Soil Consistency and Atterberg Limits

Lecture Outline:

1. Soil Consistency
2. Atterberg Limits
3. Liquid Limit (LL)
4. Plastic Limit (PL)
5. Shrinkage Limit (SL)
6. Plasticity Index (PI)
7. Liquidity Index (LI)
8. Plasticity Chart

**Soil Consistency**

- **What is Soil Consistency?**

  Consistency is a term used to indicate the degree of firmness of cohesive soils. The consistency of natural cohesive soil deposits is expressed qualitatively by such terms as very soft, soft, stiff, very stiff and hard.

- The physical properties of clays greatly differ at different water contents. A soil which is very soft at a higher percentage of water content becomes very hard with a decrease in water content.

- However, it has been found that at the same water content, two samples of clay of different origins may possess different consistency. One clay may be relatively soft while the other may be hard. Further, a decrease in water content may have little effect on one sample of clay but may transform the other sample from almost a liquid to a very firm condition.

- Water content alone, therefore, is not an adequate index of consistency for engineering and many other purposes.
Soil Consistency

• Water content significantly affects properties of Silty and Clayey soils (unlike sand and gravel).

1. Strength decreases as water content increases.

2. Soils swell-up when water content increases.

3. Fine-grained soils at very high water content possess properties similar to liquids.

4. As the water content is reduced, the volume of the soil decreases and the soils become plastic.

5. If the water content is further reduced, the soil becomes semi-solid when the volume does not change.
Atterberg Limits

- Atterberg, a Swedish scientist, considered the consistency of soils in 1911, and proposed a series of tests for defining the properties of cohesive soils. Strength decreases as water content increases.

- 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. Hence, on an arbitrary basis, depending on the moisture content, the behavior of soil can be divided into 4 basic states: solid, semisolid, plastic, and liquid.
Atterberg Limits

- **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.

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

- **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.
Liquid Limit (LL)

- In the lab, the **Casagrande Liquid Limit Device** is used for determining the **liquid limits** of soils (ASTM D 4318).
- the *LL* is defined as the moisture content (%) required to close a 2-mm wide groove in a soil pat a distance of 12.7 mm along the bottom of the groove after 25 blows.
Liquid Limit (LL)

**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 12.7 mm.
- Take a sample and find the moisture content.
- Run the test three times [N~(10-20), N~(20-30) and N~(35-45)].
- Plot number of blows vs moisture content and determine the liquid limit (LL) (moisture content at 25 blows).
Liquid Limit (LL)

- Flow curve for liquid limit determination of a clayey silt:
Plastic Limit (PL)

• The plastic limit (PL) is defined as the moisture content (%) at which the soil when rolled into threads of 3.2mm in diameter, will crumble. It is the lower limit of the plastic stage of soil.

• 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 3.2mm.
  • Continue rolling until the thread crumbles into several pieces.
  • Determine the moisture content of about 6g of the crumbled soil.
Shrinkage Limit (SL)

• The **Shrinkage limit** (SL) *is defined as* the moisture content, in percent, at which the volume of the soil mass ceases to change.

• **Procedure:**
  • Shrinkage limit tests (ASTM D-427) are performed in the laboratory with a porcelain dish about 44mm in diameter and about 12.7mm high.
  • The inside of the dish is coated with petroleum jelly and is then filled completely with wet soil. Excess soil standing above the edge of the dish is struck off with a straightedge.
  • 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 determined by the displacement of mercury.
  • The wax-coated soil pat is then cooled. Its volume is determined by submerging it in water.
Shrinkage Limit (SL)

- The *Shrinkage limit* (SL) can be determined as:

\[
SL = \left( \frac{M_1 - M_2}{M_2} \right) (100) - \left( \frac{V_i - V_f}{M_2} \right) (\rho_w) (100)
\]
Typical Values of Atterberg Limits

- Atterberg limits values for the clay minerals (Mitchell, 1993):

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Liquid Limit (%)</th>
<th>Plastic Limit (%)</th>
<th>Shrinkage Limit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montmorillonite</td>
<td>100–900</td>
<td>50–100</td>
<td>8.5–15</td>
</tr>
<tr>
<td>Nontronite</td>
<td>37–72</td>
<td>19–27</td>
<td></td>
</tr>
<tr>
<td>Illite</td>
<td>60–120</td>
<td>35–60</td>
<td>15–17</td>
</tr>
<tr>
<td>Kaolinite</td>
<td>30–110</td>
<td>25–40</td>
<td>25–29</td>
</tr>
<tr>
<td>Hydrated Halloysite</td>
<td>50–70</td>
<td>47–60</td>
<td></td>
</tr>
<tr>
<td>Dehydrated Halloysite</td>
<td>35–55</td>
<td>30–45</td>
<td></td>
</tr>
<tr>
<td>Attapulgite</td>
<td>160–230</td>
<td>100–120</td>
<td></td>
</tr>
<tr>
<td>Chlorite</td>
<td>44–47</td>
<td>36–40</td>
<td></td>
</tr>
<tr>
<td>Allophane (undried)</td>
<td>200–250</td>
<td>130–140</td>
<td></td>
</tr>
</tbody>
</table>
Plasticity Index ($PI$)

- The **plasticity index** ($PI$) is the difference between the liquid limit and the plastic limit of a soil: $PI = LL - PL$

- Plasticity index indicates the degree of plasticity of a soil. The greater the difference between liquid and plastic limits, the greater is the plasticity of the soil. A cohesionless soil has zero plasticity index. Such soils are termed non-plastic. Fat clays are highly plastic and possess a high plasticity index.

- The plasticity index is important in classifying fine-grained soils. It is fundamental to the Casagrande plasticity chart (Chapter 5), which is currently the basis for the Unified Soil Classification System.

<table>
<thead>
<tr>
<th>$PI$</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Nonplastic</td>
</tr>
<tr>
<td>1–5</td>
<td>Slightly plastic</td>
</tr>
<tr>
<td>5–10</td>
<td>Low plasticity</td>
</tr>
<tr>
<td>10–20</td>
<td>Medium plasticity</td>
</tr>
<tr>
<td>20–40</td>
<td>High plasticity</td>
</tr>
<tr>
<td>&gt;40</td>
<td>Very high plasticity</td>
</tr>
</tbody>
</table>

- Burmister (1949) classified the plasticity index in a qualitative manner as follows:
Liquidity Index \((LI)\) and Consistency Index \((CI)\)

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

  \[
  LI = \frac{w - PL}{LL - PL}
  \]

  where \(w\) is 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: \(LI > 1\).

- Soil deposits that are heavily overconsolidated may have a natural moisture content less than the plastic limit. In this case: \(LI < 1\).

- The **consistency index** \((CI)\) is defined as:

  \[
  CI = \frac{LL - w}{LL - PI}
  \]

- If \(w = LL\), the consistency index is zero and if \(w = PI\), then \(CI = 1\).
Activity (A)

- Skempton (1953) defined the activity (A) of clay as:

\[ A = \frac{PI}{\% \text{ of clay - size fraction, in weight}} \]

- The clay soil can be classified inactive, normal or active:
  1. Inactive clays: \( A < 0.75 \)
  2. Normal clays: \( 0.75 < A < 1.40 \)
  3. Active clays: \( A > 1.40 \)

- Typical values of A (Skempton, 1953):

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Activity, A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kaolinite</td>
<td>0.3–0.5</td>
</tr>
<tr>
<td>Illite</td>
<td>0.5–1.2</td>
</tr>
<tr>
<td>Montmorillonite</td>
<td>1.5–7.0</td>
</tr>
<tr>
<td>Halloysite (hydrated)</td>
<td>0.1–0.2</td>
</tr>
<tr>
<td>Halloysite (dehydrated)</td>
<td>0.4–0.6</td>
</tr>
<tr>
<td>Attapulgite</td>
<td>0.4–1.3</td>
</tr>
<tr>
<td>Allophane</td>
<td>0.4–1.3</td>
</tr>
</tbody>
</table>
Casagrande (1932) studied the relationship of the plasticity index to the liquid limit of a wide variety of natural soils and proposed a plasticity chart as shown:
Plasticity Chart

- An **A-line** separates the inorganic clays from the inorganic silts.
- Inorganic clay values lie above the **A-line**, and values for inorganic silts lie below the **A-line**.
- Organic silts plot in the same region (below the A-line and with \( LL \) ranging from 30 to 50) as the inorganic silts of medium compressibility.
- Organic clays plot in the same region as inorganic silts of high compressibility (below the **A-line and \( LL \) greater than 50**).
- 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 (Chapter 5).
- The **U-line** is approximately the upper limit of the relationship of the plasticity index to the liquid limit for any currently known soil.