**SOIL CLASSIFICATION BASICS**

Commonly based on grain size and soil consistency. Several classification systems exist:

1. **Unified Soil Classification System (USCS)** (ASTM D2487-11).
2. **American Association of State Highway and Transportation Officials (AASHTO)** (ASTM D3282-09).
5. Massachusetts Institute of Technology (MIT).
## Soil Grain Sizes

<table>
<thead>
<tr>
<th>Soil Type</th>
<th>USCS Symbol</th>
<th>Grain Size Range (mm)</th>
<th>USCS</th>
<th>AASHTO</th>
<th>USDA</th>
<th>MIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gravel</td>
<td>G</td>
<td>76.2 to 4.75</td>
<td>76.2 to 2</td>
<td>&gt;2</td>
<td>&gt;2</td>
<td></td>
</tr>
<tr>
<td>Sand</td>
<td>S</td>
<td>4.75 to 0.075</td>
<td>2 to 0.075</td>
<td>2 to 0.05</td>
<td>2 to 0.06</td>
<td></td>
</tr>
<tr>
<td>Silt</td>
<td>M</td>
<td>Fines &lt; 0.075</td>
<td>0.075 to 0.002</td>
<td>0.05 to 0.002</td>
<td>0.06 to 0.002</td>
<td></td>
</tr>
<tr>
<td>Clay</td>
<td>C</td>
<td>&lt; 0.002</td>
<td>&lt; 0.002</td>
<td>&lt; 0.002</td>
<td>&lt; 0.002</td>
<td></td>
</tr>
</tbody>
</table>

Determined by Mechanical Analysis (i.e. Sieve) and Hydrometer Analysis (ASTM D422-63 (2007) Standard Test Method for Particle-Size Analysis of Soils)
MECHANICAL SIEVE ANALYSIS
(ASTM D442, D1140 AND AASHTO T88)

Figure 7.1. from FHWA NHI-01-031.
### Soil Classification

<table>
<thead>
<tr>
<th>Sieve No.</th>
<th>Opening (mm)</th>
<th>Opening (in)</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>3/4 in</td>
<td>19</td>
<td>0.75</td>
<td>Gravel</td>
</tr>
<tr>
<td>#4</td>
<td>4.75</td>
<td>0.187</td>
<td></td>
</tr>
<tr>
<td>#6</td>
<td>3.35</td>
<td>0.132</td>
<td>Course Sand (#4 to #10)</td>
</tr>
<tr>
<td>#8</td>
<td>2.36</td>
<td>0.0937</td>
<td></td>
</tr>
<tr>
<td>#10</td>
<td>2.00</td>
<td>0.0787</td>
<td></td>
</tr>
<tr>
<td>#16</td>
<td>1.18</td>
<td>0.0469</td>
<td>Medium Sand (#10 to #40)</td>
</tr>
<tr>
<td>#20</td>
<td>0.85</td>
<td>0.0331</td>
<td></td>
</tr>
<tr>
<td>#30</td>
<td>0.60</td>
<td>0.0234</td>
<td></td>
</tr>
<tr>
<td>#40</td>
<td>0.425</td>
<td>0.0165</td>
<td></td>
</tr>
<tr>
<td>#50</td>
<td>0.300</td>
<td>0.0117</td>
<td></td>
</tr>
<tr>
<td>#60</td>
<td>0.250</td>
<td>0.0098</td>
<td></td>
</tr>
<tr>
<td>#80</td>
<td>0.180</td>
<td>0.0070</td>
<td>Fine Sand (#40 to #200)</td>
</tr>
<tr>
<td>#100</td>
<td>0.150</td>
<td>0.0059</td>
<td></td>
</tr>
<tr>
<td>#140</td>
<td>0.106</td>
<td>0.0041</td>
<td></td>
</tr>
<tr>
<td>#170</td>
<td>0.088</td>
<td>0.0035</td>
<td></td>
</tr>
<tr>
<td>#200</td>
<td>0.075</td>
<td>0.0029</td>
<td>Silt or Clay &lt;#200</td>
</tr>
<tr>
<td>#270</td>
<td>0.053</td>
<td>0.0021</td>
<td></td>
</tr>
</tbody>
</table>

**Commonly Used Standard Sieve Sizes (ASTM E11-09e1)**
**PARTICLE ANGULARITY (ROUNDNESS)**

**Definitions (from FHWA NHI-06-088)**

- **Angular** particles are those that have been freshly broken up and are characterized by jagged projections, sharp ridges, and flat surfaces.

- **Subangular** particles are those that have been weathered to the extent that the sharper points and ridges have been worn off.

- **Subrounded** particles are those that have been weathered to a further degree than subangular particles.

- **Rounded** particles are those on which all projections have been removed, with few irregularities in shape remaining.

- **Well rounded** particles are rounded particles in which the few remaining irregularities have been removed.

---

Mitchell (1976)

*Fig. 2-4. FHWA NHI-06-088.*
HYDROMETER ANALYSIS
(ASTM D442, D1140 & AASHTO T88)

Based on the principle of sedimentation of soil grains in water

Stokes Law: \( v = \frac{\rho_s - \rho_w}{18\eta} D^2 \)

Where:
- \( v \) = Velocity
- \( \rho_s \) = soil particle density
- \( \rho_w \) = water density
- \( \eta \) = water viscosity
- \( D \) = Diameter of soil particles

Figure 2.5. Das FGE (2005).
**Grain Size Distribution Results**

**Figure 2.6.** Das FGE (2005).

**Figure 5.** ASTM D2487-11.
GRAIN SIZE DISTRIBUTION TERMS

Key Particle Sizes (D = Diameter)

$D_{60} = \text{Diameter corresponding to 60\% finer in the grain size distribution.}$

$D_{30} = \text{Diameter corresponding to 30\% finer in the grain size distribution.}$

$D_{10} = \text{Diameter corresponding to 10\% finer in the grain size distribution. Also known as Effective Size.}$
**Grain Size Distribution Terms**

**Key Coefficients (C):**

\[ C_u = \text{Coefficient of Uniformity (ASTM D2487)} \]
\[ = D_{60}/D_{10} \]

\[ C_c = \text{Coefficient of Gradation} \]
\[ = \text{Coefficient of Curvature (ASTM D2487)} \]
\[ = (D_{30})^2/(D_{60} \times D_{10}) \]
### Soil Classification

<table>
<thead>
<tr>
<th>GRAVEL</th>
<th>SAND</th>
<th>SILT &amp; CLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>Medium</td>
<td>Fine</td>
</tr>
</tbody>
</table>

#### Grain Size Distribution - Example

- **Sieve Sizes**: 
  - #4
  - #10
  - #30
  - #40
  - #60
  - #100
  - #200

- **Atterberg Limit Results**: 
  - LL = 60%, PL = 40%

- **D60 = 0.45mm**
- **D30 = 0.22mm**
- **D10 = 0.08mm**

- **Cu** = \( \frac{D_{60}}{D_{10}} \)
  - Cu = 0.45mm/0.08mm
  - Cu = 5.63

- **Cc** = \( \frac{(D_{30})^2}{D_{10} \times D_{60}} \)
  - Cc = (0.22mm)/(0.08mm x 0.45mm)
  - Cc = 1.34

- **% Fines (i.e. % Passing #200 Sieve) = 9%**
**Grain Size Distribution - Example**

Figure 7.2. from FHWA NHI-01-031. Notice Axis Shift!
Multiple Samples of “Same Soil” from one site.
GRAIN SIZE DISTRIBUTION - EXAMPLE

(from Hajduk et al., 2004)
SOIL PLASTICITY – ATTERBERG LIMITS

Plasticity Index (PI)  
PI = LL - PL

Range of water content over which soil remains plastic.

Figure 2-5. FHWA NHI-06-088.
14.330 SOIL MECHANICS
Soil Classification

SOIL PLASTICITY – ATTERBERG LIMITS

Liquid Limit Device

Plastic Limit Device

Figure 24. from FHWA IF-02-034.


Liquid Limit (LL or \( w_L \)) Test

Plastic Limit (PL or \( w_P \)) Test
**Atterberg Limits – Liquid Limit**


**A**  
Assemble components & soil. Mix soil & water.

**B**  
Fill LL Device ~2/3 high with wet soil.

**C**  
Cut groove with tool.

**D**  
Lift LL Device with crank @ constant rate. Count number of blows to close groove ½ inch.

Mix soil with more water. Repeat.

Run 4 Tests
2 > 25 blows
2 < 25 blows.

Plot Number of Blows (N) on Log Scale.

LL is \( w @ N=25 \) (Round to 1%)

Example of Liquid Limit Data Plot

\[
\begin{align*}
\text{Best Fit Line:} & \quad w (\%) = -9.17 \ln(N) + 54.91 \\
R^2 & = 0.993
\end{align*}
\]
Atterberg Limits – Liquid Limit


Assemble components & soil. Mix soil & water.

Run 4 Tests. Average water content for 4 tests = \( w_p = PL \)

Roll on PL Device until 1/8 inch diameter roll is achieved.

When soil crumbles when 1/8 inch diameter is achieved, you are at PL. Take water content.
Soil Classification

Divided into two broad categories:

- **Coarse Grained Soils**
  - Gravels (G) and Sands (S)
  - < 50% passing through #200 sieve (i.e. >50% retained on #200 sieve)

- **Fine Grained Soils**
  - Silts (M) and Clays (C)
  - ≥ 50% passing through #200 sieve
UNIFIED SOIL CLASSIFICATION SYSTEM (USCS)

- Uses 2 or 4 letter Group Symbols and Group Names
  - Primary soil component first symbol
  - 4 letter symbols – either sands and gravels with
    \(5\% \leq \% \text{Fines} \leq 12\%\) or CL-ML on Casagrande Chart

- Need to know the following:
  - Grain Size Distribution
    - Percent Fines (i.e. particles finer than \#200 sieve)
    - Percent Sand
    - Percent Gravel (\#4 and \#200 sieves)
    - \(C_c\) and \(C_u\) from grain size analysis using \(D_{10}, D_{30}, D_{60}\)
  - Atterberg Limit Results (LL, PI)
**Unified Soil Classification System (USCS)**

Example of 2 Group Symbol: **SM**

- **Primary Component (Sand = S)**
- **Secondary Description (M = Silty)**

**Primary Components**
- G = Gravel
- S = Sand
- M = Silt
- C = Clay
- O = Organic

**Secondary Descriptions (Coarse Grained)**
- M = Silty
- C = Clayey
- P = Poorly Graded (same relative grain size)
- W = Well Graded (different grain sizes)

**Secondary Descriptions (Fine Grained)**
- L = Low Plasticity (Lean for Clay)
- H = High Plasticity (Fat for Clay, Elastic for Silt)
UNIFIED SOIL CLASSIFICATION SYSTEM (USCS)

Secondary Descriptions (Coarse Grained)

M = Silty: > 12% fines, PI < 4 or plots below “A” Line
C = Clayey: > 12% fines, PI > 7 and plots on or above “A” line
P = Poorly Graded: < 5% fines, $C_u < 6$ and/or $1 > C_c > 3$
W = Well Graded: < 5% fines, $C_u \geq 6$ and $1 \leq C_c \leq 3$
**Particle Size Distribution Curves**

Three Types of Curves:

- **Poorly Graded (P)**
- **Well Graded (W)**
- **Gap Graded**

*Figure 2-3. from FHWA NHI-06-088.*
UNIFIED SOIL CLASSIFICATION SYSTEM (USCS)

Secondary Descriptions (Fine Grained)

\[ L = \text{Low Plasticity (Lean for Clay)} \]
\[ LL < 50\% \]

\[ H = \text{High Plasticity (Fat for Clay, Elastic for Silt)} \]
\[ LL \geq 50\% \] (e.g. high quality pottery clay)
CASAGRANDE PLASTICITY CHART

For classification of fine-grained soils and fine-grained fraction of coarse-grained soils.

Equation of "A"-line
Horizontal at PI=4 to LL=25.5,
then PI=0.73(LL-20)

Equation of "U"-line
Vertical at LL=16 to PI=7,
then PI=0.9(LL-8)

Figure 4. (ASTM D2487-11).
I consider it essential that an experienced soils engineer should be able to judge the position of soils, from his territory, on a plasticity chart merely on the basis of his visual and manual examination of the soils. – Arthur Casagrande (1959)

Figure 2. (NAVFAC DM7.01).
USCS – **COARSE GRAINED SOILS**

(>50% RETAINED ON #200 SIEVE)

- **GRAVEL** (% gravel > % sand)
  - <5% fines
    - \( C_n \geq 4 \text{ and } 1 \leq C_s \leq 3 \):
      - \( C_s < 4 \text{ and/or } [C_s < 1 \text{ or } C_s > 3] \):
        - GW
        - GP
        - GW-GM
        - GW-GC
        - GP-GM
        - GP-GC
        - GM
        - GC
        - GC-GM
        - SW
        - SP
        - SW-SM
        - SW-SC
        - SP-SM
        - SP-SC
        - SM
        - SC
        - SC-SM
      - \( C_s \geq 4 \text{ and } 1 \leq C_s < 3 \):
    - \( C_s \geq 4 \text{ and } 1 \leq C_s < 3 \):
      - GW
      - GP
      - GW-GM
      - GW-GC
      - GP-GM
      - GP-GC
      - GM
      - GC
      - GC-GM
      - SW
      - SP
      - SW-SM
      - SW-SC
      - SP-SM
      - SP-SC
      - SM
      - SC
      - SC-SM
  - >12% fines
    - >12% fines
      - >12% fines

- **SAND** (% sand > % gravel)
  - <5% fines
    - \( C_s > 6 \text{ and } 1 \leq C_s \leq 3 \):
      - \( C_s < 6 \text{ and/or } [C_s < 1 \text{ or } C_s > 3] \):
        - GW
        - GP
        - GW-GM
        - GW-GC
        - GP-GM
        - GP-GC
        - GM
        - GC
        - GC-GM
        - SW
        - SP
        - SW-SM
        - SW-SC
        - SP-SM
        - SP-SC
        - SM
        - SC
        - SC-SM
      - \( C_s > 6 \text{ and } 1 \leq C_s < 3 \):
    - \( C_s > 6 \text{ and } 1 \leq C_s < 3 \):
      - GW
      - GP
      - GW-GM
      - GW-GC
      - GP-GM
      - GP-GC
      - GM
      - GC
      - GC-GM
      - SW
      - SP
      - SW-SM
      - SW-SC
      - SP-SM
      - SP-SC
      - SM
      - SC
      - SC-SM
  - >12% fines
    - >12% fines
      - >12% fines

Figure 3. ASTM D2487-11.
USCS – FINE GRAINED SOILS
(≥ 50% PASSING #200 SIEVE)

Figure 1. ASTM D2487-11.
### USCS Classification Example

#### US44 Expansion, Carver, MA

**Table 1.** Sample 1 Grain Size Results (ASTM D422).

<table>
<thead>
<tr>
<th>Sieve No.</th>
<th>Dia. (mm)</th>
<th>% Passing</th>
</tr>
</thead>
<tbody>
<tr>
<td>½ in</td>
<td>12.7</td>
<td>100</td>
</tr>
<tr>
<td>#4</td>
<td>4.75</td>
<td>97</td>
</tr>
<tr>
<td>#10</td>
<td>2</td>
<td>94</td>
</tr>
<tr>
<td>#20</td>
<td>0.85</td>
<td>84</td>
</tr>
<tr>
<td>#40</td>
<td>0.425</td>
<td>57</td>
</tr>
<tr>
<td>#60</td>
<td>0.25</td>
<td>32</td>
</tr>
<tr>
<td>#140</td>
<td>0.106</td>
<td>15</td>
</tr>
<tr>
<td>#200</td>
<td>0.075</td>
<td>9</td>
</tr>
</tbody>
</table>

**Table 2.** Atterberg Limits Results (ASTM D4318).

<table>
<thead>
<tr>
<th>Sample</th>
<th>LL</th>
<th>PL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>60</td>
<td>40</td>
</tr>
</tbody>
</table>

**REQUIRED:**

Determine the USCS Soil Classification based on the provided soil index testing.
Soil Classification

**USCS Classification Example**

<table>
<thead>
<tr>
<th>GRAVEL</th>
<th>SAND</th>
<th>SILT &amp; CLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>Medium</td>
<td>Fine</td>
</tr>
</tbody>
</table>

Atterberg Limit Results:
LL = 60%, PL = 40%

**Sieve Sizes**

- #4
- #10
- #30
- #40
- #60
- #100
- #200

**Graph**

- X-axis: Particle Diameter (mm)
- Y-axis: Percent (%) Finer by Weight

- Graph shows data points for different sieve sizes.

Revised 01/2013
USCS Classification Example

<table>
<thead>
<tr>
<th>GRAVEL</th>
<th>SAND</th>
<th>SILT &amp; CLAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coarse</td>
<td>Medium</td>
<td>Fine</td>
</tr>
</tbody>
</table>

Sieve Sizes

D_{60} = 0.45mm
D_{30} = 0.22mm
D_{10} = 0.08mm

Atterberg Limit Results:
LL = 60%, PL = 40%

C_{c} = (D_{30})^2/(D_{10} \times D_{60})
C_{c} = (0.22mm)/(0.08mm \times 0.45mm)
C_{u} = 1.34

C_{u} = D_{60}/D_{10}
C_{u} = 0.45mm/0.08mm
C_{u} = 5.63

% Fines (i.e. % Passing #200 Sieve) = 9%
USCS CLASSIFICATION EXAMPLE

CASAGRANDE CHART

For classification of fine-grained soils and fine-grained fraction of coarse grained soils.

- CH or OH
- CL or OL
- Fines classify as MH
- MH or OH
- ML or OL
USCS CLASSIFICATION EXAMPLE

Figure 3. ASTM D2487-11.

88% Sand
SAND % sand > % gravel

C_u = 5.63
Fines = MH
3% Gravel

ANSWER: SP-SM
(Poorly Graded Sand with Silt)
ORIGIN (Holtz and Kovacs, 1981):
This system was originally developed by Hogentogler and Terzaghi in 1929 as the Public Roads Classification System. Afterwards, there are several revisions. The present AASHTO (1978) system is primarily based on the version in 1945.

STANDARDS:

Soil Classification

Comprised of 8 Major Groups:
- A1 through A7 (with subgroups)
- A8 (Organics)

Subgroups determined from Group Index (GI)

Required Testing:
- Sieve Analysis and Atterberg Limits

Granular Materials
- (≤ 35% passes #200 Sieve)
- Using LL and PI separates silty materials from clayey materials
  (only for A2 group)

Silt-Clay Materials
- (≥ 36% passes #200 Sieve)
- Using LL and PI separates silty materials from clayey materials

General Notes:
- A-1 materials are well graded, whereas A-3 soils are clean, poorly graded sands.
- A4 & A5 are generally silts, A6 & A7 are generally clays.
AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS (AASHTO)

STEPS:

1. Determine Grain Size Distribution (AASHTO T-11 & AASHTO T-27)
2. Determine Liquid Limit (AASHTO T-89)
3. Determine Plastic Limit (AASHTO T-90)
4. Classify Soil using Table 2 ASTM 3282 (Left to Right Method, Process of Elimination)
# 14.330 SOIL MECHANICS

## Soil Classification

### AMERICAN ASSOCIATION OF STATE HIGHWAY AND TRANSPORTATION OFFICIALS (AASHTO)

**TABLE 2 Classification of Soils and Soil-Aggregate Mixtures**

<table>
<thead>
<tr>
<th>General Classification</th>
<th>Granular Materials (35% or less passing No. 200)</th>
<th>Silt-Clay Materials (More than 35% passing No. 200)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A-1-1-a</td>
<td>A-1-1-b</td>
</tr>
<tr>
<td></td>
<td>A-2-1-a</td>
<td>A-2-1-b</td>
</tr>
<tr>
<td></td>
<td>A-2-2-a</td>
<td>A-2-2-b</td>
</tr>
<tr>
<td></td>
<td>A-2-3-a</td>
<td>A-2-3-b</td>
</tr>
<tr>
<td></td>
<td>A-2-4-a</td>
<td>A-2-4-b</td>
</tr>
<tr>
<td></td>
<td>A-2-5-a</td>
<td>A-2-5-b</td>
</tr>
<tr>
<td></td>
<td>A-2-6-a</td>
<td>A-2-6-b</td>
</tr>
<tr>
<td></td>
<td>A-2-7-a</td>
<td>A-2-7-b</td>
</tr>
<tr>
<td></td>
<td>A-4-a</td>
<td>A-4-b</td>
</tr>
<tr>
<td></td>
<td>A-5-a</td>
<td>A-5-b</td>
</tr>
<tr>
<td></td>
<td>A-6-a</td>
<td>A-6-b</td>
</tr>
<tr>
<td></td>
<td>A-7-a</td>
<td>A-7-b</td>
</tr>
</tbody>
</table>

**Sieve analysis, % passing:**

<table>
<thead>
<tr>
<th>Group classification</th>
<th>No. 10 (2.00 mm)</th>
<th>No. 40 (425 μm)</th>
<th>No. 200 (75 μm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1-1-a</td>
<td>50 max</td>
<td>50 max</td>
<td>15 max</td>
</tr>
<tr>
<td>A-1-1-b</td>
<td></td>
<td>51 min</td>
<td>25 max</td>
</tr>
</tbody>
</table>

**Characteristics of fraction passing No. 40 (425 μm):**

- **Liquid limit:**
  - A-1-1-a: 6 max
  - A-1-1-b: N.P.

- **Plasticity index:**
  - A-1-1-a: 10 max
  - A-1-1-b: 11 min

- **Usual types of significant constituent materials:**
  - Stone Fragments, Gravel and Sand
  - Silty or Clayey Gravel and Sand
  - Silty Soils
  - Clayey Soils

**General rating as subgrade:**

- Excellent to Good
- Fair to Poor

---

*Plasticity index of A-7-5 subgroup is equal to or less than LL minus 30. Plasticity index of A-7-6 subgroup is greater than LL minus 30 (see Fig. 1). Reprinted with permission of American Association of State Highway and Transportation Officials.*

### Go from Left to Right, Process of Elimination

Table 2 from ASTM D3282-09 Standard Practice for Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes.
Note: 1 — A-2 soils contain less than 35% finer than 200 sieve.

FIG. 1 Liquid Limit and Plasticity Index Ranges for Silt-Clay Materials
American Association of State Highway and Transportation Officials (AASHTO)

Group Index (GI):

Empirical Formula used to evaluate soils in a group (i.e. subgroup)

\[ GI = (F_{200} - 35)[0.2 + 0.005(LL - 40)] + 0.01(F_{200} - 15)(PI - 10) \]

- The first term is determined by the LL
- The second term is determined by the PI

\[ F_{200}: \% \text{ Passing } \#200 \text{ Sieve} \]

For Groups A-2-6 and A-2-7

\[ GI = 0.01(F_{200} - 15)(PI - 10) \]

use the second term only

In general, the rating for a pavement subgrade is inversely proportional to the group index, GI.
Group Index (GI):
Empirical Formula used to evaluate soils in a group (i.e. subgroup)