2. Soil Classification

Soil Mechanics
2015 - 2016

Soil Classification

- Is the arrangement of different soils with similar properties into groups reflects soil’s physical and mechanical properties important for all design and construction purposes.

- Soil is classified according to characteristic properties such as:
  - Cohesion: cohesive soils (silt, clay) versus non-cohesive soils (sand, gravel, boulder).
  - Grain size: fine-grained soils (silt, clay) versus coarse-grained soils (sand, gravel, boulder).
Grain-Size Analysis

- By laboratory tests:
  1. Sieve analysis test
  2. Hydrometer test

Sieve Analysis Test
Sieve Analysis Test

- Stack a set of sieves on top of each other with openings of decreasing sizes from top to bottom (a pan is placed below the stack).
- Sieves numbers and opening sizes:

<table>
<thead>
<tr>
<th>Sieve No.</th>
<th>3 in</th>
<th>1 ½ in</th>
<th>¾ in</th>
<th>3/8 in</th>
<th>4</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opening Size (mm)</td>
<td>75</td>
<td>38</td>
<td>19</td>
<td>9.5</td>
<td>4.75</td>
<td>2</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sieve No.</th>
<th>20</th>
<th>40</th>
<th>60</th>
<th>100</th>
<th>140</th>
<th>200</th>
<th>PAN</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opening Size (mm)</td>
<td>0.85</td>
<td>0.425</td>
<td>0.25</td>
<td>0.15</td>
<td>0.106</td>
<td>0.075</td>
<td>PAN</td>
</tr>
</tbody>
</table>

- Shake the sieves, manually or mechanically.
- After the soil is shaken, the mass of soil retained on each sieve is determined.

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Sieve Analysis Test

Weight of sample = W gm

<table>
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<tr>
<th>Sieve No.</th>
<th>3 in</th>
<th>1 ½ in</th>
<th>140</th>
<th>200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Opening size = Particle size (mm)</td>
<td>75</td>
<td>38</td>
<td>0.106</td>
<td>0.075</td>
</tr>
<tr>
<td>Weight Retained on each sieve (gm)</td>
<td>(w_1)</td>
<td>(w_2)</td>
<td>(w_{11})</td>
<td>(w_{12})</td>
</tr>
<tr>
<td>Total weight Retained (gm)</td>
<td>(w_1)</td>
<td>(w_1 + w_2)</td>
<td>(w_{1} + \cdots + w_{11})</td>
<td>(w_{1} + \cdots + w_{12})</td>
</tr>
<tr>
<td>% Retained</td>
<td>(\frac{w_1}{W} \times 100%)</td>
<td>(\frac{w_1 + w_2}{W} \times 100%)</td>
<td>(\frac{w_1 + \cdots + w_{11}}{W} \times 100%)</td>
<td>(\frac{w_1 + \cdots + w_{12}}{W} \times 100%)</td>
</tr>
<tr>
<td>% Passing</td>
<td>100 -</td>
<td>100 -</td>
<td>100 -</td>
<td>100 -</td>
</tr>
</tbody>
</table>

Plot % Passing versus Particle size (mm)

"Grain-Size Distribution Curve, GSD"

- For coarse-grained soils, particle size > 0.075mm
Hydrometer Test

- For fine-grained soils, particle size < 0.075mm.
- Soil sample is mixed with water and additives in a graduated cylinder soil suspension.
- Larger (heavier) particles settle faster than smaller (lighter) particles.
- The density of the suspension is indirectly measured at determined time intervals, which varies with time as particles settle.
- Computation are based on Stokes formula.
- Indirect measurement of particle size.
### Grain Size Distribution Curve

#### Sieves and Hydrometer

<table>
<thead>
<tr>
<th>Sieve No.</th>
<th>3 in</th>
<th>4</th>
<th>10</th>
<th>20</th>
<th>60</th>
<th>100</th>
<th>200</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle size (mm)</td>
<td>75</td>
<td>4.75</td>
<td>2.0</td>
<td>0.85</td>
<td>0.25</td>
<td>0.15</td>
<td>0.075</td>
</tr>
<tr>
<td>% Passing</td>
<td>100.0</td>
<td>90.0</td>
<td>70.8</td>
<td>56.8</td>
<td>36.4</td>
<td>17.2</td>
<td>5.2</td>
</tr>
</tbody>
</table>

#### Arithmetic Scale

![Grain Size Distribution Curve](image)

- **Sieve No.**
- **Particle size (mm)**
- **% Passing**

#### Semi-log Scale

![Grain Size Distribution Curve](image)

- **Sieve No.**
- **Particle size (mm)**
- **% Passing**

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Semi-Log Paper

Grain Size Distribution
Grain Size Distribution

- $D_{60}$ is the diameter in the GSD curve corresponding to 60% passing.
- $D_{30}$ is the diameter in the GSD curve corresponding to 30% passing.
- $D_{10}$ is the diameter in the GSD curve corresponding to 10% passing. "effective grain size".
- Uniformity coefficient ($C_u$) = $D_{60}/D_{10}$
- Curvature coefficient ($C_c$) = $(D_{30})^2/(D_{60}D_{10})$

Well graded sand, $C_u > 6$ and $C_c = (1-3)$, otherwise, poorly graded.

Well graded gravel, $C_u > 4$ and $C_c = (1-3)$, otherwise, poorly graded.
Consistency of Cohesive Soil

- Depends on the water content of the soil.
- At very low water contents, cohesive soil sample behaves more like a solid.
- At very high water contents, the same sample may flow like a liquid.
- Therefore, based on soil water content, cohesive soil may be divided into 4 basic states: solid, semi-solid, plastic, and liquid.
- The water contents separating these 4 states are named “Atterberg Limits”

Atterberg Limits

Adding water

Dry soil

Solid state

Shrinkage limit

Plastic limit

Liquid limit

W water content

A W S

W S S

S W S

S S S

Solid state

Semi-solid state

Plastic state

Liquid state

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Atterberg Limits

Shrinkage Limit (Sh.L., $w_{Sh}$):
- Is the water content separating solid and semi-solid states
- Is the maximum water content in solid state
- Is the minimum water content in semi-solid state

Plastic Limit (P.L., $w_{P}$):
- Is the water content separating semi solid and plastic states
- Is the maximum water content in semi solid state
- Is the minimum water content in plastic state

Liquid Limit (L.L., $w_{L}$):
- Is the water content separating plastic and liquid states
- Is the maximum water content in plastic state
- Is the minimum water content in liquid state

Plasticity Index (P.I., $I_p$) = L.L. – P.L.

Atterberg limits are determined through laboratory tests.
Liquid Limit Test

Liquid limit device

Liquid limit device

Grooving tool

Grooving tool
**Liquid Limit Test**

- The liquid limit is the water content at which a standard V-shaped groove cut in the soil will just close (0.5 inch) after 25 drops.

**Plastic Limit Test**

- The plastic limit is defined as the water content at which soil crumbles when rolled into threads 3 mm in diameter.
Shrinkage Limit Test

- Put soil sample in oven until it is completely dry, and get its weight ($W_s$).
- Shrinkage limit is the water content of this sample if it is saturated with water at the same volume.
- Measure the total volume of the oven-dried sample ($V_T$):
  - Submerging the sample in water after insulating it with paraffin wax
  - Submerging the sample in mercury ($G_s,_{\text{mercury}} = 13.6$)
- Calculations:
  - $V_s = \frac{W_s}{G_s,_{\text{water}}}$
  - $V_v = V_T - V_s$
  - $W_w = V_v G_s,_{\text{water}}$
  - Sh.L. = $\frac{W_w}{W_s}$

Consistency Index of Cohesive Soil

$$CI = \frac{W_L - W}{W_L - W_P}$$

<table>
<thead>
<tr>
<th>CI</th>
<th>Soil Consistency</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 0.5</td>
<td>Very soft</td>
</tr>
<tr>
<td>0.5 – 0.625</td>
<td>Soft</td>
</tr>
<tr>
<td>0.625 – 0.75</td>
<td>Medium stiff</td>
</tr>
<tr>
<td>0.75 – 1.00</td>
<td>Stiff</td>
</tr>
<tr>
<td>1.00 – $w=w_{sh}$</td>
<td>Very stiff</td>
</tr>
<tr>
<td>$w&lt;w_{sh}$</td>
<td>Hard</td>
</tr>
</tbody>
</table>

Egyptian Code

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Relative density of coarse-grained soil

- Depends on the void ratio (e) of the soil.
- $e_{\text{max}}$ is the maximum possible void ratio, loosest packing.
- $e_{\text{min}}$ is the minimum possible void ratio, densest packing.

$$D_r(\%) = \frac{e_{\text{max}} - e}{e_{\text{max}} - e_{\text{min}}} \times 100$$

<table>
<thead>
<tr>
<th>$D_r$ (%)</th>
<th>Soil Density</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 - 15</td>
<td>Very loose</td>
</tr>
<tr>
<td>15 - 35</td>
<td>Loose</td>
</tr>
<tr>
<td>35 - 65</td>
<td>Medium dense</td>
</tr>
<tr>
<td>65 - 85</td>
<td>Dense</td>
</tr>
<tr>
<td>85 - 100</td>
<td>Very dense</td>
</tr>
</tbody>
</table>

Egyptian Code
Soil Classification Systems

1. MIT Classification System
2. Unified Soil Classification System (USCS)

MIT Soil Classification System

- Based exclusively on grain size.
- Determined by performing sieve analysis and hydrometer tests.
- Gives each soil a “group name”.

Boulders | Gravel | Sand | Silt | Clay
---|---|---|---|---
C | M | F | C | M | F | C | M | F
60 mm | 20 mm | 6 mm | 0.6 mm | 0.2 mm | 0.02 mm | 0.006 mm | 0.002 mm

C: Coarse
M: Medium
F: Fine
MIT Soil Classification System

% Boulder = 100 - % Passing 60mm = 100 - 97 = 3 %
% Gravel = % Passing 60mm - % Passing 2mm = 97 - 70.8 = 26.2 %
% Sand = % Passing 2mm - % Passing 0.06mm = 70.8 - 6.0 = 64.8 %
% Silt = % Passing 0.06 mm - % Passing 0.002 mm = 6.0 - 0.0 = 6.0 %
% Clay = % Passing 0.002mm = 0.0 %
MIT Soil Classification System

- **Soil Group Name:**
  - 50 - 35%: and
  - 35 - 15%: adjective
  - 15 - 5%: some
  - < 5%: trace of

% Boulder = 3%
% Gravel = 27.2%
% Sand = 65.8%
% Silt = 5.0%
% Clay = 0.0%

Group Name: Gravelly SAND, some silt, trace boulders

Unified Soil Classification System

- Based on grain size and/or plasticity of soil.
- Need to have grain-size distribution curve and/or Atterberg limits.
- Gives each soil a "group symbol".
- Classifies soil into two main categories:
  1. Coarse-grained soil: with less than 50% passing through sieve No. 200.
  2. Fine-grained soil: with 50% or more passing through sieve No. 200.
Unified Soil Classification System

Some or all of the following information must be known:

1. % Fine grained soil (silt and clay) = % passing the No. 200 sieve.
2. % Coarse grained soil (gravel and sand) = 100 - % passing the No. 200 sieve.
3. % Gravel = 100 - % passing the No. 4 sieve.
4. % Sand = % passing the No. 4 sieve - % passing the No. 200 sieve.
5. Uniformity ($C_u$) and curvature ($C_c$) coefficients.
6. Liquid and plastic limits of fine-grained soil (portion).

The following symbols are used:

- G = Gravel
- S = Sand
- M = Silt
- C = Clay
- W = well graded
- P = poorly graded
- L = low plasticity (L.L. < 50%)
- H = high plasticity (L.L. > 50%)
Unified Soil Classification System

% Passing sieve No. 200

< 50%  > 50%

Fine-grained soil

Coarse-grained soil

Use Plasticity Chart (A-line)

LL & PI

CH, CL
ML, MH

Unified Soil Classification System

- Plasticity Chart (A-Line):

\[ I_p = 0.73(w_L - 20) \]

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### Unified Soil Classification System

**% Passing sieve No. 200**

- Coarse-grained soil
- Fine-grained soil

#### Coarse-grained soil
- % Passing sieve No. 4
  - Sand (%Sand > %Gravel)
- % Passing sieve No. 200
  - Gravel (%Gravel > %Sand)

#### Fine-grained soil
- < 5% Care for gradation (W or P)
  - Inspect C_u, C_c
- > 12% Care for fines (M or C)
  - Inspect LL, P.I., A-line

#### % Passing sieve No. 200

- Sand (%Sand > %Gravel)
- % Passing sieve No. 200
  - Gravel (%Gravel > %Sand)

#### Dual symbol
- Examples:
  - SW - SC
  - SP - SM
  - GW - GM
  - GP - GC

### USCS Summary Table

**% Passing sieve No. 200**

- Coarse-grained soil
- Fine-grained soil

#### Coarse-grained soil
- % Passing sieve No. 4
  - Sand (%Sand > %Gravel)
- % Passing sieve No. 200
  - Gravel (%Gravel > %Sand)

#### Fine-grained soil
- < 5% Care for gradation (W or P)
  - LL & PI
- > 12% Care for fines (M or C)
  - LL, P.I., A-line

#### % Passing sieve No. 200

- Sand (%Sand > %Gravel)
- % Passing sieve No. 200
  - Gravel (%Gravel > %Sand)

#### Dual symbol
- Examples:
  - SC
  - SM
  - GC
  - GM
  - CH, CL
  - ML, MH

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# USCS Summary Table

<table>
<thead>
<tr>
<th>Criteria for assigning group symbols</th>
<th>Group symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravels</td>
<td>GW</td>
</tr>
<tr>
<td>More than 50% of fraction retained on No. 10 sieve</td>
<td>GP</td>
</tr>
<tr>
<td>Sands</td>
<td>GM</td>
</tr>
<tr>
<td>50% or more coarse fraction passes No. 4 sieve</td>
<td>GC</td>
</tr>
<tr>
<td>Clean Gravels</td>
<td>SP</td>
</tr>
<tr>
<td>Less than 5% fines</td>
<td>SM</td>
</tr>
<tr>
<td>More than 12% fines</td>
<td>SC</td>
</tr>
<tr>
<td>Clean Sands</td>
<td></td>
</tr>
<tr>
<td>Less than 5% fines</td>
<td></td>
</tr>
<tr>
<td>More than 12% fines</td>
<td></td>
</tr>
</tbody>
</table>

Use plasticity chart to determine M or C

*Gravels with 5 to 12% fines require dual symbols: GW-GM, GW-GC, GP-GM, GP-GC.

*Sands with 5 to 12% fines require dual symbols: SW-SM, SW-SC, SP-SM, SP-SC.

\[
C_c = \frac{B_{42}}{B_{60}} \quad C_o = \frac{D_{60}}{D_{42}}
\]

Use Plasticity Chart

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