... size distribution :-

Methods for determination

① Particle size analysis :-

(i) Percentage of different size of particles present in given dry sample of soil is found using particle size analysis, which is generally carried out in 2 stages

(a) Sieve analysis (for coarse grained soil)

(b) Sedimentation analysis (for fine grained soil)

(ii) In general soil consists of all sizes of particles hence both stages of analysis are necessary

(iii) Sieve analysis is true representation of particle size distribution as it is not dependent on temperature.

(iv) Results of sedimentation analysis depends on temperature

(a) Sieve analysis

(i) It is done for the soil fractions having size greater than 75 micron (μ) (For sand & Gravels)

(ii) In this analysis different types of sieves are arranged top to bottom

(iii) Sieve analysis – Coarse sieving (> 4.75 mm) Gravel

– Fine sieving (75μ to 4.75 mm) Sand

- Wet sieving
- Dry sieving

(Note :- Main objective is to find % finer than a particular sieve size

% finer = 100 – Cumulative retained over that particular sieve in %.)

(iv) Coarse sieving – 4.75, 10, 20, 40, 80 mm sieve (orders of sieve size)

(v) Fine sieving – 75, 150, 212, 300, 425, 600μ, 1mm, 2mm (In order)

– It is generally preferred to wash the soil fractions that passes from 4.75 mm sieve and retained over 75 μ before carrying fine sieving.

– It is due to clay & silt particles present in sand

– So sodium hexameta phosphate is used for washing

Wet sieving – If washing is required

Dry sieving – No washing

Aim of particle size analysis (a) to identify the % finer
(b) It means percentage of silt, clay, sand, Gravel in a particullar soil mass.

Coarse grained soil:- The size of coarse grained soil is greater than 75μ Sand (75μ – 4.75mm)
Gravel (80mm – 4.75mm)

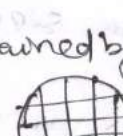
Size:- It normally indicates the diameter of a particle

Fine grained soil The particle size (< 75μ)
silt (75 – 2μ)
clay (< 2μ)

Particle size analysis

- Sieve analysis (Coarse grained soil) Ex: Sand, Gravel
  - Coarse sieving
    Gravel sieving
    (particle size > 4.75 mm)
  - Fine sieving
    Sand sieving
    (< 4.75mm)
    - Dry sieving
      (%age of silt & clay less than 5%.)
    - Wet sieving
      (%age of silt & clay more than 5%.)
- Sedimentation analysis (fine grained soil) Ex; silt, clay
  - Pipette method
  - Hydrometer method

Sieve size :- Sieve size can be obtained by two methods
(i) square opening
(ii) sieve no. * sieve no 6
6 sq. opening in 1 mm 20mm size



% retained on a particular sieve = $\frac{\text{Wt. of soil retained on that sieve}}{\text{total wt. of soil taken}} \times 100$

Cumulative % retained = Sum of % retained on all sieves of larger sizes & the % retained on that particular sieve

% finer than the sieve under reference = 100 – Cumulative % retained

Particle size Analysis

Grain size Distribution

* Grain size analysis of coarse grained soils is carried out by sieve analysis. whereas analysis of fine grained soils is by sedimentation method i.e. either by hydrometer or pipette method.
* Generally, most of soil contains both coarse as well as fine grained soils. Hence a combined analysis is usually carried out
* In combined analysis dry soil fraction retained on sieve size 4.75mm is called gravel fraction which is subjected to coarse sieve analysis and soil fraction passing through 4.75mm sieve is further subjected to fine sieve analysis.
* Fraction passing through 0.075 mm sieve is analysed by hydrometer or pipette method

Particle size analysis

- Sieve analysis (for coarse soils)
  - Coarse sieving (> 4.75 mm)
  - Fine sieving (< 4.75 mm)
    - Dry process (When fineness is small)
    - Wet process (When fineness is large)
- Sedimentation Analysis (< 0.075mm) (For fine soils)
  - Pipette method
  - Hydrometer method

Sieve Analysis

1. Coarse sieving

The fraction retained on 4.75 mm sieve is called the gravel fraction and is subjected to coarse sieve analysis

* sieves are represented either by their number or either by size. IS sieves have square size opening represented in mm

* sieve no. represents no. of square opening in 1 inch of length.

* The sieves used in coarse sieving are 80mm, 20mm, 10mm, 4.75mm

* The sample is shaken for 10 mins in the shaking machine and wt. of soil retained in each sieve is found. Let W_i = wt. retained in the ith sieve

W = total weight of soil sample taken

% weight retained on ith sieve $= \frac{W_i}{W} \times 100$

Cumulative % retained $= \frac{\text{Total wt. of soil retain upto ith sieve}}{\text{Total wt. of soil taken}} \times 100$

$= \sum_{i=1}^{i} \frac{W_i}{W} \times 100$

% finer than ith sieve (% N) = 100 − Cumulative % retained

2. Fine sieving (Sand sieving)

- Soil fraction passing through 4.75mm sieve is subjected to fine sieve analysis

- It can be performed either in dry state or wet state wet sieving is preferred when clay content is present in the sand. So sand is washed to remove the clay

- In fine sieving following sieves are arranged in decreasing order as 2mm, 1mm, 600μm, 425μm, 150μm, & 75μm

- The procedure of analysis is same as coarse analysis.

Sedimentation Analysis

* Sedimentation Analysis is used to determine grain size distribution of the soil fraction passing through 75 μm size
* It is used on the stoke's law

Stoke's law

If a spherical particle falls through infinitely large medium, then it will achieve a constant terminal velocity. Terminal velocity is given as

$$V = \frac{(\gamma_s - \gamma_l) D^2}{18\mu} = \frac{(\rho_s - \rho_l) D^2}{18\eta}$$

where

γ_s = Unit weight of spherical particle

γ_l = Unit weight of liquid

D = Dia. of falling spherical particle

μ = dynamic viscosity of liquid $\frac{N-s}{m^2}$

η = kinematic viscosity m^2/sec

Limitations of Stoke's law

1. The analysis is based on the assumption that the falling particle is spherical But in soils the finer particles are never truely spherical.
2. Stoke's law considers the velocity of free fall of a single sphere in a liquid of infinite extension where as the grain size analysis is usually carried out in a glass jar in which the extent of liquid is limited
3. The fine grains of soil carry charges on their surface and have a tendency for floc formation. If the tendency of floc formation is not prevented, the diameter measured will be the diameter of the floc and not of the individual.

Sedimentation Analysis:- (For silt & clay less than 75μ)

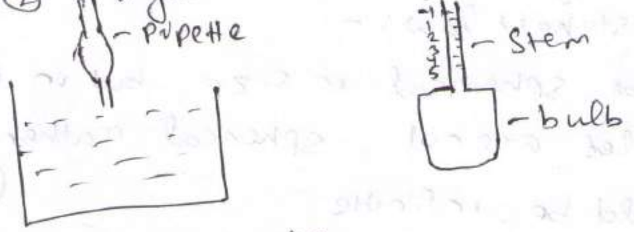
(i) Soil fractions having size less than 0.2μ cannot be analysed even by sedimentation.

(ii) Then special technique used
(a) electron microscope method
(b) X-ray method

(iii) Thus entire sedimentation analysis is based on

Stokes law $V_s = \frac{(G-1)\gamma_w d^2}{18\mu}$ V_s = velocity of particle

(iv) Sedimentation Analysis includes two methods
① Pipette method
② Hydrometer meter



Hydrometer method:

(i) It is a device used to measure density of suspension in gm/ml

(ii) volume of hydrometer below the centre of its bulb is 50% of its total volume

(iii) unlike normal scale, readings on hydrometer stem increases downward

(iv) Actual density reading can be found by following formula $R = (\rho - 1) \times 1000$ → in gm/ml

Suppose hydrometer stem reading is 10

So $R = 10 = (\rho - 1) \times 1000$

$\Rightarrow \rho = 1 + \frac{1}{100} = 1.01$

Corrections in hydrometer

① Meniscus correction - correction +ve

② Temperature correction - Generally this test carried out at 27°C when $T > 27°C \Rightarrow$ level increases

Then $R \downarrow \Rightarrow \rho \downarrow$

[correction +ve]

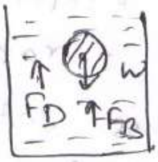
when $T < 27°C \Rightarrow$ level $\downarrow \Rightarrow R \uparrow \Rightarrow \rho \uparrow$

[correction -ve]

③ Dispersing agent correction:- Due to dispersing agent

$\rho \uparrow \Rightarrow R \uparrow$ Correction (-ve)

Sedimentation analysis is completely based on Stoke's law
- According to stoke's law if a spherical particle falls through an infinite water/fluid medium it achieves a constant terminal velocity



W = Self weight

W = Mg

FB → Buoyancy force

FD → Drag force

Terminal Velocity $V_s = 0.9d^2$

Limitations of stoke's law:-

→ Particle should be spherical in size but in actual fine grain particles are not spherical rather flaky

→ Medium should be infinite

→ Stoke's law is valid for the particles undergoing discrete settlement, but in actual fine grain soils aggregate during settlement

→ It means the stoke's law is valid for the discrete settlement, But in actual the settlement is flocculent

→ stoke's law is valid only when the flow around the settling particle is laminar But in actual the flow is not laminar.

- The particle size should be within 0.2μ to 200μ

Note: Stoke's law is applicable for spheres of dia between 0.2mm and 0.0002mm

Because: spheres of dia larger than 0.2mm falling through water cause turbulence where as for spheres with dia. less than 0.0002mm Brownian movement takesplace & the velocity of settlement is too small for accurate measurent In both cases stoke's law is not applicable.

Hydrometer Analysis :-

- It is an analysis of fine grained soils.
- Hydrometer is an instrument which is used to measure the relative density of liquid.
- Hydrometer consists of two parts
  (a) cylindrical stem
  (b) Bulb of 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 size varying from 75μ to 2μ 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 hexameta phosphate soln prepared by dissolving 33 g of Sodium hexameta-phosphate and 7 g of Sodium Carbonate in distilled water to make 1 litre solution.
- Stop watch
- Thermometer
- Scale

Procedure :- Take 50 g of soil if soil is clayey soil
- If 100g soil is taken if it is sandy soil weight accurately to 0.1g
- If soil contains considerable amount of organic matter or Calcium compounds it is pretreated

with hydrogen peroxide or hydrochloric acid
. If the soil contains less than 20% of the above mention compounds then pretreatment is not necessary.
- Soil is treated with 100 cc. of sodium hexametaphosphate solution and warm get it gently for 10 mins & transfer the contents to the cup of mechanical mixer using a jet of distilled water to wash all the traces of soil
- Stirr the soil suspension for about 15 mins
- Transfer the suspension to 1 litre jar and add distilled water till 1000 cc [1 lit]
- Take another hydrometer jar with 1000cc 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°C of water occasionally.
- mix the soil suspension in jar properly
- Immediately 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 mins 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 of 4, 9, 16, 25, 36, 49, 60 mins and at every one hr 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.

Pretreatment of soil:- Soil may contain organic matter & Gypsum which may affect the true settling velocity of silt & clay. Therefore before preparing the suspension soil a pretreatment is given by the providing oxidising agent which carries oxidisation of organic matter.

Post treatment of soil:-

→ This treatment is given after the preparation of soil suspension.

→ Soil may form flocculent structure inside the suspension and increases the actual particle size. Therefore to break the flocculent structure and make it disperse a dispersing agent is added.

Note: The finer grains of the soil carry charge on their surface & have a tendency for floc formation. A floc is an accumulation of small particles. The flocs then settle. Thus if the tendency to floc formation is not prevented the diameter measured will be diameter of the floc and not of the individual grain. Therefore in the test the soil is treated with deflocculating agent such as sodium hexametaphosphate or sodium oxalate to prevent the formation of flocs.

✱ For determining the grain size distribution of the soil fraction finer than 75μ 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 & have same average sp. gravity

- If a single sphere is allowed to fall freely through a liquid of a infinite extent, its velocity will 1st increase rapidly due to gravity but later a constant velocity is achieved and this velocity is called terminal velocity.

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

Particle size distribution curve / Grain size distribution Curve (GSD)

- It indicate the type of soil, the history & stage of its deposition & the gradation of the soil.

If soil happens to be predominantly coarse grained or fine grained this will be very clearly reflected on the curve.

OR The position or shape or slope of a curve indicate type & gradation of the soil. Smaller grain sizes go towards the right.

Uses 1. It is used in the design of pavement

2. It is used for coarse grained soil

3. It gives an idea about shear strength of the soil

4. It gives an idea about the type & gradation of the soil.

Particle size distribution curve :-

(i) It is the graphical representation of particle size analysis data

(ii) In the x-axis we take particle size in mm & in Y-axis we take percentage finer.

→ The curve represents the type & gradation of soil

→ Gradation of soil is normally divided into 3 types

(i) well graded soil

(ii) Uniformly graded/poorly graded soil

(iii) Gap graded

Well graded soil :- has good representation of grain sizes over a wide range & its gradation curve is smooth.

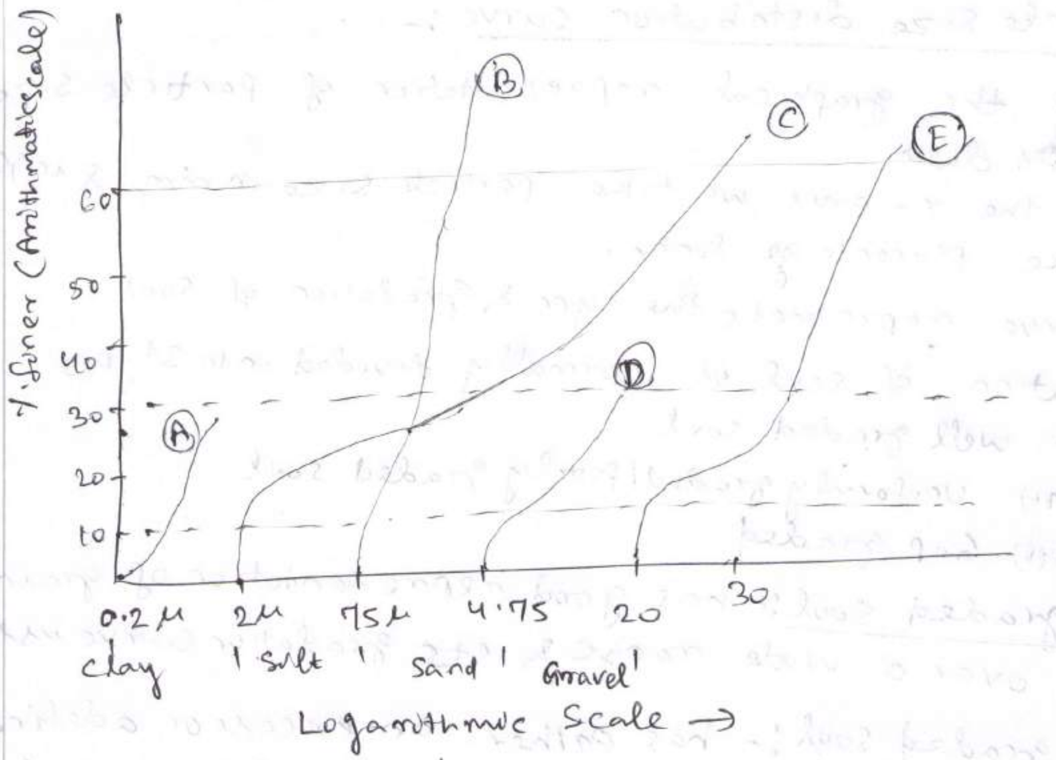
Poorly graded soil :- has either an excess or a deficiency of certain particle size or has most of the particles about the same size.

Gap graded :- It is the one in which some of the particle sizes are missing.

Allen Hazen (1892) tried to establish the particular dia. in actual spheres that would cause the same effect as a given soil & opined that the diameter for which 10% was finer would give this equivalence of a soil particle. It may be recalled that effective dia. is the dia. of a hypothetical sphere that is assumed to act in the same way as the particle of an irregular shape & that data obtained from sedimentation analysis. Using Stoke's law lead to effective diameter De of the soil particle.

Allen Hazen's $D_{10} = D_e$

The effective dia. is also termed as the effective size of the soil. It is the size related to permeability & capillarity.



FG (A) → Poorly graded soil

CG (B) – Poorly graded soil

CG (C) → well graded soil

CG (D) → Uniformly graded soil

CG (E) → Gap graded soil

D_{10} corresponds to 10% of the sample finer in weights on GSD curve. D_{10} is called effective size

D_{30} = grain diameter(mm) corresponding to 30% finer than

D_{60} = grain diameter (mm) corresponding to 60% finer than D_{60} size

Coefficient of uniformity (C_u) – It is a shape parameter

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

For sand $C_u > 6$
For gravel. $C_u > 4$

$C_u < 5$ soil is very uniform

C_u 5 to 15 medium uniformity

$C_u > 15$ very non uniform or well graded

Jumiki 1962
For sand C_u = 10 to 20
For silt C_u = 2 to 4
For clay C_u = 10 to 100

$$\text{Coefficient of curvature } (C_c) = \frac{D_{30}^2}{D_{10} \times D_{60}}$$

For well graded soil C_c lies between 1 & 3

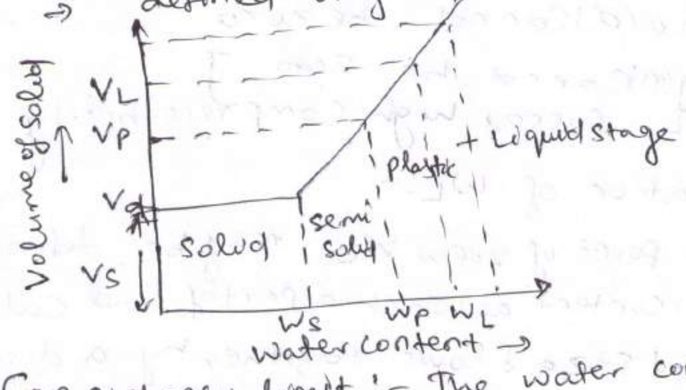
Consistency of Soil :-

(i) Consistency means the relative ease with which soil can be deformed as it denotes the degree of firmness of soil, which maybe termed as soft, stiff / hard.

[Note: Boulder > 300 mm
Cobble 80 to 300 mm
Gravel 80 to 4.75 mm
Sand 4.75 to 75 μ
Silt 75 to 2 μ
Clay < 2 μ
$1\mu = 10^{-6} m = 10^{-3} mm$]

(ii) Gravel, Sand - Coarse grained soil (Nonplastic)
silt, clay - fine grained soil (plastic)

(iii) Consistency limit is defined only for fine grained soil like silt & clay
→ defined only for plastic soil



W_L = Liquid limit
W_P = plastic limit
W_S = Shrinkage limit
V_L = volume corresponding to W_L
V_P = volume corresponding to w_p

Consistancy limit :- The water content between two state at which consistency of soil changes is called consistancy limit.

Note:- upto shrinkage limit, slope of consistency curve is constant and after shrinkage limit slope is zero

→ The greater the water content of soil smaller will be the shear strain and more will be the tendency of flow.

Consistency characteristic of soil depends on
ⓐ clay mineral
ⓑ Amount of clay mineralogy
ⓒ Absorbed water

OR The water content at which soil passes from one stage of consistency to another stage of consistency is termed as consistency limit.

LIQUID LIMIL :- (W_L)

(i) It is minimum water content at which the soil passes from liquid stage to plastic stage

or It is maximum water content at which soil passes from plastic stage to liquid stage.

or It is minimum water content at which soil have tendency to flow

Type of soil	W_L	
Gravel	Nonplastic	Coarse grained soil
Sand	Nonplastic	
Silt	30 to 40%	
Clay (Aluvval soil) & physically weathered soil	40% to 150%	
Clay (Black soil)	400% to 500%	
Clay (Bentonite soil)	400% to 800%	

Chemically weathered soil used in drilling (lubricant)

[Note :- Void ratio (e) Cannot be zero
Porosity (n) Cannot be zero]

Soil having high W_L posses high compressibility

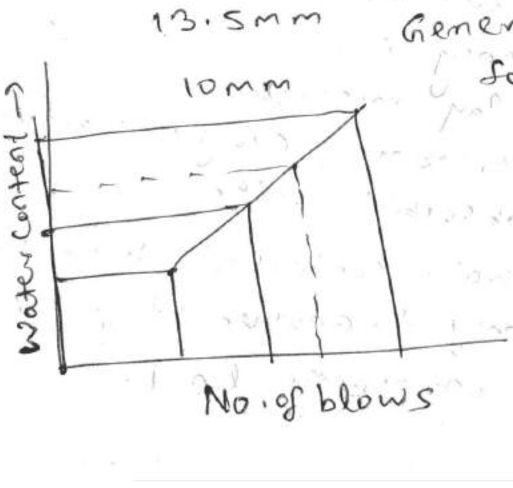
Practical determination of W_L :-

(a) From determination point of view W_L may be defined by as minimum water content at which a part of soil cut by a groove of a standard size flows together by a distance of half inch (11 to 13 mm) under the impact of 25 no. of blows where the height of impact is 1 cm.

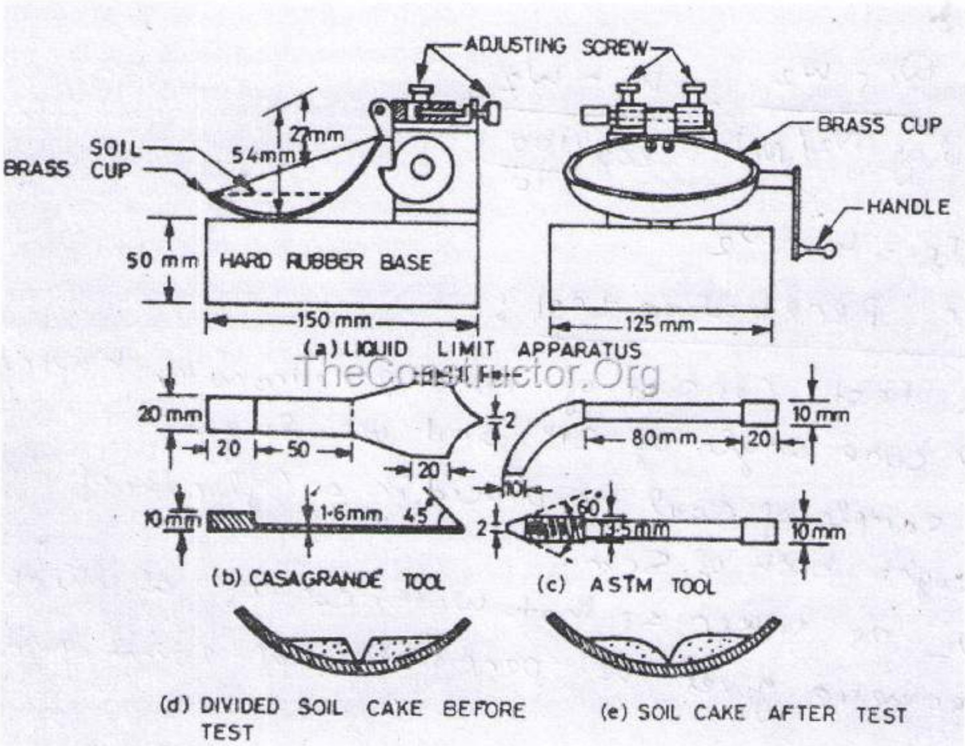
Tools for making groove :-

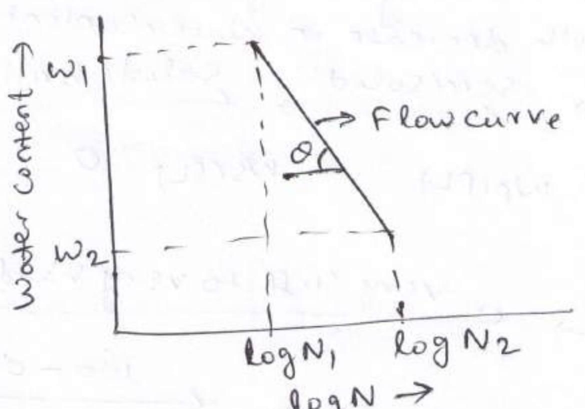
	Casagrande	ASTM (American Society of testing Machine)
Base width	2 mm	2 mm
Top width	11 mm	13.5 mm
Height	8 mm	10 mm

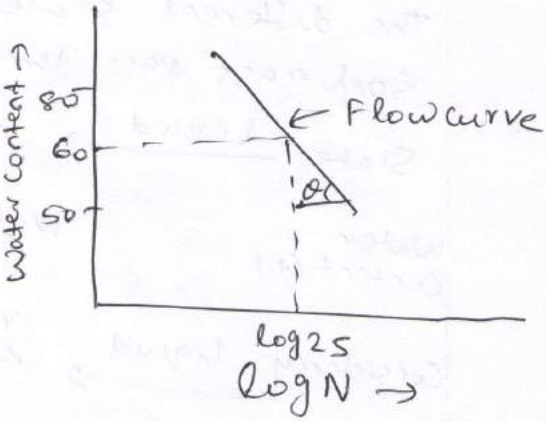
Generally used for silt.



This representation is known as flow curve







$$\text{Slope} = \tan\theta = \frac{w_1 - w_2}{\log N_2 - \log N_1} = \frac{w_1 - w_2}{\log N_2/N_1}$$

$$\text{Flow Index} = I_f = \frac{w_1 - w_2}{\log (N_2/N_1)}$$

Slope of flow curve is termed as flow Index (I_f) which representaly the rate of loss of shear strength of soil.

Let us consider two soil sample A & B

$$\text{If } \theta_A > \theta_B \Rightarrow \tan\theta_A > \tan\theta_B$$

$$\Rightarrow I_{fA} > I_{fB}$$

$I_f \propto$ loss in strength

$\Rightarrow$ loss in strength$_A$ > loss in strength$_B$

practically in order to find I_f water content corresponding to 10 & 100 no. of blows is extrapolated from flow curve.

$$I_f = \frac{W_1 - W_2}{\log(N_2/N_1)} = \frac{W_1 - W_2}{\log\left(\frac{100}{10}\right)}$$

$$\Rightarrow I_f = W_1 - W_2$$

(2) <u>Static penetration test :-</u>

(i) This test consist of cone penetrometer having central cone angle of 31° and wt. 80 gm

(ii) The sample of soil is placed in a cylinder of diameter and height both of 5cm.

(iii) W_L is taken as that water content at which cone penetrometre gives the penetration of 20mm of soil sample.

The different states of consistency through which a soil mass pass through with decrease in water content.

State	Liquid →	← Plastic →	← semisolid →	← Solid (brittle) →
Water content (%)		W_L(LL)	W_P(PL)	W_S(SL) 0
Consistency	Liquid →	← very soft to stiff →	← very stiff to very hard →	
Saturation	————————— $S = 100\%$ ————————— →			← 100 − 0% →
Volume	————————— volume decrease ————————— →			← constant volume →

Determination of Liquid Limit

Apparatus :- (1) Brass cup of liquid limit apparatus

(2) Grooving tool

(3) 425 μ IS sieve

(4) Spatula

Procedure :- Take about 100g soil sample passing 425 μ 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, 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

- The cup is given blows by manual or electrically operated motors

- The rotation of handle should be of 2 revolutions per sec.

- The number of blows required to close the groove for a distance of 12mm is noted down.

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

- 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 absicca on logarithmic scale to obtain a straight line which is known as flow curve.

Consistency of clay:—

Consistency of soil means the relative with which the 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 grained 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 into any form by pressure.
- The continuous addition of water reduces cohesion and the soil no longer retains its shape under its 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, Atterberg divided the various states of consistency.

(i) Liquid state
(ii) plastic state
(iii) Semi solid state
(iv) ~~plastic~~ Solid state

He said arbitrary limits at which the soil changes its state every time water is added.

- This limits are called Atterberg limits or Consistency 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

Determination of plastic limit :-

- Take about 30g of soil sample passing 425μ sieve.
- Some quantity of distilled water is added to it and thoroughly mixed the form soil paste which can be rolled into 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 for sign of cracking
- If no cracks 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

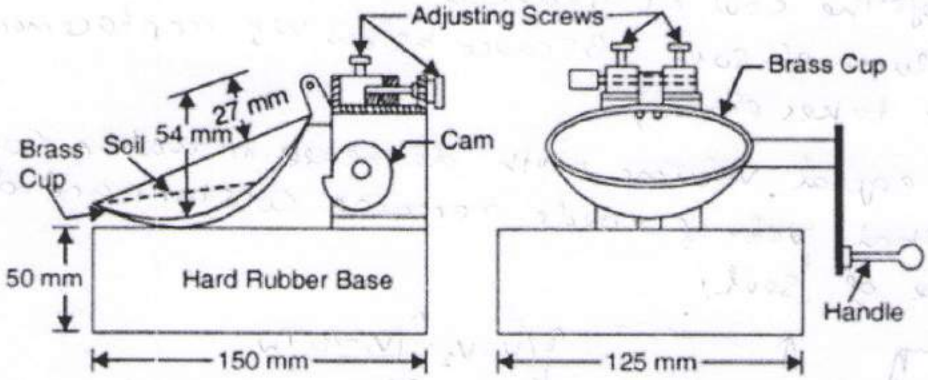
Procedure for shrinkage limit distribution

- Take 50g of soil sample passing 425μ 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 and 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 clean

Wet soil in shrinkage cup (wet soil pat) = (shrinkage cup + wet soil) − (wt. of empty shrinkage cup)
↓
M_1

- wet soil mass in shrinkage cup is kept in oven for 24 hrs 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 mercury with a flat glass plate and knowing the amount of mercury spilled pat and reducing this volume from the total volume of mercury in shrinkage dish using knowing density of liquid mercury.

Figure :-



(i) Liquid Limit Apparatus

PLASTIC LIMIT (W_p) :-

It is the minimum water content at which soil is in plastic stage of consistency

or At W_p soil posses from plastic stage of consistency to semisolid stage of consistency and viceversa

or For determination point of view W_p is defined as minimum water content at which given sample of soil can be rolled into a thread of 3mm diameter

Type of soil	W_p
Gravel	Nonplastic
Sand	Non plastic
silt	10 to 15%.
clay (Aluvialsoil)	15 to 100%.
Clay (Black soil)	200 - 250%.

Note :- When a nonplastic soil like sand is mixed with plastic soil like clay its W_L and W_p both decreases but decrease in W_L is more

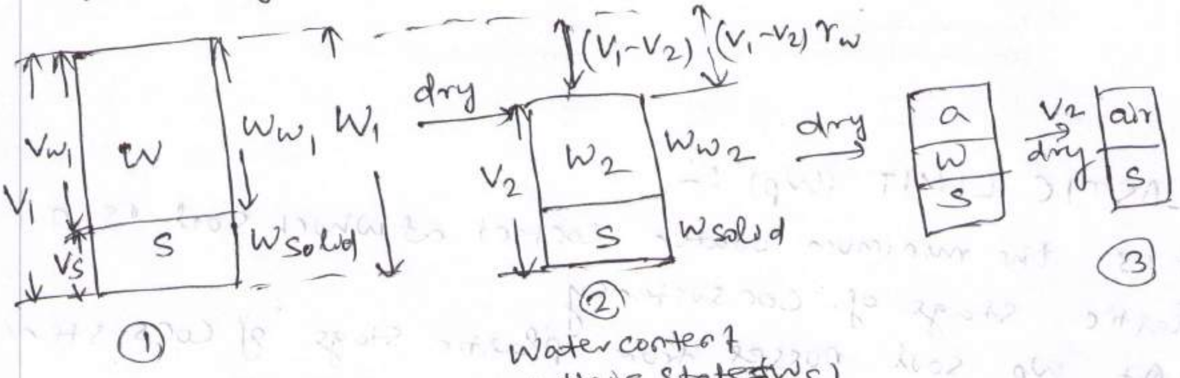
$$I_p = W_L - W_p$$

For the determination of plastic limit the glass plate is used to roll a soil ball into a 3mm diameter thread without formation of any crack.

SHRINKAGE LIMIT (W_S) :-

(i) It is defined as max. water content beyond which if water of the soil is reduced then there is no decrease in volume of soil (Because below W_S replacement of water by air takes place)

(ii) In equal volume with decrease in water content such that vol. of voids remains constant and does the volume of soil.



$$W_s = \frac{\text{wt. of water in (2)}}{\text{wt of solid in ②}}$$

wt. of water in (1) $= W_{w_1}$

loss of water $= (V_1 - V_2)\gamma_w$

$$W_s = \frac{W_{w_1} - (V_1 - V_2)\gamma_w}{W_{solid}} = \frac{W_{w_1}}{W_{solid}} - \frac{(V_1 - V_2)\gamma_w}{W_{solid}}$$

$$W_s = W_1 - \frac{(V_1 - V_d)\gamma_w}{W_{solid}}$$

or $$W_s = \frac{(V_2 - V_s)\gamma_w}{W_{solid}} = \frac{(V_d - V_s)\gamma_w}{W_{solid}} = \frac{V_d\gamma_w - V_s\gamma_w}{W_{solid}}$$

$$= \frac{V_d\gamma_w}{W_{solid}} - \frac{V_s\gamma_w}{W_{solid}} = \frac{\gamma_w}{W_{solid}/V_d} - \frac{\gamma_w}{W_{solid}/V_s}$$

$$= \frac{\gamma_w}{\gamma_{dry}} - \frac{\gamma_w}{\gamma_{solid}} \quad \left(G_s = G = \frac{\gamma_{solid}}{\gamma_w}\right)$$

$$\boxed{W_s = \frac{\gamma_w}{\gamma_{dry}} - \frac{1}{G}} \Rightarrow \boxed{W_s = \frac{1}{G_d} - \frac{1}{G}}$$

$$G_m = \frac{\gamma_{bulk}}{\gamma_w} \qquad \gamma = \frac{(G + Se)\gamma_w}{1+e}$$

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

So $W_S = \dfrac{\gamma_w(1+e)}{G\gamma_w} - \dfrac{1}{G}$

$\Rightarrow W_S = \dfrac{1+e}{G} - \dfrac{1}{G} = \dfrac{1+e-1}{G}$

$\Rightarrow \boxed{W_S = \dfrac{e}{G}}$ e = vol of void or after W_S

SHRINKAGE RATIO:-

It is defined as the ratio of decrease in volume of soil expressed as a % of its dry volume to the corresponding % change in water content above shrinkage limit.

$$R = \frac{\left(\frac{V_1-V_2}{V_d}\right)\times 100}{W_1-W_2} = \frac{(V_1-V_2)\times 100 \times W_{solid}}{V_d(V_1-V_2)\gamma_w \times 100} = \frac{W_{solid}}{\gamma_w V_d}$$

Since $W_1 - W_2 = \dfrac{(V_1-V_2)\gamma_w \times 100}{W_{solid}}$

So $\boxed{R = \dfrac{\gamma_{dry}}{\gamma_w}}$

Relation $W_S = \dfrac{\gamma_w}{\gamma_{dry}} - \dfrac{1}{G} \Rightarrow \boxed{W_S = \dfrac{1}{R} - \dfrac{1}{G}}$

Here W_S is in numerical value but not in %.

So $G = \dfrac{1}{\frac{1}{R} - W_S}$

At particular case $W_2 = W_S$

$\Rightarrow V_2 = V_S = V_d$

So $R = \dfrac{\left(\frac{V_1 - V_d}{V_d}\right)\times 100}{W_1 - W_S}$

VOLUMETRIC SHRINKAGE:-

It is defined as the decrease in volume of soil expressed as the % of its dry volume when water content of soil is reduced from its given stage upto shrinkage limit.

$V_S = R(W_1 - W_2)$

Plasticity Index :- (I_p)

It is the range of consistency in which soil exhibits plastic properties or behave like plastic material.

$$I_p = W_L - W_p$$

Types of soil	Ip (%)	Ip (%)	Plasticity
Gravel } Sand }	Non plastic	0	Non plastic
		< 7	Low plastic
Silt	— 10 – 15 %.	7–17	Medium plastic.
Clay (Aluvial soil)	15 – 100 %.	> 17	Highly plastic
Clay (Black soil)	200 – 250 %		

Note: organic soil possess high W_L generally greater than 50%. but their W_p is also comparatively high Hence its I_p is less.
Hence organic soil is highly compressible, less plastic

Plasticity :

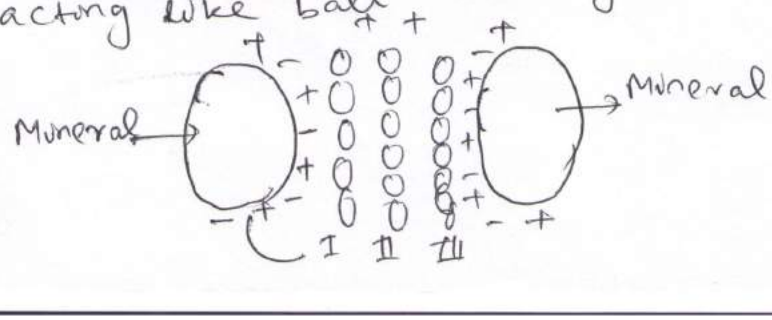
(i) It is defined as the property of soil by virtue of which it undergoes deformation without cracking and fracturing.

(ii) Plasticity of soil is due to the presence of minerals (which are electrically charged) and water in the soil.

(iii) Water is bipolar in nature align itself surrounding these electrically charged minerals that is results increase in viscosity.

(iv) As the distance of water molecule increases from solid minerals this electric force reduces which in turn decreases viscosity

Because of this water molecules slides over eachother acting like ball bearing



(Bonding between mineral & I, III of water molecule > II layer of water)

(V) due to same above effect even clay doesnot show plasticity when a nonpolarising agent like kerosene parafine was added to it.

Consistency Index (I_C):

$$I_C = \frac{W_L - W_n}{W_L - W_p} = \frac{W_L - W_n}{I_p}$$

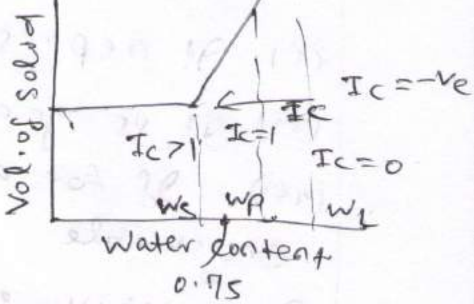
$I_C \propto \frac{1}{\text{consistency}} \propto$ degree of firmness

Case I $W_n > W_L$ then $I_C < 0$ i.e. -ve

Consistency ↑ DOF ↓ Not suitable for engg. works

Case II $W_p < W_n < W_L$ then I_C value lies in between 0 to 1. plastic stage

I_C = 0 to 0.25 (very soft soil)
= 0.25 - 0.5 (soft soil)
= 0.5 - 0.75 (medium stiff)
= 0.75 - 1 (stiff)
(Range)



Case III $W_n < W_p$ (Semisolid / solid) State then $I_C > 1$ (+ve) soil is very hard
Consistency ↓ DOF ↑
suitable for engg. work

Liquidity Index (I_L):

$$I_L = \frac{W_n - W_p}{I_p}$$

Case I $W_n > W_L$ then $I_L > 1$ soil is in liquid limit
Consistency ↑ DOF ↓
Not suitable for engg. work

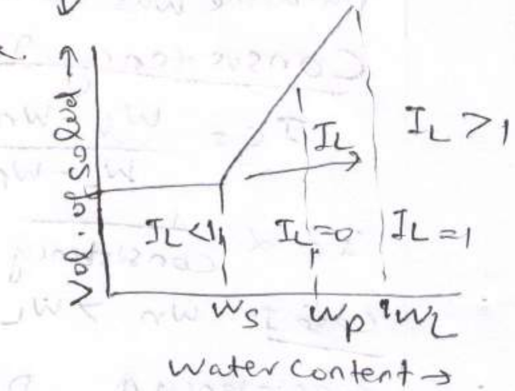
Case II $W_p < W_n < W_L$ soil is in plastic stage then I_L lies in between 0 & 1

If I_L = 0 - 0.25 (stiff)
= 0.25 - 0.5 (medium stiff)
= 0.5 - 0.75 (soft)
= 0.75 - 1 (very soft)

Case III $w_n < w_p$ (Semisolid / Solid)

Soil in hard or very hard then $I_L < 0 \Rightarrow$ DOF ↑
consistency ↓

Suitable for engineering work.



Toughness Index (I_T):

$$I_T = \frac{I_p}{I_f} = \frac{\text{Plasticity Index}}{\text{flow Index}}$$

$$= \frac{w_L - w_p}{\text{Slope of no. of blows \& water content}}$$

(i) It represents the strength of soil at plastic limit

(ii) It is generally varies between 0 to 3

(iii) If for any soil $I_T < 1$, then the soil easily crushable at its plastic limit.

Sensitivity:

(i) The consistency of undisturbed sample of clay is ~~affected~~ altered upon remoulding even at the same water content.

(ii) This change in consistency or decrease in degree of firmness (DF) or loss in strength of the sample takes place due to following two reasons

@ Due to permanent soil solid distraction.

ⓑ Due to reorientation of water molecules in soil

(iii) This loss in strength of soil is represented in terms of sensitivity which denotes the degree of disturbance of undisturbed sample of clay upon remoulding at same water content

$$\text{Sensitivity} = \frac{\text{Unconfined compressive strength (UCS) of undisturbed soil}}{\text{UCS of remoulded sample or disturbed sample}}$$

Clay – Cohesion (C), $\phi = 0$

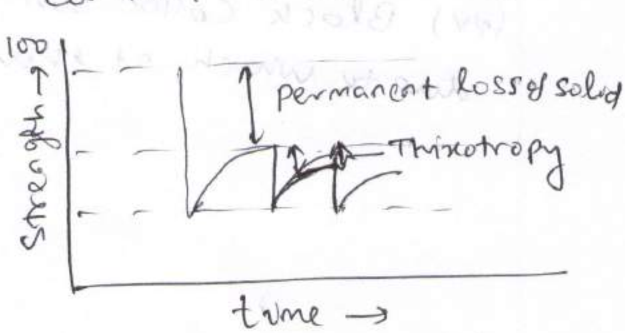
Sand – $C = 0$, ϕ

Sensitivity	Description
1	Inactive soil
2-4	Normal or low sensitive soil
4-8	Sensitive soil
8-16	extra sensitive soil
>16	unstable soil

Thixotropy :-

(i) over a period time soil regains a part of its lost strength on the account of rehabilitation of water molecules, But strength loss on the account of permanent distraction of soil solids never gain.

(ii) This property of soil by the virtue of which it regain a part of its lost strength at constant volume of void and constant water content is known as thixotropy.



Note : Soils having higher sensitivity shows higher thixotropy

soil having flocculated and dispersed etc. undergoes higher loss of strength upon regained than the soil having Coarse grained Structure.

Activity :-

(i) The behaviour or plasticity of soil depends upon type of minerals, amount of minerals and water content.

(ii) "Skempton" defined a parameter A_t (Activity) to represent the compressibility and volume change

$$\boxed{A_t = \frac{I_p}{C}}$$ $C =$ % of soil finer than 2 μ

$A_t \propto$ volume change $\propto$ Compressibility

If $A_t \uparrow \Rightarrow$ Not suitable for engineering work

Activity (At)	Description
< 0·25	Inactive soil
0·75 – 1·25	Normal soil
> 1·25	Active soil

Type of claymineral	Activity (At)
Kaolinite	0·4 – 0·5
Illite	0·5 – 1
Mont morillonite	1 – 7
Na - Mont morillonite	4 – 7
Ca - MM	1 – 5

(iii) Highly active soil is not suitable for construction work.

(iv) Black Cotton soil consist of excess of mont-morillonite due to which it shows large volume change.