## I.Introduction :

**Geotechnical engineering** is a science that encompasses all activities related to the application of soil mechanics, rock mechanics, and engineering geology.

Soil and rock are among the materials studied in geotechnical engineering with the aim of using them as construction materials (dams, road embankments, foundation bases, etc.), as storage media (household and industrial waste), and also as media for the installation of underground structures (tunnels, mining galleries, etc.).

The study of soils makes it possible to design and dimension engineering structures (bridges, buildings, etc.); its objective is to properly select the materials and tools to be used during construction.

Soil formation generally results from the deposition of layers of materials that are often different and correspond to several geological ages. In a construction project, studying the geological history of a soil is important, as it can explain many physical and mechanical properties of the soil, as well as certain phenomena that must be taken into account during the design of foundations and columns.

## II. Definition of soils:

The term "**soil**" can have different meanings, depending upon the field in which it is considered.

To a **geologist**, it is the material in the relative thin zone of the Earth's surface within which roots occur, and which are formed as the products of past surface processes. The rest of the crust is grouped under the term "**rock**".

To an engineer (un **ingénieur**,), it is a material that can be:

- **built on:** foundations of buildings, bridges
- **built in:** basements, culverts, tunnels
- **built with:** embankments, roads, dams
- **supported:** retaining walls

***Soil Mechanics*** is a discipline of Civil Engineering involving the study of soil, its behaviour and application as an engineering material.

Soil Mechanics is the application of laws of mechanics and hydraulics to engineering problems dealing with sediments and other unconsolidated accumulations of solid particles, which are produced by the mechanical and chemical disintegration of rocks, regardless of whether or not they contain an admixture of organic constituents. Soil consists of a multiphase aggregation of solid particles, water, and air. This fundamental composition gives rise to unique engineering properties, and the description of its mechanical behavior requires some of the most classic principles of engineering mechanics.

Engineers are concerned with soil's mechanical properties: permeability, stiffness, and strength. These depend primarily on the nature of the soil grains, the current stress, the water content and unit weight.

## III. Types of soils:

Different types of soils are usually identified according to the size of their particles. In soil mechanics, the simplest classification consists of grouping soils into two main classes:

- **Coarse-grained soils :** Gravels and blocks, or riprap, have an equivalent diameter greater than 80 mm. They are characterized by very high permeability.
- **Fine-grained soils :** Includes sands, silts, and clays with smaller particle sizes. Typically, **lower permeability** and higher water retention.
- **Organic soils :** They contain a high percentage of organic matter.

  OM < 3%: inorganic soil
  3% < OM < 10%: slightly organic soil
  10% < OM < 30%: moderately organic soil

## IV. Constituent Elements of Soil

From the point of view of its physical and mechanical properties, soil can be considered as a **three-phase porous system**: solid, liquid, and gas.

**Soil = solid phase + liquid phase + gaseous phase**

1. **The Gaseous Phase:**

   In Civil Engineering, the gas contained in the soil is generally air for dry soils, or a mixture of air and water vapor for moist soils. When all the voids are filled with water, the soil is said to be **saturated**.

**2. The Liquid Phase:**

Exists in several forms:

- **Constitutional water** (interlayer water)
- **Bound water** (adsorbed water)
- **Interstitial water** (free or capillary water)

**2. The Solid Phase:**

Comes from the mechanical and/or chemical disintegration of a parent rock.

- **Non-clay minerals** (Φ > 2 mm, behaving similarly to the parent rock: pulverulent soils)
- **Clay minerals** (kaolinite, illite, and montmorillonite)
- **Organic soils** (muds and peats)

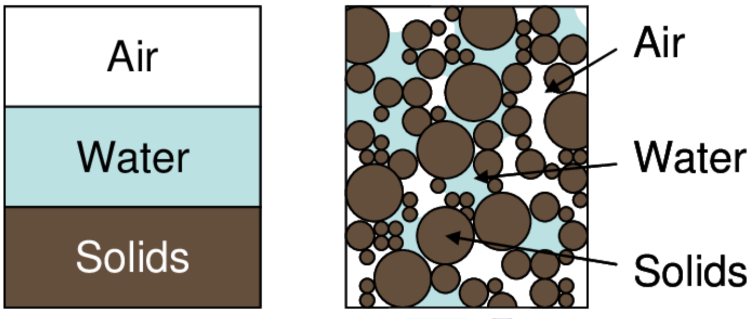


***Fig.1. Constituent Elements of Soil***

## V. Physical properties of soil:

The physical properties of a soil depend on the amount, size, shape, arrangement and mineral composition of its particles. These properties also depend on organic matter content and pore spaces.

The major soil physical properties are:

o Soil Texture

o Soil Structure

o Soil Consistence/Soil Strength

o Soil Color

o Soil Permeability

o Soil Temperature

1. **Soil texture:** Each soil separate represents a distinct physical size group. Mineral particles less than 2 millimeters in equivalent diameter and ranging between specified size limits. The names and sizes of the soil separates recognized in the United States are as follows.

| | |
|---|---|
| Very Coarse Sand | 2.0 - 1.0 mm |
| Coarse Sand | 1.0 - 0.5 mm |
| Medium Sand | 0.5 - 0.25 mm |
| Fine Sand | 0.25 - 0.10 mm |
| Very Fine Sand | 0.10 - 0.05 mm |
| Silt | 0.05 - 0.002 mm |
| Clay | 0.002 mm |

General classification is as follows:

| | |
|---|---|
| Sand | 2.0 - 0.05 mm |
| Silt | 0.05 - 0.002 mm |
| Clay | <0.002 mm |

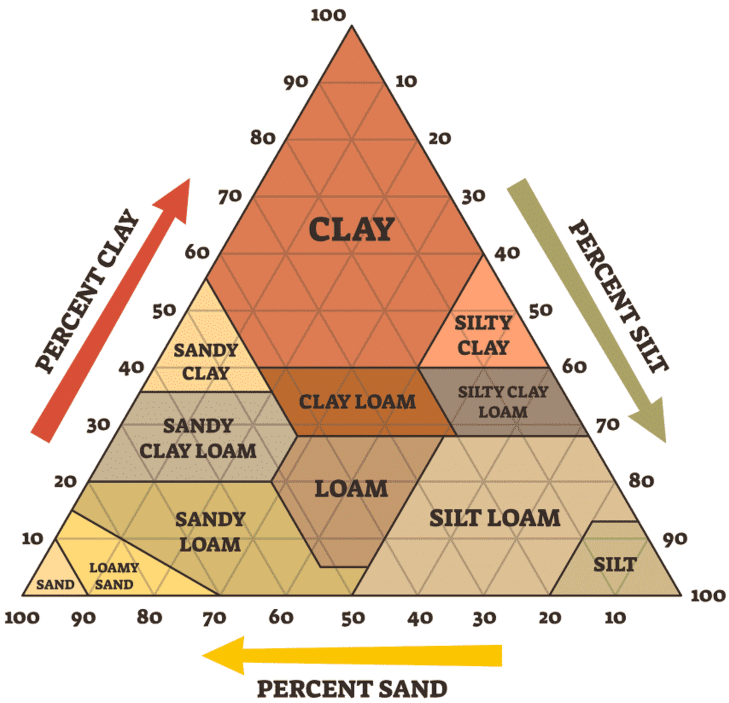


*Fig.2. Textural classification triangle for different soil types*

## 2. Soil structure:

Soil structure refers to the arrangement of sand, silt, and clay particles into secondary aggregates (*peds*), which are easy to recognize and called **structural units**. The five main types are:

1. **Platy (Structure lamellaire):** Plate-like aggregates parallel to the horizons, sometimes limiting the movement of air, water, and roots.
2. **Blocky (Structure polyédrique):** Cube-like or rounded blocks.
3. **Prismatic (Structure prismatique)/Columnar:** Vertical axis longer than horizontal; flat-topped (prismatic) or rounded-topped (columnar).
4. **Granular (Structure granulaire):** Spheroidal, porous peds.
5. **Structureless (Sol sans structure):** No visible aggregation, including **single-grain soils** (sand) or **massive soils** (solid mass without aggregates).

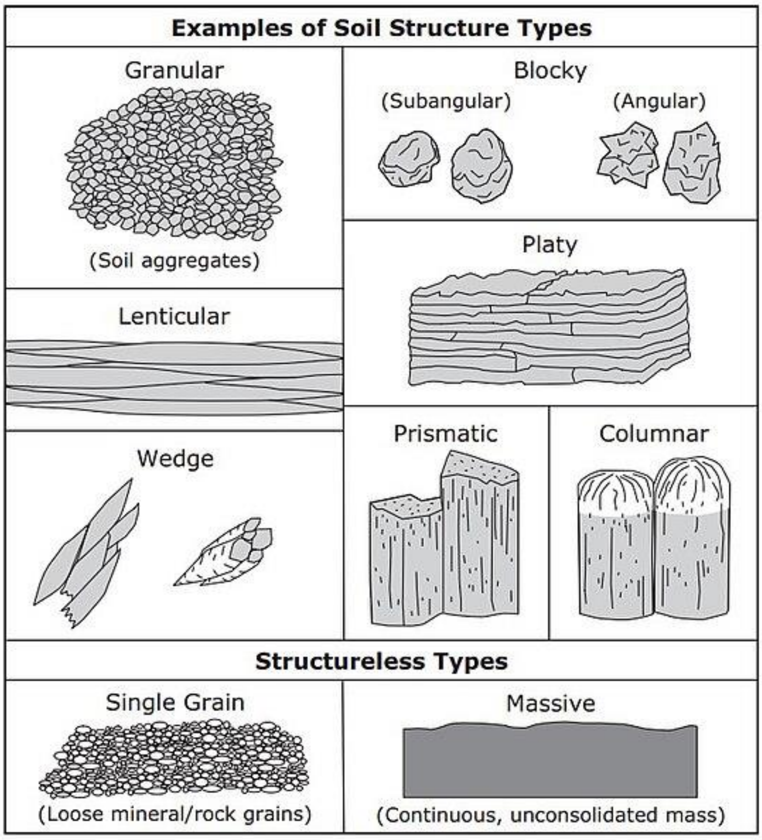


***Fig.3. Examples of soil structure types***

## 3. Soil Consistence

Soil consistency describes the soil's resistance to deformation or rupture at different moisture levels (wet, moist, dry), determined by cohesion (particle-to-particle attraction) and adhesion (water-to-particle attraction). It's assessed by how soil feels (sticky, plastic, friable) when manipulated, impacting tillage, construction, and water retention, and is classified using Atterberg limits (liquid, plastic, semi-solid, solid states)

**Evaluation Methods:**

- **Field tests:** Squeeze the soil between your fingers to check for **stickiness**, **plasticity** (ability to be molded), or **friability** (ease of crumbling).
- **Laboratory tests:** Use **Atterberg limits** (liquid, plastic, semi-solid limits) to quantify the **water content** at state changes.

## 4. Soil colour:

It is the most obvious and easily determined soil property It has little direct effect on the soil, but is an indicator of soil properties. However, there are many things we can tell about the soil by observing the color.

- Organic matter content; the more organic content the darker the soil color
- Soil color and soil temperature : dark colored soils absorb more heat so they warm up quicker and have higher soil temperatures.
- Soil color and parent material : generally dark parent material will develop into dark soils.
- Soil color and drainage:
  - soil drainage refers to the length of time a soil is waterlogged. Not how fast the soil is drained.

## 5. Soil permeability:

**Permeability** is the **speed at which air and water move through the soil** – it is influenced by the soil's **texture** and **structure**.

1. **If permeability is high:** water moves **quickly** (e.g., sand)
2. **If permeability is low:** water moves **slowly** (e.g., clay)

**Drainage** refers to the **frequency and duration of saturation**, that is, the time the soil remains **waterlogged**. It is influenced by the **position in the landscape** and

**permeability**. Even if a soil can allow water to pass through (permeable), if it is in a **low-lying area where water accumulates**, the soil remains saturated for too long. Therefore, the drainage is **poor**, because water flows out of this area slowly.

## IV. Soil identification parameters

### IV.1 Elementary soil model:

Since soil is composed of three phases: **solid, liquid (water), and gaseous (air)**, the **volumes and masses** of the elementary soil model are defined.

As the relative proportions of the three phases vary in any soil deposit, it is useful to consider a soil model which will represent these phases distinctly and properly quantify the amount of each phase. A schematic diagram of the three-phase system is shown in terms of weight and volume symbols respectively for soil solids, water, and air. The weight of air can be neglected (**Wa=0**).

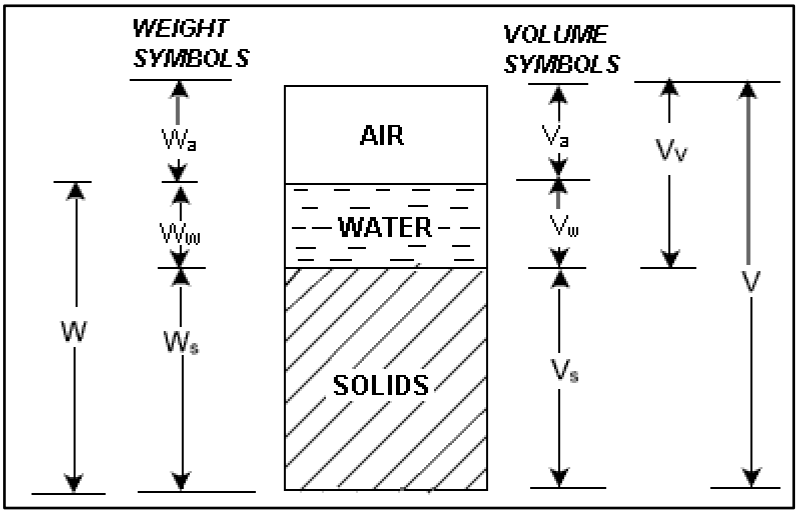


***Fig.4. Phase relation of soil***

**Definitions and Notations:**

- **Vt:** Total volume of the soil sample.
- **Va:** Volume of air contained in the soil sample.
- **Vw:** Volume of water contained in the soil sample.
- **Vs:** Volume of solid grains contained in the soil sample.
- **Vv = Va + Vw:** Volume of voids.

- **Wt:** Total weight of the soil sample.
- **Wa:** Weight of air contained in the soil sample; generally negligible.
- **Ww:** Weight of water contained in the soil sample.
- **Ws:** Weight of solid grains contained in the soil sample.
-

## IV.2 Basic Definitions

### IV.2.1 Dimensional Parameters

- **Total or bulk unit weight of soil, $\gamma_t$:**

  This is the weight per unit volume of soil, including water and air. It is also called the wet (total or apparent) unit weight, **$\gamma$h**.

  $\gamma_t = \gamma_h = W_t / V_t$ (in kN/m³, N/m³, etc.)

- **Unit weight of solid grains, $\gamma_s$:**

  This is the weight per unit volume of the solid grains. For sands, it is approximately 2.65 g/cm³, and for clays, an average statistical value is around 2.7 g/cm³. It is also called the absolute unit weight.

  $\gamma_s = W_s / V_s$

- **Unit weight of water, $\gamma_w$:**

  This is the weight per unit volume of water, equal to 9.81 kN/m³; for simplification, it is often taken as ≈ 10 kN/m³.

  $\gamma_w = W_w / V_w$

- **Dry unit weight of soil, $\gamma_d$:**

  This is the weight per unit volume of soil without interstitial water (after removal of free water). It is also called the dry unit weight.

  $\gamma_d = W_s / V_t$

- **Buoyant (or submerged) unit weight of soil, $\gamma'$:**

  This is the weight per unit volume of soil submerged under water, taking into account Archimedes' buoyant force.

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

### IV.2.2 Dimensionless Parameters

- **Density concept:**

This is the unit weight of the soil relative to that of water. We distinguish:

  - **Dry density:** ($\rho_d = \gamma_d / \gamma_w$)
  - **Wet density:** ($\rho_h = \gamma_h / \gamma_w$)
  - **Density of solid grains:**( ($\rho_s = \gamma_s / \gamma_w$ )

- **Porosity, n:**

This is the ratio of the volume of voids to the total volume of soil. and is expressed as a percentage.

$$n = \frac{V_V}{V} x 100$$

- **Void ratio, e:**

This is the ratio of the volume of voids to the volume of solid grains.

$$e = \frac{V_V}{V_S}$$

- **Water content, w:**

This is the ratio of the weight of water contained in a given soil volume to the weight of the solid elements in the same volume, usually expressed in %.

**$W = W_w / W_S . 100$**

Its value is 0% for dry soil and its magnitude can exceed 100%.

- **Degree of saturation, $S_r$:**

This is the ratio of the volume actually occupied by water to the volume of voids.

**$S_r = V_W / V_V . 100$**

For a **saturated soil**, ($V_v = V_w$) and (Sr = 100%) For a **dry soil**, ($V_w = 0$) and (Sr = 0%)

**Classification of soils according to their degree of saturation**

**Slightly moist soil:** ( $Sr \leq 0.5$ )

**Moist soil:** ( $0.5 < Sr \leq 0.8$ )

**Saturated soil:** ( $Sr > 0.8$ )

- **Compacity (or solids fraction), C:**

This is the ratio of the volume of solid grains to the total soil volume.

$$\mathbf{C = V_s / V_t}$$

## IV.2.3 Relations between soil parameters

[1] $n = \dfrac{V_v}{V_t}$ *

[2] $n = \dfrac{e}{1+e}$

[3] $n = 1 - \dfrac{\gamma_d}{\gamma_s}$

[4] $n = \dfrac{\gamma_s - \gamma_{sat}}{\gamma_s - \gamma_w}$

[5] $e = \dfrac{V_v}{V_s}$ *

[6] $e = \dfrac{n}{1-n}$

[7] $e = \dfrac{\gamma_s}{\gamma_d} - 1$

[8] $e = \dfrac{\gamma_s - \gamma_{sat}}{\gamma_{sat} - \gamma_w}$

[9] $w = \dfrac{P_w}{P_s}$

[10] $w = e \cdot S_r \cdot \dfrac{\gamma_w}{\gamma_s}$

[11] $w = \dfrac{\gamma}{\gamma_d} - 1$

[12] $w = S_r \cdot \gamma_w \cdot \left(\dfrac{1}{\gamma_d} - \dfrac{1}{\gamma_s}\right)$

[13] $S_r = \dfrac{V_w}{V_v}$ *

[14] $S_r = \dfrac{\gamma_s}{\gamma_w} \cdot \dfrac{w}{e}$

[15] $S_r = \dfrac{w}{w_{sat}}$ ($\gamma_d$ constant)

[16] $\gamma = (1+w) \cdot \gamma_d$

[17] $\gamma = \gamma_d + n \cdot S_r \cdot \gamma_w$

[18] $\gamma = (1-n) \cdot \gamma_s + n \cdot S_r \cdot \gamma_w$

[19] $\gamma = \dfrac{1+w}{1+e} \cdot \gamma_s$

[20] $\gamma = \dfrac{\gamma_s + e \cdot S_r \cdot \gamma_w}{1+e}$

[21] $\gamma_d = \dfrac{\gamma_s}{1+e}$

[22] $\gamma_d = (1-n) \cdot \gamma_s$

[23] $\gamma' = \gamma_{sat} - \gamma_w$ *

[24] $\gamma' = \dfrac{\gamma_s - \gamma_w}{1+e}$

[25] $\gamma' = (\gamma_s - \gamma_w) \cdot (1-n)$

[26] $\gamma' = \dfrac{\gamma_s - \gamma_w}{\gamma_s} \cdot \gamma_d$

$$w = \frac{W_W}{W_s} = \frac{\gamma_W . V_W}{G_s . \gamma_W . V_s} = \frac{V_W}{G_s . V_s} = \frac{S . V_v}{G_s . V_s} = \frac{S . e}{G_s}$$

$$\gamma = \frac{(G_s + S.e).\gamma_w}{1+e}$$

$$\gamma = \frac{(1+w).G_s.\gamma_w}{1+e}$$

$$\gamma_d = \frac{G_s.\gamma_w}{1+e}$$

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

$$\gamma' = \frac{[(G_s - 1) + (S - 1)e]\ x\ \gamma_w}{1+e}$$

$$\gamma' = \frac{(G_s - 1).\gamma_w}{1+e}$$

**Table 1 presents, for indicative purposes, some physical characteristics of soils.**

**Table 1. Physical characteristics of soils (after Terzaghi and Peck)**

| **Soil** | **Porosity n (%)** | **Void ratio e** | **Water content w (%)** | **Density ρd** | **Density ρh** |
|---|---|---|---|---|---|
| **Poorly graded sand** (loose state) | 46 | 0.85 | 32 | 1.43 | 1.89 |
| **Poorly graded sand** (dense state) | 34 | 0.51 | 19 | 1.75 | 2.09 |
| **Well-graded sand** (loose state) | 40 | 0.67 | 25 | 1.59 | 1.99 |
| **Well-graded sand** (dense state) | 30 | 0.43 | 16 | 1.86 | 2.16 |
| **Soft clay** | 55 | 1.20 | 45 | – | 1.77 |
| **Stiff clay** | 37 | 0.60 | 22 | – | 2.07 |
| **Soft bentonite** | 84 | 5.20 | 194 | – | 1.27 |

## V. Soil Identification :

To characterize a soil, it is necessary to determine the **nature parameters** and the **state parameters**.

➤ **Nature parameters** : indicate the intrinsic characteristics of the soil. They do not vary with time (unit weight of solid particles, grain-size distribution, Atterberg limits, organic matter content, etc.).

➤ **State parameters :** depend on the condition of the soil and describe its behavior under a given load (water content, void ratio, porosity, sand equivalent, etc.).

### V.1 Nature Parameters :

#### V.1.1 Unit Weight of Solid Particles (γs) :

The determination of the unit weight of solid particles γs is carried out using an apparatus called a **pycnometer**. A known mass of oven-dried soil ( $m_s$ ) is placed in a small flask called a pycnometer containing distilled water. After removing all air bubbles, the volume of water displaced by the solid particles ( $V_s$ ) is measured.

**Note:** For soils (except organic soils): 26 $kN/m^3$ ≤ γs ≤ 28 $kN/m^3$.

### V.1.2 Grain Size Distribution :

Grain size analysis is carried out by **dry sieving after washing** for soils whose particles are larger than **80 µm**, and by **sedimentation (hydrometer analysis)** for particles smaller than or equal to **80 µm**.

Grain size distribution is expressed by a **grain size distribution curve**, which shows the distribution of the average grain size, expressed as a percentage of the total weight of the material.

It is plotted on a **semi-logarithmic chart** with:

- ✓ **Abscissa (x-axis),** the logarithm of sieve opening sizes, in increasing values;
- ✓ **Ordinate (y-axis),** the percentage by weight of the total material represented by the fraction of soil whose particles have an average diameter smaller than the corresponding abscissa value (passing).

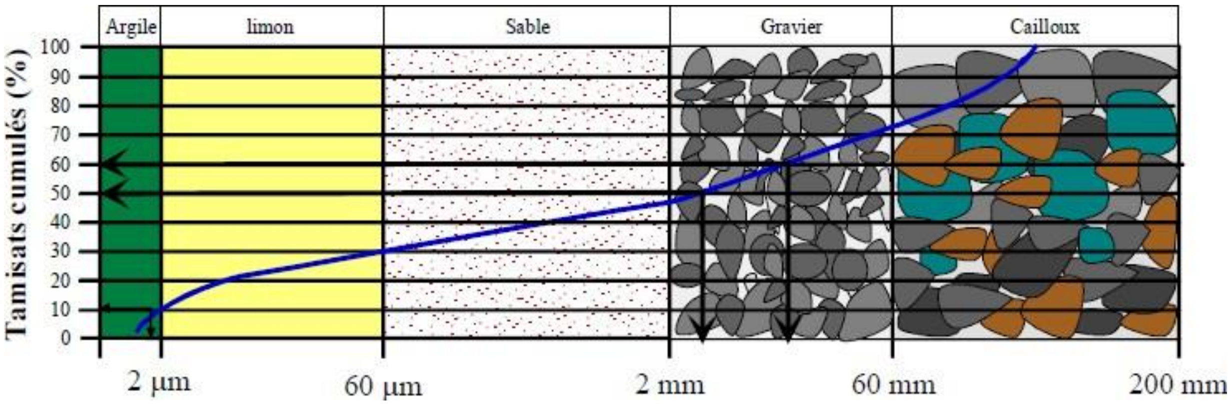


***Fig.5. Grain Size Distribution Curve***

The results are presented in the form of a **grain size distribution curve**, plotted on **semi-logarithmic axes**, from which the following can be determined:

- **Hazen's coefficient of uniformity: $C_u = D_{60} / D_{10}$**
- **Coefficient of Curvature: $C_c = D_{30}^2/(D_{10} \times D_{60})$**

**Note:** ($D_i$) is the particle diameter corresponding to **i % of cumulative percent passing** (sieve analysis).

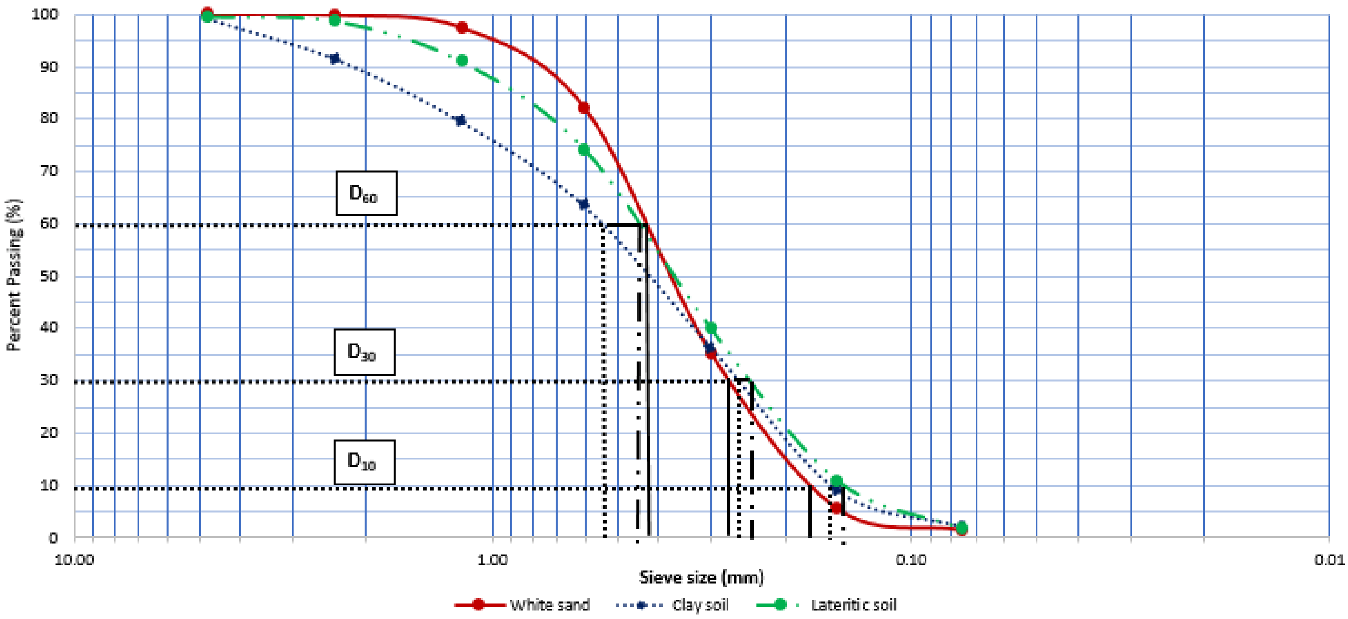


***Fig.6.Grain-size distribution curve (sieve analysis)***

For $C_u > 2$, the grain-size distribution is said to be **well spread (wide-graded)**. For $C_u < 2$, the grain-size distribution is said to be **uniform** or **narrow-graded**. The more uniform the grain-size distribution, the steeper the slope of the middle portion of the grain-size distribution curve.

When certain conditions on $C_u$ and **Cc** are satisfied, the soil is said to be **well graded**, meaning that its grain-size distribution is well spread, without predominance of any particular size fraction.

When the grain-size distribution is **discontinuous**, with predominance of a particular fraction, the soil is said to be **poorly graded**.

Well-graded soils form **naturally dense deposits** with **high bearing capacity**. They can be **easily compacted in embankments** and form **stable slopes**.

### V.1.3 Clay Content:

To identify the clay fraction, several simple tests have been developed:

- **Atterberg limits**, which characterize the consistency of fine-grained soils: **solid, plastic, and liquid** states;
- **Sand equivalent (SE)**, which determines the proportion of fine soil in sands;
- **Methylene blue test (MBV)**, a relatively recent test, applicable to both coarse-grained and fine-grained soils, which measures the **overall clay content** of the soil.

**Atterberg's Limit (consistency limits) :**

Relative ease with which the soil can be deformed is called consistency. It denotes the degree of firmness of the soil which may be termed as soft, firm, stiff or hard.

**Atterberg's limits :**

Water contents at which soil mass passes from one state to another is called consistency limits.

The various states through which the soil passes by are solid, semi solid, plastic and liquid states.

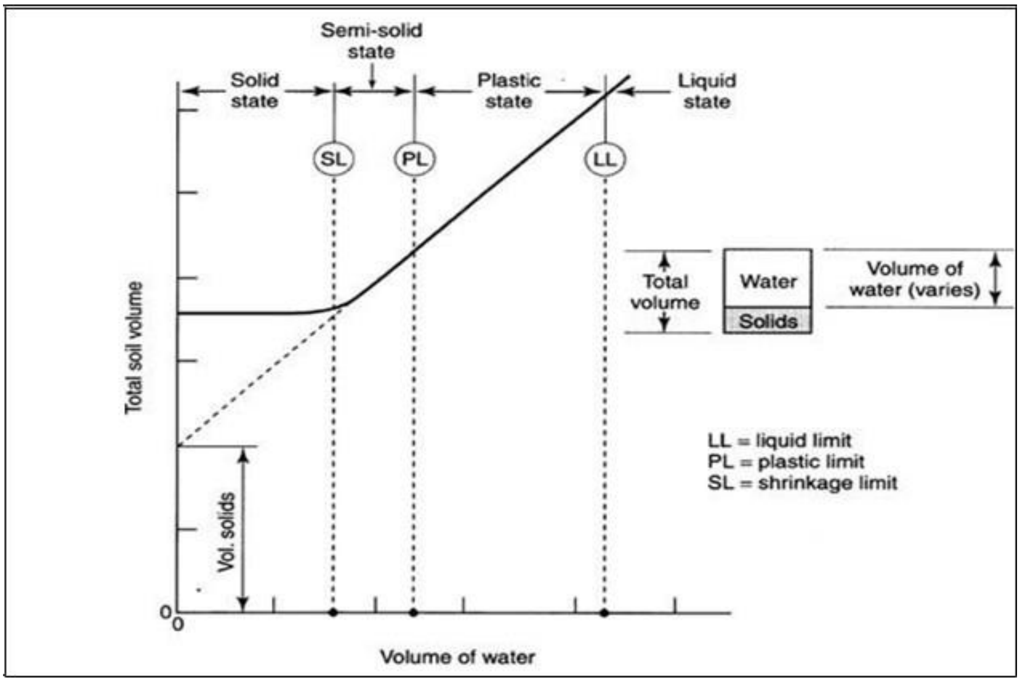


***Fig.7.Consistency limits***

**Liquid limit ($w_L$) :**

It is defined as the minimum water content at which part of the soil cut by a groove of standard dimensions will flow together for a distance of half an inch under impact of 25 blows in the device.

**Determination of liquid limit :**

It is determined using Casagrande's apparatus. It consists of the following parts.

(i) Hard rubber base
(ii) Brass cup
(iii) Handle
(iv) Adjusting screws.

*Fig.8.Casagrande apparatus*

The handle is rotated at a rate of 2 rps. Number of blows are counted until two parts of the soil sample come into contact at the bottom of the groove along a distance of 10mm. Water content corresponding to 25 blows is called liquid limit.

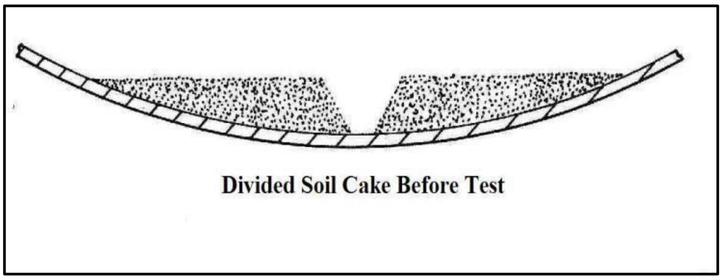


***Fig.9. Soil sample before testing with groove***

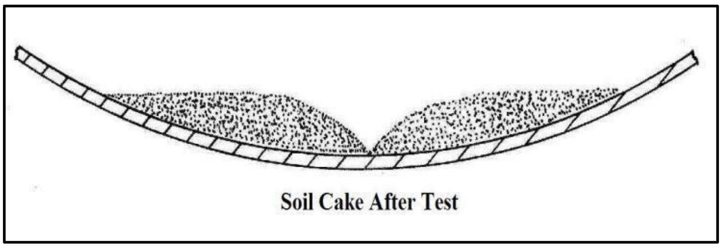


***Fig .10. soil sample after test with groove closed.***

Flow index is determined by plotting number of blows on logarithmic scale on x axis and water content along y axis.

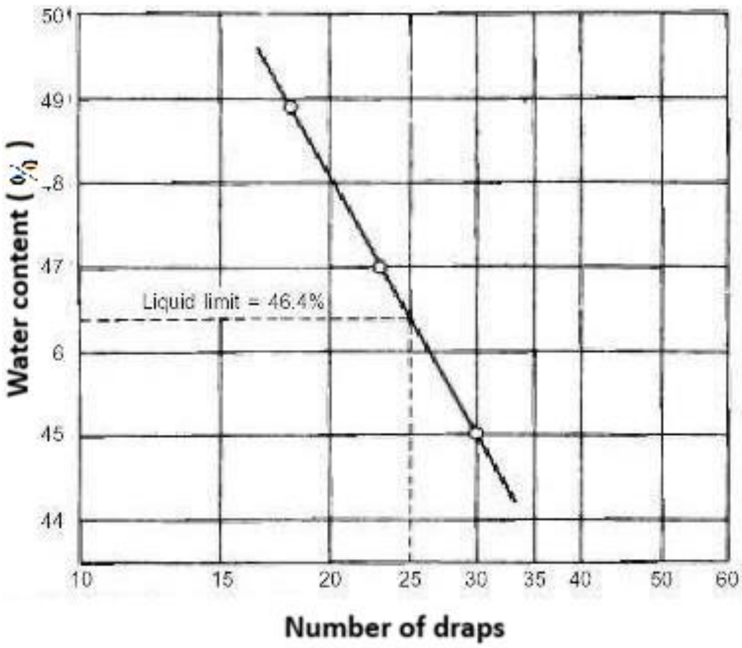


*Fig.11.flow curve*

**Plastic limit ($w_P$):**

Soil specimen passing through 425 microns is mixed with distilled water to form a plastic paste. It is rolled on a glass plate to make a thread of uniform diameter. Water content at which 3 mm diameter thread starts crumbling is called plastic limit of the soil.

***Fig.12.Crumbling of the soil particles.***

**Shrinkage limit ($S_L$) :**

It is the maximum water content at which reduction in water content will not cause decrease in volume of the soil mass. It is the lowest water content at which soil can still be saturated.

**Plasticity index ($I_P$) :**

It refers to the range of water content over which the soil will remain in the plastic state. It is equal to the difference between liquid and plastic limit.

$$I_P = w_L - w_P$$

**Consistency index ($I_C$) :**

It defines the firmness of the soil. It indicates the nearness of the water content to its plastic limit.

**V.2 State Parameters :**

They depend on the state of the soil and express, at a given moment, the distribution of the three soil phases. It is important to note that these parameters provide valuable information on the behavior of the soil when subjected to the stresses of the structures to be built.

**V.2.1 Determination of the gravimetric water content w :**

The gravimetric water content (**w**) is generally determined in the laboratory by oven-drying at 105°C. It can be performed on both granular soils and fine soils, on intact, remolded, or reconstituted samples.

It is the ratio of the mass of evaporated water (**$m_w$**) to the mass of solid particles (**$m_d$**):

$$w\ (\%) = (\text{mass of water contained} / \text{mass of solid soil particles}) \times 100$$

The natural water content (**$w_{nat}$**) is determined only on **intact samples**.

### V.2.2. Determination of the total soil density in the laboratory :

The determination of the **total density (ρ)** of a soil in the laboratory consists of measuring the mass (**M**) of a sample with a known volume (**V**), including the voids, using methods such as molding (le moulage) (sols cohérents), the cutting ring method (la trousse coupante) (for cohesive soils), or immersion (l'immersion) (for rocky soils). The applied formula is (***ρ = M/V***), often expressed in **g/cm$^3$** or **kg/m$^3$**.