Assistant Prof. Dr.Khitam Abdulhussein Saeed

Al-Mustansiriyah University

Faculty of Civil Engineering

Water Resources Engineering Department

SOIL MECHANICS

CHAPTER TWO

2020-2021

Third

Stage Students

Undergraduate students (3th stage students)
Faculty of Engineering
Mustansiriyah University
Water Resources Engineering Department

CHAPTER TWO

Soil Consistency

1. Soil Consistency (Atterberg limits)

Most of soils include a fine fraction of silt, clay or a combination. The consistency of these soils can range from a dry solid condition to a liquid form with successive addition of water and mixing as necessary to expand pore space for acceptance of water**. The Atterberg limits** are a basic measure of the critical water contents of a fine-grained soil: **its shrinkage limit, plastic limit, and liquid limit** as shown in the Figure (1). As a dry, clayey soil takes on increasing amounts of water, it undergoes distinct changes in behavior and consistency. Depending on the water content of the soil, it may appear in four states: solid, semi-solid, plastic and liquid. In each state, the consistency and behavior of a soil is different and consequently so are its engineering properties.

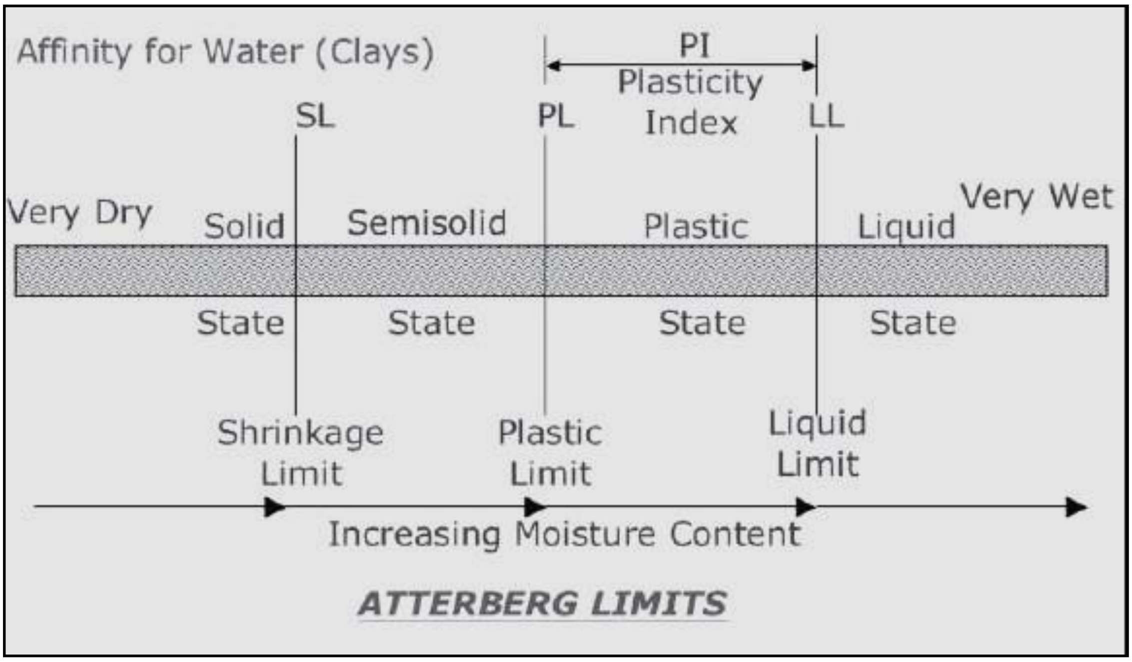


Figure 1: The Consistency Limits (atterberg limit)

1.2 Plasticity Limits

Liquid limit (L.L): is defined as the moisture content in percent at which the soil changes from liquid to plastic state.

Plastic Limit (P.L.): The moisture contents in % at which the soil changes from plastic to semi solid state.

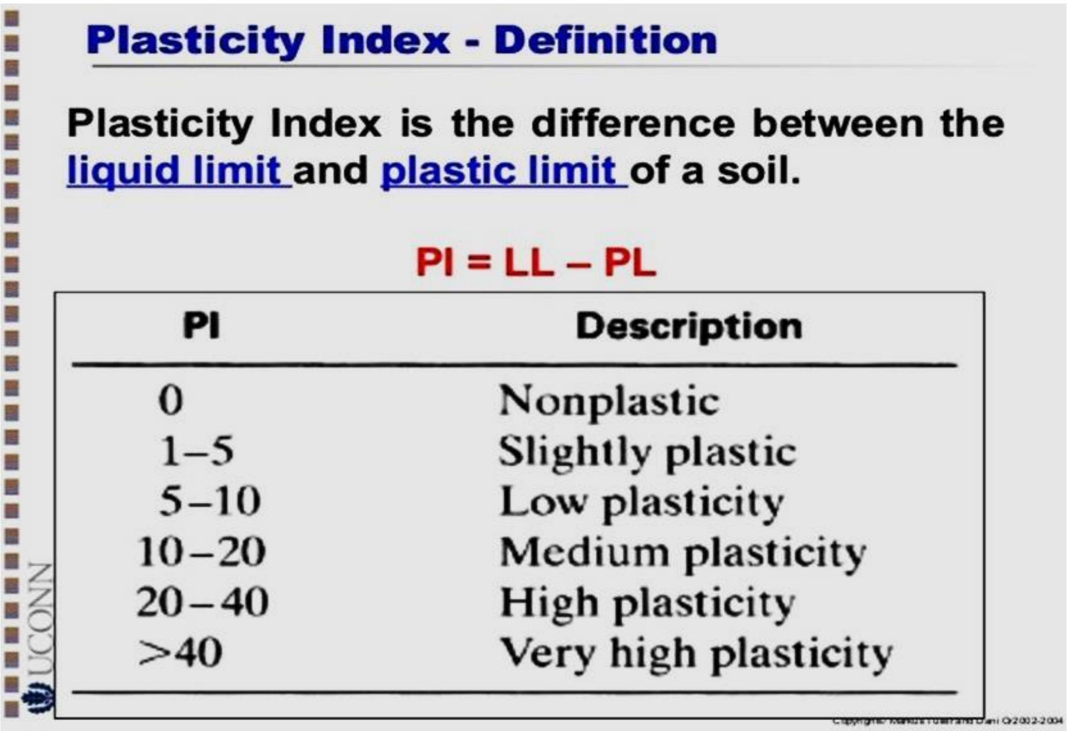
Shrinkage Limit (S.L.): The moisture contents in % at which the soil changes from semi solid to solid state.

Plasticity Index (P.I.): it is the range in moisture content when the soil exhibited its plastic behavior:

P.I = L.L – P.L

Liquidity Index (L.I. or IL) : a relation between the natural moisture contents (c^{a}) and (L.L.) and (P.L.) in form:

If LI > 1_ Then the soil at Liquid state
If LI = 1 then the soil at L.L.
If ¨LI < 1 then the soil below L.L.



Plasticity Index - Definition

Plasticity Index is the difference between the liquid limit and plastic limit of a soil.

PI = LL – PL

PI	Description
0	Nonplastic
1–5	Slightly plastic
5–10	Low plasticity
10–20	Medium plasticity
20–40	High plasticity
>40	Very high plasticity

Plasticity Characteristics Of Soils

The plasticity of a soil is its ability to undergo deformation without cracking. It is an important index property of fine grained soil, especially for clayey soils. The adsorbed water in clayey soils is leads to the plasticity of soil. Adsorbed water in the clay particles allow the particles to slip over one another. The particles do not return to its original position following the deformation of soil. The soil becomes plastic only when it has clay minerals.

ATTERBERG LIMITS

1n 1911, A Swedish agriculture engineer Atterberg mentioned that a fine grained soil can exist in four states, namely, liquid, plastic, semi-solid or solid. The water content at which the soil changes from one state to other are known as Atterberg limits or Consistency limits.

It is very important properties of fine grained soils.

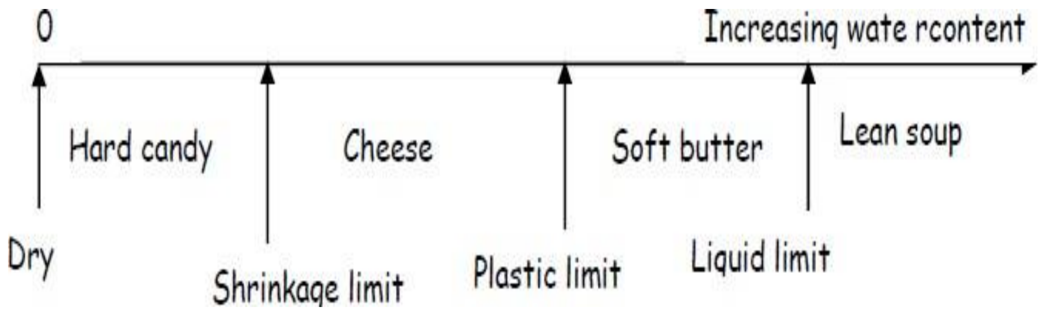


Figure 2 : Atterberg Limits

LL and SL can be understood from the study of clay water system. Adsorbed water layer is considered as an integral part of clay particle. As shown in Figure 3, when clay particles contain enough water, adsorbed water layers are not at all in contact with each other, and thus, there is no frictional resistance. It is at a liquid stage (lean soup). Now, if water is removed to a certain level at which all the adsorbed water layers are just in contact, frictional resistance will be developed at the contact points. This is considered to be the stage of LL. When it is further dried, overlapping of adsorbed water layer will take place. The limiting stage of this overlapping is the level at which all particles themselves touch each other and no further overlapping possible. This stage is considered as the SL (cheese). PL may have some degree of overlapping of adsorbed water layers (soft butter)

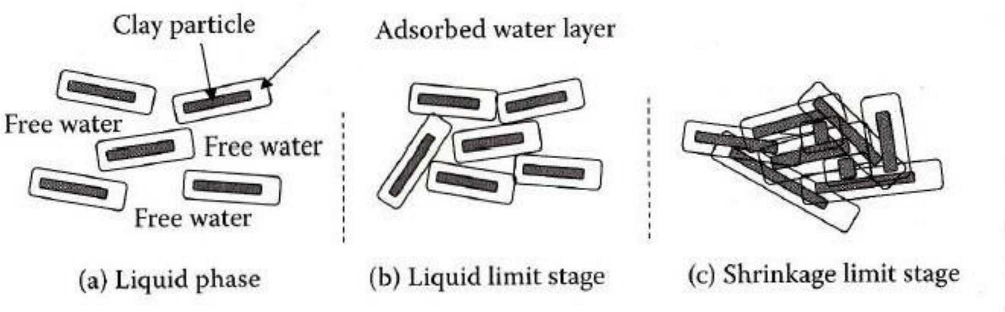


Figure 3: Clay particles with adsorbed water layers in water

Determination of Shrinkage Limit

Shrinkage limit is the smallest water content at which the soil is saturated. It is also define as the maximum water content at which a reduction of water content will not cause a decrease in the volume of the soil mass.

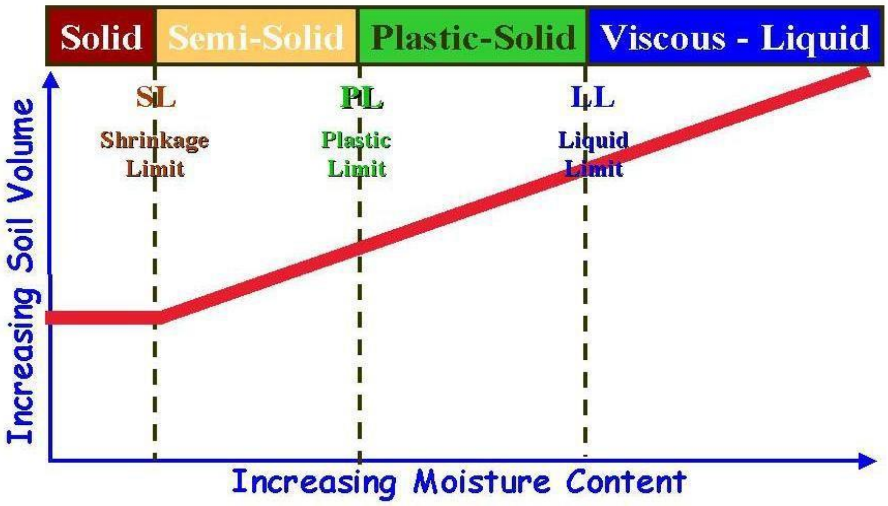


Figure 4: Definition of shrinkage limit

Figure 5(Stage(I)) shows the block diagram of a soil sample when it is fully saturated and has the water content greater than expected shrinkage limit, Figure 5 (Stage (II)) shows the sample at shrinkage limit and Figure 5 (Stage (III)) depicts the condition at oven dry state.

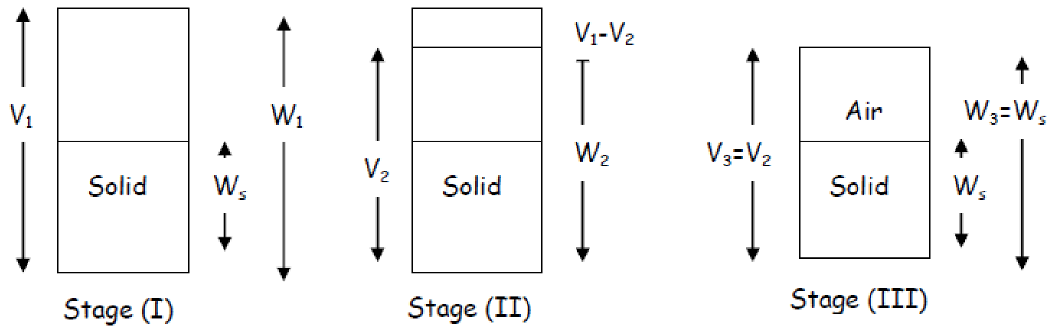


Figure 5: Stages for derivation of shrinkage limit

Weight of water in stage (I), = $W_a - W_s$

Loss of weight of water from stage (I) to stage (II), = $(V_1 - V_2)\gamma_w$

Weight of water in stage (II), = $(W_1 - W_s) - (V_1 - V_2)\gamma_w$

From definition, shrinkage limit = water content in stage (II),

$$SL = \frac{(W_1 - W_s) - (V_1 - V_2)\gamma_w}{W_s}$$

$$SL = w_1 - \frac{(V_1 - V_2)}{M_s}\gamma_w$$

Where, w_1 is the water content in stage (I).

Plasticity, Liquidity, and Consistency Indexes

Plasticity index: Plasticity index (PI) is the range of water content over which the soil remains in the plastic state and mathematically defined as, $PI = LL - PL$

Liquidity index: Liquidity index indicates the nearness of its water content to its **liquid limit**: When the soil is at its liquid limit, its liquidity index is 100% and it behaves as a liquid. When the soil is at the plastic limit, its liquidity index is zero.

Negative values of the liquidity index indicate water content smaller than the plastic limit. The liquidity index is also known as Water-Plasticity ratio.

Mathematically,

$$LI = w - wp / PI \times 100$$

Consistency index: the consistency index indicates the consistency of a soil. It shows the nearness of the water content of the soil to its plastic limit. A soil with a consistency index of zero is at the liquid limit. It is extremely soft and has negligible shear strength. On the other hand, a soil at a water content equal to the plastic limit has a consistency index of 100%, indicating that the soil is relatively firm. A consistency index of greater than 100% shows that the soil is relatively strong.

$$CI = LL - w / PI \times 100$$

ACTIVITY OF SOILS

Activity of soil is the ratio of the plasticity index and the percentage of clay fraction (finer than 2μ).

$$A = PIF$$

$$\text{Activity} = \frac{PI}{\%\ of\ clay\ size\ particles}$$

Some useful notes:

ν_s : Constant at all stages

Degree of saturation (S %) at S.L. and up to =100%

Degree of Saturation in the region from S.L. and below < 100%

ν_t dry = $\nu_{t\ at\ S.L}$

ν_v dry = $\nu_{v\ at\ S.L}$

$e_{dry} = e_{S.L}$

Relative Density: is the ration of the actual density to the maximum possible density of the soil it is expressed in terms of void ratio.

$$RD(\%) = \frac{e_{max} - e_n}{e_{max} - e_{min}} * 100$$

Or $$RD(\%) = \frac{\gamma_{dmax}}{\gamma_{dn}} * \frac{\gamma_{dn} - \gamma_{dmin}}{\gamma_{dmax} - \gamma_{dmin}} * 100$$

e_{max}: The void ratio of the soil in its loosest condition

e_{min}: The void ratio of the soil in its densest condition

e_n: The void ratio of the soil in its natural condition

γ_{dmax}: Maximum dry unit weight (at e_{min})

γ_{dmin}: Minimum dry unit weight (at e_{max})

γ_{dn}: Natural dry unit weight (at e_n)

RD	Description
$0 - \frac{1}{3}$	loose
$\frac{1}{3} - \frac{2}{3}$	medium
$\frac{2}{3} - 1$	Dense

Example 1: for a granular soil, given, $\gamma_{dry} = 17.3 \frac{kN}{m^3}$, relative density = 82%, $\omega = 8\%$ and $G_s = 2.65$. If $e_{min} = 0.44$. what would be e_{max}? what would be the dry unit weight in the loosest state?

Solution:

$$\gamma_{dry} = \frac{G_s}{1+e_n} * 10 \Longrightarrow 17.3 = \frac{2.65}{1+e_n} * 10$$

$$\therefore\ e_n = 0.53 \Longrightarrow RD = \frac{e_{max} - e_n}{e_{max} - e_{min}} * 100$$

$$0.82 = \frac{e_{max} - 0.53}{e_{max} - 0.44} \Longrightarrow \therefore\ e_{max} = 0.94$$

$$\therefore\ \gamma_{dry}\,(at\ loosest) = \frac{G_s}{1 + e_{max}}\gamma_w = \frac{2.65}{1 + 0.94} * 10$$

$$= 13.65\ kN/m^3$$

Example 2: a granular soil is compacted to moist unit weight of 20.45 at moisture content of 18% . What is relative density of the compac Given, $e_{max} = 0.85$, $e_{min} = 0.42$ *and* $G_s = 2.65$?

Solution:

$$\gamma = \frac{G_s(1+\omega_c)}{1+e_n}\gamma_w \Longrightarrow 20.45 = \frac{2.65(1+0.18)}{1+e} * 10$$

$$\therefore e_n = 0.52 \Longrightarrow RD = \frac{e_{max}-e_n}{e_{max}-e_{min}} =$$

$$RD = \frac{0.85-0.52}{0.85-0.42} * 100 = 76.74\%$$

Example 3: A dry sample of soil having the following properties, L.L. = 52%, P.L. = 30%, G_s= 2.7, e= 0.53. Find: Shrinkage limit, dry density, dry unit weight, and air content at dry state.

Solution

Dry sample $\Longrightarrow e_{dry} = e_{shrinkage} = 0.53$

$\therefore S.e_{s.l} = G_s . \omega_{c_{s.l}} \Longrightarrow$ 1*0.53 =2.7 *S.L

S.L.= 19.6%

$\rho_{dry} = \frac{G_s}{1+e} \rho_w \Longrightarrow \rho_{dry} = \frac{2.7}{1+0.53} 1 = 1.764 \frac{gm}{cm^3}$

$\therefore \gamma_{dry} = \rho_{dry} * g = 1.764 * 10 = 17.64 \ kN/m^3$

Case is dry $\Longrightarrow$ s=0

$$\therefore A = n = \frac{e}{1+e} = \frac{0.53}{1+0.53} = 0.346$$

$\therefore A = 34.6\%$