GEOTECHNICAL ENGG. – I (VI sem)

UNIT-1

(Part-2 Index properties of soil)

(Part-2 (vi) Consistency of Soils)

Index Properties of Soil:

6. Consistency of Soils:

Consistency means the relative ease with which soil can be deformed. Consistency describes the degree of firmness of the soil which may be soft, firm, stiff or hard. The property of soil is generally associated with fine-grained soils, especially clays, for which the consistency is related to a large extent to water content.

The Swedish agriculturist Atterberg divided the entire range from solid state to liquid state into four stages:

(i) the Liquid state

(ii) the Plastic state

(iii) the Semi-soil state

(iv) the Solid state

The boundary water contents at which the soil undergoes a change from one state to another is called ***'Consistency Limits'*** or ***'Atterberg Limits'***.

Consistency Limits and Indices:

The consistency limits or Atterberg limits and certain indices related to these may be defined as follows:

(i) Liquid Limit

(ii) Plastic Limit

(iii) Shrinkage Limit

These limits are expressed as percent water content.

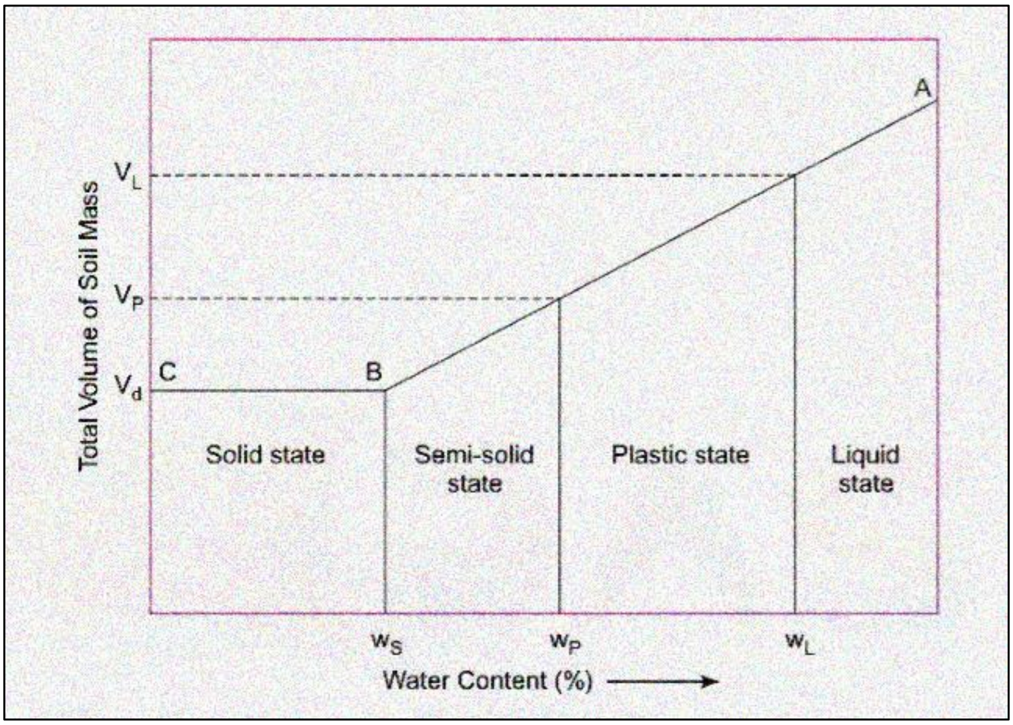

Fig 1. Consistency Limits

(i) Liquid Limit (w_L):

'Liquid limit' (LL or w_L) is defined as the arbitrary limit of water content at which the soil is just about to pass from the plastic state into the liquid state. At this limit, the soil possesses a small value of shear strength, losing its ability to flow as a liquid. It is defined as the minimum water content at which the soil is still in liquid state, but has a small shearing strength against flowing which can be measured by standard available means. With reference to standard liquid limit device, it is defined as the minimum water content at which a part of soil cut by a groove of standard dimensions, will flow together for of 12 mm under the impact of 25 blows in the device. It is measured by ***Liquid Limit Apparatus*** or ***Casagrande Apparatus***.

Determination of Liquid limit:

The test is determined in the laboratory with the help of standard liquid limit apparatus designed by Casagrande called Casagrande Apparatus. Given in IS:2720 (Part V)–1985.

The apparatus consists of a hard rubber base, over which a brass-cup is drops through a desired height. The brass cup can be raised and lowered to fall on the rubber base with the help of a cam operated by a handle. The height of fall of the cup can be adjusted with the help of adjusting screws. before starting the test, the height of call off the cup is adjusted to 1 cm.

Two types of grooving tools are used:

1. the Casagrande (BS) tool

2. ASTM tool

The IS: 9259-1979 designates these tools as a grooving tool (a) and grooving tool (b) respectively.

Casagrande tool cuts a groove of size 2 mm wide at the bottom, 11 mm wide at the top and 8 mm high while the ASTM tool cuts a groove 2 mm wide at the bottom, 13.6 mm at the top and 10 mm deep. The ASTM tool is used only for more sandy soils where the Casagrande tool tends to tear the sides of the groove.

about 120 gm of the specimen passing through 425 microns sieve is mixed thoroughly with distilled water in the evaporating dish to form a uniform paste. Portion of paste is placed in the cup where the cup rests on the base, squeezed down and spread into position and the groove is cut in the soil pat. The handle is rotated at a rate about 2 revolutions per second, and the number of blows are counted until the two parts of the soil sample come into contact at the bottom of the groove along a distance of 10 mm. After recording the number of blows, approximately 10 gm of soil from near the closed groove is taken for water content determination.

Since, it is difficult to adjust the water content precisely equal to the liquid limit when the groove should close in 25 blows, liquid limit is determined by plotting a graph between number of blows as abscissa on a logarithmic scale and the corresponding water content as ordinate.

Such a graph, known as the flow curve, is a straight line having the following equation:

$$\mathbf{w_1 - w_2 = I_f \log_{10} \frac{n_1}{n_2}}$$

where, w_1 = water content corresponding to blows, n_1

w_2 = water content corresponding to blows, n_2

I_f = slope of the curve, known as the *flow index*

Flow Index:

The flow index or the slope of the curve can be determined from the relation:

$$\mathbf{I_f = \frac{w_1 - w_2}{\log_{10} \frac{n_2}{n_1}}}$$

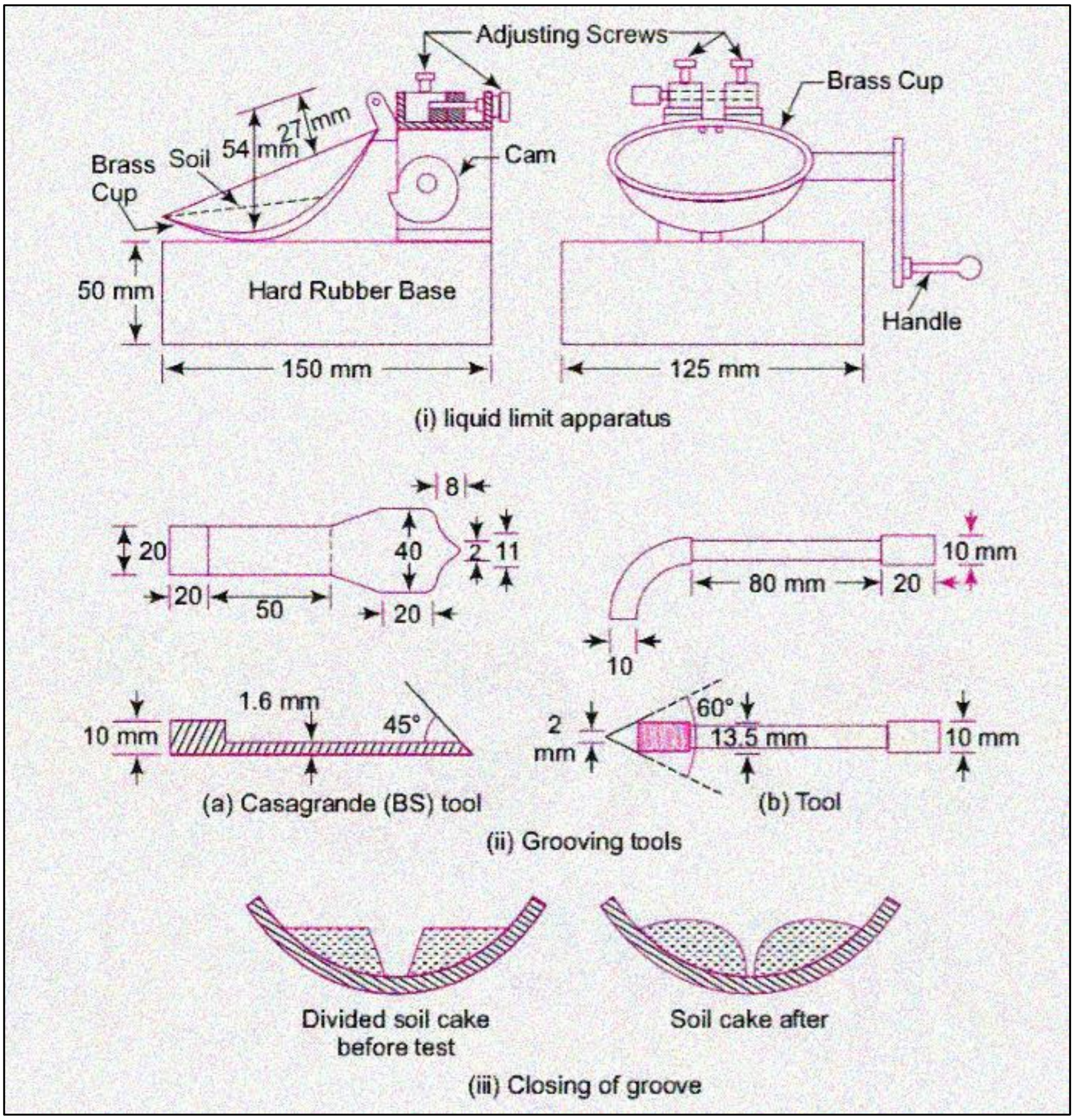

Fig 2. Liquid Limit Apparatus

(ii) Plastic Limit (w_P):

'Plastic limit' (PL or w_P) is the arbitrary limit of water content at which the soil tends to pass from the plastic state to the semi-solid state of consistency. It is defined as the minimum water content at which the soil will just begin to crumbles i.e., develops cracks when rolled into a thread approximately 3 mm in diameter. It is measured by ***Plastic Limit Test***.

Determination of Plastic limit:

A soil specimen passing through 425 microns sieve, mixed thoroughly with distilled water until the soil mass becomes plastic enough to be easily moulded with fingers. A ball is formed with about 8 gm this plastic soil mass and rolled between the fingers on a glass plate with just sufficient pressure to roll the mass into thread of uniform diameter throughout its length. When the diameter of 3 mm is reached, the soil is remoulded again into a ball. This process of rolling and remoulding is repeated until the thread starts just crumbling at a diameter of 3 mm. The crumbled treads are kept for water content determination. The test is repeated for at least three times. The plastic limit if then taken as the average of three water contents.

The plasticity index is calculated from the relation:

$$\mathbf{I_p = w_P - w_P}$$

Toughness index (I_T):

The toughness index is defined as the ratio of the plasticity index to the flow index.

$$\mathbf{I_T = I_P / I_f}$$

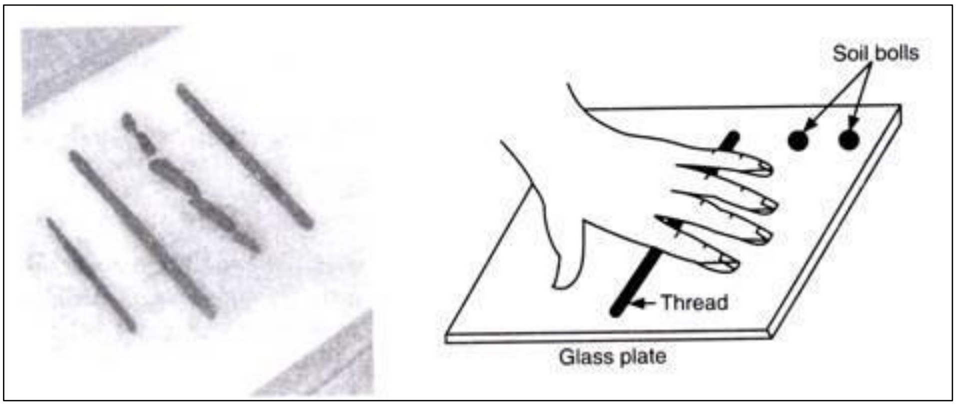

Fig 3. Plastic Limit Test

Shrinkage Limit (w_S):

'Shrinkage limit' (SL or w_S) is the arbitrary limit of water content at which the soil tends to pass from the semi-solid to the solid state. It is that water content at which a soil, regardless, of further drying, remains constant in volume.

In other words, it is the maximum water content at which further reduction in water content will not cause a decrease in volume of the soil mass, the loss in moisture being mostly compensated by entry of air into the void space. In fact, it is the lowest water content at which the soil can still be completely saturated.

The change in colour upon drying of the soil, from dark to light also indicates the reaching of shrinkage limit. Upon further drying, the soil will be in a partially saturated solid state; and ultimately, the soil will reach a perfectly dry state.

Determination of Shrinkage limit:

The method is used for determination of shrinkage limit in the laboratory. The equipment consists of porcelain evaporating dish about 12 cm in diameter with flat bottom, a stainless Steel shrinkage dish 45 mm in diameter and 15 mm in height with flat bottom, two glass plates each 75 mm X 75 mm, one of plain glass and other having three metal prongs and a glass cup 50 mm in diameter and 25 mm in height, with its top rim round smooth and level.

The volume V_1 of the shrinkage dish is first determined by filling it overflow with mercury, removing by pressing a flat glass plate over its top and then taking mass of the dish filled with mercury. The mass of the mercury contained in the dish, divided by its density (13.6 g/cm^3) gives the volume of the dish.

About 50 gm of soil passing 425 microns IS sieve is mixed with distilled water sufficient to fill the voids completely and to make soil paste enough to be worked into shrinkage dish without the inclusion of air bubbles. The inside of shrinkage dish is coated with a thin layer of Vaseline. A volume of wet soil of about one-third the volume of dish is put in its centre and the soil is caused to flow to the edges by tapping it gently on a hard surface.

The dish is gradually filled by adding more soil in instalments followed by gently tapping to exclude the inclusion of air. The excess of soil is stuck off with straight edge and soils adhering to the outside of the dish is wipe off. The dish filled with soil is done immediately weighed.

The mass M_1 of the better soil pat, of volume V_1, is thus known by subtracting the mass of the empty dish from the mass of the wet soil plus the dish is taken above. The dish is then placed in the oven. The soil pat will have volumetric shrinkage on drying.

The mass M_d of the dry soil pat is found. To find the volume V_d of the dry soil pat, the glass cup is first filled with mercury and excess mercury is removed by pressing the glass plate with three prongs firmly over the top of the cup. The cup is wiped off any mercury which may be adhering to its outside surface, placed in the evaporating dish. The dry soil pat is placed on the surface of the mercury of the cup and is carefully forced down by means of glass with prongs. The mass of the mercury so displaced added by its density give the volume V_d of the dry soil pat.

The shrinkage limit is then calculated from the following equation:

$$\mathbf{w_s = \left[w_1 - \frac{(V_1 - V_d)\gamma_w}{W_d}\right] x\ 100}$$

where, w_1 = water content of the original saturated sample of the volume V_1

V_d = dry volume of the soil sample

W_d = dry weight of the soil sample

M_d = dry mass of soil sample

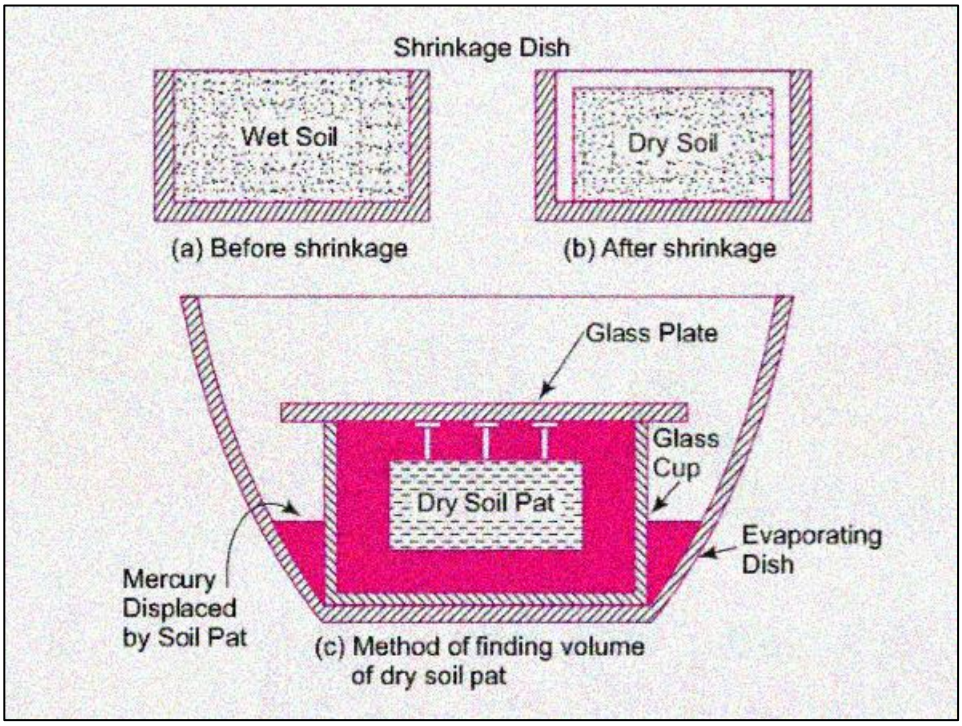

Fig 4. Shrinkage Limit Apparatus

Plasticity:

It is defined as the property of soil which allows it to be deformed rapidly, without rupture, without elastic rebound, and without volume change.

Plasticity Index (I_P):

'Plasticity index' (PI or Ip) is the range of water content within which the soil exhibits plastic properties is called plastic range and is indicated by plasticity index. The plasticity index is defined as the numerical difference between liquid limit and plastic limit of a soil.

$$\textbf{PI (or Ip)} = (\textbf{LL} - \textbf{PL}) = (w_L - w_P)$$

When the plastic limit cannot be determined, the material is said to be non-plastic (NP).

When the plastic limit is equal to or greater than the liquid limit, the plasticity index is reported as zero. Plasticity index for sands is zero.

Plasticity index	*Plasticity*
0	Non-plastic
1 to 5	Slight
5 to 10	Low
10 to 20	Medium
20 to 40	High
> 40	Very high

Table 1. Plasticity Characteristics

Liquidity Index (I_L):

'Liquidity index (LI or IL)' or 'Water-plasticity ratio' is the ratio, expressed as a percentage, the difference between the natural water content and the plastic limit, to its plasticity index.

$$\textbf{LI (or } \mathbf{I_L}\textbf{)} = \frac{\mathbf{w - w_P}}{\mathbf{I_P}}$$

where w= the natural water content of the soil

If, IL = 0, w = PL

IL = 1, w = LL

IL > 1, the soil is in liquid state

IL < 0, the soil is in semi-solid state and is stiff.

Consistency Index (I_C):

'Consistency index' or 'Relative consistency' (CI or I_C) is defined as the ratio of the difference between liquid limit and the natural water content to the plasticity index of a soil.

$$\textbf{CI (or Ic)} = \frac{\mathbf{w_L - w}}{\mathbf{I_P}}$$

where w = natural water content of the soil (water content of a soil in the undisturbed condition in the ground)

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

If, $I_C = 0$, w = LL

$I_C = 1$, w = PL

$I_C > 1$, the soil is in semi-solid state and is stiff

$I_C < 0$ or -ive, the natural water content is greater than LL, and the soil behaves just like a liquid