



ECIV 3302 Engineering Geology

Chapter 4 **PLASTICITY AND STRUCTURE OF SOIL**

Associate Professor Mazen Abualtayef

Civil and Environmental Engineering Department

Islamic University of Gaza, Palestine

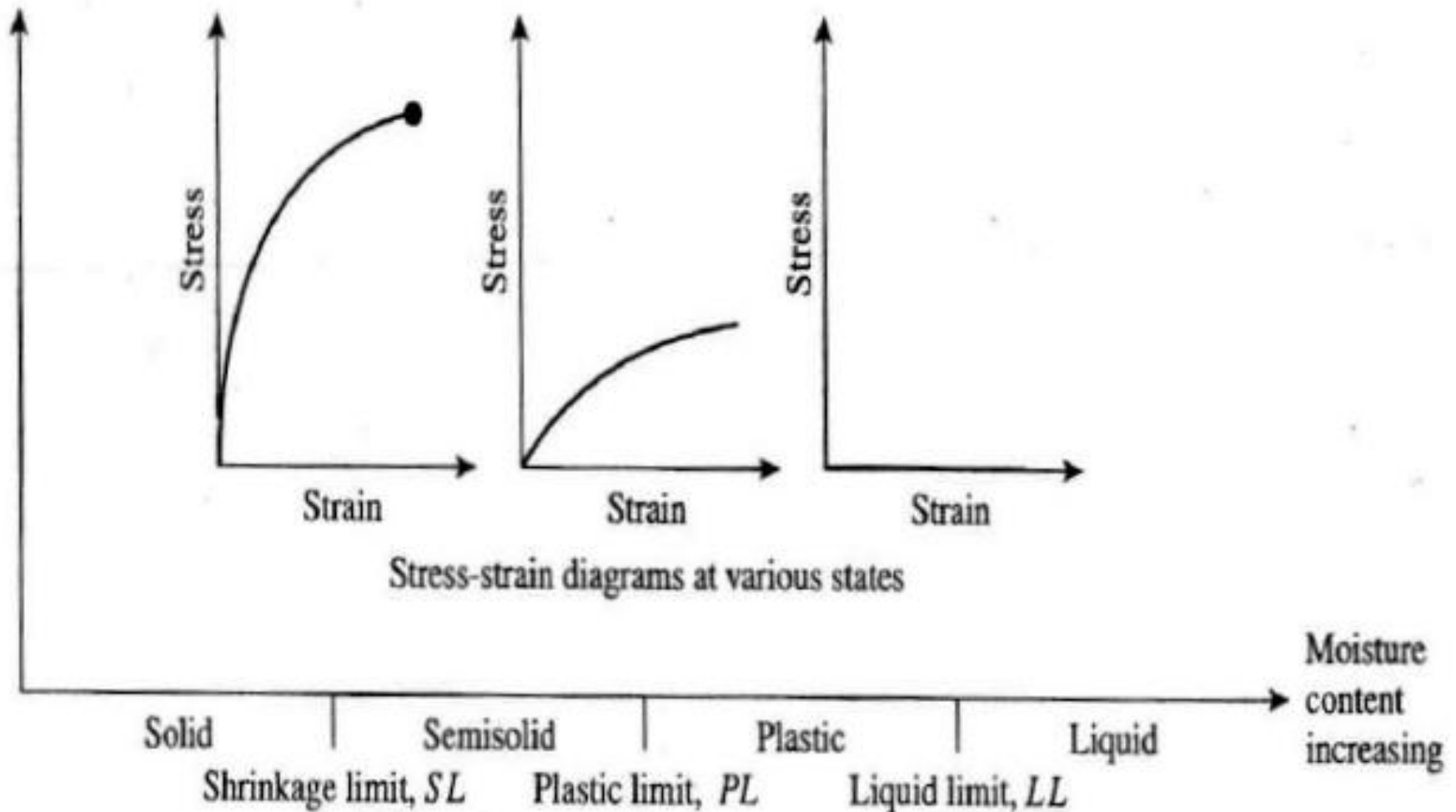
The materials are mostly adapted from the presentation of Ahmed Abu Foul

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 is caused by the adsorbed water surrounding the clay particles.
- In the early 1900s, a Swedish scientist “Atterberg” developed a method to describe the consistency of fine grained soils with varying degree of moisture content.
- At a very low moisture content, soil behaves more like a solid.
- When the moisture content is very high, the soil and water may flow like a liquid.

Introduction

- Depending on the moisture content, the behavior of soil can be divided into four basic states: solid, semisolid, plastic and liquid, as shown in Figure.

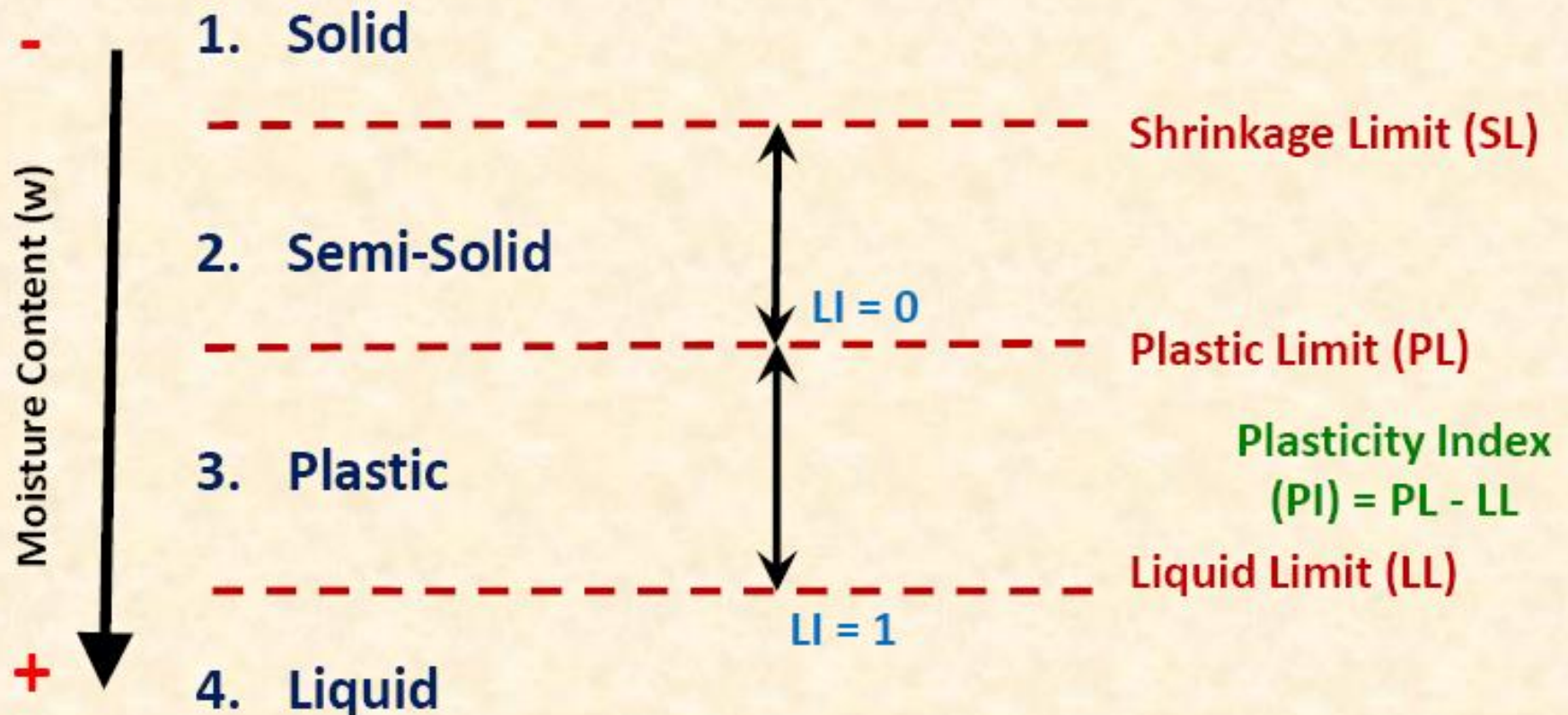


Introduction

- The moisture content at the point of transition from solid to semisolid state takes place is defined as **the shrinkage limit**.
- The moisture content at the point of transition from semisolid to plastic state is **the plastic limit**.
- The moisture content at the point of transition from plastic to liquid state is **the liquid limit**.
- These parameters are also known as **Atterberg limits or consistency limits**.

Consistency of Soil-Atterberg limit

Depending on Moisture Content soil can be divided into:



Stickiness of Soil



Non-Sticky

Slightly-Sticky

Very Sticky

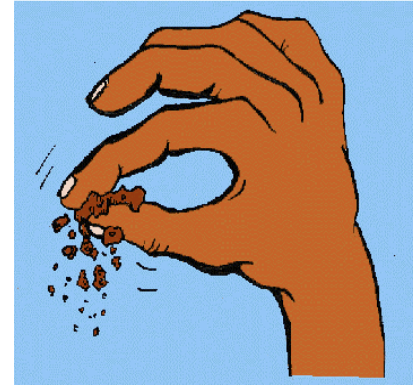
Soil Consistence

Loose*



* Soils with “single grained” structure **always** have **loose** consistence.

Friable



Firm



Extremely Firm



Liquid Limit (L.L)

Definition

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

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 12.7mm along the bottom of the groove after 25 blows.

Liquid Limit Determination

L.L Determination Methods



```
graph TD; A[L.L Determination Methods] --> B[Fall Cone  
BS1377]; A --> C[Casagrande  
ASTM D-4318]
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The diagram is a hierarchical flowchart. At the top is a purple box with the text 'L.L Determination Methods'. A line from this box branches down to two orange boxes. The left orange box contains 'Fall Cone' and 'BS1377'. The right orange box contains 'Casagrande' and 'ASTM D-4318'.

Fall Cone

BS1377

Casagrande

ASTM D-4318

Casagrande Procedures

1 • 150g air dry soil passing # 40 sieve

2 • Add 20% of water -mix thoroughly

3 • Place a small sample of soil in LL device (deepest part about 8-10mm)

4 • Cut a groove (2mm at the base)

5 • Run the device, count the number of blows, N

6 • Stop when the groove in the soil close through a distance of 0.5in

7 • Take a sample and find the moisture content

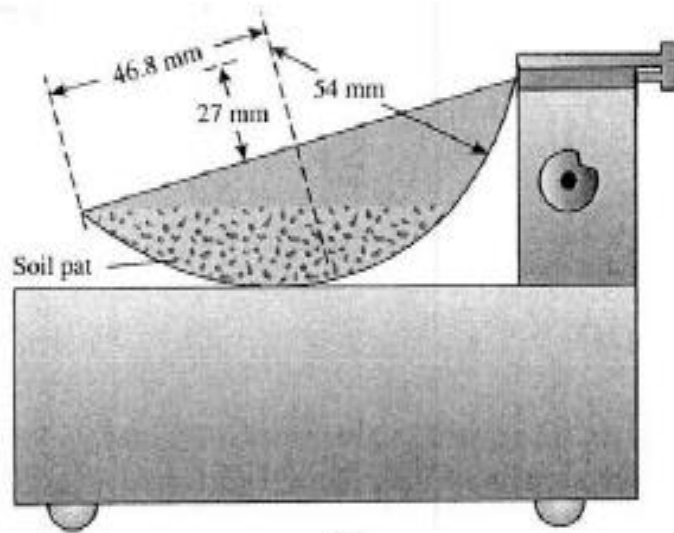
8 • Run the test three times [$N \sim (10-20)$, $N \sim (20-30)$ and $N \sim (35-45)$] and

9 • Plot number of blows vs moisture content and determine the liquid limit (LL) (moisture content at 25 blows)

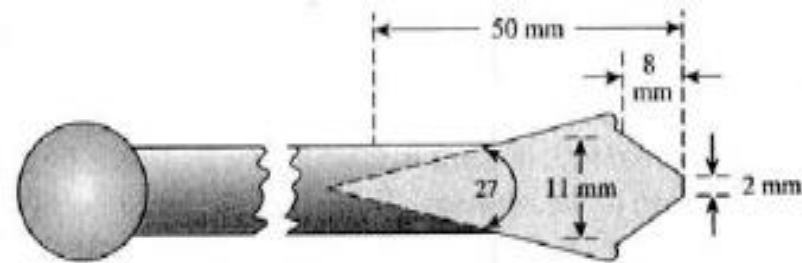
Liquid limit device consists of:

- Brass cup
- Hard rubber base

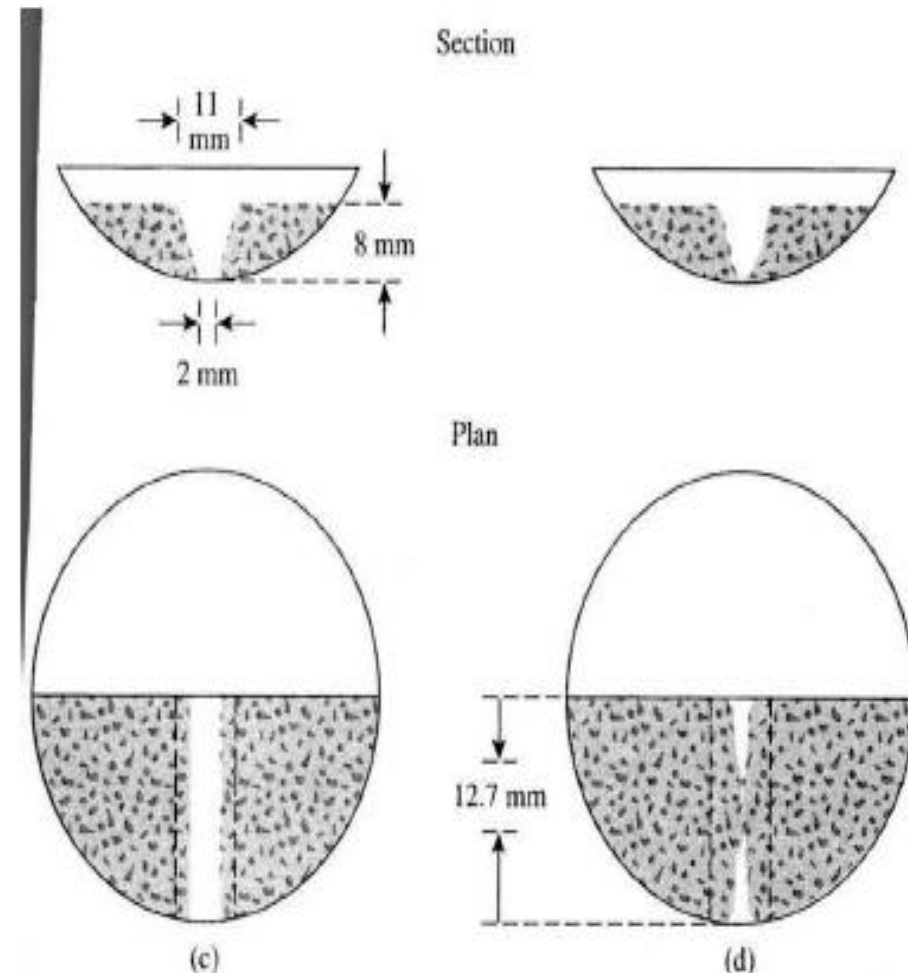
(ASTM designation D-4318)



(a)



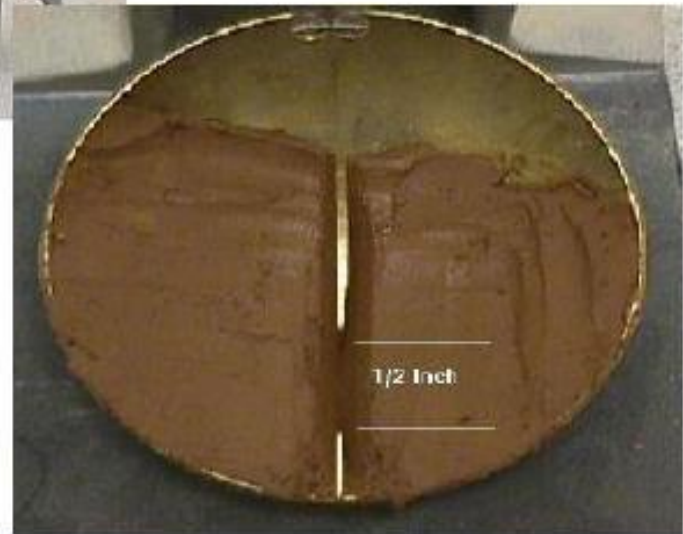
(b)



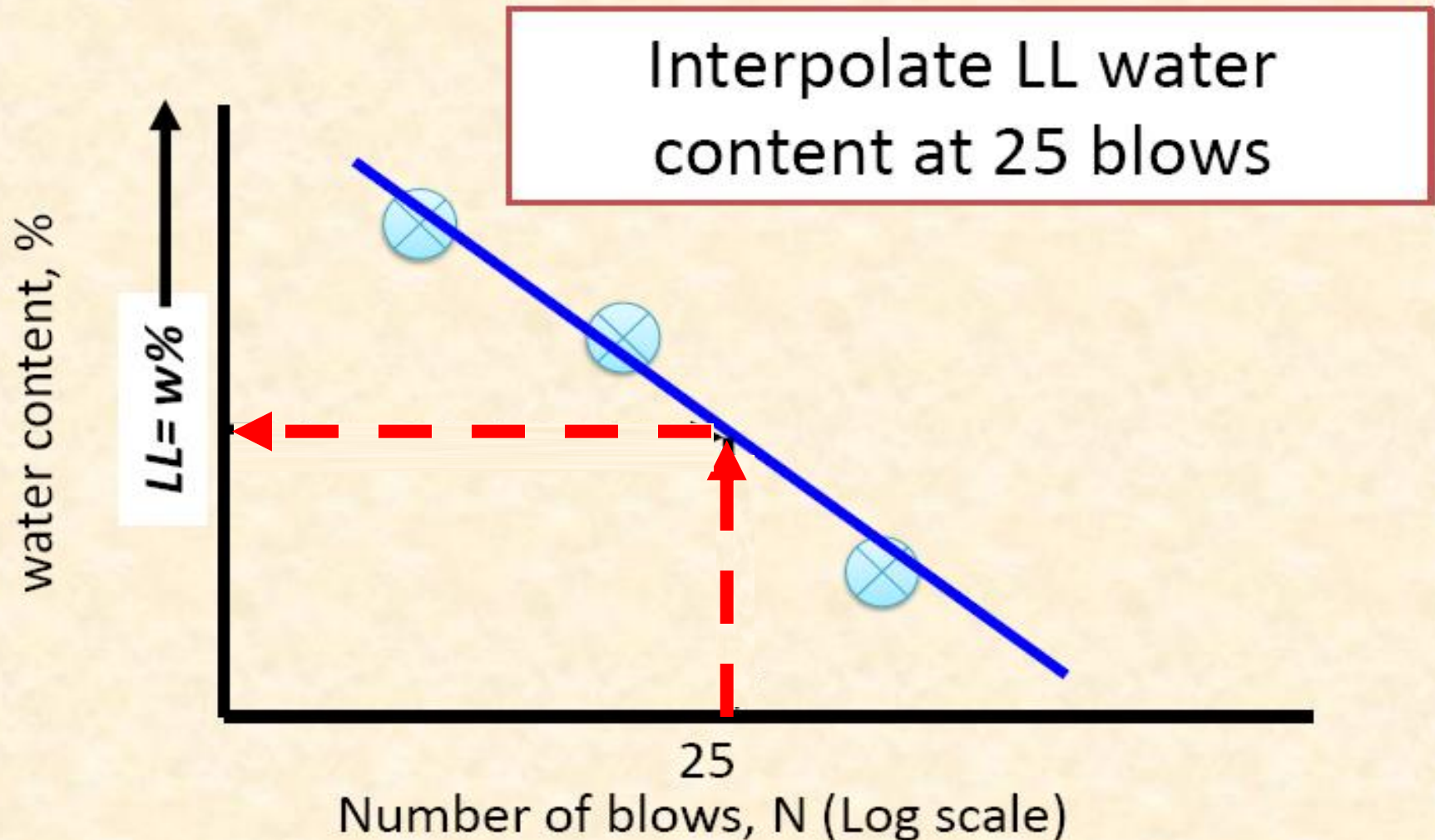
(c)

(d)

Casagrande Apparatus (ASTM D-4318)



Liquid Limit (L.L) Determination



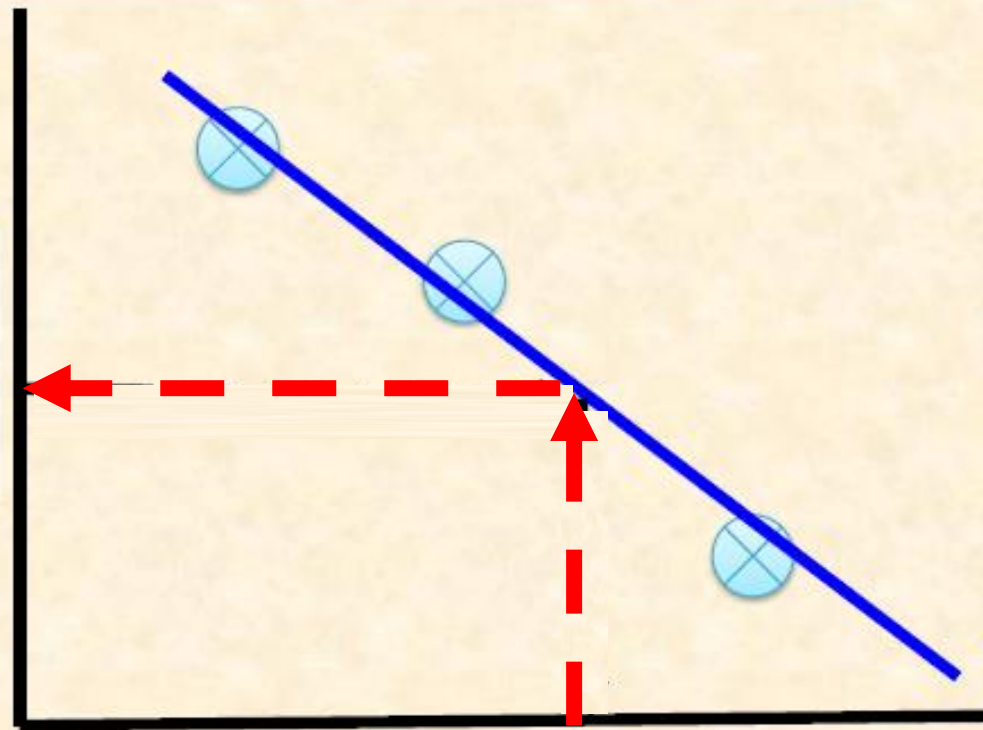
Liquid Limit (L.L) Determination

Note

The slope of line is defined as **Flow Index**

water content, %

$LL = w\%$

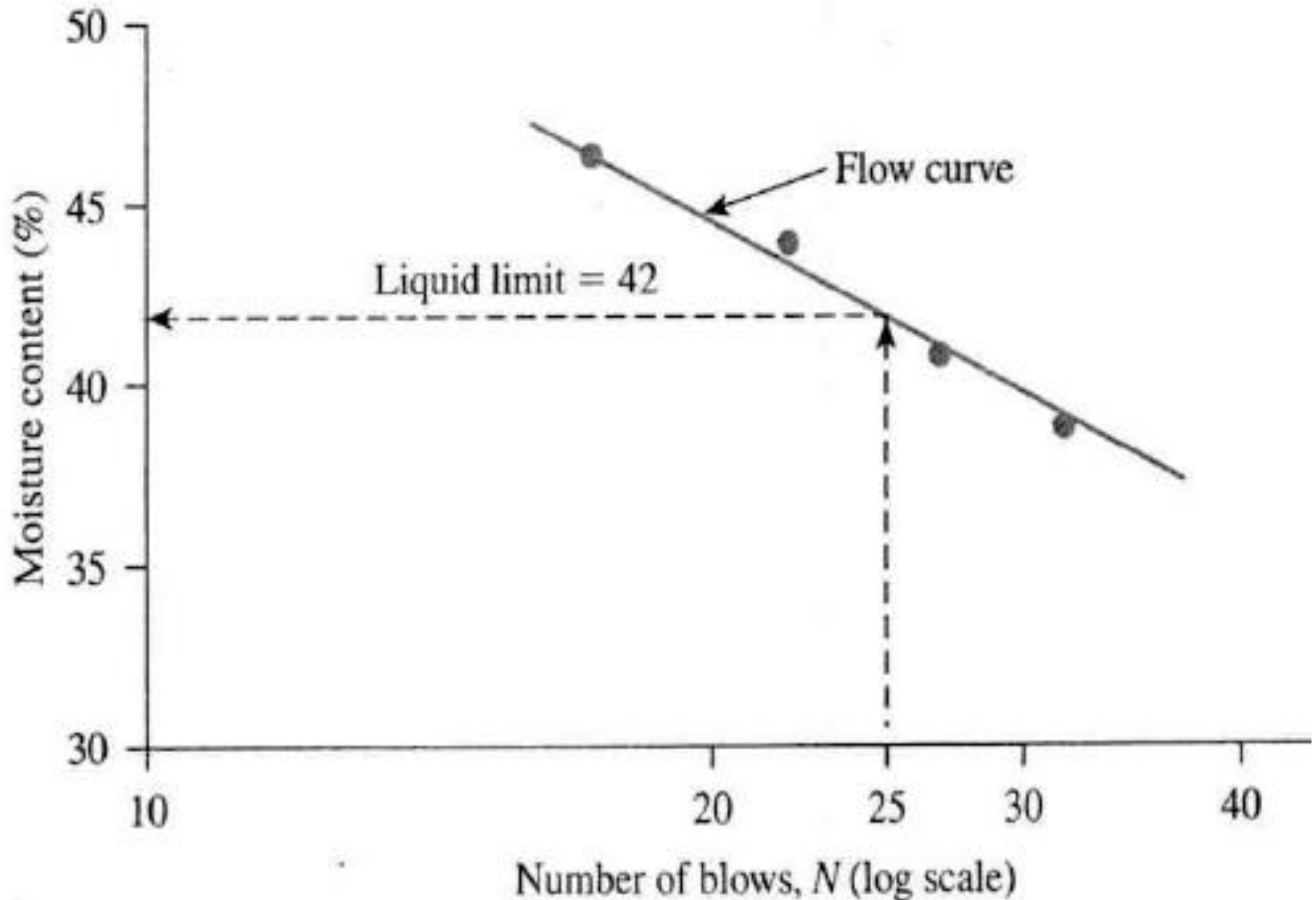


25

Number of blows, N (Log scale)

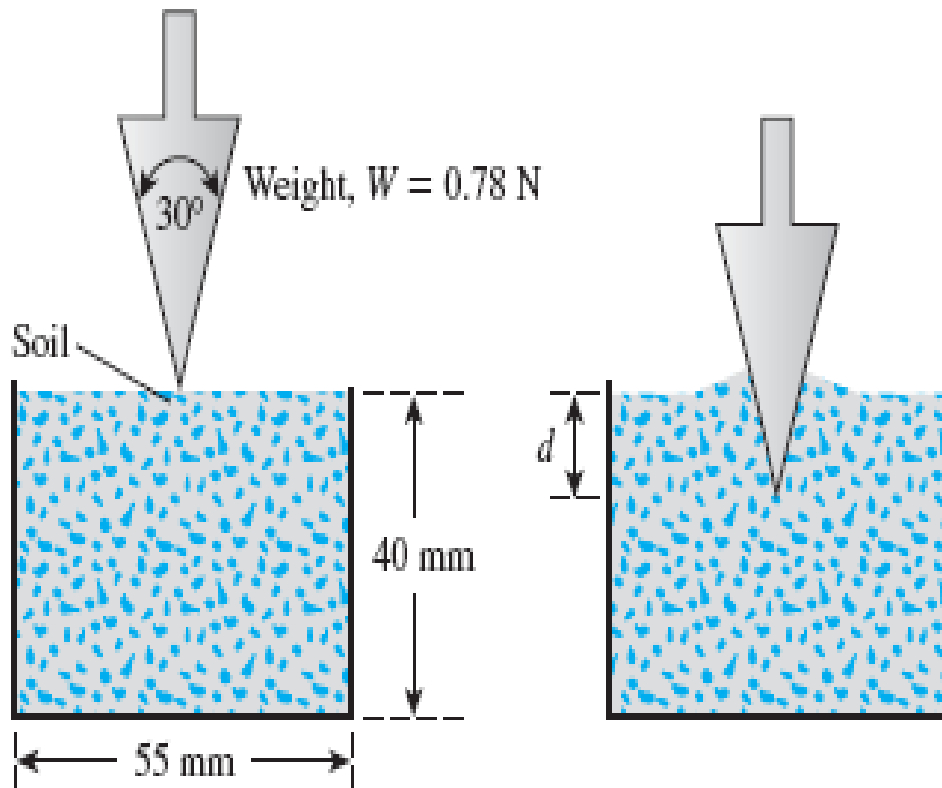
$$\text{Flow Index}(I_F) = \frac{w_1 - w_2}{\log\left(\frac{N_2}{N_1}\right)}$$

Liquid Limit (LL) Determination

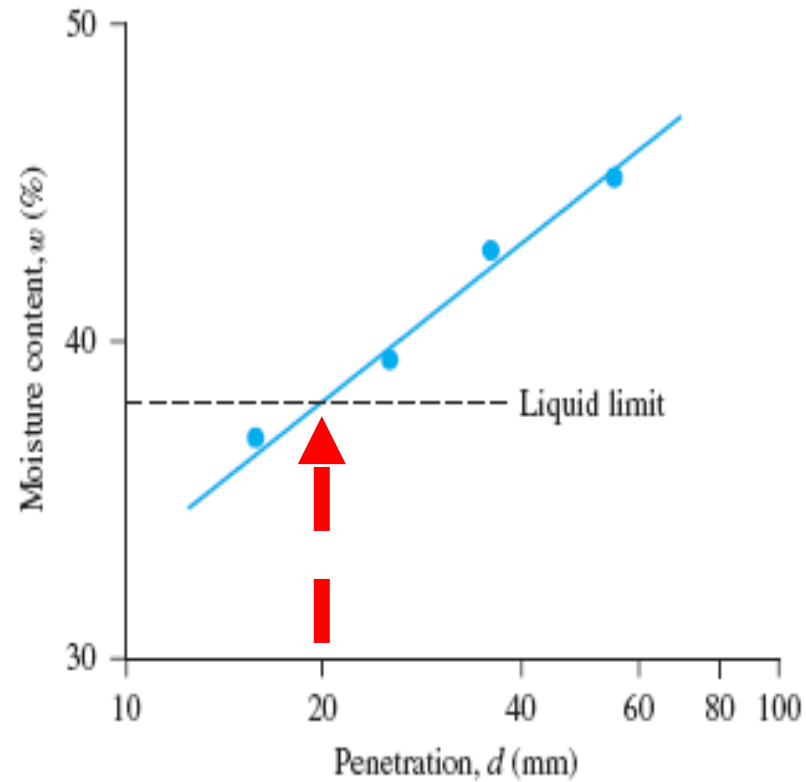


Fall cone method (B.S1377)

Another method of determining liquid limit that is popular in Europe and Asia.



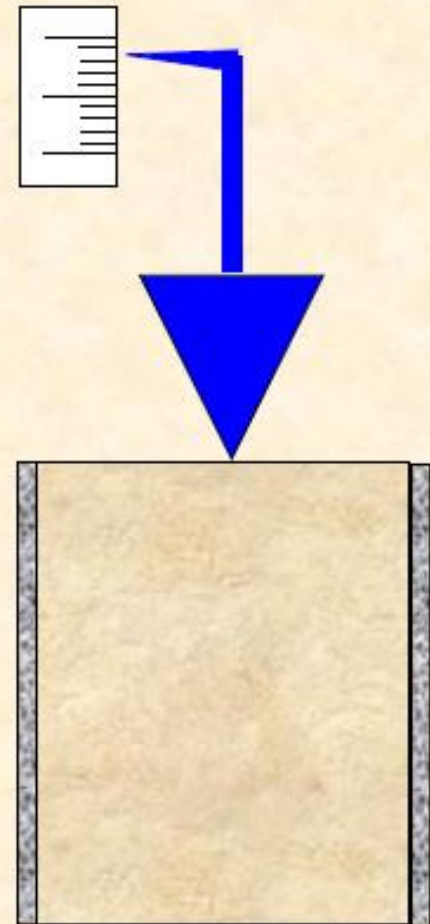
(a)



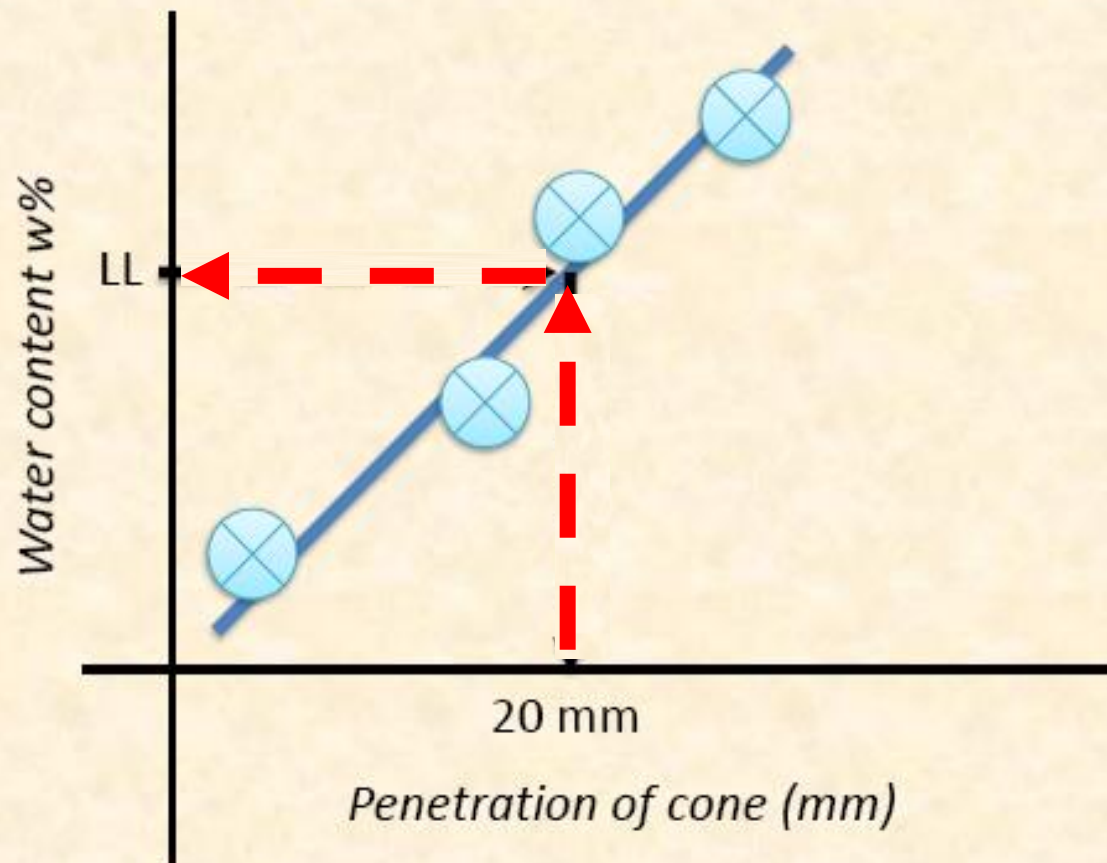
(b)

Fall Cone Method BS1377

In this test the liquid limit is determined as the moisture content at which a standard cone angle 30 and weight of 0.78 N will penetrate a distance $d=20$ mm in 5 seconds when allowed to drop from a position of point contact from a single test.



Fall Cone Method BS1377



Plastic Limit (P.L)

Definition

The plastic limit is the water content at which a soil-water paste changes from a semisolid to a plastic consistency

In the lab, the LL is defined as the water content at which a 1/8" thread of soil can be rolled out but it begins to crack and cannot then be re-rolled

Plastic Limit Determination

P.L Determination Methods

```
graph TD; A[P.L Determination Methods] --> B[Rolling]; A --> C[Fall Cone];
```

Rolling

ASTM D-4318

Fall Cone

BS1377

Plastic Limit (P.L) Procedures

1

- Take 20g of soil passing #40 sieve into a dish.

2

- Add water and mix thoroughly.

3

- Prepare several ellipsoidal-shaped soil masses by quizzing the soil with your hand.

4

- Put the soil in rolling device, and roll the soil until the thread reaches 1/8 inch.

5

- Continue rolling until the thread crumbles into several pieces.

6

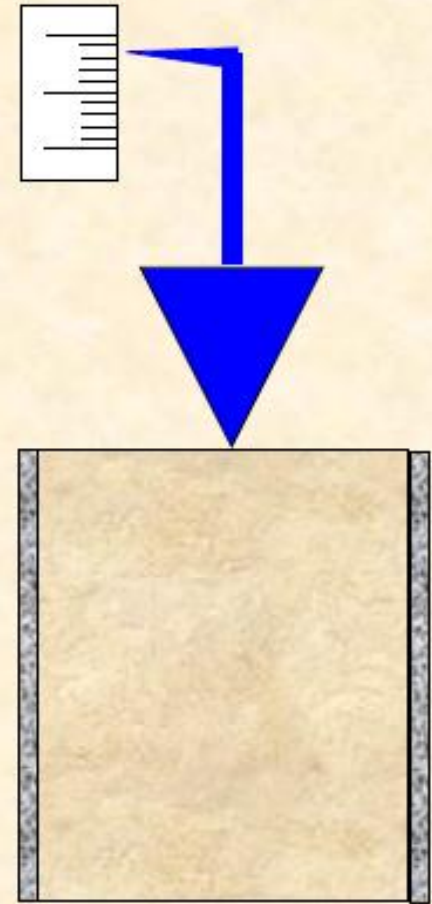
- Determine the moisture content of about 6g of the crumbled soil.

Plastic Limit (P.L)



Fall Cone Method BS1377

The fall cone method can be used to obtain the plastic limit. This can be achieved by using a cone of similar geometry in case of L.L, but with mass 2.35N . Three or four tests at varying M.C are conducted and determine d. The M.C corresponding to cone penetration of $d=20\text{mm}$ is the plastic limit.



Plastic Index(PI)

Definition

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

$$PI = LL - PL$$

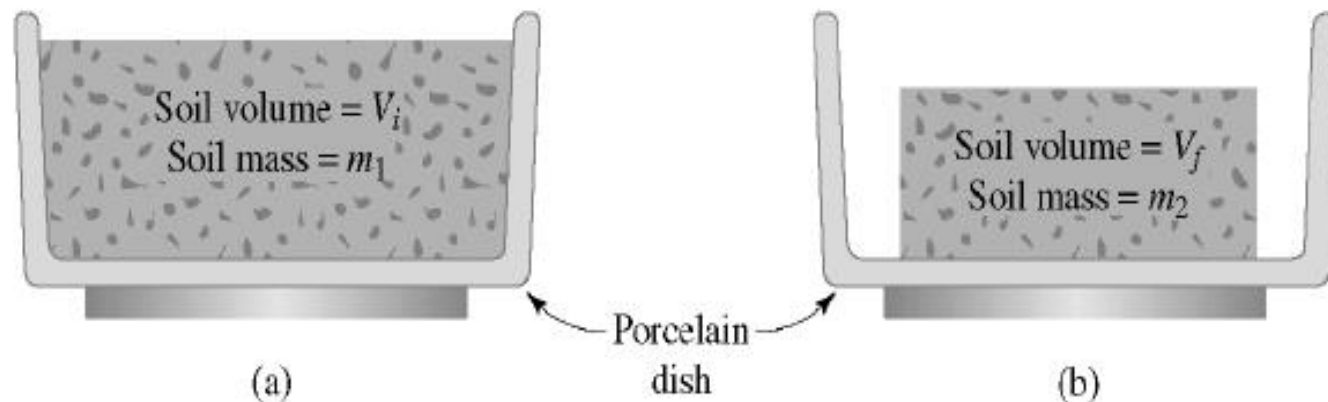
Plastic Index(PI)

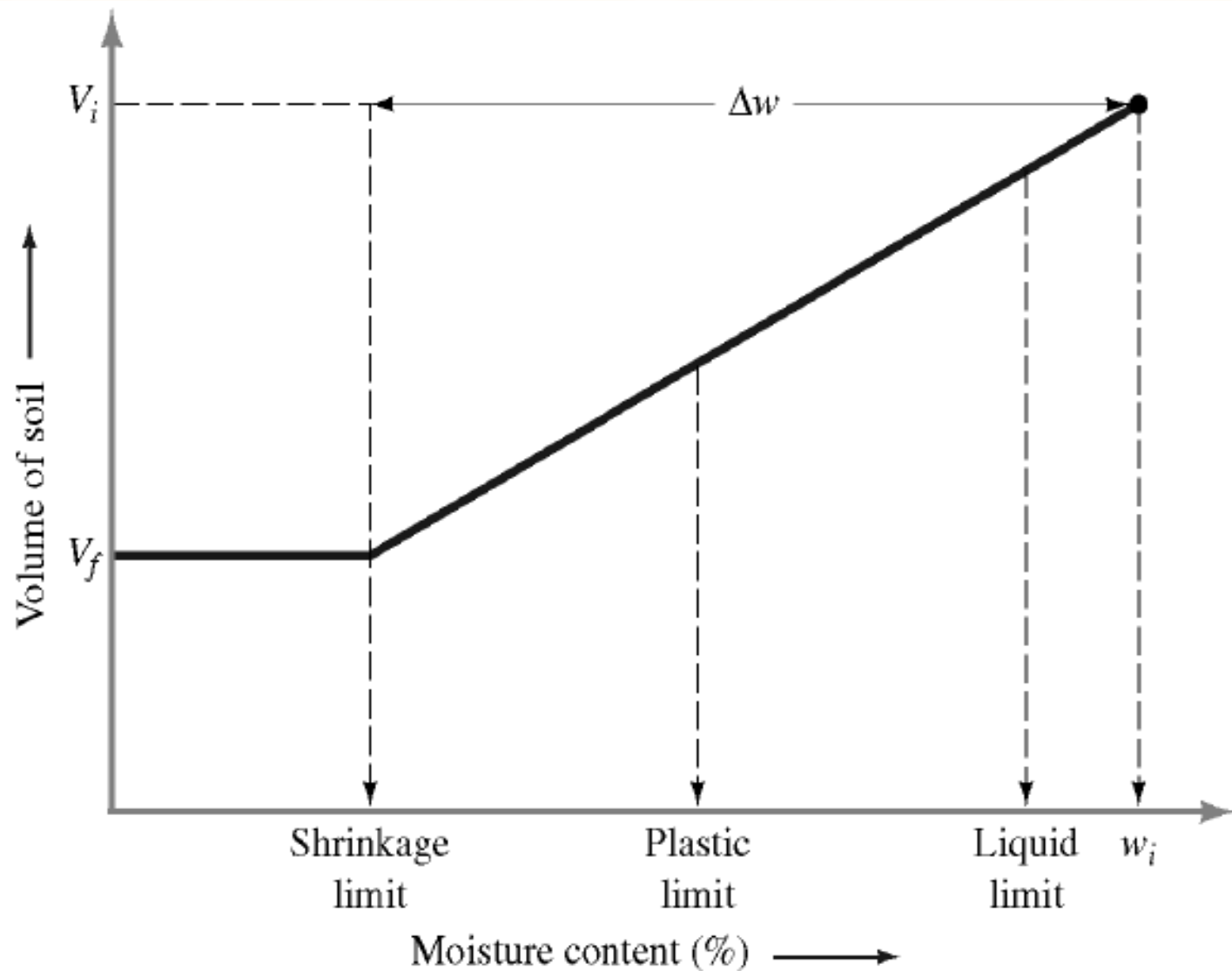
PI	Description
0	Non-plasticity
1-5	Slightly plastic
5-10	Low plasticity
10-20	Medium plasticity
20-40	Highly plasticity
>40	Vey high plasticity

Shrinkage Limit(S.L)

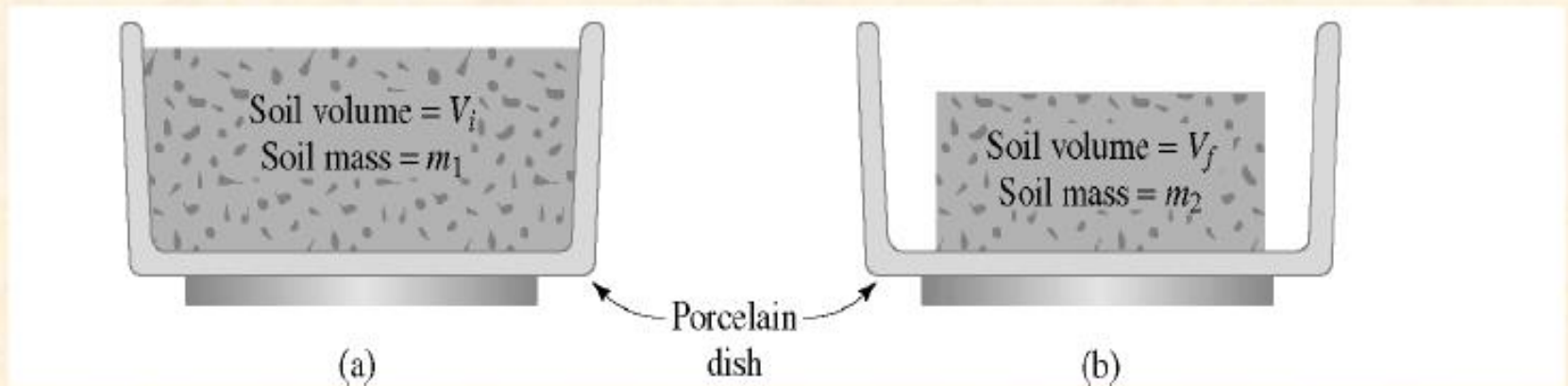
Definition

The moisture content, in percent, at which the volume of the soil mass ceases to change





$$SL = w_i (\%) - \Delta w (\%)$$



$$SL = w_i (\%) - \Delta w (\%)$$

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

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

Example 4.1

Following are the results of a shrinkage limit test:

- Initial volume of soil in a saturated state = 24.6 cm^3
- Final volume of soil in a dry state = 15.9 cm^3
- Initial mass in a saturated state = 44.0 g
- Final mass in a dry state = 30.1 g

Determine the shrinkage limit of the soil.

Solution

From Eq. (4.13),

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

$$M_1 = 44.0 \text{ g} \qquad V_i = 24.6 \text{ cm}^3 \qquad \rho_w = 1 \text{ g/cm}^3$$

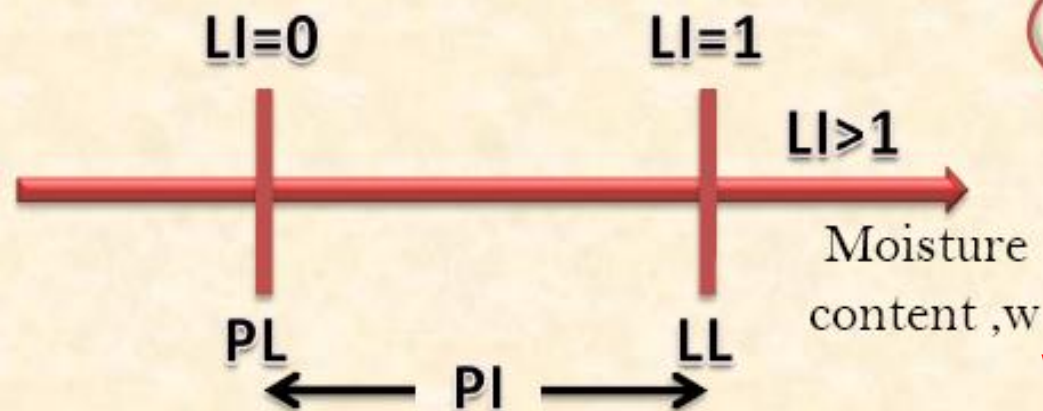
$$M_2 = 30.1 \text{ g} \qquad V_f = 15.9 \text{ cm}^3$$

$$\begin{aligned} SL &= \left(\frac{44.0 - 30.1}{30.1} \right) (100) - \left(\frac{24.6 - 15.9}{30.1} \right) (1) (100) \\ &= 46.18 - 28.9 = \mathbf{17.28\%} \end{aligned}$$

Liquidity Index and Consistency Index

Definition

The relative consistency of cohesive soil in the natural state



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

where w *in situ* moisture content of soil.

Activity (A)

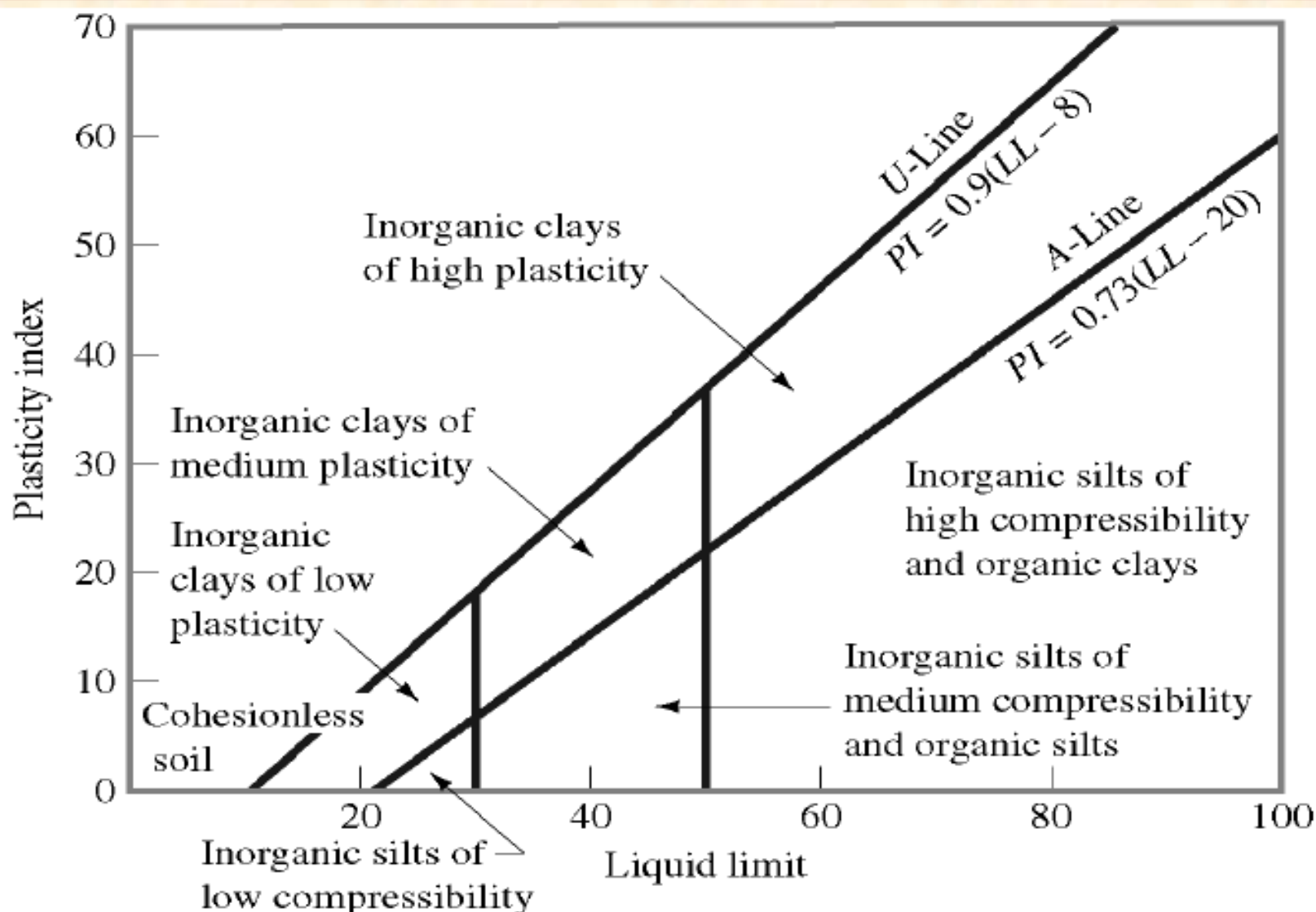
Because the plasticity of soil is caused by the adsorbed water that surrounds the clay particles, we can expect that the type of clay minerals and their proportional amounts in soil will affect the liquid and plastic limit. Skempton defined a quantity called Activity, which is the slope of the line correlation PI and % finer than $2\mu m$

$$A = \frac{PI}{(\% \text{ of clay - size fraction, by weight})}$$

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**

Plasticity Chart



Soil Structure

Soil structure is defined as the geometric arrangement of soil particles with respect to one another.

Many factors affect the structure:

- Shape
- Size
- Mineralogical composition of soil particles
- The nature and composition of soil water

In general, soils can be placed into two groups:

1. Cohesionless
2. Cohesive

Cohesionless Soils

A- Single grained Structure

In single-grained structures, soil particles are in stable positions, with each particle in contact with the surrounding ones.

The shape and size distribution of the soil particles and their relative positions influence the denseness of packing (Figure 4.18); thus, a wide range of void ratios is possible.

Cohesionless Soils

Single grained structure:

- Loose (high void ratio)
- Dense (low void ratio)

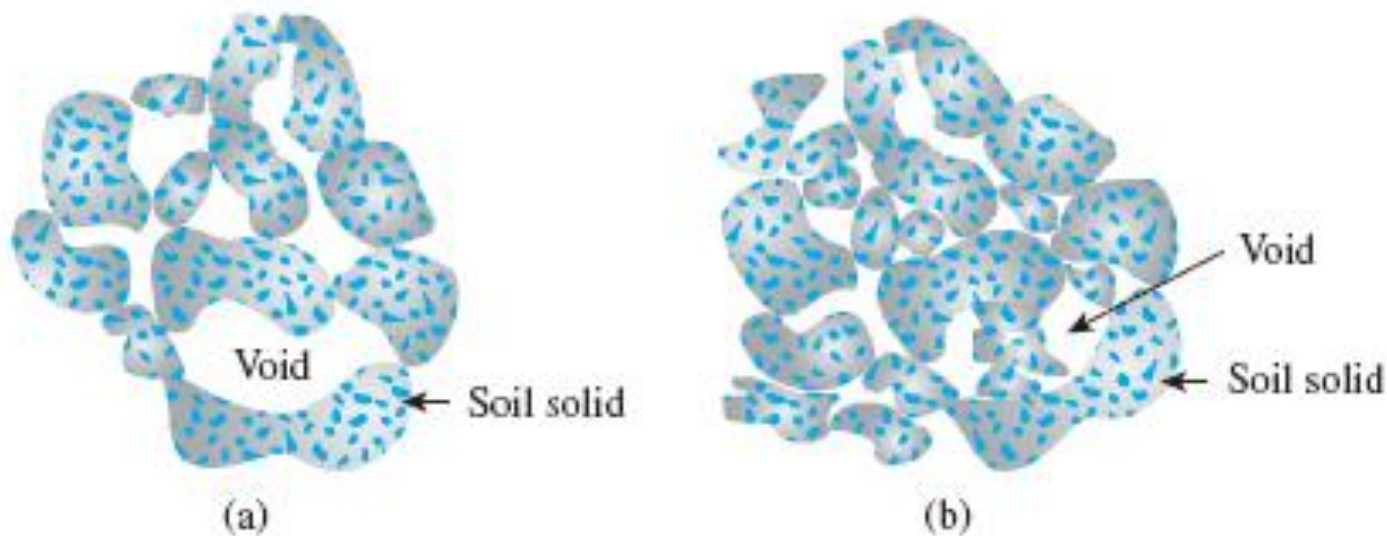


Figure 4.18
Single-grained
structure: (a) loose;
(b) dense

$$e = \frac{V_v}{V_s} = \frac{V - V_s}{V_s}$$

where V = volume of the cube = d^3

V_s = volume of sphere (i.e., solid) inside the cube

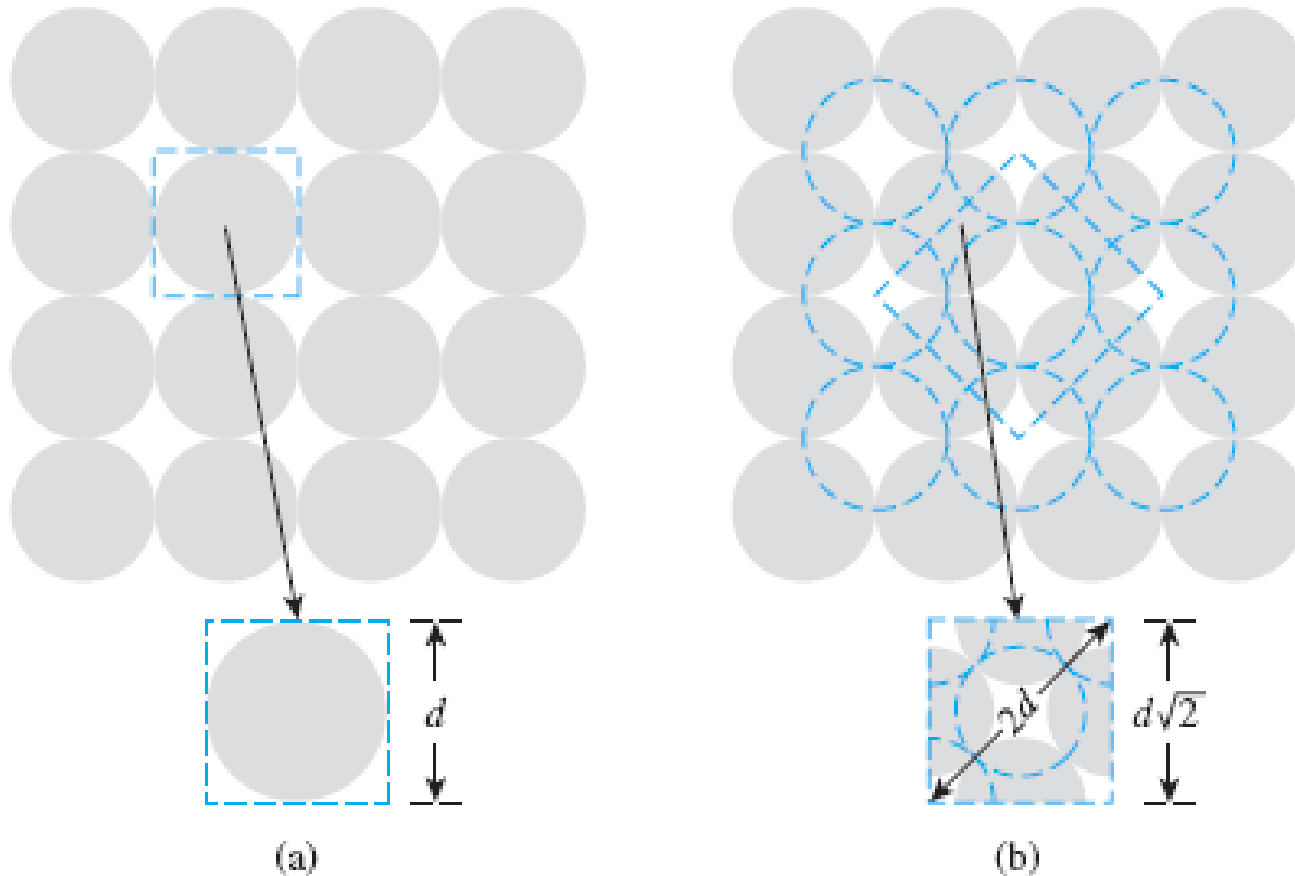
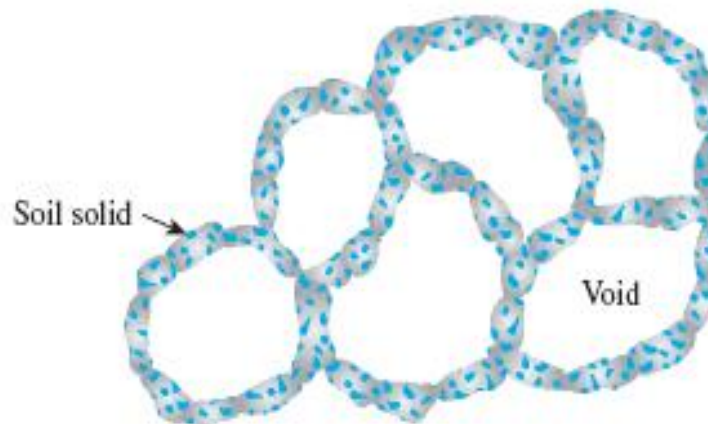


Figure 4.19 Mode of packing of equal spheres (plan views): (a) very loose packing ($e = 0.91$); (b) very dense packing ($e = 0.35$)

B- Honeycombed Structure

- In the honeycombed structure, relatively fine sand and silt form small arches with chains of particles.
- Soils that exhibit a honeycombed structure have large void ratios, and they can carry an ordinary static load.
- However, under a heavy load or when subjected to shock loading, the structure breaks down, which results in a large amount of settlement.



Cohesive Soils

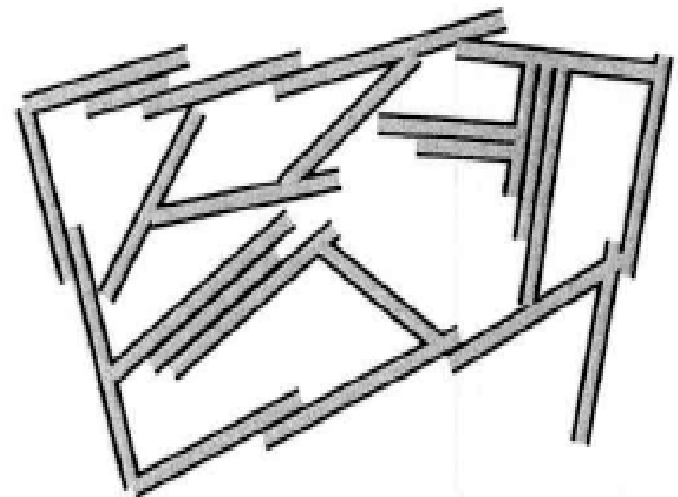
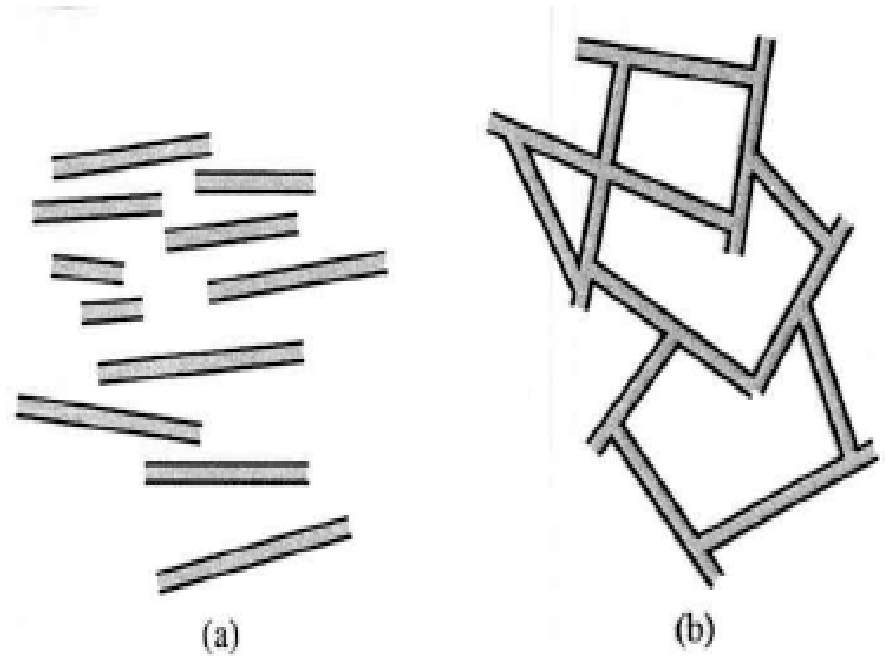
- To understand the basic structures in cohesive soils, we need to know the types of forces that act between clay particles suspended in water. Single grained structure.
- When two clay particles in suspension come close to each other, the tendency for interpenetration of the diffuse double layers results in repulsion between the particles.
- At the same time, an attractive force exists between the clay particles that is caused by van der Waals forces and is independent of the characteristics of water.
- Both repulsive and attractive forces increase with decreasing distance between the particles, but at different rates.

Cohesive Soils

- **Attractive Forces**
- **Repulsive Forces**

☐ **Dispersed Structure**

☐ **Flocculated Structure**



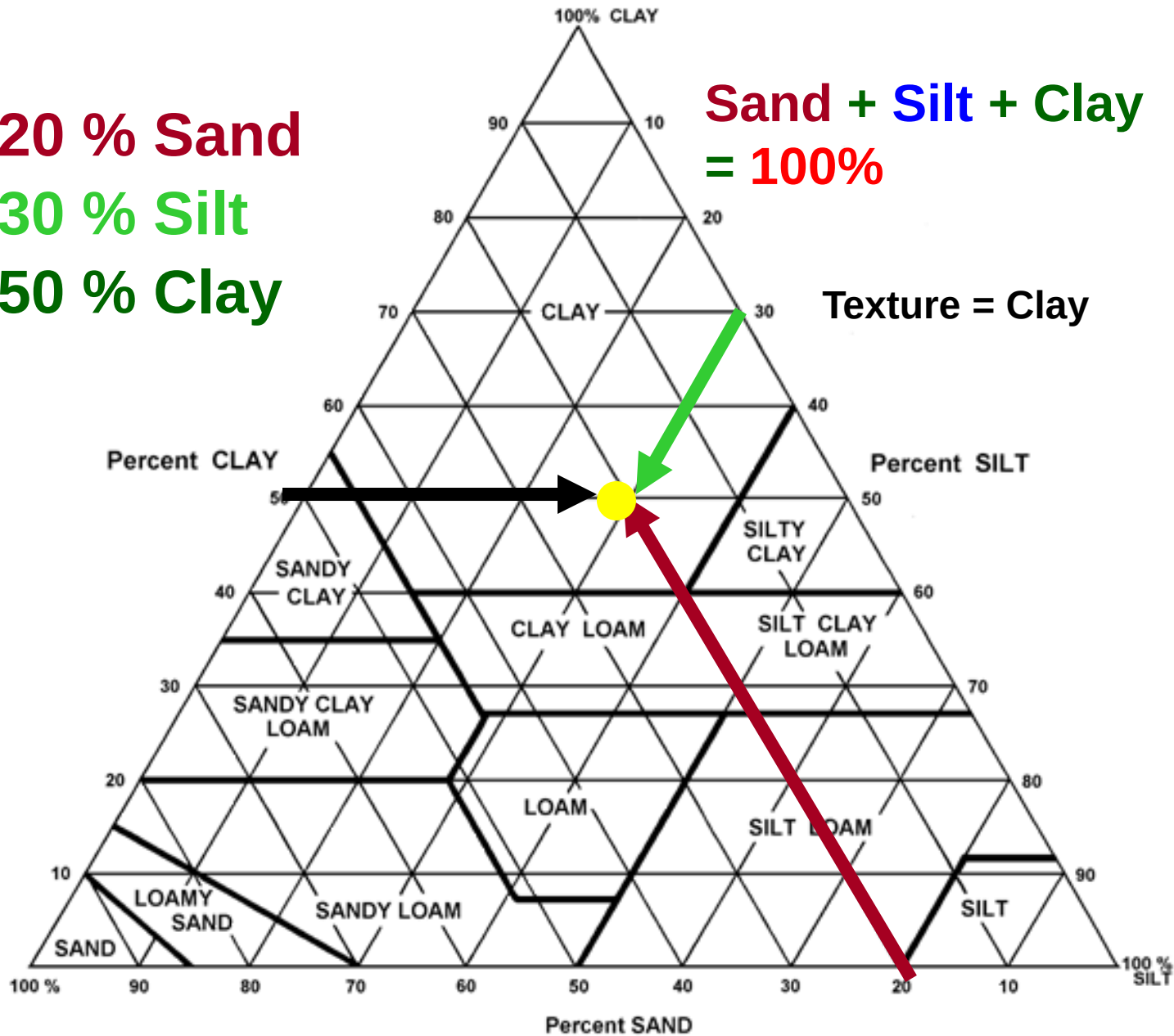
20 % Sand

30 % Silt

50 % Clay

Sand + Silt + Clay
= 100%

Texture = Clay



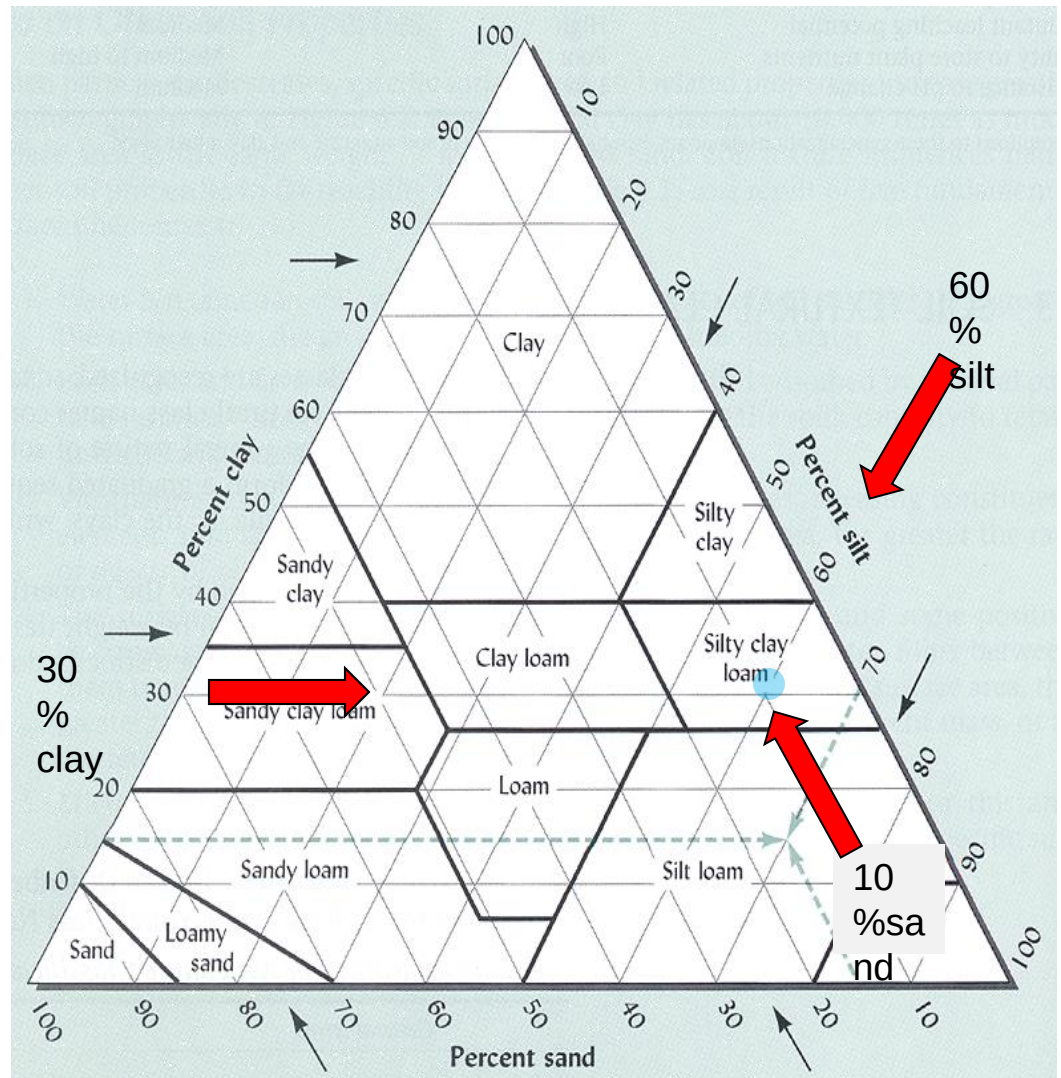
USDA Texture Triangle

Example:

- 60% silt
 - 10% sand
 - 30% clay
- = silty clay loam

What is a soil that is:

- 30% silt
- 0% sand
- 70% clay



H.W

All Problems