

b. From the figure on Page 1,  $D_{60} = 0.41 \text{ mm}$ ,  $D_{30} = 0.185 \text{ mm}$ ,  $D_{10} = 0.09 \text{ mm}$

c. 
$$C_u = \frac{D_{60}}{D_{10}} = \frac{0.41}{0.09} = 4.56$$

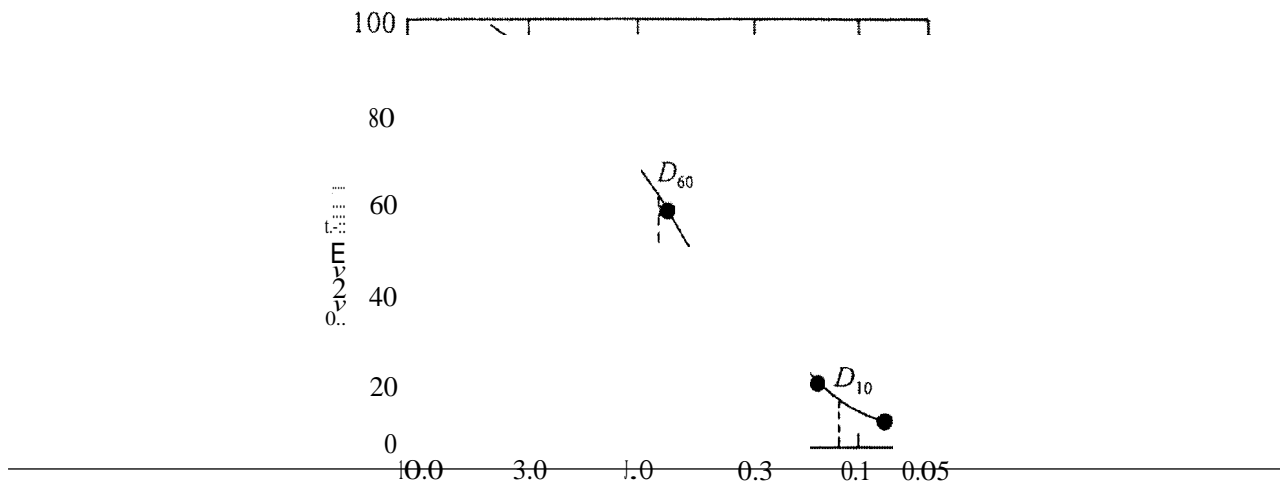
d. 
$$C_c = \frac{D_{60} - D_{10}}{(D_{60})(D_{10})} = \frac{0.41 - 0.09}{(0.41)(0.09)} = 0.928$$

2.3 a.

U.S. sieve No.	Mass of soil retained on each sieve (g)	Percent retained on each sieve	Percent finer
4	0.0	0.00	100.00
6	30.0	6.00	94.00
10	48.7	9.74	84.26
20	127.3	25.46	58.80
40	96.8	19.36	39.44
60	76.6	15.32	24.12
100	55.2	11.04	13.08
200	43.4	8.68	4.40
Pan	22.0	4.40	0.00

L500

The grain-size distribution is shown.



Grain size (mm)

- b. From the figure,  $D_{60} = 0.82 \text{ mm}$ ,  $D_{30} = 0.31 \text{ mm}$ ,  $D_{10} = 0.12 \text{ mm}$

c.  $C_u = \frac{D_{60}}{D_{10}} = \frac{0.82}{0.12} = \mathbf{6.83}$

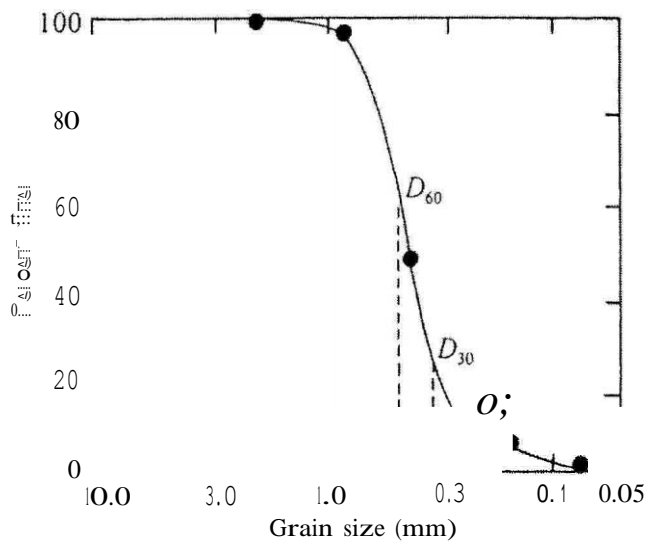
d.  $C_c = \frac{D_{i0}}{(D_{60})(D_{10})} = \frac{0.312}{(0.82)(0.12)} = \mathbf{0.98}$

2.4 a.

U.S. sieve No.	Mass of soil retained on each sieve (g)	Percent retained on each sieve	Percent finer
4	0.0	0.00	<b>100.00</b>
6	0.0	0.00	<b>100.00</b>
10	0.0	0.00	<b>100.00</b>
20	9.1	1.82	<b>98.18</b>
40	249.4	49.88	<b>48.30</b>
60	179.8	35.96	<b>12.34</b>
100	22.7	4.54	<b>7.80</b>
200	15.5	3.10	<b>4.70</b>
Pan	23.5	4.70	<b>0.00</b>

I:500

The grain-size distribution is shown in the figure.

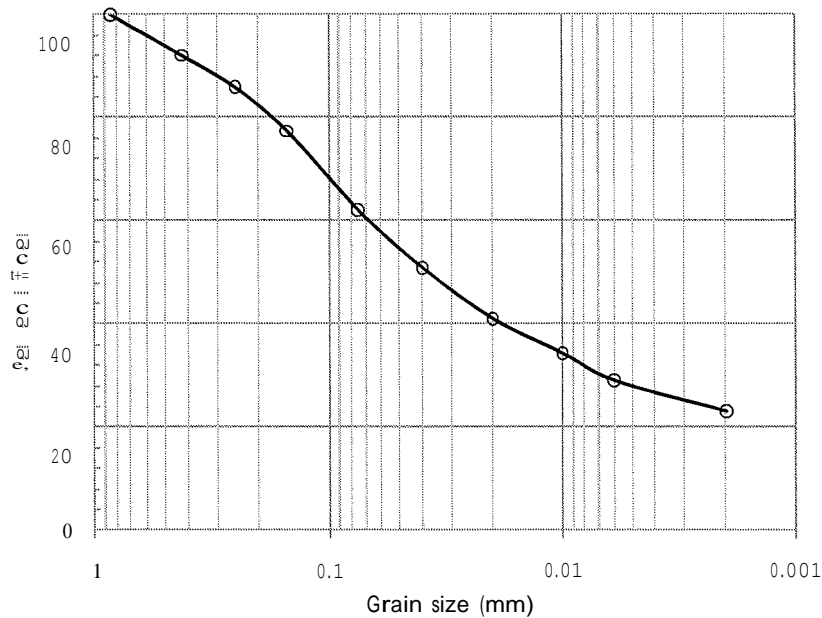


b. From the graph,  $D_{60} = \mathbf{0.48 \text{ mm}}$ ,  $D_{30} = \mathbf{0.33 \text{ mm}}$ ,  $D_{10} = \mathbf{0.23 \text{ mm}}$

c.  $C_u = \frac{0.4^8}{0.23} = 2.09$

d.  $C_c = \frac{0.332}{(0.48)(0.23)} = 0.99$

2.5 The grain-size distribution curve is shown.



From the figure: Percent finer than 2 mm = 100%  
 Percent finer than 0.06 mm = 58%  
 Percent finer than 0.002 mm = 23%

So, Gravel: 0%  
 Sand: 100 - 58 = 42%  
 Silt: 58 - 23 = 35%  
 Clay: 23 - 0 = 23%

2.6 Refer to the figure in Problem 2.5.

From Table 2.1: Portion larger than 2 mm is gravel  
 (USDA system) Portion between 2 mm and 0.05 mm is sand  
 Portion between 0.05 mm and 0.002 mm is silt  
 Portion smaller than 0.002 mm is clay



From the figure: Percent finer than 2 mm = 100%  
Percent finer than 0.06 mm = 30%  
Percent finer than 0.002 mm = 14%

So, Gravel: **0%**  
Sand:  $100 - 30 = 70\%$   
Silt:  $40 - 14 = 16\%$   
Clay:  $14 - 0 = 14\%$

2.9 Refer to the figure in Problem 2.8.

From the figure: Percent finer than 2 mm = 100%  
Percent finer than 0.075 mm = 29%  
Percent finer than 0.002 mm = 14%

So, Gravel: **0%**  
Sand:  $100 - 29 = 71\%$   
Silt:  $29 - 14 = 15\%$   
Clay:  $14 - 0 = 14\%$

2.10 Refer to the figure in Problem 2.8.

From the figure: Percent finer than 2 mm = 100%  
Percent finer than 0.075 mm = 34%  
Percent finer than 0.002 mm = 14%

So, Gravel: **0%**  
Sand:  $100 - 34 = 66\%$   
Silt:  $34 - 14 = 20\%$   
Clay:  $14 - 0 = 14\%$

2.11 Soil A:  
Percent passing 75 mm sieve = 100 (percent of gravel + sand + fines = 100)  
Percent passing 4.75 (No. 4) sieve = 67.5 (percent of sand + fines = 67.5)  
Therefore percent of gravel = 32.5  
Percent passing 0.075 mm (No. 200) sieve = 8.5  
Therefore percent of fines = 8.5 and percent of sand = 59.0  
**Soil A contains 32.5% gravel, 59.0 % sand and 8.5% fines.**

---

Soil B:

Following the same method, Percent of gravel + sand + fines = 100

Percent of sand + fines = 100

Percent of fines = 0

Therefore, **Soil B consists of 100% sand.**

2.12 Percent of gravel + sand + fines = 100

Percent of sand + fines = 63

Percent of fines = 16

Therefore, **percentages of gravel, sand and fines within the soil are 37, 47, and 16, respectively.**

2.13 a. **A has the largest (50%) percentage of gravel.**

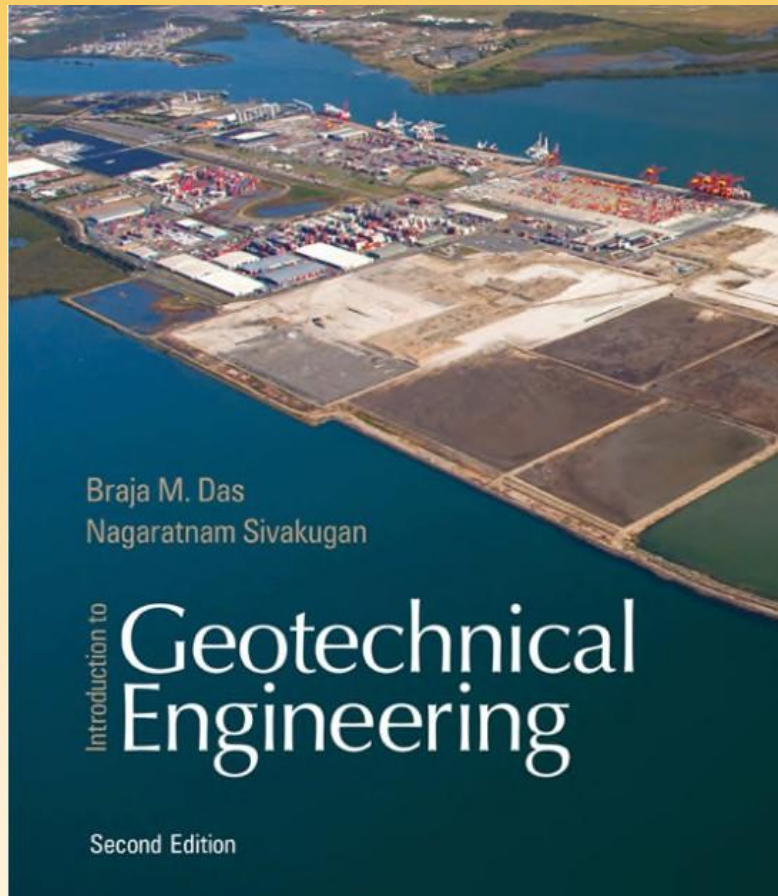
b. **C is entirely sand, with grains in the size range of 0.2–4.75 mm.**

c. **Only D contains clay fractions (less than 0.002 mm) of about 35%.**

d. **In Soil A, there are no grains in the size range of 0.2–5.0 mm. It is known as gap graded.**







# Chapter 2

## Grain-Size Analysis

# Learning Objectives and Outline

- \* To learn the size ranges for gravels, sands, and fines
- \* To understand how soils are formed
- \* To be able to develop the grain-size distribution curve

## 2.1 Introduction

- \* In engineering, soil is defined as **“an uncemented aggregate of mineral grains and decayed organic matter (solid particles) with liquid and gas in the empty spaces between the solid particles.”**
- \* The grain-size distribution in soil influences its physical properties, such as compressibility and shear strength.

## 2.2 Soil-Grain Size

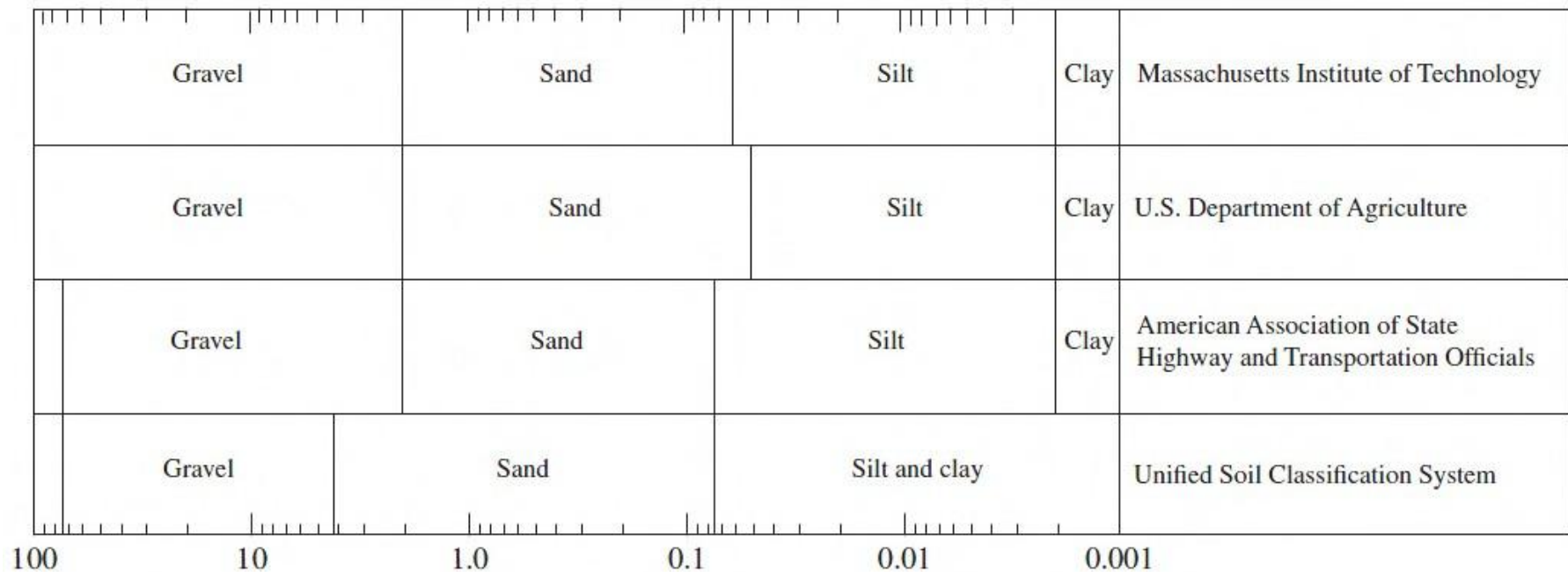
Several organizations have developed *soil-separate-size limits*:

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)	76.2 to 4.75	4.75 to 0.075	Fines (i.e., silts and clays) <0.075	

## 2.2 Soil-Grain Size Cont'd

- \* American Society of Testing and Materials (ASTM) adopted the Unified Soil Classification System.

Below are the size limits in graphical form:



## 2.2 Soil-Grain Size Cont'd

**Gravel:** Pieces of rocks with occasional grains of quartz, feldspar, and other minerals.

**Sand:** Grains that are mostly made of quartz and feldspar. Other minerals may be present at times.

**Silts:** The microscopic soil fractions which consist of very fine quartz grains and some flake-shaped grains that are micaceous mineral fragments.

**Clays:** Mostly flake-shaped microscopic grains of mica, clay minerals, and other minerals. Grains are classified as *clay* based on their size; they do not always contain *clay minerals*.

## 2.2 Soil-Grain Size Cont'd

- \* Three major types of clay minerals:
  - \* Kaolinite
  - \* Illite
  - \* Montmorillonite
- \* Their mineralogy, flakiness, and the large surface areas make the clays plastic and cohesive.
- \* Montmorillonite clays can swell in the presence of water which enters between layers. These expansive clays cause billions of dollars worth of annual damage to roads and buildings.



## 2.3 General Soil Deposits

Most of the soils that cover the earth are formed by the weathering of various rocks. The two general types of weathering are:

- \* **Mechanical Weathering:** Physical forces such as running water, wind, ocean waves, glacier ice and frost action break down rocks into smaller pieces
- \* **Chemical Weathering:** Chemical decomposition of the original rock. In this case, the original materials may be changed to something entirely different

## 2.3 General Soil Deposits Cont'd

- \* When the soil produced by the weathering process is transported by physical agents to other places, these deposits are called *transported soils*.
  - \* **Alluvial:** Deposited by running water
  - \* **Glacial:** Deposited by glacier action
  - \* **Aeolian:** Deposited by wind action
  
- \* The soils that stay in the place of their formation are referred to as *residual soils*.

## 2.3 General Soil Deposits Cont'd

- \* In addition to transported and residual soils, there are *peats* and *organic soils*.
- \* Organic soils have the following characteristics:
  - \* Usually found in low-lying areas with a high ground water table
  - \* Moisture content ranges from 200%-300%
  - \* Highly compressible
  - \* Under loads, a large amount of settlement is derived from secondary consolidation

## 2.4 Some Local Terms for Soils

1. *Caliche*: Mostly found in the desert. Derived from Latin word "calix," meaning lime
2. *Gumbo*: Highly plastic, clayey
3. *Adobe*: Highly plastic, clayey soil found in southwestern U.S.
4. *Terra Rosa*: Residual, red, derived from limestone and dolomite
5. *Muck*: Organic soil with a very high moisture content
6. *Muskeg*: Organic soil deposit
7. *Saprolite*: Derived from mostly insoluble rock, residual
8. *Loam*: Mixture of various grain sizes
9. *Laterite*: Iron oxide and aluminum oxide accumulation, leaching of silica

## 2.5 Grain-Size Analysis

- \* The size of grains may widely vary in a natural soil deposit.
- \* Determining the nature of distribution of the grain size and the degree of plasticity in a given soil is important for design purposes.
- \* Grain-size analysis for grain sizes  $> 0.075$  mm is done by sieve analysis.
- \* **Sieve Analysis:**  
Shaking of the soil sample through a set of sieves that have progressively smaller openings.



## 2.5 Grain-Size Analysis Cont'd

- \* To conduct a sieve analysis, one must first oven-dry the soil and then break all lumps into small grains.
- \* The soil is then shaken through a stack of sieves with openings of decreasing size from top to bottom.
- \* The smallest sized sieve should be the U.S No. 200 sieve.
- \* After the process, the mass of soil retained on each sieve is determined.

## 2.5 Grain-Size Analysis Cont'd

Calculation for a sieve analysis:

- \* Determine the mass of soil retained on each sieve ( $M_1, M_2, \dots, M_n$ ), and in the pan ( $M_p$ )

- \* Determine the total mass of the soil:

$$M_1 + M_2, \dots + M_n + M_p = \Sigma M$$

- \* Determine the cumulative mass of soil retained above each sieve. For the  $i$ th sieve, it is  $M_1 + M_2 + \dots + M_i$

- \* The mass of soil passing the  $i$ th sieve is:

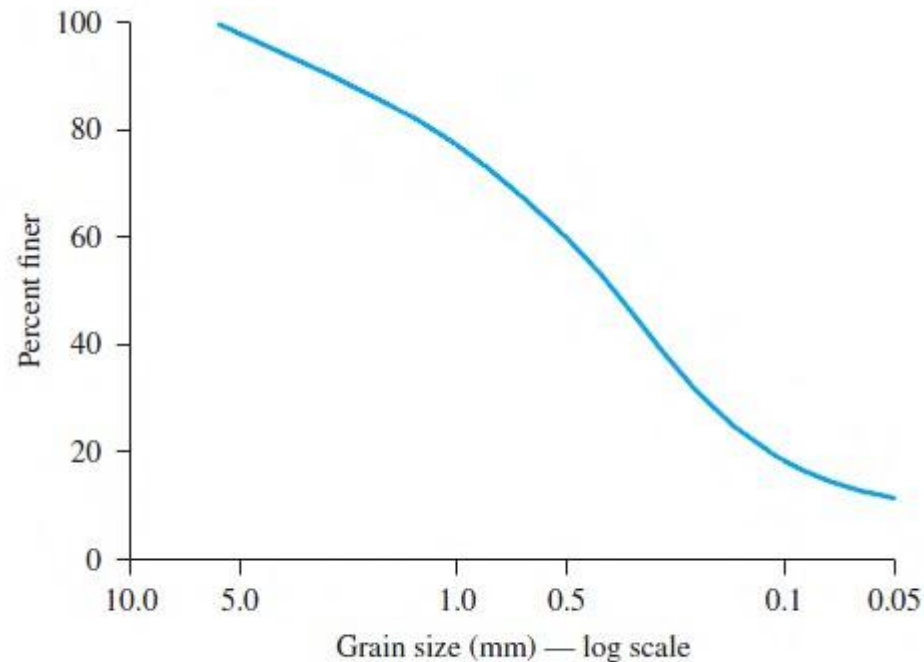
$$\Sigma M - (M_1 + M_2 + \dots + M_i)$$

- \* The percent of soil passing the  $i$ th sieve (or percent finer) is:

$$F = \frac{\Sigma M - (M_1 + M_2 + \dots + M_i)}{\Sigma M} * 100$$

## 2.5 Grain-Size Analysis Cont'd

- \* Once the percent finer for each sieve has been calculated, values are plotted on semilogarithmic graph paper.
- \* This plot is called the *grain-size distribution curve*:

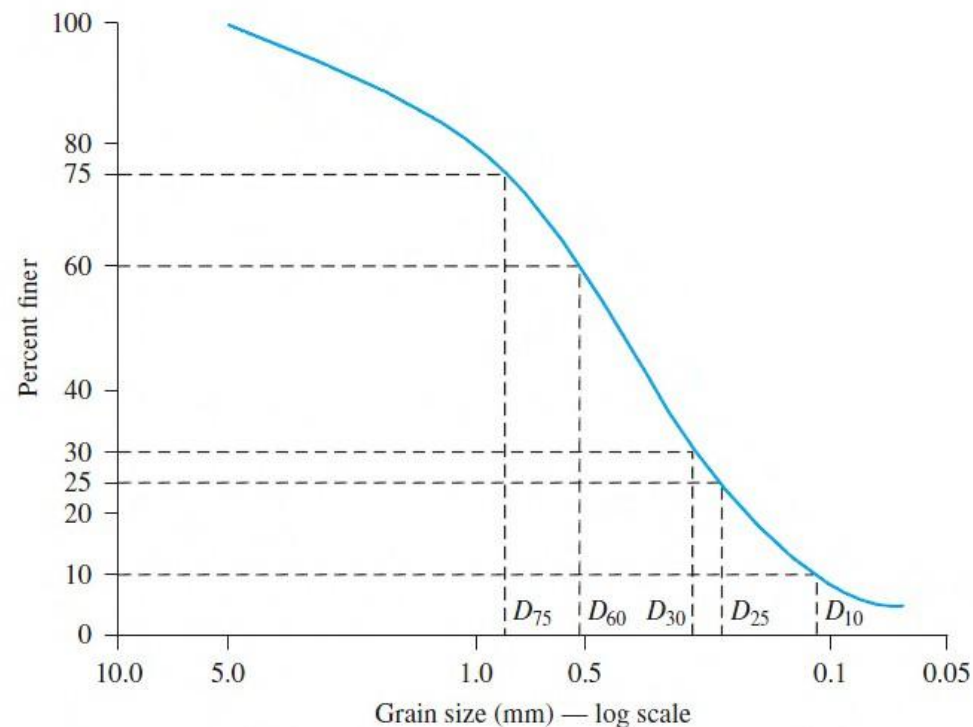




## 2.6 Grain-Size Distribution Curve

The grain-size distribution curve can be used to determine the following four parameters:

**1) Effective Size ( $D_{10}$ ):** Diameter corresponding to 10% finer. It is a good measure to estimate the hydraulic conductivity and drainage through the soil.



## 2.6 Grain-Size Distribution Curve Cont'd

### 2) Uniformity Coefficient ( $C_u$ ):

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

### 3) Coefficient of Gradation ( $C_c$ ):

$$C_c = \frac{D}{D \times D}$$

### 4) Sorting Coefficient ( $S_0$ ):

$$S_0 = \sqrt{(D_{75}/D_{25})}$$