CE 240
Soil Mechanics & Foundations
Lecture 3.1

Soil Consistency, Atterberg Limits

(Das, Ch. 3)

Outline of this Lecture

1. Soil consistency
2. Atterberg Limits
3. Liquid Limit, LL
4. Plastic Limit, PL
5. Plasticity Index, PI

What is Soil Consistency ?

- **Soil consistence provides a means of describing the degree and kind of cohesion and adhesion between the soil particles as related to the resistance of the soil to deform or rupture.**

- **Since the consistence varies with moisture content, the consistence can be described as dry consistence, moist consistence, and wet consistence.**

- **Consistence evaluation includes rupture resistance and stickiness.**

What is Soil Consistency ? (cont.)

- The rupture resistance is a field measure of the ability of the soil to withstand an applied stress or pressure as applied using the thumb and forefinger.

- Soil consistency is defined as the relative ease with which a soil can be deformed use the terms of soft, firm, or hard.

- Consistency largely depends on soil minerals and the water content.

Cohesion & Adhesion

- **Cohesion** is the attraction of one water molecule to another resulting from hydrogen bonding (water-water bond).

- **Adhesion** is similar to cohesion except with adhesion involves the attraction of a water molecule to a non-water molecule (water-solid bond).

When We Describe Consistency – We Attempt to Describe the Following

- Engineering/Environmental
  - Rupture Resistance – Moist and Dry Consistency
  - Stickiness – Wet Consistency
  - Plasticity- Wet Consistency
- Geophysical
  - Manner and Type of Failure
  - Penetration Resistance

Rupture Resistance

- **A measure of the strength of the soil to withstand an applied stress**

- **Moisture content is also considered**
  - **Dry**
  - **Moist (field capacity)**

Dry Consistency

Class	Description
Loose	Non-coherent Symbol L or LO or lo
Soft (<8 N)	Soil crushes under very low pressure
Slightly Hard (8 to < 20 N)	Soil material crushes- low pressure - little resistance
Modera. Hard (20 to < 40 N)	Soil material crushes- moderate pressure - resistance
Hard (40 to < 80 N)	Soil material crushes under strong pressure
Very Hard (80 to < 160 N)	Can not be crushed between thumb and forefinger.
Extremely Hard	Pressure applied by foot with full body

1 Newton (N) = 0.224 lb/ft

Dry and Moist Consistency

Moist	Dry	Stress Specimen Fails
Loose	Loose	0
Very Friable	Soft	< 8 N
Friable	Slightly Hard	8 to < 20 N
Firm	Moderately Hard	20 to < 40 N
Very Firm	Hard	40 to < 80 N
Extremely Firm	Very Hard	80 to < 160 N

1 Newton (N) = 0.224 lb/ft

Wet Consistency

- Describe Stickiness
  - The capacity of soil to adhere to other objects
  - Estimated at moisture content that displays maximum adherence between thumb and fore finger
- Describe Plasticity
  - Degree a soil can be molded or reworked causing permanent deformation without rupturing.

Stickiness Classes

- **Non-Sticky** – little or no soil adheres to fingers after release of pressure

- **Slightly Sticky** – soil adheres to both fingers after release of pressure with little stretching on separation of fingers

- **Moderately Sticky –** soil adheres to both fingers after release of pressure with some stretching on separation of fingers

- **Very Sticky -** soil adheres firmly to both fingers after release of pressure with stretches greatly on separation of fingers

Non-Sticky

Slightly-Sticky

Very Sticky

Why Plasticity?

Water Content Significantly affects properties of Silty and Clayey soils (unlike sand and gravel). Plasticity property describes the response of a soil to change in moisture content.

- Strength decreases as water content increases
- Soils swell-up when water content increases
- Fine-grained soils at very high water content possess properties similar to liquids
- As the water content is reduced, the volume of the soil decreases and the soils become plastic
- If the water content is further reduced, the soil becomes semi-solid when the volume does not change

Plasticity

- The degree to which puddled or reworked soil can be permanently deformed without rupturing
- Evaluation done by forming a 4 cm long wire of soil at a water content where maximum plasticity is expressed

Atterberg Limits

- Liquid Limit (LL) is defined as the moisture content at which soil begins to behave as a liquid material and begins to flow

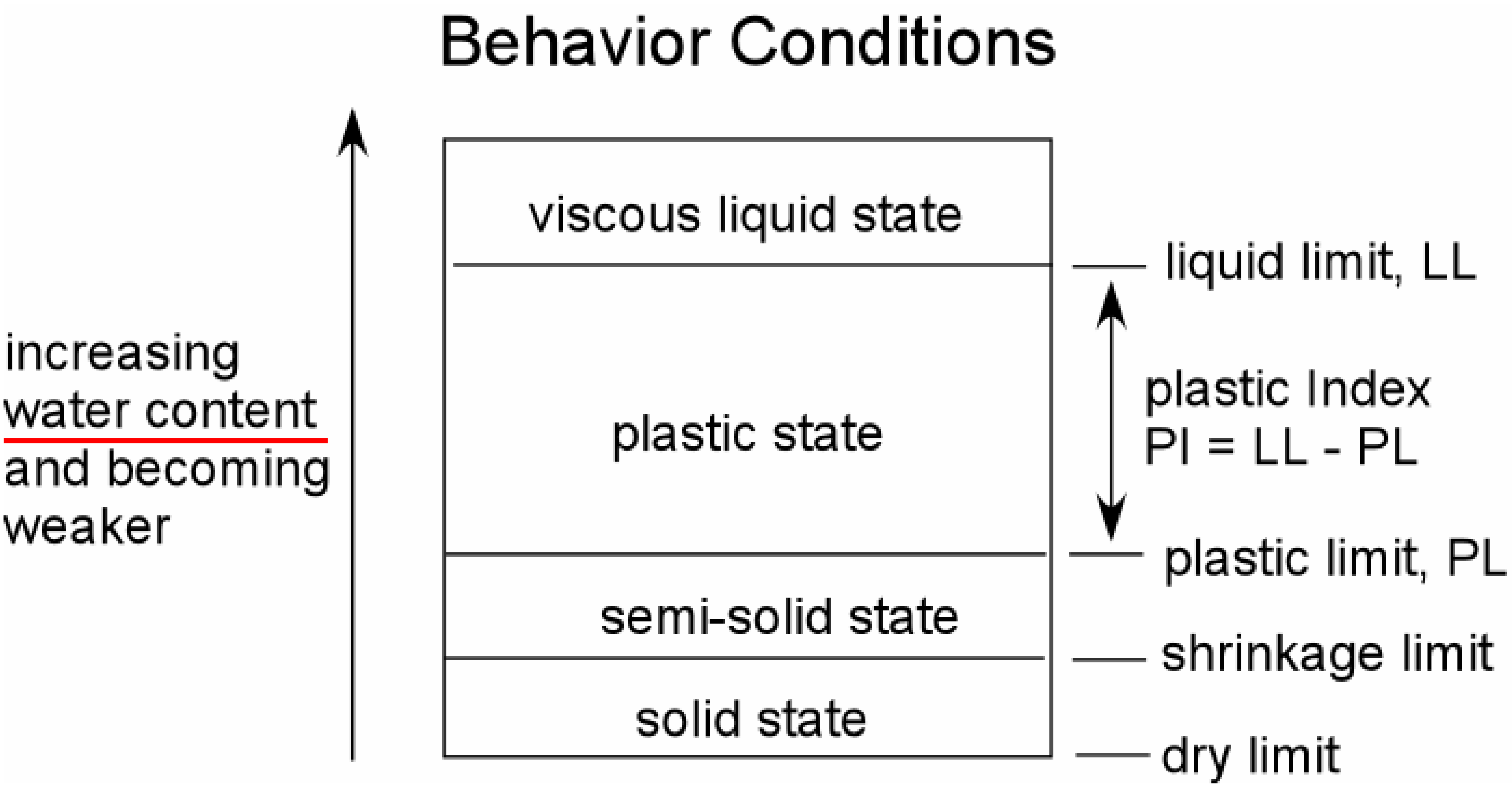
  (Liquid limit of a fine-grained soil gives the moisture content at which the shear strength of the soil is approximately 2.5kN/m^2)

- Plastic Limit (PL) is defined as the moisture content at which soil begins to behave as a plastic material
- Shrinkage Limit (SL) is defined as the moisture content at which no further volume change occurs with further reduction in moisture content.

  (*SL represents the amount of water required to fully saturate the soil (100% saturation)*)

Consistency of Soils

Atterberg limits are the limits of water content used to define soil behavior. The consistency of soils according to Atterberg limits gives the following diagram.



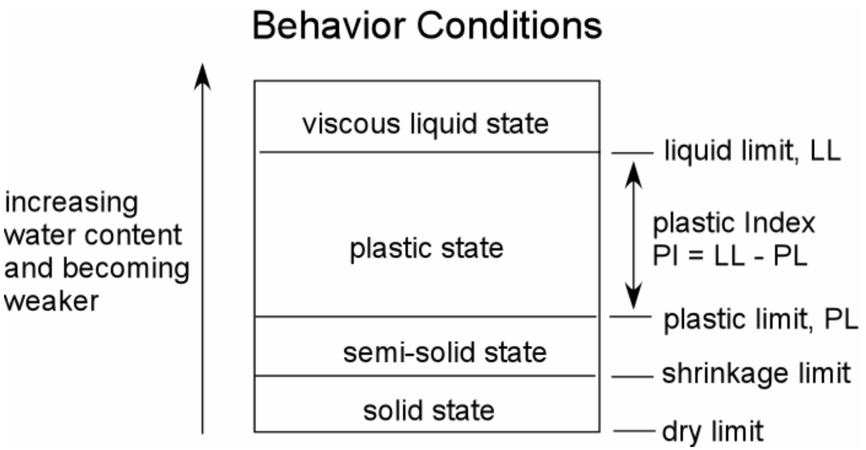
LL: The lowest water content above which soil behaves like liquid, normally below 100.

PL: The lowest water content at which soil behaves like a plastic material, normally below 40.

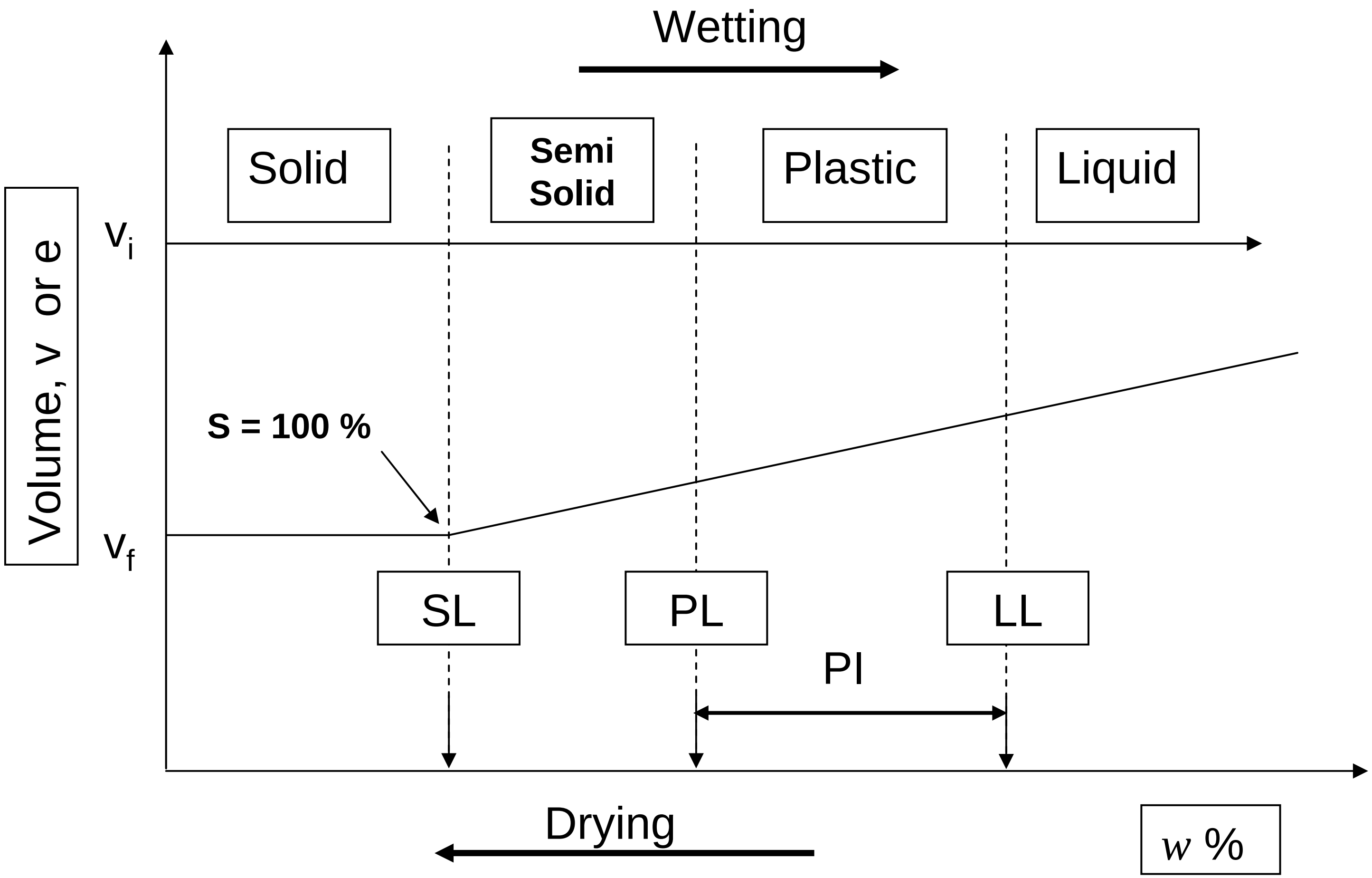
PI: The range between LL and PL.

Shrinkage limit: the water content below which soils do not decrease their volume anymore as they continue dry out. – needed in producing bricks and ceramics .

Consistency of Soils



Atterberg Limits (cont.)

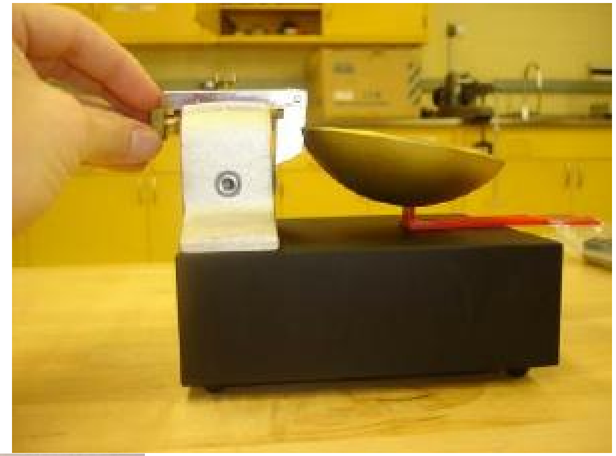


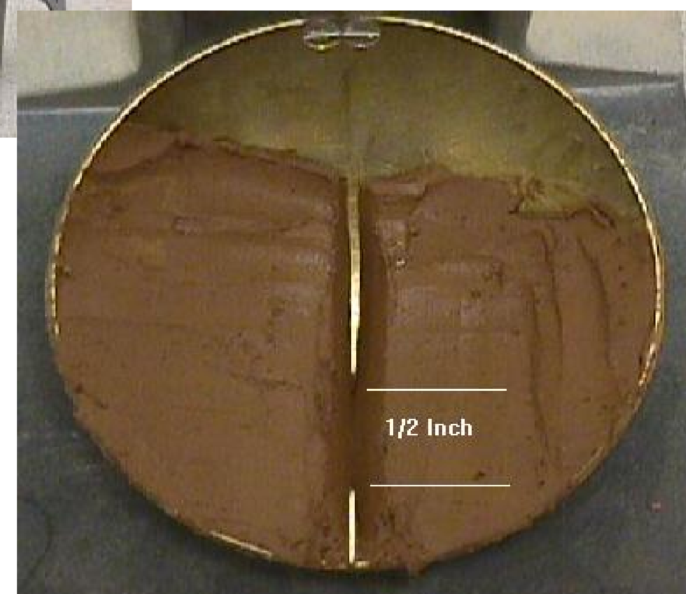
Liquid Limit (LL)

- In the lab, the LL is defined as the moisture content (%) required to close a 2-mm wide groove in a soil pat a distance of 0.5 in along the bottom of the groove after 25 blows.
- ASTM D 4318
- Soil sample size 150g passing # 40 sieve
- Equipment: Casagrande liquid limit device

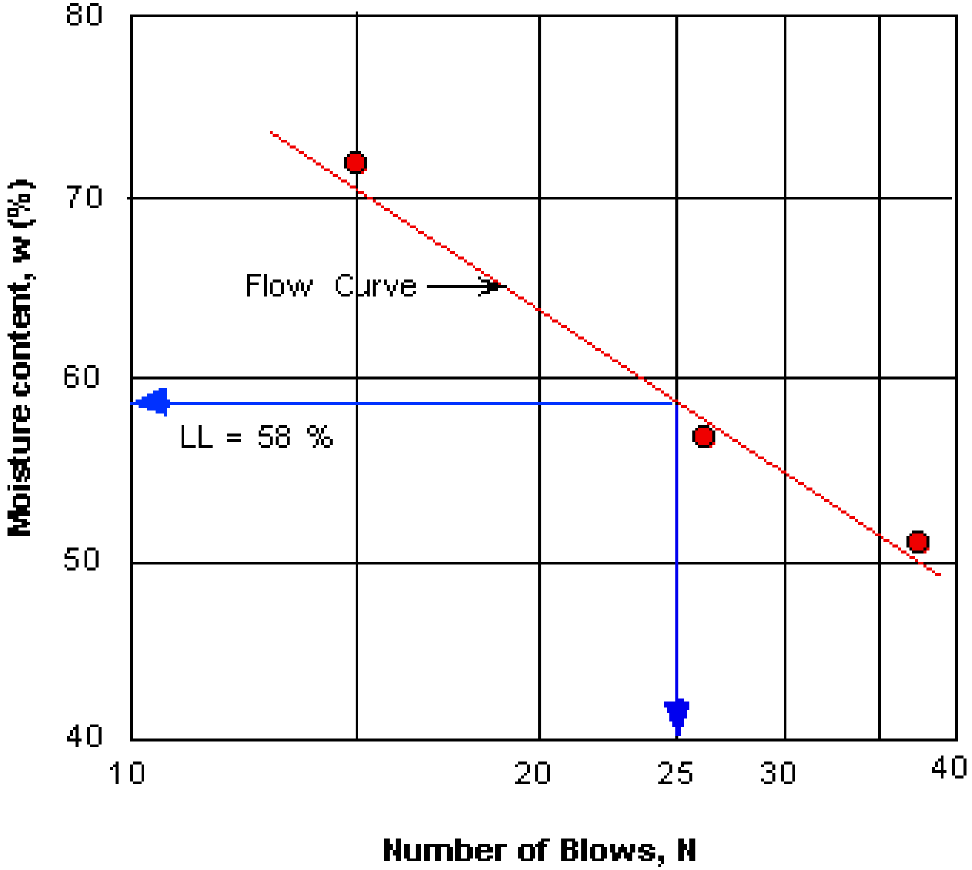
Liquid Limit (Procedure)

- 150g air dry soil passing # 40 sieve
- Add 20% of water - mix thoroughly
- Place a small sample of soil in LL device (deepest part about 8-10mm)
- Cut a groove (2mm at the base)
- Run the device, count the number of blows, N
- Stop when the groove in the soil close through a distance of 0.5in
- Take a sample and find the moisture content
- Run the test three times [N~(10-20), N~(20-30) and N~(35-45)] and
- Plot number of blows vs moisture content and determine the liquid limit (LL) (moisture content at 25 blows)




1/2 Inch

Determining LL



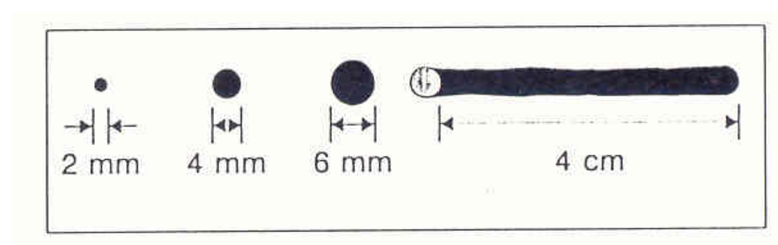
Plastic Limit (PL)

- The moisture content (%) at which the soil when rolled into threads of 3.2mm (1/8 in) in diameter, will crumble.
- Plastic limit is the lower limit of the plastic stage of soil
- Plasticity Index (PI) is the difference between the liquid limit and plastic limit of a soil

Plastic Limit (cont.)

Plasticity Class

- **Non-Plastic** – will not form a 6 mm dia, 4 cm long wire, or if formed , can not support itself if held on end
- **Slightly Plastic** – 6 mm dia, 4 cm long wire wire supports itself, 4 mm dia, 4 cm long wire wire does not
- **Moderately Plastic** – 4 mm dia, 4 cm long wire wire supports itself, 2 mm dia, 4 cm long wire wire does not
- **Very Plastic** – 2 mm dia, 4 cm long wire wire



Plastic Limit (Procedure)

- **Take 20g of soil passing #40 sieve into a dish**
- **Add water and mix thoroughly**
- **Prepare several ellipsoidal-shaped soil masses by quizzing the soil with your hand**
- **Put the soil in rolling device, and roll the soil until the thread reaches 1/8 in**
- **Continue rolling until the thread crumbles into several pieces**
- **Determine the moisture content of about 6g of the crumbled soil.**

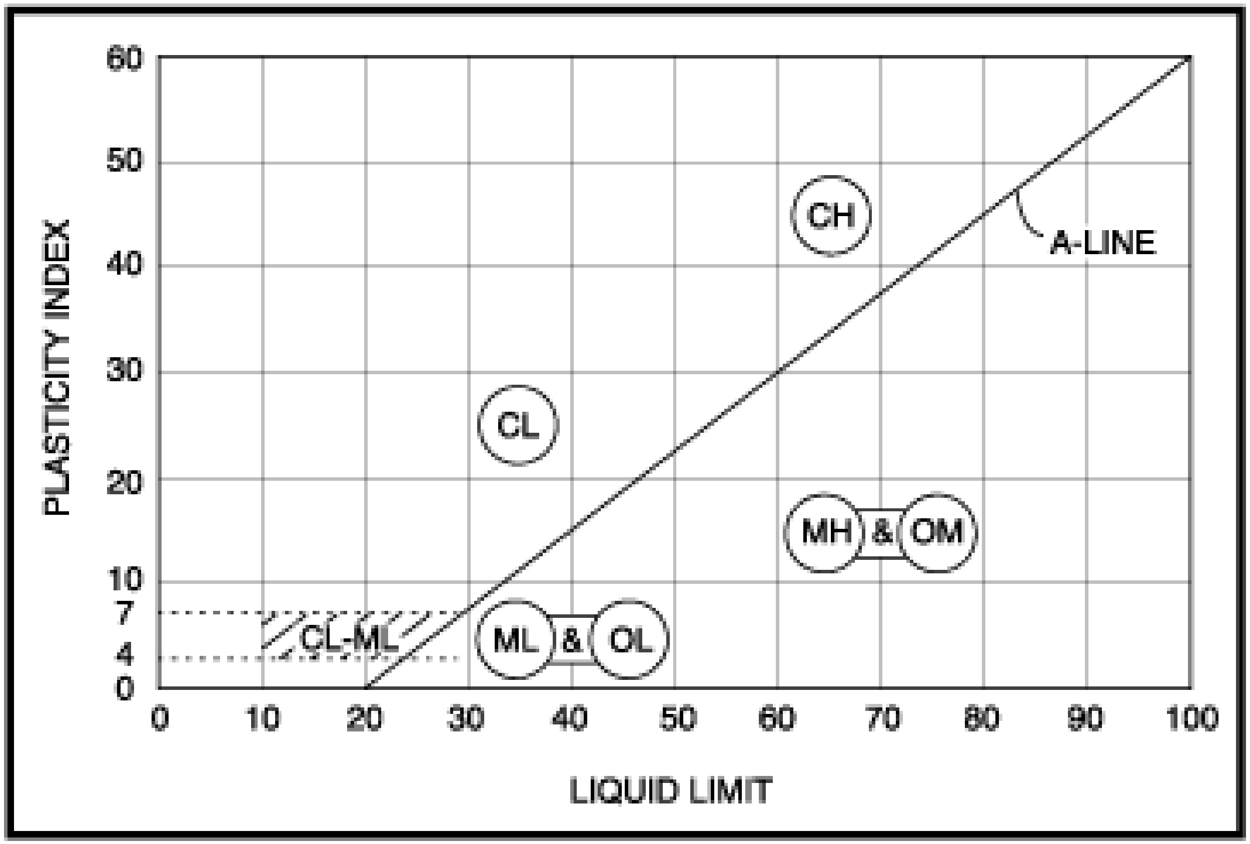
Plasticity Index, PI

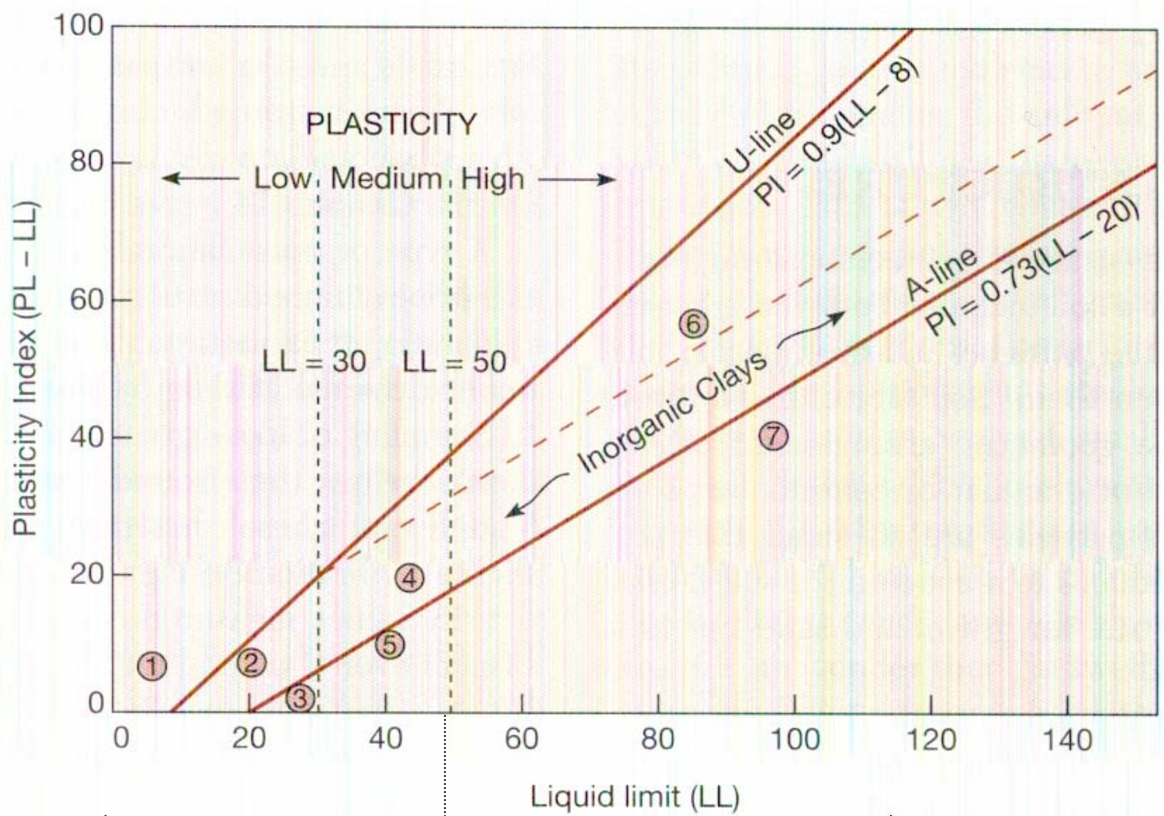
- Plasticity Index is the difference between the liquid limit and plastic limit of a soil

$$PI = LL - PL$$

- After finding LL and PI use plasticity chart to classify the soil

Plasticity Chart





Increase permeability and decrease compressibility

Lower compressibility **Higher compressibility**

Key:

1) Cohesionless soils
2) Inorganic clays, low plasticity
3) Inorganic silts, low compressibility
4) Inorganic clays, medium plasticity
5) Inorganic silts and organic clays, medium compressibility
6) Inorganic clays, high plasticity
7) Inorganic silts and organic clays, high compressibility

West, Figure 7.11 Plasticity Chart

Example 3.7

Following are the results of a shrinkage limit test:

- Initial volume of soil in a saturated state = 16.2 cm^3
- Final volume of soil in a dry state = 10.8 cm^3
- Initial mass in a saturated state = 44.6 g
- Final mass in a dry state = 32.8 g

Determine the shrinkage limit of the soil.

Solution

From Eq. (3.52),

$$SL = \left(\frac{M_1 - M_2}{M_2}\right)(100) - \left(\frac{V_i - V_f}{M_2}\right)(\rho_w)(100)$$

$$M_1 = 44.6\text{g} \qquad V_i = 16.2 \text{ cm}^3 \qquad \rho_w = 1 \text{ g/cm}^3$$

$$M_2 = 32.8\text{g} \qquad V_f = 10.8 \text{ cm}^3$$

$$SL = \left(\frac{44.6 - 32.8}{32.8}\right)(100) - \left(\frac{16.2 - 10.8}{32.8}\right)(1)(100)$$

$$= 35.97 - 16.46 = \mathbf{19.51\%}$$

3.11 Liquidity Index and Consistency Index

The relative consistency of a cohesive soil in the natural state can be defined by a ratio called the *liquidity index*, which is given by

$$LI = \frac{w - PL}{LL - PL} \tag{3.55}$$

where w = *in situ* moisture content of soil.

The *in situ* moisture content for a sensitive clay may be greater than the liquid limit. In this case (Figure 3.20),

$$LI > 1$$

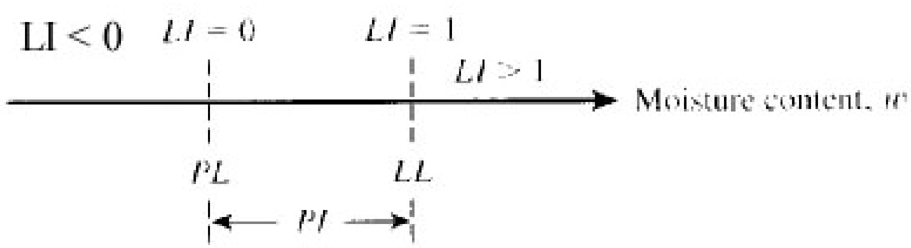


Figure 3.20 Liquidity index

Soil deposits that are heavily overconsolidated may have a natural moisture content less than the plastic limit, in this case we have $LI < 0$

Why Atterberg Limits ?

- **Atterberg limits are important to describe the consistency of fine-grained soils**
- **A fine-grained soil usually exists with its particles surrounded by water.**
- **The amount of water in the soil determines its state or consistency**
- **Four states are used to describe the soil consistency;**

  solid, semi-solid, plastic and liquid

Why Atterberg Limits ? (cont.)

- **The knowledge of the soil consistency is important in defining or classifying a soil type or predicting soil performance when used a construction material. The soil consistency is a practical and an inexpensive way to distinguish between silts and clays.**

Estimating Clay Mineralogy Using Consistency and Color

Wet Consistence	Moist Consistence	Moist Matrix Color	Estimated Mineralogy
Very Sticky Very Plastic	Firm to Very Firm or greater	10YR 2.5Y 5Y	2:1 Smectite
Slightly Sticky to Sticky Slightly Plastic to Plastic	Friable to Firm	2.5YR or Redder (e.g. 10R, 7.5R)	1:1 Kaolinite
Sticky Plastic	Firm	5YR 7.5YR 10YR	Mixed, 1:1 and 2:1

Reading Assignment:

Das, Ch. 3

Homework:

3.18, 3.20