Basic definations :-

Soil :- Soil means the loose unconsolidated inorganic material on the earth's crust produced by the disintegration of rocks, overlined hard rock with or without organic matter.

Geotechnical engineering deals with soil, rock and underground water and their relation to design, construction and operation of engineering projects.

Soil formation :- Due to weathering of rocks, disintegration and decomposition of rocks and minerals at or near earth surface through natural, chemical and mechanical agents into smaller grains

Factors of weathering :-

① Natural weathering [Atmospheric] changes in temperature and pressure

② mechanical weathering [Erosion and transportation]

It happens due to wind, water, glacious

③ chemical weathering :-

crystal growth, oxidation, carbonation, Leaching by water.

Deposits :-

① Alluvial soil deposited :-

Deposited from suspension in the running water.

② Lacustrine deposits :-

Deposited from Suspension in still, fresh water of lakes.

③ Marine deposits :- Deposited from Suspension in Sea water.

④ Aeolian deposit :- A -> Air

Deposited from transportation by wind

⑤ Glacious deposit :- Transported by large mass of ice.

* Deposits directly made by melting of glacious are called till.

* At terminal melting glaciour drops materal in the form of ridges known as terminal moraine

Ground moraine :- The land which was once glaciour and on which till has been deposited is called ground moraine.

* outwash :- outwash is the soil carried by the melting water in front.

⑥ Gravity deposit :- Foot of hills or steap slopes by gravity. [colluvial soil]

Ex :- Talus

09/02/2017

Mass :- mass is a measure of a amount of object matter an object contains. mass is an independent quantity

Density :-

measure of how much mass an object contains per unit volume.

weight :- It is the force excerted by gravity on an object. It is an dependent quantity.

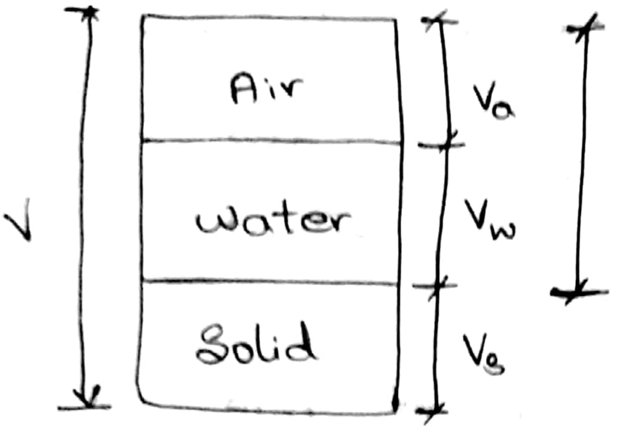
Phase diagram :-

phase is a completely different homogeneous System.

3 - phase

Volumetric

V = Air + water



$V_v = V_a + V_w$

$V \rightarrow$ Total volume

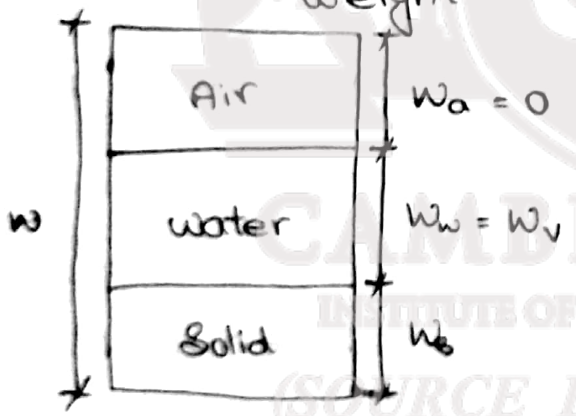
$V_a \rightarrow$ volume of air

$V_w \rightarrow$ volume of water

$V_s \rightarrow$ volume of solid

$V_v \rightarrow$ Volume of voids

weight



$W \rightarrow$ Total weight

$W_a \rightarrow$ weight of air

$W_w \rightarrow$ weight of water

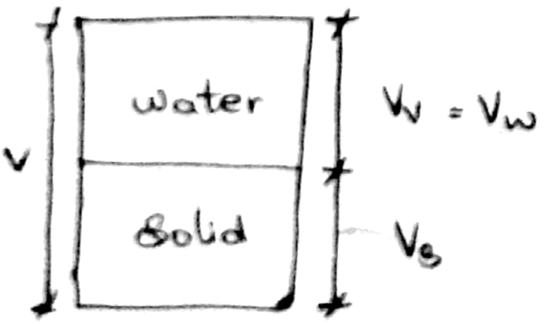
$W_s \rightarrow$ weight of solid

$W_v \rightarrow$ weight of voids

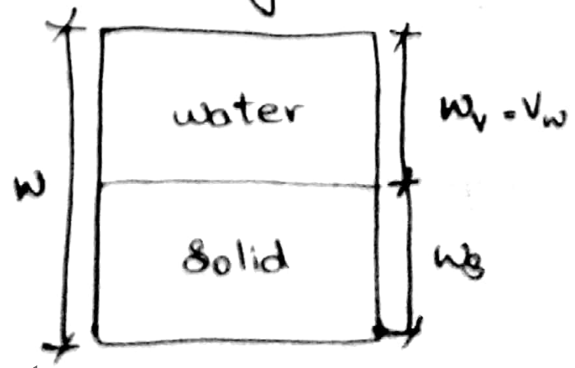
Saturated

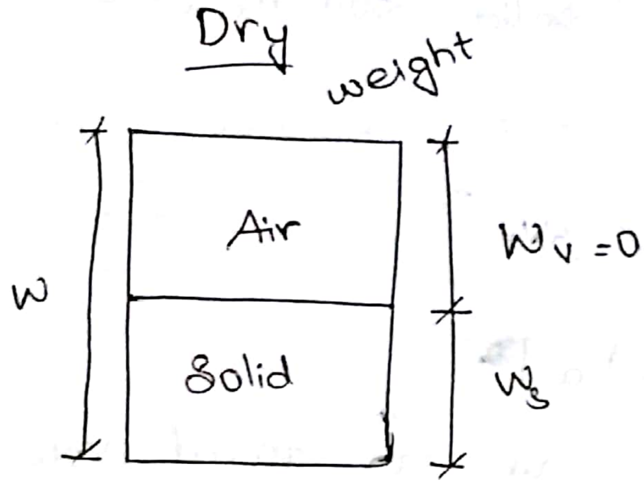
2 phase

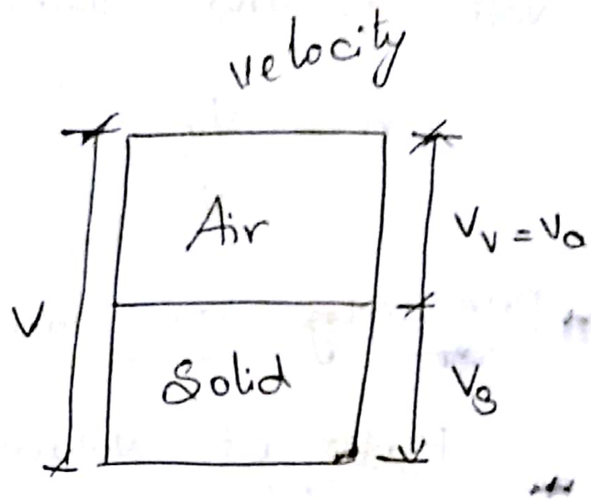
velocity



weight







Basic terminology :-

water content (w) (or) moisture content :-

It is a ratio of weight of water to weight of solids (dry) of soil mass.

$$w = \frac{W_w}{W_{s(dry)}} \times 100$$

Based on voids :-

Void ratio :- (e)

Ratio of volume of voids to volume of solids.

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

Void ratio :- Void ratio is used in soil mechanics to characterize the natural state of soil

→ In void ratio V_s (volume of solid) remains relatively constant on application of pressure, but V_v alone changes.

Voids to the volume of Solid Soil mass.

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

percentage air voids :- $[n_a]$

Ratio of volume of air to total volume of Solid (soil) Voids

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

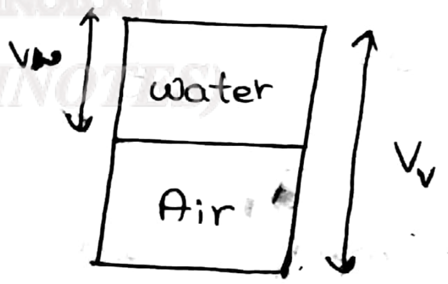
Air content :-

It's the ratio of volume of air voids to the total volume of voids.

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

Degree of Saturation :- Ratio of volume of water to the volume of Voides.

$$S = \frac{V_w}{V_v} \times 100$$



$$0 < S < 100$$

Density of Soil

Quantity	Definition	Formula
① Bulk density $[\rho]$	Total mass of soil per unit of its total volume	$\frac{m}{V}$ g/cm³, kg/m³

Quantity	Defination	Formula
② Dry density [ρ_d]	mass of solids per unit ~~of~~ of it's total volume of soil [prior to dry]	$\frac{m_d}{V}$
③ Density of solids [ρ_s]	mass of soil solids per unit volume of solids	$\frac{m_d}{V_s}$
④ Saturated density [ρ_{sat}]	Bulk density at saturation of soil mass	$\frac{m}{V}$ (Saturated) g/cm^3
⑤ Submerge density [ρ or ρ_{sub}] or [buoyant density]	It is the density of the submerged mass of soil solids per unit total volume be of soil mass	$\frac{m_{d(sub)}}{V}$ $\rho' = \rho_{sat} - \rho_w$ ρ_w = Density of water $1 g/cm^3$ $9.81 kN/m^3$ $1000 kg/m^3$

__Unit__ __weight__ [γ]

	weight per unit volume	
① Bulk (moist) (γ)	Total weight (ω) of a soil mass per unit of its total volume.	$\frac{\omega}{V}$

② Dry (γ_d)	weight of solids per unit of its total volume [prior to dry] of Soil mass	$\frac{W_d}{V}$
③ unit weight of Solids (γ_s)	weight of Soil Solids per unit weight of Solids alone	$\frac{W_s}{V_s}$
④ unit weight of water [γ_w]	weight of water per unit volume of the water Note:- It has a convinient Value at 4° c	$\frac{W_w}{V_w}$
⑤ Saturated unit weight [γ_{sat}]	It is a bulk unit weight of Soil mass in saturated condition	$\frac{W}{V}$ (sat)
⑥ Submerged unit weight [γ_{sub}]	It is the unit weight of Soil in Submerged condition	$\frac{W_s}{V}$ (sub)

Specific Gravity :-

It is the ratio of unit weight of so to unit weight of pure water at a given temperature or standard temp

Note:

* Low value for coarse grained soil
* organic matter also leads to very low values.
* Soils high in iron or mica exhibits high value

Index properties :-

① Specific gravity :- [Determination by pycnometer method and Specific gravity bottle method

② water content

a) oven drying method
b) pycnometer method [Quick method]
c) Sand-bath method
d) calcium - carbide method

③ In-situ density :-

a) core cutter method
b) Sand replacement method

④ particle size ~~Ana~~ :-

a) particle size Analysis

⑤ Sedimentation Analysis

a) Hydrometer Analysis

⑥ Atterberg's limits

a) Liquid limit

b) plastic limit

c) shrinkage limit

⑦ Relative density :-

⑧ Thixotropy

⑨ Sensitivity of clay

⑩ Activity of clay

Specific gravity determination

* It is used for computation of several quantities such as void ratio, degree of saturation, unit weight of solids and unit weight of soil in various states.

* It is determined by pycnometer and specific gravity bottle.

procedure :-

* weigh empty, dry pycnometer bottle [w_1]

* 300 g of oven dried sample, placed in pycnometer and ~~weight~~ weighed [w_2].

* Pycnometer + Soil + water is filled and closed and air entraped in Soil is removed by sturring with a glass rod. $[W_3]$

* pycnometer + full water $[W_4]$

* weight of dry Soil W_s $W_2 - W_1$

* weight of water having the Same volume as that of Solids $= (W_2 - W_1) - (W_3 - W_4)$

Specific gravity of So

$$G = \frac{(W_2 - W_1)}{(W_2 - W_1) - (W_3 - W_4)}$$

G values are usually reported at 27°c.

If T°c is the test temperature, the Specific gravity at 27°c is given by

$$\underset{(27°c)}{G_s} = \underset{(T°c)}{G_s} \times \frac{\text{specific Gravity of water } (T°c)}{\text{Specific Gravity of water } (27°c)}$$

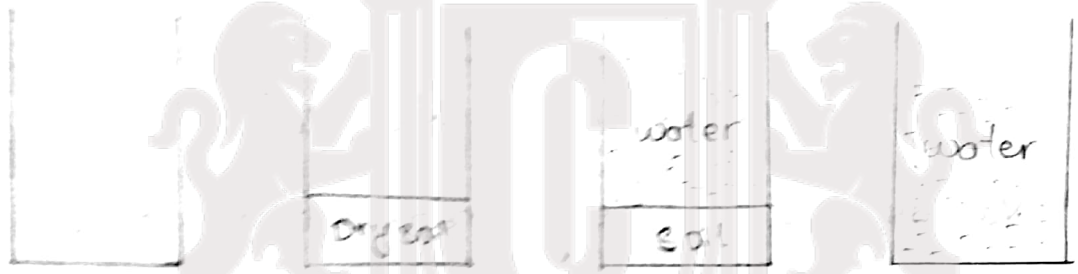
Soil Sample to be taken should pass through 4.75 mm Sieve.

<u>Note</u>:- This method can be used for any type of Soil preferebly cohesion less Soil.

Specific gravity bottle method :-

Same procedure is followed as of pycnometer method but by using Specific gravity bottle

* Take 1/3rd of oven dried sample in both methods



water content

a) oven dry method :-

* It is the simplest method
* oven control temperature of 105 - 110°c for 24 hours in general case.
* Temperature above 110°c might breaks Cystalline structure of clay particles and also the chemically bonded water molecules get evaporated.

* 60°c is recommended for organic soils to avoid oxidation of organic matter in the sample.

* In case of sandy soils, complete drying can be achieved in 4-6 hours.

* clay samples require 16 to 20 hours.

* A clean non corridable container whie is weighed accurately to 0.01 g

* About 30-40 g of Voi moist sampl is taken and weighed accurately after being placed in the container.

* The container which the sample is kept in the oven and taken out after 24 hours and weighed again

w_1 = weight of empty container

w_2 = weight of container + moist soil sample

w_3 = container + dried sample

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

$$w = \frac{(w_2 - w_3)}{(w_3 - w_1)} \times 100$$

Sand Bath method :-

Sand bath method of determining water content is very quick field method when the facility of an electric oven is not available.

* wet soil sample is put in a container and dried by placing it on a sand bath. The sand bath is heated over a kerosene stove. The wet soil sample dries quickly.

* The water content is then determine using the formula

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

Pyconometer method of determination of water content [quick set method]

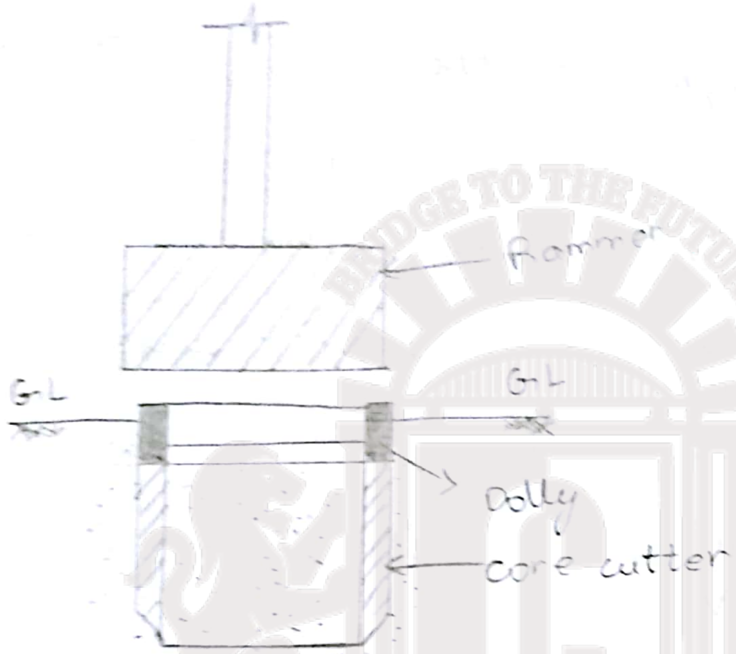
* Same procedure as specific gravity

$$w = \left[\frac{(W_2 - W_1)}{(W_3 - W_4)} \times \left[\frac{G_s - 1}{G_s}\right] - 1\right] \times 100$$

G_s = specific Gravity of soil.

In - situ Density :-

→ core - cutter method
→ Sand - Replacement method
→ water Replacement method



* Core cutter method

This method consists of driving a core cutter of known volume (1000 cc) in to the soil after placing it on a cleaned soil surface.

* The core cutter is usually provided with a 25 mm high.
* The driving of the core cutter is usually done by hitting the dolly mounted on top of the core cutter with a suitable hammer or rammer
* The cutter filled with a soil is removed

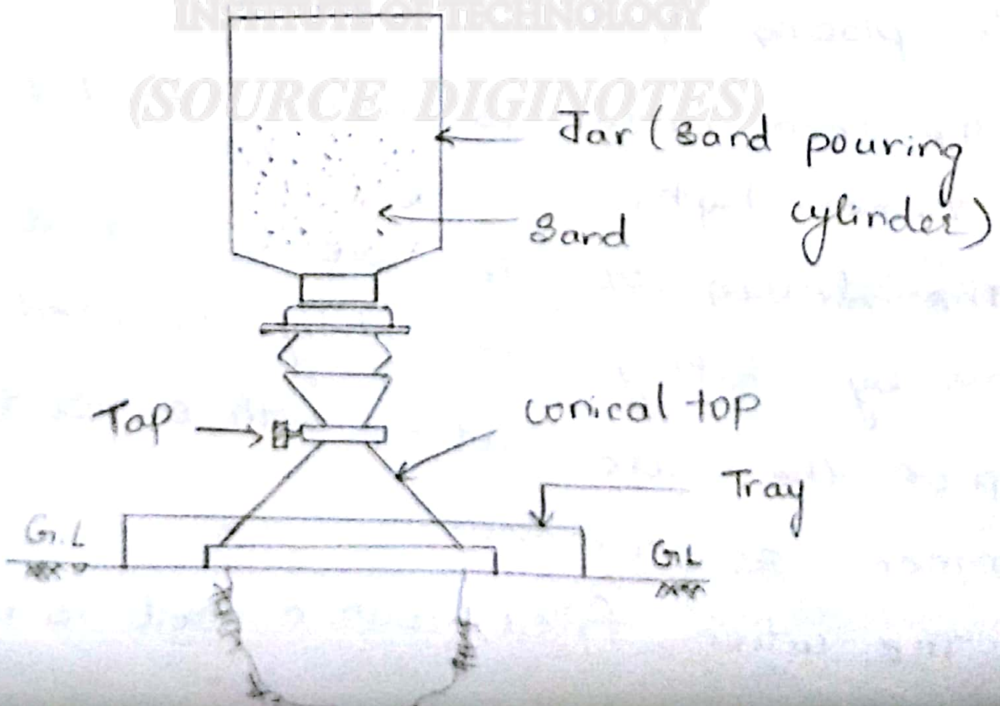
and the excess soil trimmed off. The core cutter with a soil is weighed.

* The volume of the cutter is calculated by from the dimensions of the cutter and the insitu unit weight is determined by dividing the weight of the soil in the cutter by the volume of the cutter. If the water content of the soil in the cutter is determined in the laboratory, the dry unit weight of the soil can also be computed.

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

Core cutter cannot be used in the case of hard or gravelly soils.

Sand Replacement method :-



* The core cutter can not be used in the case of gravelly or hard soils.
* The principle of the sand replacement method consists in obtaining the volume of the soil excavated by filling in the hole in-situ from which it is excavated with sand, previously calculated for it's unit weight, and thereafter determining the weight of the sand required to fill the hole.
* The apparatus consists of the sand poring cylinder, tray with a central circular hole, container for caliberation, balance, scoop.

*procedure :-

* The site is clean and a square tray with a central opening in it is placed on the cleaned surface.
* The dia of opening made in soil is same as tray opening or hole and depth of about 15 cm.
* The soil excavated from hole is weighed
* The apparatus full of dry and clean sand is placed over the hole centrally.

* Now the tap is open and the sand is allowed to fill the excavated hole and the conical end.
* when no further flow of sand takes place, the tap is closed and the sand remaining in the jar is weighed again.
* The cone filled with sand is also weighed.
* Thus the weight of sand filling the excavated hole is computed.
* The unit weight of sand in the jar is computed by pouring sand in a caliberating can of ~~load~~ known dimensions and weighing the sand in the calibration can.
* ~~The~~ Having computed the unit weight of sand in the bottle and the weight of sand required to fill the excavated hole, the volume of the hole is determined.
* By dividing the weight of the excavated soil by its volume, the in-situ unit weight of the soil is determined.
* <u>Note</u>:- For bouldery soil a large hole of about 30 cm to 1m dia and 30cm to 1md is excavate

particle Size Analysis

↳ Sieve Analysis

→ Sedimentation Analysis

Sieves are wire screens having square openings. Sieve analysis is a dry analysis.

* According to I.S 460 - 1962 (revised) the Sieve number is the mesh width expressed in mm for larger sizes, μ (micro) for small sizes.

* A sieve with a mesh opening of 4.75 mm is designated as 4.75 mm sieve and a 500 μ sieve refers to a sieve with a mesh opening of 0.5 mm

* Sieves vary from 80 mm to 75 ~~mm~~ μ

* A representative soil sample is separated in to two fractions by sieving through 4.75 mm sieve. i.e., coarse & fine.

* Coarse → Retaining on 4.75 mm sieve which is again sieved using 80 mm, 20 mm, 10 mm and 4.75 mm sieves.

Fine → passing 4.75 mm, 2 mm, 1 mm, 600 μ, 425 μ, 300 μ, 212 μ, 150 μ and 75 μ

* For a particular soill all the sieves ~~are~~ may not be required.

* only Such Sieves are Selected as would give a good grain size distribution curve

procedure :-

* A Suitable quantity of dry and pulverized Soil of known weight [about 500 g] is taken and is sieved for a ~~cotlect~~ Selected Set of Sieves arranged according to their Sizes

* Largest Sieve at top and Smallest at bottom with a pan reciever at the bottom most end.

* The top Sieve is closed by a lid and the whole Set up is Shaken for about 10 min using mechanical Sieve Shaker are manual.

* Now the amount of Soil retained on each Sieve is weighed to the nearest of 0.1 g.

* on the basis of the total weight of Sample taken and the weight of Soil Retained on each Sieve. The % of total weight of Soil passing through each Sieve [also termed as % finer than] can be calculated as below.

$$\%\ \text{retained on particular sieve} = \frac{\text{weight of Soil retained on that Sieve}}{\text{Total weight of Soil taken}} \times 100$$

Cummulative % retained

Sum of % retained on all sieves of larger sizes and the % retained on that particular sieve.

Sieves	% retained	% commulative retained
4.75	10%	
2 mm	20%	30
1 mm	10%	40
600 μ	10%	40
425 μ		
		100

% finer than the sieve under reference = 100% − cummulative % retained

<u>Note</u> :- Finest sieve used in the sieve analysis is 75 μ

* If the portion passing 75 μ is substantial, a wet analysis is carried out.

BIS Soil classification (Based on Grain Size)

	2μ (0.002 mm)		75μ (0.075 mm)	425μ (0.425 mm)	2.0 mm	4.75 mm	20 mm	80 mm
CLAY SIZE	SILT SIZE		FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE SIZE
			SAND SIZE			GRAVEL SIZE		

Sedimentation Analysis

- → Hydrometer Analysis
- → Pipette Analysis

For determining the grain size distribution of the soil fraction finer than 75 μ in size. Sedimentation Analysis is a wet analysis

* It is based on Stoke's law. According to this law, velocities of spherical, fine particles free falling through a liquid is different for different sizes.
* In soils, the grains are of different shapes but it is assumed that they are spherical and have the same average specific gravity.
* If a single sphere is allowed to fall freely

through a liquid of a infinite extent, it's velocity will first increase rapidly due to gravity but later a constant velocity is achieved and this velocity is called terminal velocity. Terminal velocity is achieved within a short time, According to Stoke's law, terminal velocity is given by

$$V = \frac{\gamma_s - \gamma_l}{18\eta} \times D^2 \ \text{cm/s} \qquad \eta = \frac{\mu}{g}$$

$\gamma_s \rightarrow$ unit weight of soil grains (g/cm³)

$\gamma_l \rightarrow$ unit weight of liquid (g/cm³)

$\eta \rightarrow$ Viscosity of liquid (g - s/cm²)

$D \rightarrow$ Diameter of the grain (cm)

Hydrometer Analysis :-

It is an analysis of fine grain soils.

* Hydrometer is a instrument which is used to measure the relative density of a liquid.
* Hydrometer consists of two parts
  ① Cylindrical stem
  ② Bulb at bottom made with mercury
* The lower the density of the liquid, the more the hydrometer will sink.
* Ex:- Consider water and petrol

petrol is less dense than water
So the depth of inversion of hydrometer in petrol is more than water.

* Hydrometer analysis is based on stoke's law.
* It is used in case of fine grained soil for sizes varying from 75 μ to 2 μ, has design of sieve for these sizes is not practicable.

Equipments:

* Hydrometer
* Dispersion cup with mechanical stirrer
* Two glass jar of one litre capacity
* Deflocculating agent [sodium hexa metaphosphate solution prepared by dissolving 33g of sodium hexa metaphosphate and 7g of sodium carbonate in distilled water to make 1 litre solution.
* Stop watch
* Thermometer
* Scale

Procedure :-

* Take 50g of Soil if the Soil is clayey soil
* If 100g Soil is taken if it is Sandy soil. weight accurately to 0.1 g.
* If Soil contains considerable amount of organic matter or calcium compounds it is pre treated with hydrogen peroxide or hydrochloric acid.
* If the Soil contains less than 20% of the above mention compounds, then pre-treatment is not necessary.
* Soil is treated with 100 cc of Sodium hexa meta phosphate Solution. and warm yet it gently for 10 minutes. and transfer the contents to the cup of mechanical mixer using a jet of distilled water to wash all the traces of Soil.
* Sturr the Soil Suspension for about 15 min.
* Transfer the Suspension to 1 litre jar and add distilled water till 1000 cc [1 litre].
* Take another hydrometer jar with 1000 cc distilled water to store the hydrometer in between consecutive readings of the Soil Suspension to be Recorded. Note down the S.G readings and temp $t^{o}c$ of water

occasionally.

* mix the Soil Suspension in jar properly.

* Immidiately after mixing place the jar on table and insert hydrometer and take readings at $\frac{1}{4}$, $\frac{1}{2}$, 1, & 2 minutes

* After 2 min reading take out hydrometer and place it in another jar filled with distilled water. Repeat this step after taking every reading.

* Take Subsequent hydrometer readings at 4, 9, 16, 25, 36, 49, 60 min and at evey one hour thereafter till the hydrometer reads 1000 approximately.

* care should be taken to see that every time the hydrometer reading is taken it should be still without any movement.

Consistency of clay

* Consistency of Soil means the relative with which soil can be deformed

* Consistency denotes degree of firmness of the soil which may be termed as soft, firm, stiff and are hard

* This term is mostly used for fine grain soils for which consistency is related to a large extent to water content.

* Fine grained soil may be mixed with water to form a plastic paste. which can be moulded in to any form by pressure.

* The continous addition of water reduses cohesion and the soil no longer retains its shape under it's own weight, but flows as a liquid,

* Enough water may be added until the soil grains are dispersed in suspension

* If water is evaporated from such a soil suspension, the soil passes through various changes or stages or states of consistency.

* In 1911, Swedish agriculturalist, Attenberg divided the various states of consistency.

i) Liquid state
ii) plastic state
iii) Semi - Solid state
(iv) Solid State

* He said orbitary limits at which the soil changes it's state every time water is added.

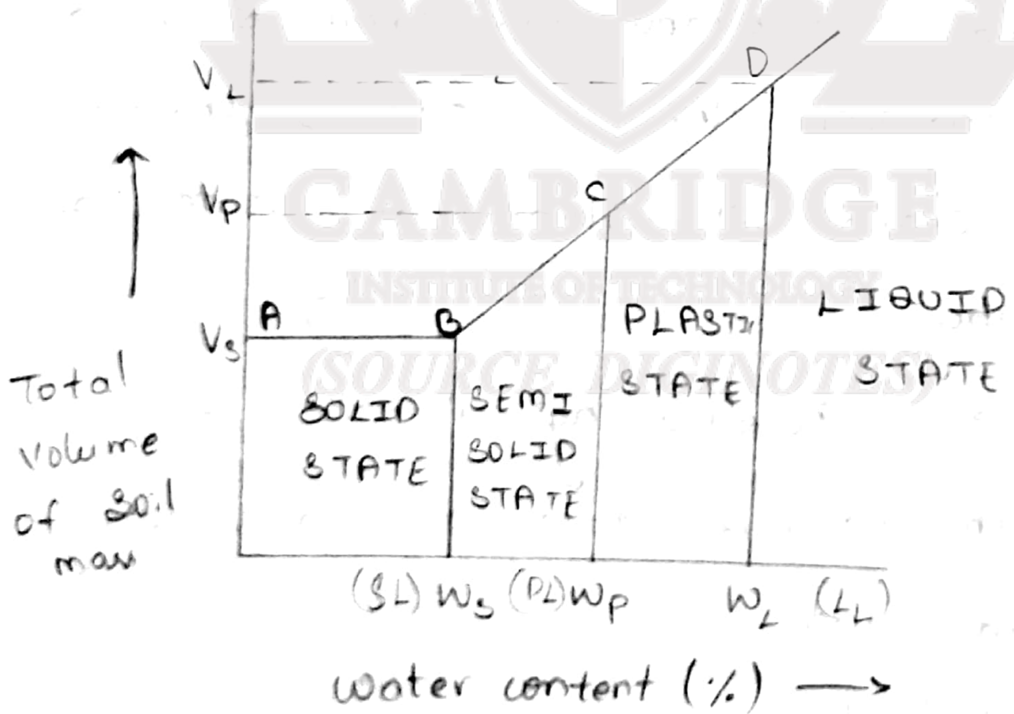
* This limits are called Atterberg limits or consstency limits.

* Thus, consistency limits are the water contents at which the soil mass passes from one state to next.

① Liquid limit

② plastic limit

③ Shrinkage limit



w_s → water content at Shrinkage limit

w_p → water content at plastic limit

w_L → water content at liquid limit

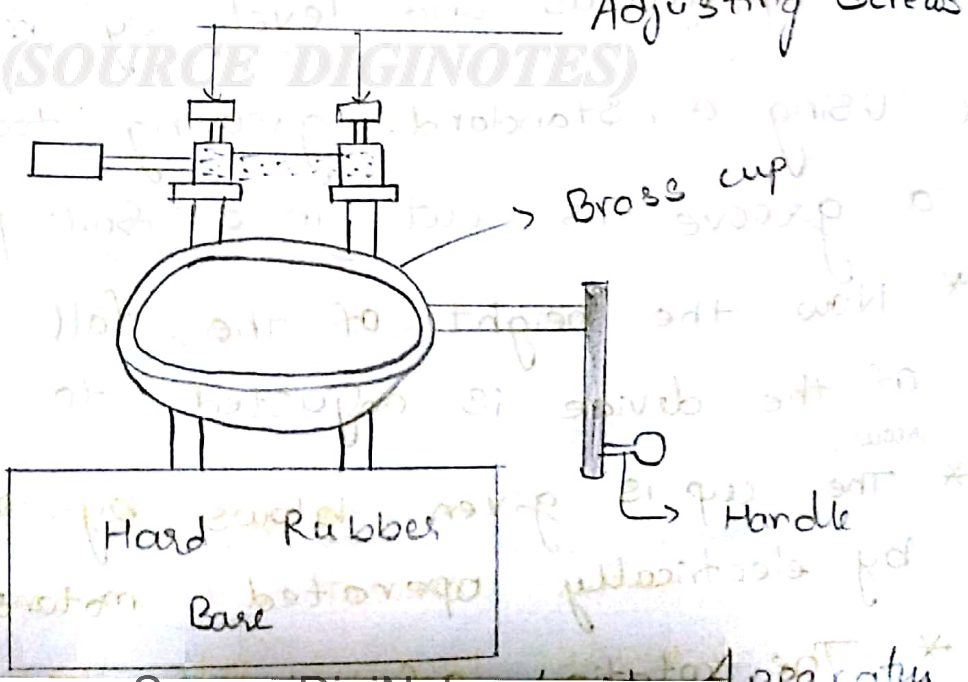
Determination of Atterberg limits or consistency limits

1 LIQUID LIMIT :-

It is defined as the minimum water content in which the soil is still in the liquid state, but as small shearing strength against flowing which can be measured by standard available means.

Liquid limit can be determined by A. casagrande liquid limit apparatus.

→ with reference to the device liquid limit can be defined as the minimum water content at which a part of soil cut by group of standard dimensions will flow together for a distance of 12 mm under an impact of 25 blows. in the device.



procedure.

(2)

Apparatus. Brass cup of liquid limit apparatus

(2) Grooving tool (ASTM tool)

(3) 425 μ IS sieve

(4) Spatula

procedure.

* Take about 100 g soil sample passing 425 μ IS sieve

* Some quantity of distilled water is mixed to it to form a soil paste of uniform colour

* Some of the soil is placed in brass cup of apparatus and level by means of spatula

* Using a standard grooving tool (ASTM tool), a groove is cut in a soil pat in the cup

* Now the height of the fall of the cup of the device is adjusted to 1cm.

* Now, The cup is given blows by manual or by electrically operated motors.

* The rotation of the handle should be

of 2 revolutions per sec.

* The number of blows required to close the groove for a distance of 12 mm is [approximate] noted down.

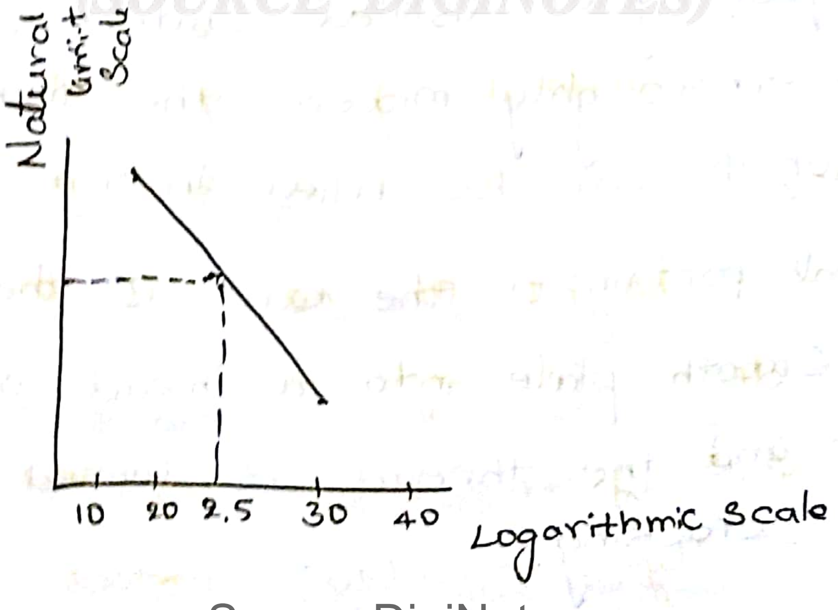
* Some quantity of soil at groove closed portion is taken for water content determination

(3)

* The procedure is repeated for 4 concurrent trails for taking number of blows and water content.

* It is convinient to increase water content in successive steps and obtain low counts near about 40, 30, 20 & 10

* The water content values are plotted as ordinate on natural scale against number of blows as absis on logarithemic scale. to obtain a straight line. which is known as flow curve.



From the plot the liquid limit is obtained as water content corresponding to 25 crores

PLASTIC LIMIT

plastic limit is the water content corresponding to an arbitrary limit between the plastic and semi solid states of consistency of soil

* According to the experiment, it is defined as the minimum water content at which the soil will just begin to crumble when rolled in to a thread approximately 3mm in diameter

procedure:-

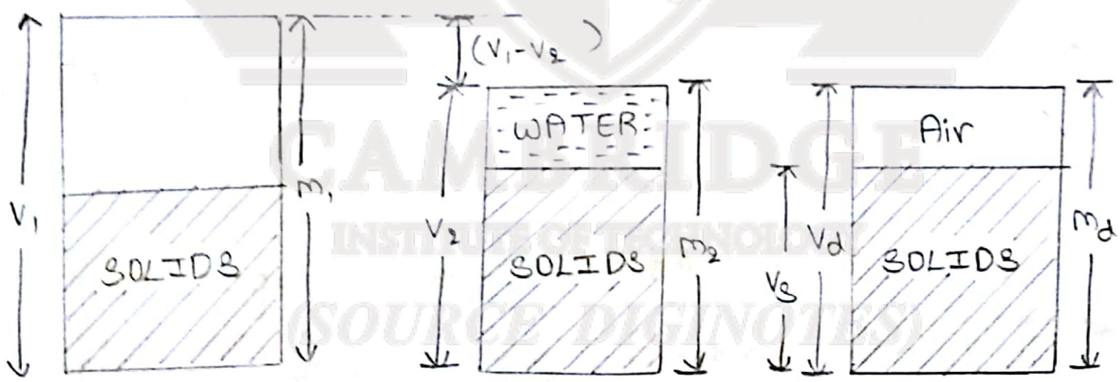
* Take about 30 g of soil sample passing 425 μ ISsieve
* Some quantity of distilled water is added to it and thoroughly mixed the form soil paste which can be rolled in to a ball.
* A small portion of the ball is then rolled on a smooth plate into a thread of 3mm diameter and the thread is looked afor sign of cracking.
* If no cracks are seen the thread is rolled again

till cracks are developed for 3mm diameter.

* A portion of the thread is taken for water content determination which gives the plastic limit.

SHRINKAGE LIMIT :- [W_s] [SL]

If a Saturated Soil Sample is take is allowed to dry up gradually, its volume will go on reducing till a stage will come after which the reduction in soil water will not result in further reduction in the total volume of the soil sample. The water content corresponding to that stage is known as shrikage limit.



a) original soil pat

b) Soil pat at shrinkage limit

c) Dry soil pat

m_1 = mass of wet soil pat

V_1 = Volume of wet soil pat

m_d = mass of dry soil pat

V_d = Volume of dry soil pat

According to above diagram

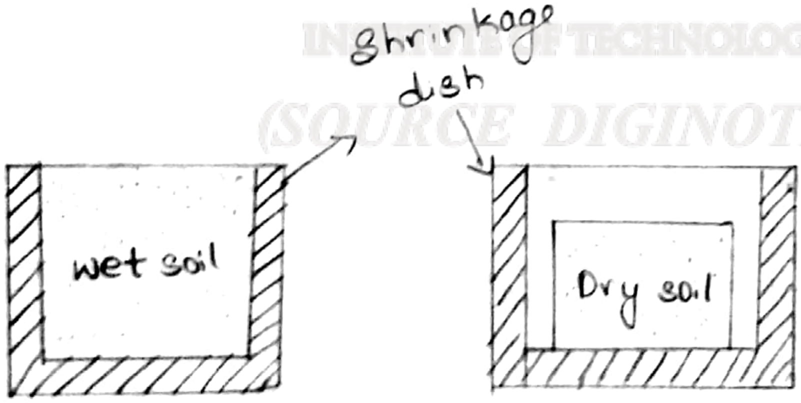
$$W_s = \frac{\text{mass of water in fig (b)}}{\text{mass of soil solids}}$$
[shrinkage limit]

* mass of water in fig (b) = mass of water in fig (a) − loss of mass of water from fig (a) to fig (b)

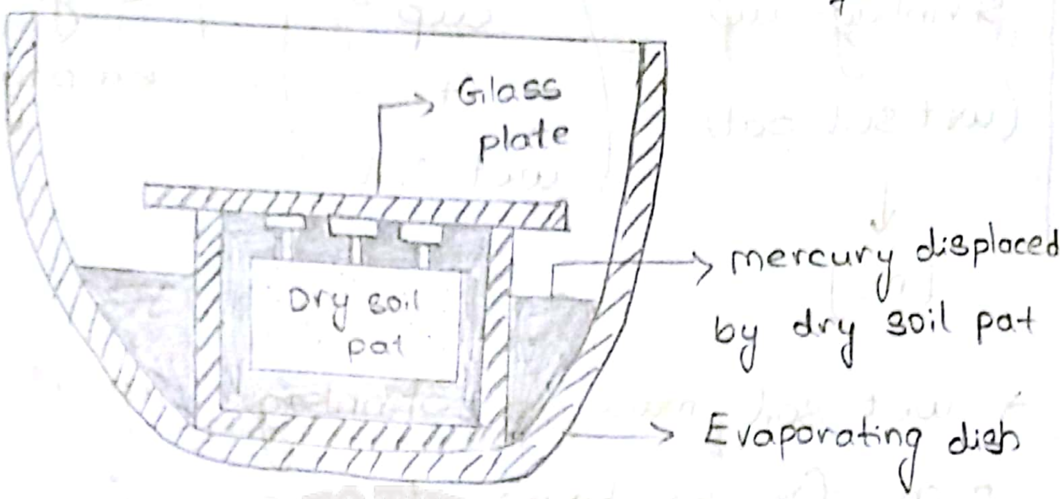
$$= [(m_1 - m_d) - (v_1 - v_d)\gamma_w]$$

where $V_2 = V_d$

$$w_s = \frac{[(m_1 - m_d) - (v_1 - v_d)\gamma_w]}{m_d} \times 100$$



a) Before shrinkage b) After shrinkage



c) method of finding volume of dry soil pat

procedure for shrinkage limit distribution

* Take 50 g of soil sample passing 425 μ IS sieve in a porcelain dish.
* Add distilled water and mix thoroughly to form a paste of slightly flowing consistency
* where weigh empty shrinkage dish which is greased inside.
* Shrinkage cup is filled with soil paste in three layers by tapping the cup after each layer to remove air voids.
* The surface of soil is levelled and outside of cup is clean and weighed again.
*

[wet soil in shrinkage cup (wet soil pat) = (shrinkage cup + wet soil) − (weight of empty shrinkage cup)]
↓
[m_1]

* wet soil mass in shrinkage cup is kept in oven for 24 hours at 105 - 110°C.
* Now the shrunk and dried up soil pat in shrinkage cup is weighed (m_d)
* The volume of wet soil is equal to volume of shrinkage dish (V_1) and the volume of dry soil pat is found using mercury displacement method. (V_d)
* The shrinkage dish is filled with mercury which is placed in evaporating dish and the dry soil pat is pressed inside mercu[ry] with a flat glass plate. and knowing the amount of mercury spilled pat and reduc[e] this volume from the total volume of mercury in shrinkage dish using knowing density of liquid. mercury.

Alternate method (Shrinkage limit)

If Specific gravity of soil is known then Shrinkage limit (w_s). 9

$$\boxed{W_s = \frac{V_d}{M_d} \times \gamma_w - \frac{1}{G}} \quad \%$$

Consistency Indices [Atterberg Indices]

① Plasticity Index (I_P)
② Flow Index (I_F)
③ Toughness Index (I_T)
④ Consistency Index (I_c)
⑤ Liquidity Index (I_L)

① plasticity Index:- [I_P]

It is the range of moisture content over which the soil exhibits plasticity.

It is defined as liquid limit minus plastic limit

$$I_P = W_L - W_P$$

② Flow Index (I_F)

Flow index indicates the rate of loss in shearing strength upon increase in water content.

* A soil which higher value of flow index possess lower shear strength when compare to a higher value of flow index.

* Flow index, I_F is the slope of the flow curve [It's a straight line] obtain between the number of blows in and the water content in the casagrande test for determination of liquid limit.

<u>Reference</u>:- For flow curve please refer the graph given in liquid limit determination

$$I_F = \frac{w_1 - w_2}{\log_{10}(N_2/N_1)}$$

where

w_1 = water content corresponding to number of blows N_1

w_2 = water content corresponding to number of blows N_2

③ <u>Toughness Index</u> :- $[I_T]$

It indicates the shear strength of a soil at plastic limit.

* Toughness Index is defined as the ratio of the plasticity index to the flow index.

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

Note :- I_T generally lies in the range of 0 - 3.

* If $I_T < 1$, the soil can be easily crumbled. [broken into small pieces]

(4) Consistency Index [I_c] Relative consistency

The insitu behaviour of a saturated, fine grain soil deposit at it's natural water content may be studied by their consistency index.

→ It is defined as the ratio of the different between the liquid limit and natural water.

content to the plasiticity index

$$I_c = \frac{\omega_L - \omega}{I_P}$$

where ω = natural water content

(5) Liquidity Index (I_L)

It is used for scaling the natural water content of soil sample to the liquids.

It is defined as the ratio of the different between the natural water content of a soil to its plasticity limit.

$$I_L = \frac{w - w_p}{I_p}$$

where , w = natural water content

Relative Density or Density Index $[I_D]$:

The degree of denseness or looseness of natural deposits of coarse ~~grade~~ grained soils can be determined in terms of their relative density.

Relative Density $[I_D]$ is defined as the ratio of the difference between void ratio of a cohessionless soil in the loosest state and void ratio in its natural state to the difference between its void ratio in the loosest state and void ratio in the densest state.

$$I_D = \frac{\overset{(\text{loose})}{e_{max}} - e_{nat}}{\underset{(\text{loose})}{e_{max}} - e_{min}\,(\text{dense soil})}$$

where e_{max} = void ratio in the loosest state

e_{min} = void ratio in the densest state

e_{nat} = void ratio obtained in the field in the natural state.

ACTIVITY :- OF CLAYS :- [Ac]

Activity of clay is the capacity of soil to hold water

* The properties of clays and their behaviour is influenced by presence of certain clay minerals even in small quantities
* The thickness of water bound around the clay depends on type of clay mineral,
* Thus placiticity of clay depends on
  1. The nature of clay mineral present
  2. Amount of clay mineral present
* on the basis of lab tests, Skempton (1953) observed that for a givel soil the plasticity index is directly proportional to the percentage of clay size fraction
  [i.e, percentage by weight finer than 0.002 mm]
* He introduce the concept of activity by relating the plasticity to the quantity of clay size particles ~~and~~ and defined activity (Ac) as the ratio of plasticity index to the percentage to the weight of soil particles of diameter smaller than 2μ present in a soil.

$$A_c = \frac{I_p}{C_w}$$ (Liquid limit and plastic limit)
(wet analysis)

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I_p = plasticity index

C_w = percent by weight of clay sizes

Activity can be determined by results of usual lab tests such as wet analysis, liquid limit and plastic limit

Activity (A_c)	classification
< 0.75	Inactive
0.75 to 1.40	Normal
> 1.40	Active

mineral present in clayey soil	Activity (A_c)	classification
Kaolinite	< 0.75 0.4 to 0.5	Inactive soil
Illite	0.75 to 1.40 0.5 to 1.0	Normal soil
montmorillonite (Black cotton soil or Black soil	> 1.40 1.0 to 7.0	Active soil

Sensitivity of clays (S_t):-

The degree of disturbance of undisturbed clay sample due to remoulding (change in structure) is expressed by sensitivity.

→ Sensitivity is defined as the ratio of unconfined compression strength (q_u) in undi-sturbed state to that of remoulded state without change in water content

$$S_t = \frac{q_u \text{ (undisturbed)}}{q_u \text{ (remoulded)}}$$

→ The sensitivity of most clays fall in the range of 1 to 8

→ clay soil having sensitivity greater than that is called quick sensitivity.

Thixotropy of clays:-

when sensitive clays are used in construction they loose strength due to remoulding during construction operations. However, with passage of time the strength increases to time though not to the same original level. This phenomenon of strength loss - strength gain with no change in volume or water content is called thixotrophy (thixotropy is greek word,) 'Thixis' meaning touch and troprin means to change.

→ Thus Thixotropy is defined as an isotherma reversible, time dependent process which occurs under constant composition and Volume, there by a material softens, as a result of remoulding and then gradually returns to its original strength when allowed to rest.

Note:- Larger sensitivity leads to larger thixotrophy hardening.

plasticity chart :-

→ Fine grained soils are those which more than 50% of the material as particle size.

→ clay particles have a flaky to which water adheres (adhesion) thus imparting the property of plasticity

→ plasticity chart (graph) which aids for identifications of fine grained soil by there plasticity characteristics into different catagories such as clays, silts or organic soil

→ A plasticity chart is based on the values of liquid limit and plasticity Index (I_p) is provided in ISSCS (Indian standard soil classification system) to aid classification

According to USCS (Unified Soil classification system)

C = clays

M = silts

O = organic soils

CL = Low - plasticity cla

ML = Low - plasticity silts

CH = High - plasticity clay

MH = High - plasticity silts

OH = High - plasticity organic soil

I = Inorganic

O = organic

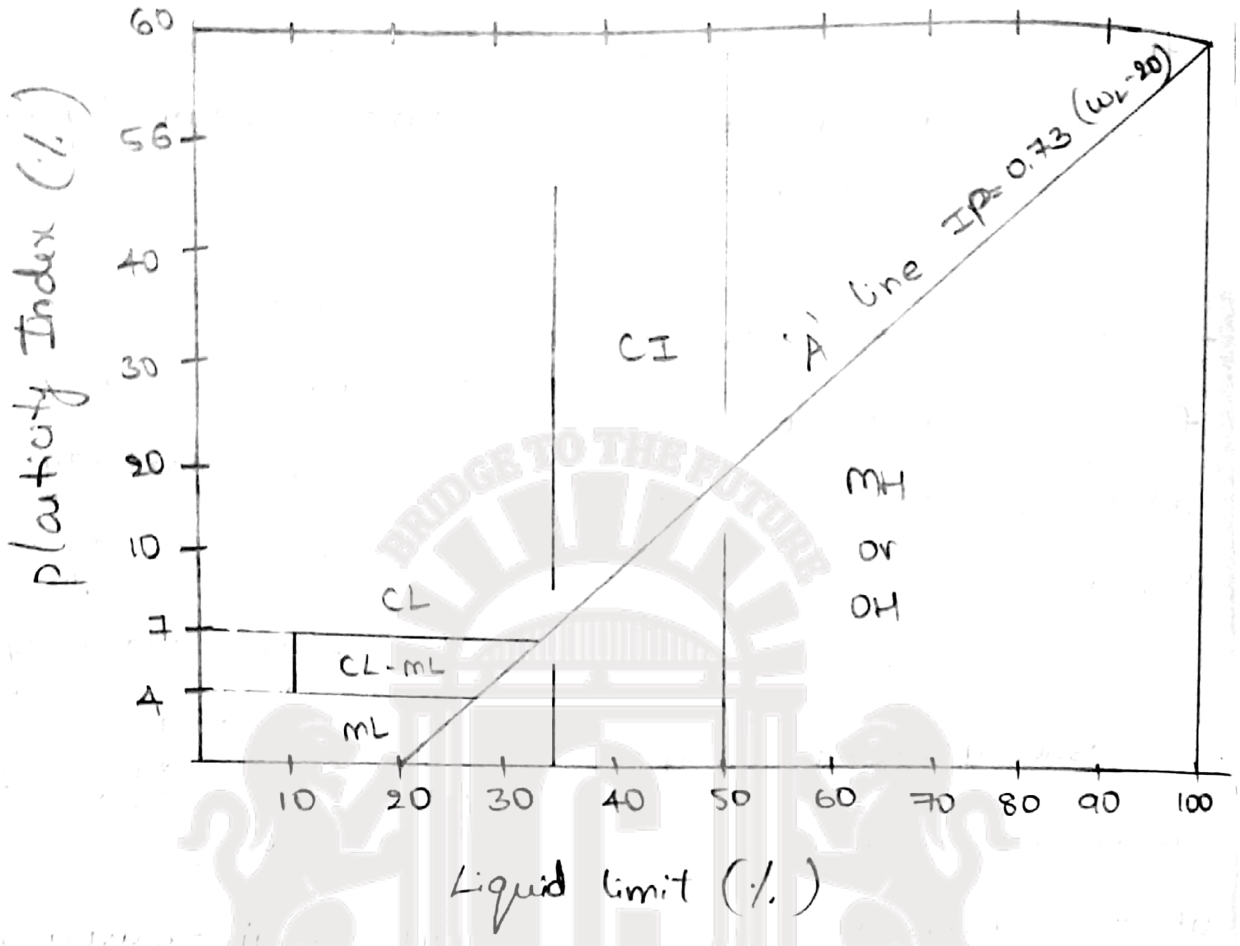
H = High plasticity

L = Low plasticity

CI = Inorganic clay

MI = Inorganic silts

= organic silts



The 'A' line in a chart is expressed as

$I_p = 0.73 \; (w_L - 20)$

→ Depending on the point in the chart, fine soils are divided into clay (c), silts (m), organic soils (o)

→ The organic content is expressed as the percentage of the mass of organic matter in a given mass of soil to the mass of the dry soil solids.

Three divisions of plasticity is also defined as follows

Low plasticity	$w_L < 35\%$
Intermediate plasticity	$35\% < w_L < 50\%$
High plasticity	$w_L > 50\%$

The 'A' line and vertical lines at w_L equal to 35% and 50% seperates the soils into various classes

Unified Soil classification System :

* It was originally developed by Casagrande (1940). USCS was used for airfild construction during world wate 2.
* It was later [1952) modified to make it applicable to other construction like foundation, earthdams, earth canals, earth slopes, etc.
* The System was adopted by American Society of testing materials [ASTM] and later by BIS [
* Varies soils are classified into 4 major groups
  (i) Coarse Grained
  (ii) Fine Grained

(iii) organic soils

(iv) Peat

* According to USCS

(i) coarse grained soils are classified on the basis of their grain size distribution.

(ii) If more than 50% of soil is retained on USC No. 200 (0.075 mm), it is designated as coarse grained soil.

(iii) If 50% or more fraction is retained on US sieve 4.75 mm it is designated as gravel (G), otherwise it is called Sand (S).

Soil type	prefix	Sub Group	Suffix
① Gravel	G	(i) well Graded	w
② Sand	S	(ii) poorly Graded	P
③ silt	M	(iii) silty	M
④ clay	C	(iv) clayey	C
⑤ organic	O	(v) $w_L < 50\%$	L (Low plasticity)
⑥ peat	Pt	(vi) $w_L > 50\%$	H (High plasticity)

I (Intermediate or medium Plasticity for ISCS)

(2) Fine grain Soils :-

A soil is termed fine grained if more than 50% of Soil Sample passes number 200 USE (0.075 mm)

* Fine grain Soils are Subdivided into (m) Silt, clay (c) based on their liquid limit (ω_L). and plasticity index (I_P).

* organic Soils [o] are also included in this group

* plasticity chart is used to divide this Soils again into organic and inorganic Soils

peat :- [turf]

A brown material consisting of partially decomposed vegetable (matter) planning a deposit on acidic, baggy, grouned which is dried for use in gardening and as fuel.

ISCS (Indian standard classification System) [ISI 1498 - 1970]

* ISCS was first developed in 1959 and was revised in 1970.

* This revised version is based on USCS with the modification that the fine grain Soils have been Subdivided into 3 groups.

(low, medium and high plasticity) as against only two groups (low and high) in the USCS.

* The ISCS classifies the soils into 18 groups as against 15 groups of USCS.

* Divisions, soils are broadly divided into 3 divisions

① Coarse grained soils

└→ Gravel (G)
└→ Sands (S)

In this soils, more than half the total material by mass is larger than 75 μ IS sieve.

② <u>Fine grained soils</u> :-

↳ (a) Inorgain silts and very fine sands (M)
↳ (b) Inorganic clays (C)
↳ (c) organic silts and clays and organic matter (O)

In fine grain soils more than half the material by mass is smaller than 75 μ sieve.

(a) Inorganic silts and clays of low compressibility (L)

$w_L < 35$

(b) silts and clays of medium compressibility (I)

$35 < w_L < 50$

(c) Silts and clay of High compressibility

$w_L > 50$

③ High organic soils :- and other misillaneous soil materials

This soil contain large %'s of fibrous organic matter, such as peat and the particles of decomposed vegetation. In addition certain soils containing shells, concretions, cinders and other non-soil materials in sufficient quantities are also grouped in this division.

0.002 mm (2μ) | 0.075 mm (75μ) | 0.425 mm (425μ) | 2 mm | 4.75 mm | 20 mm | 80 mm | 300 mm

Clay (size)	Silt (size)	Fine	medium	coarse	medium	coarse	Cobble	Boulder
		Sand			Gravel			

BIS soil classification (Based on Grain size)
(of Indian Standard)