# INS 3121
# SOIL MECHANICS

## CONSISTENCY LIMITS

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# 4.1 Introduction

- When clay minerals are present in fine-grained soil, the soil can be remolded in the presence of some moisture without crumbling.
- This cohesive nature (plasticity of soil) is caused by the adsorbed water surrounding the clay particles.
- In the early 1900s, a Swedish scientist named Atterberg developed a method to describe the consistency of fine-grained soils.
- A method for describing the limit consistency of fine-grained soils on the basis of moisture content

# 4.1 Introduction

- Depending on the moisture content, the behavior of soil can be divided into four basic states—solid, semisolid, plastic, and liquid.
- The boundary of these states is called Atterberg Limit

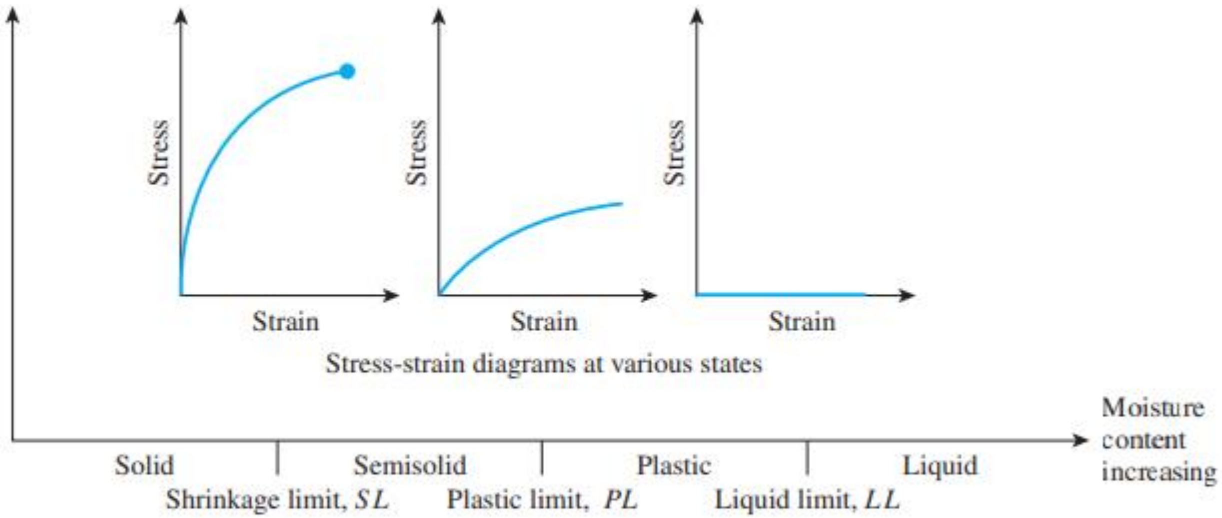
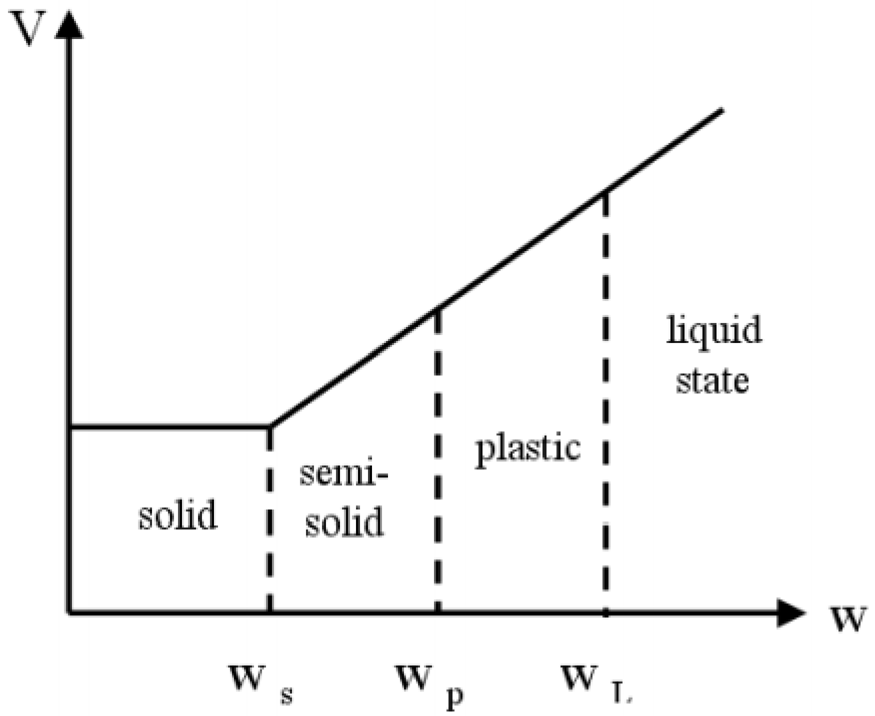



*Figure 4.1* Atterberg limits



# 4.1 Introduction

1. Liquid Limit, $\omega_L$, LL, Liquid State : No shear strength
2. Plastic Limit, $\omega_p$ , PL, Plastic State : could be molded and retain as shape
3. Shrinkage Limit, $\omega_s$ , SL, Semi-Solid : Soil crumbles with remolding

# 4.1 Introduction

- Plastic Index, $I_p$

$$I_p = \omega_L - \omega_p$$

- Shrinkage Index, $I_s$

$$I_s = \omega_p - \omega_s$$

- Liquidity Index, $I_L$

$$I_L = \frac{\omega - \omega_p}{I_p}$$

- Consistency Index, $I_c$

$$I_c = \frac{\omega_L - \omega}{I_p}$$

$$I_c + I_L = 1$$

# 4.2 Liquid Limit (LL)

- Liquid limit : the moisture content, in percent, required to close a distance of 12.7 mm along the bottom of the groove (see Figures 4.2 c and d) after 25 blows.

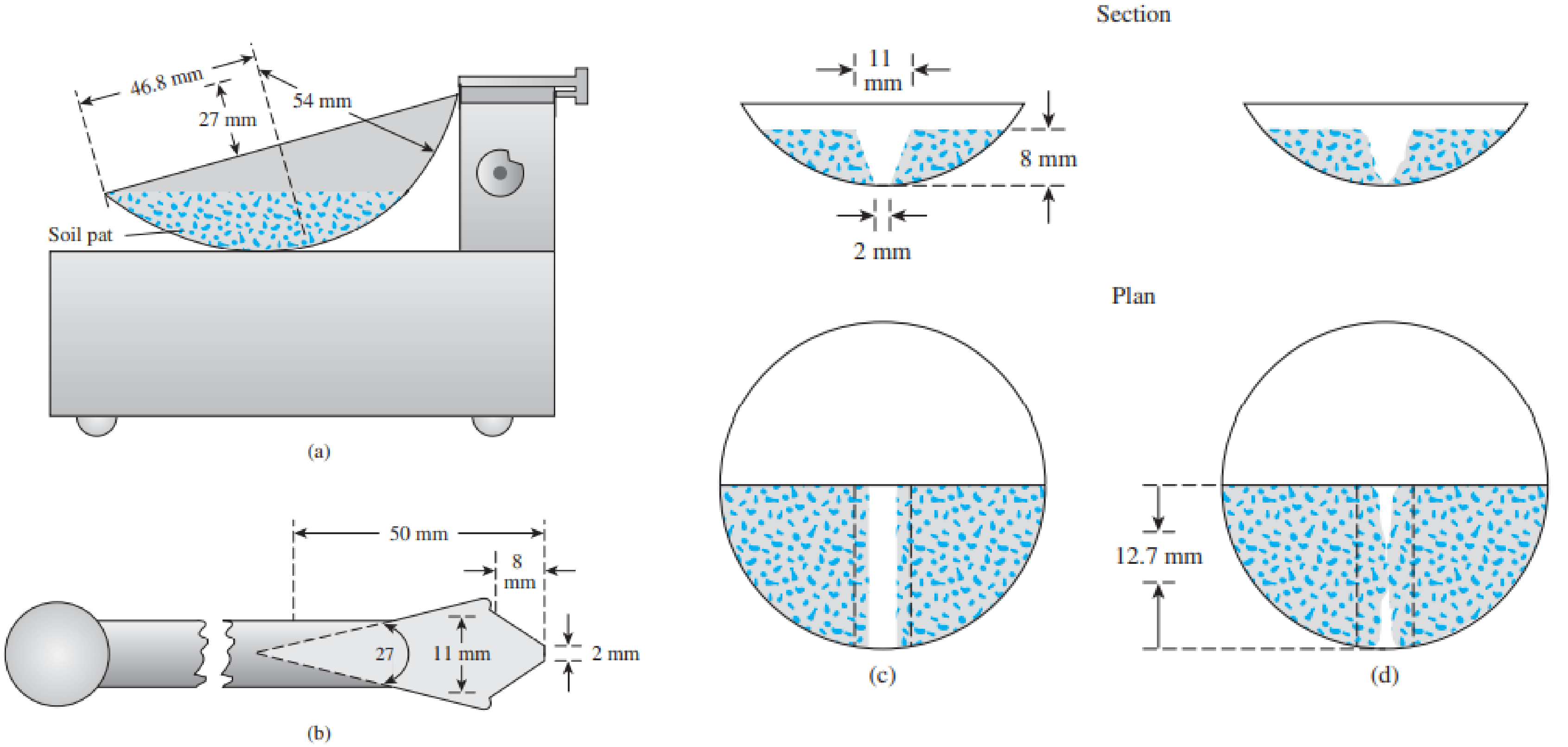



*Figure 4.2* Liquid limit test: (a) liquid limit device; (b) grooving tool; (c) soil pat before test; (d) soil pat after test

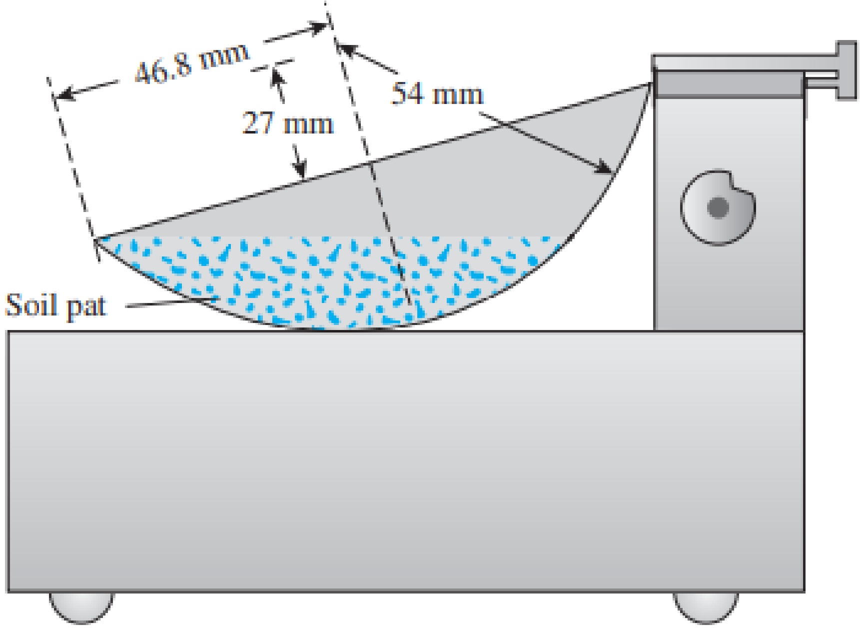
# 4.2 Liquid Limit (LL)

[Liquid limit test]

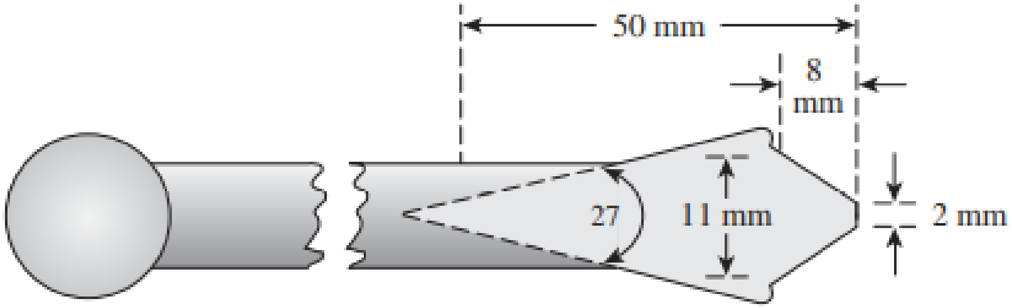
1. Place a soil paste in the cup.

2. A groove is then cut at the center of the soil pat with the standard grooving tool.

3. By the use of the crank-operated cam, the cup is lifted and dropped from a height of 10 mm.




(a)




(b)

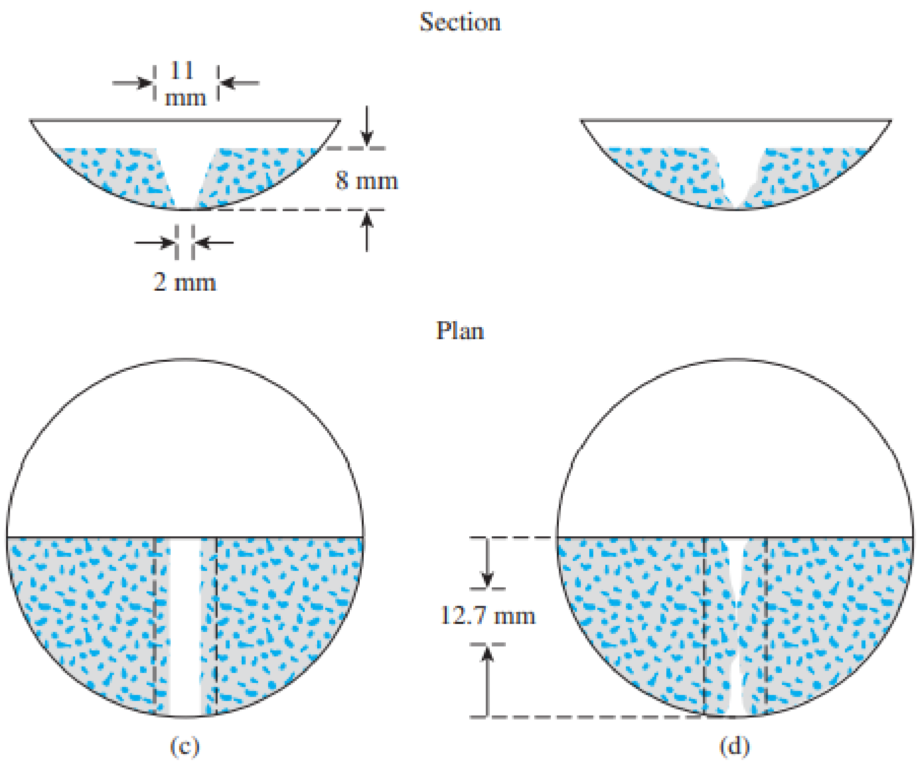
# 4.2 Liquid Limit (LL)

Liquid limit test

4. Count the number of blows N for the groove in the soil to close through a distance of 13 mm

5. Collect a moisture sample from the soil in the cup in a moisture can

6. Add more water to the soil paste (within 10 – 50 of the number of blows measured)



# 4.2 Liquid Limit (LL)

Liquid limit test

7. Determine the moisture content for each of the three trials

8. Plot a semilog graph for moisture content (arithmetic scale) versus number blows N (log scale)

9. From the straight line, determine the moisture content corresponding to 25 blows. This is the Liquid Limit of the soil.

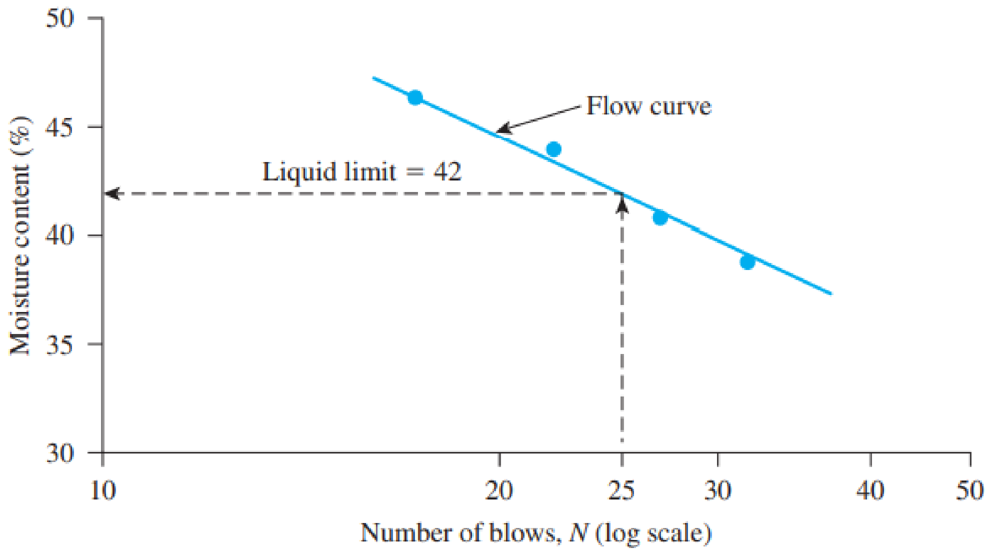



***Figure 4.5***
Flow curve for liquid limit determination of a clayey silt

# 4.2 Liquid Limit (LL)

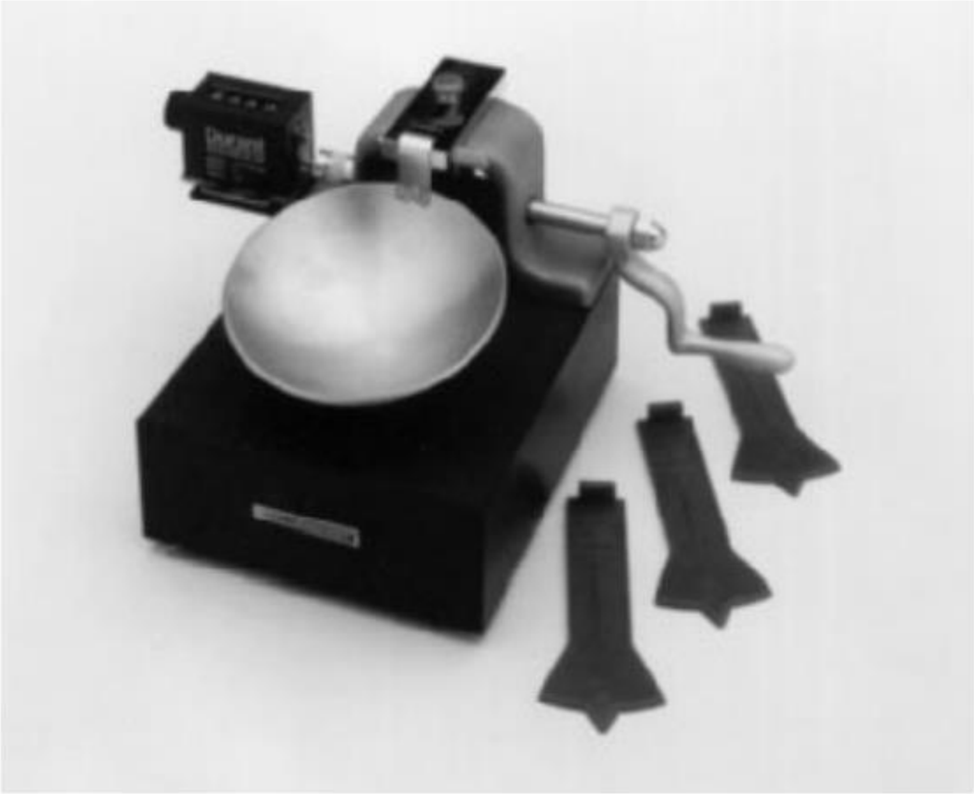
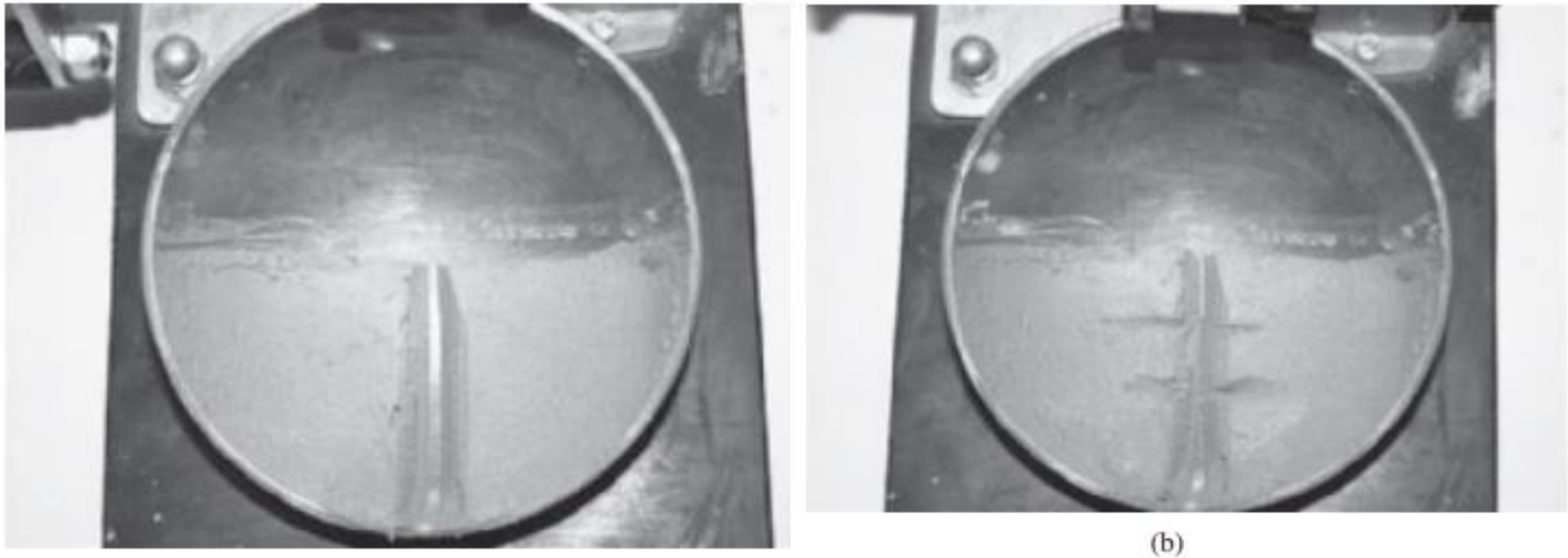


*Figure 4.3* Liquid limit test device and grooving tools (*Courtesy of ELE International*)

# 4.2 Liquid Limit (LL)



(a) (b)

**Figure 4.4**
Photographs showing the soil pat in the liquid limit device: (a) before test; (b) after test [*Note*: The half-inch groove closure in (b) is marked for clarification] (*Courtesy of Braja M. Das, Henderson, Nevada*)

# 4.3 Plastic Limit (PL)

- Plastic limit: the moisture content, in percent, at which the soil crumbles, when rolled into threads of 1/8 in. (3.2mm) in diameter.

- Plasticity index (PI)

- PI = LL - PL

# 4.3 Plastic Limit (PL)

Plastic Limit Test

1. Add water to the soil and mix thoroughly

2. Prepare several ellipspidally shape soil masses by squeezing the soil with your fingers.

3. Take one of the ellipsoidally shaped soil massess and roll it on a ground glasss plate using the palm of hand

4. The thread being rolled crumbles into several pieces when it reaches a diameter 4.2 mm.

5. Collect the small crumbled pieces to measure water content. The moisture content is the Plastic Limit of the soil.

**Figure 4.7** Rolling of soil mass on ground glass plate to determine plastic limit (*Courtesy of Braja M. Das, Henderson, Nevada*)

# 4.3 Plastic Limit (PL)

Plastic Limit Test

**Table 4.1** Typical Values of Liquid Limit, Plastic Limit, and Activity of Some Clay Minerals

| Mineral | Liquid limit, *LL* | Plastic limit, *PL* | Activity, *A* |
|---|---|---|---|
| Kaolinite | 35–100 | 20–40 | 0.3–0.5 |
| Illite | 60–120 | 35–60 | 0.5–1.2 |
| Montmorillonite | 100–900 | 50–100 | 1.5–7.0 |
| Halloysite (hydrated) | 50–70 | 40–60 | 0.1–0.2 |
| Halloysite (dehydrated) | 40–55 | 30–45 | 0.4–0.6 |
| Attapulgite | 150–250 | 100–125 | 0.4–1.3 |
| Allophane | 200–250 | 120–150 | 0.4–1.3 |

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

# 4.4 Shrinkage Limit (SL)

## Shrinkage Limit Test

1. Porcelain dish about 1.75 in. (44.4mm) in diameter and about ½ in. (12.7 mm) in height.

2. The inside of the dish is coated with petroleum jelly and is then filled completely with wet soil.

3. The mass of the wet soil inside the dish is recorded.

4. The soil pat in the dish is then oven dried.

5. The volume of the oven-dried soil pat is determined by the displacement of mercury.

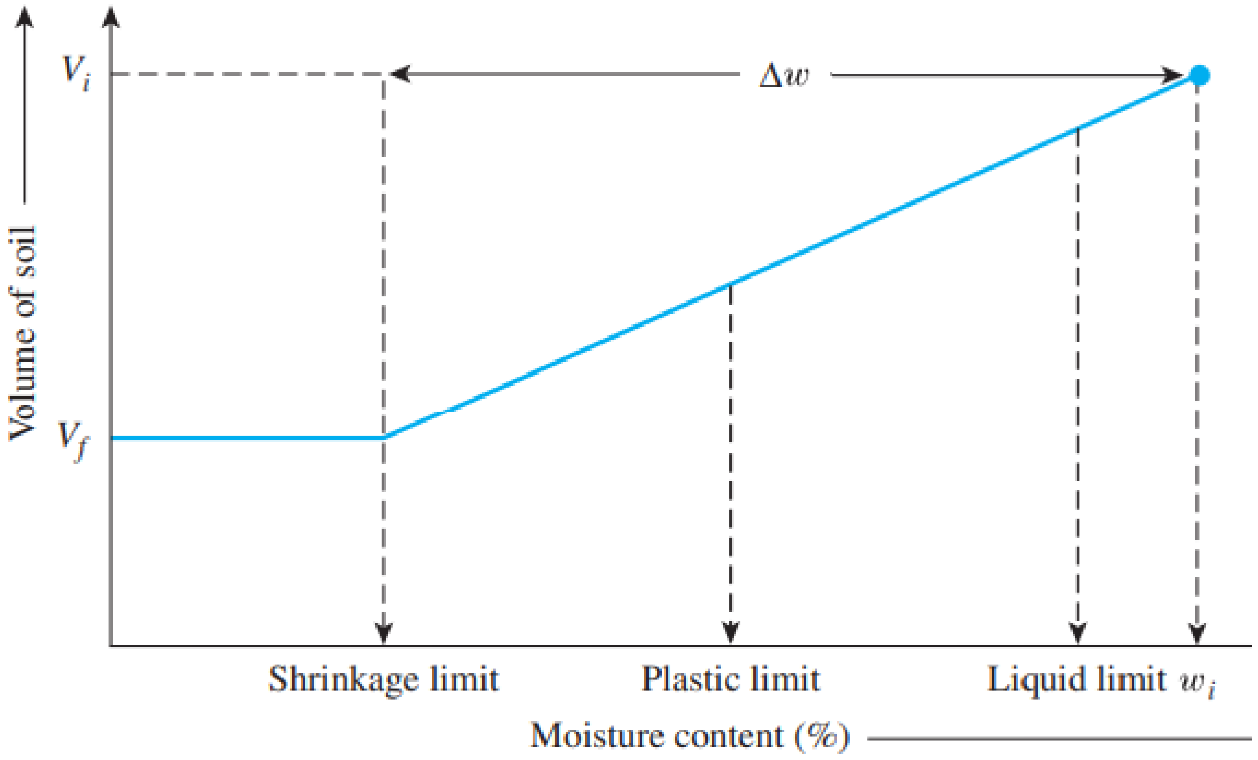



**Figure 4.9** Definition of shrinkage limit

# 4.4 Shrinkage Limit (SL)

Shrinkage Limit

- $SL = \omega_i - \Delta\omega(\%)$

- $\omega_i = \frac{(M_1 - M_2)}{M_2} \times 100$

- $\Delta\omega_i = \frac{(V_i - V_f)\rho_w}{M_2} \times 100$

- $SL = \frac{M - M_2}{M_2} \times 100 - \frac{(V_i - V_f)\rho_w}{M_2} \times 100$

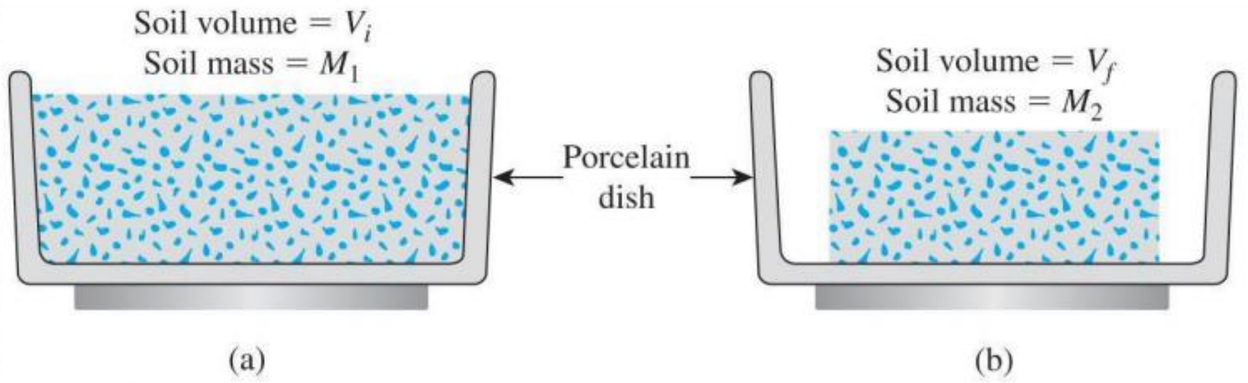



**Figure 4.10** Shrinkage limit test: (a) soil pat before drying; (b) soil pat after drying

# 4.5 Liquidity Index (LI)

- Liquidity Index(LI) : $LI = \frac{w - PL}{LL - PL}$
- LI > 1 : Flow like Liquid
- LI < 0 : Heavily over consolidated soil

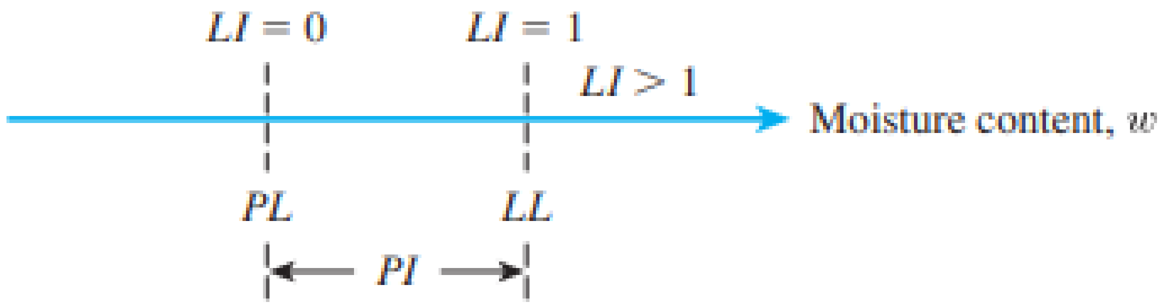



Figure 4.11 Liquidity index

# 4.6 Activity

- $A = \dfrac{PI}{(\%of\ clay{-}size\ fraction, by\ weight)}$
- A < 0.75 (low activity) kaolinite
- 0.75 < A < 1.25 (moderate) illite
- A > 1.25 (high activity) montmorillonite
- The smaller the particle diameter of the soil, the higher the surface area per unit weight of the soil.
- The type of clay minerals and their proportional amounts in a soil affects the liquid and plastic limits.
- The plasticity index of a soil increases linearly with the percentage of clay-size fraction (% finer than 2 mm by weight) present (Skempton, 1953)

# 4.6 Activity

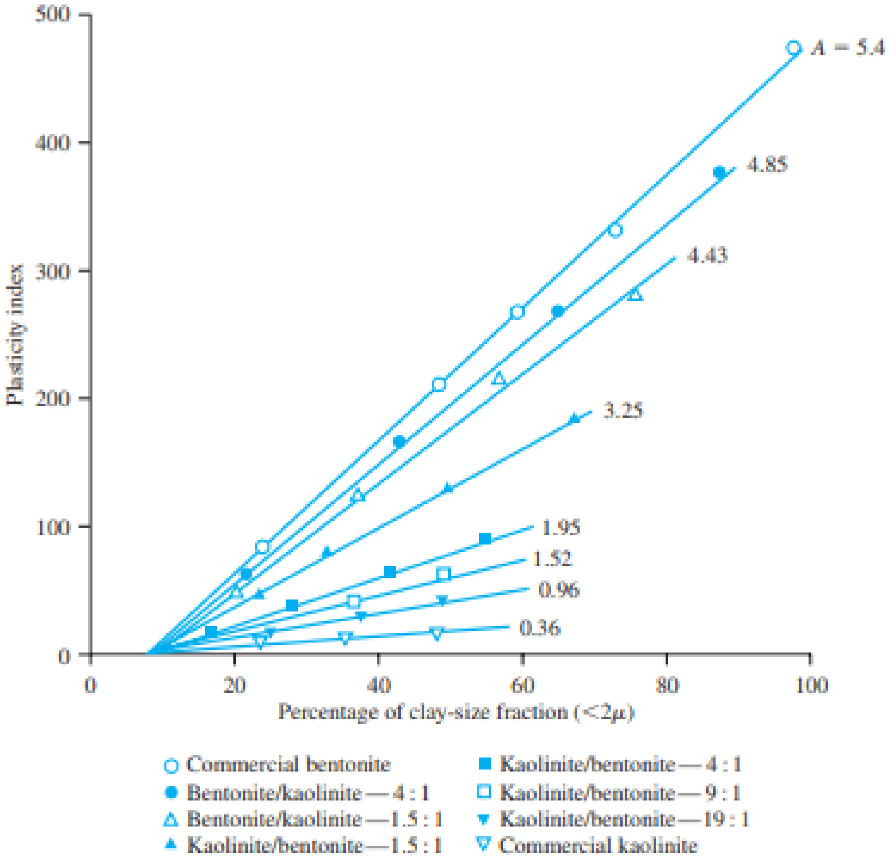



**Figure 4.13** Relationship between plasticity index and clay-size fraction by weight for kaolinite/bentonite clay mixtures (*After Seed, Woodward, and Lundgren, 1964a. With permission from ASCE.*)

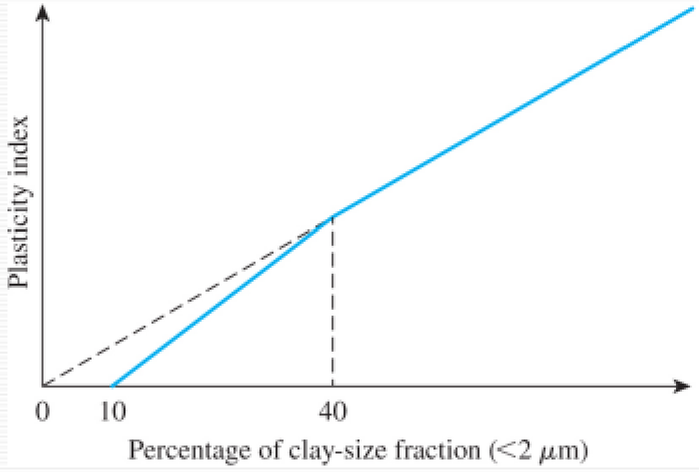



**Figure 4.15** Simplified relationship between plasticity index and percentage of clay-size fraction by weight (*After Seed, Woodward, and Lundgren, 1964b. With permission from ASCE.*)

# 4.7 Plasticity Chart

- Casagrande (1932) studied the relationship of the plasticity index to the liquid limit of a wide variety of natural soils. He proposed a plasticity chart
- The important feature of this chart is the empirical A-line that is given by the equation PI = 0.73(LL-20)
- An A-line separates the inorganic clays from the inorganic silts.
- The information provided in the plasticity chart is of great value and is the basis for the classification of fine-grained soils in the Unified Soil Classification System.

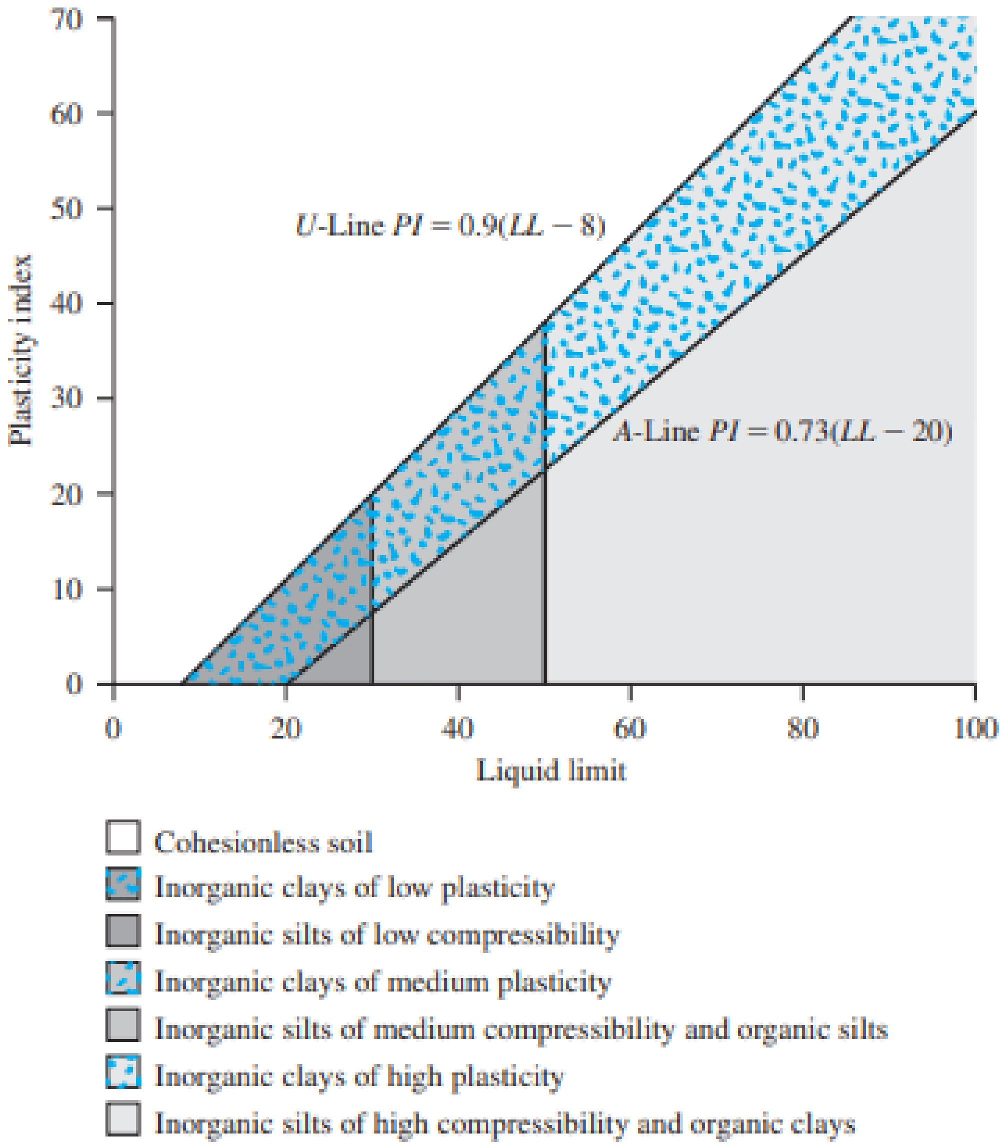



**Figure 4.16** Plasticity chart

# Summary&Essential Points

- This chapter discussed (a) plasticity of soil and related topics.
- Liquid limit, plastic limit, and shrinkage limit tests of fine-grained soil are indicators of the nature of its plasticity. The difference between the liquid limit and plastic limit is called the plasticity index. Liquid limit and plasticity index are required parameters for classification of fine-grained soils.