# 3 CLASSIFICATION OF SOIL

## 3.1 Introduction

Fine-grained soils and coarse-grained soils are different in their characteristics, and can be found mixed in different proportions. Depending on the usage, there are different ways of classifying soils. They are classified differently for agriculture, roadwork, and general geotechnical applications.

- For most geotechnical applications, soils are classified using Unified Soil Classification System (**USCS**).
- For roadwork, they are classified using the guidelines developed by the American Association of State Highway and Transportation Officials (**AASHTO**).
- For agricultural work on soils, **U.S. Department of Agriculture** textural classification system is appropriate.

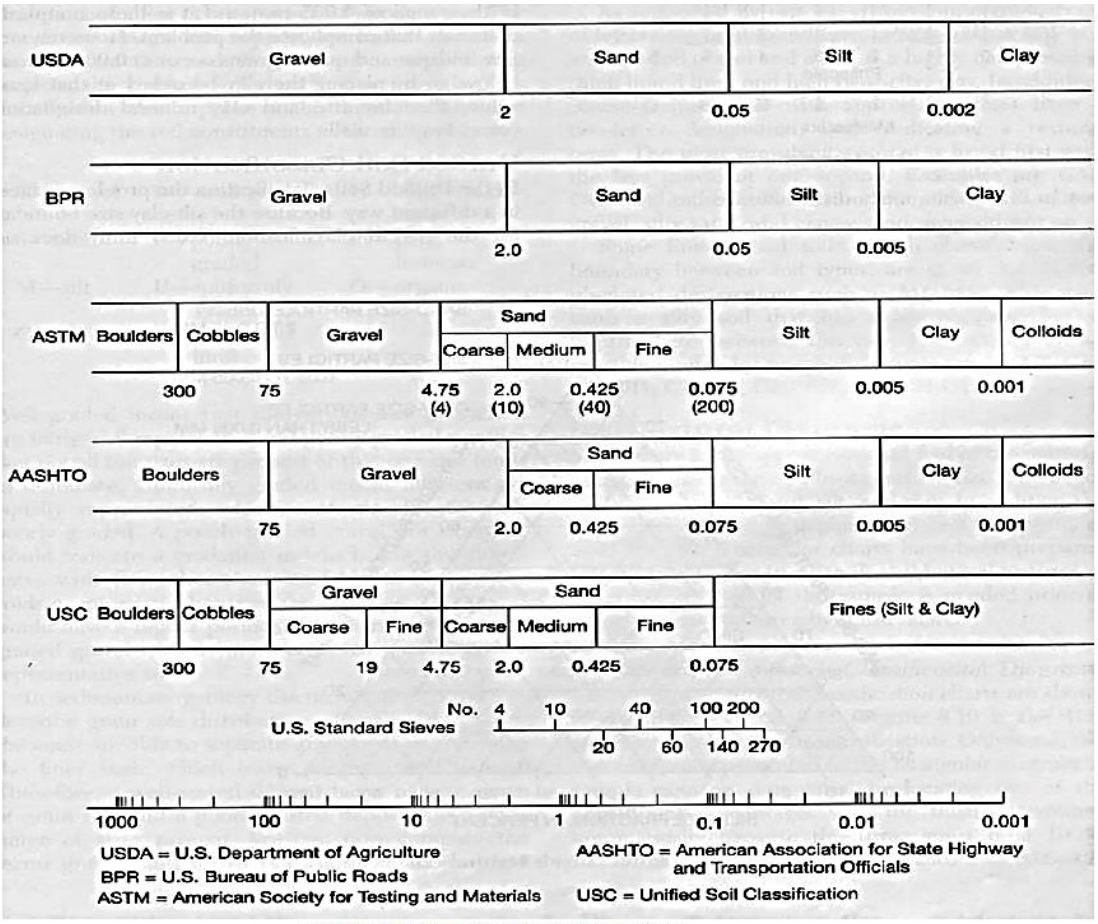
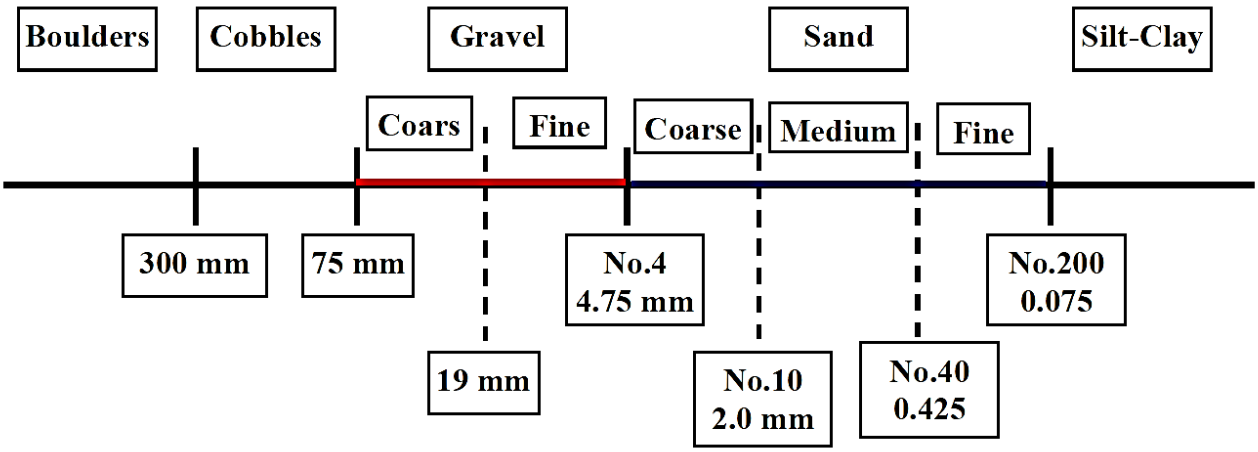



**Figure 3.1: Soil classification systems.**

## 3.2 USCS classification

- The system was first developed by Professor A. Casagrande (1948) for the United States Army Corps of Engineers (USACE).
- The method is standardized in ASTM D-2487 as "Unified Soil Classification System (USCS)".
- Coarse-grained soils that are gravelly and sandy in nature with less than 50% passing through the No. 200 sieve.
- Fine-grained soils that are silty and clayey in nature with 50% or more passing through the No. 200 sieve.

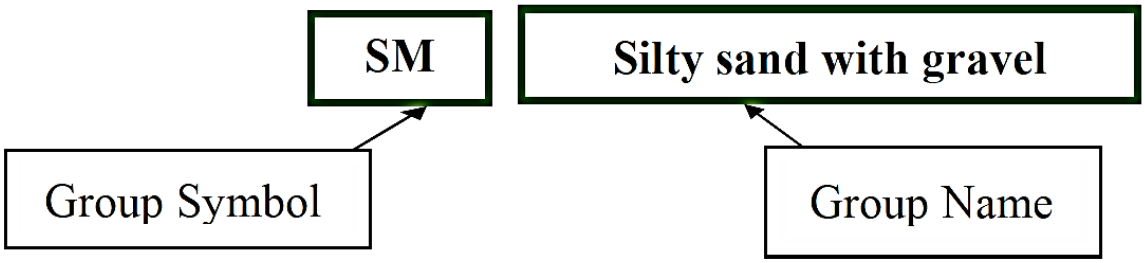



**Soil symbols:**

- **G: Gravel**
- **S: Sand**
- **M: Silt**
- **C: Clay**
- **O: Organic**
- **Pt: Peat**

- **Liquid limit symbols:**
- **H: High LL (LL>50)**
- **L: Low LL (LL<50)**
- **Gradation symbols:**
- **W: Well-graded**
- **P: Poorly-graded**

• A typical USCS classification would be:



## Classification of soils

The unified soil classification system, fondly known as USCS (ASTM D 2487-17), is the most popular soil classification system, used worldwide, including North America. The coarse-grained soils are classified mainly based on the grain size distribution. The fine-grained soils are classified based on the Atterberg limits. The rules followed in USCS are summarized below.

1. The cut-off between coarse-grained soils and fine-grained soils is 0.075 mm (sieve no. 200).

2. Soils where more than 50% of the grains are coarse grains are classified as coarse-grained soils. Otherwise, they are fine-grained soils.

3. The major soil groups are: Gravels (4.75–75 mm), Sands (0.075–4.75 mm), and fines (<0.075 mm) which are separated into Silts and Clays depending on Atterberg limits (not grain sizes). These four major soil groups have symbols of G, S, M, and C, respectively.

4. A coarse-grained soil having more gravels than sands is classified as a gravel and vice versa.

5. The fine-grained soil is classified as clay or silt depending on whether it plots above or below the A-line in Casagrande's PI-LL chart (plasticity chart).

6. The soils are assigned a two-letter symbol (XY), where the first letter (X) is the symbol for the major soil group and the second (Y) is the descriptor. The coarse-grained soils (G and S) are described as well graded (W), poorly graded (P), silty (M), or clayey (C), with possible symbols of GW, GP, GM, GC, SW, SP, SM, and SC. The fine-grained soils (M and C) are described as low plastic (L) or high plastic (H), depending on whether the liquid limit is less or greater than 50. They can have a symbol of ML, MH, CL, or CH. Fine-grained soils with high organic content are given the group symbol O (for organic) and described as low or high in plasticity (L or H). Table 3.7 summarizes the two-letter symbols for the different soil groups.

| Major soil group (X) | Descriptor (Y) | Group symbols (XY) |
|---|---|---|
| Gravel (G)<br>Sand (S) | Well graded (W)<br>Poorly graded (P)<br>Silty (M)<br>Clayey (C) | GW, GP, GM, GC<br>SW, SP, SM, SC |
| Silt (M)<br>Clay (C)<br>Organic (O) | Low plasticity (L)<br>High plasticity (H) | ML, MH<br>CL, CH<br>OL, OH |

When there is 5–12% fines within the soil, it is given a dual symbol in the form XY-XZ, where X is the major soil type (G or S), Y denotes the gradation (W or P), and Z defines the fines as silty or clayey (M or C).

7. In describing a gravel containing ≥15% sands, include “with sand” in the group name. In describing a sand containing ≥ 15% gravels, include “with gravel” in the group name.

8. CH and CL are described as fat and lean clays, respectively, in the group names. MH and ML are described as elastic silt and silt, respectively. For the precise group names of the different fine-grained soils, the reader is suggested to refer the flow chart in ASTM D 2487-17. The CL-ML soil (see plasticity chart) is called a silty clay.

9. In a fine-grained soil containing more than 30% coarse grains, depending on whether sands or gravels are predominant, add “sandy” or “gravelly” to the group name. When both sands and gravels are more than 15%, add “with sand” or “with gravel” to the group name.

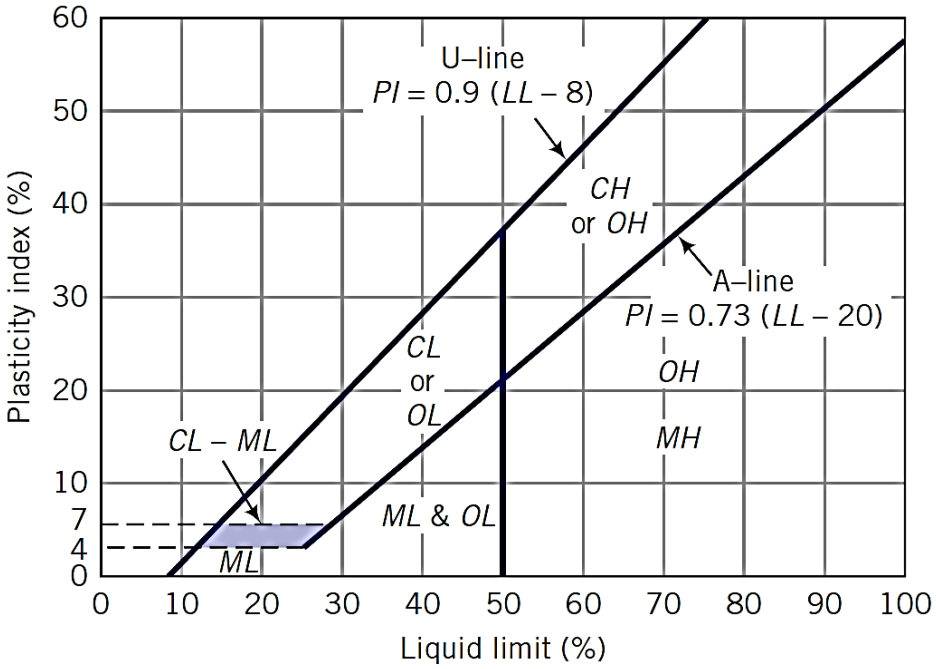
10. In general, the symbols are assigned based on the percentage of fines contained within the soil.

- <5% fines: GW, GP, SW, SP
- 5–12% fines: GW-GM, GW-GC, GP-GM, GP-GC, SW-SM, SW-SC, SP-SM, SP-SC
- 12–50% fines: GM, GC, SM, SC (When the fines classify as CL-ML, use dual symbol GC-GM or SC-SM, and include “silty clayey” to the group name)
- >50% fines: ML, MH, CL, CH

11. Organic soils show a reduction in liquid limit when oven dried. If the reduction in LL is more than 25%, it is assigned a group symbol OH or OL, depending on whether the LL is greater or less than 50. It is called organic clay if it plots above the A-line and organic silt if it plots below the A-line.

*Organic soils have dark grey, black, or blue color and an unpleasant odor. Peats have very high organic content, with a symbol Pt.*

12) The group names are summarized in Figures given in the text book.

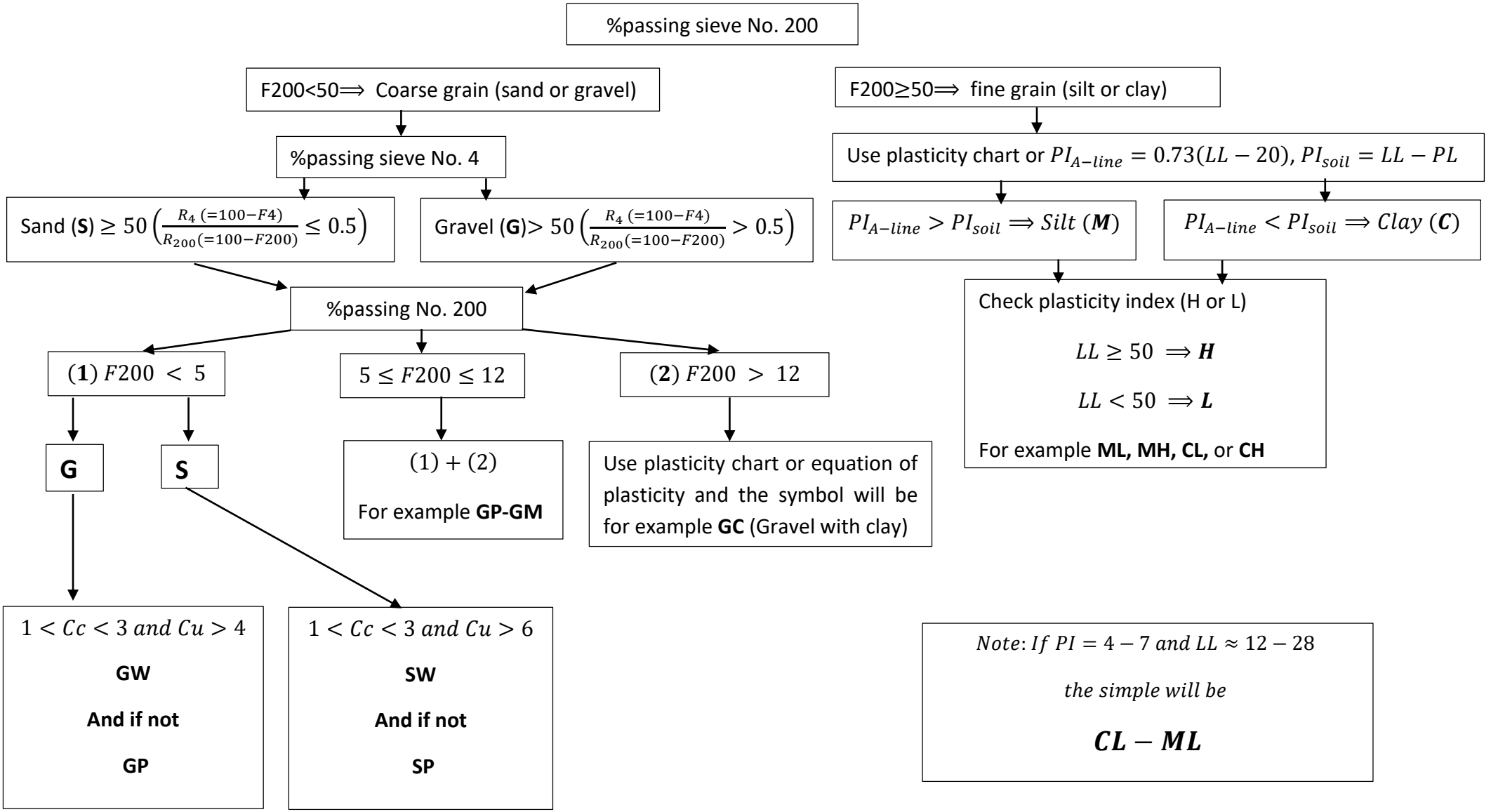



Engineering Use Chart (after Wagner, 1957).

| Typical names of soil groups | Group symbols | Important properties: Permeability when compacted | Shearing strength when compacted and saturated | Compressibility when compacted and saturated | Workability as a construction material |
|---|---|---|---|---|---|
| Well-graded gravels, gravel-sand mixtures, little or no fines | GW | Pervious | Excellent | Negligible | Excellent |
| Poorly graded gravels, gravel–sand mixtures, little or no fines | GP | Very Pervious | Good | Negligible | Good |
| Silty gravels, poorly graded gravel-sand-silt mixtures | GM | Semipervious to impervious | Good | Negligible | Good |
| Clayey gravels, poorly graded gravel-sand-clay mixtures | GC | Impervious | Good to fair | Very low | Good |
| Well-graded sands, gravelly sands, little or no fines | SW | Pervious | Excellent | Negligible | Excellent |
| Poorly graded sands, gravelly sands, little or no fines | SP | Pervious | Good | Very low | Fair |
| Silty sands, poorly graded sand-silt mixtures | SM | Semipervious to impervious | Good | Low | Fair |
| Clayey sands, poorly graded sand-clay mixtures | SC | Impervious | Good to fair | Low | Good |
| Inorganic silts and very fine sands, rock flour, silty, or clayey fine sands with slight plasticity | ML | Semipervious to impervious | Fair | Medium | Fair |
| Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silky clays, lean clays | CL | Impervious | Fair | Medium | Good to fair |
| Organic silts and organic silt-clays of low plasticity | OL | Semipervious to impervious | Poor | Medium | Fair |
| Inorganic silts, micaceous or diatomaceous fine sandy, or silty soils, elastic silts | MH | Semipervious to impervious | Fair to poor | High | Poor |
| Inorganic clays of high plasticity, fat clays | CH | Impervious | Poor | High | Poor |
| Organic clays of medium to high plasticity | OH | Impervious | Poor | High | Poor |
| Peat and other highly organic soils | Pt | – | – | – | – |

| | | |
|---|---|---|
| GW | <15% sand | Well-graded gravel |
| | ≥15% sand | Well-graded gravel with sand |
| GP | <15% sand | Poorly graded gravel |
| | ≥15% sand | Poorly graded gravel with sand |
| GW-GM | <15% sand | Well-graded gravel with silt |
| | ≥15% sand | Well-graded gravel with silt and sand |
| GW-GC | <15% sand | Well-graded gravel with clay (or silty clay) |
| | ≥15% sand | Well-graded gravel with clay and sand (or silty clay and sand) |
| GP-GM | <15% sand | Poorly graded gravel with silt |
| | ≥15% sand | Poorly graded gravel with silt and sand |
| GP-GC | <15% sand | Poorly graded gravel with clay (or silty clay) |
| | ≥15% sand | Poorly graded gravel with clay and sand (or silty clay and sand) |
| GM | <15% sand | Silty gravel |
| | ≥15% sand | Silty gravel with sand |
| GC | <15% sand | Clayey gravel |
| | ≥15% sand | Clayey gravel with sand |
| GC-GM | <15% sand | Silty clayey gravel |
| | ≥15% sand | Silty clayey gravel with sand |
| SW | <15% gravel | Well-graded sand |
| | ≥15% gravel | Well-graded sand with gravel |
| SP | <15% gravel | Poorly graded sand |
| | ≥15% gravel | Poorly graded sand with gravel |
| SW-SM | <15% gravel | Well-graded sand with silt |
| | ≥15% gravel | Well-graded sand with silt and gravel |
| SW-SC | <15% gravel | Well-graded sand with clay (or silty clay) |
| | ≥15% gravel | Well-graded sand with clay and gravel (or silty clay and gravel) |
| SP-SM | <15% gravel | Poorly graded sand with silt |
| | ≥15% gravel | Poorly graded sand with silt and gravel |
| SP-SC | <15% gravel | Poorly graded sand with clay (or silty clay) |
| | ≥15% gravel | Poorly graded sand with clay and gravel (or silty clay and gravel) |
| SM | <15% gravel | Silty sand |
| | ≥15% gravel | Silty sand with gravel |
| SC | <15% gravel | Clayey sand |
| | ≥15% gravel | Clayey sand with gravel |
| SC-SM | <15% gravel | Silty clayey sand |
| | ≥15% gravel | Silty clayey sand with gravel |

## Soil Mechanics-Third Class



## Example 3.1

Classify the following soils using USCS, giving them the symbol and description.

| | Soil *A* | Soil *B* | Soil *C* |
|---|---|---|---|
| % retained on 75 mm sieve | 6 | 0 | 0 |
| % passing 4.75 mm sieve | 68 | 100 | 56 |
| % passing 75 μm sieve | 20 | 82 | 3 |
| Coefficient of curvature | 2.4 | 1.2 | 2.7 |
| Coefficient of uniformity | 15.2 | 9.3 | 35.8 |
| Liquid limit | 40 | 60 | - |
| Plastic limit | 18 | 28 | - |

**Solution**

*Soil A:*

Percentage of fines = 20, % sands = 68 − 20 = 48, % gravels = 94 − 68 = 26

There are about 6% cobbles.

The fines with $LL = 40$ and $PI = 22$ plot above the A-line, and hence are classified as clays.

**The soil is a clayey sand with gravel, with the symbol SC.**

*Soil B:*

Percentage of fines = 82, % sands = 100 − 82 = 18, % gravels = 0

The fines with $LL = 60$ and $PI = 32$ plot above the A-line, and hence are classified as clays.

**The soil is a fat clay with sand, with symbol CH.**

*Soil C:*

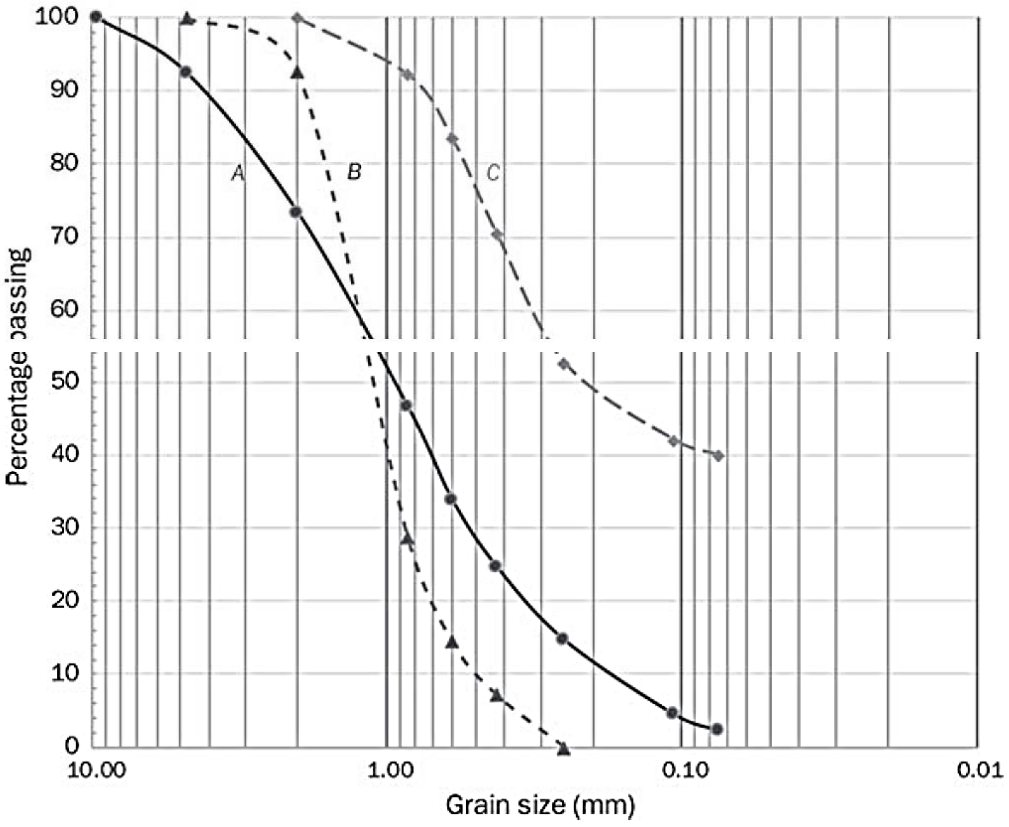
Percentage of fines = 3, % sands = 56 − 3 = 53, % gravels = 44

**The soil is a well-graded sand with gravels, with symbol of SW.**

## Example 3.2

The grain size distribution data for three soils *A*, *B*, and *C* are given in the table below. The liquid limit and plastic limit for soil C are also given. The grain size distribution curves are shown in Fig. 3.14. Classify the three soils according to USCS, giving their descriptions and symbols.

| Grain size (mm) | % Passing | | |
|---|---|---|---|
| | Soil *A* | Soil *B* | Soil *C* |
| 9.50 | 100 | | |
| 4.75 | 92.5 | 100 | |
| 2.00 | 73.4 | 92.6 | 100 |
| 0.85 | 46.7 | 28.9 | 92.3 |
| 0.60 | 33.9 | 14.5 | 83.5 |
| 0.425 | 24.8 | 7.2 | 70.5 |
| 0.25 | 14.7 | 0 | 52.7 |
| 0.106 | 4.5 | | 42.1 |
| 0.075 | 2.3 | | 40.1 |
| Liquid limit | | | 65 |
| Plastic limit | | | 26 |



**Solution** The percentages of the fines, sands, and gravels are summarized below along with the $D_{10}$, $D_{30}$, and $D_{60}$ values for the soils $A$ and $B$, which are coarse-grained soils.

| Soil | % fines | % sands | % gravels | $D_{10}$ (mm) | $D_{30}$ (mm) | $D_{60}$ (mm) | $C_u$ | $C_c$ |
|---|---|---|---|---|---|---|---|---|
| A | 2.3 | 90.2 | 7.5 | 0.17 | 0.52 | 1.25 | 7.35 | 1.27 |
| B | 0 | 100 | 0 | 0.50 | 0.87 | 1.20 | 2.40 | 1.26 |
| C | 40.1 | 59.9 | 0 | - | - | 0.32 | - | - |

Soil $A$ is a well-graded sand (SW).
Soil $B$ is a poorly graded sand (SP).
Soil $C$ is a clayey sand (SC).

## Example 3.3

The results of the particle-size analysis of a soil are as follows:

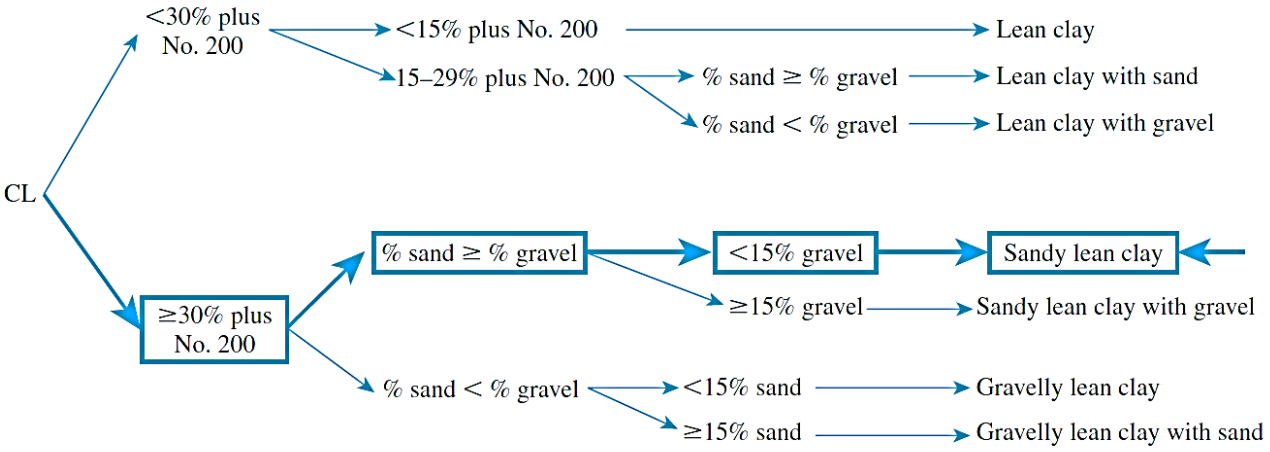
Percent passing through the No. 10 sieve = 100
Percent passing through the No. 40 sieve = 80
Percent passing through the No. 200 sieve = 58

The liquid limit and plasticity index of the minus No. 40 fraction of the soil are 30 and 10, respectively. Classify the soil by the Unified classification system.

### Solution

Refer to Table 5.2. Since 58% of the soil passes through the No. 200 sieve, it is a fine-grained soil. Referring to the plasticity chart in Figure 5.3, for $LL = 30$ and $PI = 10$, it can be classified (group symbol) as CL.

In order to determine the group name, we refer to Figure 5.5 and Figure 5.7, which is taken from Figure 5.5. The percent passing No. 200 sieve is more than 30%. Percent of gravel = 0; percent of sand = (100 − 58) − (0) = 42. Hence, percent sand > percent gravel. Also, percent gravel is less than 15%. Hence the group name is **sandy lean clay**.



## Example 3.4

For a given soil, the following are known:

- Percentage passing through No. 4 sieve = 70
- Percentage passing through No. 200 sieve = 30
- Liquid limit = 33
- Plastic limit = 12

Classify the soil using the Unified Soil Classification System. Give the group symbol and the group name.

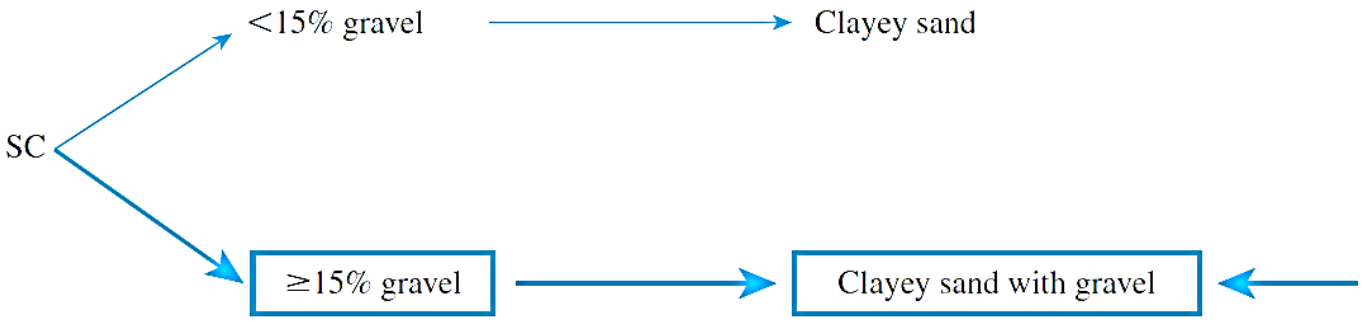
### Solution

Refer to Table 5.2. The percentage passing No. 200 sieve is 30%, which is less than 50%. So it is a coarse-grained soil. Thus

$$\text{Coarse fraction} = 100 - 30 = 70\%$$
$$\text{Gravel fraction} = \text{percent retained on No. 4 sieve} = 100 - 70 = 30\%$$

Hence, more than 50% of the coarse fraction is passing No. 4 sieve. Thus, it is a sandy soil. Since more than 12% is passing No. 200 sieve, it is SM or SC. For this soil, $PI = 33 - 12 = 21$ (which is greater than 7). With $LL = 33$ and $PI = 21$, it plots above the $A$-line in Figure 5.3. Thus the group symbol is **SC**.

For the group name, refer to Figure 5.4 and Figure 5.8 (which is taken from Figure 5.4). Since the percentage of gravel is more than 15%, it is **clayey sand with gravel**.



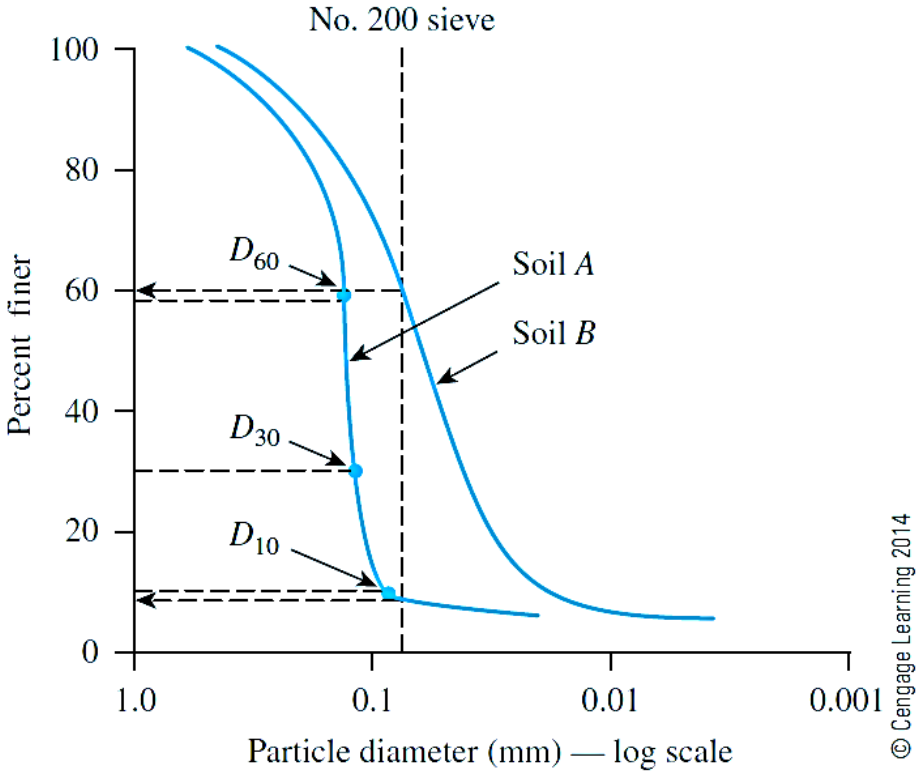
## Example 3.5

The following figure gives the grain-size distribution of two soils. The liquid and plastic limits of minus No. 40 sieve fraction of the soil are as follows:

| | Soil *A* | Soil *B* |
|---|---|---|
| Liquid limit | 30 | 26 |
| Plastic limit | 22 | 20 |



Determine the group symbols and group names according to the Unified Soil Classification System.



## Solution

### Soil *A*

The grain-size distribution curve (Figure 5.9) indicates that percent passing No. 200 sieve is 8. According to Table 5.2, it is a coarse-grained soil. Also, from Figure 5.9, the percent retained on No. 4 sieve is zero. Hence, it is a sandy soil.
From Figure 5.9, $D_{10} = 0.085$ mm, $D_{30} = 0.12$ m, and $D_{60} = 0.135$ mm. Thus,

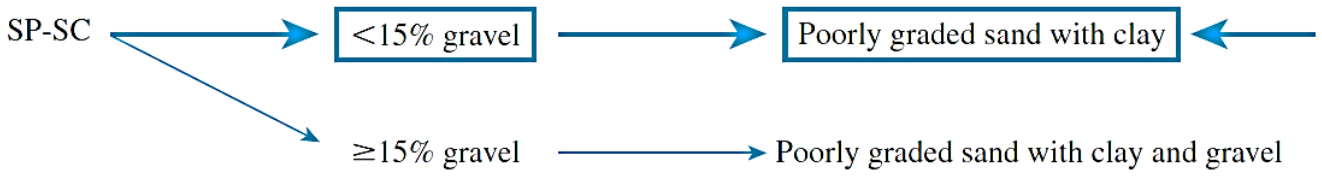
$$C_u = \frac{D_{60}}{D_{10}} = \frac{0.135}{0.085} = 1.59 < 6$$

$$C_c = \frac{D_{30}^2}{D_{60} \times D_{10}} = \frac{(0.12)^2}{(0.135)(0.085)} = 1.25 > 1$$

With $LL = 30$ and $PI = 30 - 22 = 8$ (which is greater than 7), it plots above the *A*-line in Figure 5.3. Hence, the group symbol is **SP-SC**.

In order to determine the group name, we refer to Figure 5.4 and Figure 5.10.

$$\text{Percentage of gravel} = 0 \text{ (which is} < 15\%)$$




So, the group name is **poorly graded sand with clay**.

### Soil *B*

The grain-size distribution curve in Figure 5.9 shows that percent passing No. 200 sieve is 61 (>50%); hence, it is a fine-grained soil. Given: $LL = 26$ and $PI = 26 - 20 = 6$. In Figure 5.3, the *PI* plots in the hatched area. So, from Table 5.2, the group symbol is **CL-ML**.

For group name (assuming that the soil is inorganic), we go to Figure 5.5 and obtain Plus No. 200 sieve $= 100 - 61 = 39$ (which is greater than 30).

Percentage of gravel = 0; percentage of sand = 100 − 61 = 39

Thus, because the percentage of sand is greater than the percentage of gravel, the soil is **sandy silty clay** as shown in Figure 5.11.