UNIT II

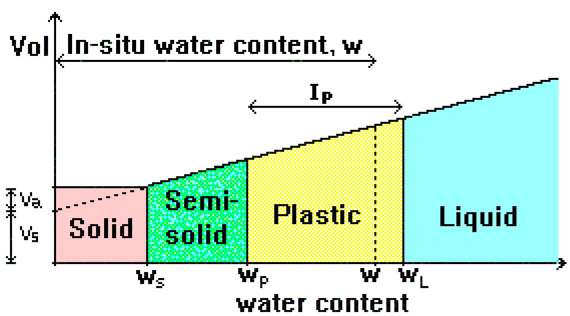
PHYSICAL STATES AND INDEX PROPERTIES OF FINE GRAINED SOILS

Plasticity is an important index property of fine grained soils. The plasticity of soil is its ability to undergo deformation without cracking or fracturing. The presence of clay minerals and adsorbed water is necessary to impart plasticity characteristics to a soil. Clay particles carry a negative charge on their surfaces. Water molecules which are dipolar are attracted towards the clay surface. This phenomenon is known as adsorption and the water so attracted to the clay surface is called adsorbed water. Thus, clay particles are separated by layers of adsorbed water. Adsorbed water allows the clay particles to irreversibly slip over each when the soil is subjected to deformation. Thus the deformation is plastic.

The soil does not become plastic when either the soil contains non-clay minerals or a non-polarizing liquid such as kerosene or paraffin oil (instead of dipolar water) is mixed with clay minerals.

Consistency is a property associated with fine grained soils only. Consistency is a term used to indicate the degree of firmness of a soil in a qualitative manner. It indicates the ease with which a soil can be deformed.

Depending upon the water content, the physical and mechanical behavior of fine grained soil sis linked to four distinct states of consistency: (i) liquid state (ii) plastic state (iii) semi-solid state, and (iv) solid state. The boundary water content at which the soil undergoes a change from one state to another are called **consistency limits** or **Attterberg limits.**



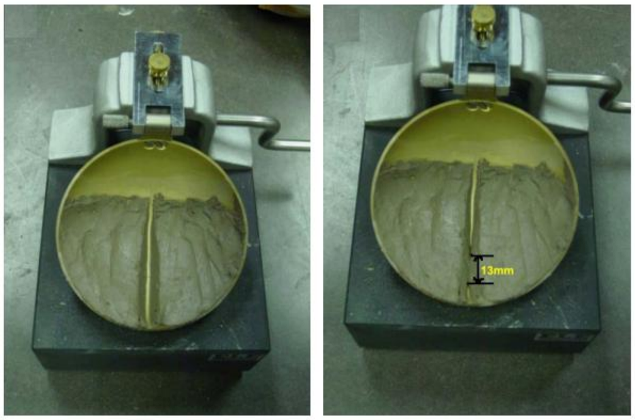
A soil containing a large quantity of water is in a liquid state. It offers no shearing resistance and can flow like liquids. As the water content is reduced, a stage comes when the soil just begins offering resistance to flow. This is the stage when the sample changes from possessing no shear strength to having infinitesimal shear strength and changes from the liquid to the plastic state. The boundary water content between the liquid state and plastic state is called the liquid limit. In the plastic state, the soil has plasticity characteristics and can be moulded to any shape without rupturing or cracking.

With further reduction of water content, the soil changes from plastic state to semi solid state at a boundary water content which is called plastic limit. In the semi-solid state, the soil does not have plasticity; it becomes brittle. The soil crumbles when pressure is applied.

Upto the semi-solid state, the soil is fully saturated and any reduction in the volume of water will result in almost equal reduction in the volume of soil mass.

With further reduction in water content from semi-solid state, the volume of soil does not decrease (or shrink) any further but remains constant. The soil changes from semi-solid state to solid state at a boundary water content which is called shrinkage limit. Below the shrinkage limit, the sample begins to dry up at the surface and the sample is no longer saturated.

Determination of Liquid Limit



The **consistency** of a fine-grained soil refers to its firmness, and it varies with the water content of the soil.

A gradual increase in water content causes the soil to change from ***solid*** to ***semi-solid*** to ***plastic*** to ***liquid*** states. The water contents at which the consistency changes from one state to the other are called **consistency limits** (or **Atterberg limits**).

The three limits are known as the shrinkage limit ($\mathbf{W_S}$), plastic limit ($\mathbf{W_P}$), and liquid limit ($\mathbf{W_L}$) as shown. The values of these limits can be obtained from laboratory tests.

Two of these are utilised in the classification of fine soils:

Liquid limit ($\mathbf{W_L}$) - change of consistency from plastic to liquid state
Plastic limit ($\mathbf{W_P}$) - change of consistency from brittle/crumbly to plastic state

The difference between the liquid limit and the plastic limit is known as the **plasticity index** ($\mathbf{I_P}$), and it is in this range of water content that the soil has a plastic consistency. The consistency of most soils in the field will be plastic or semi-solid.

Example 1: A soil has void ratio = 0.72, moisture content = 12% and G_s= 2.72. Determine its
(a) Dry unit weight
(b) Moist unit weight, and the
(c) Amount of water to be added per m^3 to make it saturated.
Use $\gamma_w = 9.81 kN/m^3$

Solution:

(a) $\gamma_d = \frac{G_s.\gamma_w}{1+e} = \frac{2.72 \, x \, 9.81}{1+0.72}$ = 15.51 kN/m^3

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

$= \frac{1+0.12}{1+0.72} \, x \, 2.12 \, x \, 9.81$ = 17.38 kN/m^3

(c) $\gamma_{sat} = \frac{G_s + e}{1+e}.\gamma_w$

$= \frac{2.72+0.72}{1+0.72} \, x \, 9.81$ = 19.62 kN/m^3

Water to be added per m^3 to make the soil saturated

= $\gamma_{sat} - \gamma$ = 19.62 – 17.38 = 2.24 kN

Example 2: The dry density of a sand with porosity of 0.387 is 1600 kg/m^3. Find the void ratio of the soil and the specific gravity of the soil solids. [Take $\gamma_w = 1000 \, kg/m^3$]

n = 0.387

γ_d = 1600 kg/m^3

Solution:

(a) e = $\frac{n}{1-n} = \frac{0.387}{1-0.387}$ = 0.631

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

$\therefore$ G$_s$ = $\frac{(1+e)}{\gamma_w}.\gamma_d = \frac{1+0.631}{1000} \, x \, 1600 = 2.61$

CHAPTER 4

Soil Classification

Soil classification is the arrangement of soils into different groups such that the soils in a particular group have a similar behavior. A classification system must be simple to use, and the number of soil groups not too many in number. Most soil classification systems use simple index properties for placing soils in a certain group. The most commonly used properties are grain-size distribution and plasticity. The most widely used classification system in the USA is the Unified Soil Classification System (USCS), which is used in most parts of the world with some modifications.

The USCS was developed by Casagrande (1948). According to the USCS, the coarse grained soils are classified on the basis of grain-size distribution and the fine grained soils (whose behavior is controlled by the plasticity) on the basis of their plasticity characteristics. Coarse grained soils are designated as either gravel (G) or sand (S). Fine grained soils are subdivided into silt (M) and clay (C), based on their liquid limit and plasticity index. Both gravel and sand are further divided into four sub groups, namely, GW and SW, GP and SP, GM and SM, GC and SC depending on GSD and nature of fines in the soil. The values of C_u and C_c determine whether the soil is well graded (W) or poorly graded (P). The A-Line on the Casagrande's plasticity chart separates the more clay like materials form those that are silty and also the organic from the inorganic. Silt, clay and organic fractions are further subdivided into soils soils possessing low (L) or high (H) plasticity when the liquid limit is less than 50% and more than 50%, respectively.

Indian Standard Soil Classification System

The Indian Standard Soil Classification System (ISSCS) is based on the Unified Soil Classification System (USCS), with one major difference being the subdivision of silts, clays and organic fractions into three categories as against two in the USCS.

Classification Based on Grain Size

The range of particle sizes encountered in soils is very large: from boulders with dimension of over 300 mm down to clay particles that are less than 0.002 mm. Some clays contain particles less than 0.001 mm in size which behave as colloids, i.e. do not settle in water.

In the **Indian Standard Soil Classification System (ISSCS),** soils are classified into groups according to size, and the groups are further divided into coarse, medium and fine sub-groups. The grain-size range is used as the basis for grouping soil particles into boulder, cobble, gravel, sand, silt or clay.

Very coarse soils	**Boulder size**		**> 300 mm**
	Cobble size		**80 - 300 mm**
Coarse soils	**Gravel size (G)**	***Coarse***	**20 - 80 mm**
		Fine	**4.75 - 20 mm**

	Sand size (S)	***Coarse***	**2 - 4.75 mm**
		Medium	**0.425 - 2 mm**
		Fine	**0.075 - 0.425 mm**
Fine soils	**Silt size (M)**		**0.002 - 0.075 mm**
	Clay size (C)		**< 0.002 mm**

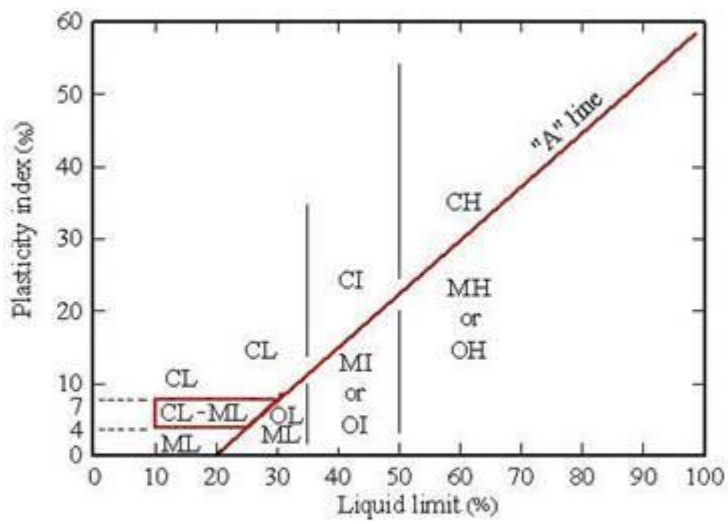
Gravel, sand, silt, and clay are represented by **group symbols G, S, M, and C** respectively.

Physical weathering produces very coarse and coarse soils. Chemical weathering produces generally fine soils.

Coarse grained soils are those for which more than 50% of the material has particle sizes greater than 0.075 mm. Coarse grained soils are designated as either gravel (G) or sand (S).

Fine-grained soils are those for which more than 50% of the material has particle sizes less than 0.075 mm. Clay particles have a **flaky** shape to which water adheres, thus imparting the property of **plasticity**.

A **plasticity chart** , based on the values of liquid limit (**W_L**) and plasticity index (**I_P**), is provided in **ISSCS** to aid classification. The **'A' line** in this chart is expressed as **$I_P = 0.73 (W_L - 20)$**.



Depending on the point in the chart, fine soils are divided into **clays (C)**, **silts (M)**, or **organic soils (O)**. The organic content is expressed as a 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 are 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%** separate the soils into various classes.

For example, the combined symbol **CH** refers to clay of high plasticity.

Soil classification using group symbols is as follows:

Group Symbol	Classification
Coarse soils	
GW	Well-graded GRAVEL
GP	Poorly-graded GRAVEL
GM	Silty GRAVEL
GC	Clayey GRAVEL
SW	Well-graded SAND
SP	Poorly-graded SAND
SM	Silty SAND
SC	Clayey SAND
Fine soils	
ML	SILT of low plasticity
MI	SILT of intermediate plasticity
MH	SILT of high plasticity
CL	CLAY of low plasticity
CI	CLAY of intermediate plasticity
CH	CLAY of high plasticity
OL	Organic soil of low plasticity
OI	Organic soil of intermediate plasticity
OH	Organic soil of high plasticity
Pt	Peat

Step-by-step procedure for soil classification

1. Determine whether the soil is of organic origin or coarse grained or fine grained.

   If 50% or more of the soil by weight is retained on 75µ sieve, it is coarse grained; if not, it is fine grained.

2. If the soil is coarse grained:

(a) Obtain the GSD curve from sieve analysis. The soil retained on 75 µ sieve is called coarse fraction (+75 µ). If 50% or more of the coarse fraction is retained on 4.75 mm sieve, classify the soil as gravel; if not, classify it as sand.

(b) If the soil fraction passing through 75 µ sieve (i.e. containing little or no fines) is less than 5%, the soil is identified as either clean gravel or clean sand; determine the gradation of the soil by calculating C_u and C_c from the GSD curve. If well graded, classify the soil as GW or SW; if poorly graded, classify as GP or SP.

(c) If more than 12% passes through 75 µ sieve, the soil is identified as either dirty gravel or dirty sand; perform the liquid limit and plastic limit tests on the soil passing 425 µ sieve. Use the I.S. Plasticity chart to determine the classification (GM, GC, GM-GC, SM, SC or SM-SC).

(d) If between 5% and 12% passes through the 75 µ sieve, the soil is assigned a dual symbol appropriate to its gradation and plasticity characteristics (GW-GM, GW-GC, GP-GM, GP-GC, SW-SM, SW-SC, SP-SM, SP-SC).

3. If the soil is fine grained (inorganic):

(a) Determine w_L, w_P and I_P.

(b) If the limits plot below the A-line, classify as silt (M). Further, if $w_L < 35$, classify as ML; if w_L is between 35-50, classify as MI; if $w_L > 50$, classify as MH.

(c) If the limits plot above the A-line, classify as clay (C). Further, if $w_L < 35$, classify as CL; if w_L is between 35-50, classify as CI; if $w_L > 50$, classify as CH.

(d) If the limits plot in the hatched zone, classify as CL-ML. If the limits plot close to the A-line, use appropriate dual symbols as CL-ML, CI-MI, CH-MH. If the limits plot close to $w_L = 35\%$, use appropriate dual symbols ML-MI, or CL-CI. If the limits plot close to $w_L = 50\%$, use appropriate symbols MI-MH, or CI-CH.

4. If the soil is of organic origin, classify the soil as OL, OI or OH depending on plasticity characteristics. Appropriate boundary classification (OL-OI or OI-OH) may be used when the limits plot close to $w_L = 35\%$ and $w_L = 50\%$.

5. If the soil has about 50% each of fines and coarse grained fractions:

(a) Determine whether the coarse grained fraction is gravel (G) or sand (S).

(b) Determine w_L and w_P.

(c) Depending on whether the limits plot above the A-line or below the A-line, classify as C or M. Based on w_L, classify as L, I or H.

(d) Assign appropriate dual symbol such as GM-ML, GM-MI etc.

Field Identification of soils

Activity
"Clayey soils" necessarily do not consist of 100% clay size particles. The proportion of clay mineral flakes (< 0.002 mm size) in a fine soil increases its tendency to swell and shrink with changes in water content. This is called the **activity**of the clayey soil, and it represents the degree of plasticity related to the clay content.

Activity = (Plasticity index) /(% clay particles by weight)

Classification as per activity is:

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

Liquidity Index
In fine soils, especially with clay size content, the existing state is dependent on the current water content (**w**) with respect to the consistency limits (or Atterberg limits). The **liquidity index (LI)** provides a quantitative measure of the present state.

$$LI = \frac{w - W_P}{I_P}$$

Classification as per liquidity index is:

Liquidity index	Classification
> 1	Liquid
0.75 - 1.00	Very soft
0.50 - 0.75	Soft
0.25 - 0. 50	Medium stiff
0 - 0.25	Stiff
< 0	Semi-solid

Visual Classification

Soils possess a number of physical characteristics which can be used as aids to identification in the field. A handful of soil rubbed through the fingers can yield the following:

SAND (and coarser) particles are visible to the naked eye.

SILT particles become dusty when dry and are easily brushed off hands.

CLAY particles are sticky when wet and hard when dry, and have to be scraped or washed off hands.

Example

The following test results were obtained for a fine-grained soil:

W_L= 48% ; W_P = 26%
Clay content = 55%
Silt content = 35%
Sand content = 10%
In situ moisture content = 39% = w

Classify the soil, and determine its activity and liquidity index

Solution:

Plasticity index, $I_P = W_L – W_P = 48 – 26 = 22\%$

Liquid limit lies between 35% and 50%.

According to the Plasticity Chart, the soil is classified as CI, i.e. clay of intermediate plasticity.

$$\Rightarrow Activity = \frac{I_P}{Clay\ content} = \frac{22}{25} = 0.88$$

Liquidity index , $LI = \frac{w - W_P}{I_P} = \frac{39 - 26}{22} = 0.59$

The clay is of normal activity and is of soft consistency.