UNIT-1

Introduction

Soil Formation : (or) Origin of Soils

Soils are formed by weathering of rocks due to mechanical disintegration or chemical decomposition.

When the rock surface gets exposed to atmosphere for an appreciable time, it disintegrates or decomposes into small particles, and thus the soils are formed.

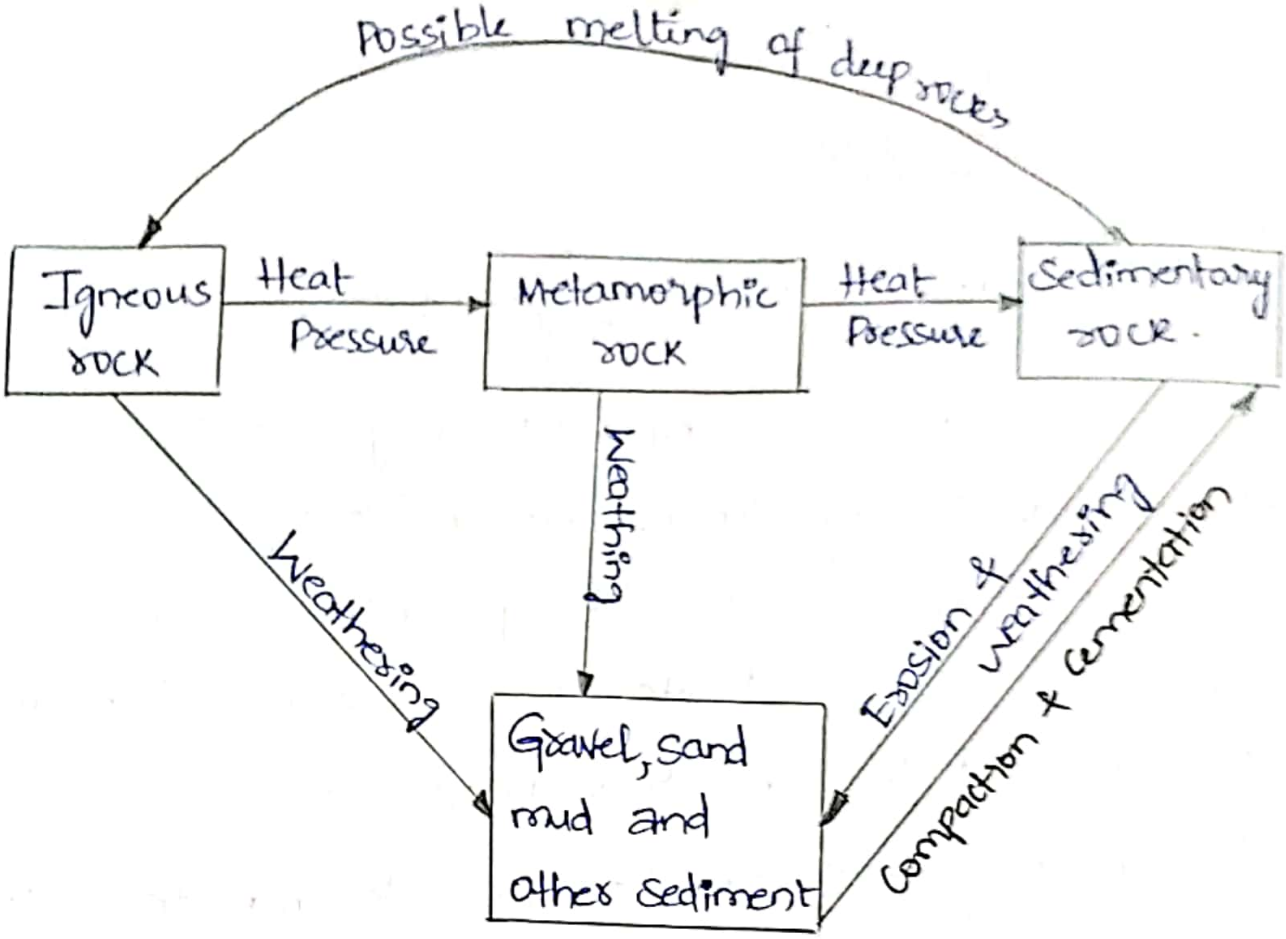
Soil may be considered as an incidental material obtained from the geological cycle which goes continuously in nature.

The soil formation is cyclic is called "Geological cycle".

The process of soil formation is called "Pedogenesis".

* If the soil stays at the place of its formation just above the parent rock, it is known as residual/sedentary soil.

* When the soil has been deposited at a place away from the place of its origin, it is called as transported soils.



Igneous Rock: Formed through the cooling and solidification of Magma or Lava.

Eg: Granite, Basalt & Pumice, Diorite, Pegmatite

Metamorphic Rock: Formed when rock is subjected to physical changes like pressure, heat

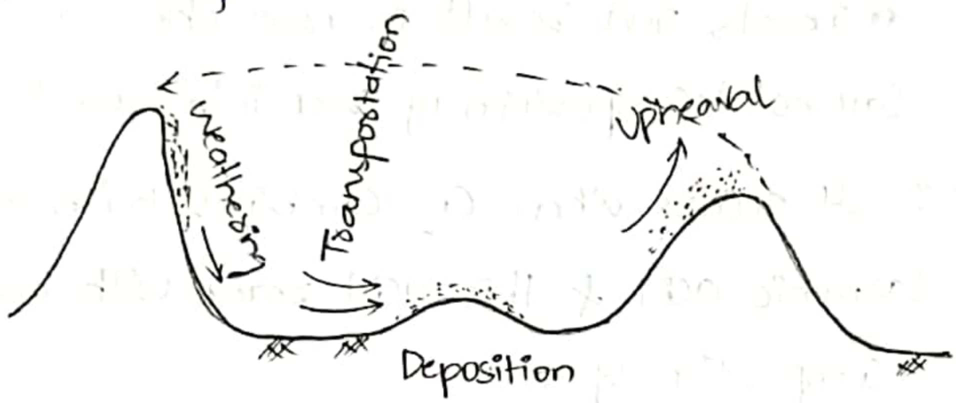
Eg: Marble, Slate & quartzite, Gneiss

Sedimentary Rock: Formed by the accumulation or deposition of mineral or organic particles at earth's surface followed by Cementation.

Eg: Sandstone, shale, limestone & Dolomite, flint

Exposed rocks are eroded and degraded by various Physical and chemical processes. There are different stages in the geological cycle of soil formation in transported soil.

1. Weathering / Erosion
2. Transportation
3. Deposition of weathered materials
4. Upheaval



Weathering:

Rock disintegration also called weathering is one of the important geological process.

Physical weathering:

Rock disintegrates into smaller fragments due to various agencies like running water, heavy wind, temperature changes, rainfall, expansion due to freezing of water and human activities. Eg: Sand & Gravel.

Chemical weathering:

Fragmented rock materials obtained by physical weathering sometimes changes their mineral composition and new compounds are formed. This phenomenon is referred as "Chemical weathering".

Chemical weathering is caused by oxidation, hydration, Carbonation.

Eg: Silts & Clays

Oxidation : It occurs when O_2 combine with minerals in rocks and results in decomposition of rocks.

Hydration : It occurs when water combines with the rock minerals and result in new chemical compound & causes decomposition of rock into small particles.

Carbonation : It occurs when CO_2 combines with water to form carbonic acid & this acid reacts with rock and causes decomposition of rocks.

Transportation and Deposition :

The soils formed at a place may be transported to other places be agents of transportation such as water, wind, ice and gravity.

1. Water transported soil :

Flowing water is one of the most important agents of transportation of soils. Running water carries a large quantity of soil either in suspension or by rolling along the bed. Water erodes the hills and deposits the soils in the valleys.

All type of soils carried and deposited by water are known as "Alluvial deposits".

Alluvial Deposits

Deposits made in lakes are called Lacustrine deposits.

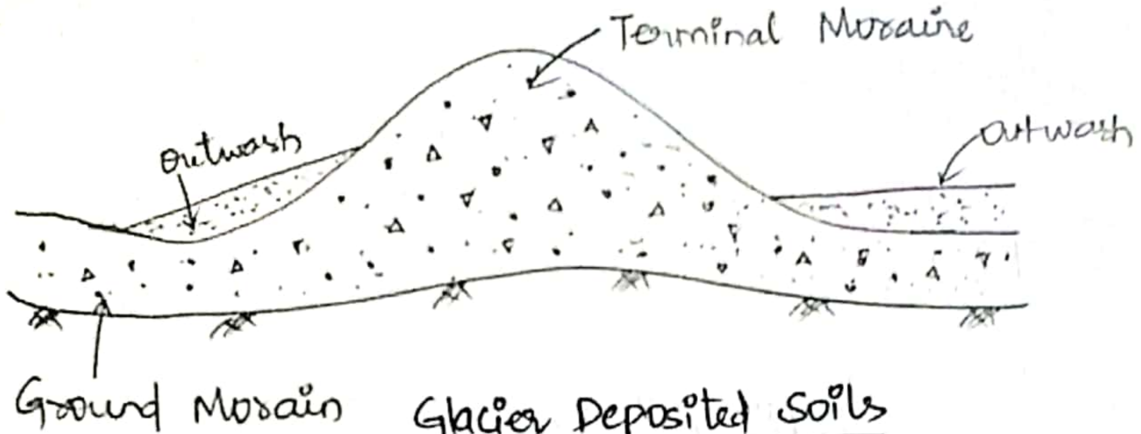
Marine deposits are formed when the flowing water carries soils to ocean or sea.

2. Wind transported soil :

Like water, wind can erode, transport and deposit fine grain soils. The soils that have been transported and deposited by wind are called "Aeolian deposits." [Large Sand dunes and Loess are deposits made by wind]

3. Glacier - Deposited soils :

Glaciers are large masses of ice formed by the Compaction of snow. As the glaciers grow and move, they carry with them soils varying in size from fine grained to huge boulders. Soils get mixed with the ice and are transported far away from their original position. Drift is the term used for the deposits made by glaciers directly or indirectly. Deposits directly made by melting of glaciers are called till.



Glacier Deposited Soils

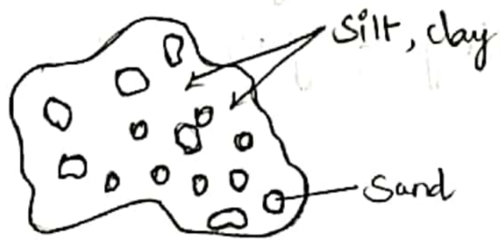
4. Gravity Deposits:

Soils can be transported through short distances under the action of gravity. Gravity Deposited soils are Colluvial Soil or talus

Soil Structure

Soil Structure can be defined as the arrangement of Soil particles (Sand, Silt and clay) and their aggregates into Certain defined Pattern.

Single particles when assembled, appear as larger particles and Known as aggregates. Aggregation of soil particles can occur in different patterns, resulting in different soil structures. The Circulation of water in the soil varies greatly according to structure.



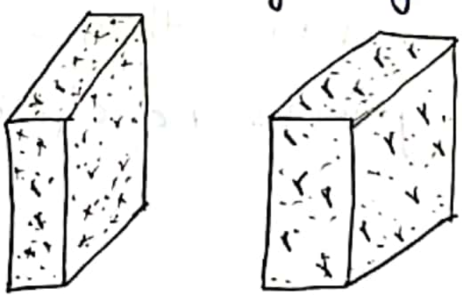
Types of Soil Structure:

1. Platy Structure:

The units are flate and plate like. They are generally oriented horizontally and occur in recently deposited clay soils.

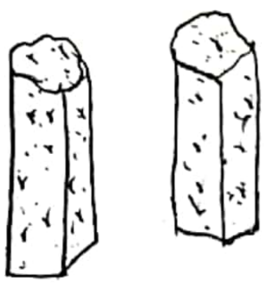
2. Prismatic Structure:

Such type of structure is found in clayey soils in arid and semi-arid regions. These are vertically oriented aggregates in which individual units are bounded by flat to rounded vertical faces. Units are distinctly longer vertically



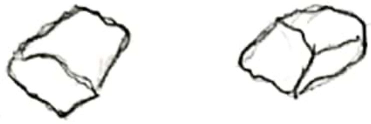
3. Columnar:

The units are similar to prisms and bounded by flate or slightly rounded vertical faces.



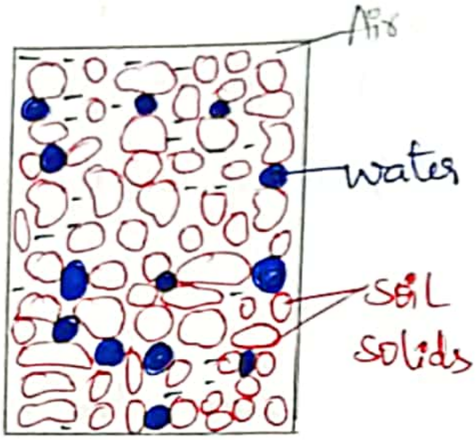
4. Blocky structure:

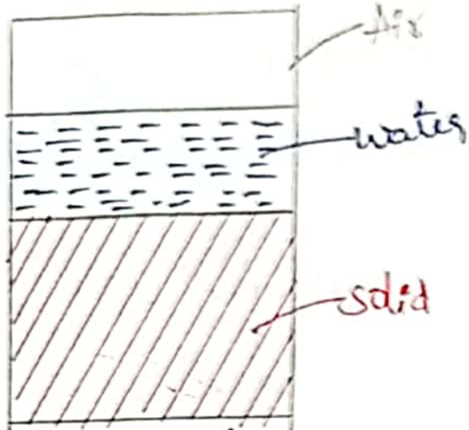
These are soil particles that cling together in nearly square or angular blocks having more or less sharp edges. Relatively large blocks indicates that the soil resists penetration and movement of water.



5. Granular and crumb structures:

These are most favourable structures for plant growth. These are individual particles of sand, silt and clay grouped together in small, nearly spherical grains. Water circulates very easily through such soils. Rounded aggregates not more than 2cm in diameter are called granules and when granules are especially porous called crumb.





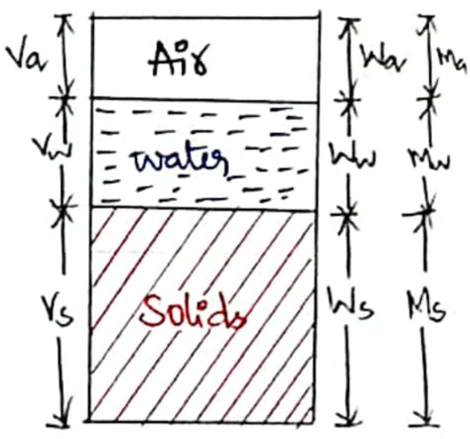
3-Phase Diagram

A soil mass consists of solid particles which forms a porous structure. The voids in the soil mass may be filled with air, with water or partly with air and partly with water.

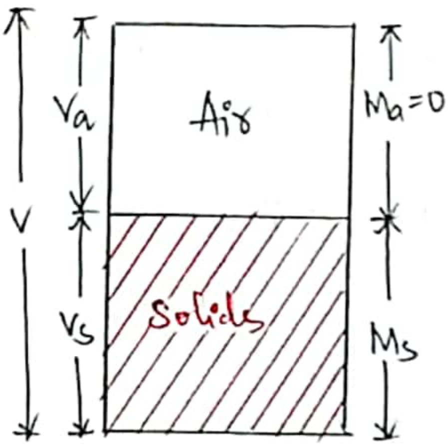
Soil mass ⇒ soil solids + water + air

Blended together to form a complex material

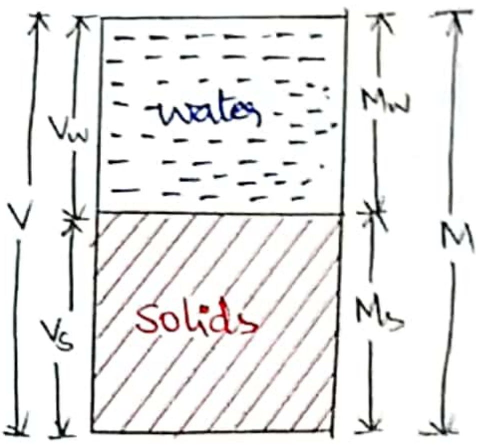
However, for convenience, all the solid particles are seggregated and placed in the lower layer of the 3-phase diagram. Likewise, water and air particles are placed separately and this 3-phase diagram is also known as "Block diagram".



3-phase diagram



Dry state



Saturated state

When the soil is absolutely dry, the water phase disappears then three-phase system becomes two-phase system.

When the soil is fully saturated, there is no air phase.

V_s = Volume of soil solids

V_w = Volume of water

V_a = Volume of air

V_v = Sum of the volumes of water and air

$$V_v = V_w + V_a$$

V = Total volume of soil mass

M_a = Mass of air = 0

M_w = Mass of water

M_s = Mass of soil solids

M = Total mass of soil mass

W_a = Weight of air = 0

W_w = Weight of water

W_s = Weight of soil solids

W = Total weight of soil mass

Water Content (or) Moisture Content :

The water content is defined as the ratio of the mass of water to the mass of solids.

$$w = \frac{M_w}{M_s} \times 100 \quad (\%)$$

$$w \geq 0\%$$

Volumetric Relationships :

1. **Void Ratio :** It is defined as the ratio of the volume of voids to the volume of solids.

$e > 0$

$$e = \frac{V_v}{V_s} \quad \text{(expressed in decimal)}$$

- For coarse grained soils, the void ratio is generally smaller than that for grained soils.

2. **Porosity :** It is defined as the ratio of the volume of voids to the total volume.

$0 < n < 100$

$n \neq 0, n \neq 100\%$

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

Note :

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

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

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

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

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

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

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

3. Degree of Saturation (S):

It is defined as the ratio of the volume of water to the volume of voids

$$S = \frac{V_w}{V_v} \times 100 \ (\%)$$

Dry soil = 0%

Saturated soil = 100%

Partially saturated soil = $0 < S < 100\%$

4. Air Content (a_c):

It is defined as the ratio of the volume of air to the volume of voids.

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

Dry soil = 100%

Sat. soil = 0%

Partially Sat. soil = $0 < a_c < 100$

5. Percentage Air Voids (n_a):

It is defined as the ratio of the volume of air to the total volume.

$$n_a = \frac{V_a}{V} \times 100 \ (\%)$$

Note:

$$a_c = \frac{V_a}{V_v} \Rightarrow a_c = \frac{V_v - V_w}{V_v}$$

$V_v = V_a + V_w$

$V_a = V_v - V_w$

$$a_c = 1 - \frac{V_w}{V_v}$$

$$a_c = 1 - S$$

$$\boxed{S + a_c = 1}$$

Mass-Volume Relationships :

1. **Bulk Density (ρ) :** [Wet Mass Density / Density]

It is defined as the ratio of total mass of soil to the total volume

(or)

It is defined as the total Mass per unit Volume.

$$\rho = \frac{M}{V}$$

Units: kg/m^3 (or) g/cc

2. **Dry Density (ρ_d) :**

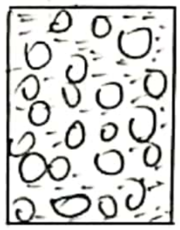
It is defined as the mass of solids per unit volume

$$\rho_d = \frac{M_s}{V}$$

3. **Saturated Density : (ρ_{sat})**

It is defined as the mass of soil when it is in fully saturated condition to the volume

$$\rho_{sat} = \frac{M_{sat}}{V}$$



Saturated

4. ~~Saturated~~ **Submerged Density : (ρ_{sub})**

It is defined as the submerged mass of soil ~~to the~~ per unit volume

$$\rho' = \frac{M_{sub}}{V}$$

Note : $\rho' = \rho_{sat} - \rho_w$

Submerged

Weight-Volume Relationships:

1. Bulk Unit weight: (γ)

It is defined as the total weight of soil per unit volume

$$\gamma = \frac{W}{V}$$

Units: N/m^3 (or) kN/m^3

2. Dry unit weight: (γ_d)

It is defined as the weight of soil solids per unit volume

$$\gamma_d = \frac{W_s}{V}$$

3. Saturated unit weight: (γ_{sat})

It is defined as the weight of soil when it is fully saturated per unit volume

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

4. Submerged unit weight: (γ_{sub})

It is defined as the submerged weight of soil per unit volume

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

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

$$\gamma' = \frac{\gamma_{sat}}{2}$$

Specific Gravity (G):

It is defined as the ratio of the weight of a given volume of solids to the weight of an equivalent volume of water at 4°C.

$$G = \frac{W_s}{V_s \cdot \gamma_w} = \frac{\gamma_s}{\gamma_w}$$

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

Gravel, Sand	=	2.65 - 2.68
Silty Sands, Silts	=	2.66 - 2.70
Inorganic clays	=	2.68 - 2.8
organic soils	=	1.2 - 1.4

Natural soils
⇓
2.65 - 2.80

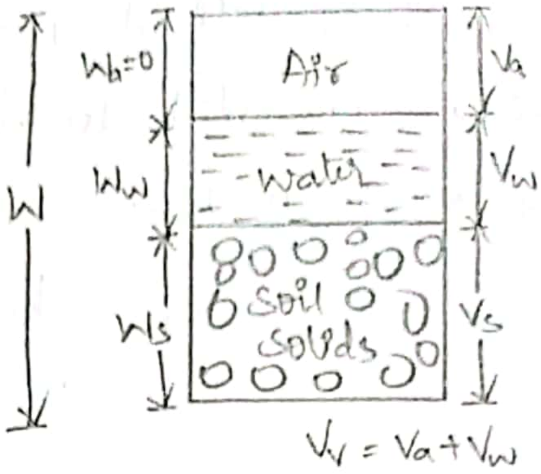
Mass Specific gravity: {Apparent/Bulk Specific Gravity}

It is defined as the ratio of mass density of soil to the mass density of water

$$G_m = \frac{\rho}{\rho_w}$$

Some Important Relationships :

1. Relationship between W_s, W_w & W



$$W = W_s + W_w + W_a^{\nearrow 0}$$

$$W = W_s + W_w$$

$$W = W_s\left[1 + \frac{W_w}{W_s}\right]$$

$$W = W_s(1+w) \qquad \because \text{Water content } (w) = \frac{W_w}{W_s}$$

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

2. Relationship between "e" and "n" :

$$\text{Porosity } (n) = \frac{V_v}{V} \qquad V = V_s + V_w + V_a$$

$$= V_s + V_v$$

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

$$= \frac{\left(\frac{V_v}{V_s}\right)}{\frac{V_s}{V_s} + \frac{V_v}{V_s}}$$

$$= \frac{\left[\frac{V_v}{V_s}\right]}{1 + \left[\frac{V_v}{V_s}\right]} \qquad \because e = \frac{V_v}{V_s}$$

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

3. Relationship between e, S, w and G

Void ratio $(e) = \frac{V_v}{V_s}$

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

$$= \frac{V_v}{V_w} \times \frac{\left(\frac{W_w}{\gamma_w}\right)}{\left(\frac{W_s}{\gamma_s}\right)}$$

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

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

$$= \frac{V_v}{V_w} \cdot \frac{W_w}{W_s} \cdot \frac{\left(\frac{1}{\gamma_w}\right)}{\left(\frac{1}{\gamma_s}\right)}$$

$$= \frac{V_v}{V_w} \cdot \frac{W_w}{W_s} \cdot \frac{\gamma_s}{\gamma_w}$$

$$= \frac{V_v}{V_w} \cdot \frac{W_w}{W_s} \cdot \frac{G_s \cdot \gamma_w}{\gamma_w}$$

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

$\gamma_s = G_s \cdot \gamma_w$

$$e = \frac{1}{S} \cdot w \cdot G_s$$

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

$$Se = wG$$

4. Relation between γ, G, e, w and γ_w

$$\gamma = \frac{W}{V} = \frac{W_s + W_w}{V_s + V_v} = \frac{W_s\left[1 + \frac{W_w}{W_s}\right]}{V_s\left[1 + \frac{V_v}{V_s}\right]}$$

$$\frac{W_w}{W_s} = w \quad \text{and} \quad \frac{W_s}{V_s} = \gamma_s = G.\gamma_w$$

$$\gamma = \frac{G.\gamma_w(1+w)}{1+e} \qquad w = \frac{Se}{G}$$

$$\gamma = \frac{G.\gamma_w\left(1 + \frac{Se}{G}\right)}{1+e}$$

$$= \frac{G.\gamma_w\left[\frac{G + Se}{G}\right]}{1+e}$$

$$\gamma = \left(\frac{G+Se}{1+e}\right).\gamma_w$$

a) If soil is saturated, $[S = 1]$

$$\gamma_{sat} = \frac{G + 1 \times e}{1+e}.\gamma_w$$

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

b) Dry soil $(S=0)$

$$\gamma_{dry} = \frac{G + 0 \times e}{1+e}.\gamma_w$$

$$\gamma_{dry} = \frac{G\gamma_w}{1+e}$$

c) Submerged soil

$$\gamma' = \gamma_{sat} - \gamma_w = \left(\frac{G+e}{1+e}\right)\gamma_w - \gamma_w \Rightarrow \gamma_w\left[\frac{G+e}{1+e} - 1\right]$$

$$\Rightarrow \gamma_w\left[\frac{G + e - 1 - e}{1+e}\right] \Rightarrow \gamma' = \left(\frac{G-1}{1+e}\right).\gamma_w$$

5. Relation between γ, γ_d, w

$$\gamma = \frac{W}{V} = \frac{W_s + W_w}{V}$$

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

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

$$\gamma = \gamma_d \cdot (1+w)$$

$$\gamma_d = \frac{\gamma}{(1+w)}$$

6. Relation between γ_d, G, w, n_a

$$V = V_s + V_w + V_a$$

$$1 = \frac{V_s}{V} + \frac{V_w}{V} + \frac{V_a}{V}$$

$$= \frac{V_s}{V} + \frac{V_w}{V} + n_a$$

$$\because \gamma_s = \frac{W_s}{V_s} \Rightarrow V_s = \frac{W_s}{\gamma_s}$$

$$V_s = \frac{W_s}{G \cdot \gamma_w}$$

$$1 - n_a = \frac{V_s}{V} + \frac{V_w}{V}$$

$$= \frac{\left(\frac{W_s}{G \cdot \gamma_w}\right)}{V} + \frac{\left(\frac{w W_s}{\gamma_w}\right)}{V}$$

$$\because \gamma_w = \frac{W_w}{V_w} \Rightarrow V_w = \frac{W_w}{\gamma_w}$$

$$V_w = \frac{w \cdot W_s}{\gamma_w}$$

$$= \frac{W_s}{V \cdot G \cdot \gamma_w} + \frac{w W_s}{V \cdot \gamma_w}$$

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

$$W_w = w \cdot W_s$$

$$= \frac{\gamma_d}{G \cdot \gamma_w} + \frac{\gamma_d \cdot w}{\gamma_w}$$

$$1-n_a = \frac{\gamma_d}{G \cdot \gamma_w} + \frac{w \cdot \gamma_d}{\gamma_w}$$

$$1-n_a = \frac{\gamma_d}{\gamma_w}\left[\frac{1}{G} + w\right]$$

$$(1-n_a)\gamma_w = \gamma_d\left[\frac{1+Gw}{G}\right]$$

$$\gamma_d = \frac{(1-n_a) \cdot \gamma_w}{\left(\frac{1+Gw}{G}\right)}$$

$$\gamma_d = \frac{G\gamma_w(1-n_a)}{1+wG}$$

Note :

1. $W_s = \frac{W}{1+w}$
2. $n = \frac{e}{1+e}$
3. $e = \frac{n}{1-n}$
4. $Se = wG$
5. $\gamma = \left(\frac{G+Se}{1+e}\right) \cdot \gamma_w$
6. $\gamma_{sat} = \left(\frac{G+e}{1+e}\right) \cdot \gamma_w$
7. $\gamma_d = \frac{G\gamma_w}{1+e}$
8. $\gamma' = \left(\frac{G-1}{1+e}\right) \cdot \gamma_w$
9. $\gamma_d = \frac{\gamma}{1+w}$
10. $\gamma_d = \frac{(1-n_a)G\gamma_w}{1+wG}$

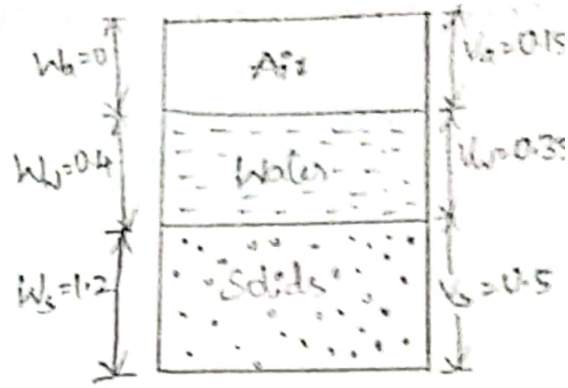
1. Figure shows a block diagram for a soil sample, having volumes and weights in "cm^3" and "g" respectively

Determine 1) Degree of Saturation

2) Void ratio

3) Water content

4) Saturated Unit weight



Sol

1) $S = \frac{V_w}{V_v} = \frac{0.35}{0.5} \times 100$

$= 70\%$

$V_w = 0.35$
$V_a = 0.15$
$V_v = 0.35 + 0.15$
$= 0.5$

2) $e = \frac{V_v}{V_s} = \frac{0.5}{0.5} = 1$

3) Water content $(w) = \frac{W_w}{W_s} = \frac{0.4}{1.2} \times 100 = 33.33\%$

4) $\gamma_{sat} = \left[\frac{G + Se}{1+e}\right] \cdot \gamma_w$

$= \left[\frac{2.1 + (0.7 \times 1)}{1+1}\right] \cdot \gamma_w$

$\gamma_{sat} = 1.4$ g/cc

$Se = wG$

$G = \frac{Se}{w}$

$= \frac{0.7 \times 1}{0.333}$

$G = 2.1$

2) An oven dry soil has mass specific gravity of 1.5 g/cc. If bulk density of soil in its natural state is 2 g/cc, then the water of soil in natural state will be ______

Given,

$\gamma = 2\ g/cc$, $G_m = 1.5$

$$G_m \Rightarrow \frac{\gamma_d}{\gamma_w} = 1.5$$

$$\gamma_d = 1.5 \times 1 = 1.5\ g/cc$$

$$\gamma_d = \frac{\gamma}{1+w} \Rightarrow 1.5 = \frac{2}{1+w}$$

$$1+w = \frac{2}{1.5} \Rightarrow 1+w = 1.333$$

$$w = 1.33 - 1$$

$$w = 0.333$$

$$w = 33.33\%$$

3) A soil sample in its undisturbed state was found to have volume of 105 cm^3 and mass of 201g. After oven drying mass got reduced to 168g. Calculate i) Water content ii) Void ratio iii) Porosity iv) Degree of saturation. Take Specific gravity as 2.7

Given,

$V = 105\ cm^3$, $M = 201\ g$, $M_d = 168\ g$, $G = 2.7$

$$M_w = 201 - 168 = 33\ g$$

i) $w = \frac{M_w}{M_s} = \frac{33}{168} \times 100 = 19.6\% = 0.196$

ii) Void ratio : (e)

$$\rho_d = \frac{M_d}{V} = \frac{168}{105} = 1.6 \text{ g/cc}$$

$$\rho_s = \frac{201}{105} = 1.91 \text{ g/cc}$$

$$\rho_d = \frac{G\rho_w}{1+e}$$

$$1+e = \frac{G \cdot \rho_w}{\rho_d}$$

$$e = \frac{2.7 \times 1}{1.6} - 1 = 1.687 - 1$$

$$e = 0.687$$

iii) Porosity: (n) $n = \frac{e}{1+e} = \frac{0.687}{1+0.687} = 0.407$

iv) Degree of Saturation: (S) $= \frac{wG}{e}$

$$= \frac{0.196 \times 2.7}{0.687} \times 100$$

$$S = 77\%$$

4) A moist soil sample weighs 3.52 N and after drying in oven, its weight reduced to 2.9 N. The specific gravity and mass specific gravity of soil are 2.65 & 1.85 respectively. Determine the water content, void ratio, porosity and Degree of Saturation (Take $\gamma_w = 10 \text{ KN/m}^3$)

Given data,

$M_s = 3.52$ N, $M_d = 2.9$ N, $G = 2.65$, $G_m = 1.85$

$\gamma_w = 10 \text{ KN/m}^3$

a) water content (w) $= \frac{3.52 - 2.9}{2.9} = 0.2138 = 21.38\%$

$$G_m = \frac{\gamma}{\gamma_w} = 1.85$$

$$\gamma = 1.85 \times 10 = 18.5 \ kN/m^3$$

$$\gamma_d = \frac{\gamma}{1+w} = \frac{18.5}{1+0.2138} = 15.24 \ kN/m^3$$

b) Void ratio : $1+e = \frac{G\gamma_w}{\gamma_d} \Rightarrow e = \frac{G\gamma_w}{\gamma_d} - 1$

$$= \frac{2.65 \times 10}{15.24} - 1$$

$$e = 0.74$$

c) Porosity : $n = \frac{e}{1+e} = \frac{0.74}{1+0.74} = 0.425$

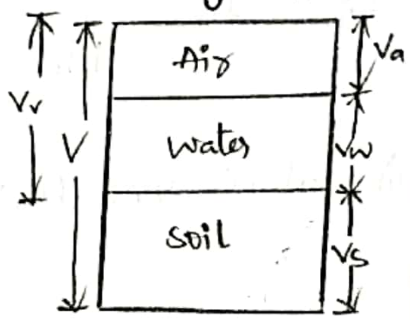
d) Degree of Saturation : $S = \frac{wG}{e} = \frac{0.2138 \times 2.65}{0.74}$

$$S = 0.765 = 76.5\%$$

5) A Sampler with a volume of 60 cm³ is filled with saturated soil sample. The specific gravity of soil solids is 2.65. When the oven dry soil is poured into a graduated cylinder filled with water, it displaces 40 cm³ of water. What is the natural moisture content and dry unit weight of soil?

Volume of Sampler = Volume of soil

$$V = 60 \ cm^3$$



When ~~water~~ soil is poured into cylinder, it displaces 40 cm³ of water

$$V_s = 40\ cm^3$$

$$V = V_v + V_s$$

$$V_v = V - V_s$$

$$= 60 - 40 = 20\ cm^3$$

$$e = \frac{V_v}{V_s} = \frac{20}{40} = 0.5$$

$e = 0.5$, $S = 1$, $G = 2.65$

a) $$w = \frac{Se}{G} = \frac{1 \times 0.5}{2.65} = 18.86\%$$

b) $$\gamma_d = \frac{\gamma}{1+w} \qquad \gamma = \frac{G+Se}{1+e} \cdot \gamma_w$$

$$= \left[\frac{2.65 + (1 \times 0.5)}{1+0.5}\right] \cdot 1$$

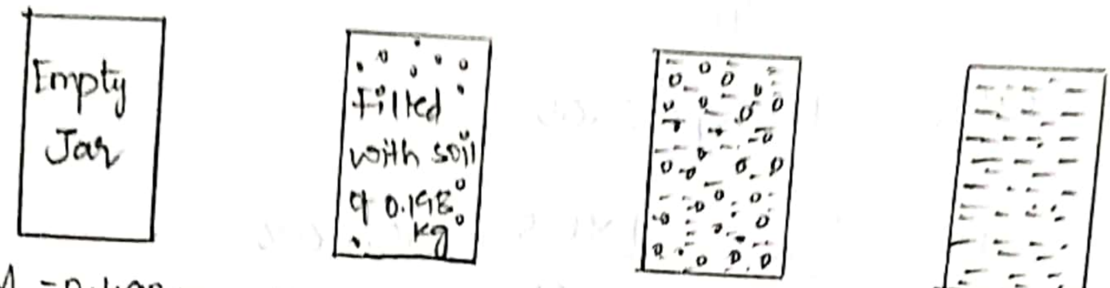
$$\gamma = 2.1\ g/cc$$

$$\gamma_d = \frac{2.1}{1+w}$$

$$= \frac{2.1}{1+0.1886}$$

$$\gamma_d = 1.76\ g/cc$$

Q) The mass of an empty Jar was 0.498 kg. When Completely filled with water, its mass was 1.528 kg. An Oven-dried sample of soil of mass 0.198 kg was placed in the Jar and water was added to fill the Jar and its mass was found to be 1.653 kg. Determine the specific gravity of particles.



$M_1 = 0.498$ kg $M_2 = 0.198 + 0.498$ $M_3 = 1.653$ kg $M_4 = 1.528$ kg

$$\text{Specific Gravity } (G) = \frac{M_2 - M_1}{(M_2 - M_1) - (M_3 - M_4)}$$

$$= \frac{0.198 + 0.498 - 0.498}{(0.198 + 0.498 - 0.498) - (1.653 - 1.528)}$$

$$G = 2.71$$

A Soil Sample has void ratio of 35% & the specific gravity is 2.7. Calculate the

i) Porosity   ii) Dry ~~Density~~ Unit weight   iii) Unit weight of Soil If it is 75% Saturated

iv) Submerged Unit weight

Given,   Assume $\gamma_w = 9.81\ KN/m^3$

$e = 35\% = 0.35$

$G = 2.7$

i) $n = \frac{e}{1+e} = \frac{0.35}{1+0.35} = 0.259$

ii) $\gamma_d = \frac{G\gamma_w}{1+e} = \frac{2.7 \times 9.81}{1+0.35} = 19.62\ KN/m^3$

iii) $\gamma_{sat} = \frac{G+se}{1+e} \cdot \gamma_w = \frac{2.7 + (0.75 \times 0.35)}{1+0.35} \times 9.81$

$= 21.53\ KN/m^3$

iv) $\gamma_{sub} = \frac{G-1}{1+e} \cdot \gamma_w = \frac{2.7-1}{1+0.35} \times 9.81 = 12.35\ KN/m^3$

A Soil Sample has wet density of 20 KN/m^3 and dry density of 18 KN/m^3. If the specific gravity of soil is 2.67, Calculate the void ratio, porosity, moisture content and degree of saturation. Assume unit weight of water = 10 KN/m^3

Given data, $\gamma_{wet} = \gamma_b = \gamma = 20\ KN/m^3$

$\gamma_d = 18\ KN/m^3$, $G = 2.67$, $\gamma_w = 10\ KN/m^3$

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

$1+e = \frac{G\gamma_w}{\gamma_d} = \frac{2.67 \times 10}{18}$

$1+e = 1.483$

$e = 1.483 - 1 = 0.483$

ii) $n = \frac{e}{1+e} = \frac{0.483}{1+0.483} = 0.326$

iii) $\gamma_d = \frac{\gamma}{1+w} \Rightarrow 1+w = \frac{\gamma}{\gamma_d} = \frac{20}{18}$

$1+w = 1.111$

$w = 1.111 - 1$

$= 0.111 = 11\%$

iv) $Se = wG$

$S = \frac{wG}{e} = \frac{0.111 \times 2.67}{0.483} = 0.614 = 61.4\%$

Calculate the following from the given table,

	Volume (cc)	Weight (g)
Air	0.2	0
water	0.3	0.3
Soil solids	0.5	1

a) Degree of Saturation
b) void ratio
c) water content
d) Saturated ~~unit wt.~~ density

Take $G = 2.7$, ~~$\gamma = 9.81 kN/m^3$~~, $\rho = 1$ g/cc

Given,

$V_a = 0.2$ cc, $V_w = 0.3$ cc, $V_s = 0.5$

$W_w = 0.3$ g, $W_s = 1$ g/cc

a) $S = \frac{V_w}{V_s} = \frac{0.3}{0.5} = 0.6 = 60\%$

b) $e = \frac{V_v}{V_s} = \frac{0.2+0.3}{0.5} = 1$

c) $w = \frac{W_w}{W_s} = \frac{0.3}{1} = 0.3 = 30\%$

d) $\gamma_{sat} = \frac{G+Se}{1+e} \cdot \gamma_w$

$$\rho_{sat} = \frac{G+Se}{1+e} \cdot \rho_w = \frac{2.7+(0.6\times1)}{1+1} \times 1$$

$$= 1.65 \text{ g/cc}$$

A soil has a volume of 100 cc and mass of 200g and on oven drying for 24 hours the mass is reduced to 100g. Determine Dry density.

$$\gamma_d / \rho_d = \frac{M_d}{V} = \frac{100}{100} = 1 \text{ g/cc} = 9.81 \text{ KN/m}^3$$

A soil deposit having water content 15%, G = 2.5 and void ratio 0.5, calculate degree of saturation.

$$Se = wG$$

$$S = \frac{0.15 \times 2.5}{0.5} = 0.75 = 75\%$$

A soil has a volume of 100 cc and mass of 200g. On oven drying mass has reduced to 150g. Calculate water content

$$w = \frac{M_w}{M_s} = \frac{200-150}{150} \times 100 = 33\%$$

Relative Density : [Degree of Density]

The most important index aggregate property of a cohesionless soil is its relative density. The engineering properties of a mass of cohesionless soil depend to a large extent on its relative density (D_r) is also known as Density Index (I_D). It is the index which quantifies the degree of packing b/w loosest & densest packing of coarse grained soil.

$$D_r = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100$$

where e_{max} = Max. void ratio of the soil in loosest condition

e_{min} = Min. void ratio of the soil in densest condition

e = Void ratio in the natural state.

D_r (%)		Denseness
< 15	-	Very loose
15-35	-	Loose
35-65	-	Medium Dense
65-85	-	~~Very~~ Dense
85 to 100	-	Very Dense

$$\rho_d = \frac{G\rho_w}{1+e}$$

$$e = \frac{G\rho_w}{\rho_d} - 1$$

$$D_r = \frac{\left[\frac{G\rho_w}{\rho_{min}} - 1\right] - \left[\frac{G\rho_w}{\rho_d} - 1\right]}{\left[\frac{G\rho_w}{\rho_{min}} - 1\right] - \left[\frac{G\rho_w}{\rho_{max}} - 1\right]}$$

$$= \frac{\frac{G\rho_w}{\rho_{min}} - 1 - \frac{G\rho_w}{\rho_d} + 1}{\frac{G\rho_w}{\rho_{min}} - 1 - \frac{G\rho_w}{\rho_{max}} + 1}$$

$$= \frac{\frac{1}{\rho_{min}} - \frac{1}{\rho_d}}{\frac{1}{\rho_{min}} - \frac{1}{\rho_{max}}} \Rightarrow \frac{\frac{\rho_d - \rho_{min}}{\rho_{min}\,\rho_d}}{\frac{\rho_{max} - \rho_{min}}{\rho_{min} \cdot \rho_{max}}}$$

$$= \frac{\rho_d - \rho_{min}}{\rho_{min} \cdot \rho_d} \times \frac{\rho_{min} \cdot \rho_{max}}{\rho_{max} - \rho_{min}}$$

$$D_r = \frac{\rho_{max}}{\rho_d}\left[\frac{\rho_d - \rho_{min}}{\rho_{max} - \rho_{min}}\right]$$

A saturated sand deposit have natural moisture content of 30%. It was noticed that the max. & min. void ratios are 0.95 and 0.40 resp. Assume specific gravity of sand as 2.7. The sand deposit would be classified as ______

Given,

$w = 0.3, \; G = 2.7, \; S = 1$

$e_{max} = 0.95, \; e_{min} = 0.4$

$$e = \frac{wG}{S} = \frac{0.3 \times 2.7}{1}$$

$$e = 0.81$$

$$I_D = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100$$

$$= \frac{0.95 - 0.81}{0.95 - 0.4} \times 100 = 25.45\%$$

∴ The sand deposit would be classified as Loose.

The density of sand backfill is 1746 Kg/m³, the water content was 8.6% and the ~~unit weight~~ Density of soil solid was 2.6 g/cc. In the laboratory, the void ratio was found to be 0.642 & 0.462 in loosest & densest state respectively. What is the relative density of the fill.

Given, $\rho_{sand} = 1746 \; Kg/m^3, \; w = 0.086, \; \rho_s = 2.6 \; g/cc$

$e_{max} = 0.642, \; e_{min} = 0.462$

$e = ?$ $\rho = \frac{G(1+w)}{1+e} \cdot \rho_w$

$G = \frac{\rho_s}{\rho_w} = \frac{2.6}{1} = 2.6$

$$1746 = \frac{2.6(1+0.086)}{1+e} \times 1000$$

$$1+e = \frac{2.6(1+0.086)}{1746} \times 1000$$

$$e = 1.617 - 1 = 0.617$$

$$I_D = \frac{e_{max} - e}{e_{max} - e_{min}} = \frac{0.642 - 0.617}{0.642 - 0.462} \times 100$$

$$I_D = 13.89\%$$

The natural void ratio of a saturated sand sample is 0.6 and density index is 60%. If void ratio in loosest state is 0.9, then the water content corresponding to densest state will be ____ (Take $G = 2.7$)

Given, $e = 0.6$, $I_D = 60\%$, $e_{max} = 0.9$, $e_{min} = ?$

$$I_D = \frac{e_{max} - e}{e_{max} - e_{min}} \times 100 \Rightarrow \frac{0.9 - 0.6}{0.9 - e_{min}} \times 100 = 60$$

$$e_{min} = 0.4$$

$S e_{min} = wG$

$$w = \frac{S\, e_{min}}{G} = \frac{1 \times 0.4}{2.7} = 15\%$$

Index Properties of Soil

Soil Index Properties refer to the properties of the soil that help to classify and identify the properties of soil for Purposes of engineering.

Eg: Particle size distribution
- Particle shape
- Relative Density
- Consistency
- Water Content.

Grain Size Analysis:

It is a method of separation of soils into different fraction based on the particle size.

This is done in 2 stages:

Grain Size Analysis

- Sieve Analysis [For Coarse soils] → Particle size greater than 75 μ — Gravel, Sand
- Sedimentation analysis [For fine soils] → Particle size smaller than 75 μ — Silt, clay

Sieve-Analysis:

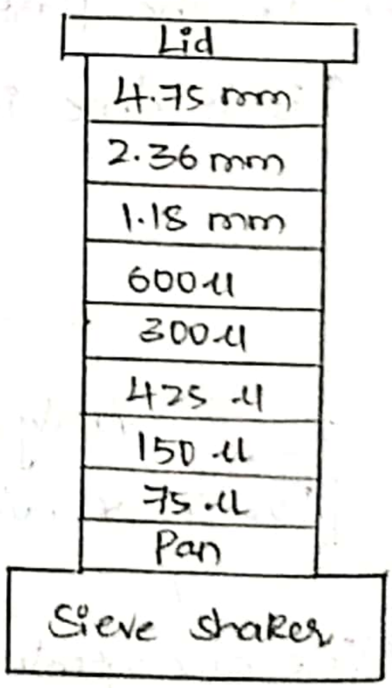
To classify the coarse grained soils, soil is sieved through set of sieves.

- Sieves are generally made of spun brass and phosphor bronze (or stainless steel) cloth.
- Sieves of varying sizes ranging from 80 mm to 75 µ are available.

$$1\,\mu = 10^{-6}\,m = 10^{-3}\,mm$$

Procedure:

1. Sieves from 4.75 mm to 75 µ are stacked one over the other, with decreasing size from top to bottom. and Pan is placed at the bottom and Lid at the top
2. The soil sample free from lumps and which was oven-dried shall be taken. (About 500g)
3. The soil sample is placed over the top sieve i.e., 4.75 mm and lid is placed on the top.
4. The whole assembly is kept on a mechanical sieve shaker and the machine is started.

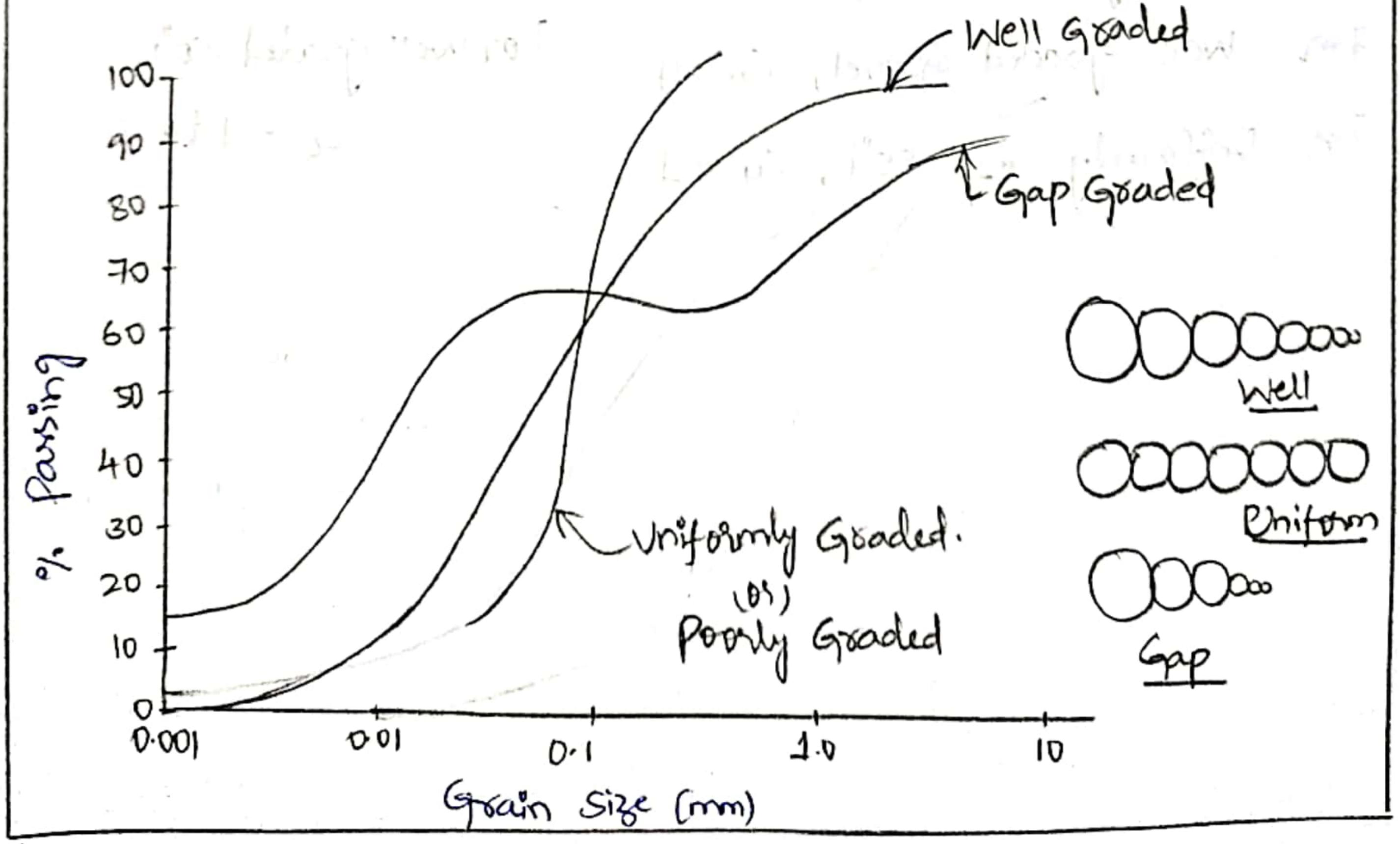


5. Normally, 10 minutes of shaking is sufficient for most soils.

6. After 10 minutes, machine is stopped and soil retained on each sieve and on pan is weighed.

Total Mass of soil taken = 500g

Sieve Size (mm)	Mass of Sieve (M_1) g	Mass of Sieve+Soil retained (M_2) g	Mass of soil retained (M_2-M_1), g	% soil retained $\frac{M_2-M_1}{500}\times100$	Cummulative % Soil retained	% Finer = 100 – Cumm. % Soil retained
4.75						
2.36						
1.18						
0.6						
0.425						
0.3						
0.15						
Pan						



Coefficient of Uniformity : [C_u]

It represents particle size range of distribution curve

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

Coefficient of Curvature : [C_c]

It represents shape of particle size distribution curve

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

D_{10} = Size in mm Such than 10% of particles are finer than this Size (Effective Size)

D_{30} = 30 % of particles are finer than this Size

D_{60} = 60% " " " " " " "

For Well graded soil , $C_u \geq 6$

For Well graded Gravel, $C_u > 4$

For Uniformly " soil, $C_u = 1$

For well graded soil,

$C_c = 1$ to 3

From the results of a Sieve analysis given below, Plot a grain-size distribution curve and then determine,

i) The effective size
ii) The Coefficient of uniformity
iii) The " " curvature

Weight of soil taken for sieve analysis was 500g

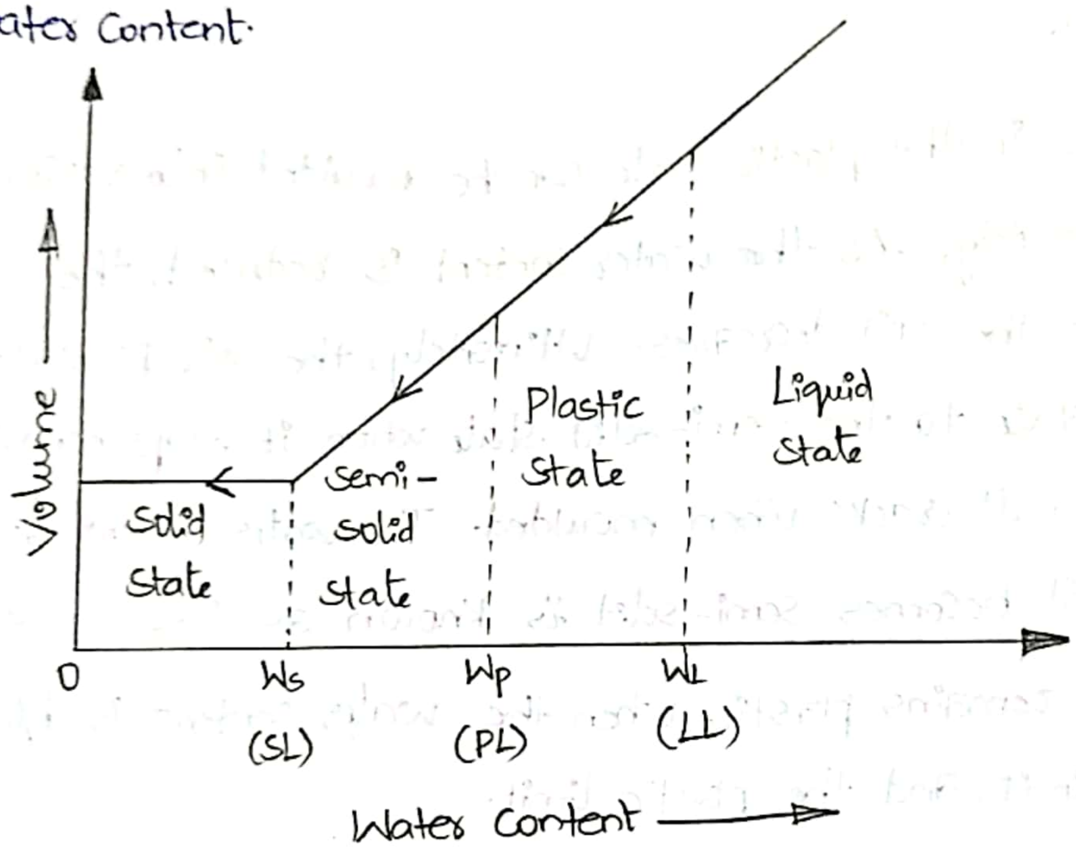
Sieve Size		Wt. of Soil retained in each sieve, g
4.75 mm	–	3.8
2.36 mm	–	32.2
1.18 mm	–	52.8
0.6 mm	–	38.7
0.3 mm	–	122.5
0.15 mm	–	159.9
0.075 mm	–	26.4

Sieve size (mm)	Weight retained	% Retained on each Sieve	% Cumm. retained	% finer
4.75	3.8	0.76	0.76	99.24
2.36	32.2	6.44	7.2	92.8
1.18	52.8	10.56	17.76	82.24
0.6	38.7	7.74	25.5	74.5
0.3	122.5	24.5	50	50
0.15	159.9	31.98	81.98	18.02
0.075	26.4	5.28	87.26	12.74

Consistency Limits

Consistency means relative ease with which the soil can be deformed. It also denotes the degree of firmness of soil which may be termed as soft, stiff or Hard.

Indirectly, it also represents the strength of the soil. This term is used for fine grained soil & is related with water content.



The water contents at which the soil changes from one state to the other are known as Consistency limits or Atterberg's Limits.

A soil containing high water content is in Liquid state. It offers no shearing resistance and can flow like water/ Liquids. It has no resistance to shear deformation and therfore the shear strength is equal to zero.

As the water content is reduced, the soil becomes stiffer and starts developing resistance to shear deformation. At some particular water content, the soil becomes plastic. The water content at which the soil changes from the liquid state to the plastic state is known as Liquid Limit. The liquid limit is the water content at which the soil ceases to be liquid.

The soil in the plastic state can be moulded into various shapes. ~~Ultimately~~, As the water content is reduced, the plasticity of the soil decreases. Ultimately, the soil passes from the plastic state to the semi-solid state when it stops behaving as a plastic. It cracks when moulded. The water content at which the soil becomes semi-solid is known as Plastic Limit.

The soil remains plastic when the water content is b/w the liquid limit and the plastic limit.

When the water content is reduced below the plastic limit, the soil attains a semi-solid state. In the semi-solid state, the volume of the soil decreases with a decrease in water content till a stage is reached when further reduction of the water content does not cause any reduction in the volume of the soil. The water content at which the soil changes from semi-solid state to the solid state is known as Shrinkage Limit

1. Liquid Limit:

It is defined as the minimum water content at which soil has tendency to flow.

The liquid limit is determined in the Laboratory by Casagrande's apparatus.

Casagrande's apparatus:

The Casagrande's device consists of a brass cup which drops through a height of 1 cm on a hard base when operated by the handle. The device is operated by turning the handle which raises the cup and lets it drop on the rubber base.

Procedure:

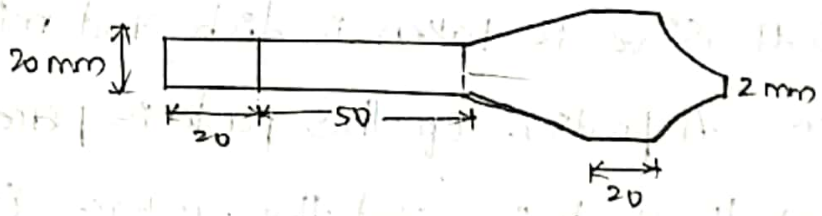
About 120g of an air-dried sample passing through 425 μ sieve is taken in dish and mixed with distilled water. A portion of this paste is placed in the cup of the liquid limit device and the surface is smoothened and levelled with spatula to a max. depth of 1 cm. A groove is cut through the sample along the symmetrical axis of cup using a standard grooving tool.

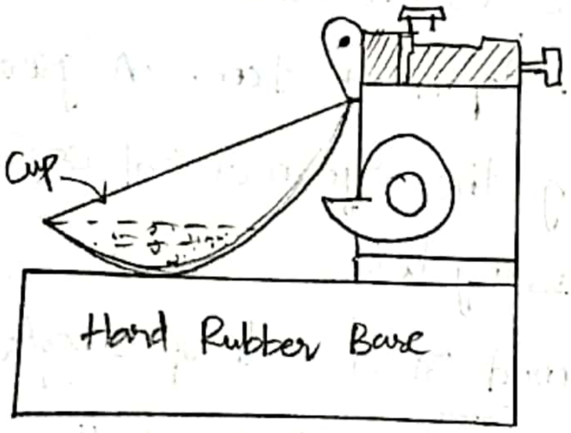
After that, the handle is turned at a rate of 2 rev/second until the 2 parts of the soil sample come into contact at the bottom of the groove along a distance of 12 mm. Some portion of soil near the closed groove is taken for water content determination.

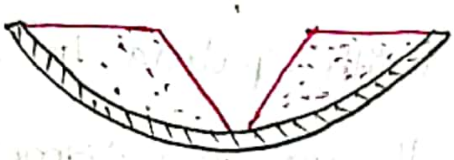
The soil in the cup is transferred to dish containing the soil paste and mixed thoroughly after adding more water and the test is repeated.

The liquid limit is the water content at which the soil is sufficiently fluid to flow when the device is given 25 blows. As it is difficult to get exactly 25 blows for the sample to flow, the test is conducted at diff. water contents so as to get blows in the range of 10 to 40.

A plot is made between the water content as ordinate and the number of blows on ~~log scale~~ as abscissa. The plot is approximately a straight line and is known as ~~abscissa~~. Flow Curve.

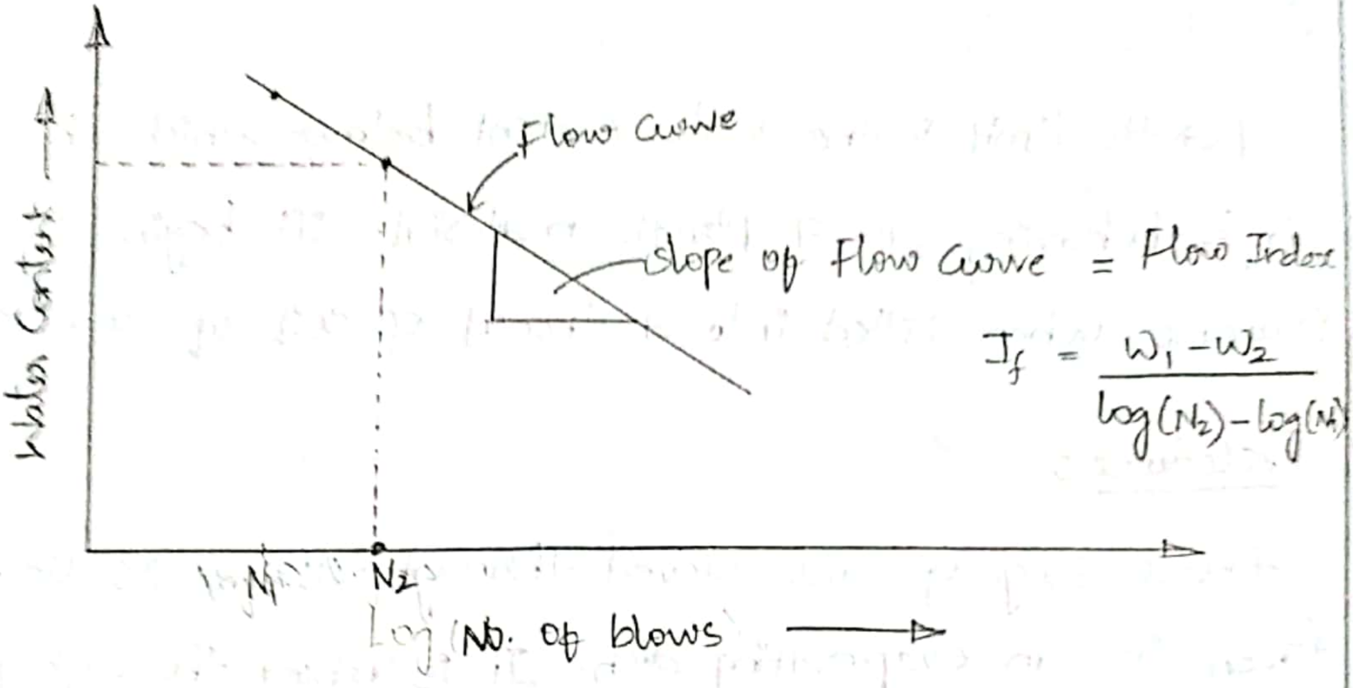






Soil Before Test

Soil After Test



Flow Index (I_f) $= \dfrac{W_1 - W_2}{\log(N_2) - \log(N_1)}$

$$I_f = \frac{W_1 - W_2}{\log\left(\frac{N_2}{N_1}\right)}$$

A test for the determination for the liquid limit was carried on a soil sample. The following set of observations were taken. Plot the flow curve and determine the liquid limit and the flow index.

No. of Blows (N)	38	27	20	13
Water Content (w) %	47.5	49.5	51.9	53.9

From Graph, $W = 50\%$

$$I_f = \frac{52.4 - 50}{\log\left(\frac{25}{15}\right)} = 10.8\%$$

2. Plastic Limit:

Plastic Limit is the water content below which the soil stops behaving as a plastic material. It begins to crumble when rolled into a thread of soil of 3mm dia.

Procedure:

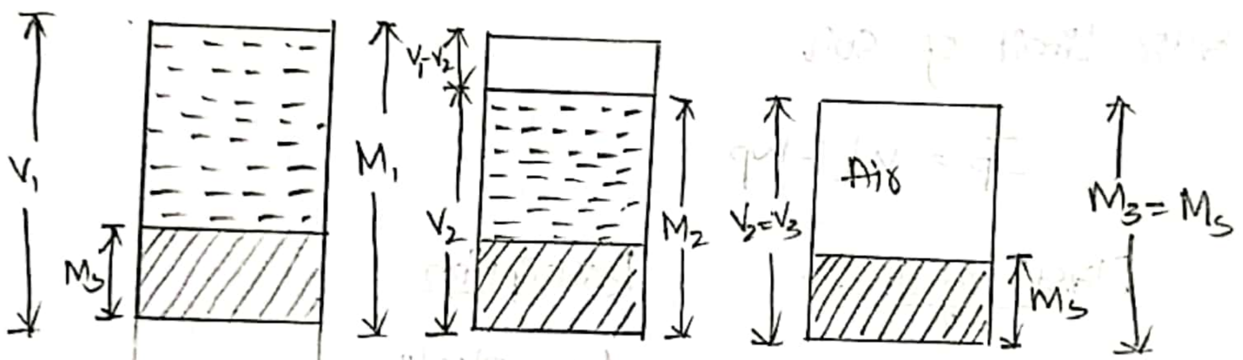
About 30 g of soil sieved through 425 μ IS sieve is taken in an evaporating dish. It is mixed thoroughly with distilled water till it becomes plastic and can be easily moulded with fingers.

About 10 g of the plastic soil mass is taken in one hand and a ball is formed. The ball is rolled with fingers on a glass plate to form a soil thread of uniform diameter. The rate of rolling is kept about 80 to 90 strokes per minute. If the diameter of thread becomes smaller than 3 mm, without crack formation, it shows that the water content is more than plastic limit.

The water content at which the soil can be rolled into a thread of approx. 3 mm in diameter without crumbling is known as the plastic limit.

3. Shrinkage limit :

It is defined as the maximum water content of soil does not lead to the reduction in the volume of soil because below the shrinkage limit, replacement of water by air in equal volume takes place on reducing the water content. It is the minimum water content at which soil is just completely saturated.



I. Fully saturated II. Sample at shrinkage limit III. Dry state

Let M_s be the mass of soil solids

★ Mass of water in stage I $= M_1 - M_s$

Loss of mass of water from stage I to stage II $= (V_1 - V_2)\rho_w$

★ Mass of water in stage II $= (M_1 - M_s) - (V_1 - V_2)\rho_w$

Shrinkage Limit = Water content in stage II

$$w_s = \frac{(M_1 - M_s) - (V_1 - V_2)\rho_w}{M_s}$$

$$w_s = \frac{(M_1 - M_s)}{M_s} - \frac{(V_1 - V_2)\rho_w}{M_s}$$

$$w_s = w_1 - \frac{(V_1 - V_2)\rho_w}{M_s}$$

Consistency Indices

1. Plasticity Index: (I_P)

It is defined as the difference between the Liquid limit and Plastic Limit of soil.

$$I_P = W_L - W_P$$

Plasticity Index		Description
0	–	Non-plastic
<7	–	Low plastic
7-17	–	Medium "
>17	–	High "

2. Shrinkage Index: (I_s)

It is defined as the difference between the plastic limit and Shrinkage Limit.

$$I_s = W_P - W_S$$

3. Liquidity Index : (I_L)

$$I_L = \frac{W - W_P}{I_p}$$ W = Natural water content of soil

Liquidity Index is also known as Water-plasticity ratio

4. Consistency Index : (I_c)

$$I_c = \frac{W_L - W_n}{I_P}$$ ★ It is also known as relative Consistency.

5. Toughness Index : (I_t)

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

6. Activity : $$A_t = \frac{I_P}{\% \text{ Clay}}$$

Activity	Description
<0.75	Inactive
0.75 - 1.25	Normal
>1.25	Active

A Soil has the liquid Limit of 25% and flow Index of 12.5%. If the plastic limit is 15%, determine the plasticity Index and the toughness Index.

If the water content of the soil in its natural Condition in the field is 20%, find the Liquidity index and the relative Consistency.

Given, $W_L = 25\%$, $W_P = 15\%$, $I_f = 12.5\%$

$w = 20\%$

★ $I_P = W_L - W_P = 25 - 15 = 10\%$

★ $I_t = \frac{I_P}{I_f} = \frac{10}{12.5} = 0.8 = 80\%$

★ $I_L = \frac{w - W_P}{I_P} \times 100 = \frac{20 - 15}{10} \times 100 = 50\%$

★ $I_C = \frac{W_L - w}{I_P} = \frac{25 - 20}{10} \times 100 = 50\%$

IS Classification of Soil

Basically soil is divided into 2 types

Soil
- Coarse grained
- Fine-grained.

Gravel – G
Sand – S
Silt – M
Clay – C

Coarse grained: If 50% or more than 50% of soil retained on 75 μ Sieve [Gravel, Sand]

Fine-grained: If 50% or more than 50% of soil passing through 75 μ Sieve. [Silt, Clay]

I. Coarse grained soil :

1. Coarse grained soil is further divided into 2 types:

Coarse grained soil
- Gravel
- Sand

a) If gravel fraction > Sand fraction ⇒ GRAVEL
[4.75 mm – 80 mm] [75 μ – 4.75 mm]

b) If Sand fraction > Gravel fraction ⇒ SAND
[75 μ – 4.75 mm] [4.75 mm – 80 mm]

2. Coarse grained soil is further classified on the basis of % fineness.

a) When % fineness < 5% [Check C_u & C_c]

Gravel
- Well Graded Gravel : $C_u > 4$ & $C_c = 1$ to 3
  GW
- Poorly Graded Gravel : $C_u \ngtr 4$ (OR) $C_c < 1$ or $C_c > 3$
  GP

Sand
- Well Graded Sand : $C_u > 6$ & $C_c = 1$ to 3
  SW
- Poorly Graded Sand : $C_u \ngtr 6$ (OR) $C_c < 1$ or $C_c > 3$
  SP

b) When % fineness > 12% [Check I_p]

Gravel
- GC : Clayey Gravel
  $I_p > 7\%$, C > M
- GM : Silty Gravel
  $I_p < 4\%$, M > C
- GM – GC
  I_p : 4 – 7%

Sand
- SC : Clayey Sand
  $I_p > 7\%$, C > M
- SM : Silty Sand
  $I_p < 4\%$, M > C
- SM – SC
  I_p : 4 – 7%

II. Fine grained Soil :

Fine grained soil is divided into 2 types

Fine grained Soil
- Silt (M)
- Clay (C)

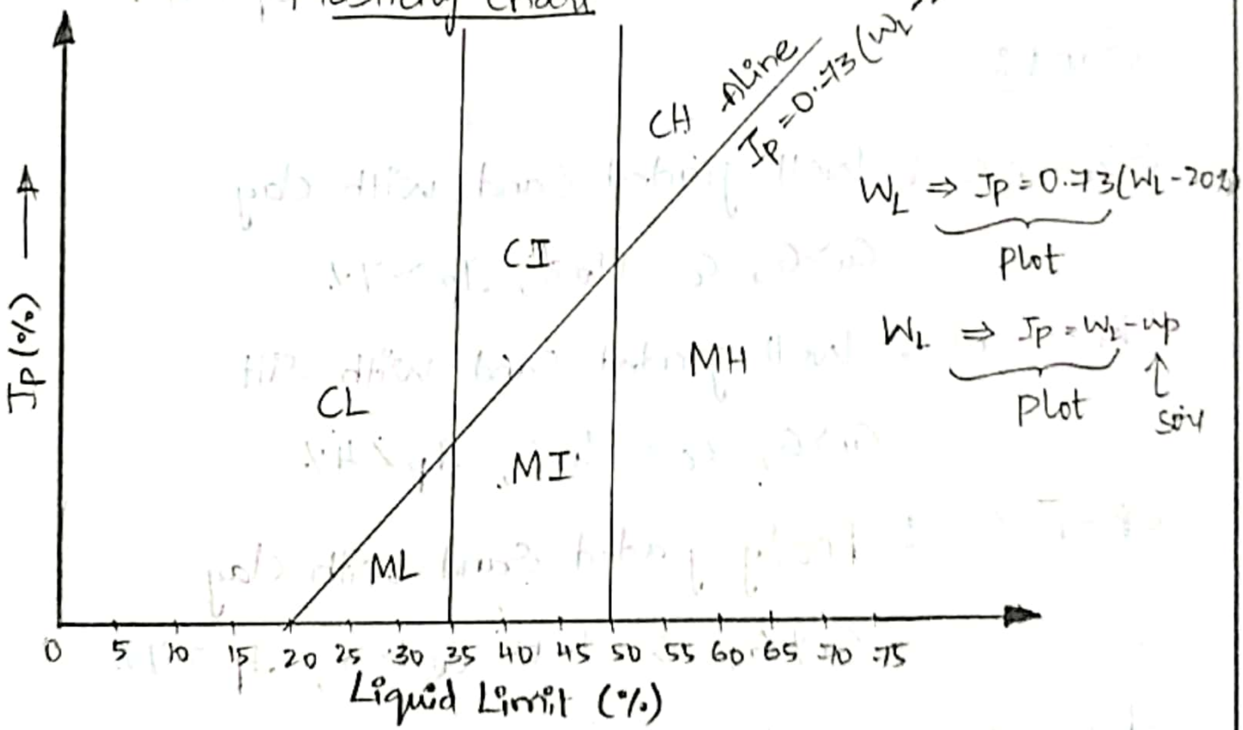
1) Fine-grained soil is further classified into

Low-Compressible (L) : $W_L < 35\%$

Intermediate-Compressible (I) : $W_L = 35 - 50\%$

High - Compressible (H) : $W_L > 50\%$

2) Plasticity chart



If I_P of soil > I_P of A-line, the soil lie above A-line and it will be clay

If I_P of soil < I_P of A-line, the soil will lie below A-line and it will be silt.

c) When % fineness is between 5% to 12%

Gravel:

GW-GC : Well graded Gravel with Clay
$C_u > 4$ & $C_c = 1$ to 3, $I_p > 7\%$

GW-GM : Well graded Gravel with Silt
$C_u > 4$ & $C_c = 1$ to 3, $I_p < 4\%$

GP-GC : Poorly graded Gravel with clay
$C_u \ngtr 4$ & $C_c < 1$ or $C_c > 3$, $I_p > 7\%$

GP-GM : Poorly graded Gravel with silt
$C_u \ngtr 4$ & $C_c < 1$ or $C_c > 3$, $I_p < 4\%$

Sand:

SW-SC : Well graded Sand with clay
$C_u > 6$, $C_c = 1$ to 3, $I_p > 7\%$

SW-SM : Well graded Sand with Silt
$C_u > 6$, $C_c = 1$ to 3, $I_p < 4\%$

SP-SC : Poorly graded Sand with clay
$C_u \ngtr 6$, $C_c < 1$ or $C_c > 3$, $I_p > 7\%$

SP-SM : Poorly graded Sand with Silt
$C_u \ngtr 6$, $C_c < 1$ or $C_c > 3$, $I_p < 4\%$

IS Classification

	Soils							
Boulder (mm)	Cobble (mm)	Coarse grained Soil					Fine grained soil	
		Gravel		Sand			Silt (mm)	Clay (mm)
		Coarse (mm)	Fine (mm)	Coarse (mm)	Medium (mm)	Fine (mm)		
>300	300–80	20–80	4.75–20	2–4.75	0.425–2	0.075–0.425	0.002–0.075	<0.002

Sieve	
4.75	C.S
2.36	
1.18	M.S
600 µ	
425 µ	F.S
300 µ	
150 µ	
75 µ	Silt
2 µ	
Pan	

1) From a particle size distribution curve of a sandy soil, the following data is obtained :

Size of particle (mm)	% Finer
0.48	60
0.33	30
0.21	10

Determine the Uniformity Coefficient & Curvature Coefficient. Is this soil well graded or poorly graded.

$D_{60} = 0.48$ mm, $D_{30} = 0.33$, $D_{10} = 0.21$ mm

$$C_u = \frac{D_{60}}{D_{10}} = \frac{0.48}{0.21} = 2.28$$

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} = \frac{(0.33)^2}{0.48 \times 0.21} = 1.08$$

For well graded sand : $C_u > 6$ & $C_c = 1$ to 3

But here $C_u = 2.28$

So, it is a poorly graded sand.

2) Laboratory sieve analysis was carried out on a soil sample using a complete set of standard IS-sieves. Out of 500g of soil used in the test, 200g was retained on IS 600μ, 250g was retained on IS 500μ and the remaining 50g was retained on IS 425μ. Find the C_u & classify the soil.

Sol.

Sieve size	wt. retained (g)	Cum. wt. retained (g)	% Cumm retained	% Finer
600 μ	200	200	40	60
500 μ	250	450	90	10
425 μ	50	500	100	0

$D_{60} = 0.6$ mm, $D_{10} = 0.5$ mm

$$C_u = \frac{D_{60}}{D_{10}} = \frac{0.6}{0.5} = 1.2$$

The soil is between 75μ – 4.75 mm, hence the soil is Sandy soil.

For well-graded soil : $C_u > 6$ & $C_c = 1$ to 3

Here $C_u \not> 6$, so soil is Poorly graded Sand.

Classify the soil for the data given :

1000g of soil was used,

Liquid limit = 40%

Plastic Limit = 18%

Sieve Size (mm)	Wt. retained (g)
4.75	20
0.075	730

The soil classification is

a) GM b) SM c) GC d) ML–MI

Out of 1000g, 730g is retained on 75μ Sieve.

more than 50% is retained on 75 μ, soil is Coarse grained

★ Soil is b/w 75μ & 4.75 mm → Sand

$I_p = 40 - 18 = 22\% > 7\%$

% Finer (25%) > 12% → $I_p > 7\%$

∴ Soil is clayey sand.

As per the Indian Standard Soil classification system, a soil sample of silty clay with Liquid Limit 40% and Plasticity of 28% is classified as

a) $W_L = 40\% \Rightarrow 35-50\% \Rightarrow$ Intermediate (I)

b) I_p of soil $= 28\%$

I_p of Aline $= 0.73(W_L - 20)$

$= 0.73(40-20)$

$= 8.76\%$

I_p of soil > I_p of A-line ⇒ clay

∴ Soil is Intermediate Compressible clay [CI]