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ENCE 331: Soil Plasticity

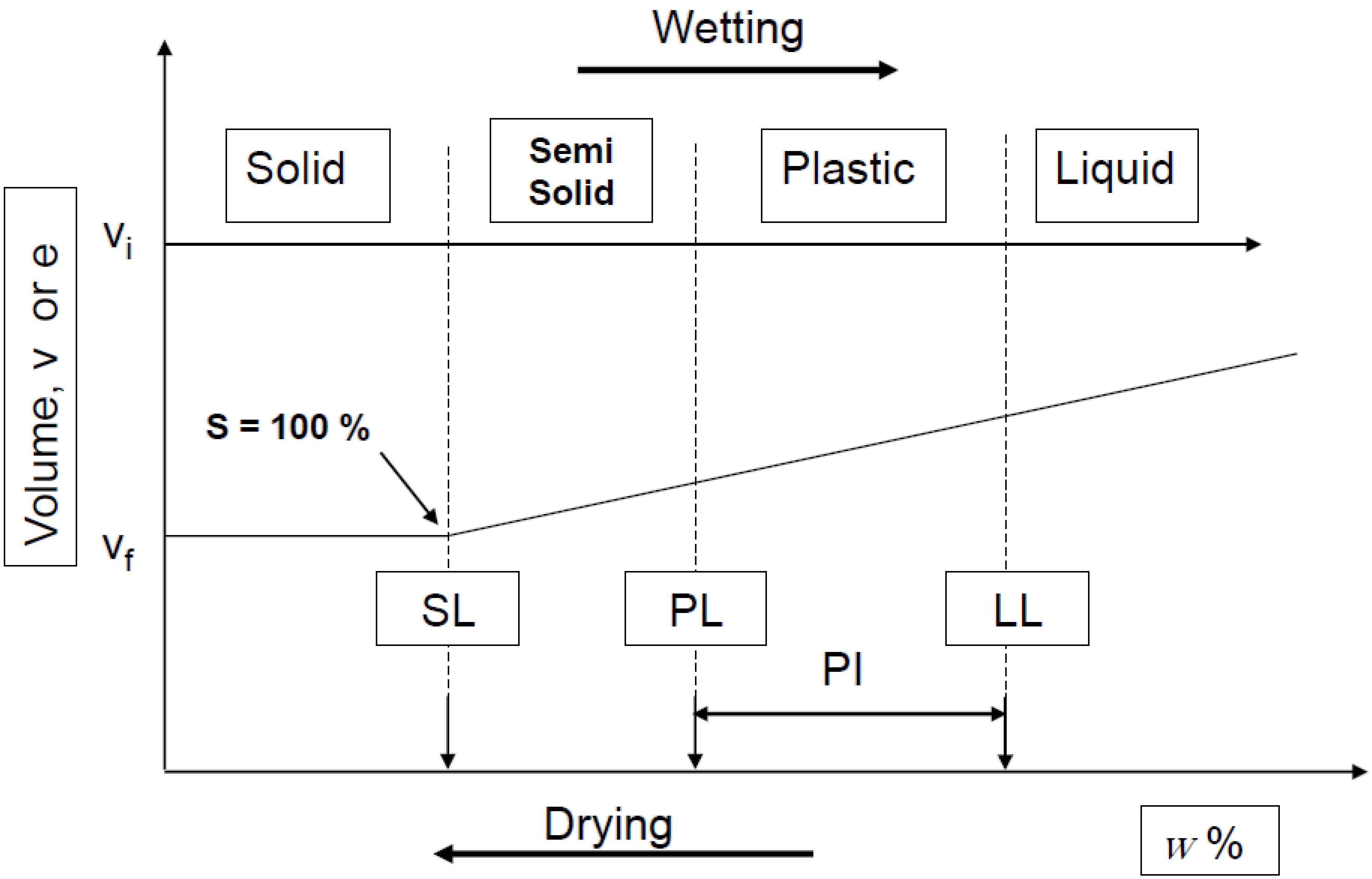
Classification of fine-grained soils

- The classification system uses the term "fines" to describe everything that passes through a # 200 sieve (<0.075mm)
- No attempt to distinguish between silts and clays in terms of particles sizes since the biggest difference between silt and clay is not their particle sizes, but their physical and chemical structures
- The soil consistency is used as a practical and an inexpensive way to distinguish between silts and clays
- Plastic property is important because it describes the response of a soil to change in moisture content

Why Plasticity ?

- Water Content Significantly affects properties of Silty and Clayey soils (unlike sand and gravel)
  - 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

Atterberg Limits



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 $2.5 kN/m^2$)

- 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.

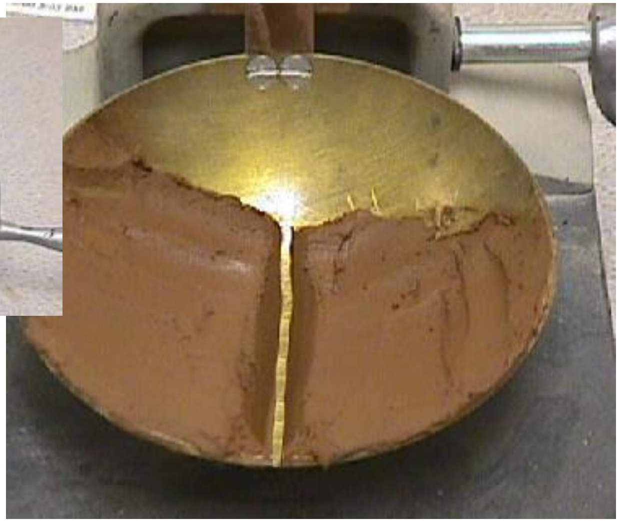
SL represents the amount of water required to fully saturate the soil (100% saturation)

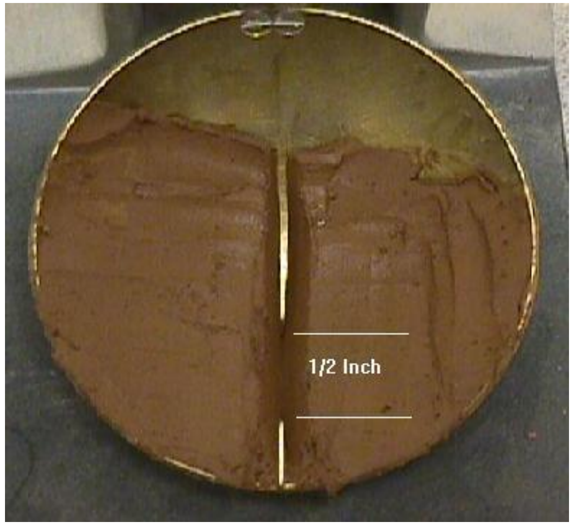
- Plasticity Index (PI) is the difference between the liquid limit and the plastic limit of a soil

Plasticity index is an indication of how much water the soil can absorb without turning into liquid

Liquid Limit

- In the lab, the LL is defined as the moisture content (%) required to close a 2-mm wide groove in a soil pat 12 mm (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

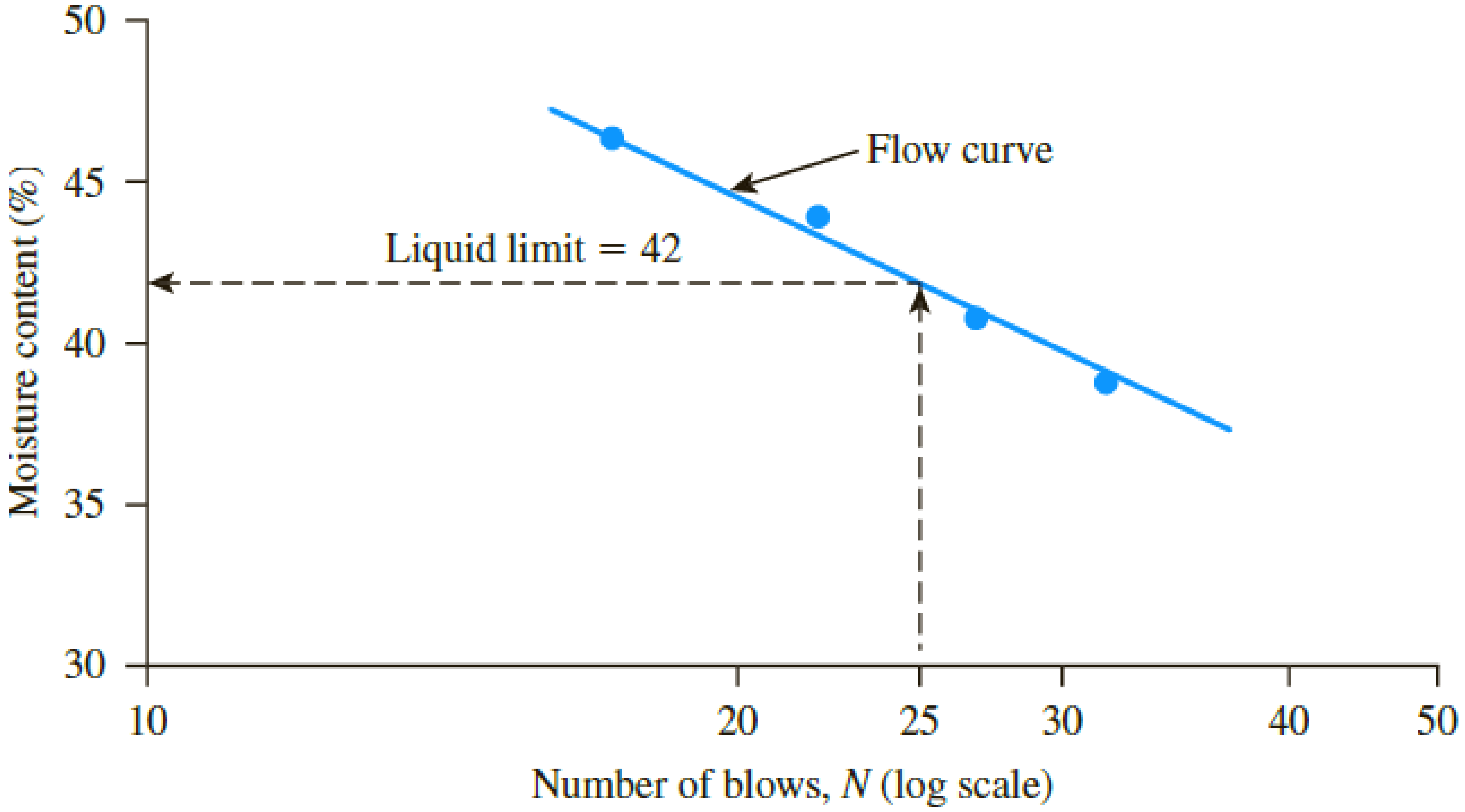




Liquid Limit

- 150g air dry soil passing # 40 sieve and 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) and Run the device, count the number of blows, N
- Stop when the groove in the soil close through 12 mm (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 on a semilogarithmic scale and determine the **liquid limit (LL)** (moisture content at 25 blows)
- The slope of the best fit line on the semilogarithmic scale is defined as the **flow index (I_f)**

Liquid Limit



Liquid Limit

- ONE Point method

$$LL = w_N\left(\frac{N}{25}\right)^{\tan\beta}$$

where N = number of blows in the liquid limit device for a 12.5 mm (≈ 0.5 in.) groove closure

w_N = corresponding moisture content

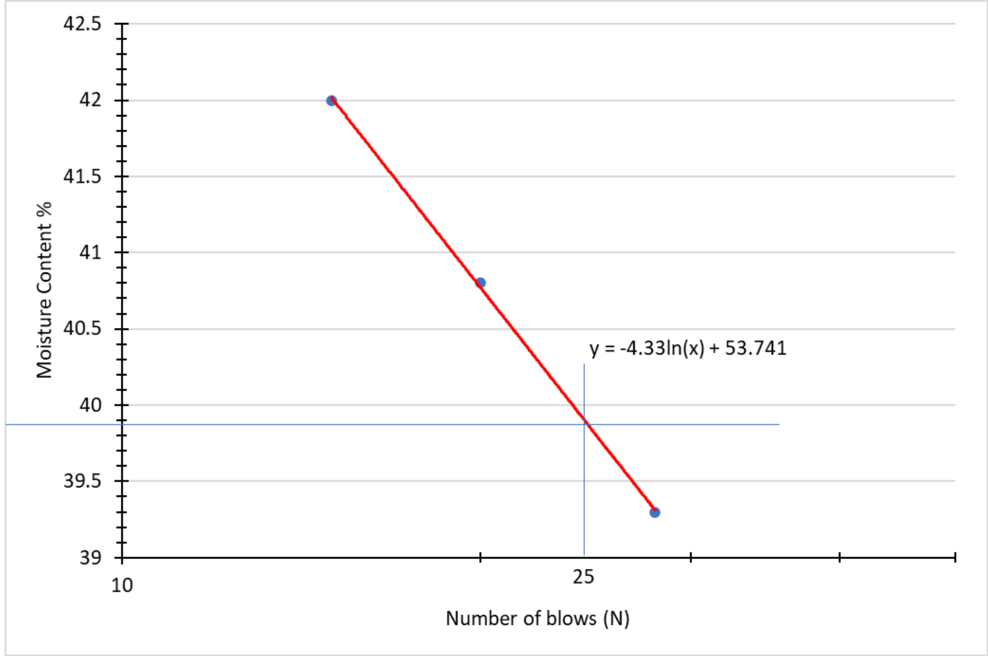
$\tan\beta$ = 0.121 (but note that $\tan\beta$ is not equal to 0.121 for all soils)

Liquid Limit

- Example:

The Following table shows the results of a test conducted in the laboratory. Determine the liquid limit (LL) and the flow index (I_f).

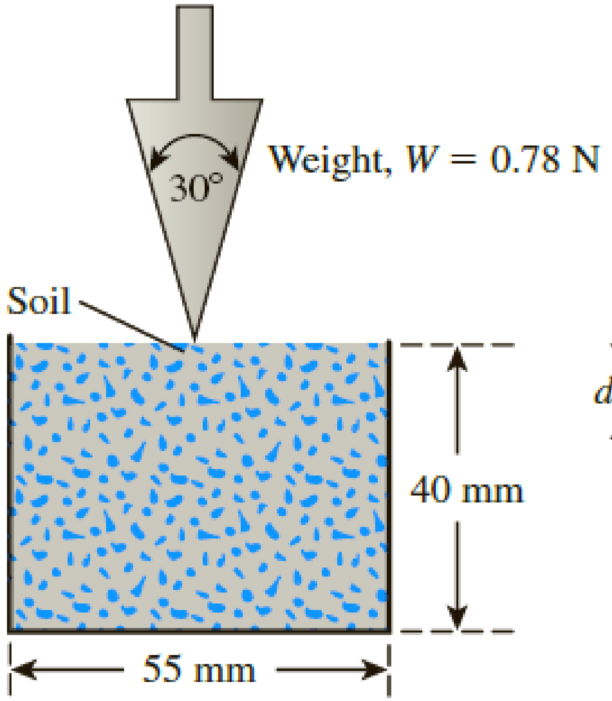
  - If only one liquid limit was conducted, N = 20 and the moisture content = 40.8%. Estimate the liquid limit of the soil by the one-point method.

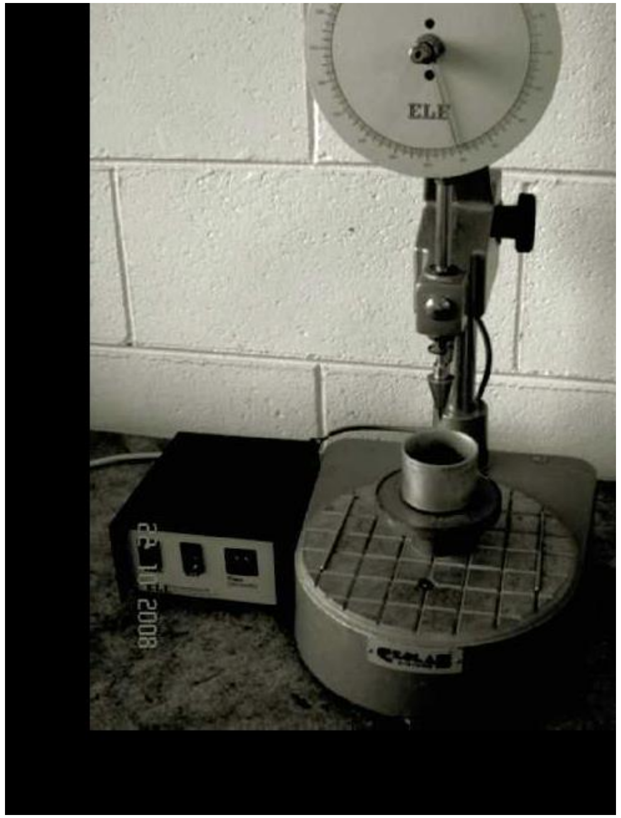


Number of blows, *N*	Moisture content (%)
15	42.0
20	40.8
28	39.3

Liquid Limit

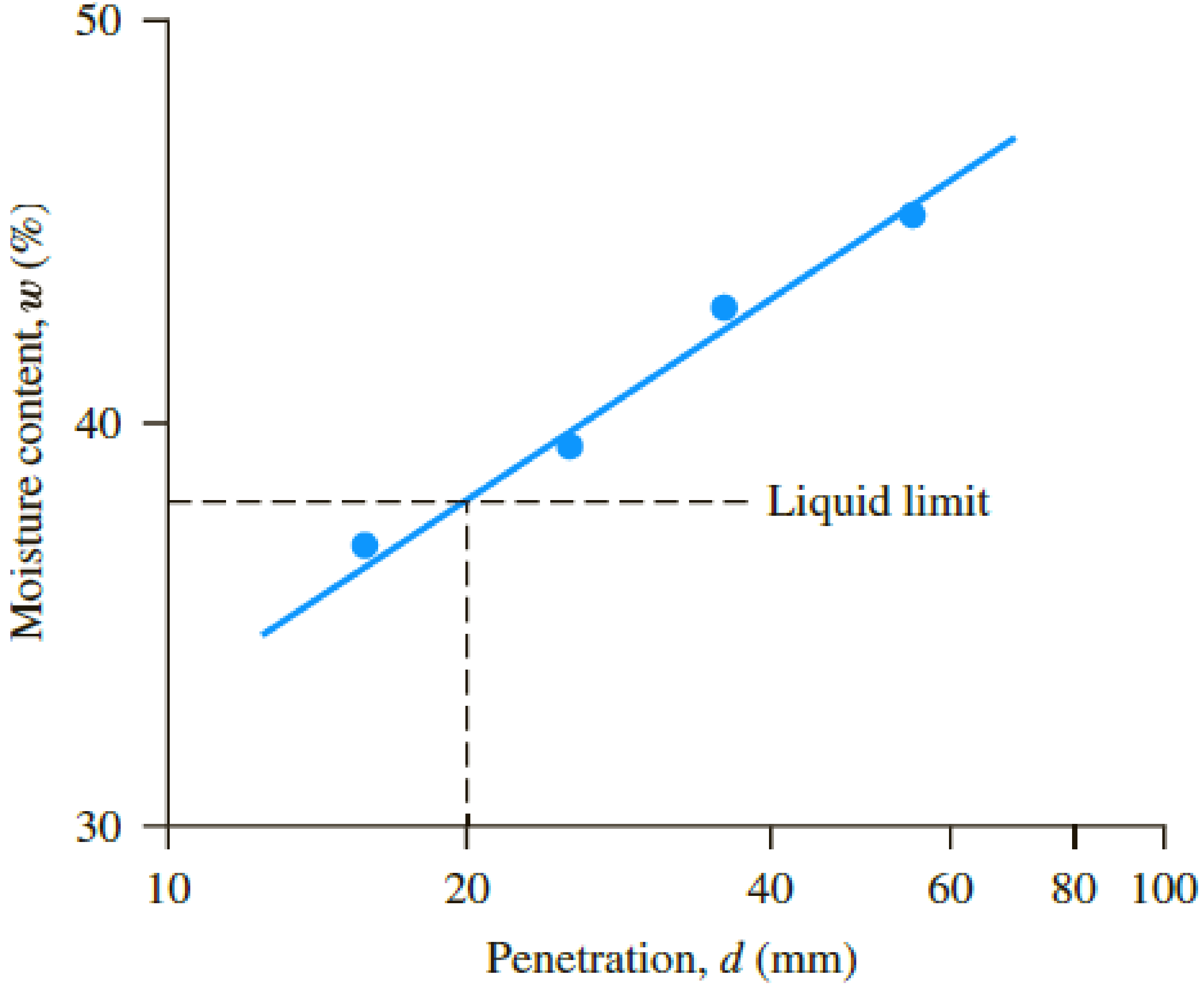
- Fall cone method
  - liquid limit is defined as the moisture content at which a standard cone of apex angle 30° and weight of 0.78 N (80 gf) will penetrate a distance **d = 20 mm** in **5 seconds** when allowed to drop from a position of point contact with the soil surface
  - British Standard—BS1377





Liquid Limit

- Fall cone method

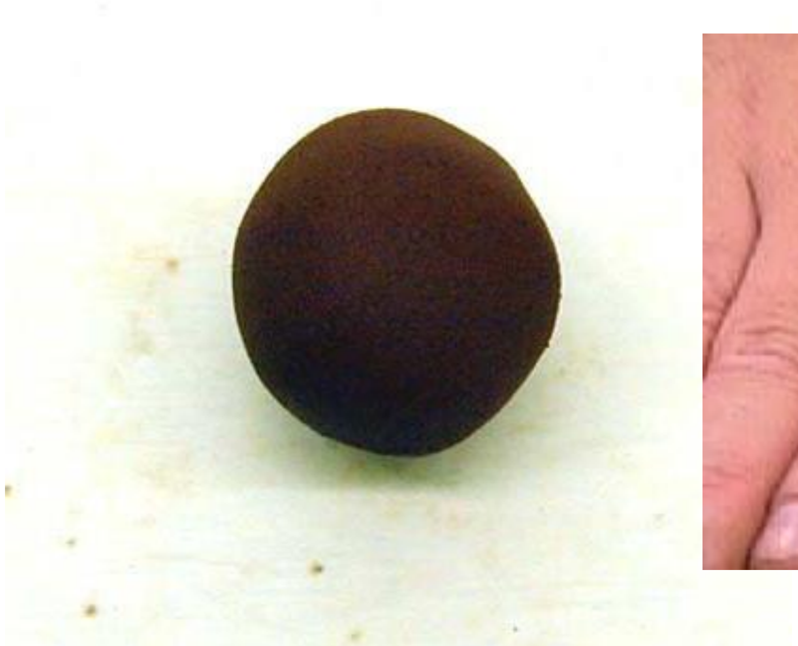


$$LL = \frac{w}{0.77 \log d}$$

$$LL = \frac{w}{0.65 + 0.0175d}$$

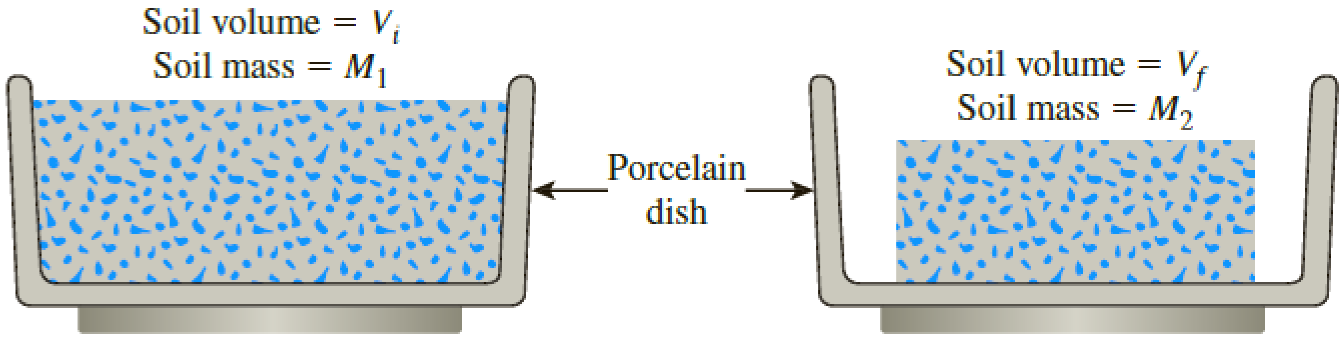
Plastic Limit (PL)

- The moisture content (%) at which the soil when rolled into threads of 3.2mm (1/8 in) in diameter, will crumble.
- ASTM D 4318
- Soil sample size 20g passing #40 sieve



Shrinkage Limit (PL)

- The moisture content, in percent, at which the volume of the soil mass ceases to change.
- ASTM (2014) Test Designation D-4943
- A porcelain dish about 44 mm (1.75 in.) in diameter and about 12.7 mm (12 in.) high.
- The mass of the wet soil inside the dish is recorded. The soil pat in the dish is then oven-dried. The volume of the oven-dried soil pat is then determined.



Mineral	Shrinkage limit
Montmorillonite	8.5–15
Illite	15–17
Kaolinite	25–29

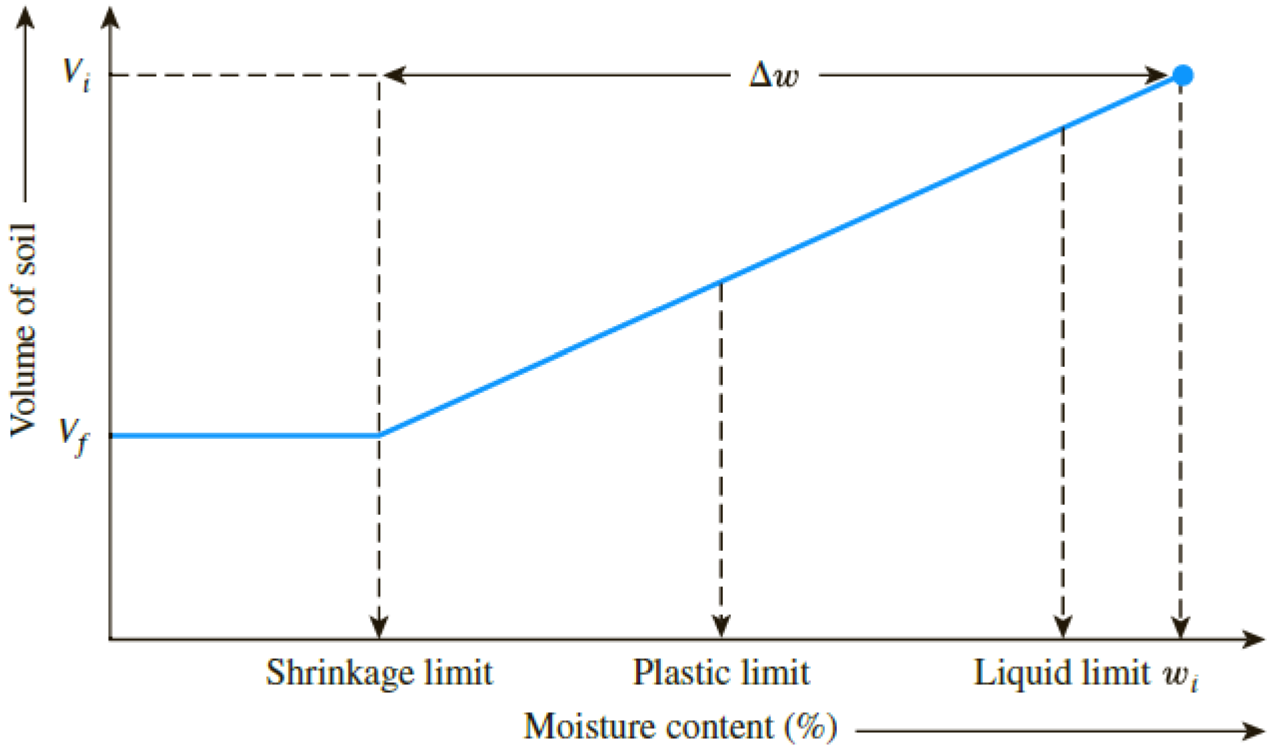
Shrinkage Limit (PL)

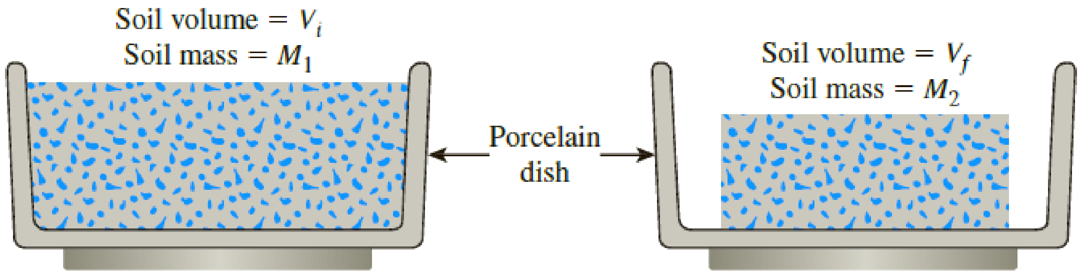
$$SL = w_i\,(\%) - \Delta w\,(\%)$$

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

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

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





Shrinkage Limit (PL)

- Other parameters
  - Shrinkage ratio (SR) : the ratio of the volume change of soil as a percentage of the dry volume to the corresponding change in moisture content

$$SR = \frac{\left(\frac{\Delta V}{V_f}\right)}{\left(\frac{\Delta M}{M_2}\right)} = \frac{\left(\frac{\Delta V}{V_f}\right)}{\left(\frac{\Delta V \rho_w}{M_2}\right)} = \frac{M_2}{V_f \rho_w}$$

$$G_s = \frac{1}{\frac{1}{SR} - \left(\frac{SL}{100}\right)}$$

  - Maximum expected volumetric shrinkage (VS) at given moisture contents (w) can be calculated as

$$VS\,(\%) = SR[w(\%) - SL]$$

Shrinkage Limit (PL)

- Example

  The Atterberg limits of a clayey soil are:

  - LL= 52%
  - PL= 30%
  - SL=18%

  The specimen of the soil shrinks from a volume of 39.5 cm^3 at the liquid limit to a volume of 24.2 cm^3 at the shrinkage limit.

  Calculate the specific gravity of soil solids (G_s)

Shrinkage Limit (PL)

- Solution:

$$G_s = \frac{\frac{M_s}{V_s}}{\rho_w},$$ we need to find Mass of solids and volume of solids

The difference in Volume between LL state and SL state is equal to Volume of water lost in drying the sample:

$$V_{w,lost} = 15.3\ m^3 \rightarrow M_w = 15.3\ g$$

From the block diagrams:

$$M_{w,lost} = (M_s + 0.52M_s) - (M_s + 0.18M_s) = 15.3g \rightarrow M_s = 45\ g$$

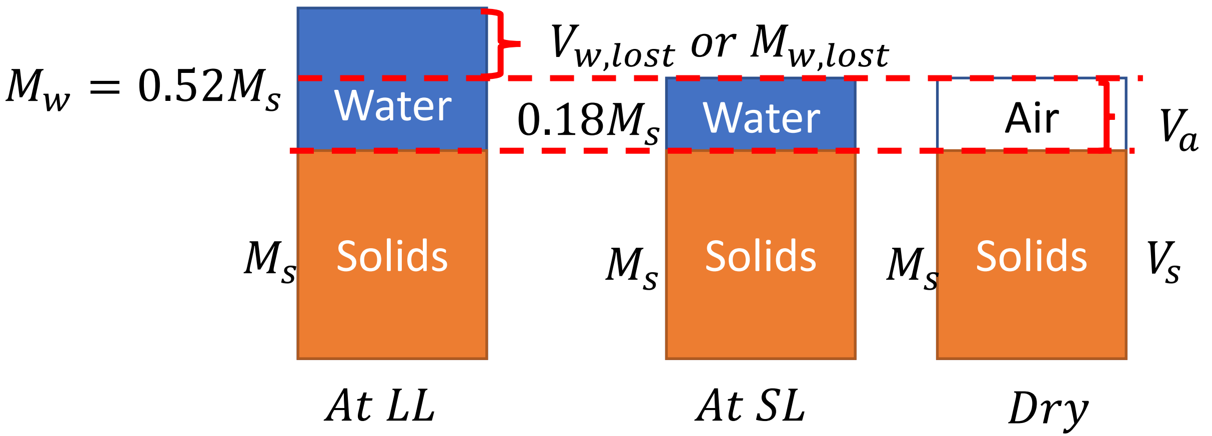
Volume of air in the dry state is equal to the volume of water at SL state

$$M_{w,SL} = 0.18 * M_s = 8.1\ g$$

$$V_{w,SL} = 8.1\ cm^3$$

$$V_s = 24.2 - 8.1 = 16.1\ cm^3$$

$$G_s = \frac{\frac{M_s}{V_s}}{\rho_w} = \frac{\frac{45}{16.1}}{1} = 2.8$$



Plasticity Index & Liquidity Index

- Liquidity Index (LI): The relative consistency of a cohesive soil in the natural state

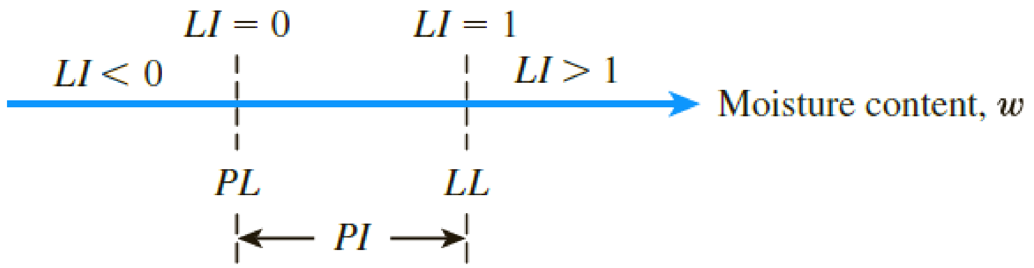
$$LI = \frac{w - PL}{LL - PL}$$

  - The in-situ moisture content for a sensitive clay may be greater than the liquid limit, when remolded, can be transformed into a viscous form to flow like a liquid.
  - Soil deposits that are heavily over consolidated may have a natural moisture content less than the plastic limit

- Consistency index (CI): indicates the consistency (firmness) of a soil

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

  - Soil at the liquid limit will have a consistency index of 0, while soil at the plastic limit will have a consistency index of 1.



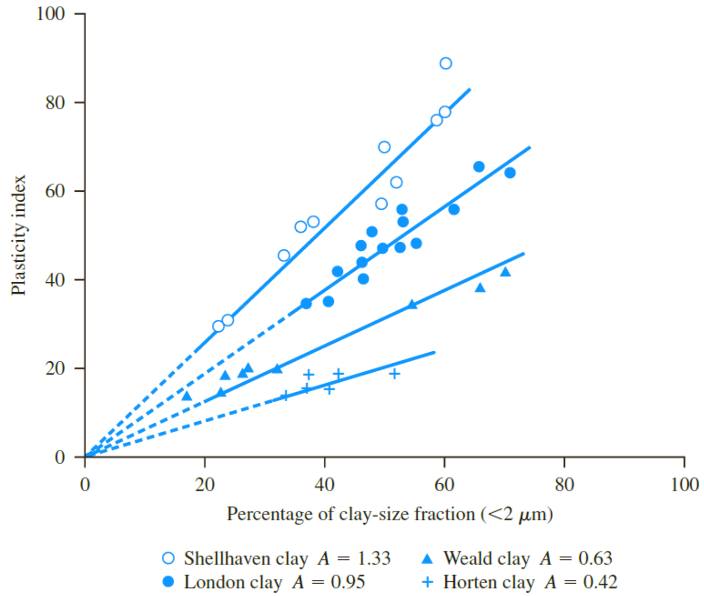
Activity

- Skempton (1953) observed that the plasticity index of a soil increases linearly with the percentage of clay-size fraction (% finer than 2 μm by weight)
  - Activity: the slope of the line correlating PI and % finer than 2 μm

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

  - Activity is used as an index for identifying the swelling potential of clay soils

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



Plasticity Chart