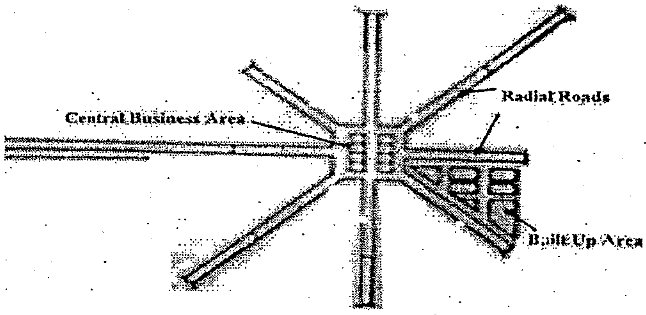
| PLAN | AREA | YEAR | ROAD DENSITY | GUIDANCE |
|---|---|---|---|---|
| 1st 20 year plan | Nagpur | 1943 – 1963 (1961 finished) | 16 km | IRC |
| 2st 20 year plan | Bombay | 1961 – 1981 | 32 km | IRC |
| 3rd 20 year plan | Lucknow | 1981 – 2001 | 82 km | Ministry of shipping and transport of India |

7) ROAD PATTERNS :

- Rectangular or Block Pattern
- Star and Block Pattern
- Star and Grid Pattern
- Radial and Circular Pattern

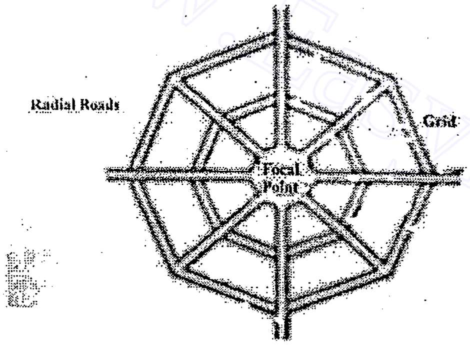
Star and Block Pattern :

Radial (Star) and Block Pattern

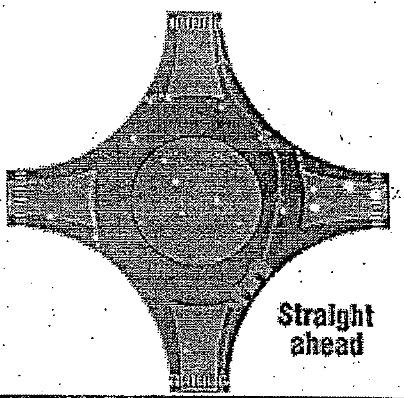



Star and Grid Pattern:

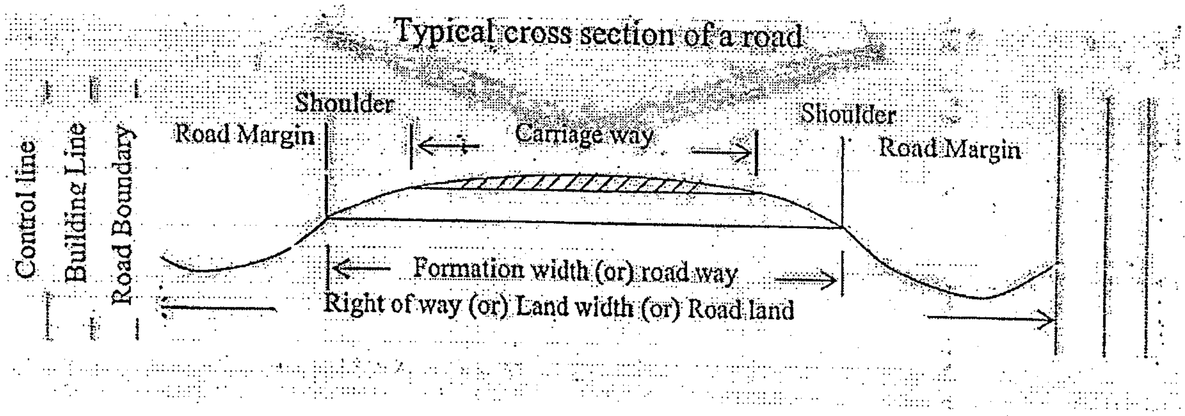
Radial (Star) and Grid Pattern




Radial and circular pattern:

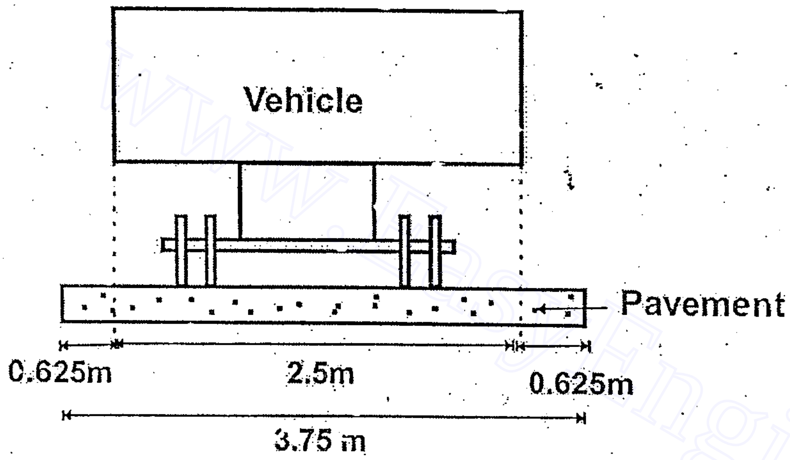


## 8) CROSS SECTION OF A ROAD :

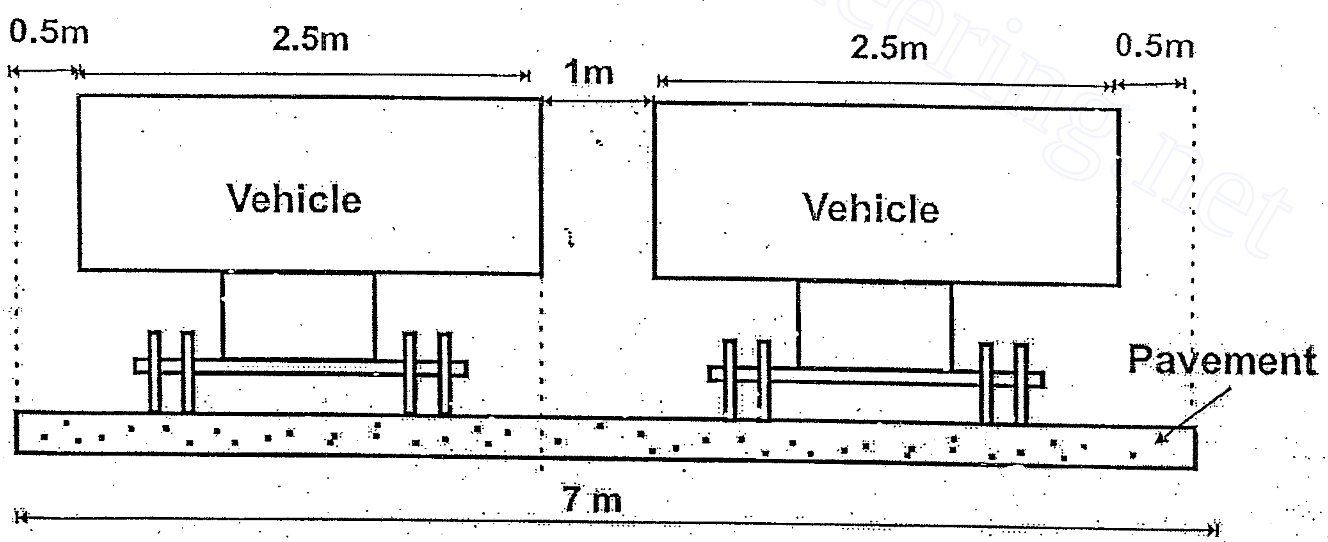



## 9) TYPES OF LANE :

**Single lane :**




**Double lane :**



## 10) CLASSIFICATION OF ROADS :

- According to Nagpur road development plan, Roads are classified into five types.
  1. National Highway (NH)
  2. State Highway (SH)
  3. Major District Roads (MDR)
  4. Other District Roads (ODR)
  5. Village Roads (VR)

  → Rural roads

- According to Lucknow road development plan, Roads are classified into three types.

  Yamuna to Gurgaon → Express way
  1. Primary Roads (expressway and National Highway)
  2. Secondary Roads (State highway and Major District Road)
  3. Tertiary Roads (Other District Road + Village Road = Rural Road)

11) According to Lucknow Road Plan,

1. Length of National Highway $= \frac{A}{50}$ (Area in km$^2$)
2. Total length of State Highway $= \frac{A}{25}$ (or) $62.5N - \frac{A}{50}$ (whichever is greater)

   N → No. of towns or cities
3. Total length of MDR $= \frac{A}{12.5}$ (or) 90 N (whichever is greater)
4. Total length of Rural Road $= \frac{82}{100} x\, A_{Total} - NH - SH - MDR$

12) According to IRC, there are following values of road dimensions :

| S. No | TYPE OF ROAD | MINIMUM WIDTH OF PAVEMENT (CARRIAGE WAY) |
|---|---|---|
| 1 | Single lane | 3.75 m |
| 2 | Double lane without kerb | 7.0m |

→ Min. width of pavement (carriage way)

| | | |
|---|---|---|
| 3 | Double lane with kerbs | 7.5m |
| 4 | Intermediate carriage way | 5.5m |
| 5 | Multi lane | 3.5m per lane |
| 6 | Residential area road | 3m |
| 7 | Village road | 3m |

| S. No | TYPE OF ROAD | min WIDTH OF FORMATION (ROAD WAY) |
|---|---|---|
| 1 | National Highway (NH) | 12 m |
| 2 | State Highway (SH) | 12m |
| 3 | Major District Roads (MDR) | 9m |
| 4 | Other District Roads (ODR) | 7.5m (single lane) and 9m (double lane) |
| 5 | Village Roads (VR) | 7.5m |

13) The minimum roadway width of Single lane bridge is 4.25 m

14) According to Lucknow road development plan, there are four types of urban roads :

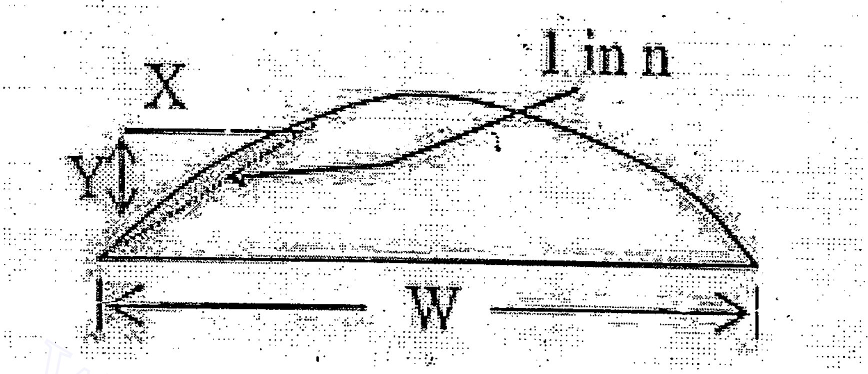
| S.No. | TYPE OF ROAD | SPEED |
|---|---|---|
| 1 | Arterial Road | 80 km/hr |
| 2 | Sub Arterial road | 60 km/hr |
| 3 | Collector's ~~road~~ Street | 50 km/hr |
| 4 | Local street | 30 km/hr |

15) **CAMBER OR CROSS SLOPE :**

To drain off the rain water from the road surface.

**Type of Camber based on shape :**

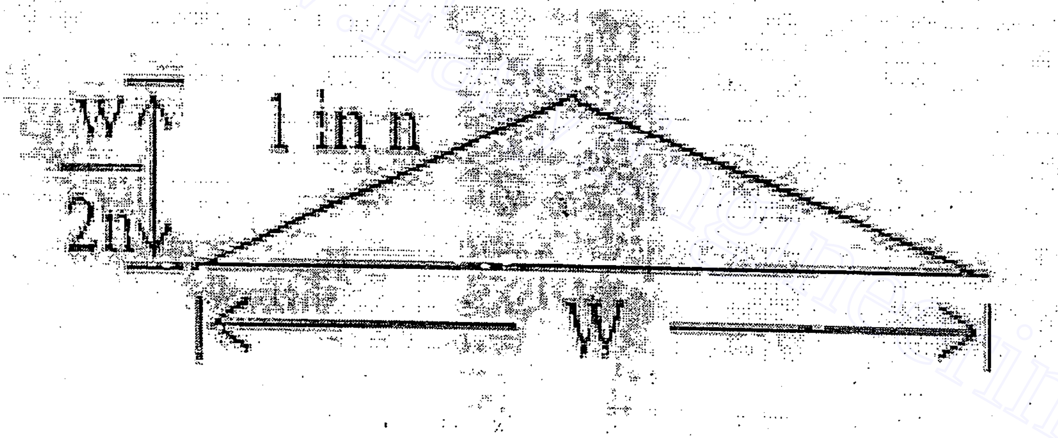
(a) Parabolic or elliptic shape



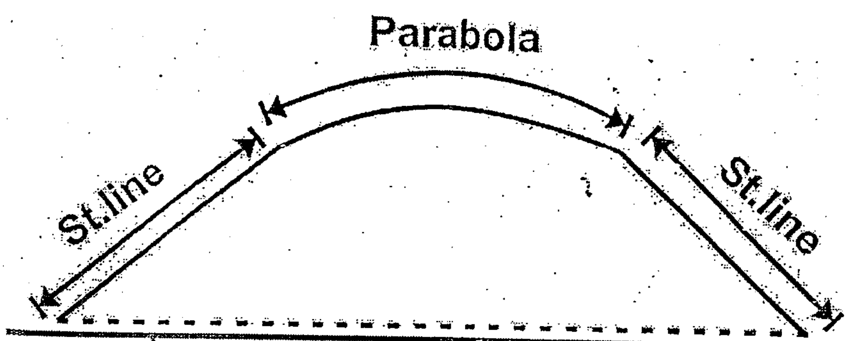

$1 \rightarrow y$

$n \rightarrow x$

b) Straight line camber:




c) Combination of straight and parabolic slope:

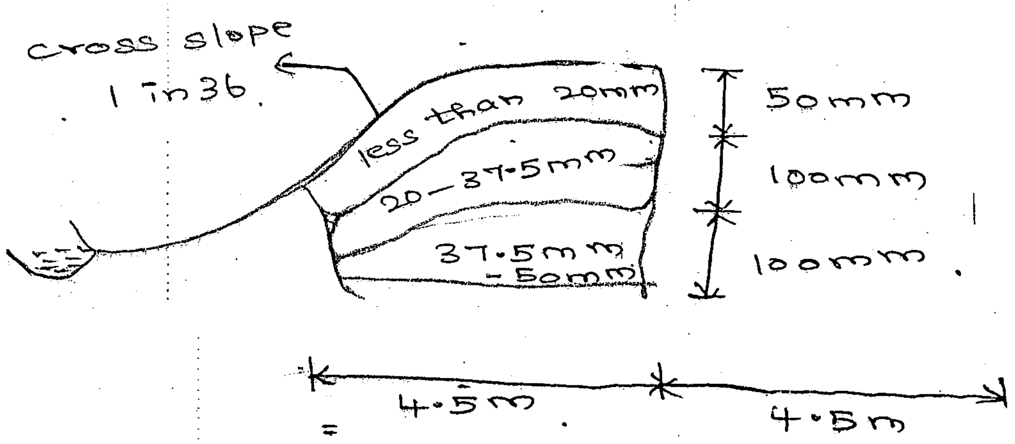


**Recommended values of camber for different types of road surfaces:**

| S.No | Type of road surface | Range of camber in areas of rainfall range | |
|---|---|---|---|
| | | **Heavy** | **Light** |
| 1 | Cement concrete and high ~~type~~ quality bituminous surface | 1 in 50 (2%) | 1 in 60 (1.7%) |
| 2 | Thin bituminous surface | 1 in 40 (2.5%) | 1 in 50 (2.0%) |
| 3 | WBM, gravel | 1 in 33 (3%) | 1 in 40 (2.5%) |
| 4 | Earthen Road | 1 in 25 (4%) | 1 in 33 (3%) |

# TRANSPORTATION ENGINEERING.

## Planning and Development of Highways




* John Macadamoan (1827) is the father of modern roadway.
* He was the surveyor general of London.
* He suggested only 25cm thickness of pavement in 3 different layers as shown in the above figure.
* According to him the cross slope (camber) should be 1 in 36. to drain of rain water.
* Highway is a mode of transportati having 2 degrees of freedom.
* The road density is the length of road in Km/100 Km² area.
* In India the road development was investigated under the chairmanshi of Mr. Jayakar. (1927).

* Mr. Jaykar suggested to set up IRC (1934) and CRF (1929).

* In India CRRI (1950) was started in 1950 in Delhi.

24/-5/2015 (3)

# TRANSPORTATION ENGINEERING.

## Rodad Development Plan in India:

### 1st 20 yr Road Plan:

* Nagpur (1943-1963)
* But complete in 1961.
* Road density 16 km/100 km² Area of India.
* Road classification
  - → NH
  - → SH.
  - → M.D.R
  - → O.D.R. } Rural Roads.
  - → village Road } Rural Roads.
* Under IRC. supervision.

### 2nd 20 yr Road Plan:

* Bombay. (1961 - 1981)
* Road density → 32 km/100 km² are
* IRC supervision.

### 3rd 20 yr Road Plan:

* Lucknow (1981 - 2001).
* Road density → 82 km/100 km².
* Under Ministry of shipping & Road Transport of India.

According to Nagpur road development plan there are following types of road.

(i) National highway. NH1 – Delhi-Ambala-Amritsar
(ii) State highway (SH)
(iii) major district road. (M.D.R)
(iv) other District road (O.D.R) } Rural roads
(V) Village Road

According to Lucknow Road Development there are 3 types of roads.

1. Primary Road (Expressway & N.H)
2. Secondary Road (S.H & M.D.R)
3.) Tertiary Road (O.D.R & village road)

According to Lucknow Road Development Plan.

(1.) Length of N.H = $\frac{A}{50}$. (Area in $km^2$)

(2.) Length of S.H. = $\frac{A}{25}$ (or) $62.5\,N - \frac{A}{50}$.

(Adopt greater leng

3.) Length of M.D.R. = $\frac{A}{12.5}$ (or) $90\,N$

N (No. of towns)

4.) Length of Rural Rod = $\left(\frac{82}{100} \times A_{total}\right) - N.H$

$- S.H - M.D.R$

Total area of India = $328 \times 10^6$ Ha.

$= 328 \times 10^6 \times 10^4 \ m^2$

$= \frac{328 \times \cancel{10^6} \times 10^4}{\cancel{10^6}}$ km

$= 328 \times 10^4 \ km^2$

Length of NH $= \frac{328 \times 10^4}{50} = 65600$ km

Length of SH $= \frac{328 \times 10^4}{25} = \cancel{80800}$ 131200 km

Length of M.D.R $= \frac{328 \times 10^4}{12.5} = \cancel{164000}$ 262400 Km.

$= \frac{82 \times 328 \times 10^4}{100} - 65600 - 131200 - \cancel{328000}$ 262400.

Length of Rural Road = 2230,400 km.

i) Total Area = 16,000 $km^2$.

N = 20 towns.

Solution:

Length of N.H $= \frac{16,000}{\cancel{2}50} = 320$ Km.

Length of S.H $= \frac{16,000}{25} = 640$ km

$= (62.5 \times 20) - 320 = 930$ km.

Length of S.H = 930 km.

Length of M.D.R $= \frac{16,000}{12.5} = 1280$ km.

$= 90 \times 20 = 1800$ km.

Length of M.D.R = 1800 km.

Length of Rural road

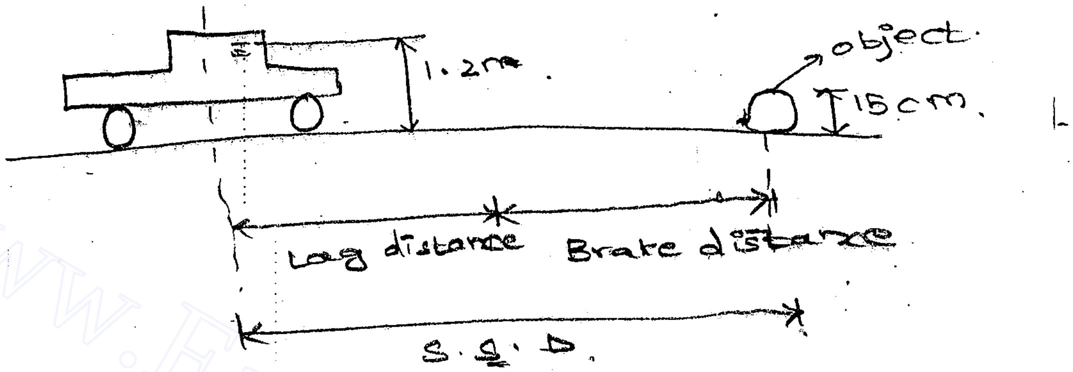
$$= (0.82 \times 16000) - 320 - 930 - 1800$$

$$= 10,070 \text{ km}.$$

# Geometrical Design of Highway

## Stopping Sight Distance (S.S.D):

$\frac{1}{2} \times$ I.S.D, (or) Head light. Distance (or) Non-passing distance.




Lag distance ($d_1$):

$$\text{Speed} = \frac{\text{distance}}{\text{Time}} \rightarrow \text{Reaction time}$$

According to IRC reaction time for S.S.D = **2.5 seconds.**

(Based on PIEV theory)

$$d_1 = \text{velocity of vehicle} \times \text{Reaction time}$$

$$= 0.278\, Vt$$

$V \rightarrow$ in km/hr

$t \rightarrow$ seconds

Lag distance depends upon

* Velocity of vehicle.
* Reaction time

Brake distance ($d_2$) :

Kinetic Energy = Frictional workdone in stopping the vehicle

$$\frac{1}{2} \times m \times v^2 = F_f \times d_2.$$

$$\frac{1}{2} \times m \times V^2 = \mu R \times d_2.$$

$R = W$

$\mu = f$.

$$\frac{1}{2} \times \frac{\cancel{W}}{g} \times V^2 = f \times \cancel{W} \times d_2$$

$$d_2 = \frac{(0.278 V)^2}{2 \times g \times f}.$$

$$\boxed{d_2 = \frac{v^2}{254 f}}$$

$$S.S.D = 0.278\ vt + \frac{V^2}{254 f}.$$

S.S.D on a rising gradient.

$$S.S.D = 0.278 Vt + \frac{V^2}{254 (f+n)}.$$

S.S.D on a falling gradient.

$$S.S.D = 0.278\ Vt + \frac{V^2}{254 (f-n)}$$

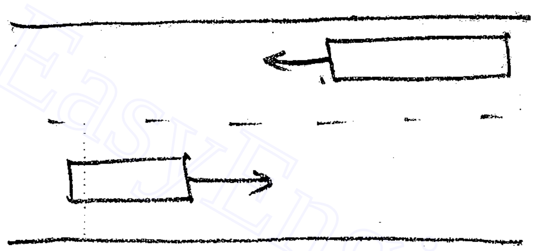
General formula.

$$S.S.D = 0.278 Vt + \frac{V^2}{254 [f \pm n]}.$$

S.S.D:

Safe distance b/w moving vehicle with the driver's eye level at a height of 1.2m above the road surface and an object of 15cm high, ~~prona~~ so that collision ~~ca~~ can be ~~altered~~ averted in case of stopping the vehicle.

S.S.D in case of double lane and 2 way traffic. (or) single lane, one way traffic.



$$\boxed{S.S.D = S.S.D}$$

S.S.D in case single lane 2 way traffic:

$$S.S.D = S.S.D_1 + S.S.D_2.$$

$$\underset{(I.S.D)}{S.S.D} = 2 \times S.S.D \quad [v_1 = v_2)$$

Braking distance : dependent on

(a) velocity of vehicle

(b) Co-efficient of longitudinal friction

(c) Longitudinal gradient of road

(d) Road characteristics.

(e) Efficiency of brake.

Co-efficient of longitudinal friction as per IRC.

| Velocity (km/hr) | "f" |
|---|---|
| 0 – 20 | 0.4 |
| 40 | 0.38 |
| 50 | 0.38 |
| 60 | 0.36 |
| 65 | 0.36 |
| 80 | 0.35 |
| 100 | 0.35 |

1) Find the minimum sight distance to avoid head on collision of 2 cars approaching @ 90 km/hr and 60 km/hr use reaction ~~dri~~ time of driver 2.5 f = 0.7 and $\eta$ = 50% in either case.

$$S.S.D = S.S.D_1 + S.S.D_2$$

$$= (0.278 \times 90 \times 2.5) + \left(\frac{90^2}{254 \times 0.35}\right) + (0.278 \times 60 \times 2.5) + \left(\frac{60^2}{254 \times 0.35}\right)$$

$$S.S.D. = 285.83 \text{ m.}$$

2.) Calculate  S.S.D for V = 50 km/hr

for (a) 2 way traffic in a 2 lane road

(b) 2 way traffic in a single lane road.

Take f = 0.37 and t = 2.5 s.

Soln :

V = 50 km/hr.

(a) 2 way - 2 lane Road.

$$S.S.D = S.S.D.$$
$$= (0.278 \times 50 \times 2.5) + \frac{50^2}{254(0.37)}$$
$$\boxed{S.S.D = 61.35\,m.}$$

(b) 2 way - single lane Road.

$$S.S.D = 2 \times S.S.D.$$
$$= 2 \times 61.35.$$
$$\boxed{S.S.D = 122.7\,m.}$$

3.) Determine the co-efficient of longitudinal friction such that $d_2 = d_1$ on a 2% rising gradient. Take ~~speed~~ $V = 50$ k

Soln :

$$d_1 = d_2.$$
$$0.278 \times \cancel{V} \times t = \frac{V^{\cancel{2}}}{254(f+n)}$$
$$0.278 \times 2.5 \times 254\left(f + \frac{2}{100}\right) = 50.$$
$$\boxed{f = 0.263.}$$

26/8/2015 (7)

# TRANSPORTATION ENGINEERING

## SUPERELEVATION (OR) CANT (OR) BANKING (km/hr)

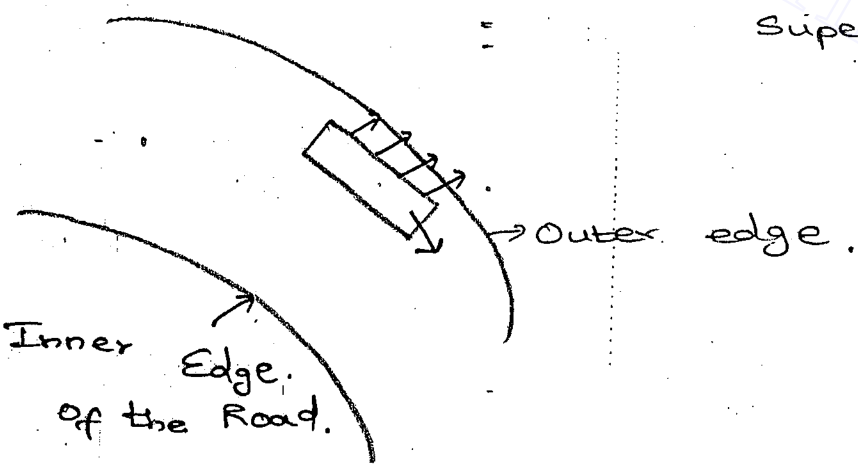
**Super elevation:**

It is a transverse slope provided along the width of road. to counteract the centrifugal force at the curved section so, that the vehicle will be in equilibrium in transverse direction to have full design speed along the length of the road.

Super elevation takes care of both over turning and skidding.

**SUPER ELEVATION:**

Highway on a Curve without Superelevation.



 T-SIDDHARTH



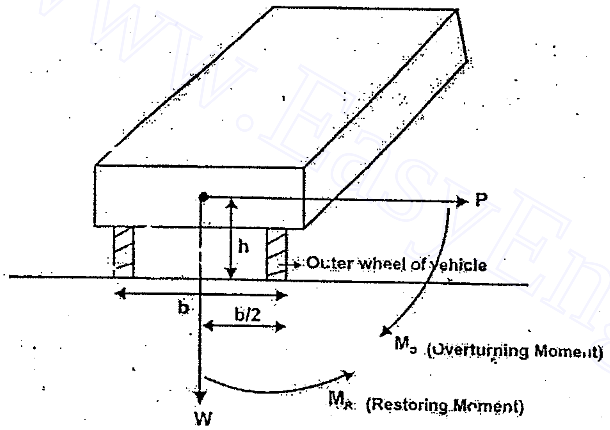
# TERZAGHI INSTITUTE

## TRANSPORTATION

### SUPER ELEVATION : → along the width of road

1. The transverse slope provided for roadway to develop centripetal force to counteract centrifugal force at the curve section, so that the vehicle will be in equilibrium in transverse direction to have full design speed along the length of the road is called as Super elevation or Cant or Banking.
2. Super elevation takes care of both overturning and skidding.
3. The symbol used for super elevation = e = $\tan\theta$ (or) = slope

✓ **BASED ON OVERTURNING:**




For safety,

$M_R > M_O$

$w \times \frac{b}{2} > P \times h$

$\frac{b}{2h} > \frac{P}{w}$

$\frac{b}{2h} > \frac{\frac{mv^2}{R}}{mg}$

$\therefore \frac{b}{2h} \geq \frac{v^2}{gR}$

$M_O$ → Overturning moment

$M_R$ → Restoring moment

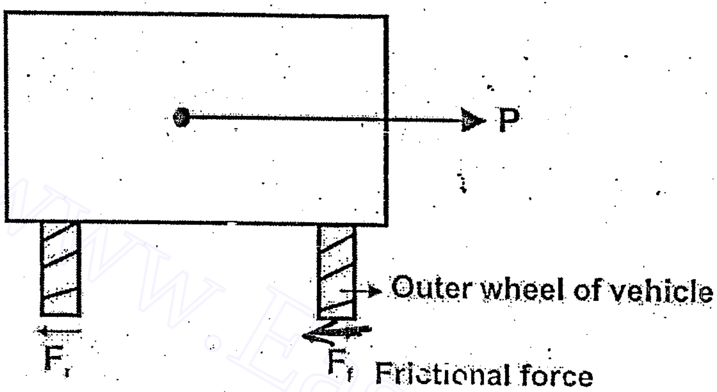
$$\frac{b}{2h} > \frac{\left(\frac{1000}{60 \times 60} V\right)^2}{9.81 \times R}$$

$$\frac{b}{2h} > \frac{v^2}{127\,R}$$

$$\therefore \quad e > \frac{v^2}{127R}$$

$$\boxed{\frac{P}{W} = \frac{v^2}{gR} = \frac{v^2}{127R} \text{ (Centrifugal ratio)}}$$

✓ **BASED ON SKIDDING :**




For safety,

$F_f \geq P$

$\mu \times w \geq P$

$\mu \geq \frac{P}{w}$

$\mu \geq \frac{P}{mg}$

$\therefore \mu \geq \frac{v^2}{gR}$

$f \geq \frac{v^2}{127R}$ → $\cancel{\left(\frac{1000}{60*60}\right)^2} v$

$\therefore \; e + f \geq \frac{v^2}{127R}$

$\boxed{According\ to\ IRC, f(coefficient\ of\ lateral\ friction) = 0.15}$

$f > \frac{P}{W}$

$f \geq \frac{\cancel{m}v^2/R}{\cancel{m}g}$

$\because P = \frac{mv^2}{R}$

$f \geq v^2/Rg$

$\geq \frac{\left(\frac{1000}{60*60} v\right)^2}{R*9.8}$

$\geq \frac{v^2}{R\,127}$



v → Design Speed in Km/hr

R → Radius of curve in m

4. For equilibrium Cant (Super elevation), the inner and outer wheel experience equal pressure,

$$e = \frac{v^2}{gR} = \frac{v^2}{127R}$$

Neglect "f" if it is equilibrium cant

5. If super elevation is not possible, then

$$f = \frac{v^2}{gR} = \frac{v^2}{127R}$$

6. For mixed traffic condition, $\Rightarrow \boxed{V = 0.7 V_d}$

$V_d \Rightarrow$ Design speed

$$e = \frac{v^2}{225R}$$

**Maximum super elevation (as per IRC):**

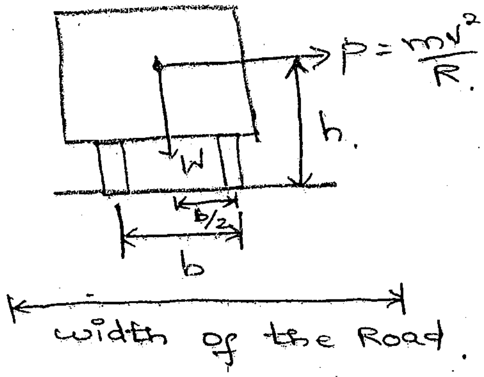
| Super elevation | Terrain |
|---|---|
| e ≤ 7% (1 in 15) | In plain and rolling terrains |
| e ≤ 10% (1 in 15) | Mountain zone without snow |
| e ≤ 4% | Urban road |

* Import in TNPSC

| Transverse Slope | Terrain |
|---|---|
| 0 to 10% | Plain zone |
| 10 to 25% | Rolling zone |
| 25 t0 65% | Mountainous zone |
| > 65% | Valley zone |

*

Downloaded From : www.EasyEngineering.net




a) Safety Against Overturning:

Overturning moment $(M_o) = P \times h$.

Resisting moment $(M_R) = W \times b/2$.

For safety,

$$M_R \geq M_o$$

$$\frac{W \times b}{2} \geq P \times h$$

$$\frac{b}{2h} \geq P/W$$

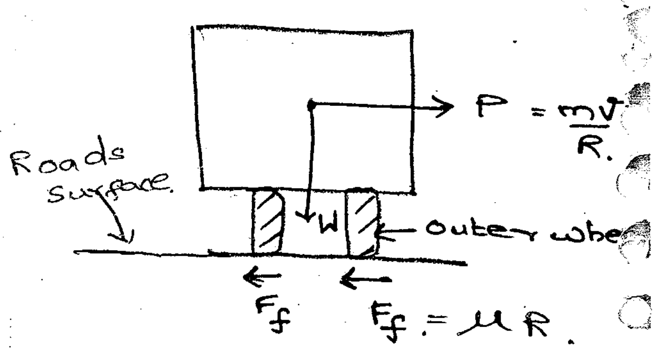
$$\frac{b}{2h} \geq \frac{(mv^2/R)}{mg}$$

$$\frac{b}{2h} \geq \frac{v^2}{gR}$$

$$\boxed{\frac{b}{2h} \geq \frac{V^2}{127R}}$$

(b) Safety Against Skidding.






$$F_f \geq P$$

$$\mu R \geq P$$

$$\cancel{f N \geq \frac{mv^2}{R}}$$

$$f \times W \geq \frac{mv^2}{R}$$

$$f \geq \left( \frac{\frac{mv^2}{R}}{mg} \right)$$

$$f \geq \frac{v^2}{gR}$$

$$\boxed{f \geq \frac{V^2}{127R}}$$

$$e + f \geq \frac{V^2}{127R}$$

e = in %
V – km/hr
R – m

$$e + f = \frac{V^2}{127R}$$

For equilibrium cant, the inner and outer wheel should experience equal pressure [neglect f].

$$\boxed{e = \frac{V^2}{127R}}$$

If super elevation is not possible.

$$\boxed{f = \frac{V^2}{127R}}$$

For mixed traffic condition:

$V = 0.75 \times V_{design}$. $\quad e = \frac{(0.75V)^2}{127R}$

$$\boxed{e = \frac{V^2}{225R}}$$

| Topography | Transverse slope (natural) |
|---|---|
| Plain zone | 0 to 10 % |
| Rolling zone | 10% to 25% |
| Mountaineous zone | 25% to 65% |
| Valley zone. | > 65%. |

| Topography | Max. super elevation. |
|---|---|
| 1.) Plain and Rolling Topography | $e \leq 7\%$. |
| 2.) Mountaineous Terrain | $e \leq 10\%$. |
| 3.) Urban | $e \leq 4\%$ |

1.) The design speed on a road having radius 100 m. is 400 km/hr. Determine e if $f = 0.15$.

$$e = \frac{V^2}{127R} - f$$

$$= \left(\frac{40^2}{127 \times 100}\right) - 0.15.$$

$$e = -0.02$$

∴ Super elevation need not to be provided

$$e = 0.$$

2.) $V = 80$ kmph, $R = 250$ m, Determine

* $e$ if $f = 0.15$. (plain zone)
* equilibrium cant
* $f$ if $e$ is not possible

Solution:

* $$e = \frac{V^2}{127R} - f$$

$$= \left(\frac{80^2}{127 \times 250}\right) - 0.15$$

$$e = 0.0515$$

$$e = 5.15\%$$

* $$e = \frac{V^2}{127R} = \frac{80^2}{127 \times 250} = 0.2015$$

$$e = 20.15\%$$

Not ok.

$V = \sqrt{e \times 127 \times R}$

$= \sqrt{0.07 \times 127 \times 2}$

$\boxed{V = 47 \text{ kmph}}$

* $$f = \frac{V^2}{127R} = 0.2015.$$

$$f = 0.2015.$$

Not ok

$V^2 = f \times 127 \times R.$

$V = \sqrt{0.15 \times 127 \times 25}$

$\boxed{V = 69 \text{ (or) } 65 \text{ km}}$

Note:

centrifugal ratio is $\frac{P}{W}$ (or) $\frac{V^2}{gR}$ (or) $\frac{V^2}{127R}$

3.) V = 100 kmph, R = 450 m, Determine the central rise and Rise of outer edge. Take total width 7.5m .. plain and rolling zone.

Solution :

$$e = \frac{V^2}{225R} = \frac{100^2}{225 \times 450} = 9.88\% > 7$$

Restrict $e = 7\%$

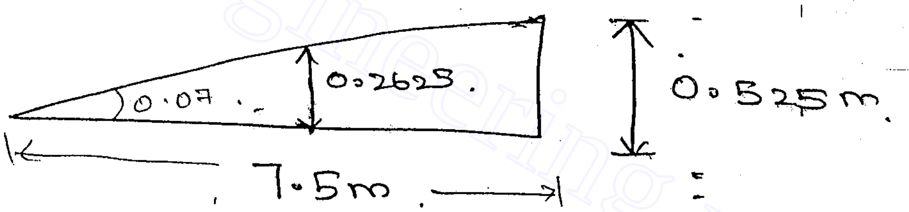
$$e + f = \frac{V^2}{127R}$$

$$f = \frac{100^2}{127 \times 450} - 0.07$$

$= \cancel{0.245}$

$= 0.105 < 0.15$

$\therefore e = 0.07$




$$\frac{x}{7.5} = 0.07$$

$x = 0.07 \times 7.5$

Rise @ outer edge. $x_1 = 0.525\,m$

Rise @ centre $x_2 = \frac{0.525}{2} = 0.2625\,m$

4) R = 100m , V = 50 kmph , f = 0.15 . Find rate of super elevation if full lateral friction is consider.

$$e = \frac{V^2}{127R} - f$$

$$= \left(\frac{50^2}{127 \times 100}\right) - 0.15$$

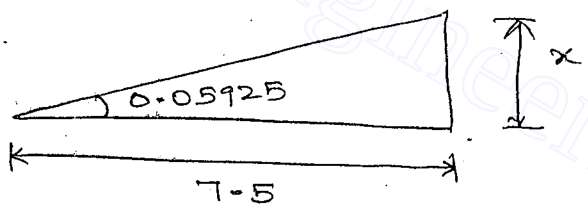
$$= 0.046$$

$$e = 1 \text{ in } 21.35$$

5) R = 480m , B = 7.5m , V = 80km/hr . The rising of outer edge of pavement w.r.t inner edge, to cater to the mixed traffic condition is ________

$$e = \frac{V^2}{225R}$$

$$e = 0.05925 \text{ m}$$




$$x = 0.05925 \times 7.5$$

$$\boxed{x = 0.44 \text{ m}}$$

## Camber For Different Types Of Roads.

| S.NO | Type Of Road | Camber (transverse slope) Heavy rainfall zone | Camber (transverse slope) Light rainfall zone. |
|---|---|---|---|
| 1. | Cement concrete Road and high quality Bituminous Surface | 1 in 50 (2%) | 1 in 60 (1.7%) |
| 2. | Thin bituminous surface. | 1 in 40 (2.5%) | 1 in 50 (2%) |
| 3. | Water bound Macadam. | 1 in 33 (3%) | 1 in 40 (2.5%) |
| 4. | Earthen Road. | 1 in 25 (4%) | 1 in 33 (3%) |

## Width Of Carriage Way

| S.NO | Classification. | Carriage Way. |
|---|---|---|
| 1. | Single lane. | 3.75m |
| 2. | Double lane without kerb | 7m |
| 3. | Double lane with kerb. | 7.5m |
| 4. | Intermediate Lane. | 5.5m |
| 5. | Multi lane. | 3.5m/lane. |

Width of Roadway (or) formation. } = Carriage way + Shoulders (Includes Median).

* Right of Way:
Area of land required for the road along its alingment.

width of Formation:

| Type of Road. | Width of formation |
|---|---|
| N.H | 12 m |
| S.H | 12 m |
| M.D.R | 9m |
| O.D.R | 7.5m (single lane) & 9m (Double) |
| V.R | 7.5m. |

* The minimum roadway width of a single lane / bridge = 4.25 m.

* According to Lucknow Road Development plan there are 4 types of urban (city roads).

| Types of Urban Road | Speed. |
|---|---|
| (i) Arterial Road. | 80 kmph |
| (ii) Sub-arterial Road | 60 kmph. |
| (iii) Collector's Road. | 50 kmph |
| (iv) Local street. | 30 kmph. |

* In Nagpur Road development plan adopted. Star and grid pattern is adopted.

Golden Quadrilateral Road Projection :



Total length - 5846 km.

City connected - Delhi, Kolkatta, Chennai, Mumbai.

Project cost - 58,000 crore.

NH4 - Madras ~~Chennai~~ - Banglore - Pune.

NH5 - Madras - Calcutta.

NH7 - Varanasi - Kanayakumari.

# SURVEYING

→ Importance Of surveying

→ Principles and classification

→ Mapping Concepts

→ Co-ordinate system

→ Map projections

→ Measurements of distance and directions.

→ Leveling

→ Theodolite traversing

→ Plane Table surveying

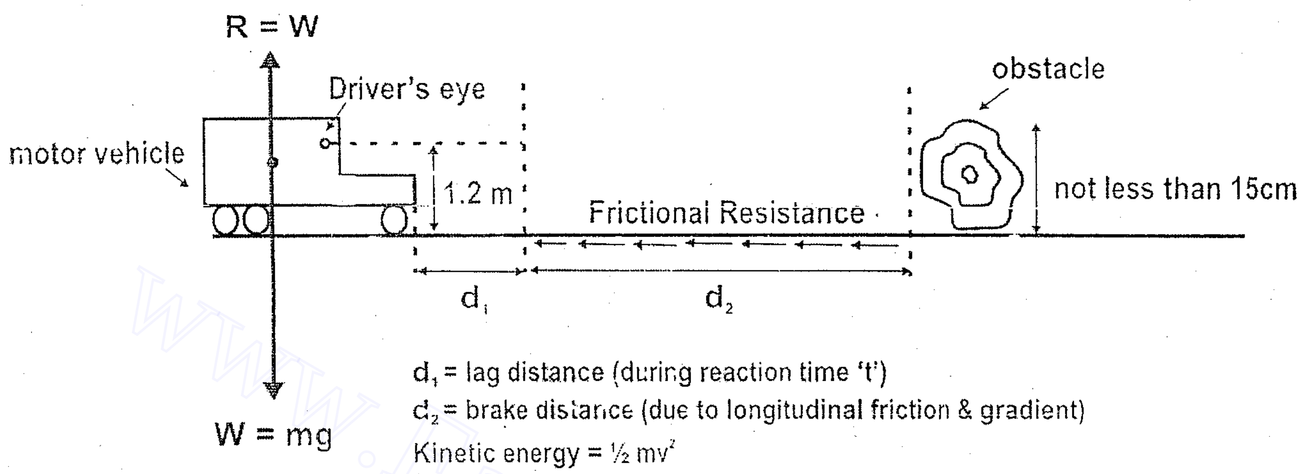
→ Errors and Adjustments

→ Curves.

# TERZAGHI INSTITUTE

## TRANSPORTATION

### SSD (STOPPING SIGHT DISTANCE / HEAD LIGHT DISTANCE / NON PASSING DISTANCE / HALF OF INTERMEDIATE SIGHT DISTANCE)




$d_1$ = lag distance (during reaction time 't')
$d_2$ = brake distance (due to longitudinal friction & gradient)
Kinetic energy = $\frac{1}{2} mv^2$
Frictional W.D = ($F_r$ x $d_2$)

✓ SSD is the safe distance between an obstacle on the road and the vision of the obstacle by driver's eye.

✓ SSD is dependent on

(a) Height of an obstacle (15cm)

(b) Driver's eye position above road (1.2m)

(c) Road characteristics.

✓ SSD is mainly dependent on

(a) Reaction time 't' (2.5 seconds)

(b) Velocity of the motor vehicle (v)

(c) Longitudinal friction (f)

(d) Efficiency of brake

(e) Gradient (longitudinal) of road

✓ **REACTION TIME :**

- Reaction time as per IRC is (t) = 2.5sec
- Reaction time is dependent on PIEV theory
  - **Perception :**
    - Sensation time from eye to brain via nerves.
  - **Intellection :**
    - Time required to understand the situation by brain.
  - **Emotion :**
    - Due to fear, anger and superstition.
  - **Volition :**
    - The final decision.

✓ **LAG DISTANCE :** ($d_1$)

- Lag distance is the distance travelled by motor vehicle during reaction time.

$d_1$ = velocity x time

$d_1 = v \times t$

where, t = 2.5 sec

$$d_1 = \frac{v \times 1000}{60 \times 60} t$$

$$\boxed{d_1 = 0.278vt}$$

here, v is in km/hr, t is in sec

- Lag distance is dependent on :
  - Speed
  - reaction time.
- It is independent of :
  - longitudinal friction.
  - longitudinal gradient.

## ✓ BRAKE DISTANCE : ($d_2$)

- Brake distance is the distance travelled by ~~one~~ vehicle after application of brakes.
- It is dependent on :
  - Velocity
  - Longitudinal friction
  - Gradient
  - Efficiency
- It is based on Kinetic energy of moving vehicle.

  Kinetic energy of moving vehicle = Friction Work Done

  K.E = Frictional W.D

  $\frac{1}{2} mv^2 = F_f x\ d_2$

  $\frac{1}{2} mv^2 = (\mu R) x\ d_2$

  $\frac{1}{2} mv^2 = (\mu W) x\ d_2$ $\quad \because W = mg$

  $\frac{1}{2} mv^2 = (\mu\ x\ mg) x\ d_2$ $\quad \mu = f \quad$ (IRC)

  $d_2 = \frac{V^2}{2gf}$

  where, f is the coefficient of longitudinal friction which is dependent on speed & the road characteristics.
- f = 0.4 to 0.35
- If the speed increases, the coefficient of longitudinal friction decreases.

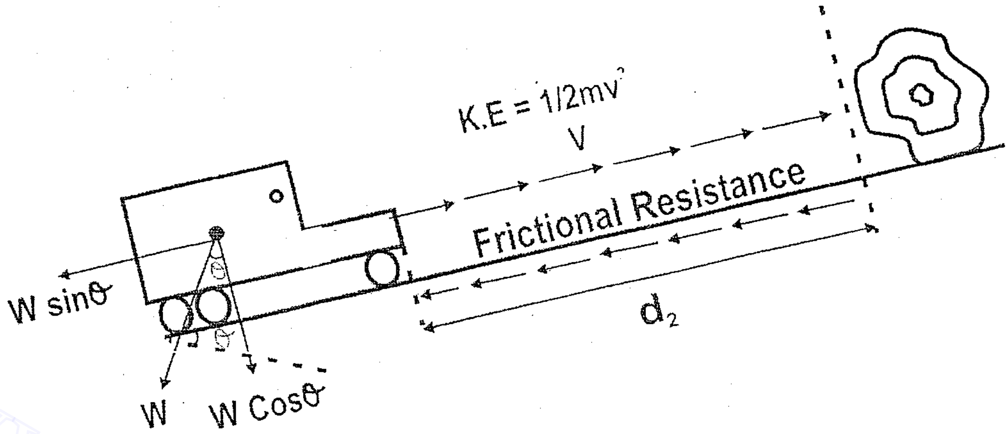
  $d_2 = \frac{\left(\frac{v\ x\ 1000}{60\ x\ 60}\right)^2}{2\ x\ 9.81\ xf}$

  $d_2 = \frac{V^2}{254f}$

  (d in 'm'; V in km/hr)

- ➢ Brake distance is dependent on gradient also (longitudinal)

✓ **BRAKE DISTANCE DUE TO RISING GRADIENT :**




K.E = Total work done in opposite direction

K.E = Force x distance

$\frac{1}{2} mv^2 = (F_f + W\sin\theta) \times d_2$

$\frac{1}{2} mv^2 = (\mu R + W\sin\theta) \times d_2$

$\frac{1}{2} mv^2 = (f \times W\cos\theta + W\sin\theta) \times d_2$

$\frac{1}{2} mv^2 = W(f\cos\theta + \sin\theta) \times d_2$

$\frac{1}{2} mv^2 = mg\,(f\cos\theta + \sin\theta) \times d_2$

$$d_2 = \frac{V^2}{2g} \times \frac{1}{[f\cos\theta + \sin\theta]}$$

if $\theta$ is small, cos o =1, $\sin\theta = \tan\theta = n$

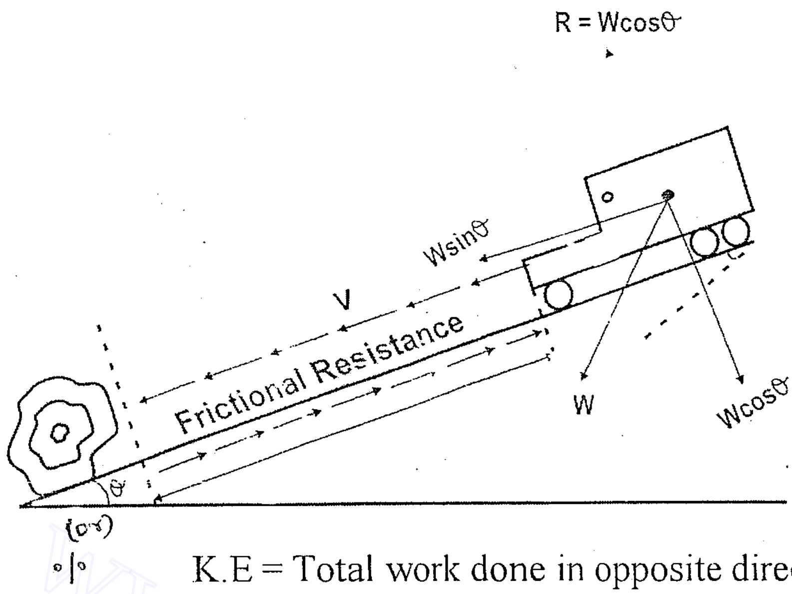
$$\therefore d_2 = \frac{V^2}{2g} \times \frac{1}{[f+n]}$$

$$d_2 = \frac{V^2}{254} \times \frac{1}{[f+n]}$$

$d_2$ decreases in rising gradient

## ✓ BRAKE DISTANCE DUE TO FALLING GRADIENT :

R may be in θ (or) %




K.E = Total work done in opposite direction

K.E = Force x distance

$\frac{1}{2} mv^2 = (F_f - WSin\theta) \times d_2$

$\frac{1}{2} mv^2 = (\mu R - WSin\theta) \times d_2$

$\frac{1}{2} mv^2 = (f \times Wcos\theta - WSin\theta) \times d_2$

$\frac{1}{2} mv^2 = W(f\, cos\theta - Sin\theta) \times d_2$

$\frac{1}{2} mv^2 = mg\,(f\, cos\theta - Sin\theta) \times d_2$

$$d_2 = \frac{V^2}{2g} \times \frac{1}{[f cos\theta - sin\theta]}$$

if $\theta$ is small, cos o =1, $sin\theta = tan\theta = n$

Rising gradient ⇒ +n

Falling gradient ⇒ −n

$$d_2 = \frac{V^2}{2g} \times \frac{1}{[f-n]}$$

$$d_2 = \frac{V^2}{254} \times \frac{1}{[f-n]}$$

$d_2$ increases in falling gradient

$$S.S.D = d_1 + d_2$$

$$= 0.278\, Vt + \frac{V^2}{254(f \pm n)}$$

✓ **FINAL SSD :**

- SSD = lag distance + Brake distance

$$\left[SSD = 0.278\ Vt + \frac{V^2}{254(f \pm n)}\right]$$

✓ **TWO LANES WITH TWO WAY TRAFFIC :**

$$SSD = Vt + \frac{V^2}{2g(f \pm n)}$$

✓ **SINGLE LANE WITH TWO WAY TRAFFIC :** ( Intermediate Sight Distance)

ISD $\cancel{SSD} = SSD_1 + SSD_2$

ISD $\cancel{SSD} = V_1 t_1 + \frac{V_1^2}{2g(f \pm n)} + V_2 t_2 + \frac{V_2^2}{2g(f \pm n)}$

$SSD = 2(SSD_1)$ [If $V_1 = V_2$]

**NOTE:**

The value of longitudinal friction as per IRC :

| VELOCITY (km/hr) | f |
|---|---|
| 20 - 30 | 0.4 |
| 40 | 0.38 |
| 50 | 0.38 |
| 60 | 0.36 |
| 65 | 0.36 |
| 80 | 0.35 |
| 100 | 0.35 |

# TERZAGHI INSTITUTE

## TRANSPORTATION

### OVERTAKING SIGHT DISTANCE (OSD) :

- ✓ OSD is the minimum distance open to the vision of a driver of a vehicle intending to overtake a slow moving vehicle safely against the vehicle in opposite direction.
- ✓ OSD is also called safe passing distance.
- ✓ Even though OSD is not required in some cases but the minimum value of OSD is provided is more than SSD.
- ✓ The minimum length of zone of overtaking shall be 3 times OSD and the desirable length of zone of OSD shall be 5 times OSD.
- ✓ The value of OSD is dependent on following factors (or) parameters :
  - (a) The speed of overtaking vehicle, $V_a$
  - (b) The speed of overtaken vehicle (slow moving), $V_b$
  - (c) Speed of vehicle from opposite direction, $V_c$
  - (d) Acceleration of overtaking vehicle, $a$
  - (e) Reaction time of driver of overtaking vehicle (fast moving), $t$ = 2 seconds
  - (f) Minimum distance between overtaking and overtaken vehicle, $S$
  - (g) The gradient of the road
- ✓ If the speed of Overtaken vehicle (Slow moving vehicle) is unknown, then it may be taken as (speed of fast moving vehicle – 16Km/hr.) $V_a = V_c$ ; $V_b = V_a - 16$ km/hr
- ✓ If the speed of the vehicle from opposite direction is not known then it may be taken as equal to the speed of fast moving vehicle or overtaking vehicle.
- ✓ Consideration of vehicle from opposite direction shall be made only when it is two way traffic (Two lanes). In case of single lane (one way traffic) vehicle from opposite direction shall not be considered.

- ✓ According to IRC, the minimum clearance distance between two vehicle must be $(6m + 0.7\ V_{slow\ moving\ vehicle})$ $\Rightarrow S = (6m + 0.7V_b)$
- ✓ The acceleration of overtaking vehicle is higher at slow speed and it is lower at fast speed.
- ✓ The value of total OSD is given as below :
  - ➢ OSD = $d_1 + d_2$ (Single lane – one way traffic)
  - ➢ OSD = $d_1 + d_2 + d_3$ (Double lane – two way traffic)
  - ➢ Minimum length of Overtaking zone = 3 x OSD
  - ➢ Desirable length of Overtaking zone = 5 x OSD

  Where,
  - ➢ $d_1 = V_b \times t$,  $t = 2$ sec

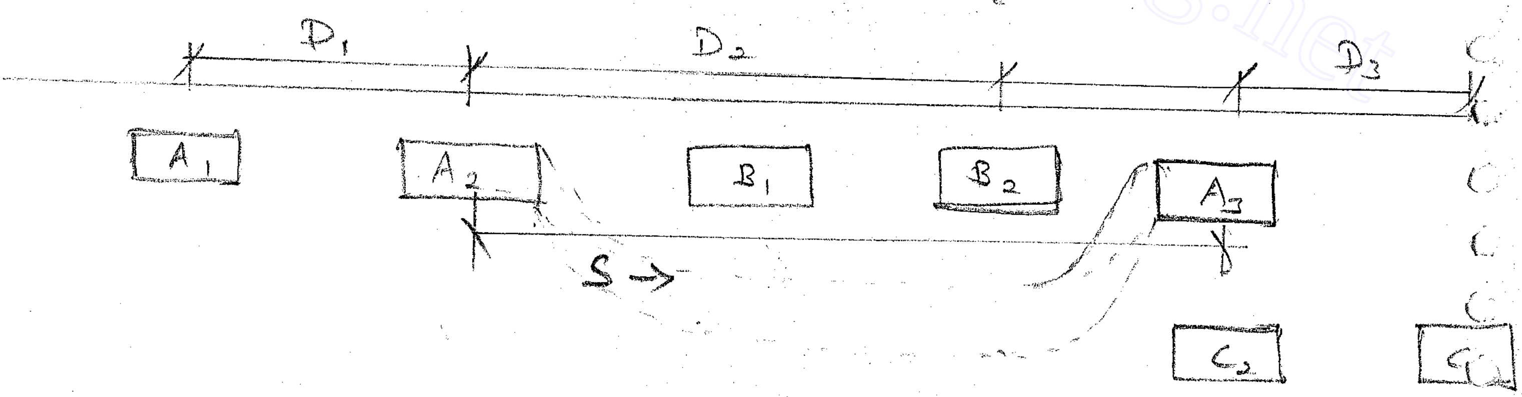
    $V_b$ (slow moving overtaken)
  - ➢ $d_2 = 2S + b$  $b = V_b \times T$

    $S = (6 + 0.7V_b)$

    S is the minimum clearance between the vehicles
  - ➢ $d_3 = V_c \times T$

    Take $V_c = V_a$ (if not given)

    $$T = \sqrt{\frac{4S}{a}}\ \text{sec}$$



# TERZAGHI INSTITUTE

## TRANSPORTATION

### OVERTAKING SIGHT DISTANCE (OSD) :

- ✓ OSD is the minimum distance open to the vision of a driver of a vehicle intending to overtake a slow moving vehicle safely against the vehicle in opposite direction.
- ✓ OSD is also called safe passing distance.
- ✓ Even though OSD is not required in some cases but the minimum value of OSD is provided is more than SSD. OSD > SSD
- ✓ The minimum length of zone of overtaking shall be 3 times OSD and the desirable length of zone of OSD shall be 5 times OSD.
- ✓ The value of OSD is dependent on following factors (or) parameters :
  - (a) The speed of overtaking vehicle $(V_a)$
  - (b) The speed of overtaken vehicle (slow moving) $(V_b)$
  - (c) Speed of vehicle from opposite direction $(V_c)$
  - (d) Acceleration of overtaking vehicle $(a)$
  - (e) Reaction time of driver of overtaking vehicle (fast moving) ($t$ = 2 s.)
  - (f) Minimum distance between overtaking and overtaken vehicle $(s)$.
  - (g) The gradient of the road
- ✓ If the speed of Overtaken vehicle (Slow moving vehicle) is unknown, then it may be taken as (speed of fast moving vehicle – 16Km/hr. ) $V_b = V_A - 16$ .
- ✓ If the speed of the vehicle from opposite direction is not known then it may be taken as equal to the speed of fast moving vehicle or overtaking vehicle. $V_c = V_A$.
- ✓ Consideration of vehicle from opposite direction shall be made only when it is two way traffic (Two lanes). In case of single lane (one way traffic) vehicle from opposite direction shall not be considered.

$O.S.D = d_1 + d_2 + d_3$ (2 lane)

$O.S.D = d_1 + d_2$ (1 lane)

- ✓ According to IRC, the minimum clearance distance between two vehicle must be ($6m + 0.7\ V_{slow\ moving\ vehicle}$) $S = (6 + 0.7V_b)$ m/s.
- ✓ The acceleration of overtaking vehicle is higher at slow speed and it is lower at fast speed. $V\uparrow\ a\downarrow$, $V\downarrow\ a\uparrow$
- ✓ The value of total OSD is given as below : $V \propto \frac{1}{a}$
  - ➢ OSD = $d_1 + d_2$ (Single lane – one way traffic)
  - ➢ OSD = $d_1 + d_2 + d_3$ (Double lane – two way traffic)
  - ➢ Minimum length of Overtaking zone = 3 x OSD
  - ➢ Desirable length of Overtaking zone = 5 x OSD

  Where,
  - ➢ $d_1 = V_b \times t$, → 2s.

    $V_b$ (slow moving overtaken)
  - ➢ $d_2 = 2S + b$ → $V_b T$. $b = V_b \times T$

    $S = (6 + 0.7V_b)$

    S is the minimum clearance between the vehicles
  - ➢ $d_3 = V_c \times T$

    Take $V_c = V_a$ (if not given)

    $$T = \sqrt{\frac{4S}{a}}\ \text{sec}$$

Note :

$V_a, V_b, V_c$ in m/s.

## OVERTAKING SIGHT DISTANCE (OSD):

* OSD is the minimum distance open to the vision of a driver of a vehicle intending to overtake a slow moving vehicle safely against the vehicle in opposite direction

* OSD is also called as safe passing distance

* Eventhough OSD is not required in some case but minimum value of OSD > SSD

* Minimum length of zone of overtaking shall be 3 times of OSD and desirable length of zone of overtaking sight distance shall be 5 times of OSD.

* The value of OSD is dependent on following factors (or) Parameters:
  (a) Speed of overtaking vehicle ($V_a$)
  (b) Speed of overtaken vehicle ($V_b$)
  (c) Speed of vehicle from opposite direction ($V_c$)
  (d) Acceleration of overtaking vehicle (a)
  (e) Reaction time of driver of overtaking vehicle (fast moving) (t)
  (f) Minimum distance between overtaking and overtaken vehicle (s)
  (g) The gradient of the road.

* If the speed of overtaken vehicle ($V_b$) is  unknown, then it may be taken as $V_a - 16$ (km/hr).

* If the speed of vehicle from opposite direction is not known then it may be taken as equal to speed of fast moving vehicle or overtaking vehicle ($V_c = V_a$)

* Consideration of vehicle from opposite direction shall be made only when it is two way traffic (Two lanes). In case of single lane (one way traffic) vehicle from opposite direction shall not be considered

$$O.S.D = d_1 + d_2 + d_3 \quad (\text{2 lane traffic, 2 way})$$

$$O.S.D = d_1 + d_2 \quad (\text{1 way traffic}).$$

* According to IRC, the minimum clearance distance between two vehicles must be $= 6 + (0.7V_b)$

* The acceleration of overtaking vehicle is higher at slow speed and it is lower at fast speed.

* The value of total OSD is given as below:

→ $OSD = d_1 + d_2$ (single lane - one way traffic)

→ $OSD = d_1 + d_2 + d_3$ (Double lane - 2 way traffic)

→ Min. length of overtaking zone $= 3 \times O.S.D$

→ Min Desirable length of overtaking zone $\} = 5 \times O.S.D$

$\rightarrow \quad d_1 = V_b \times t$

($t = 2s$ according to IRC)

$\rightarrow \quad d_2 = 2s + b$

$s = 6 + (0.7 V_b)$

$b = V_b \times T$

$T = \sqrt{\frac{4s}{a}}$ (seconds)

$\rightarrow \quad d_3 = V_c \times T$

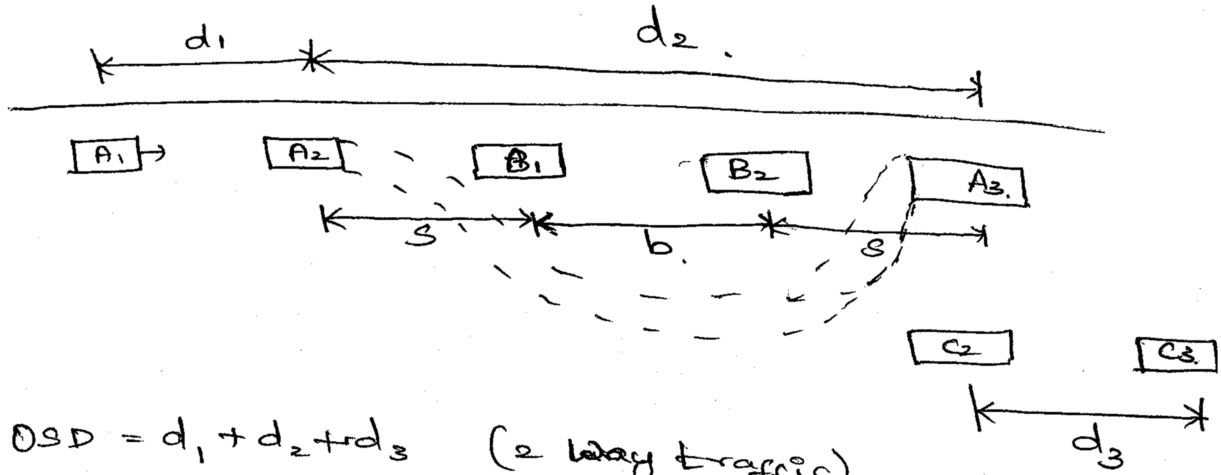
$V_a = V_c$ (if $V_c$ is not given)

$V_b = V_a - 16$ (km/hr) (if $V_b$ is not given)

11/9/2015



## OVERTAKING SIGHT DISTANCE (SAFE PASSING DISTANC (m/s)




$OSD = d_1 + d_2 + d_3$ (2 way traffic)

$OSD = d_1 + d_2$ (1 way traffic)

$V_a$ - speed of fast moving vehicle

$V_b$ - speed of slow moving vehicle

$V_c$ - speed of vehicle in opp. direction.

$d_1 = V_b \times t$ $\boxed{V_b = V_a - 16}$ if not $V_d$ given

$t = 2$ second according to IRC.

$d_2 = 2s + b.$

$= 2s + V_b \times T$

$= 2s + \left(V_b \times \sqrt{\frac{4s}{a}}\right)$

$$\boxed{\begin{array}{c} T = \sqrt{\frac{4s}{a}} \\ s = 6 + 0.7 V_b \end{array}}$$

$d_3 = V_c \times T.$

$$\boxed{O.S.D = d_1 + d_2 + d_3.}$$

$$d_2 = UT + \frac{1}{2}aT^2$$

$$2s + \cancel{V_b \times T} = \cancel{V_b \times T} + \frac{1}{2}aT^2$$

$$\boxed{T = \sqrt{\frac{4s}{a}}}$$

* $V_a = V_c$
* $V_b = V_a - 16$ km/hr

1.) Determine the value of O.S.D in a one way traffic where design speed is 80 km/hr and $V_b$ = 50 km/hr. Take $a = 0.9\ m/s^2$. Also determine min length of OSD.

<u>Given:</u>

$V_a = V_c = 80$ km/hr $= 22.22$ m/s  $V_b = 50$ km/hr $= 13.89$ m/s.

$a = 0.9\ m/s^2$

$d_1 = V_b \times t = 13.89 \times 2 = 27.78$ m.

$d_2 = 2s + V_b \times T$  $s = 6 + 0.7V_b$

$= 6 + 0.7(13.89)$

$= (2 \times 15.723) + (\cancel{50}\,13.89 \times 8.36)$  $\boxed{s = 15.723\ m}$

$\boxed{d_2 = \cancel{449.42}\ 147.57\ m}$  $T = \sqrt{\frac{4s}{a}}$

$= \sqrt{\frac{4 \times 15.723}{0.9}}$

$O.S.D = 27.78 + \cancel{449.42}\ 147.57$ m.

$\cancel{OSD} = \cancel{477.2}$ m. 175.35 m.

$\boxed{O.S.D = 477.2\ m.}$  $\boxed{T = 8.36\ s.}$

Minimum Length of overtaking zone $\} = 3 \times 477.2$

$= \underline{1431.6\ m}$

Given :

$V_a = V_c = 80 \text{ km/hr}$ $= 22.22 \text{ m/s}.$

$V_b = 50 \text{ km/hr}$ $= 13.89 \text{ m/s}$

$d_1 = V_b \times t = 13.89 \times 2 = 27.78 \text{ m}.$

$d_2 = 2S + b.$

$= 2S + V_b T$

$= (2 \times 15.723) + (13.89 \times 8.36)$

$d_2 = 147.56 \text{ m}$

$S = 6 + 0.7 V_b$

$= 6 + (0.7 \times 13.89)$

$\boxed{S = 15.723 \text{ m}}$

$T = \sqrt{\frac{4S}{a}}$

$= \sqrt{\frac{4 \times 15.723}{0.9}}$

$\boxed{T = 8.36 \text{ s}}$

$O.S.D = d_1 + d_2$

$= 27.78 + 147.56$

$\boxed{O.S.D = 175.34 \text{ m}}$

Overtaking zone $= 3 \times O.S.D$

$= 3 \times 175.34$

$\boxed{\text{Overtaking zone} = 526.02 \text{ m}}$

1. Calculate OSD and Min. length of overtaking zone. and desirable length of overtaking. Take $a = 0.99\ m/s^2$. conside 2-lane traffic $V_b = 40$ km/hr. $V_a = 70$ km/hr.

Solution:

$V_a = 19.44\ m/s$ $V_b = 11.11\ m/s$.

$S = 6 + (0.7 \times 11.11)$

$S = 13.78\ m$.

$T = \sqrt{\frac{4S}{a}}$.

$= 7.46\ m/s^2$.

$O.S.D = d_1 + d_2 + d_3$.

$= (11.11 \times 2) + (2 \times 13.78)$

$+ (11.11 \times 7.46) + (19.44 \times 7.46)$.

$O.S.D. = 277.683\ m$.

Min length of O.~~S.D~~ zone $= 277.68 \times 3$.

$= 833.049\ m$.

Desirable length of O.T zone $= 277.68 \times 5$.

$= 1388\ m$.

2) calculate O.S.D for N.H having $V_d = 96\ km/h$



$a = 0.7\ m/s^2$. (2 lane 2 way ~~traffic~~).

$V_d = 26.67\ m/s$ $V_b = 22.22\ m/s$

$d_p$

$S = 6 + 0.7 V_b$

$= 21.56$.

$T = 11.098\ sec$

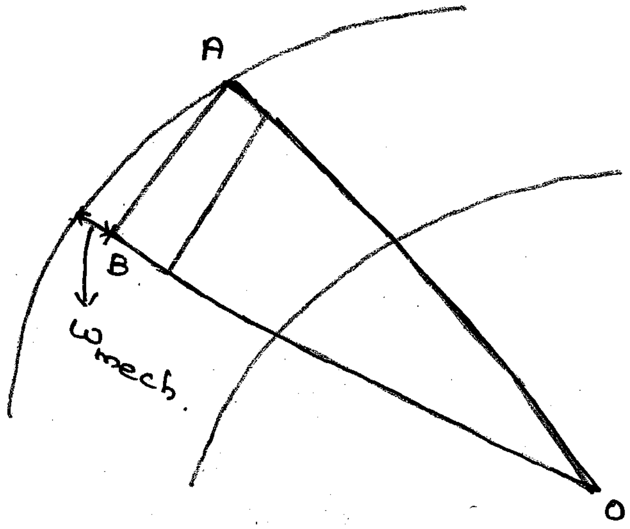
$O.S.D = (22.22 \times 2) + (2 \times 21.56)$

$+ (22.22 \times 11.098)$

$+ (26.67 \times 11.098)$.

$\boxed{O.S.D = 630.14\ m}$.

# EXTRA WIDENING OF ROADS ON CURVES.




Extra widening = $W_{phys} + W_{mech}$

$$W_{phys} = \frac{V}{9.5\sqrt{R}}$$

V – Velocity in km/h
R – Radius of curve in m

$W_{mech}$:

Consider $\Delta^{le}$ OAB.

$$OA^2 = OB^2 + AB^2$$

$$R^2 = (R - W_{mech})^2 + l^2$$

$$\cancel{R^2} = \cancel{R^2} - 2RW_{mech} + \cancel{W_{mech}^2}^{\,0} + l^2$$

$$2RW_{mech} = l^2$$

$$W_{mech} = \frac{l^2}{2R}$$

Depending on no. of lanes $\boxed{W_{mech} = \frac{nl^2}{2R}}$

$$\boxed{\text{Extra Widening} = \frac{V}{9.5\sqrt{R}} + \frac{nl^2}{2R}}$$

1. Determine Extra width of road and total width of road on a horizontal curve where $V_{design}$ = 70 kmphr and R = 250 m. Take rigid wheel base = 7 m
Normal width of road = 7.5 m.



Solution:

$$\text{Extra widening} = \frac{V}{9.5\sqrt{R}} + \frac{nl^2}{2R}$$

$$= \frac{70}{9.5\sqrt{250}} + \frac{2 \times 7^2}{2 \times 250}$$

$$\boxed{\text{Extra widening} = 0.66\,m}$$

Total width of road = 7.5 + 0.66.

$$\boxed{\text{Total width of road} = 8.16\ m}$$

22/9/2015





## EXTRA WIDENING OF HORIZONTAL CURVE:

* On a horizontal curve of a roadway, If the radius of the curve is small (< 300m), then there is a chane of off-tracking of the moving vehicle. to consider the off-tracking of the vehicle the width of the pavement on the horizontal curve must be increased called extra-widening.

* Purpose Of Widening:

→ Due to the turning of the steering only the front wheels will turn and the rear wheels will not follow the front wheel immediately.

→ This is due to the large rigid whe base (6m to 7m).

→ If the speed of the moving vehicle is higher than design speed then existing super elevation will not help ~~the~~ to counteract the centrifugal force and hence skidding of vehicle takes place.

→ For greater visibility it is the tendancy of the driver to take the vehicle to the outer edge of the road due to which  physcological effect may develop and there is a chance of off-tracking or overturning the vehicle.

→ To have a high clearance b/w the vehicles from the opposite direction

→ It is the tendancy of a driver to have high clearance b/w the vehicle in the opposite direction and the concerned vehicle.

TOTAL EXTRA WIDENING INCLUDES physcological widening and mechanical widening.

$$W_{total} = W_{psy} + W_{mech}.$$

$$W_{total} = \frac{V}{9.5\sqrt{R}} + \frac{nl^2}{2R}.$$

* According to IRC min. Extra widening should not be less than 60 cm.

* If the Radius is more than 300m then there is no need of extra wideni

1. Determine total width of pavement on a horizontal curve where $V_{design} = 80$ km/hr. Normal width = 7m and $l = 6$m. The lateral skidding = 0.15 and $e_{max} = 7\%$.



Solution:

$$e + f = \frac{V^2}{127R}.$$

$$R = \frac{V^2}{127(0.07+0.15)}$$

$$= \frac{80^2}{127(0.07+0.15)}$$

$$R = 229.06 \text{ m}.$$

$$W_{total} = \frac{V}{9.5\sqrt{R}} + \frac{nl^2}{2R}.$$

$$= \frac{80}{9.5\sqrt{229.06}} + \frac{2\times 6^2}{2\times 229.06}.$$

$$\boxed{W_{total} = 0.713 \text{ m}} > 60 \text{ cm}$$

Total width of pavement = 7 + 0.713

= 7.713 m.

# SURVEYING



- → Importance of surveying
- → Principles and classification
- → Mapping Concepts
- → Co-ordinate system
- → Map projections
- → Measurements of distance and directions.
- → Leveling
- → Theodolite traversing
- → Plane Table surveying
- → Errors and Adjustments
- → Curves.

# TERZAGHI INSTITUTE

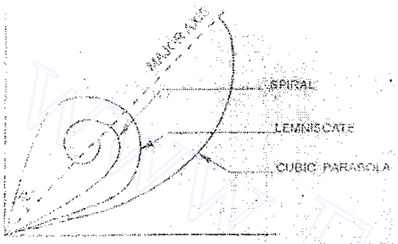
## TRANSPORTATION ENGINEERING

### TRANSITION CURVE (GEOMETRICAL DESIGN OF HIGHWAYS)

Transition curve is a horizontal curve having profile other than circular such that its radius varies from ∞ at the tangent point to the radius of the main circular curve.
infinity (R)

**TYPES OF TRANSITION CURVE :**

1. Spiral (for highway of any deflection angle)
2. Lemniscate or Bernoulli (for roadway having small deflection angle) (or) Bernoulli's Lemniscate
3. Cubic parabola (adopted for railways)




- Most ideal transition curve is spiral
- The most ideal condition to be fulfilled by an ideal transition curve is the rate of change of centrifugal acceleration (c) must be consistent
- Due to the introduction of transition curve, the main curve shifts inwards.

  Shift, S = $\frac{L^2}{24R}$

**LENGTH OF TRANSITION CURVE :**

1. **For Plain & Rolling terrain :**

   $\boxed{L = 2.7\frac{V^2}{R}}$

   Where,
   V = velocity of vehicle (km/hr)
   R = Radius (m)
   L = Length of transition curve (m)

   Extra widening at curve $= \frac{nl^2}{2R} + \frac{V}{9.5\sqrt{R}}$

2. **For mountainous & steep terrain :**

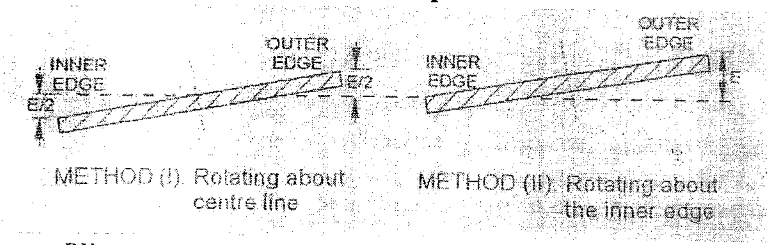
   $L = \frac{V^2}{R}$ V → km/hr

3. **Based on rate of change of centrifugal acceleration :**

   $L = \frac{V^3}{CR}$
   V = velocity of vehicle (m/s)
   Where, C = Rate of Centrifugal acceleration (0.5 to 0.8) $m/s^3$

$C = \frac{80}{75+V}$ (V is in km/hr)

**4. Based on rate of introduction of super elevation :**




$L = \frac{eBN}{2}$ (Centre line of rotation)

L = eBN (inner edge of rotation & heavy rainfall zone)

Where,

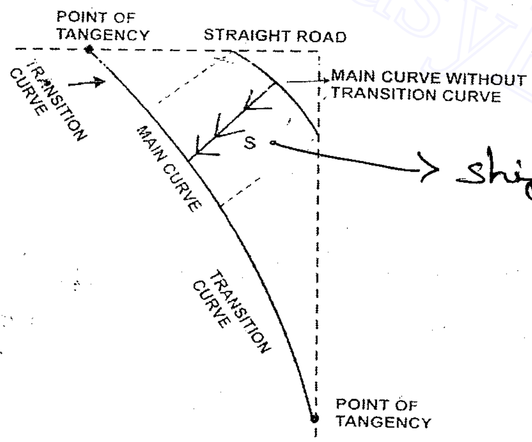
B = width of road with extra widening

N = rate of change of super elevation (or) Rate of introduction of super Elevation

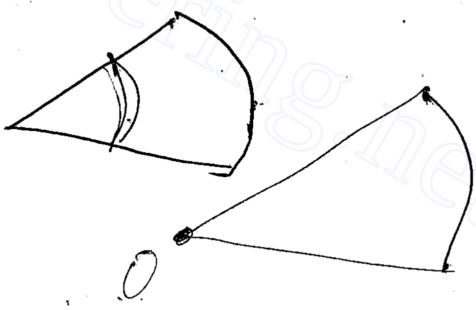
$e = \frac{V^2}{225\,R}$ (Super elevation)

**Note** : If V is greater than design value, adopt the design value as per Super elevation and do the check for friction.

**Adopt Greatest value of above four**




shift, $= \frac{l^2}{24R}$ . R → Radius of main curve



$S = \frac{L^2}{24\,R}$

**Note :**

If 'e' is not given then,

$e = \frac{V^2}{225R}$

check if $e \leq 7\%$

if not, restrict to 7%

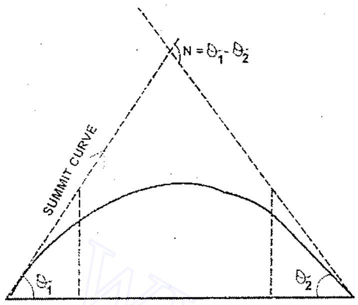
Then check, $e + f = \frac{V^2}{127R}$, f should be $\leq 0.15$

# TERZAGHI INSTITUTE

## TRANSPORTATION ENGINEERING

### SUMMIT CURVE AND VALLEY CURVE (VERTICAL CURVES)

**SUMMIT CURVE :**




$N = +\theta_1 - (-\theta_2)$

(+) = Rising gradient

(-) = Falling gradient

N = Deviation angle in rad

**BASED ON FOLLOWING CONDITIONS SUMMIT CURVE IS DESIGNED :**

1. L > SSD
2. L < SSD
3. L > OSD
4. L < OSD

**(1) L > SSD :** ( S ) → SSD

$$L = \frac{NS^2}{4.4}$$

**(2) L < SSD :**

$$L = 2S - \frac{4.4}{N}$$ , S → SSD

**(3) L > OSD :**

$$L = \frac{NS^2}{9.6}$$ , S → OSD

**(4) L < OSD :**

$$L = 2S - \frac{9.6}{N}$$ , S → OSD

- In practice, the shape of summit curve is simple parabola and for valley curve is cubic parabola.
- According to IRC, the value of ruling, limiting gradient and Exceptional Gradient :

| TYPE OF TERRAIN | RULING GRADIENT | LIMITING GRADIENT | EXPERIMENTAL/ EXCEPTIONAL GRADIENT |
|---|---|---|---|
| Plain and rolling terrain | 1 in 30 (3.33 %) | 1 in 20 (5%) | 1 in 15 (6.7%) |
| On mountainous zone | 1 in 20 (5%) | 1 in 16.7 (5.9%) | 1in 14.28 (7%) |
| Steep terrain | 1 in 16.7 (5.9%) | 1 in 14.3 (7%) | 1 in 12.5 (8%) |

**VALLEY CURVE :**

Valley curve is also called as Sag curve.

**LENGTH OF VALLEY CURVE IS DEPENDENT ON FOLLOWING PARAMETERS:**

1. Comfort condition
2. Length of SSD
3. Deviation angle
4. Rate of change of centrifugal acceleration

**(1) Based on comfort condition :**

$$L = 2\left[\frac{NV^3}{C}\right]^{1/2}$$

Where,

N = Deviation angle (m/sec$^3$)

C = rate of Centrifugal acceleration

V = velocity of vehicle (m/s)

here, $C = \frac{80}{75+V}$ (V is in km/hr)

**(2) If length > SSD :**

$$L = \frac{NS^2}{(1.5+0.035S)}$$ S → SSD

**(3) L < SSD :**

$$L = 2S - \frac{(1.5+0.035S)}{N}$$

***Adopt greatest value among above three***

- Whenever a horizontal curves lies on a raising gradient, then the resistance offered to the vehicle increases. Therefore, the raising gradient should be lowered down.
- According to IRC, if the raising gradient is more than 4% then grade compensation is must.

Grade compensation = $\frac{30+R}{R}$

(or)

Grade compensation = $\frac{75}{R}$

***Adopt Lesser value between two***