MADE EASY
CIVIL ENGINEERING
Soil Mechanics
BY-Ram Sir

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India's Best Institute for IES, GATE & PSUs

CHAPTER-1
INDEX PROPERTIES OF SOIL

SOIL MECHANICS

Index properties of soil helps in classification and identification of soil.

1. Water content
2. Unit weight
3. Specific gravity
4. Particle size distribution
5. Consistency
6. Sensitivity
7. Thixotropy
8. Activity
9. Collapsibility

1. Water Content

Water content can be determined using any of the following methods.

A. Oven drying method
B. Sand bath method
C. Alcohol method
D. Calcium carbide method
E. Radiation method
F. Torsion Balance Method and infrared method
G. Pycnometer Method

A. Oven Drying Method

- This is most accurate laboratory method.
- In this method moist sample of soil is placed in empty container of known mass (W_1) and after placing, it is weighed again (W_2).
- Container with moist soil sample is placed in temperature controlled oven for drying.

- For Inorganic soil, temperature is maintained between 105°C to 110°C for 24 hours.
- For organic soil, temperature is not increased beyond 60°C in order to avoid oxidation of organic matters.4
- ➢ For soil having gypsum, temperature is limited to 80°C in order to avoid, loss of water of crystallization (Structural water).

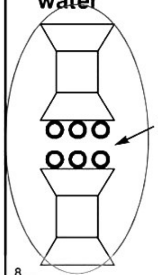
NOTE:

In no case, temperature is increased beyond 110°C because it results in destruction of soil solids causing loss of structural water.

NOTE : In oven drying, all types of soil water (free water, capillary water, absorbed water) are removed, except structural water or water of crystallization (if present).

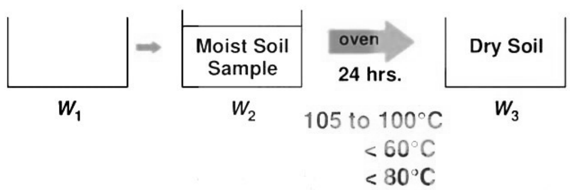
Soil Water

- Structural water
- Adsorbed water
- Capillary water
- Free/Gravity water



- After drying container with dry soil is again weighed (W_3) and water content is measured as follows

$$\omega = \frac{\text{Weight of water}}{\text{Weight of solids}} \times 100 = \frac{W_2 - W_3}{W_3 - W_1} \times 100$$

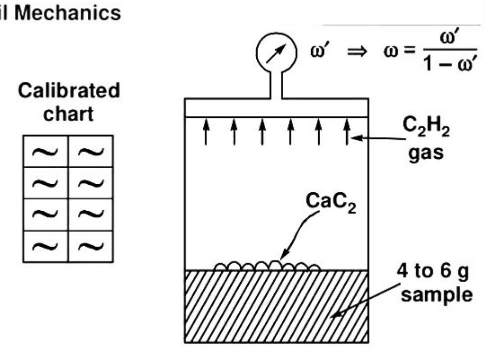


D. Calcium Carbide Method

- It is one of the quickest methods to find water content of soil which gives the result within 5 to 7 minutes.
- It is field method.

- In this method 4 to 6 g (fixed weight is taken due to calibration) of sample is placed in moisture meter and calcium carbide is added in it which reacts with the water present in the sample resulting in the formation of acetylene gas that exerts pressure over the gauge which is further calibrated to give water content of soil is terms of total mass of soil. (′)

$$\omega' \Rightarrow \omega = \frac{\omega'}{1-\omega'}$$



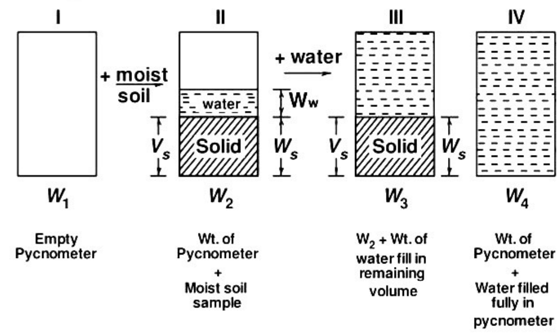
$$CaC_2 + H_2O \rightarrow C_2H_2 \uparrow + Ca(OH)_2$$

Acetylene

G. Pycnometer Method

- It is quick method gives results within 10 to 20 mins.
- This method is used for those soil for which (sp. Gravity) is known.
- Pycnometer is 900 ml flash having conical top with 6 mm diameter circular hole at its centre for the removal of air.
- This method is suitable for cohesionless soil (because remove of entrapped gases in difficult from cohesive soils).

Steps of Observation:



Weight of water in moist soil sample = $W_2 - W_1 - W_s$

It can be seen that, if from W_3, weight of solid is removed and replaced by the weight of an equivalent volume of water, the weight W_4 is obtained.

$$W_4 = W_3 - W_s + V_s \;_{w}$$

Weight of water having equivalent volume

$V_s = V_s \;_{w}$

$$W_4 = W_3 - W_s + \frac{W_s}{G\gamma_w} \cdot \gamma_w \qquad \square \gamma_s = \frac{W_s}{V_s} = G.\gamma_w$$

$$W_3 - W_4 = W_s\left(1 - \frac{1}{G}\right)$$

$$W_s = W_3 - W_4\left(\frac{G}{G-1}\right) \quad \rightarrow \text{(A)}$$

$$\text{water content} = \frac{\text{Weight of water}}{\text{Weight of solids}} \times 100$$

$$\omega = \frac{W_2 - W_1 - W_s}{W_s} \times 100 = \left(\frac{W_2 - W_1}{W_s} - 1\right) \times 100$$

$$\boxed{\omega = \left(\frac{W_2 - W_1}{W_3 - W_4}\left(\frac{G-1}{G}\right) - 1\right) \times 100}$$

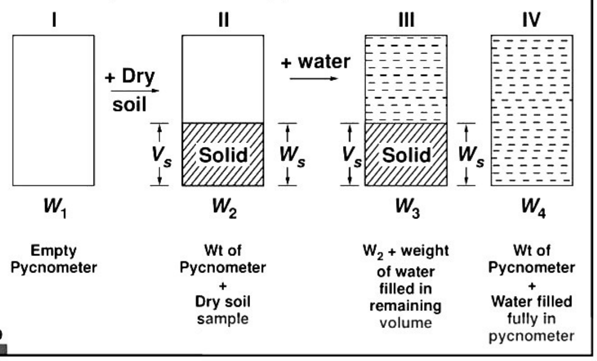
2. Specific Gravity

- Specific gravity of soil can be computed using 50 ml density bottle, 500 ml flask or by pycnometer.
- Specific gravity of solids is given as

$$G = \frac{\text{Weight of solids of given volume}}{\text{Weight of water having same volume}}$$

Soil Mechanics

Step of observation: In this method <u>dry soil</u> sample is used in pycnometer



Soil Mechanics

Weight

Weight of solids = Dry cut of soil mass = $W_2 - W_1 = W_d$

Weight of water in III = $W_3 - W_2$

Weight of water in IV = $W_4 - W_1$

Weight of water having same volume as that of soil solids (V_s) = Weight of water in IV Weight of water in III

$= W_4 - W_1 - (W_3 - W_2) = W_4 - W_3 + W_2 - W_1$

Soil Mechanics

$$G = \frac{\text{Weight of solids of given volume}}{\text{Weight of water having same volume}}$$

$$G = \frac{W_2 - W_1}{W_4 - W_3 + W_2 - W_1} = \frac{W_d}{W_4 - W_3 + W_d}$$

Soil Mechanics

NOTE : Kerosene is used instead of water for fine grained soil. Because it is better wetting agent than water. If kerosene is used instead of water, then SG is calculated as

$$G = \frac{W_2 - W_1}{W_4 - W_3 + W_2 - W_1} \times G_k = \frac{\gamma_s}{\gamma_{kerosene}} \times G_k$$

$$= \frac{\gamma_s}{\gamma_k} \times \frac{\gamma_k}{\gamma_\omega} = \frac{\gamma_s}{\gamma_\omega}$$

(G_k = specific gravity of kerosene)

Soil Mechanics

3. <u>Unit Weight of Soil</u>

A. Core –Cutter method
B. Water displacement method
C. Sand replacement method
D. Submerged density metho

A. <u>Core-Cutter Method</u>:

- **It is field method.**
- **Core cutter of known volume 1000 CC is pushed into the ground and then core containing soil is taken out from the ground.**

Soil Mechanics

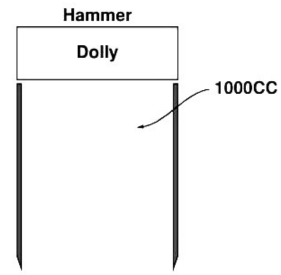
- **Weight of core with soil sample (W_2) and empty core (W_1) is measured. Hence bulk unit weight is given as**

$$\gamma_b = \frac{\text{Weight of soil}}{\text{Volume}} = \frac{W_2 - W_1}{V}$$

- By measuring water content of given sample, dry unit weight can be calculated as

$$\gamma_d = \frac{\gamma_b}{1+\omega}$$

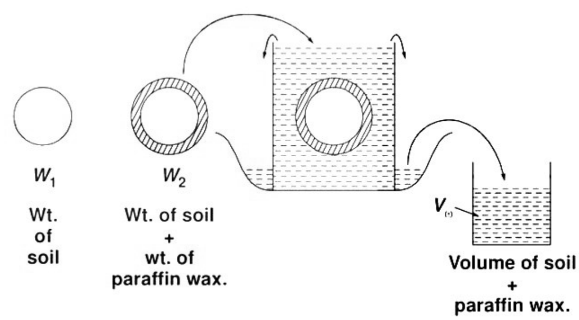
- This method is generally not suitable for gravels, sand and dry soil.
- It is generally used for soft silt and clay.



B. Water Displacement Method:

- This method is generally used for cohesive soils that are highly sticky in nature.
- In this method, sample of soil is trimmed into more or less uniform shape and weighed (W_1)
- Sample is then coated with paraffin wax and is again weighed (W_2), coating prevent entry of water into sample.

Water Displacement Method



- The coated specimen of soil is immersed slowly in a container, that is completely filled with water and volume of water displaced by coated specimen is V .

$$\text{Volume of paraffin wax} = \frac{W_2 - W_1}{\gamma_{PW}} = \frac{W_2 - W_1}{G_{PW}\gamma_\omega}$$

V = Volume of soil + Volume of paraffin wax.

Volume of soil = V – Volume of paraffin wax

$$= V_\omega - \frac{W_2 - W_1}{\gamma_{PW}}$$

$$\text{Unit weight of soil} = \frac{\text{Weight of soil}}{\text{Volume of soil}} = \frac{W_1}{V_\omega - \left(\frac{W_2 - W_1}{PW}\right)}$$

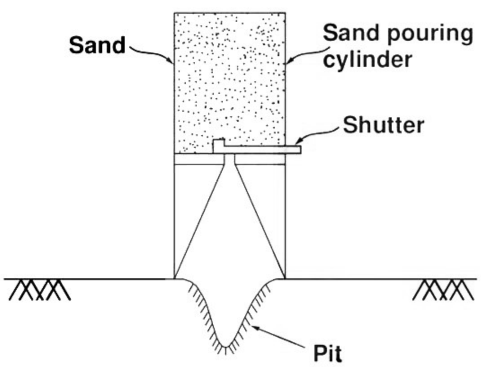
C. Sand Replacement Method:

- It is field method.
- A small pit is excavated and the excavated soil sample is a weighted.
- A calibrated cylinder containing sand is placed over the excavated pit and is filled with sand.
- Volume of the pit is obtained from the calibrated cylinder

- The bulk unit weight is calculated as

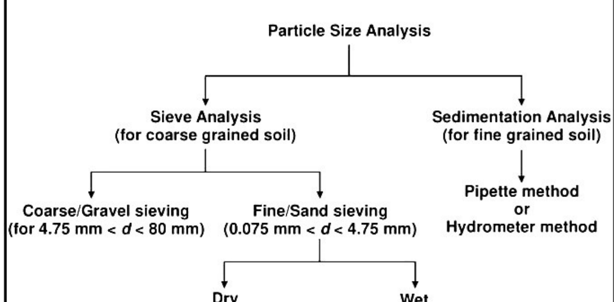
$$\gamma_b = \frac{\text{Weight}}{\text{Volume}}$$

- It is suitable for gravel, sand and dry soil.



4. Particle Size Distribution Analysis

Coarse grained soil	Gravel	4.75 mm	to	80 mm
	Sand	75 μm 0.075 mm	to to	4.75 mm 4.75 mm
Fine grained soil	Silt	2 μm 0.002 mm	to to	75 μm 0.075 mm
	Clay	< 2μm < 0.002 mm		



Sieve Analysis

- Sieve analysis is done for the soil fraction size greater than 0.075 mm. It means particles which are retained over 75   sieve.
- As per IS460:1962 sieves are designed by the size of the square opening in mm (or)   m (1 micron = 10^{-6}m = 10^{-3} mm = 1   m)

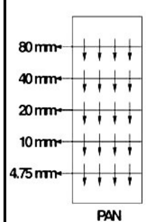
- In this method different sieves are arranged one over each other is descending order of their size.
- An oven dried sample of soil is placed over top most sieve and sieving is done atleast for 10 min either manually or in sieve shaker.
- Weight of soil fractions retained over each sieve is noted to compute the percentage finer corresponding to given size of sieve.

% finer (%N) = 100 – cumulative % weight retained.

(a) Coarse Sieve / Gravel Sieving:

- It is done for soil fraction having size greater than 4.75 mm. It means retained over 4.75 mm sieve.
- Standard sieves used are 80 mm, 40 mm, 20 mm, 10 mm and 4.75 mm

For Example :



Sieve size (mm)	Wt. Retained	%Wt. Retained	Cumulative %Wt. Retained	%N 100-Cumulative %Wt. Retained
80	10g	10%	10%	90%
40	30g	30%	40%	60%
20	30g	30%	70%	30%
10	20g	20%	90%	10%
4.75	10g	10%	100%	0%
	100g			

(b) Fine Sieving / Sand Sieving

- It is done for soil fraction that passes through 4.75 mm sieve but are retained over 0.075 mm sieve.
- Standard sieves used are 2 mm, 1 mm, 600 , 425 , 212 , 150 , 75 .
- The result of the sieve analysis represented in terms of size of the particle and corresponding % finer.
- It is generally preferred to wash the soil fraction that passes through 4.75 mm sieve before carrying out sieving in order to separate clay and silt particles present over sand this process is termed as wet sieving.

(c) Sedimentation Analysis

- Sedimentation analysis is carried out for the soil fraction having size less than 0.075 mm or which passes through the 0.075 mm sieve.
- Particles having size less than 0.2 (0.0002 mm) can not be analyses even by sedimentation. For them special techniques like electron microscope and X-ray diffraction techniques are used.

- Sedimentation analysis is based on stoke's law, according to which velocity of particle undergoing settlement within infinite medium is depend upon size, shape and mass of the particle.
- According to <u>stokes law</u>, terminal velocity is given as

$$V_s = \frac{(\gamma_s - \gamma_\omega)d^2}{18\mu} = \frac{(G-1)\gamma_\omega d^2}{18\mu}$$

Where, = Dynamic viscosity of water; d = Particle size

- At, 20°C, dynamic viscosity of water is 0.01 poise and suppose, G = 2.65 then

m mm

$v_s = 899250\, d^2\ m/s$ $v_s = 0.899\, d^2\ m/s$

- At 29°C, dynamic viscosity of water is 0.00855 poise, then

mm

$v_s = 1.07\, d^2\ m/s$

(d) Limitation of Stoke's law

1. Particles undergoing settlement is assumed to be spherical but in actual, fine grained particles are flaky in nature.
2. The medium in which settlement takes place is assumed to be infinite but in actual, sedimentation jar has finite dimension.
3. The particles is assumed to be undergoing discrete settling. But in actual fine grained particles aggregates during the settlement

4. Stoke's law is valid for the particles having size range between 0.2 mm to 0.2 m.

- If the size of particle is greater than 0.2 mm gravity acceleration sets up during settlement due to turbulent motion as a result of which constant velocity is not achieved throughout the settlement.
- If the size of particle is less than 0.2 m, then Brownian motion setup which does not allow settlement of particle.

General Procedure for Sedimentation Analysis:

- Sedimentation analysis can be carried out either by pipette method or by hydrometer method.

Method of preparation of soil suspension is same in both method as follows:

Pretreatment

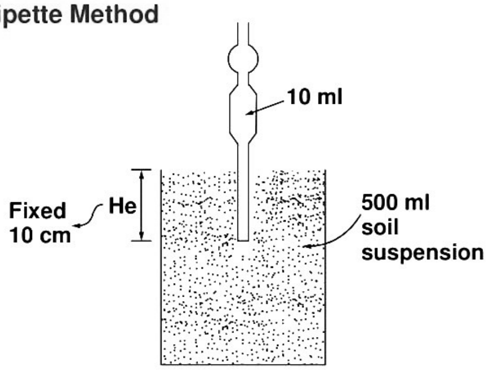
- Before preparing soil suspension, organic matter and calcium compounds present in soil should be removed in order to avoid the aggregation of solids during settlement.

- Organic matters are removed by oxidizing agents like hydrogen peroxide (H_2O_2) which carries out oxidation of organic matters and calcium compounds are removed by 0.2 N, HCl.
- Soil passing through 75 m sieve is mixed in water to prepare standard volume of soil suspension.
- In pipette method, 12 to 30 gram of soil is added in water for preparation of 500 ml soil suspension total volume and In hydrometer method, 24 to 60 g of soil is added in water for preparation of 1000 ml of soil suspension.

Post treatment

- After preparing suspension, dispersing agents or deflocculating agent is added in it to prevent the flocculation of solids during the settlement.
- Commonly used deflocculating agents are <u>sodium hexa metaphosphate</u>, sodium carbonate, sodium oxilate, sodium phosphate.

Pipette Method



- In this method 10 ml of sample is collected from soil suspension at fixed sampling depth at 10 cm at different time intervals.
- The collected sample is further being tested for mass of solids (m_d) present in it by oven drying method.
- The size of particles that settles in the soil suspension by distance of sampling depth (He = 10 cm) is computed using Stoke's law.

$$V_s = \frac{(G-1)\gamma_\omega d^2}{18\mu} = \frac{He}{t}$$

$$d^2 = \frac{18\mu}{(G-1)\gamma_\omega} \cdot \frac{He}{t}$$

$$d = \sqrt{\frac{18\mu}{(G-1)\gamma_\omega}} \cdot \sqrt{\frac{He}{t}} = k\sqrt{\frac{He}{t}}$$

where, $k = \sqrt{\frac{18\mu}{(G-1)\gamma_\omega}}$

where, t = Time is second after which the pipette is immersed in soil suspension.

% finer (%N) corresponding to computed size of particle 'd' which settles in suspension by He in given time t is analyzed as

$$\%N = \frac{\text{Mass of solids/unit volume at depth He at time '}t\text{'}}{\text{Mass of solids per unit volume initially}}$$

$$= \frac{(m_d / V_P)}{M / V_{soil}} \times 100$$

Where,

m_d : mass of solids in collected sample from sampling depth He at time 't'

V_P : Volume of pipette (10 ml)

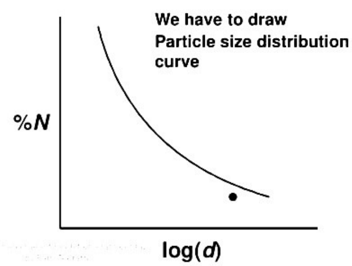
M : Mass of solids added initially of the preparation of soil suspension (12 to 30 g)

V : Total volume of suspension (500 ml)

If effect of dispersing agent is also to be considered

$$\%N = \frac{\frac{m_d}{V_P} - \frac{m'}{V}}{\frac{M}{V}} \times 100$$

Where, m' : Mass of dispersing agent added for the preparation of soil suspension.



Hydrometer Method

- Hydrometer is a device which is used for the measurement of density of the suspension /specific gravity of soil suspension at depth He at time *t*.

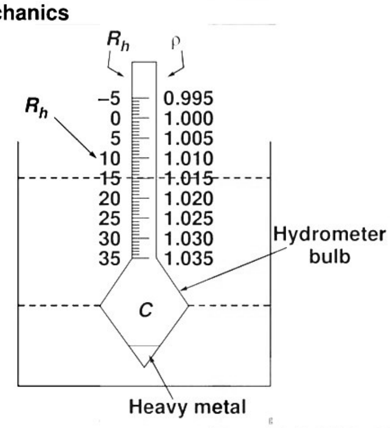
$$\rho_{ss} = 1 + \frac{R_h}{1000}$$

$$G_{ss} = \frac{\rho_{ss}}{\delta_{\omega}} = \frac{\rho_{ss}}{1\ g/cc} = 1 + \frac{R_h}{1000}$$

Where, R_h : Corrected hydrometer reading

- Volume of hydrometer below the centre of its bulb is approximate 50% of its total volume.
- Reading on the hydrometer increase downward.
- For calibration, reading on the hydrometer is marked as

R_h = (– 1) × 1000



- In hydrometer method %N (m_d) is computed indirectly by noting density of suspension at sampling depth He at different time intervals.
- In pipette method, sampling depth was constant (He = 10 cm) whereas in hydrometer method sampling depth goes on increasing with increase in time and settlement of particles, due to which calibration of hydrometer and sedimentation jar is done before each test.

- The size of particles that settle in suspension by a distance of sampling depth He in any time t is given as

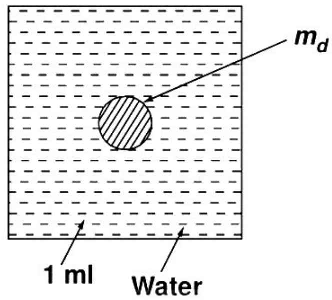
$$d = k\sqrt{\frac{H_e}{t}}$$

$$\text{Where} \quad k = \sqrt{\frac{18\mu}{(G-1)\gamma_{\omega}}}$$

- %N corresponding to noted size of particle d is computed indirectly by noting density of the suspension at sampling depth He at any time *t* as

$$\%N = \frac{\frac{R_h}{1000} \times \frac{G}{G-1}}{\frac{M}{V}} \times 100$$

Let m_d is mass of solids per ml of suspension at sampling depth of He at given times t.



Volume of solids = $\dfrac{m_d}{G\rho_\omega}$

Volume of water = $1\text{ ml} - \dfrac{m_d}{G\rho_\omega}$

Mass of water = $\left(1\text{ ml} - \dfrac{m_d}{G\rho_\omega}\right)\rho_\omega$

Total mass of 1 ml suspension =

$$m_d + \left(1\text{ ml} - \frac{m_d}{G\rho_\omega}\right)\rho_\omega = m_d + \left(1 - \frac{m_d}{G}\right)$$

= 1 g/cc

Density of 1 ml suspension = $\dfrac{\text{Mass}}{\text{Volume}} = \dfrac{m_d + 1 - \dfrac{m_d}{G}}{1\text{ ml}}$

$$= m_d + 1 - \frac{m_d}{G} \qquad \text{...(i)}$$

As per hydrometer reading,

$$\text{Density,} \quad \rho_{ss} = 1 + \frac{R_h}{1000} \qquad \text{...(ii)}$$

$$\frac{R_h}{1000} = \frac{(G-1)m_d}{G}$$

$$\Rightarrow \quad m_d = \frac{R_h}{1000}\left(\frac{G}{G-1}\right)$$

$$\%N = \frac{\text{Mass of solid per unit volume at He at time } t}{\text{Mass per unit volume initially}} \times 100$$

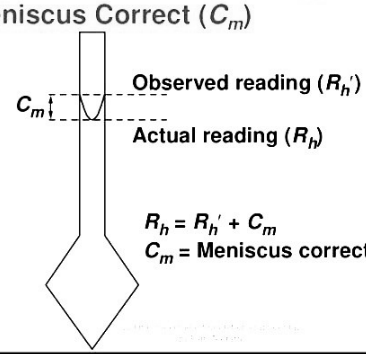
$$= \frac{m_d / 1\text{ ml}}{M / V} \times 100$$

$$\%N = \frac{\dfrac{R_h}{1000} \times \left(\dfrac{G}{G-1}\right)}{\dfrac{M}{V}} \times 100$$

M : Mass of the solids added initially (in grams)
V : Total volume of soil suspension (1000 ml)

The observed reading of hydrometer are further being corrected for the following:

1. Meniscus Correct (C_m)



$R_h = R_h' + C_m$
C_m = Meniscus correction

- Due to presence of turbidity in soil suspension upper level of meniscus is noted instead of lower, which leads to the reduced value of the observation being noted. Hence meniscus correction applied is positive.

2. Temperature Correction (C_T)

- **The calibration of hydrometer is done at 27°C.**
- **If the temperature during the test is greater than 27°C, it results is reduced value of observation being noted. Hence correction applied is positive and vice versa.**

$$\text{Temp} > 27°\text{C} \quad C_T = +\text{ve}$$

$$\text{Temp} < 27°\text{C} \quad C_T = -\text{ve}$$

$$R_h = R_h' \pm C_T$$

3. Dispersing Agent Correction (C_d)

- **Addition of dispersing agent is suspension increase its density, which results in increased value of observation being noted. Hence dispersing agent correction applied is negative.**

$R_h = R_h' - C_D$

Composite Correction:

$$C = C_m \pm C_T - C_D$$

$$R_h = R_h' \pm C$$

Particle Size Distribution Curve

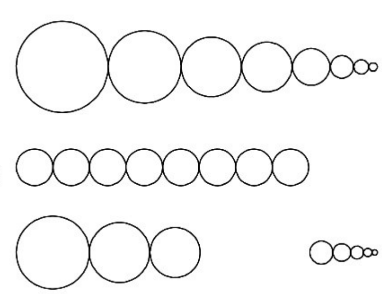
- **In this curve, %N (finer) is expressed on y-axis and corresponding size of particle is expressed on x-axis is log-scale.**
- **This curve helps in analyzing the type and gradation of soil.**
- **The soil may be termed as well graded soil, Poorly/uniformly graded soil & gap graded soil.**

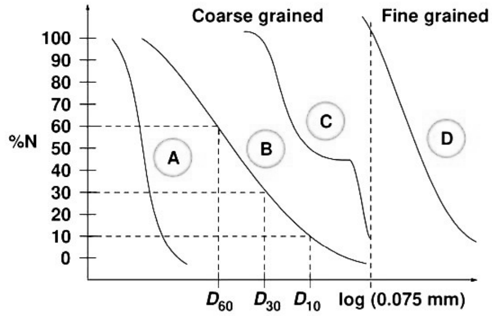
- **If the soil has good representation of all the sizes of the particle present in it, it is termed as well graded soil.**
- **If the soil consists of excess of one size of particles or is in deficient of another size of particles (or it consist of same size of particles) it is termed as poorly graded soil [or uniformly graded soil-in later case]**
- **If certain size of particles is missing from soil, it is known as gap graded soil.**

Well graded

Poorly graded/
Uniformly graded

Gap graded





Curve A : Uniformly/poorly graded coarse grained soil
Curve B : Well graded coarse grained soil
Curve C : Gap graded coarse grained soil
Curve D : Well graded fine grained soil

From particle size distribution curve, D_{10}, D_{30}, D_{60}, can be found out.

D_{10} - Effective size, defined by Allen Hazen, size in mm such that 10% of particles are finer than this size.
D_{30} - Size in mm such that 30% of particles are finer than this size.
D_{60} - Size in mm such that 60% of particles are finer than this size.

Coefficient of Uniformly (C_u)

- It represents particle size range of distribution curve.
- It is defined as ratio of D_{60} size of particles to the D_{10} size of particles.

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

- For uniformly graded soil, C_u 1 (or less than 2)
- For well graded sand, $C_u > 6$
- For well graded Gravel, $C_u > 4$

Coefficient of Curvature (C_c)

- If represents shape of particle size distribution curve
- It is defined as

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

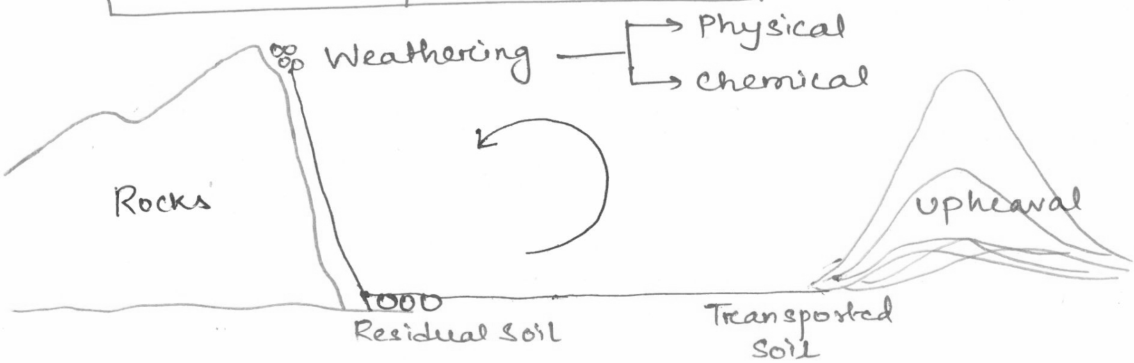
- For well graded soil, C_c should be in the range of 1 to 3
- If C_c is less than 1 or greater than 3, then soil is gap graded soil.

GATE : 15 – 18 Marks

IES — PRE → 16–21 Questions
IES — MAINS → 100–110 Marks

BOOK – Gopal Ranjan & Rao

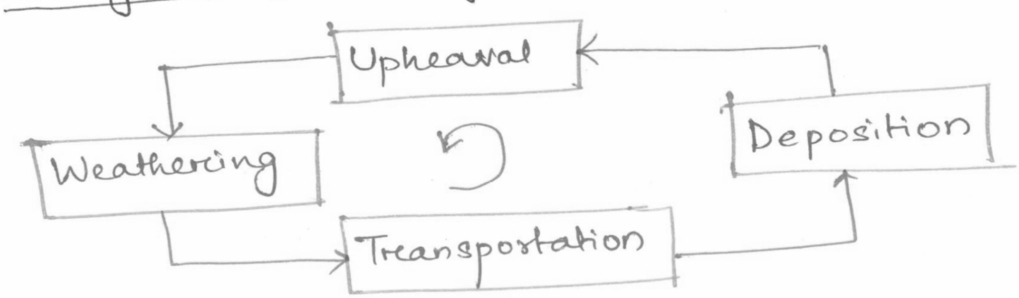
Ch:1 – Properties of Soil



<u>Soil</u>:- Disintegrated part of rocks

<u>Pedogenesis</u>:- Process of formation of soil

<u>Geological Cycle of formation of soil</u>



<u>Father of Soil Mechanics</u> : "Karl Von Terzaghi"

Types of Soil

Physically Weathered Soil

Type of Soil	Agent	Region
① Alluvial Soil	Running Water	River Basin
② Lacustrine	Fresh & Still Water	Lakes & Ponds
③ Marine Soil	Sea Water	At Seashore
④ Glacial (Till)	Ice	Glaciers
⑤ Colluvial (Talus)	Gravity	Mountain Valleys
⑥ Aeolian (Sand Dunes)	Wind	Desert
⑦ Loess	Wind Blown Silt	Desert

NOTE: In Loess, when water content is increased, it becomes soft and collapsible.

Chemically Weathered Soil

⑧ Marl Soil :- It is formed due to chemical decomposition of aquatic plants and animal bones. It contain high amount of Calcareous Compound.

(9) Tuff Soil :- It is volcanic ash transported by wind or water.

(10) Bentonite Soil :- It is Chemically weathered Volcanic ash (residual soil). It shows high plasticity, high swelling and shrinkage due to presence of high amount of "Montmorillonite" clay mineral. It is also used as lubricant in drilling operation.

(11) Black Cotton Soil :-
- It is formed from Basalt.
- It is residual soil.
- It contain high amount of Montmorillonit[e] due to which it shows high swelling & shrinkage, high plasticity & low shear strength.
- It occupies more than 20% area of Indi[a]

(12) Laterite Soil :- (Red)
- It is formed due to Leaching (washing out of silicious compound and accumulation of iron & aluminium oxide)
- It is found in Western Ghats, Eastern Ghats and Great North East (Illite Mineral)

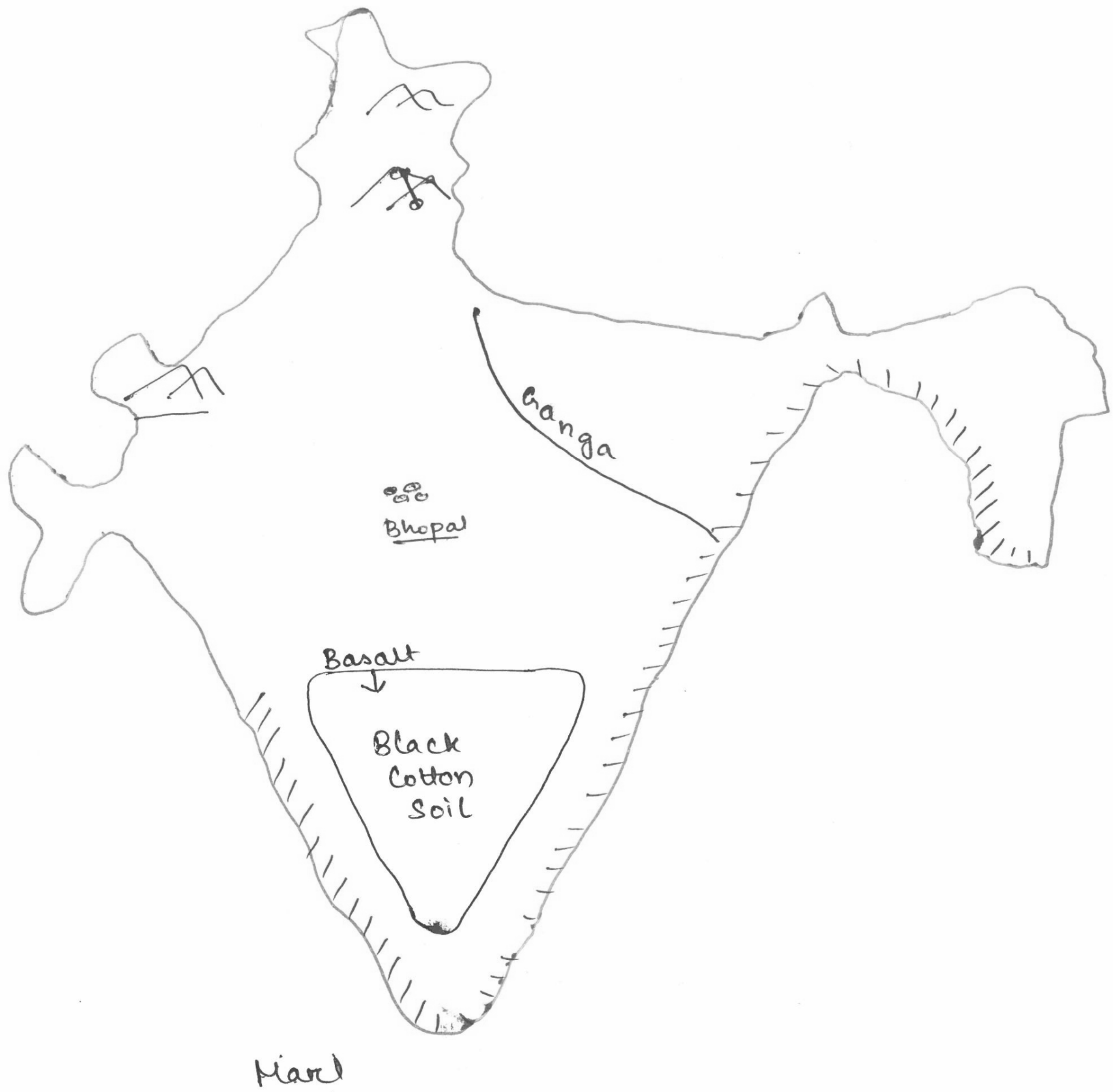
(13) Organic Soils :-

- Muck Soil :- It is the mixture of organic & inorganic soil.

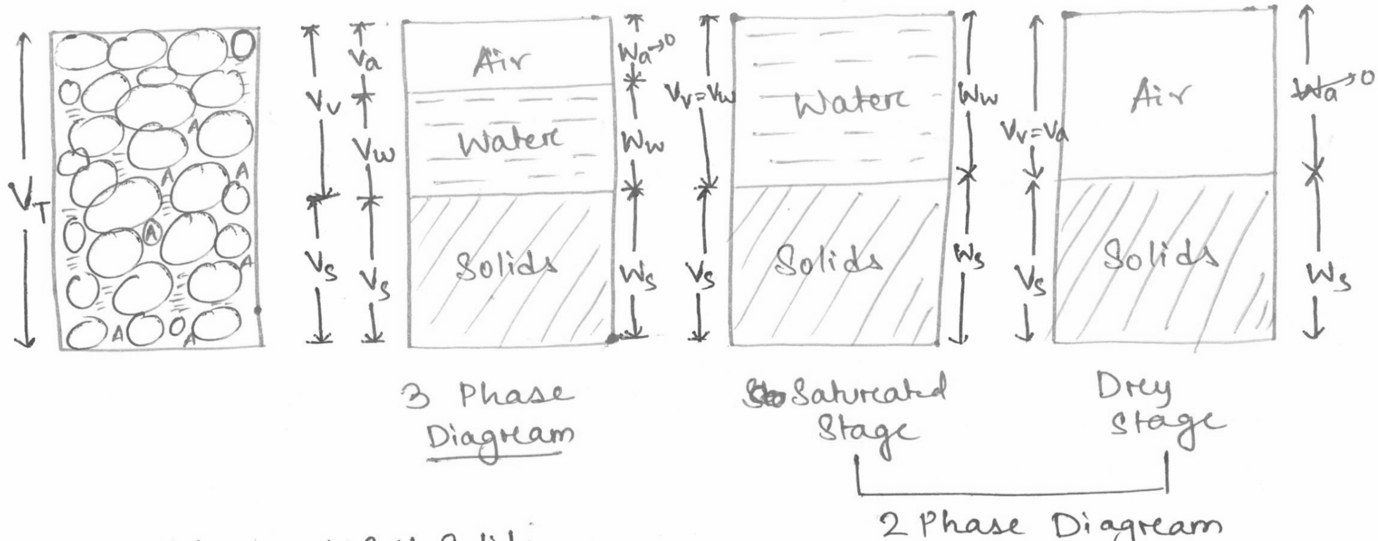
- Peat Soil :- It almost entirely consist of vegetative matters in different stages of decomposition. It possess black to dark brown colour and organic odour. It is highly compressible soil.

• Humus Soil :- It is the top layere of Earth which Contain grass and grassroots.

Loam Soil :- It is the mixture of Sand, Silt and clay.



Phase Diagram



$V_s \to$ Volume of Soil Solids

$V_T \to$ Total volume of Soil mass

Important Definitions

(1) Water Content / Moisture Content (w)

$$w = \frac{\text{Wt. of Water}}{\text{Wt. of Solids}} \times 100 = \frac{W_w}{W_s} \times 100 = \frac{M_w}{M_s} \times 100$$

NOTE (1): Range of w $\quad w \geq 0\%$

NOTE (2): Relation in between W_s, w & W_{TOTAL}

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

$$1 + w = 1 + \frac{W_w}{W_s} \quad \text{(Adding 1 on both sides)}$$

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

$$1 + w = \frac{W_{TOTAL}}{W_s}$$

** $$W_s = \frac{W_{TOTAL}}{1+w}$$ **

* $$M_s = \frac{M_{TOTAL}}{1+w}$$

NOTE (3) :- Water Content can also be represented w.r.t total wt. of soil mass, which is called apparent Water Content (w').

$$w' = \frac{\text{wt. of water}}{\text{Total wt. of soil}} * 100 = \frac{W_W}{W_{TOTAL}} * 100 = \frac{M_W}{M_{TOTAL}} * 100$$

Range of w' $\boxed{0 \le w' < 100\%}$

$w' \neq 100\%$ because if $w' = 100\%$ then $W_W = W_{TOTAL}$ which is not possible in soil mass.

- w is more significant than w' because solids are stable quantity and while total weight changes with change in weight of water.

(2) Void Ratio (e)

$$\boxed{e = \frac{\text{Volume of Voids}}{\text{Volume of Solids}} = \frac{V_V}{V_S}}$$

Range : $\boxed{e > 0}$

- It is represented as decimal fraction

(3) Porosity (n)

$$\boxed{n = \frac{\text{Vol. of Voids}}{\text{Total Vol. of Soil}} * 100 = \frac{V_V}{V_T} * 100}$$

Range : $\boxed{0 < n < 100\%}$

$n \neq 100\%$ because if $n = 100\%$ then $V_V = V_T$ which is not possible in soil mass.

NOTE: Relation between e & n

$$n = \frac{V_v}{V_T} = \frac{V_v}{V_v + V_s} = \frac{V_v}{V_v\left[1 + \frac{V_s}{V_v}\right]} = \frac{1}{\frac{1}{e} + 1}$$

**

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

e in terms of n

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

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

NOTE: Though size of void is more in coarse grained soil but void ratio or porosity is more in fine grained soil due to presence of more no. of voids (Clay is highly Porous, less Permeable)

NOTE: Relation in between V_s, V_{TOTAL} & e

$$e = \frac{V_v}{V_s}$$ (adding 1 both sides)

$$1 + e = 1 + \frac{V_v}{V_s}$$

$$1 + e = \frac{V_s + V_v}{V_s} = \frac{V_{TOTAL}}{V_s}$$

**

$$\boxed{V_s = \frac{V_T}{1+e}}$$

④ Degree of Saturation (S)

$$S = \frac{\text{Vol. of water}}{\text{Vol. of Voids}} \times 100 = \frac{V_w}{V_v} \times 100$$

for dry Soil $S = 0\%$

for Saturated Condⁿ $S = 100\%$

for Partially Saturated $0 < S < 100\%$

⑤ Air Content (a_c)

$$a_c = \frac{\text{Vol. of air}}{\text{Vol. of void}} \times 100 = \frac{V_a}{V_v} \times 100$$

$a_c = 100\%$

$a_c = 0\%$

$0 < a_c < 100\%$

NOTE : $S + a_c = 1$

⑥ Percentage of Air Voids (η_a)

$$\eta_a = \frac{\text{Volume of air}}{\text{Total vol. of Soil mass}} \times 100 = \frac{V_a}{V_T} \times 100$$

Range of η_a :- $0 \le \eta_a < 100\%$

NOTE :- Relation in between η_a & a_c.

$$\eta_a = \frac{V_a}{V_T} = \frac{V_a}{V_T} * \frac{V_v}{V_v}$$

$$\eta_a = \frac{V_v}{V_T} * \frac{V_a}{V_v}$$

($\frac{V_v}{V_T} \rightarrow n$, $\frac{V_a}{V_v} \rightarrow a_c$)

$$\eta_a = n \cdot a_c$$

Percentage of Voids = n = Porosity

⑦ Unit Weight (γ)/Density (ρ)

(A) Bulk/Total Unit Wt. ($\gamma_b / \gamma_t / \gamma$)

or [Bulk density ($\rho_b / \rho_t / \rho$)]

$$\gamma_b / \gamma_t / \gamma = \frac{\text{Total wt. in existing Condition}}{\text{Total Volume of Soil}}$$

$$\gamma_b / \gamma_t / \gamma = \frac{W_{TOTAL}}{V_{TOTAL}}$$ N/m³, KN/m³

$$\rho_b / \rho_t / \rho = \frac{M_{TOTAL}}{V_{TOTAL}}$$ gm/cc, kg/m³

⇒ Mass → gm, kg

Density (ρ) = $\frac{\text{Mass}}{\text{Volume}}$

↓

gm/cc, kg/m³

✱ $\rho_w = 1$ gm/cc, 1000 kg/m³

⇒ Weight ($W = mg$) → N, KN

Unit wt. (γ) = $\frac{\text{Weight}}{\text{Volume}}$

↓

$\frac{N}{m^3}$, $\frac{KN}{m^3}$

✱ $\gamma_w = 9810 \frac{N}{m^3}$, 9.81 KN/m³

(B) Saturated Unit Weight (γ_{sat}) or Saturated Density (ρ_{sat})

$$\gamma_{sat} = \frac{\text{Total wt. in Saturated Condition}}{\text{Total Volume of Soil}}$$

$$\gamma_{sat} = \frac{W_{sat}}{V_{TOTAL}}$$

$$\rho_{sat} = \frac{M_{sat}}{V_{TOTAL}}$$

(C) Dry Unit Weight (γ_d) or Dry Density (ρ_d)

$$\gamma_d = \frac{\text{Total wt. in dry Condition}}{\text{Total Volume of Soil}} = \frac{W_{dry}}{V_T}$$

$$\gamma_d = \frac{W_s}{V_T}$$ N/m³, KN/m³

$$\rho_d = \frac{M_{dry}}{V_T} = \frac{M_s}{V_T}$$ gm/cc, kg/m³