SOIL MECHANICS-I

Class Notes

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Soil :- It is defined as
"The material naturally obtained from weathering or decomposition or disintegration of rocks" OR
"Soil is the unaggregated or uncemented deposits of minerals and organic particles covering large portion of earth crust."

Soil Mechanics :- It is defined as
"It is the discipline in which the soil is studied Theoretically and Practically" OR
"It is the branch of civil engineering which deals with the properties, behaviour and performance of soil as structural material"

History :- The knowledge of the use of soil extends into prehistoric times. However, in 1930 "Soil Mechanics" was established as a branch of civil engineering.
Dr. K. Terzaghi's contribution in the field of soil Mechanics have been immense and he is fittingly called the "Father of Soil Mechanics". The term soil mechanics was coined by him. In 1942 he published is book "Introduction to Soil Mechanics" and later on published another book "Soil Mechanics by Terzaghi and Peck"

Purpose :- The purpose of this branch is
→ to replace old method of construction
→ to learn and elevuate the properties of soil.

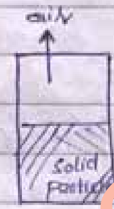
Soil Constituents :- A soil mass is commonly considered to consist of solid particles, enclosed voids or interspaces. Thus there are two constituents of soil
1) Soil or Solid Particles
2) Voids

If we take a sample of soil and compress it we will get voids which may be filled with air, with water, or partly with air and partly with water and soil solids particles.

On the basis of consistituents the soil types are

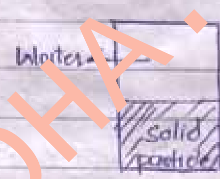
1- Dry Soil :-

If only air is present in the voids of the compressed soil then it is called dry soil



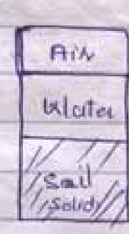
2- Saturated Soil :-

If only water is present in the voids then it is called saturated soil



3- Partially Saturated Soil:-

If water along with air is present in the voids then it is called partially saturated or 3 phase Soil System



Formation of Soil OR WEATHERING OF ROCKS :-

" The conversion, decomposition or disintegration of intact mass of rock mechanically or chemically to small pieces is called weathering "

There are two types of weathering
1) Mechanical Weathering
2) Chemical Weathering.

MECHANICAL WEATHERING :- In this type the rock is disintegrated mechanically. i.e no change in chemical comp of the
The three actions that happen in mechanical weathering are

1- Grinding
2- Abrassion
3- Shattering

The different ~~agencies~~ physical agencies due to which weathering is caused are

→ periodical temperature changes
→ Impact and splitting action of flowing water
→ Splitting action of ice
→ Wind action
→ plants and animals
→ earth quake etc.

CHEMICAL WEATHERING :- Chemical weathering may be caused due to

1→ hydration
2→ carbonation
3→ [illegible]
4→ oxidation and
→ leaching by organic acid

clay minerals are obtained due to chemical weathering.

Types of Soil :-

ACCORDING TO ORIGIN :- the types of soil are
1- Residual Soil
2- Transportation Soil.

RESIDUAL SOIL :- is soil which remains in place directly over the parent rock and relatively shallow in depth. form → { Soil Mechanic & foundation }

TRASPORTATION SOIL :- " is soil which is taken away to other place after decomposition and disintegration."

The deposits of transported soil may be considerable in depth and their homogenity or heterogenity depends upon manner of their transportation and deposition. The various agencies of transporting and redepositing soil are → water
→ ice
→ wind
→ gravity

water-formed, transported soil are termed as alluvial, marine or lacustrine
~~By glacier either by its ice/or/its ... water termed as glacial drift.~~
~~water~~ Material picked up, ~~disintegra~~ mixedup, disintegrated, transported and redeposited by glacier ice or water issued from it is called glacial drift
~~loss~~ Loess is the wind blown silt or sand.
Soil transported by gravitational forces are termed as colluvial.

ACCORDING TO GRAIN SIZE :-

According to grain size there are three main groups.
1- Coarse grain soil
2- fine grain soil
3- Organic soil

Coarse Grain Soil :- or cohesion less soil

In coarse grain soil the particles have large size and donot have any intermolecular attractive forces.

These particles can be seen with naked eye without using any instrument. Cohesion less soil is formed due to physical disintegration of rocks.

It is further subdivided into
1- Gravel particles :- That component of coarse grain soil in which particle size is larger than 2mm

2- Sand Particles :- The component of coarse grain soil in which particle size is greater than .075 mm and smaller than 2mm

FINE GRAIN SOIL :- OR Cohesive soil

In fine grain soil the particles are small in size and have intermolecular forces of attraction.

These particles can not be observed with naked eye.
It is further sub-divided into
1- Silt :- have particle size ~~larger~~ smaller than .075mm and ~~smaller~~ larger than .002 mm
2- Clay :- The particle size is smaller than .002 mm.

ORGANIC SOIL :- The soil formed by the decomposition of organic matter

→ The organic matter may include vegetables & animals

→ This is a very poor soil having low bearing capicity

→ It is not good for construction purposes but ideal for agriculture.

→ The example is peat.

-: IDENTIFICATION OF SOIL :-

For the identification of soil we may perform the following test -

1- **VISUAL EXAMINATION :-** In visual examination we observe with naked eye the following properties

→ Colour

→ gradation

→ Angularity

and decide whether it is coarse grain or fine grained soil

2- **FEEL TEST :-** In feel test we take small amount of soil and a few drops or cc of water ~~and~~, rub it between our fingers and observe that

[illegible]

→ If large particles than it is sand.

[illegible]

→ If small particle than it is silt

→ If small and soapy than clay

3- **ROLLING TEST :-**

In rolling test take the sample soil add few drops of water and make a ball out of it by keeping

keeping it on the palm and rolling it. Now convert it into a thread.

→ If it immediatly crumbles ~~and does~~ without assuming thread shape then it is sandy soil

→ If it is converted to thread of 3mm than clayey soil

→ If it is converted to a ball and cracks appear then it is silty soil.

4. STRENGTH TEST :- Take soil and add few cc or drops of water make a cube out of it place it in sun or in oven at 105°C When all the water is removed then try to break it by hand.

→ In case of sandy soil it will break easily
→ In case of silty soil some pressure is required
→ In case of clay it can't break easily.

5. DIPERSION TEST :- Take some dry soil and put it in a glass of water i.e transparent glass ~~as~~
→ In case of sandy soil the particles will settle down in a very short time i.e few seconds
→ In case of silty soil, it will take some time to settle down
→ In case of clayey soil, it will take a lot of time to settle down.

All of the above tests are ~~are~~ the simple and are performed to get the general idea about soil type.

SIMPLE SOIL PROPERTIES :-

UNIT WEIGHT :- It is defined as
"The weight of substance per unit of its volume"
It is also called specific weight and is represented by " γ "

$W = W_a + W_w + W_s$
$V = V_a + V_w + V_s$

a- Bulk Unit Weight :- is total weight divided by total volume.
{include the wt & volume of water and air}

$$\gamma_B = \frac{\text{total wt of soil mass}}{\text{total volume of soil mass}} = \frac{W}{V}$$

b- Unit wt of Soil Solids :- γ_s

$$\gamma_s = \frac{\text{wt of soil solids}}{\text{Volume of soil solids}} = \frac{W_s}{V_s}$$

c- Dry Unit wt of Soil :- γ_d

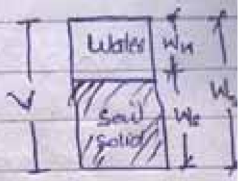
$$\gamma_d = \frac{\text{wt of Soil Solids}}{\text{total volume of soil solids}} = \frac{W_s}{V} = \frac{W_d}{V}$$

If dry soil the contain only air and soil solid
i.e total wt = wt of air + wt of soil solids dry

$W_s = W_a + W_d$ (W_a negligible)

$W_s = W_d$

d. Saturation Unit Weight :-



$$\gamma_{(sat)} = \frac{\text{total wt of saturated soil}}{\text{total volume of saturated soil}}$$

$$\gamma_{sat} = \frac{W_{(sat)}}{V}$$

The first one and last are same only difference is that the first one contains airs whereas in last saturated soil i.e only water

UNITS :- The units of all of the above are lb/ft^3 or kg/m^3

In Soil Mech Mass and weight are same thus use unit kg instead of Newton

9. SPECIFIC GRAVITY :-

It is the ratio of wt of given volume of substance to ratio of wt of equal volume of distilled water

$$G = \frac{\text{wt of given volume of substance}}{\text{wt of equal volume of water.}} = \frac{\gamma_s}{\gamma_w}$$

→ Bulk or Apparent or Mass Specific gravity :-

$$G_m = \frac{\text{Bulk unit wt of solid solids}}{\text{Bulk unit wt of water}}$$

$$G_m = \frac{\gamma_B}{\gamma_w}$$

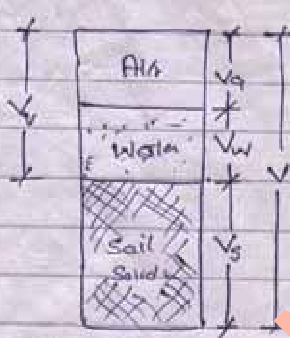
$\frac{\text{Mass}}{\text{Volume}}$ or $\frac{\text{weight}}{\text{volume}}$ is equal to unit weight γ thus here wt of given volume i.e $\frac{W}{V} = \gamma$

→ Specific Gravity of Soil Solid or Absolute Specific gravity :-

$$G_s = \frac{\text{unit wt of Soil Solids}}{\text{unit wt of water}} = \frac{\gamma_s}{\gamma_w}$$

VOLUME RATIOS :-

→ **Void Ratio :-**



partially saturated soil

$$\text{Void ratio} = e = \frac{\text{volume of voids}}{\text{volume of soil solids}}$$

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

→ **Porosity :-**

$$\text{Porosity} = n = \frac{\text{volume of voids}}{\text{Total volume of soil mass}}$$

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

It is generally expressed in percentage.

→ **Degree of Saturation :-** The ratio of volume of water to the volume of void in a given soil sample.

$$S = \frac{\text{Volume of water}}{\text{volume of voids}} = \frac{V_w}{V_v} \times 100$$

Weight Ratio :-

$$\text{Water content } w = \frac{\text{weight of water}}{\text{weight of soil solids}}$$

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

OR

$$\text{Moisture content} = \frac{\text{weight of moisture}}{\text{weight of soil solid}}$$

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

Water content and moisture content are similar and

$$\frac{W_w}{W_s} \times 100 = \frac{W_w}{W_d} \times 100$$

as wt of dry soil

$$W_d = W_a + W_s$$

$$W_d = W_s$$

Air Content :- is defined as "the ratio of volume of air voids to the volume of voids.

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

as $V_a = V_v - M_w$

$$a_c = 1 - \frac{M_w}{V_s} = 1 - S_r$$

RELATIONSHIPS :-

1- RELATION BETWEEN VOID RATIO & POROSITY :-

$$\text{Void Ratio} = e = \frac{V_v}{V_s}$$

as we know $V = V_v + V_s$

$$\therefore \quad V_s = V - V_v$$

Replace, V_s we get

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

Dividing by V

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

as we known that Porosity $= n = \frac{V_v}{V}$

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

2- RELATION BETWEEN VOID RATIO & POROSITY :-

$$\text{Porosity} = n = \frac{V_v}{V} = \frac{V_v}{V_v + V_s} \qquad \text{as } V = V_v + V_s$$

$$= \frac{\frac{V_v}{V_s}}{\frac{(V_v + V_s)}{V_s}} = \frac{\frac{V_v}{V_s}}{\frac{V_v}{V_s} + \frac{V_s}{V_s}} \qquad e = \frac{V_v}{V_s}$$

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

3. Relationship Between Water Content (w), Void Ratio (e), Degree of Saturation (S) and Specific Gravity of Soil Solids (G_s).

Water content = $w = \frac{W_w}{W_s} \times 100$ —(a)

As, $\gamma_w = \frac{W_w}{V_w}$ | γ = specific wt

$W_w = \gamma_w V_w$ —(i)

and $\gamma_s = \frac{W_s}{V_s}$

$W_s = \gamma_s V_s$ —(ii)

putting in eq-(a) the (i) & (ii) we get

$w = \frac{\gamma_w V_w}{\gamma_s V_s}$ —(b)

As we know $G_s = \frac{\gamma_s}{\gamma_w}$ ∴ $\gamma_s = \gamma_w G_s$ —(iii)

As we know $S = \frac{V_w}{V_v}$ ∴ $V_w = S V_v$ —(iv)

Degree of saturation (S)

putting (iii) & (iv) in eq-(b)

$w = \frac{\gamma_w V_w}{\gamma_s V_s} = \frac{\gamma_w . S . V_v}{\gamma_w . G_s . V_s}$

as we know that $e = \frac{V_v}{V_s}$, Thus

$w = \frac{S}{G_s} \frac{V_v}{V_s} = \frac{S e}{G_s}$

$w = \frac{eS}{G_s}$ —(3)

4- Relationship Between Bulk Unit Weight (γ_B), Unit weight of water (γ_w), Specific gravity of Soil Solids (G_s), water content (w) and void ratio (e) of soil.

Bulk unit weight $= \gamma_B = \frac{W}{V}$ ——(a)

total weight $= W = W_a + W_w + W_s$ ($W_a = 0$, negligible)

$W = W_w + W_s$ ——(i)

total Volume $= V = V_v + V_s$ ——(ii)

putting (i) & (ii) in eq (a), we get

$$\gamma_B = \frac{W}{V} = \frac{(W_w + W_s)}{(V_v + V_s)} \times \frac{\frac{W_s}{W_s}}{\frac{V_s}{V_s}}$$

$$= \frac{W_s\left[\frac{W_w}{W_s} + \frac{W_s}{W_s}\right]}{V_s\left[\frac{V_v}{V_s} + \frac{V_s}{V_s}\right]}$$

As we know

$w = \frac{W_w}{W_s}$ ——(a)

$e = \frac{V_v}{V_s}$ ——(b)

$\gamma_s = \frac{W_s}{V_s}$ ——(c)

$$\gamma_B = \gamma_s \frac{[w + 1]}{[e + 1]} \quad \text{——(b)}$$

Now as we know that

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

$\gamma_s = \gamma_w G_s$ putting in (b)

$$\gamma_B = \gamma_w G_s \frac{(w + 1)}{(e + 1)} = \frac{\gamma_w G_s (1 + w)}{(1 + e)} \quad \text{——(4)}$$

5- Relationship between Bulk Unit Weight (γ_B), Unit Weight of water (γ_w), Specific gravity of soil solids (G_s), Voids Ratio (e) & Degree of Saturation of Soil (S) :-

First derive the equation till here i.e eq(4)

$$\gamma_B = \frac{\gamma_w G_s (1+w)}{(1+e)} \quad \text{---} (a)$$

Now, according to eq ③

$$w = \frac{eS}{G_s} \quad \text{---} (i)$$

putting (i) in eq (a), we get

$$\gamma_B = \frac{\gamma_w G_s \left[1 + \frac{eS}{G_s}\right]}{(1+e)}$$

$$\gamma_B = \frac{\gamma_w G_s \left[\frac{G_s + eS}{G_s}\right]}{(1+e)}$$

$$\gamma_B = \frac{\gamma_w [G_s + eS]}{(1+e)} \quad \text{---} (5)$$

6- Dry Unit Weight (γ_d), Unit wt of water (γ_w), Specific Gravity (G_s) of soil solids (G_s), Void Ratio (e)

first obtain equation --(4)

$$\gamma_B = \frac{\gamma_w G_s [1+w]}{(1+e)}$$

For dry soil $w = 0$ i.e no water content

and $\gamma_B = \gamma_d$

$$\gamma_d = \frac{\gamma_w G_s (1+0)}{(1+e)}$$

$$\gamma_d = \frac{\gamma_w G_s}{1+e} \quad \text{——— (6)}$$

7- Dry Unit weight (γ_d), Bulk Unit wt (γ_B) & water content content of Soil (w)

$$\text{water content} = w = \frac{W_w}{W_s}$$

$$1 + w = \frac{W_w}{W_s} + 1$$

$$1 + w = \frac{W_w + W_s}{W_s}$$

As we know that $W = W_a + W_w + W_s$

$$W = W_w + W_s$$

Thus

$$1 + w = \frac{W}{W_s}$$

$$W_s = \frac{W}{1+w}$$

$$\frac{W_s}{V} = \frac{\left(\frac{W}{1+w}\right)}{V}$$

$$\gamma_d = \frac{\frac{W}{V}}{1+w}$$

$$\gamma_d = \frac{\gamma_B}{1+w} \quad \text{——— (7)}$$

Problems :- 9

Problem No-1 :-

A soil sample weighs 950 gm and its volume is 510 cc. If dry wt of sample is 890 gm & specific gravity of soil solid is 2.65 determine.

a- water content b- Void Ratio
c- Porosity d- Degree of Saturation.

Data:-

total wt of soil sample = 950 gm
" volume " " " = 510 cc
dry weight " " " = 890 gm
Specific gravity = 2.65

Required :-

a) Water content b) Void ratio
c) Porosity d) Degree of Saturation.

Solution :-

a) Water content (w) :-

$$w = \frac{W_w}{W_d} * 100 = \frac{W - W_d}{W_d} * 100$$

$$= \left(\frac{950 - 890}{890}\right) * 100$$

$$= 6.74 \%$$

b) Void Ratio (e) :-

$$\gamma_d = \frac{\gamma_w G_s}{1+e} \quad \text{and} \quad \gamma_d = \frac{W_d}{V}$$

$$\frac{890}{510} = \frac{1 * 2.65}{1+e} \qquad \gamma_w = 1 \text{ gm per cc or } 62.4 \text{ lb}$$

$$e = \left[\frac{2.65}{\frac{890}{510}} - 1\right]$$

$e = .5185$

c) Porosity (n) :-

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

$$= \frac{.5185}{(1+.5185)} * 100$$

$$= 34.145\%$$

d) Degree of Saturation (s) :-

$$w = \frac{e.S}{G_s}$$

$$S = \frac{wG_s}{e}$$

$$= \frac{6.74 * 2.65}{.58185}$$

$$= 34.45\%$$

Problem 2:-

The wet unit weight is 120 lb/ft^3 if its specific gravity is 2.67 & specific gravity of soil solid ? and water content of soil mass is 12% find dry unit weight, void ratio, porosity and Degree of saturation.

Given Data:-

wet unit wt of soil = 120 lb/ft^3 = γ_B

Specific gravity of soil solid = 2.67

water content = 12%

Required:-

a) Dry unit wt   b) Void Ratio
c) Porosity   d) Degree of Saturation.

Solution

a) Dry unit weight:-

wet unit wt is equal to bulk unit wt

$$\gamma_d = \frac{\gamma_B}{1+w} = \frac{120}{(1+.12)}$$

$$= 107.14 \ lb/ft^3$$

b) Void Ratio :-

$$\gamma_d = \frac{\gamma_w G}{1+e}$$

$$107.14 = \frac{62.4 \times 2.67}{1+e}$$

$\gamma_w = 1$ in SI
$= 62.4$ in FPS.

$$e = 0.555$$

c) Porosity :-

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

$$= \frac{.555}{1+.555} \times 100$$

$$= 35.69 \%$$

d) Degree of Saturation :-

$$w = \frac{eS}{G_s}$$

$$S = \frac{w G_s}{e}$$

$$= \frac{12 \times 2.6}{.555}$$

$$= 57.33 \%$$

Problem #03:-

A saturated soil has a unit wt of 114 lb/ft³ and water content of 36%. calculate its void ratio and specific gravity of soil solids.

Data:-

Unit wt of saturated soil = 114 lb/ft³

water content = 36%

Required:-

Specific gravity of soil solid = ?

Void ratio " " " = ?

Solution:-

a) Specific Gravity:-

first using the equation

$$w = \frac{eS}{G_s} \qquad e = \frac{wG_s}{S}$$

for saturated soil S = 1 or 100%

$$\therefore \quad e = \frac{.36 G_s}{1} \text{ or } \frac{36\, G_s}{100}$$

$$e = .36 G_s$$

Now use the equation

$$\gamma_s = \frac{\gamma_w G_s [1+w]}{(1+e)}$$

$$114 = \frac{62.4 \times G_s [1+.36]}{(1+.36 G_s)}$$

$$G_s = 2.6$$

b) Void Ratio:-

$$e = .36\, G_s$$

$$e = .36 \times 2.6$$

$$e = .936$$

Attenberg's Limits :-

These limits are named after swedish agriculturist Atterberg.

Fine grained soil may be mixed with water to form a plastic paste which can be moulded into any form by pressure. The addition of water reduces the cohesion until material no longer retains its shape under its own weight, & flows as liquid. Enough water may be added until the soil grains are dispersed in a suspension.

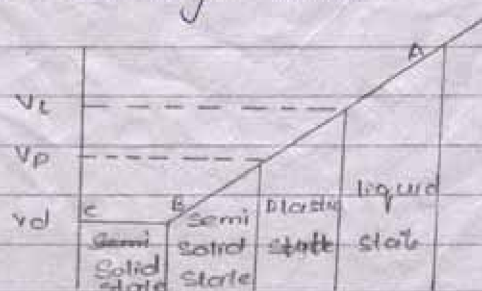
In 1911 atterberg divided the entire range from liquid to solid into four stages:

i) liquid state
ii) the plastic state
iii) the semi-solid state
iv) the solid state

He set arbitrary limits in terms of water content. Thus, the consistency limits are the water contents at which soil masses passes from one state to the next.

The atterberg's limits which are most useful for engineering purposes are

1- liquid limit
2- plastic limit
3- Shrinkage limit.



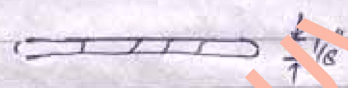
Liquid Limit :- (w_L)

It was defined by Casa Granda

The minimum water content at which 25 blows will close a groove of standard dimension for a distance of 1/2" when groove is made in the soil paste placed in the liquid limit device.

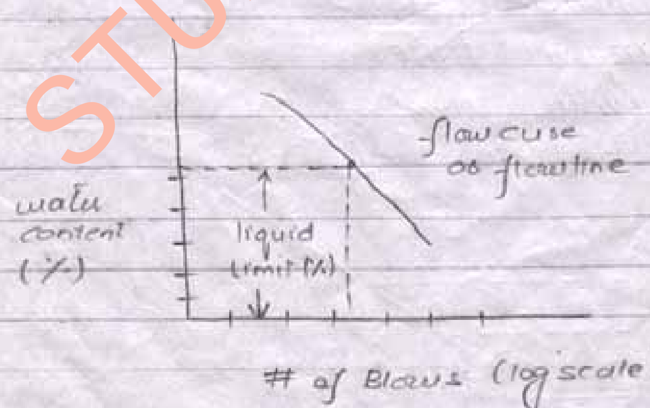
Plastic limit (w_p) :-

of soil is the minimum water content at which soil mass starts crumbling when rolled into a thread of 1/8 in diameter.



Shrinkage limit :- (w_s) :-

The water content at which further loss of water will not cause any reduction in the volume of soil mass.



1→ **Plasticity Index** :-

The difference b/w liquid limit and plastic limit is called P.I

$$P.I = L.L - P.L$$

2→ **Liquidity Index** :-

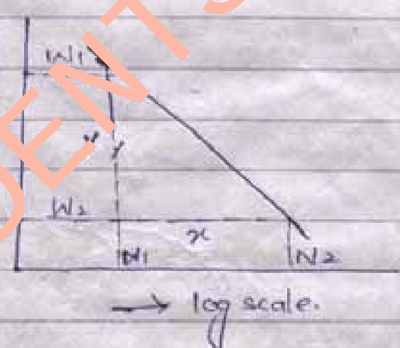
It is the difference b/w water content and plastic limit divided by Plasticity index

$$L.I = \frac{\text{water content} - \text{Plastic limit}}{\text{Plasticity Index}}$$

$$= \frac{w - P.L}{P.I}$$

3→ **Flow Index** :- The slope of flow curve is called flow index

$$F.I = \frac{w_1 - w_2}{\log \frac{N_2}{N_1}}$$



$$F.I = y = \frac{w_1 - w_2}{\log(N_2 - N_1)} = \frac{w_1 - w_2}{\log \frac{N_2}{N_1}}$$

4→ **Toughness Index** :- The ratio of Plastic Index & flow index

$$T.I = \frac{P.I}{F.I}$$

VOLUMETRIC SHRINKAGE :- (V.S)

It is defined as

"Ratio of decrease in volume of soil mass to the dry volume of soil when the soil is reduced to shrinkage limit.

It is usually expressed in percentage.

OR

The decrease in volume of soil expressed as percentage of its dry volume.

$$V.S = \left(\frac{V - V_d}{V_d}\right) * 100$$

Shrinkage Ratio :-

It is defined as

" The ratio of the volume decreased expressed as percentage to dry volume to the decrease in water content when the water content is reduced to shrinkage limit.

$$S.R = \frac{\left(\frac{V - V_d}{V_d}\right) * 100}{W - w_s} = \frac{V.S}{w - w_s}$$

OR

$$\text{Volumetric Shrinkage} = S.R * (w - w_s)$$

Shrinkage Limit :-

$$\text{Shrinkage limit} = w_s = \left[w - \frac{(V - V_d)\gamma_w}{W_d} \right] * 100 \quad \text{---(1)}$$

(w → water content)

The eq (1) can also be written as.

$$\left(\frac{(V - V_d)\,\gamma_w}{W_d}\right) * 100 = w - w_s \quad \text{---(2)}$$

As we know that $S.R = \dfrac{\left(\frac{V - V_d}{V_d}\right) * 100}{w - w_s}$

Replace $w - w_s$ by eq(2)

$$S.R = \frac{\left(\frac{V - V_d}{V_d}\right) * 100}{\left(\frac{V - V_d}{W_d}\right) * \gamma_w * 100} = \frac{\frac{1}{V_d}}{\frac{\gamma_w}{W_d}}$$

$$S.R = \frac{W_d}{V_d * \gamma_w}$$

and specific gravity of soil in dry state $\gamma_d = \dfrac{W_d}{V_d}$

$$S.R = \frac{\gamma_d}{\gamma_w} \quad G_d$$

Thus we can say that shrinkage ratio is spe equal to specific gravity at dry state

$$S.R = \frac{\left[\frac{V - V_d}{V_d}\right] * 100}{w - w_s} = \frac{\gamma_d}{\gamma_w}$$

Determination of Liquid and Plastic Limits

The liquid limit is determined in laboratory with the help of the standard liquid limit apparatus designed by casagrande. The apparatus consist of a hard rubber over which a brass cup drops through a desired height. The brass cup can be raised and lowered to fall on the rubber base with the help of a cam operated by a handle. The height of fall of cup can be adjusted with the help of adjusting screws.

Before starting the test, the height of fall of the cup is adjusted to 1 cm. Two types of grooving tools are used

→ casagrande tool
→ ASTM tool

The casagrande tool cuts a groove of size 2 mm wide at the bottom, 11 mm wide at top and 8 mm height.

About 120gm of the specimen passing through 425 micron sieve mixed thoroughly with distilled water in ~~the evaporation~~ a dish to form a uniform paste. A portion of paste is placed in the cup ~~over the spot where the cup rests on the base~~, squeezed down and spread into position and the groove is cut into the soil pat. The handle is rotated at the rate of 2 revolutions per second and no of blows are counted until two parts of soil sample come in contact at the bottom of groove along a distance of 10mm.

Since it is difficult to adjust the water content precisely equal to liquid limit when groove should close in 25 blows, the liquid limit is determined by plotting graph between no. of blows at abscissa on a logarithmic scale and corresponding water content as ordinate. Such a graph, known as FLOW CURVE, is a straight line having following equation

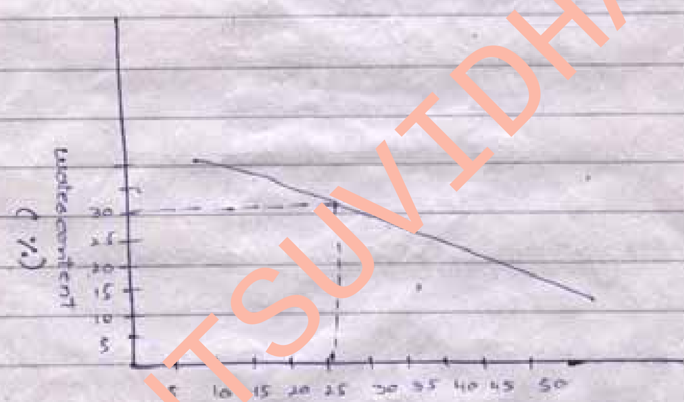
$$w_1 - w_2 = I_f \log_{10} \frac{n_2}{n_1}$$

w_1 = water content corresponding blows n_1

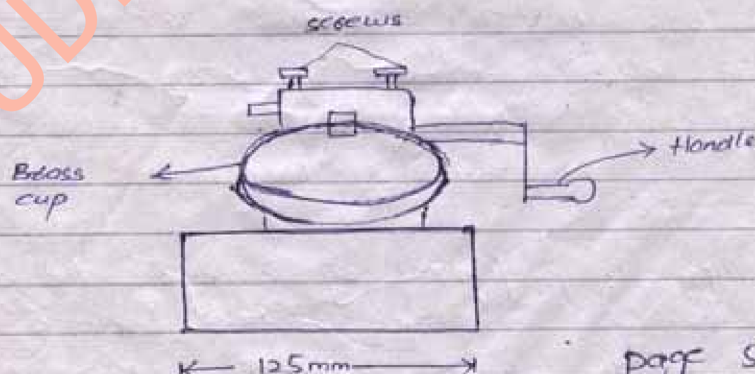
w_2 = " " " " n_2

I_f = Slope of curve, known as FLOW INDEX

Graph:



No. of blows (log scale)



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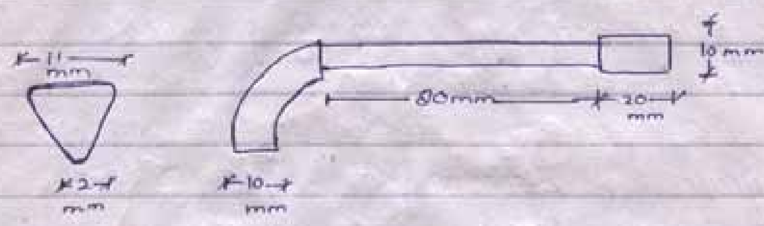
liquid limit apparatus



Dia ⇒ the Grooving tool

Sieve Analysis :-

The percentage of various sizes of particles in a given dry soil sample is found by a particle size analysis or mechanical analysis. The mechanical analysis is performed in two stages

i. sieve analysis

ii. sedimentation analysis or wet mechanical analysis.

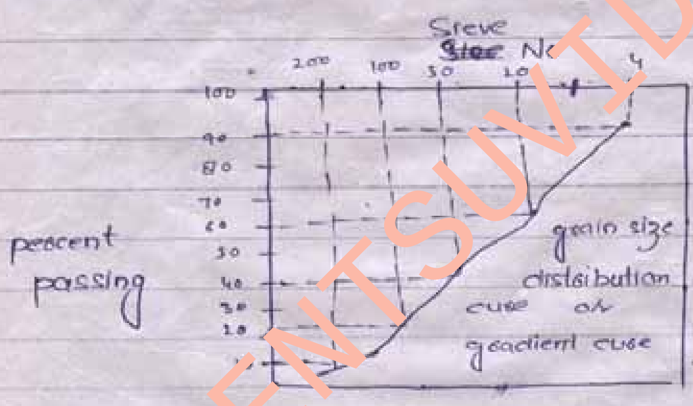
The first stage is meant for coarse-grained soils only, while second stage for fine-grained soils. The sieve analysis is, however, the true representative of grain size distribution, since the test is not affected by the temperature.

In BS and ASTM standards, the sieve sizes are given in terms of the number of opening per inch. The no. of openings per square inch is equal to the square of the no. of the sieve.

Sieving is performed by arranging the various sieves one over the other in the order of their mesh openings - the largest aperture sieve being kept at the top and the smallest aperture sieve at the bottom. A receiver is kept at the bottom and a cover is kept at the top of whole assembly - The soil sample is put on the top sieve and whole assembly is then shaked. The postion of soil retained on sieve is weighed - The percentage of soil retained on each sieve is calculated on the basis of total weight of soil sample taken and from these results, percentage passing through each sieve is ~~than~~ calculated.

On the basis of data obtained a graph is made having sieve along x-axis & percent passing along y-axis.

The graph curve shows what type of soil sample has been taken.

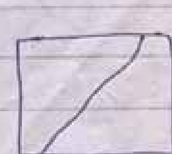


The curve is called grain size distribution curve or simply gradient curve.

On the basis of the curve the different type of soil are

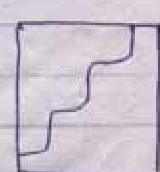
1- Well Graded Soil :-

It is good for construction and have great strength

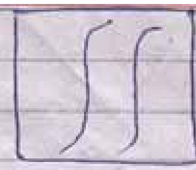


2- Poorly Graded Soil :-

Some of the particles are missing, also called Gap



3- Uniformly Graded Soil:-
consist of particles of same size



OBJECTS of Sieve Analysis:-

The main objects of sieve analysis are

1- to determine which type of soil it is.

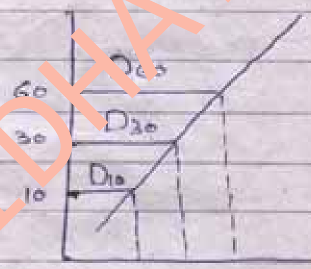
2- From the curve obtain two coefficient

a- Uniformity co-efficient

b- co-efficient of Curvature.

Uniformity Co-efficient :-

$$C_u = \frac{D_{60}}{D_{10}}$$



If its value is

less than 5 Uniformly graded.

between 5 and 15

More than 15

Co-efficient of Curvature :-

$$C_c = \frac{(D_{30})^2}{(D_{10} * D_{60})}$$

If its value lies between 1 and 3 than it is a good soil.

Mechanical Analysis :-

The percentage of various sizes of particles in a given dry soil sample is found by a Particle size analysis or mechanical analysis. By mechanical analysis is meant the separation of a soil into its different size fractions. The mechanical analysis is performed in two stages i) sieve analysis and 2) sedimentation analysis or wet mechanical analysis.

The sieve analysis is for coarse grain soil whereas the sedimentation analysis is for finer grain soil. In general a sample may contain both coarse grained particles as well as fine grained particles. If a portion passes 75 micron sieve size, sedimentation analysis is done for further sub-division of particle size distribution.

Sedimentation Analysis :-

In the ~~wet mechanical analysis, or~~ sedimentation analysis soil fraction finer than 75 micron size is kept in suspension in liquid (usually water) medium.

There are two methods of sedimentation analysis

1. Hydrometer Analysis / Method
2. Pipette Analysis.

The sedimentation analysis is based on Stoke's law.

STOKES LAW :- ~~According fact~~ According to stokes law.

If a sphere is allowed to fall in a liquid which is of indefinite extent, its velocity will increase rapidly at first as in start under the acceleration of gravity (g) however a constant velocity (terminal velocity) is reached within few seconds which is maintained indefinitely as long as the condition are not changed - This velocity is given mathematically as

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

where

v = velocity of settlement or fall of sphere.

γ_s = unit wt of sphere

γ_w = wt of water

μ = viscosity of water

D = diameter of sphere.

Limitations OR Assumption :-

Application of stokes law to the observation, direct or indirect, of the rate of fall of a large number of soil particles suspended in water in a container is inaccurate because.

1. The particles are never truly spherical; infact the shape may bear little resemblance to sphere.

2- The body of water is not indefinite in extent

3- Since many particles are present, the fall of any particle is influenced by the presence of other particles

4- Similarly, particles near the side walls of the container are affected by the presence of wall.

5- An average value for specific gravity of grain is used; the value of some particles may differ appreciably from the average value.

HOW TO MAKE STOKE LAW FOR ACCURATE:-

For first item, the concept of an equivalent diameter is introduced; any particle which has same velocity of fall as of sphere of same unit weight and of diameter D will be said to have an equivalent diameter D.

For the 2nd ~~rest of~~ item, if a fairly large container and a relatively small amount of soil are used ~~they can be minimized. For~~

For concentrations of less than 50 gm per liter it has been shown that the influence of particles on each other is not appreciable.

The small quantity of soil in very large container will help reduce the friction along the wall surface.

As far as last ~~p~~ item is concerned the difference in specific gravity is not of major importance as we use average value.

Thus by using above ~~assumptions~~ ~~or~~ methods we can make stoke's law accurate.

VALIDITY :-

The law is applicable or valid for spheres between about .2mm and .0002mm in diameter falling through water

HYDROMETER METHOD :-

In this method a suitable amount of soil is taken and is passed through the specified sieve (Different tasks have different requirements). Then it is placed in the oven for drying at about 100 — 105 °C. The sample to used is accurately weighed and mixed with the distilled water in a glass or beaker ~~to~~ and shaked well.

To have proper dispersion of soil, a dispersing agent called deflocculating agent is added to the soil. Some common dispersing agents are sodium oxalate, sodium silicate and sodium polysulphate like sodium hexametaphosphate.

At the commencement (شروع) of sedimentation test soil particles are assumed to be uniformly distributed.

A hydrometer is then introduced at different time interval in the mixture to determine the Density ~~specific gravity~~ ~~from the readings on the~~ ~~hydrometer~~ Dens.

The hydrometer consist of a bulb and a calibrated tube called stem. at one end of the bulb (the other end of bulb is closed). The readings on hydrometer stem give the density of the soil suspension situated at the centre of bulb at any time.

At the beginning the density very high because lot of particles will be in suspended form. Slowly the particles starts settling down and with it the value of density also decreases. When we will immerse the hydrometer second time it will give us reading lesser than the first one.

The readings are then recorded in table having following requirement

→ time elapsed → hydrometer Reading
→ temperature → He
→ η → D
→ % finer

time elapsed	Hydrometer Reading	temp	He	η	D

time elapsed & hydrometer reading are recorded during the experiment.

temperature may also be obtained by using different instruments at the spot.

→ He is the effective depth

→ $$\nu = \frac{(\gamma_s - \gamma_w) D^2}{1.8 \mu}$$

$$D = \sqrt{\frac{1.8 \mu \nu}{\gamma_s - \gamma_w}} \quad \text{---(i)}$$

As we know that

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

$$\gamma_s = G_s \gamma_w$$

In C.G.S system $\gamma_w = 1$ g/cc

$$\gamma_s = G_s$$

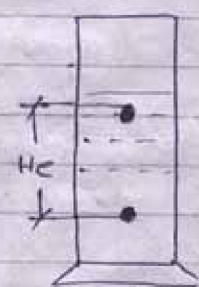
& G_s can be founded by experiment.

Regarding other quantities in equation

μ is constant only ν is variable.

→ $$\nu = \frac{\text{Distance}}{\text{time}}$$

$$\nu = \frac{He}{t}$$



→ Percentage fines means the % still remaining in suspension. and is given by

$$P = \frac{R \cdot a}{W} \times 100$$

R = hydrometric reading (variable)

W = weight of soil solid.

$$a = \text{constant} = \frac{G}{G-1}\left[\frac{2.65-1}{2.65}\right]$$

A hydrometer consists
A streamlined hydrometer is used for determinations of grain size.

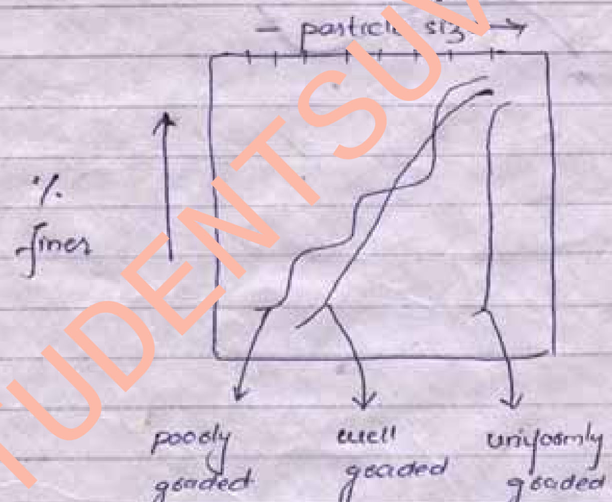
CORRECTIONS:

The corrections are then applied to make the reading more accurate. Some of the corrections are

→ Meniscus Correction
→ temperature correction
→ Dispersing agent correction

Graph :-

A graph is then plotted b/w % fines on y-axis & particle size on x-axis i-e last two columns of table



OBJECT :-

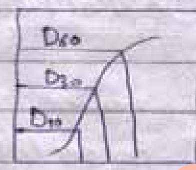
The object of test is

1) determine which type of soil
2) find coefficients

~~coefficient of~~

a) Uniformity co-efficient :-

$$C_u = \frac{D_{60}}{D_{10}}$$



b) Coefficient of Curvature :-

$$C_c = \frac{D_{30}}{D_{10} \times D_{60}}$$

If C_c is $1 \rightarrow 3$ Then good soil

Made by :-
Fazl-i-Wahab

Pipette Method :-

The pipette method is a standard sedimentation method used in laboratory. The equipment consist of pipette, a jar and a number of sampling bottles.

METHOD OF SOIL SUSPENSION :-

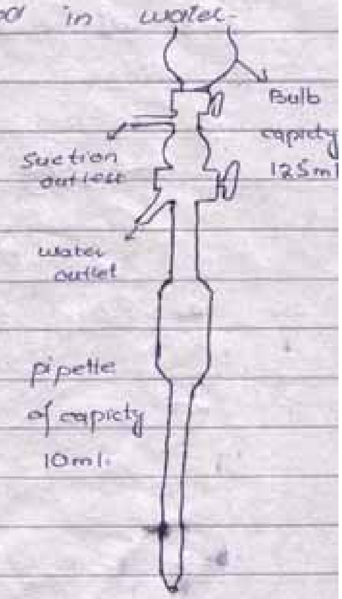
In this method a suitable amount of soil is taken -----

Same as In Hydrometer Method.

--- soil particles are assumed to be uniformly distributed.

TAKING SAMPLE :-

In this method a pipette is used to get a sample and then that sample is dried to get the amount of soil suspended in water. The pipette consists of i) a 125 ml bulb with stop cock for keeping the distilled water ii) a three way stop cock iii) suction and waste water outlets iv) sampling pipette of 10 ml capacity. The method consists on drawing off samples of soil suspension, 10ml in volume, by means of the pipette from a depth of 10cm (He) at various time intervals after the commencement of sedimentation



The pipette should be inserted in the boiling tube about 10 seconds before the selected time intervals and the time taken for sucking the sample should not be more than 10 to 20 seconds. Each sample, so taken, is transferred into suitable sampling bottles and dried in oven. The weight W/o of solids per ml of suspension is thus found by taking the dry weight and dividing it by 10.

Table:- The table for pipette method have the following columns.

time Elapsed	wt of soil solids in 10cc suspension	wt of soil per cc	wt of soil solids per cc of suspension	V	D	% finer (P)

→ time elapsed is noted down with the help of a stop watch or any another time measuring instrument

→ wt of soil solids in 10cc suspension by drying the sample in oven and noting down the value

→ Dividing wt of soil solids in 10cc by 10 will get wt of soil per cc. ~~This will be constant as wd/500 where wd is constant {which amount of soil taken in the beginning}~~ Ws/10 where Ws is the soil mass obtained for every sample which is variable. So this quantity will be variable

→ wt of solids per cc for suspension is obtained by dividing the whole soil solid mass taken in begining by 500 i.e total amount of water taken

$\frac{Wd}{500}$ as Wd is constant so it will remain constant.

→ v is distance covered by time

$$v = \frac{He}{t}$$

→ D can be calculated by formula.

$$v = \left(\frac{\gamma_s - \gamma_w}{1.8\mu}\right) D^2$$

$$D = \sqrt{\frac{1.8\mu v}{\gamma_s - \gamma_w}} \quad \text{—(1)}$$

~~For~~ As we know that

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

$$\gamma_s = G_s \gamma_w$$

~~and G_s can be founded~~

In CGS system $\gamma_w = 1$ g/cc

$$\gamma_s = G_s$$

So in the experiment γ_s is founded from G_s which is founded by experiment, μ is a constant quantity, γ_w is 1 g/cc, v is distance divided by time $v = \frac{He}{t}$

putting the values in eq (1) will give us value of D.

→ percentage finer is obtained by formula

$$P = \frac{\text{wt of soil solid per cc at 10cm depth}}{\text{wt of dry soil per cc in soil under suspension}}$$

$$= \frac{\left(W_s/_{10}\right)}{\left(W_d/_{500}\right)}$$

Problem :-

After performing laboratory test on two soil samples A and B the following data was obtained.

Given Data :-

	Soil A	Soil B
liquid limit (%)	36	74
plastic limit (%)	20	29
water content (%)	28	64

Calculate the following for each of the sample

Required :-

plasticity Index = ?

liquidity Index = ?

Solution :-

Soil A :-

Plasticity Index = P.I = 36 − 20

= 16 %

$$\text{liquidity Index} = \frac{W - P.L}{P.I}$$

$$= \frac{28 - 20}{16} = .5$$

Soil B :-

plasticity Index = P.I = 74 − 29

= 45 %

$$\text{liquidity Index} = \frac{W - P.L}{P.I}$$

$$= \frac{64 - 29}{45} = .77$$

Problem :-

A saturated sample of clay has weight or mass of 38.74 gm and volume of 19.5 cc. After drying its mass and volume reduces to 30.6gm and 15.95 cc respectively. Find shrinkage limit, volumetric shrinkage, shrinkage ratio and specific gravity of soil sample.

Given Data:-

Initial mass / wt of soil sample $W = 38.74gm$

Initial volume of " " " $V = 19.5$ cc

Mass / Wt of dry soil $W_d = 30.6gm$

Volume " " " $V_d = 15.95$ cc

Required :-

a- Shrinkage limit = ?

b- Volumetric shrinkage = ?

c- Shrinkage ratio = ?

d- Specific gravity of soil solids = ?

Solution :-

a) Shrinkage limit $= W_s = \left(w - \frac{(V-V_d)\gamma_w}{W_d}\right) \times 100$

$$= \left(\left(\frac{38.74-30.6}{30.6}\right) - \frac{(19.5-15.95)(1)}{30.6}\right) \times 100$$

$$= 15\ \%$$

b) Volumetric Shrinkage $V.S = \left(\frac{V-V_d}{V_d}\right) \times 100$

$$= \left(\frac{19.5-15.95}{15.95}\right) \times 100$$

$$= 22.26\ \%$$

c) Shrinkage Ratio $S.R = \frac{\gamma_d}{\gamma_w} = \frac{W_d}{V_d \times \gamma_w}$

$$= \frac{30.60}{} = 1.92$$

d) Specific gravity :-
(Using 2nd eq of shrinkage limit)

$$w_s = \left(\frac{\gamma_d}{\gamma_w} - \frac{1}{G_s}\right) \times 100 = \frac{1}{\frac{30.6}{15.95}}$$

$$.15 = \left(\frac{1}{\frac{30.6}{15.95}} - \frac{1}{G_s}\right)$$

$$G_s = 2.695$$

Classification of Soil

The different types of classification of soil are.

a. Grain Size Classification or Particle Size Classification :-

1. U.S Bureau Classification :-

Clay	Silt	Sand				Gravel	
		Very fine	fine	Medium	Coarse	fine	Coarse

.002 mm, .05 mm, .1 mm, .25 mm, .5 mm, 1.0 mm, 2.0 mm

2. ASTM Classification :-

Colloidal clay	Clay	Silt	Sand		Gravel
			Fine sand	Coarse Sand	

.001 mm, .005 mm, .074 mm, .25 mm, 2.00 mm

3- MIT Classification :- (V. Important)
(Massachusett institute of technology)

Clay			Silt			Sand			Gravel
fine	Medium	Coarse	fine	Medium	Coarse	fine	Medium	Coarse	

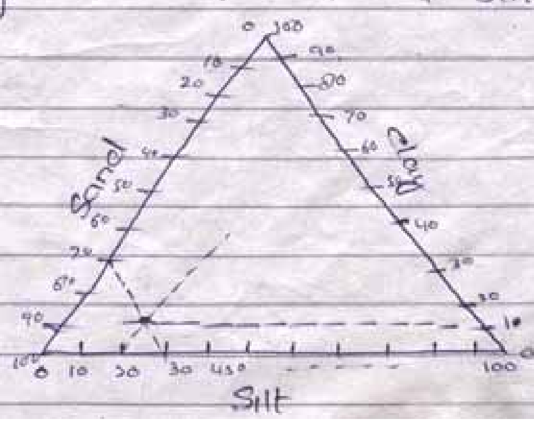
.0002 mm, .0006 mm, .002 mm, .006 mm, .02 mm, .06 mm, .20 mm, .60 mm, 2 mm

4- Soil Classification by triangular chart :- It consist of a triangle divided on each side into 10 equal parts having reading from 0 → 100. The whole triangle into 11 different areas and soil lieing in the range of any area is given the name of that area.

Example :-
Sand = 70%
silt = 20%
clay = 10%

from 70 on sand draw line parallel to clay
" 20 " silt " " " " sand
" 10 " clay " " " " silt

These lines will intersect at a pt & the pt lie in any area will given the name of area.



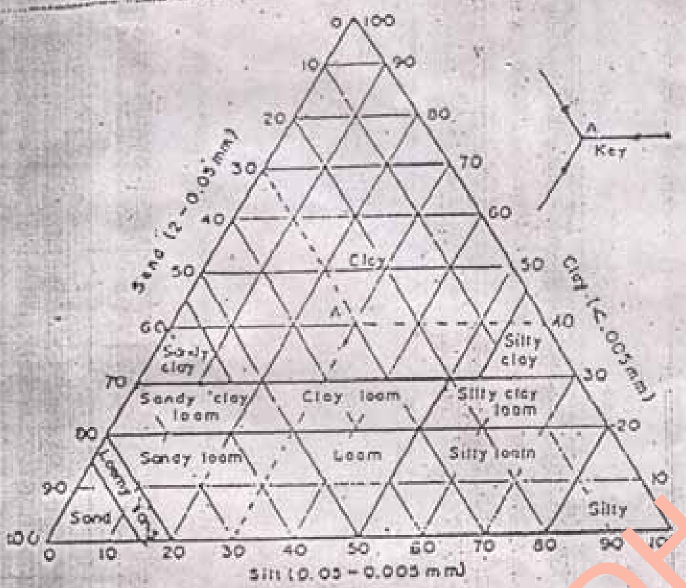


FIG. 4·2
Textural classification chart
(Adapted from U.S. Public Roads Administration)

Classification of Soils for Engineering Purposes
ASTM Designation D-2487

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Major Divisions		Group Symbols	Typical Names	Classification Criteria	
Gravels 50% or more of coarse fraction retained on No. 4 sieve	Clean Gravels	GW	Well-graded gravels and gravel-sand mixtures, little or no fines	$C_u = D_{60}/D_{10}$ Greater than 4; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
		GP	Poorly graded gravels and gravel-sand mixtures, little or no fines	Not meeting both criteria for GW	
	Gravels with Fines	GM	Silty gravels, gravel-sand-silt mixtures	Atterberg limits plot below "A" line or plasticity index less than 4	Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols
		GC	Clayey gravels, gravel-sand-clay mixtures	Atterberg limits plot above "A" line and plasticity index greater than 7	
Sands More than 50% of coarse fraction passes No. 4 sieve	Clean Sands	SW	Well-graded sands and gravelly sands, little or no fines	$C_u = D_{60}/D_{10}$ Greater than 6; $C_c = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ Between 1 and 3	
		SP	Poorly graded sands and gravelly sands, little or no fines	Not meeting both criteria for SW	
	Sands with Fines	SM	Silty sands, sand-silt mixtures	Atterberg limits plot below "A" line or plasticity index less than 4	Atterberg limits plotting in hatched area are borderline classifications requiring use of dual symbols
		SC	Clayey sands, sand-clay mixtures	Atterberg limits plot above "A" line and plasticity index greater than 7	
Liquid limit 50% or less		ML	Inorganic silts, very fine sands, rock flour, silty or clayey fine sands	Plasticity chart (see below)	
		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays		
		OL	Organic silts and organic silty clays of low plasticity		
Liquid limit greater than 50%		MH	Inorganic silts, micaceous or diatomaceous fine sands or silts, elastic silts		
		CH	Inorganic clays of high plasticity, fat clays		
		OH	Organic clays of medium to high plasticity		
organic soils		Pt	Peat, muck and other highly organic soils	Visual-manual identification	

Classification on basis of percentage of fines:
Less than 5% Pass No. 200 sieve — GW, GP, SW, SP
More than 12% Pass No. 200 sieve — GM, GC, SM, SC
5% to 12% Pass No. 200 sieve — Borderline classification requiring use of dual symbols

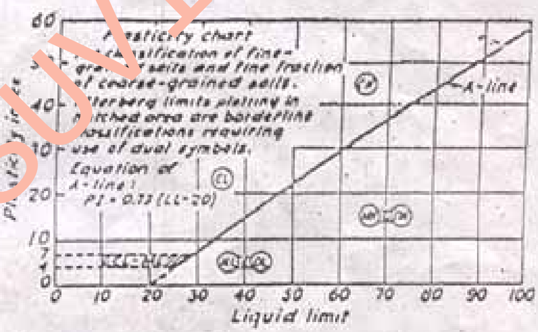


Table 3.3 AASHTO Soil Classification System

General classification	Granular materials (35 per cent or less passing No. 200)							Silt-clay materials (More than 35 per cent passing No. 200)			
Group classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1a	A-1b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5; A-7-6
Sieve analysis percent passing No. 10 / No. 40 / No. 200	[illegible] max, 30 [illegible], 1[illegible] max	50 max, 25 max	51 min, 10 max	35 max	35 max	35 max	35 min	36 min	36 min	36 min	36 min
Characteristics of fraction passing No. 40: Liquid limit / Plasticity index	6 max		[illegible]	40 max, 10 max	41 min, 10 max	40 max, 11 min	41 min, 11 min	40 max, 10 max	41 min, 10 max	40 max, 11 min	41 min, 11 min
Group index	0		0	0		4 max		8 max	12 max	16 max	20 max
Usual types of significant constituent materials	Stone fragments, gravel and sand		Fine sand	Silty or clayey gravel and sand				Silty soils		Clayey soils	
General rating as subgrade	Excellent to good							Fair to poor			

[illegible] or muck is by visual classification and is not shown in the table

$$S.R = \frac{\gamma_d}{\gamma_w}$$

$$S.R = \frac{\gamma_d}{\gamma_w} \qquad \frac{\gamma_d}{\gamma_w} \qquad \frac{\gamma_d}{\gamma_w} \qquad \frac{\gamma_d}{\gamma_w}$$

$$S.L = \left(w_s = w - \left(\frac{(V - V_d)\gamma_w}{W_d} \right) \right) \times 100$$

$$S.R = \frac{\gamma_d}{\gamma_w} \;\Big\} \rightarrow$$

$$w_s = \left[\frac{\gamma_w}{\gamma_d} - \frac{1}{G} \right]$$

$$w_s = \left[\frac{\gamma_w}{\gamma_d} - \frac{1}{G} \right.$$

CHAPTER # 04

Permeability and Seepage :-

Permeability is defined as the property of ~~a porous~~ material ~~which~~ to permits the passage or seepage of water (or other fluids) through its ~~interconnecting~~ ~~voids~~ pores or voids.

A material having continuous voids is called permeable. Gravels are highly permeable while stiff clay is least permeable and hence such a clay may be termed as impermeable.

Impervious is the material which don't allow the fluid to pass through.

HEAD :- The total head any pt is equal to the ~~(example)~~ sum of i) velocity head ii) Datum head iii) Pressure head

Total head = Datum head + Pressure head + Velocity head

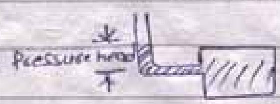
Types Of Head :-

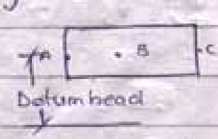
i) Datum head :- height from the datum line.

ii) Pressure head :- Rise of water in tube

iii) Velocity Head = $\frac{v^2}{2g}$

where v is velocity & g is acceleration due to gravity.





Heads always drops as move away from capillary.

loss of head = $h_1 - h_2$

h_1 = head at pt A h_2 head at pt 2

GROUP INDEX :-

$$G.I = .2a + .005ac + .01bd$$

where

a = that portion of %age of soil passing sieve #200 which is greater than 35 and not exceeding 75 which is expressed as a whole no from 0 to 40.

b = that portion of %of soil passing sieve #200 which is greater than 15 and not exceeding 55 which is expressed as a whole no from 0 to 40

c = that portion of liquid limit of soil greater than 40 and not exceeding 60 expressed as whole no- from 0 to 20

d = that portion of plasticity Index of soil greater than 10 & not exceeding 30 expressed as whole no- from 0 to 20

Example :-

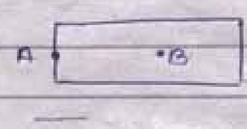
Soil passing sieve No 200 = 55%
liquid limit = 60%
plastic limit = 40

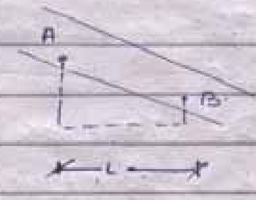
P.I = 60 − 40 = 20
a = 55 − 35 = 20
b = 55 − 15 = 40
c = 60 − 40 = 20
d = 20 − 10 = 10
∵ P.I = LL − PL =
GI = .2×20 + .005 × 20×20 + .01×40×10
= 4 + 2 + 4
= 10

If a exceeds from 75 or equal to 75 − 35 = 40 and 80 − 35 = 40 and also 85 − 35 = 40 same for other values of = PI − 10 = (60−40)−10 = 10 = 10   29.

Hydraulic Gradient :- i

It is the loss of head divided by the horizontal distance or length in which this loss has taken place.





Darcy's LAW :-

The law of flow of water through soil was first studied by Darcy (1856). This law states that "The velocity of water is always proportional to the hydraulic gradient".

Mathematically :-

velocity ∝ Hydraulic gradient

$v \propto i$

$v = ki$

Multiplying A on both sides

$A v = k i A$ —(1)

where k is constant of proportionality

Q or q stands for Discharge and is equal to

$Q = \frac{V}{t} = \frac{\text{volume}}{\text{time}}$

$Q = A * \frac{L}{t}$ → velocity

$Q = A * v$ —(2)

putting (2) in eq (1) we get

$Q = kiA$

which is Darcy's equation

~~If also~~ ~~Q = ...~~

~~If ... then ...~~

where

Q = flow or discharge

K = co-efficient of proportionality

i = Hydraulic gradient

A = Area of cross-section

Co-efficient of Permeability :-

Now

$$K = \frac{Q}{i \cdot A}$$

If i = 1 then

$$K = \frac{Q}{A}$$

Then K is called **co-efficient of permeability**

and K is defined as

" The discharge or rate of flow per unit area of soil mass under unit hydraulic gradient".

Validity :-

1) Flow will be laminar i.e the particle move in straight line and does not intersect each other

If particles cross or intersect each other it is called turbulence flow.

2- Reynold no. should be less than or equal to 1

$$\text{Reynold No.} = \frac{v \cdot d \cdot \gamma_w}{\eta g}$$

where v = velocity

γ_w = unit wt of water d = dia of particle

η = viscosity of water g = acceleration due to gravity

3- Particle size should not be greater than 3mm.

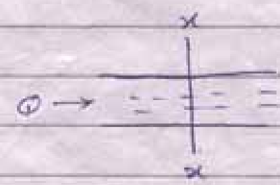
The above conditions must be satisfied for the validity of the law.

DISCHARGE & SEEPAGE VELOCITY :- There are two types of velocity i) Discharge & ii) Seepage velocity

$A = A_s + A_v$

and $Q = A \cdot v$

$v = \frac{Q}{A}$



Discharge velocity is represented by v and seepage velocity by v_s

DISCHARGE VELOCITY :- ~~The velocity (discharge) of flow v is~~ the rate of flow or discharge of water per unit of total cross-sectional area A of soil-

$$v = \frac{Q}{A}$$

Seepage Velocity :- The rate of discharge of percolating water per unit cross sectional of area of voids perpendicul to the direction of flow is called "seepage velocity".

Since flow takes place through voids, the actual or true velocity of flow will be more than the discharge velocity & this actual velocity is seepage velocity.

Mathematically

$$Q = A_v v_s$$

$$v_s = \frac{Q}{A_v}$$

where A_v = area of openings or voids

From the definitions of the discharge velocity and seepage velocity, we have:

$$Q = vA = v_s A$$

$$v = \frac{A_v}{A} v_s$$

as we know that $\frac{A_v}{A}$ = porosity = n

$$v = n v_s$$

and $n = \left(\frac{e}{1+e}\right)$

$$v = \left(\frac{e}{1+e}\right) v_s = n v_s$$

Made by :→

Fazl-i-Wahab

Determination of Co-efficient of Permeability (K) of Soil :-

These are two method of determination of co-efficient in the lab and one method in field

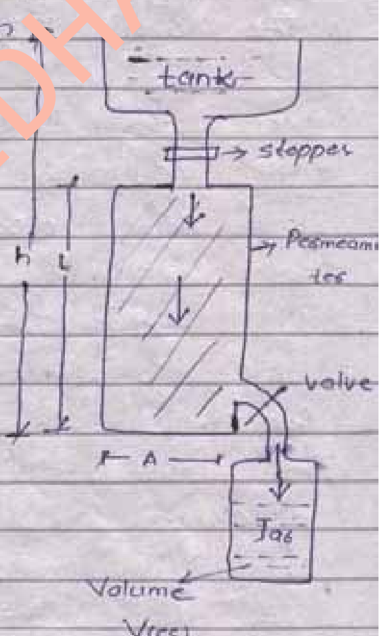
The two methods to determine co-efficient of permeability in lab are

1. Constant head permeability test
2. Falling / Variable head permeability test

CONSTANT HEAD PERMEABILITY TEST :-

The apparatus used in this test is known as constant head Permeameter. Fist the dimension of the cylinder in which soil sample is kept are noted down i.e length, height, area etc. Then soil is placed in the apparatus and the two values are opened. The time and amount of water are noted down and then used to find

$$Q = \frac{V}{t} = \text{Volume in cc}$$



Then all the data is placed in the darcy's law and the co-efficient of permeability is calculated.

According to Darcy's law

$$Q = K\,i\,A \quad \text{and} \quad i = h/L$$

$$K = \frac{Q \times L}{h \times A}$$

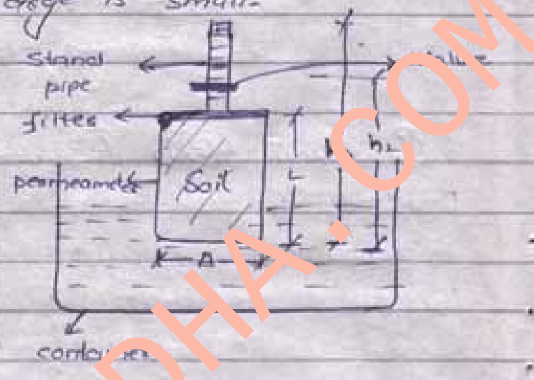
L = length of cylinder h = head

A = Area of cylinder

FALLING OR VARIABLE HEAD TEST :-

As constant head test is used for coarse grain soil only where a reasonable discharge can be collected in a given time falling head test was introduced. The falling or variable head test is used for relatively less permeable soil where the discharge is small.

First find the area of soil sample, Area of stand pipe then open valve and let the water come down



When water starts coming down close the valve and note the water level in stand pipe h_1 is the initial reading i.e before allowing the water to flow and h_2 is the reading when water level has fallen down due to flow of water, also note the time for which the valve was ~~allowed to~~ open.
In porous soil the water level will fall very quickly.

$$K = \frac{a \cdot L \cdot \log h_1/h_2}{A(t_2 - t_1)}$$

OR — In some books

$$K = \frac{2.3 \times a \cdot L \log \frac{h_1}{h_2}}{A(t_2 - t_1)}$$

where

a = area of crosssection of stand pipe
L = length/height of soil sample
A = area of soil
t = time of fall of water level from h_1 to h_2

Let water level in stand pipe drop by dh in time dt velocity of fall $= v = \frac{dh}{dt}$

when water level increase it is taken +ve and when fall it is taken −ve.

Now rate of flow $q = Q = av = a * -\frac{dh}{dt}$ — (A)

and from darcy's law

$Q = q = KiA$ — (B)

$q = K\frac{h}{L}A$ — (1)

comparing (1) and (A) we get

$K\frac{h}{L}A = -a\frac{dh}{dt}$

$\frac{KA}{L}dt = -a\frac{dh}{h}$

Integrating we get

$\frac{KA}{L}\int_{t_1}^{t_2} dt = -a\int_{h_1}^{h_2}\frac{dh}{h}$

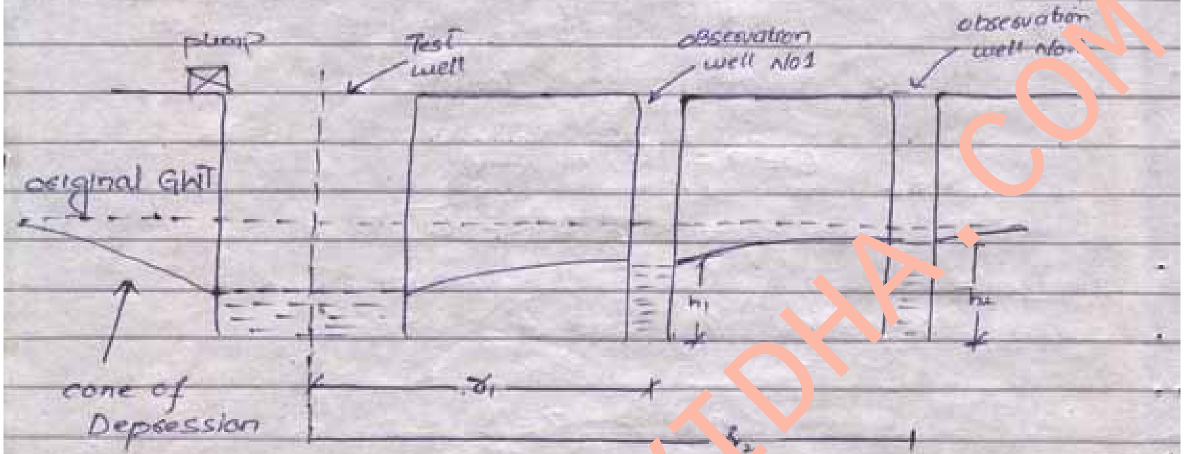
$\frac{KA}{L}(t_2-t_1) = -a\log\frac{h_1}{h_2}$

$K = \left(\frac{a \cdot L}{A(t_2-t_1)}\log\frac{h_1}{h_2}\right)$

$K = 2.303\left[\frac{a \cdot L \log_{10}\frac{h_1}{h_2}}{At}\right]$

DETERMINATION OF CO-EFFICENT OF PERMEABILITY OF SOIL IN FIELD :-

The fig given below shows three different wells excavated in the ground to find the coefficient of permeability. This is a very labourious job.



Find r_1, r_2, h_1, h_2. Then find the rate of pumping i.e discharge by noting down water collected in container and the time taken by it.

$$Q = V/t = \frac{\text{Volume collected in container}}{\text{time taken}}$$

let

r_1 = Horizontal distance of Obscevation well no 1 from main well

r_2 = Horizontal " " " " No-2

h_1 = height of obsevation well No-1

h_2 = " " " " No-2

$$\text{Dischage} = Q = V/t$$

Then

$$K = \frac{2.303\, Q \log \frac{r_2}{r_1}}{\pi (h_2^2 - h_1^2)}$$

FACTORS AFFECTING PERMEABILITY OF SOILS :-

According to Poiseuilles equation

$$Q = D_s^2 \cdot \frac{\gamma_w}{\eta} \cdot \frac{e^3}{1+e} \cdot C \cdot i \cdot A \rightarrow (A)$$

According to Darcy law

$$Q = K i A \longrightarrow (B)$$

Comparing (A) & (B) we get

$$K \cdot i \cdot A = D_s^2 \cdot \frac{\gamma_w}{\eta} \cdot \frac{e^3}{1+e} \cdot C \cdot i \cdot A$$

$$K = D_s^2 \cdot \frac{\gamma_w}{\eta} \cdot \frac{e^3}{1+e} \cdot C$$

1- **EFFECT OF GRAIN SIZE :-**

According to Hazen

$$K \propto D_{10}^2$$

means K is linearly dependent on Diameter of soil

2- **EFFECT OF PROPERTIES OF PORE WATER :-**

$$K \propto \frac{\gamma_w}{\eta}$$

Now if we have two samples of soil Then

$$K_1 \propto \frac{\gamma_{w1}}{\eta_1} \qquad K_2 \propto \frac{\gamma_{w2}}{\eta_2}$$

$$\frac{K_1}{K_2} = \frac{\gamma_{w1}/\eta_1}{\gamma_{w2}/\eta_2} = \frac{\eta_2}{\eta_1}$$

when other factors remain constant the effect of property of water on the values of permeability are

3 EFFECT OF VOID RATIO :-

$$K \propto \frac{e^3}{1+e} \, c$$

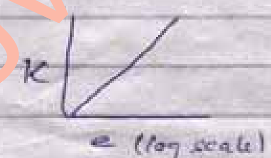
If $K_1 \propto \frac{e_1^3}{1+e_1} c$ $\quad K_2 \propto \frac{e_2^3}{1+e_2} c_2$

$$\frac{K_1}{K_2} = \frac{\frac{e_1^3}{1+e_1} c_1}{\frac{e_2^3}{1+e_2} c_2}$$

for coarse or sandy soil $c_1 = c_2$

$$\frac{K_1}{K_2} = \frac{\frac{e_1^3}{1+e_1}}{\frac{e_2^3}{1+e_2}}$$

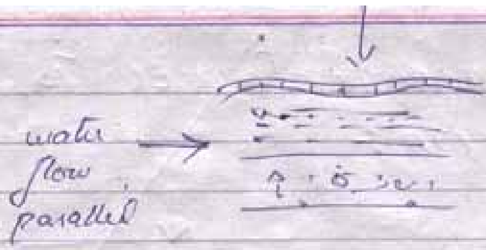
K and e have a linear relationship. If K increase e increase. Thus the graph will be a straight line.



4- Structural Arrangement of Particles & Stratification:

The structural arrangement of the particles may vary, at the same void ratio, depending upon the method of decomposition or compacting the soil mass.

The effect of structural disturbance is much pronounced in fine-grained soils. Stratified soil masses have marked variation in their permeabilities in direction parallel and perpendicular to stratification, the permeability parallel to the stratification being always greater.



5- EFFECT OF Adsorbed water :- If water surrounds each particle it will reduce the pore area / space thus decreasing permeability.

The adsorbed water means water taken from the atmosphere.

6 Effect of Gases / Air etc :- When no air the permeability will increase & vice versa.

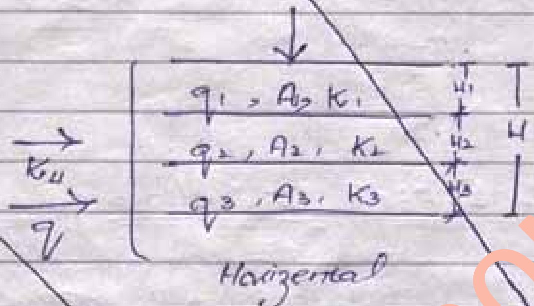
Permeability of Stratified Soil :- In nature soil mass may consist of several layers deposited one above the other. The average permeability of the whole deposit will depend upon the direction of bedding. Thus we consider both the cases of flow

i) Parall to bedding plane

ii) Perpendicular to bedding plane.

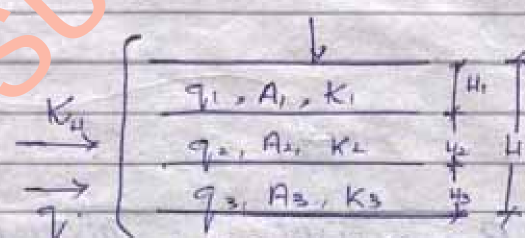
i) AVERAGE PERMEABILITY PARALLEL TO Layer OR STRATA :-

let $q_1, q_2, q_3 \dots q_n$ be the discharge, $A_1, A_2, A_3 \dots A_n$ be the areas, $K_1, K_2, K_3 \dots K_n$ be



i) Average Permeability Parallel To Layer or Strata :-

let q be the total discharge. Then



$$q = q_1 + q_2 + q_3 \dots + q_n \quad \text{--- (1)}$$

q = discharge
A = Area
H = Height
K = permeability

According to Darcy's law

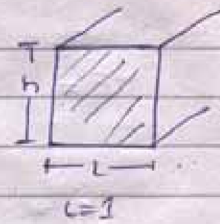
$q = K \cdot i \cdot A$ so

$q_1 = K_1 i_1 A_1 \quad q_2 = K_2 i_2 A_2 \quad q_3 = K_3 i_3 A_3 \dots$

Since i is same for all

$$q_1 = K_1 i A_1 \quad q_2 = K_2 i A_2 \quad q_3 = K_3 i A_3 \quad \dots \text{--- (2)}$$

For a unit length



$$A = 1 * H = 1 * H$$

$$A = H$$

Thus

$$A_1 = H_1, \quad A_2 = H_2, \quad A_3 = H_3 \quad \text{—③}$$

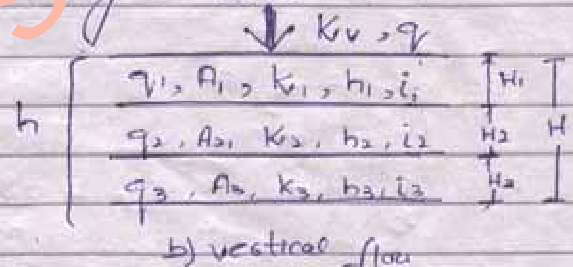
putting eq ② & ③ in eq① we will get

$$q = K_H i H = K_1 i H_1 + K_2 i H_2 + K_3 i H_3$$

$$K_H H = K_1 H_1 + K_2 H_2 + K_3 H_3$$

$$K_H = \frac{K_1 H_1 + K_2 H_2 + K_3 H_3}{H}$$

B) Average Permeability Perpendicular or Vertical to Strata or layers (K_V) :-



b) vertical flow

In this case, velocity of flow, and hence unit discharge will be same through each layer. However hydraulic gradient & hence the head loss through each layer will be different. Denoting the head loss through layer by $h_1, h_2 \text{---} h_n$

q = discharge
A = Area.
K = permeability
h = head loss
i =
H = height.

The total head loss is

$$h = h_1 + h_2 + h_3 + \text{---} h_n \quad \text{—①}$$

Now as we know.

$$i = \frac{\text{Head loss}}{\text{distance (here it is height)}}$$

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

and $h = iH$ — ②

So, $h_1 = i_1 H_1$ $h_2 = i_2 H_2$ $h_3 = i_3 H_3$ ----- ③

putting values of ② & ③ in ① we get

$$iH = i_1 H_1 + i_2 H_2 + i_3 H_3 \quad \text{— (5)}$$

Now, as we know that according to ______

$$v = Ki$$

$$i = \frac{v}{K}$$ v is same for all layers.

$$i_1 = \frac{v}{K_1}, \quad i_2 = \frac{v}{K_2}, \quad i_3 = \frac{v}{K_3}$$

putting in eq (5) the values of i we get,

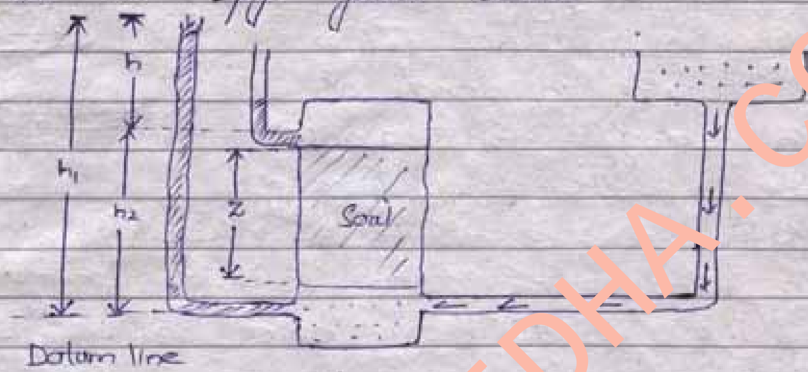
$$\frac{v}{K} H = \frac{v}{K_1} H_1 + \frac{v}{K_2} H_2 + \frac{v}{K_3} H_3$$

$$K_v = \frac{H}{\frac{H_1}{K_1} + \frac{H_2}{K_2} + \frac{H_3}{K_3}}$$

Seepage Pressure :-

The seepage pressure is the pressure exerted by the water on soil through which it percolates.

to derive an equation for seepage pressure we will use the fig. given below



Volume of soil = Area * z

$V = A \cdot z$

As we know that

$$i = \frac{h_1 - h_2}{z} = \frac{h}{z} \quad \text{--- (1)}$$

Seepage pressure = $\gamma_w h$

Multiplying & dividing by z

$$= \gamma_w * h * \frac{z}{z}$$

From eq (1) $h/z = i$ thus

Seepage $= \gamma_w i z$

For Seepage force $(P = F \times A)$

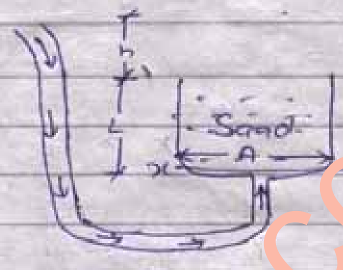
Seepage force $= \gamma_w \cdot i * z \cdot A$ & $Az = V$

$= \gamma_w \cdot i \cdot V$

Seepage force per unit Volume = $\frac{\gamma_w \cdot i \cdot V}{V}$

$= \gamma_w \cdot i$

Quick Sand :->



When seepage pressure due to upward flow of water in sand or in sandy soil balances the downward force of gravity, a condition of instability arises in the sand then sand or sandy soil in this condition is called quick sand.
Therefore quick sand is not a type of material or sand but a condition of instability which coarse grain or granular soil may attain under certain circumstances. In this condition the hydraulic gradient is called critical gradient.

Upward force

upward force = ~~(h+L)~~
$= (h+L) A \cdot \gamma_w$ —— ①.

Downward force :-
will be due to the weight of sand.

As we know

$\gamma_B = \frac{W}{V}$ —— ①

and $\gamma_B = \frac{\gamma_w [G_s + e \cdot S]}{1+e}$ —— ②

Comparing 1 & 2

$$\frac{W}{V} = \frac{\gamma_w (G_s + e.S)}{1+e}$$

$V = A \cdot L$

$$W = \frac{\gamma_w (G_s + e.S)}{1+e} A L$$

for saturated soil $S = 1$, so

$$W = \gamma_w \left[\frac{G_s + e}{1+e}\right] A \times L$$

At Balance:-

$$(h+L) A \gamma_w = \gamma_w \left[\frac{G_s + e}{1+e}\right] A \times L$$

Divide both sides by L

$$\frac{h}{L} + 1 = \frac{G_s + e}{1+e}$$

$$\frac{h}{L} = \frac{G_s + e}{1+e} - 1$$

$$\frac{h}{L} = \frac{G_s + e - 1 - e}{1+e}$$

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

critical hydraulic gradient