1 DEFINITION OF SOIL

1.1 INTRODUCTION

The purpose of this chapter is to introduce you to the composition and particle sizes of soils. Soils are complex, natural materials, and soils vary widely. The composition and particle sizes of soils influence the load-bearing and settlement characteristics of soils.

1.2 DEFINITIONS OF KEY TERMS

- Minerals are chemical elements that constitute rocks.
- Rocks are the aggregation of minerals into a hard mass.
- Soils are materials that are derived from the weathering of rocks.
- Effective particle size (D_{10}) is the average particle diameter of the soil at the 10th percentile; that is, 10% of the particles are smaller than this size (diameter).
- Average particle diameter (D_{50}) is the average particle diameter of the soil.
- Uniformity coefficient (Cu) is a numerical measure of uniformity (majority of grains are approximately the same size).
- Coefficient of curvature (CC) is a measure of the shape of the particle distribution curve (other terms used are the coefficient of gradation and the coefficient of concavity).

1.3 COMPOSITION OF SOILS

1.3.1 Soil formation

- Engineering soils are formed from the physical and chemical weathering of rocks. Soils may also contain organic matter from the decomposition of plants and animals.
- Physical weathering involves reduction of size without any change in the original composition of the parent rock. The main agents responsible for this process are exfoliation, unloading, erosion, freezing, and thawing.
- Chemical weathering causes both reductions in size and chemical alteration of the original parent rock. The main agents responsible for chemical weathering are hydration, carbonation, and oxidation.
- Soils that remain at the site of weathering are called residual soils. These soils retain many of the elements that comprise the parent rock.

- Alluvial soils, also called fluvial soils, are soils that were transported by rivers and streams. The composition of these soils depends on the environment under which they were transported and is often different from the parent rock.
- The profile of alluvial soils usually consists of layers of different soils. Much of our construction activity has been and is occurring in and on alluvial soils.

1.3.2 Soil types

- Gravels, sands, silts, and clays are used to identify specific textures in soils. We will refer to these soil textures as soil types; that is, sand is one soil type, clay is another. Texture refers to the appearance or feel of a soil.
- Sands and gravels are grouped together as coarse-grained soils. Clays and silts are fine-grained soils. Coarse-grained soils feel gritty and hard. Fine grained soils feel smooth.
- The coarseness of soils is determined from knowing the distribution of particle sizes, which is the primary means of classifying coarse-grained soils.
- Currently, many soil descriptions and soil types are in usage. A few of these are listed below.

■ Alluvial soils are fine sediments that have been eroded from rock and transported by water, and have settled on river- and streambeds.

■ Collovial soils (collovium) are soils found at the base of mountains that have been eroded by the combination of water and gravity.

■ Eolian or Aeolian soils are sand-sized particles deposited by wind.

■ Expansive soils are clays that undergo large volume changes from cycles of wetting and drying.

■ Glacial soils are mixed soils consisting of rock debris, sand, silt, clays, and boulders. formed by transportation and deposition of glaciers

■ Gypsum is calcium sulfate formed under heat and pressure from sediments in ocean brine.

■ Lacustrine soils are mostly silts and clays deposited in glacial lake waters.

■ Lateritic soils are residual soils that are cemented with iron oxides and are found in tropical regions.

■ Loam is a mixture of sand, silt, and clay that may contain organic material.

■ Loess is a wind-blown, uniform, fine-grained soil.

■ Marine soils are sand, silts, and clays deposited in salt or brackish water.

■ Marl (marlstone) is a mud (see definition of mud below) cemented by calcium carbonate or lime.

■ Mud is clay and silt mixed with water into a viscous fluid.

1.3.3 Soil minerals

Minerals are crystalline materials and make up the solids constituent of a soil. Minerals are classified according to chemical composition and structure.

- Most minerals of interest to geotechnical engineers are composed of oxygen and silicon, two of the most abundant elements on earth.
- Quartz (a common mineral in rocks) is the principal mineral of coarse-grained soils. Quartz is hard and composed of silicon dioxide (SiO_2) in colored, colorless, and transparent hexagonal crystals.
- Clay minerals are made up of phyllosilicates, which are parallel sheets of silicates.

Clay minerals are complex aluminum silicates composed of two basic units:

a) Silica Tetrahedron

❖ Each tetrahedron unit consists of four oxygen atoms surrounding a silicon atom.

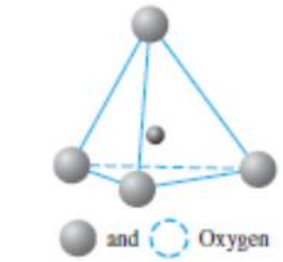
❖ The combination of tetrahedral silica units gives a silica sheet. Three oxygen atoms at the base of each tetrahedron are shared by neighboring tetrahedral.

b) Alumina Octahedron

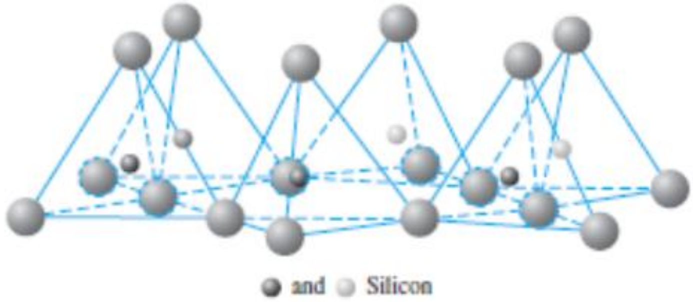
❖ The octahedral units consist of six hydroxyls surrounding an aluminum atom.

❖ The combination of the octahedral aluminum hydroxyl units gives an octahedral sheet (gibbsite sheet).

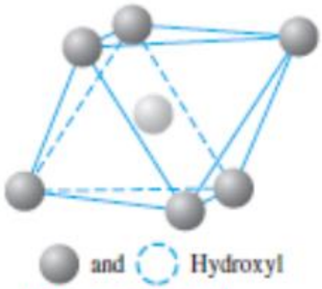
❖ Sometimes magnesium replaces the aluminum atoms in the octahedral units; in this case, the octahedral sheet is called a brucite sheet



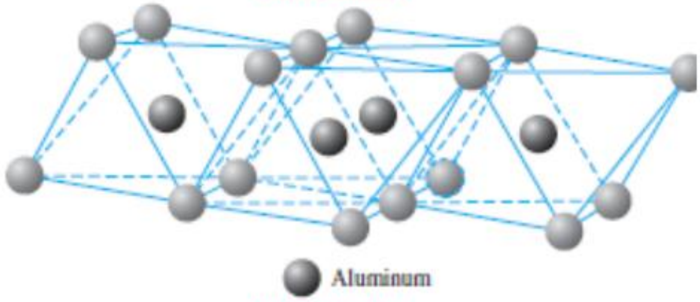
Silica Tetrahedron



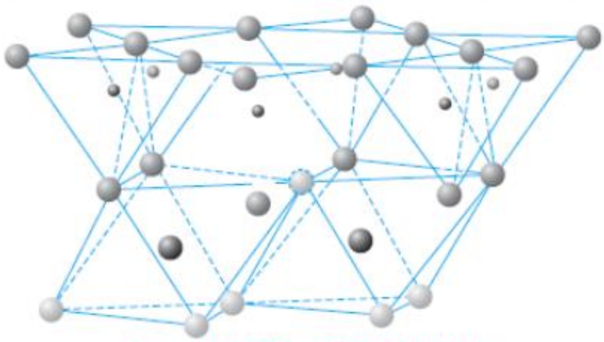
Silica Sheet



Alumina Octahedron



Gibbsite Sheet



Elemental Silica-Gibbsite Sheet

<u>The three important clay minerals are:</u>

a) Kaolinite

Consists of repeating layers of elemental silica-gibbsite sheets in a 1 :1 lattice. Each layer is about 7.2 Å thick. The layers are held together by hydrogen bonding. (1 Å = 10^{-10} m; Å = Angstrom).

❖ Kaolinite occurs as platelets, each with a lateral dimension of 1000 to 20,000 Å and a thickness of 100 to 1000 Å.

❖ The surface area per unit mass is defined as specific surface. The surface area of the kaolinite particles per unit mass is about 15 m^2 /g.

b) Illite

Consists of a gibbsite sheet bonded to two silica sheets-one at the top and another at the bottom. It is sometimes called clay mica.

❖ The illite layers are bonded by potassium ions.

❖ Illite particles generally have lateral dimensions ranging from 1000 to 5000 Å and thicknesses from 50 to 500 Å.

❖ The specific surface of the particles is about 80 m^2 /g.

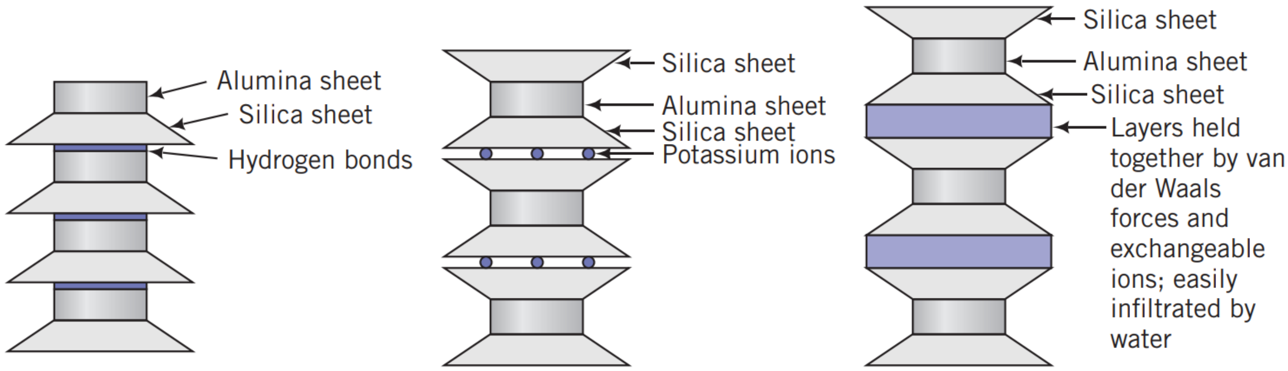
c) Montmorillonite

Montmorillonite has a structure similar to that of illite-that is, one gibbsite sheet sandwiched between two silica sheets.

❖ In montmorillonite, there is isomorphous substitution of magnesium and iron for aluminum in the octahedral sheets.

❖ Particles of montmorillonite have lateral dimensions of 1000 to 5000 Å and thicknesses of 10 to 50 Å.

❖ The specific surface is about 800 m^2 /g.



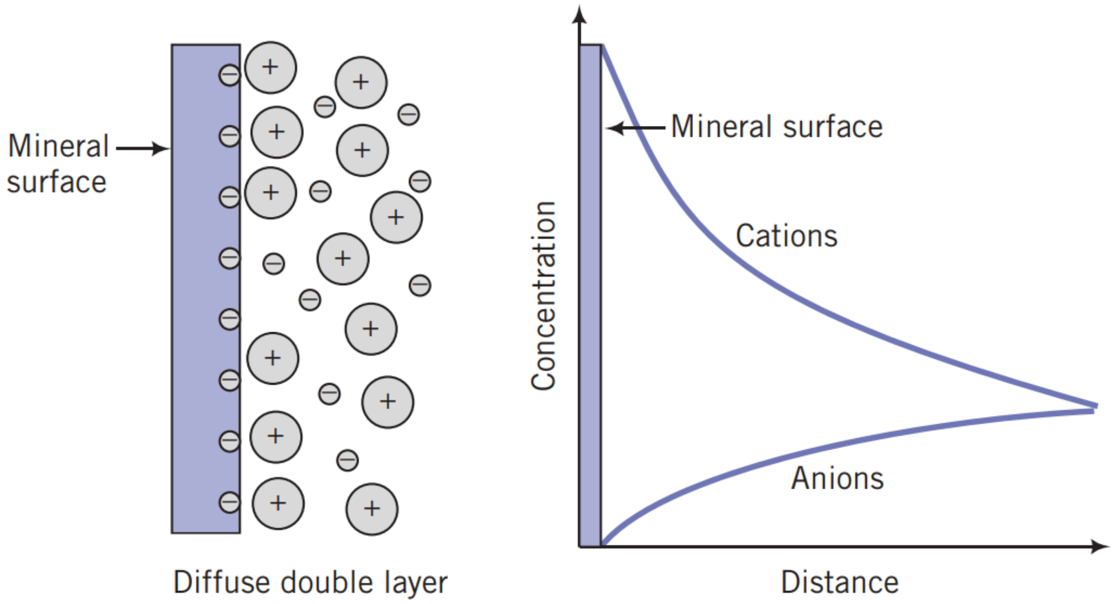
(*a*) Kaolinite (*b*) Illite (*c*) Montmorillonite

1.3.4 Surface forces and adsorbed water

If we subdivide a body, the ratio of its surface area to its volume increases. For example, a cube with sides of 1m. has a surface area of $6m^2$ If we subdivide this cube into smaller cubes with sides of 0.1m, the original volume is unchanged, but the surface area increases to $60m^2$.

- The surface area per unit mass (specific surface) of sands is typically $50ft^2$ per lb, whereas for clays it is as high as 50 × 105 ft^2 per lb (montmorillonite).
- The clay–water interaction coupled with the large surface areas results in clays having larger water-holding capacity in a large number of smaller pore spaces compared with coarse-grained soils.
- The surface charges on the particles of fine-grained soils are negative (anions). These negative surface charges attract cations and the positively charged side of water molecules from surrounding water.

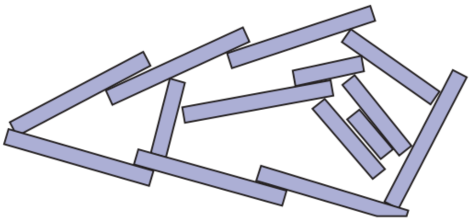
- Consequently, a thin film or layer of water, called adsorbed water, is bonded to the mineral surfaces. The thin film or layer of water is known as the **diffuse double layer**. The largest concentration of cations occurs at the mineral surface and decreases exponentially with distance away from the surface.



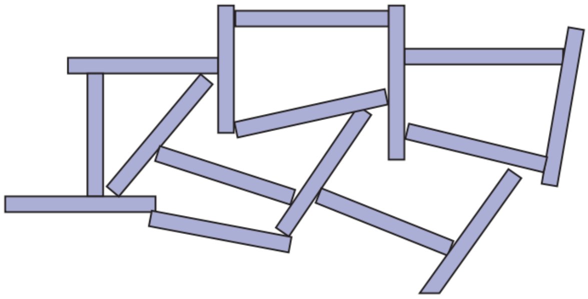
1.3.5 Soil fabric

Soil (minerals) particles are assumed to be rigid. During deposition, the mineral particles are arranged into structural frameworks that we call soil fabric.

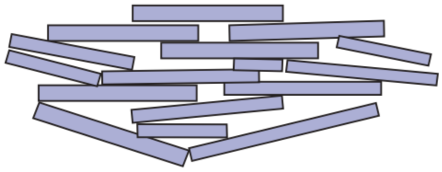
- Each particle is in random contact with neighboring particles. The environment under which deposition occurs influences the structural framework that is formed. In particular, the electrochemical environment has the greatest influence on the kind of soil fabric that is formed during deposition of fine-grained soils.
- Two common types of soil fabric—**flocculated** and **dispersed**—are formed during soil deposition of fine-grained soils.
- A flocculated structure, formed in a saltwater environment, results when many particles tend to orient parallel to one another.
- A flocculated structure, formed in a freshwater environment, results when many particles tend to orient perpendicular to one another.
- A dispersed structure occurs when a majority of the particles orient parallel to one another.



(*a*) Flocculated structure—saltwater environment

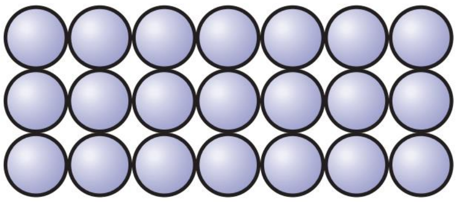


(*b*) Flocculated structure—freshwater environment

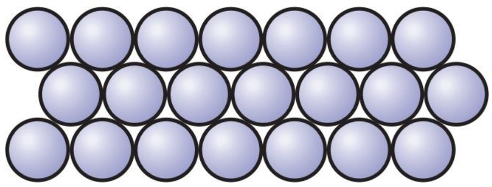


(*c*) Dispersed structure

If the rigid particles of coarse-grained soils can be approximated by spheres, then the loosest packing (maximum void spaces) would occur when the spheres are stacked one on top of another. The densest packing would occur when the spheres are packed in a staggered pattern.



(*a*) Loose



(*b*) Dense

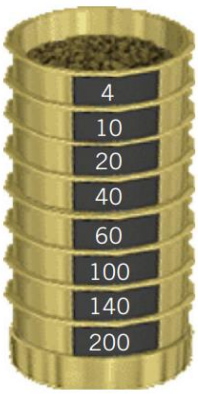
Key points

1. Soils are derived from the weathering of rocks and are broadly described by terms such as gravels, sands, silts, and clays.
2. Physical weathering causes reduction in size of the parent rock without change in its composition.
3. Chemical weathering causes reduction in size and chemical composition that differs from the parent rock.
4. Gravels and sands are coarse-grained soils; silts and clays are fine-grained soils.
5. Coarse-grained soils are composed mainly of quartz.
6. Clays are composed of three main types of minerals: kaolinite, illite, and montmorillonite.
7. The clay minerals consist of silica and alumina sheets that are combined to form layers. The bonds between layers play a very important role in the mechanical behavior of clays. The bond between the layers in montmorillonite is very weak compared with kaolinite and illite. Water can easily enter between the layers in montmorillonite, causing swelling.
8. A thin layer of water, called adsorbed water, is bonded to the mineral surfaces of soils. This layer significantly influences the physical and mechanical characteristics of fine-grained soils.

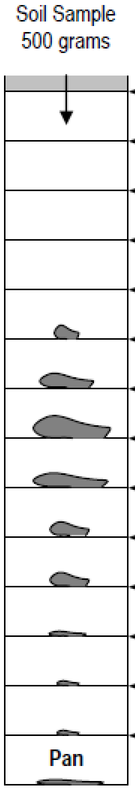
1.4 DETERMINATION OF PARTICLE SIZE

1.4.1 Particle size of coarse-grained soils

The distribution of particle sizes or average grain diameter of coarse-grained soils—gravels and sands—is obtained by screening a known weight of the soil through a stack of sieves of progressively finer mesh size. A typical stack of sieves is shown in the following figure.



Sieve no.	Opening (mm)
3/8″	9.53
4	4.75
10	2
20	0.85
40	0.425
100	0.15
200	0.075



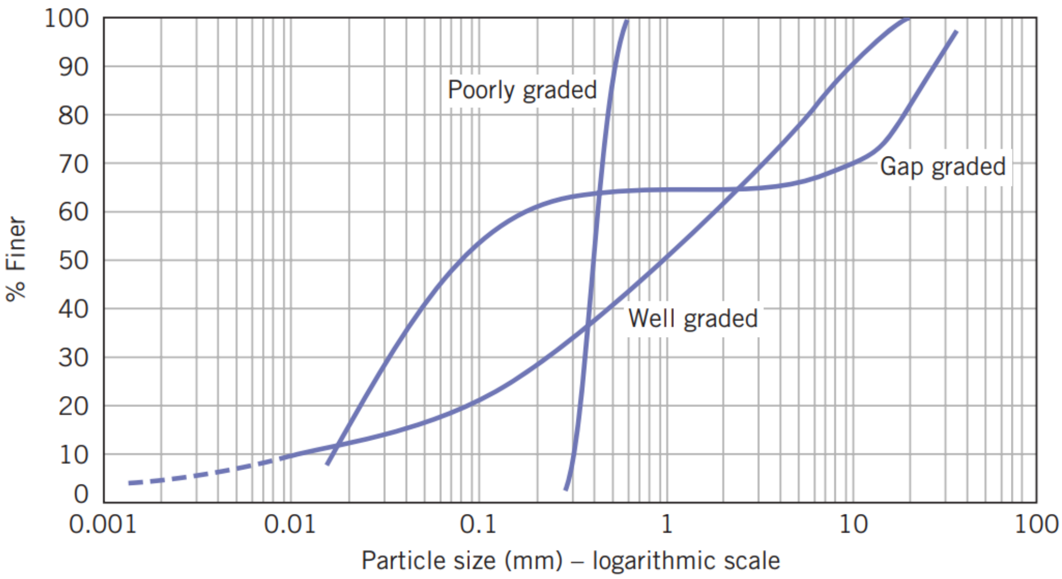
Sieve	Mass Retained on Sieve	Mass Passing Sieve	Percentage Passing Sieve
Lid			
19.0 mm Sieve	0 grams	500 grams	100% passing
13.2 mm Sieve	0 grams	500 grams	100% passing
9.50 mm Sieve	0 grams	500 grams	100% passing
6.70 mm Sieve	0 grams	500 grams	100% passing
4.75 mm Sieve	25 grams	475 grams	95% passing
2.36 mm Sieve	75 grams	400 grams	80% passing
1.18 mm Sieve	150 grams	250 grams	50% passing
600 µm Sieve	115 grams	135 grams	27% passing
425 µm Sieve	35 grams	100 grams	20% passing
300 µm Sieve	30 grams	70 grams	14% passing
212 µm Sieve	20 grams	50 grams	10% passing
150 µm Sieve	10 grams	40 grams	8% passing
75 µm Sieve	15 grams	25 grams	5% passing
Pan	25 grams	0 grams	0% passing

- The particle size distribution curve shows the type of distribution of various sizes particles.

❖ poorly graded soil (most grains have the same size);

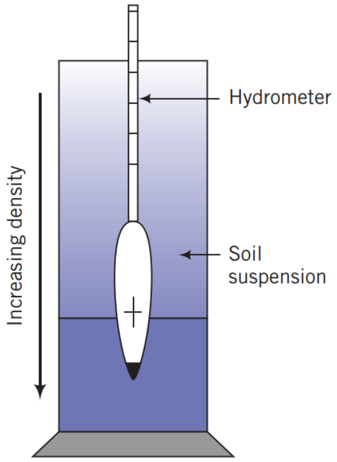
❖ well graded soil (wide range distribution of the particle sizes);

❖ gab graded soil (have a combination of two or more uniformly graded fractions).



1.4.2 Particle size of fine-grained soils

The screening process cannot be used for fine-grained soils—silts and clays—because of their extremely small size. The common laboratory method used to determine the size distribution of fine-grained soils is a hydrometer test. The hydrometer test involves mixing a small amount of soil into a suspension and observing how the suspension settles in time. Larger particles will settle quickly, followed by smaller particles.



The hydrometer test uses Stokes law (for the velocity of a free-falling sphere in suspension) to determine grain size smaller than 0.075 mm (sieve no.200). In the hydrometer analysis, the soil passing from sieve no.200 is placed in suspension and by use of Stokes' equation the equivalent particle size and percent of soil in suspension are computed.

Stokes' Law

A sphere falling freely through a liquid of infinite extent will accelerate rapidly to a certain maximum velocity and will continue at that velocity as long as conditions remain the same.

$$v = \frac{\rho_s - \rho_w}{18\eta} \times D^2$$

where

v: velocity of the particle;

ρs: density of soil particles;

ρw: density of water;

η: viscosity of water;

D: diameter of soil particles.

From the Stokes' equation, rearranging the factors we can get

$$D = \sqrt{\frac{18\eta v}{\rho_s - \rho_w}} = \sqrt{\frac{18\eta}{\rho_s - \rho_w}}\sqrt{\frac{L}{t}}$$

Where : $v = \frac{Distance}{time} = \frac{L}{t}$

With: $\rho_s = G_s \rho_w \quad \Longrightarrow \quad G_s = \frac{\rho_s}{\rho_w} = \frac{\gamma_s}{\gamma_w}$

Gs is the specific gravity of the soil particle and defined as the ratio of the unit weight of a given material to the unit weight of water. The expected value of Gs for different types of soils are:

Type of Soil	Gs value
Sand	2.65 -2.67
Silty sand	2.67–2.70
Inorganic clay	2.70 –2.80
Soils with mica or iron	2.75 –3.00
Organic soils	< 2.00

❖ Stokes' Law is applicable to spheres varying from 0.02 mm to 0.0002 mm in diameter.

❖ Inaccuracies for using the Stokes' equation to determine the particle size occur due to the following factors:

a) Soil particles are not spheres;

b) The fluid is not of infinite extent;

c) Turbulence caused by larger particles falling.

1.5 CHARACTERIZATION OF SOILS BASED ON PARTICLE SIZE

The grading curve is used for textural classification of soils. Various classification systems have evolved over the years to describe soils based on their particle size distribution. Each system was developed for a specific engineering purpose. The popular system is the Unified Soil Classification System (USCS), the American Society for Testing and Materials (ASTM) system (a modification of the USCS system).

Name of organization	Grain size (mm)			
	Gravel	Sand	Silt	Clay
Massachusetts Institute of Technology (MIT)	>2	2 to 0.06	0.06 to 0.002	<0.002
U.S. Department of Agriculture (USDA)	>2	2 to 0.05	0.05 to 0.002	<0.002
American Association of State Highway and Transportation Officials (AASHTO)	76.2 to 2	2 to 0.075	0.075 to 0.002	<0.002
Unified Soil Classification System (U.S. Army Corps of Engineers, U.S. Bureau of Reclamation, and American Society for Testing and Materials)	76.2 to 4.75	4.75 to 0.075	Fines (i.e., silts and clays) <0.075	

Note: Sieve openings of 4.75 mm are found on a U.S. No. 4 sieve; 2-mm openings on a U.S. No. 10 sieve; 0.075-mm openings on a U.S. No. 200 sieve. See Table 2.5.

- the USCS system by ASTM and denote it as ASTM-USCS. Soils are separated into two categories.
- One category is coarse-grained soils, which are thus delineated if more than 50% of the soil is greater than 0.075mm (No. 200 sieve).
- The other category is fine-grained soils, which are thus delineated if more than 50% of the soil is finer than 0.075mm.
- Coarse-grained soils are subdivided into gravels and sands, while fine-grained soils are divided into silts and clays.
- Each soil type—gravel, sand, silt, and clay—is identified by grain size, as shown in the following table. Clays have particle sizes less than 0.005mm.

Table 1-1

Soil type	Description	Grain size, *D*
Gravel	Rounded and/or angular bulky hard rock, coarsely divided	Coarse: Passes 3 in. sieve and retained on ¾ in. sieve. Fine: Passes ¾ in. and retained on No. 4 (4.75 mm) sieve.
Sand	Rounded and/or angular hard rock, finely divided	Coarse: Passes No. 4 sieve (4.75 mm) and retained on No. 10 (2.0 mm) sieve. Medium: Passes No. 10 (2.0 mm) sieve and retained on No. 40 (0.425 mm) sieve. Fine: Passes No. 40 sieve (0.425 mm) and retained on No. 200 (0.075 mm) sieve.
Silt	Particle size between clay and sand, nonplastic or very slightly plastic, exhibiting little or no strength when dried	Passing No. 200 (0.075 mm); smaller than 0.075 mm and greater than 0.005 mm.
Clay	Particles smooth and mostly clay minerals, exhibiting plasticity and significant strength when dried but reduced in strength by water	Passing No. 200 (0.075 mm); smaller than 0.005 mm.

- Two coefficients have been defined to provide guidance on distinguishing soils based on the distribution of the particles.

1. **Uniformity coefficient (Cu)**: defined as:

$$C_u = \frac{D_{60}}{D_{10}}$$

where D_{60} is the diameter of the soil particles for which 60% of the particles are finer, and D_{10} is the diameter of the soil particles for which 10% of the particles are finer. Both of these diameters are obtained from the grading curve.

❖ Apparently, larger Cu means the size distribution is wider and vice versa. Cu= 1 means uniform, all grains are in the same size, such as dune sands.

2. **Coefficient of curvature (Cc)**: (other terms used are the coefficient of gradation and the coefficient of concavity) defined as:

$$C_c = C_z = \frac{D_{30}^2}{D_{60} \times D_{10}}$$

The limits of uniformity coefficient and the coefficient of concavity to characterize well graded and poorly graded are as follows:

Well graded	gravel content > sand content	$Cu \geq 4;\ 1 \leq CC \leq 3$
	sand content > gravel content	$Cu \geq 6;\ 1 \leq CC \leq 3$
Poorly graded	gravel content > sand content	$Cu < 4;\ CC < 1$ or $CC > 3$
	sand content > gravel content	$Cu < 6;\ CC < 1$ or $CC > 3$

Key points

1. A sieve analysis is used to determine the grain size distribution of coarse-grained soils.
2. For fine-grained soils, a hydrometer analysis is used to find the particle size distribution.
3. Particle size distribution is represented on a semi-logarithmic plot of percentage finer (ordinate, arithmetic scale) versus particle size (abscissa, logarithmic scale).
4. The particle size distribution plot is used to delineate the different soil textures (percentages of gravel, sand, silt, and clay) in a soil.
5. The effective size, D_{10}, is the diameter of the particles of which 10% of the soil is finer. D_{10} is an important value in regulating flow through soils and can significantly influence the mechanical behavior of soils.
6. D_{50} is the average grain size diameter of the soil.
7. Two coefficients—the uniformity coefficient and the coefficient of curvature—are used to characterize the particle size distribution. Poorly graded soils have steep gradation curves. Well graded soils are indicated by relatively flat particle distribution curves and have uniformity coefficients >4, coefficients of curvature between 1 and 3. Gap-graded soils are indicated by one or more humps on the gradation curves.

EXAMPLE 1.1 *Calculation of Percentage Finer than a Given Sieve in a Sieve Analysis Test*

A particle analysis test was conducted on a dry soil. The total mass used in test was 500 grams. All 500 grams passed the No. 4 sieve. The total mass retained above the No. 200 sieve was 220 grams. Determine (**a**) the percentage of soil retained on the No. 200 sieve, (**b**) the percentage finer than the No. 200 sieve, and (**c**) the percentage of coarse-grained and fine-grained soil particles.

Strategy Calculate the cumulative percentage retained on the No. 200 sieve, and then subtract it from 100 to get percentage finer than. Use Table 1.1 to guide you to get the amount of each soil type.

Solution 1.1

Step 1: Determine percentage retained on No. 200 sieve.

Mass retained above the No. 200 sieve, $M_r = 220$ grams.

Total mass, $M_t = 500$ grams.

% retained on No. 200 sieve = cumulative % retained (mass retained on all sieves with sizes greater than or equal to No. 200), which is

$$\frac{M_r}{M_t} \times 100 = \frac{220}{500} \times 100 = 44\%$$

Step 2: Determine percentage finer than on No. 200 sieve.

% finer than No. 200 sieve = 100 − cumulative % retained on No. 200 sieve = 100 − 44 = 56%.

Step 3: Determine % coarse-grained and fine-grained particles.

% coarse-grained soil particles = % of particles greater than No. 200 sieve = 44%.

% fine-grained soil particles = % of particles finer than No. 200 sieve = 56%.

EXAMPLE 1.2 *Calculating Particle Size Distribution and Interpretation of Soil Type from a Sieve Analysis Test*

A sieve analysis test was conducted using 650 grams of soil. The results are as follows.

Sieve no.	3/8″	4	10	20	40	100	200	Pan
Opening (mm)	9.53	4.75	2	0.85	0.425	0.15	0.075	
Mass retained (grams)	0	53	76	73	142	85.4	120.5	99.8

Determine (**a**) the amount of coarse-grained and fine-grained soils, and (**b**) the amount of each soil type based on the ASTM-USCS system.

Strategy Calculate the percentage finer and plot the gradation curve. Extract the amount of coarse-grained soil (particle sizes $\geq$ 0.075 mm) and the amount of fine-grained soil (particle sizes $<$ 0.075 mm). Use Table 1.1 to guide you to get the amount of each soil type.

Solution 1.2

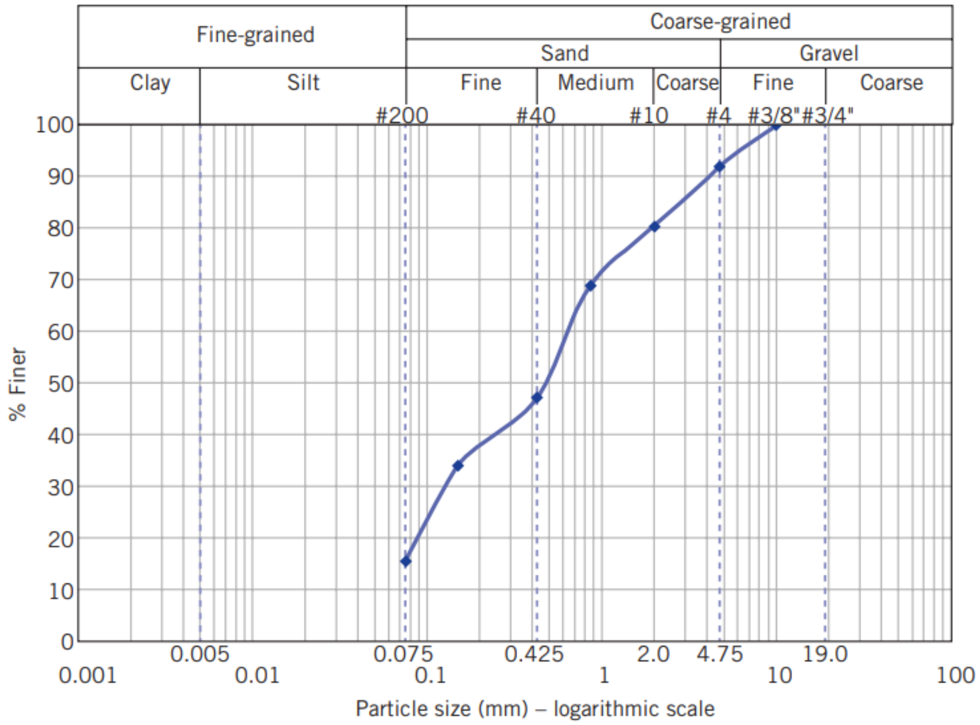
Step 1: Set up a table or a spreadsheet to do the calculations.

A	B	C	D	E	F
Sieve no.	**Opening (mm)**	**Mass retained (grams), M_r**	**% Retained ($100 \times M_r/M_t$)**	**Σ (% Retained) (Σ column D)**	**% Finer (100 − column E)**
3/8″	9.53	0	0.0	0.0	100.0
4	4.75	53.0	8.2	add 8.2	91.8
10	2.00	76.0	11.7	19.9	80.1
20	0.85	73.0	11.2	31.1	68.9
40	0.425	142.0	21.9	52.9	47.1
100	0.15	85.4	13.1	66.1	33.9
200	0.075	120.5	18.5	check 84.6	15.4
Pan		99.8	15.4		
	Total mass = M_t =	649.7	100.0		

Note: In the sieve analysis test, some mass is lost because particles are stuck in the sieves. Use the sum of the mass after the test. You should always check that the sum of the soil retained on all sieves plus the pan is equal to 100% (column D in the table).

Step 2: Plot grading curve.

See Figure E1.2.



Step 3: Extract soil type.

(a) The amount of fine-grained soil is the percentage finer than the No. 200 sieve (opening = 0.075 mm). The amount of coarse-grained soil is the percentage coarser than the No. 200 sieve; that is, the cumulative percentage retained on the No. 200 sieve is

$$\% \text{ fine-grained soil} = 15.4\%.$$

$$\% \text{ coarse-grained soil} = 100 - 15.4 = 84.6\%.$$

Check answer: % fine-grained soil + % coarse-grained soil must be 100%.

That is: 15.4 + 84.6 = 100%.

(b)

$$\text{Fine gravel } (\%) = 8.2$$

$$\text{Total gravel } (\%) = 8.2$$

$$\text{Coarse sand } (\%) = 11.7$$

$$\text{Medium sand } (\%) = 33.0$$

$$\text{Fine sand } (\%) = 31.7$$

$$\text{Total sand } (\%) = 76.4$$

$$\text{Silt} + \text{clay } (\%) = 15.4$$

Check answer: total gravel (%) + total sand (%) + silt (%) + clay (%) must equal 100%

That is: 8.2 + 76.4 + 15.4 = 100%

EXAMPLE 1.3 *Interpreting Sieve Analysis Data*

A sample of a dry, coarse-grained material of mass 500 grams was shaken through a nest of sieves, and the following results were as given in the table below.

(a) Plot the particle size distribution (gradation) curve.

(b) Determine (1) the effective size, (2) the average particle size, (3) the uniformity coefficient, and (4) the coefficient of curvature.

(c) Determine the textural composition of the soil (the amount of gravel, sand, etc.).

Sieve no.	Opening (mm)	Mass retained (grams)
4	4.75	0
10	2.00	14.8
20	0.85	98.0
40	0.425	90.1
100	0.15	181.9
200	0.075	108.8
Pan		6.1

Strategy The best way to solve this type of problem is to make a table to carry out the calculations and then plot a gradation curve. Total mass (M) of dry sample used is 500 grams, but on summing the masses of the retained soil in column 2 we obtain 499.7 grams. The reduction in mass is due to losses mainly from a small quantity of soil that is stuck in the meshes of the sieves. You should use the "after sieving" total mass of 499.7 grams in the calculations.

Solution 1.3

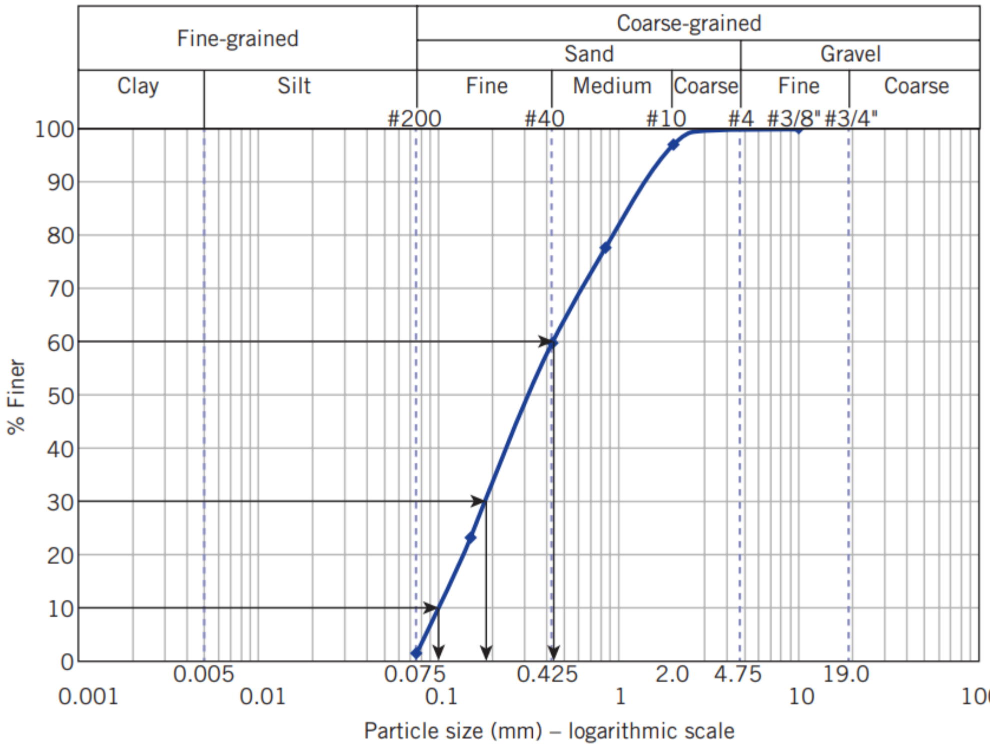
Step 1: Tabulate data to obtain percentage finer.

See the table below.

Sieve no.	Mass retained (grams), M_r	% Retained $(M_r/M) \times 100$	Σ% retained	% Finer
4	0	0	0	100 − 0 = 100
10	14.8	3.0	add 3.0	100 − 3.0 = 97.0
20	98.0	19.6	22.6	100 − 22.6 = 77.4
40	90.1	18.0	40.6	100 − 40.6 = 59.4
100	181.9	36.4	77.0	100 − 77 = 23.0
200	108.8	21.8	98.8	100 − 98.8 = 1.2
Pan	6.1	1.2	check	
	Total mass M_t = 499.7	100.0		

Step 2: Plot the gradation curve.

See Figure E1.3 for a plot of the gradation curve.



Step 3: Extract the effective size.

$$\text{Effective size} = D_{10} = 0.1 \text{ mm}$$

Step 4: Extract percentages of gravel, sand, silt, and clay.

$$\text{Gravel} = 0\%$$

$$\text{Sand} = 98.8\%$$

$$\text{Silt and clay} = 1.2\%$$

Check answer: gravel (%) + sand (%) + silt (%) + clay (%) must equal 100%.

That is: 0 + 98.8 + 1.2 = 100%

Step 5: Calculate Cu and CC.

$$Cu = \frac{D_{60}}{D_{10}} = \frac{0.45}{0.1} = 4.5$$

$$CC = \frac{(D_{30})^2}{D_{10}D_{60}} = \frac{0.18^2}{0.1 \times 0.45} = 7.2$$

EXAMPLE 1.4 *Calculation of Particle Diameter from Hydrometer Test Data*

After a time of 1 minute in a hydrometer test, the effective depth was 0.8 cm. The average temperature measured was 68°F and the specific gravity of the soil particles was 2.7, calculate the diameter of the particles using Stokes's law. Are these silt or clay particles?

Strategy This is straight forward application of Equation (1.3).

Solution 1.4

Step 1: Calculate the particle diameter using Stokes's law.

$z = 0.8$ cm and $t_D = 1$ minute. For the temperature and specific gravity of the soil particles, $K = 0.01341$

$$D = K\sqrt{\frac{z}{t_D}} = 0.01341\sqrt{\frac{0.8}{1}} = 0.012 \text{ mm}$$

Step 2: Identify the soil type.

Silt particles have sizes between 0.075 mm and 0.005 mm.

Therefore, the soil particles belong to the silt fraction of the soil.

Key points

1. Fine-grained soils have much larger surface areas than coarse-grained soils and are responsible for the major physical and mechanical differences between coarse-grained and fine-grained soils.
2. The engineering properties of fine-grained soils depend mainly on mineralogical factors.
3. Coarse-grained soils have good load-bearing capacities and good drainage qualities. Changes in moisture conditions do not significantly affect the volume-change characteristics under static loading.
4. Fine-grained soils have low load-bearing capacities and poor drainage qualities. Changes in moisture conditions strongly influence the volume-change characteristics and strength of fine-grained soils.