CIVIL ENGINEERING

GEOTECHNICAL ENGINEERING

8.3 Index properties of Soils

The numerical results obtained on the basis of classification tests are termed as Index properties of soils.

eg. Grain size distribution, Relative density, Atterberg limits

The Index properties of soils can be used in

- Identification and Classification of soils and
- Rough estimation of Engineering behaviour

The Index properties of soils:

Specific Gravity (G):

It is the ratio of the weight of soil solids to the weight of an equivalent volume of water.

$$G = \frac{\gamma_s}{\gamma_w} = \frac{\text{Unit weight of solids}}{\text{Unit weight of water}}$$

- Useful in the determination of void ratio, degree of saturation, unit weight of soil, particle size by wet analysis, critical hydraulic gradient, zero air voids, etc.,

i. Density Bottle Method:

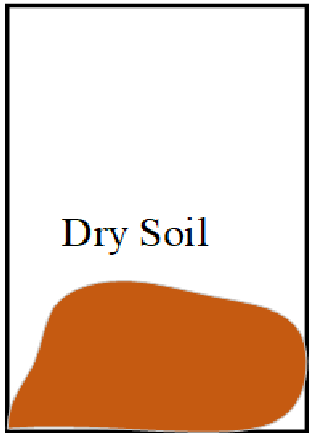
Suitable for fine grained soils having more than 90% passing through 2 mm IS sieve

ii. Measuring Flask Method:

Suitable for fine grained and medium grained soils.

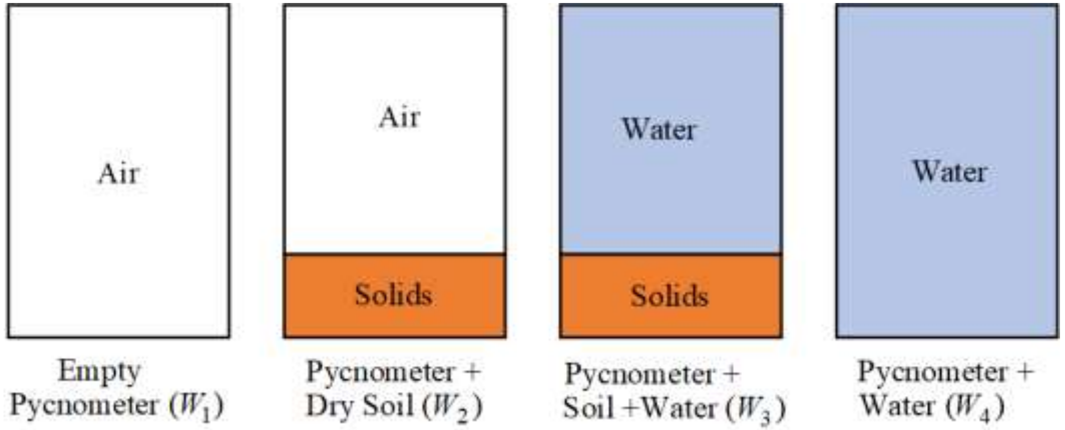
iii. Pycnometer Method:

- Used only for coarse grained soils.
- Oven dried sample is used.



Pycnometer + Dry Soil

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



W_1 = Weight of empty pycnometer
W_2 = Weight of pycnometer + dry soil
W_3 =Weight of pycnometer + soil + water
W_4 =Weight of pycnometer + water

If kerosene is used instead of distilled water, then

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

G_k = Specific gravity of kerosene at test temperature

Kerosene is preferred to water if the soil sample is of clay because of the better wetting capacity.

- Specific gravity of solids is generally reported at $27^0 C$.
- The specific gravity of soil is directly proportional to the specific gravity of water at the test temperature.
- Specific gravity of water is taken as unity at 4^0 C.

Particle Size Distribution:

- Sieve analysis – suitable for Coarse grained soils (4.75mm-80mm)
- Dry sieve analysis - suitable for cohesionless soils.(.075mm-4.75 mm)
- Wet sieve analysis - suitable for soil contains fines.(.075mm -4.75)

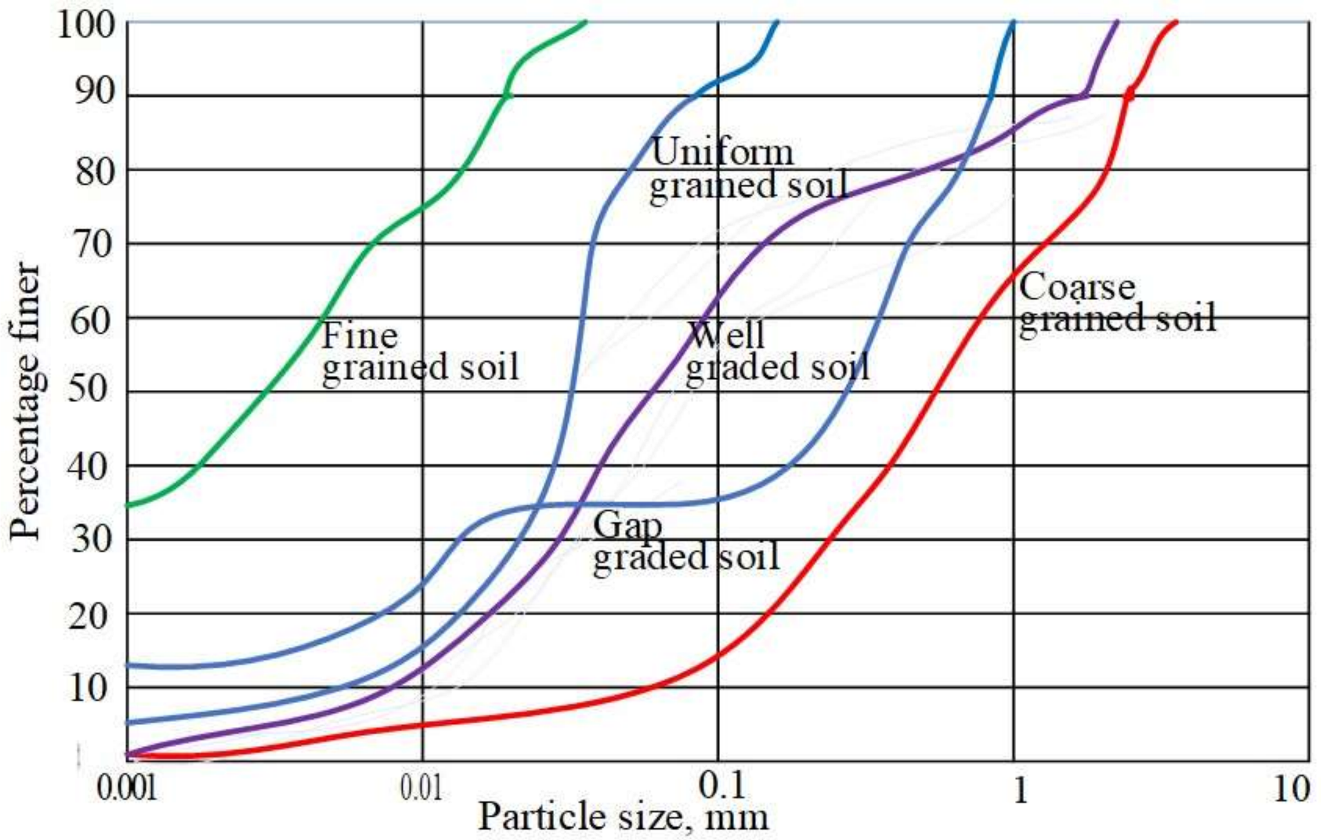
- Sedimentation analysis -suitable for fine grained soils finer than 75μ mm size. Sedimentation analysis is based on Stoke's Law.
- Stoke's Law is valid only if the size of particle is between 0.2 mm and 0.2μ (0.2 to 0.0002 mm).

Gravel	80 mm to 4.75 mm
Sand	4.75 mm to 0.075mm
Silt	0.075 mm to 0.002 mm
Clay	less than 0.002 mm

Particle size Distribution Curve:

T > 27 ^{0}C, C_t is +ve

T< 27 ^{0}C is –ve



- It gives an idea about type of soil and gradation of soil.
- The distribution of particles of different sizes on a soil mass is called Grading.
- The grading of soils - determined from the particle size distribution curve.
- Fine grained soil - Curve situated higher or to the left
- Coarse grained soil - Curve situated to the right
- Gap graded or Skip graded soils - Curve with a hump represents the soil in which zone of some intermediate size of particles missing.
- Well graded soil - Flat S- Curve represents a soil which contains the particle of different sizes in good proportion
- Uniform soil - Steep curve indicates a soil containing the particles of almost same size.

Coefficient of Uniformity(C_u):

- It is a measure of particle size range.

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

Sieve Size in mm	Wt. Retained	Cumulative Wt. Retained	Cumulative % Wt. retained	% Passing
4.75	160	160	40	60
2.36	140	300	75	25
1.18	60	360	90	10
600	40	400	100	0
150	0	400	100	0

Coefficient of Uniformity(C_u):

D_{60}: Particle size in mm such that 60% of the soil is finer than this size.

D_{10} : Particle size in mm such that 10% of the soil is finer than this size.

D_{10} : is sometimes called effective size or effective diameter.

C_u : is always greater than 1.

$C_u = 1$ Uniform soil

$C_u < 2$ Uniform soil

$C_u > 4$ Well graded gravel

$C_u > 6$ Well graded sands

Coefficient of Curvature (C_c) :

- It represents shape of the particle size curve

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

D_{30} : Particle size in mm such that 30% of the soil is finer than this size.

- For uniform soil $C_c = 1$
- For well graded sand $1 < C_c < 3$

2. Soil Aggregate properties

- Properties of fine grained soils.
- Dependent on the soil mass as a whole - represents the collective behaviour of a soil
- Soil aggregate properties are influenced by
  - Soil history
  - Mode of formation
  - Soil structure

The properties are

- Water content
- In-situ Density
- Density Index
- Constituency limits or Atterberg's Limits

I. Water content

A. Direct Methods:

a. Oven Drying Methods:

- Most accurate method
- Laboratory method
- Temperature to be maintained in the oven 105^0C-110^0C. Excess temperature may result the loss of chemically bonded water around clay particles.
- For highly organic soils a low temperature of about 60^0C is preferable-to prevent the oxidation of the organic matter.
- If Gypsum is present in soils, temperature should not be more than 80^0C but for long time-to prevent loss of water of crystallization of gypsum.

Water content, $w = \frac{\text{Weight of water}}{\text{Weight of dry soil}} \times 100$

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

W : Weight of container with lid + wet soil

W_d : Weight of container with lid + dry soil

b. Calcium Carbide Method or Rapid Moisture Tester Method:

- Quick method (about 10 minutes)
- Principle - based on the reaction occurs between a carbide reagent and soil moisture.
- Acetylene gas produced exerts pressure and is correlated to the moisture content.

$$w = \frac{w_r}{1 - w_r} \times 100$$

w_r: Moisture content expressed as a decimal fraction.

- Useful for field control compaction (eg: for embankments)

c. Sand Bath Method:

- It is a field method but not accurate.
- Due to high temperature - breakage of the crystalline structure of soil.
- Not suitable for organic soils containing higher percentage of Gypsum - on heating loses its water of crystallisation.

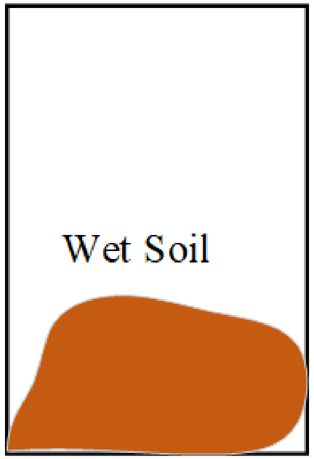
d. Alcohol Method:

- No control over the temperature
- Not suitable for soils containing large percentage of organic matter or Gypsum.

e. Pycnometer Method:

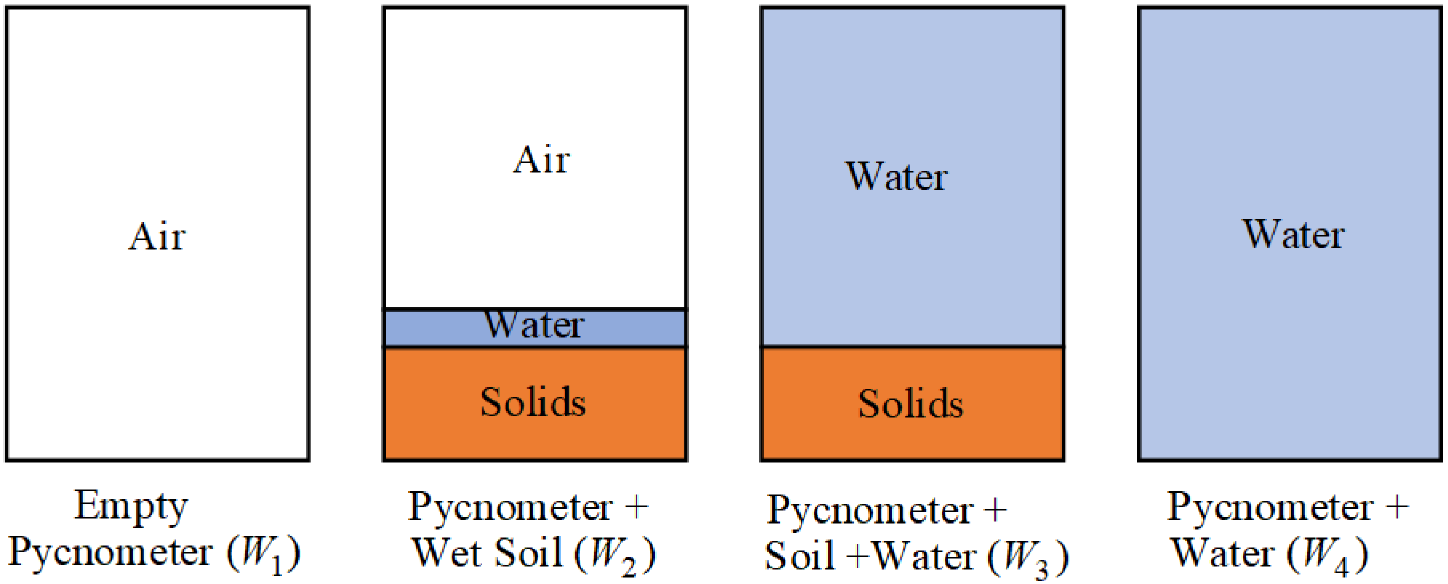
- Suitable for coarse grained soils only.
- Used when Specific Gravity of the soil solids is known.

Water content, $w = \left[\frac{W_2 - W_1}{W_3 - W_4} \times \left(\frac{G-1}{G} \right) - 1 \right]$



Pycnometer + Wet Soil

Pycnometer Method



$$\text{Water content, } w = \left[\frac{W_2 - W_1}{W_3 - W_4} \times \left(\frac{G-1}{G}\right) - 1\right]$$

f. Radiation Method:

- Extremely useful for the determination of water content of a soil in the insitu-condition.

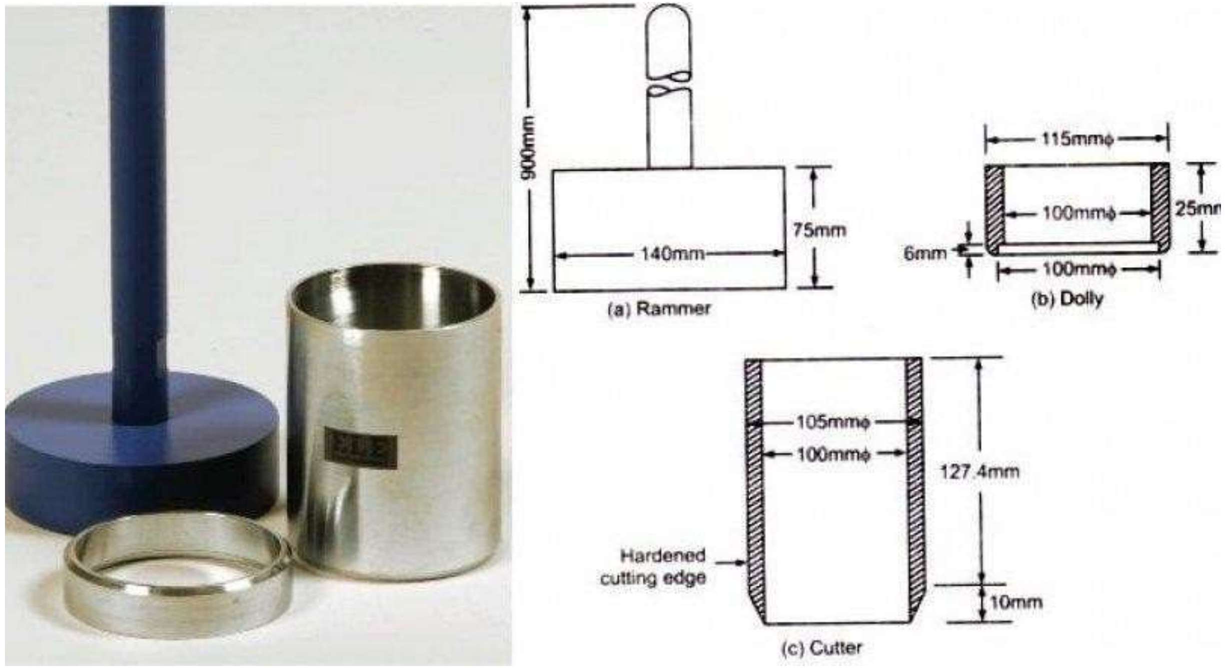
g. Torsion Balance Method:

- Since drying and weighing occurs simultaneously, the method is useful for soils which quickly reabsorb moisture after drying.
- To find water content at different depths below ground level

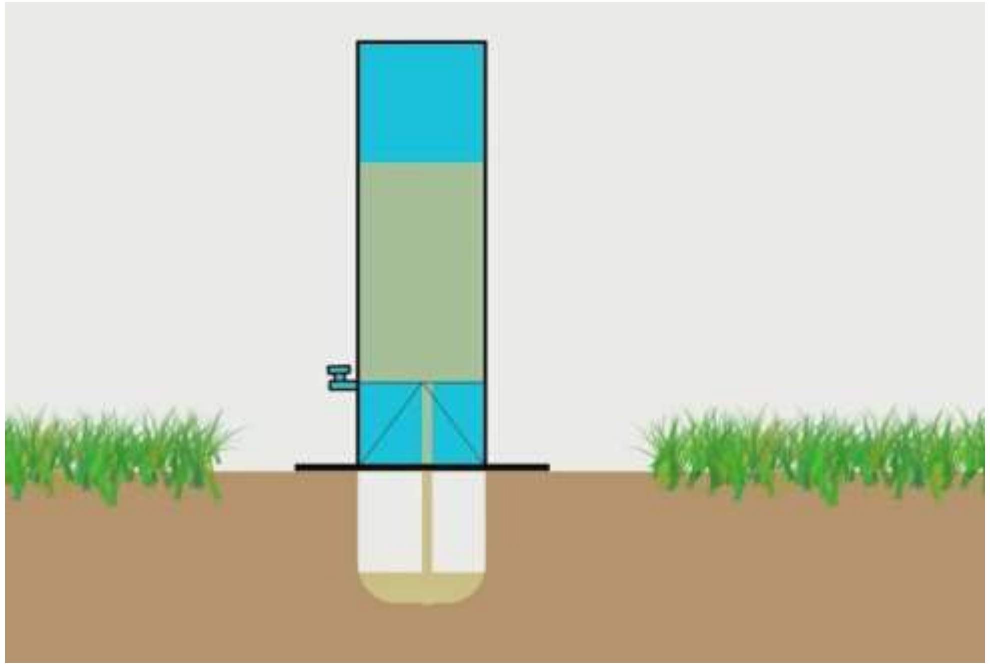
h. Core Cutter method:

h. Sand Replacement Method:

- Used for various particle sizes, from fine grained soils to coarse grained soils.



Core cutter method



Sand replacement method

Relative Density or Density Index (I_D) :

- Used in relation to coarse grained soils or sands.
- Indicate relative compactness of soil mass.

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

$$I_D = \frac{\dfrac{1}{\gamma_{d\,min}} - \dfrac{1}{\gamma_d}}{\dfrac{1}{\gamma_{d\,min}} - \dfrac{1}{\gamma_{d\,max}}}$$

$$I_D = \frac{\gamma_{d\,max}}{\gamma_d}\left[\frac{\gamma_d - \gamma_{d\,min}}{\gamma_{d\,max} - \gamma_{d\,min}}\right]$$

e_{max} : Maximum void ratio or Void ratio in loosest state.

e_{min} : Minimum void ratio or Void ratio in densest state

e : Natural void ratio.

Void ratio in any state is determined by

$$e = \frac{G \, . \gamma_w}{\gamma_d} - 1 \qquad\qquad e = \frac{V \, . G \, . \gamma_w}{W_s} - 1$$

- The concept of density index is applicable only to coarse grained soil because accuracy in the determination of volume is more in coarse grained soils than in clay soils.
- Density index (I_D) is a function of void ratio

Range of $I_D : 0 \le I_D \le 100$

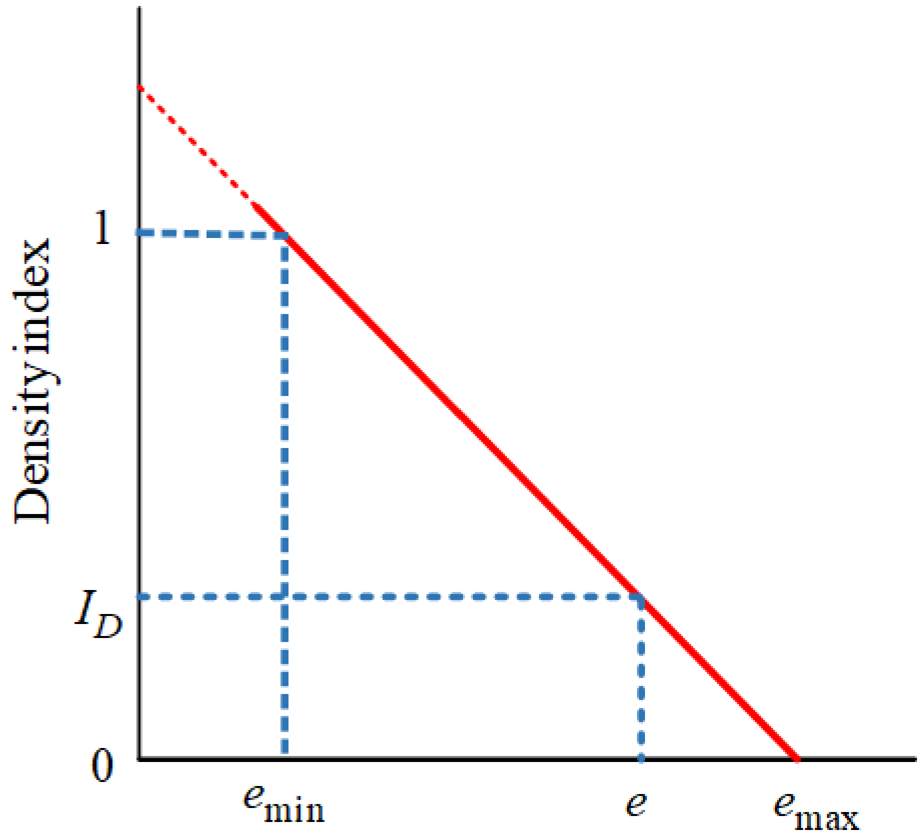
$I_D = 0$ Loosest state

$= 1$ Densest state

Sand is in the loosest state, $e_{max} = \frac{V_{v\max}}{V_{s\min}}$

Sand is in the densest state, $e_{min} = \frac{V_{v\min}}{V_{s\max}}$

I_D	Denseness of soil
< 15	Very loose
15-35	loose
35-65	medium dense
65-85	dense
>85	very dense



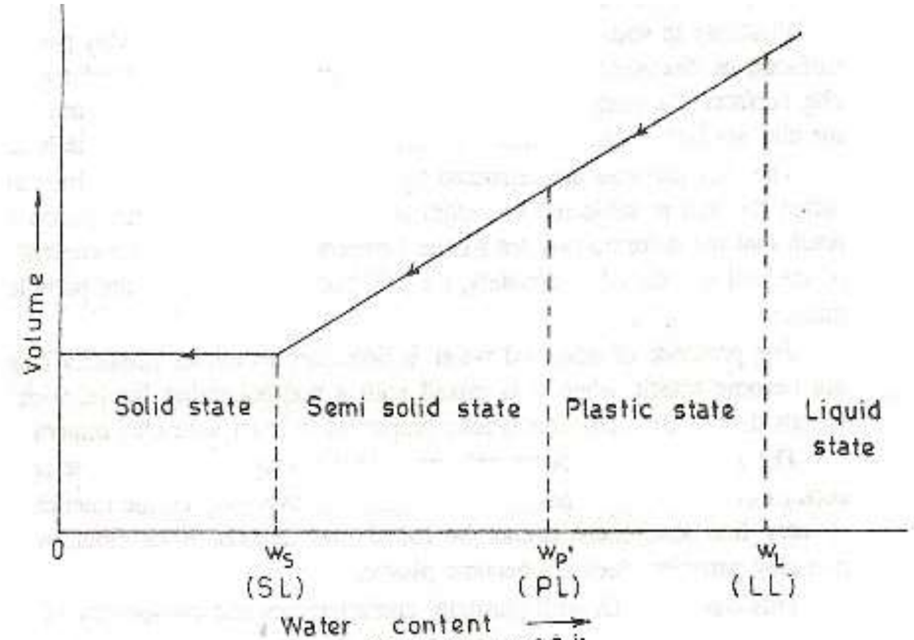
Consistency of clay soils:

- Used for fine grained soils
- Consistency of a soil - resistance offered by the soil against forces that tend to deform or rupture the soil aggregate.
- Consistency in cohesive soil in an indicator of shear strength.
- Stages of consistency - Liquid, Plastic and Semi-solid.
- Atterberg's Limits are the water contents at which soil mass passes from one state to the next state.
- Consistency or Atterberg limits – Liquid Limit (LL), Plastic Limit (PL), Shrinkage Limit (SL).
- Plasticity of a soil is the property which allows to be deformed without rupture, without elastic rebound and without noticeable change is volume.

Liquid Limit (LL or w_L):

- It is the water content at which the soil is just about to pass from the plastic state to the liquid state.

- At liquid limit, the soil possess a small value of shear strength, losing its ability to flow as a liquid.
- Minimum water content at which the soil tends to flow as a liquid.



Different states of Soil.

- Casagrande apparatus is used to determine liquid limit.
- If the base is softer than standard rubber, liquid limit of soil always increases.
- Soil passing through 425 micron IS Sieve is used for the test.

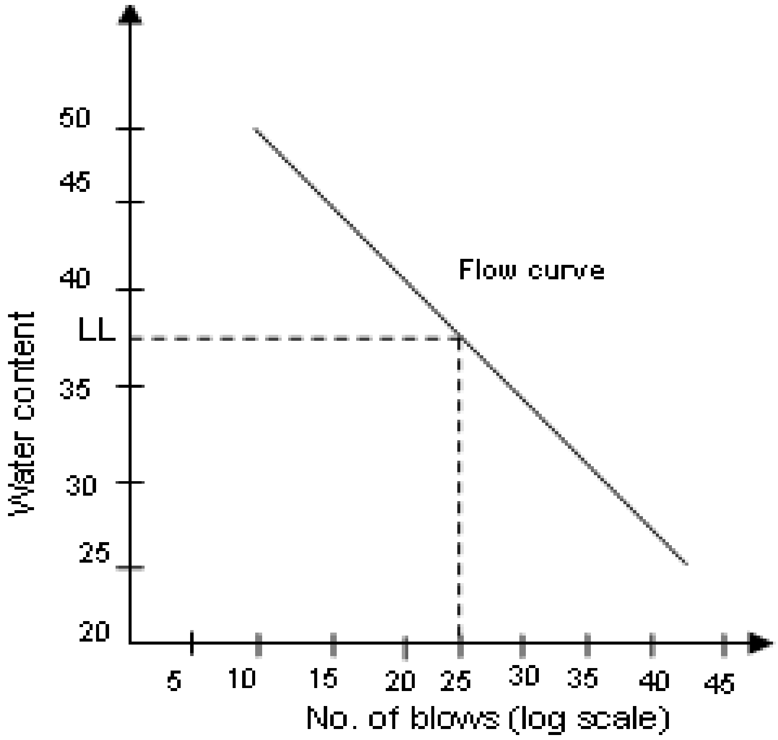
Casagrande Apparatus

Liquid limit test

- The drop of the cup on hard base is 1cm.
- The shear strength of the soil at liquid limit is about 27 kN/m^2
    - The moisture content corresponding to 25 blows from the flow curve is taken as the liquid limit of the soil
    - Flow curve gives an idea of shear strength variation with water content of soil

I_f: Flow index or Slope of the flow curve

$$I_f = \frac{(w_2 - w_1)}{\log_{10}\left(\frac{N_1}{N_2}\right)}$$



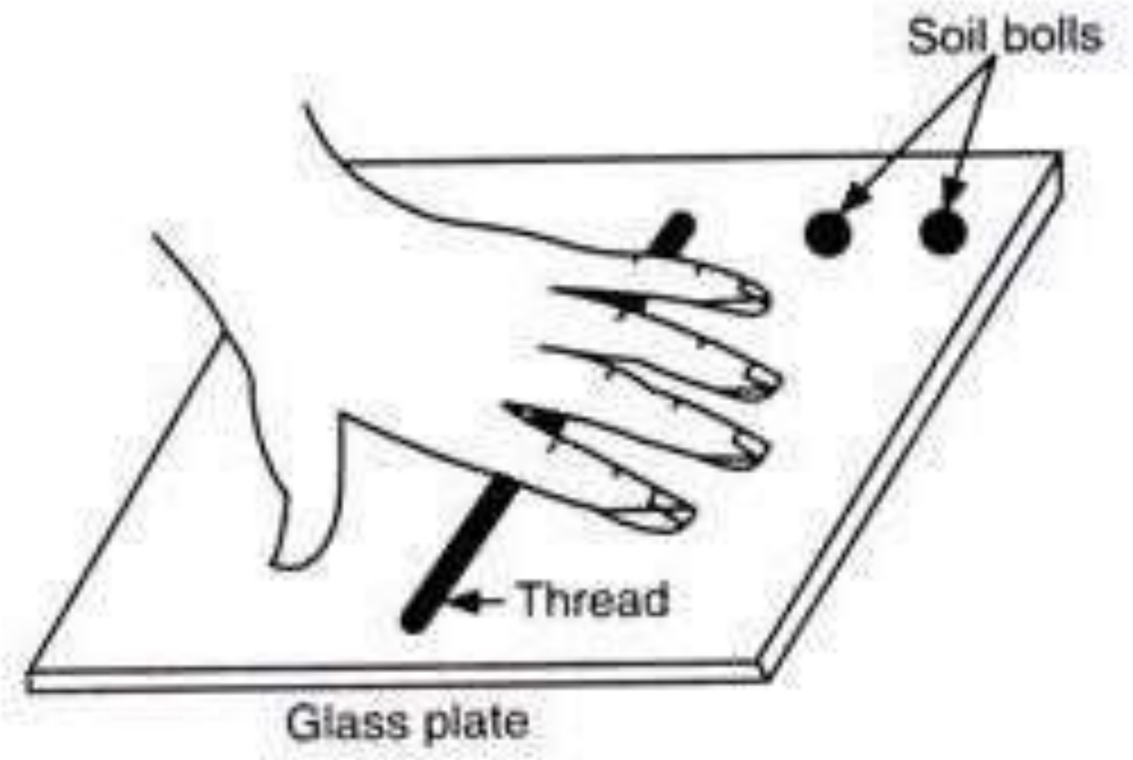
Plastic Limit (PL or w_P):

- It is the water content at which the soil tends to pass from the plastic state to the semi solid state.
- The minimum water content at which the soil can be rolled into a thread of 3 mm in diameter without crumbling.
- It is called thread test.

Shrinkage Limit (SL or w_S):

The volume of 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. At this state the soil is said to have reached semi-solid state.

- Shrinkage limit is lowest water content at which a soil can still be completely saturated.
- It is the water content at which the soil tends to pass from the semi-solid state to the solid state.

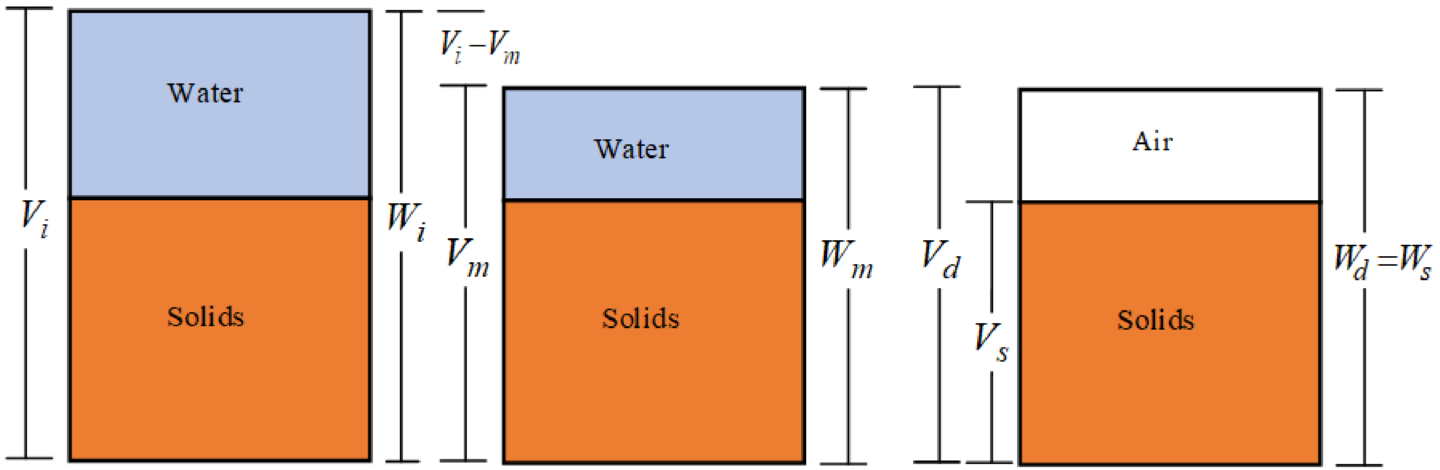


Plastic limit test

- It is the maximum water content at which further reduction is water content will not cause a decrease in volume of the soil mass.
- At shrinkage limit the shrinkage ceases.
- Expansion soils have i. More liquid limit ii. Less plastic limit iii. Less shrinkage limit iv more volumetric shrinkage.
- On addition of lime to swelling soils

  i. Liquid limit decreases ii. Plastic limit increases

  iii. Shrinkage limit increases. iv. Swelling potential decreases.



Soil pat at initial stage

Let W_i : Initial weight of soil pat

W_d : Dry weight of the soil pat $= W_s$

V_i : Initial volume of the soil pat

V_d : Dry volume of the soil pat $= V_m$

Initial weight of water $= W_i - W_d$

Loss of water from initial stage to the shrinkage limit $= (V_i - V_m).\gamma_w$

Weight of water at shrinkage limit $= (W_i - W_d) - (V_i - V_m).\gamma_w$

Shrinkage limit, $w_s = \dfrac{(W_i - W_d) - (V_i - V_m)\gamma_w}{W_d} \times 100$

$$w_s = \left[w_i - \frac{(V_i - V_d)\gamma_w}{W_d} \right] 100$$

$$w_s = \frac{(V_d - V_s)\gamma_w}{W_d} \times 100 = \left[\frac{\gamma_w}{\gamma_d} - \frac{1}{G} \right] \times 100 \qquad \gamma_d = \frac{G.\gamma_w}{1+e} \qquad w_s = \frac{1+e}{G} - \frac{1}{G} = \frac{e}{G}$$

e : Void ratio of the soil at its minimum volume.

Shrinkage Ratio (SR):

It is the ratio of the volume change expressed as percent of the dry volume to the corresponding change in moisture content from the initial value to the shrinkage limit.

$$SR = \frac{\left[\frac{V_i - V_d}{V_d} \times 100\right]}{(w_i - w_s)}$$

$$SR = \frac{W_d}{V_d \gamma_w}$$

$$SR = \frac{\gamma_d}{\gamma_w} = G_{m(dry)} = \left(\frac{W_d}{W_w}\right)_{\text{samevolume}}$$

Change in water content, $w_i - w_s = \frac{(V_i - V_d)\gamma_w}{W_d}$

- Shrinkage ratio is equal to the mass Specific Gravity of the soil in its dry state.

Volumetric Shrinkage or Volume change (V_s):

- It is defined as the percentage decrease in the volume of a soil mass when the water content is reduced from an initial value to the shrinkage limit.

$$V_s = \frac{V_i - V_d}{V_d} \times 100 = SR\,(w_i - w_s)$$

Degree of shrinkage (S_r):

- It is the ratio of the difference between initial volume and final volume of the soil sample to its initial volume.

$$S_r = \frac{V_1 - V_2}{V_1} \times 100$$

S_r	Quality of Soil
< 5	Good
5 – 10	Medium
10 – 15	Poor
> 15	Very poor

Linear shrinkage (L_s):

It is defined as the decrease is one dimension of the soil mass expressed as percentage of the initial dimension, when the water content is reduced from a given value to the shrinkage limit.

Plasticity Index (PI or I_P):

It is the range of water content within which the soil exhibits plastic properties It is the difference between liquid limit and plastic limit

I_P = Liquid Limit – Plastic Limit= LL – PL

Plasticity index for sands is zero

Plasticity Index	Plasticity
0	Non-Plastic
1 – 5	Slight
5 – 10	Low
10 – 20	Medium
20 – 40	High
> 40	Very high

•Increasing order of plasticity index: Illite < kaolinite < Montmorillonite

Liquidity Index or Water Plasticity ratio (LI or I_L):

It is the ratio of the difference between the natural water content and plastic limit to the plasticity index.

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

w : Natural water content

w_P : Plastic limit

I_P : Plastic index.

If $I_L = 0$ $\quad w = PL$

$I_L = 1$ $\quad w = LL$

$I_L > 1$ Soil is in liquid state

$I_L < 0$ Soil is in semi-solid state and stiff

Consistency Index or Relative Consistency (CI or I_C):

- It is the ratio of the difference between liquid limit and the natural water content to the plasticity index of a soil.

$$I_C = \frac{LL - w}{PI} = \frac{w_L - w}{I_p}$$

If

$I_C = 0$	$w = LL$
$I_C = 1$	$w = PL$
$I_C > 1$	Soil is in semi solid state
$I_C < 0$	Soil is in liquid state

- useful in the study of the field behaviour of saturated fine grained soils.

$$CI + LI = 1$$

Classification of consistency

Consistency	CI	LI
Very stiff	1.00	< 0.00
Stiff	1.00 – 0.75	0.00 – 0.25
Medium	0.75 – 0.50	0.25 – 0.50
Soft	0.50 – 0.25	0.50 – 0.75
Very soft	0.25 – 0.00	0.75 – 1.00

Shrinkage Index (SI or I_S):

- It is defined as the difference between the plastic and shrinkage limits of a soil
- It is the range of water content within which a soil is in a semisolid state of consistency.

$$I_S = PL - SL$$

Shrinkage index = Plastic limit – Shrinkage limit

Toughness Index (I_T):

- It is defined as the ratio of the plasticity index to the flow index

$$I_T = \frac{I_P}{I_f} = \frac{\text{Plasticity index}}{\text{Flow index}}$$

- Larger the value of I_T, better is the shear strength of soil at its plastic limit.
- Remoulding causes loss of strength of soil
- As the particle size decreases, Liquid limit, Plastic limit and Plasticity index increases when it contain clay minerals
- If silt is added to clay, Liquid limit, Plastic limit and Plasticity index decreases.

Thixotropy:

- Thixotropy is the phenomenon of strength loss - strength gain with no change in volume of water content.
- The loss of strength on remoulding of soil is due to
  - i. The permanent destruction of the structure is the in-situ condition
  - ii. The reorientation of the molecules in the adsorbed layers.
- The gain in strength of soil is due to
  - i. Rehabilitation of the molecule structure
  - ii. Re-establishment of chemical equilibrium
- Remolded soil may regain some of its lost strength with time
- Loss / gain of strength of soil over a period of time depends on the type of clay minerals
- Montmorillonite absorb large quantities of water experience greater thixotropic effects then other clay minerals
- Thixotrophic fluids used in drilling operations - drilling mud

Activity of soil (A):

- Skempton introduced the concept of activity.
- It is the ratio of the plasticity index to the percentage of clay fraction finer than 2 μ.

$$A = \frac{I_P}{C}$$

- It is the measure of the water holding capacity of the clayey soil.
- The swelling and shrinkage characteristics are represented by Activity Number.
- Clay containing kaolinite will have relatively low activity
- Clays containing montmorillonite will have high activity

Activity, A	Soil type
<0.75	Inactive
0.75 to 1.25	Normal
>1.25	Active

Sensitivity (S_t):

- Sensitivity of a clay is defined as the ratio of the unconfined compression strength of the natural or undisturbed state to that in the remoulded state.

$$S_t = \frac{q_u\,(\text{Undistrubed})}{q_u\,(\text{Remoulded})}$$

Sensitivity	Classification	Remarks
2 – 4	Normal or less sensitivity	Honeycomb
4 – 8	Sensitivity	Honey or flocculent structure
8 – 16	Extra sensitivity	Flocculent structure
> 16	Quick	Unstable