SOIL MECHANICS

THIRD YEAR

DEPARTMENT OF CIVIL ENGINEERING

UNIVERSITY OF BAGHDAD

Prepared By

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Soil Mechanics

Course Contents

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Tel.:

Prerequisite: Solid Mechanics, Engineering Mechanics and Fluid Mechanics

Text Book: ***Principle of Geotechnical Engineering***, By B. M. Das and K. Sobhan, 2014, 8th edition, SI, Global Engineering: Christopher M. Shortt.

Suggested Texts:

- ***Soil Mechanics,*** By T. W. Lambe and R. V. Whitman, 1969, John Wiley & Sons.
- ***Craig's Soil Mechanics,*** By R. F Craig, 2004, 7th edition, Spon Press.
- ***Soil Mechanics and Foundation,*** By Muni Budhu, 2011, 3rd Edition, John Wiley & Sons, Inc.
- ***Soil Mechanics, Basic Concepts and Engineering Applications***, By A. Aysen, 2002, A. A. Balkema Publishers.
- ***Soil Mechanics***, By Arnold Verruijt, 2006, http://geo.verruijt.net.

Overview

A major specialty area within civil engineering, geotechnical engineering focuses on how soil and rock support and affect the performance of structure built on or below the earth's surface. Also, soil may be used as construction material. This course will be introducing the student to the basic principles that govern the behavior of soils, geotechnical properties of soil and other geotechnical works. The topics to be covered in this course are:

Course Objective

An understanding of these basic concepts is essential in the design of foundations for structures, retaining walls, tunnels, excavations, earth fills, stability of earth slopes, sanitary landfill, and environmental remediation projects. Specifically, a student completing this course will:

- **Understanding the basic principles of soil mechanics and geotechnical engineering.**
- **Learn the relevant terms and soil tests needed to describe and predict the behavior of a soil, permitting the student to work effectively with specialist in geotechnical engineering.**

- **Solve fundamentals problems related to the flow of pore water, compression and consolidation, and shear strength of soil as required in geotechnical design.**
- **Acquire the background knowledge needed to complete more advanced courses in geotechnical engineering (Foundation Eng., Advance soil mechanics and modeling).**

Homework Assignments

Appropriate homework will be assigned after covering a specific material. These assignments are due one week from the date they are assigned. Copying the assignments of other students is not a responsible behavior and will not be tolerated. Delay in submission the assignments will be graded in decrease as the time between the due dates.

Laboratory

Will performs a number of experiments on different types of soils to improve our understanding of the material [i.e. water content, liquid and plastic limits, particle size distribution (Mechanical and hydrometer method), specific gravity of soil solids, compaction test, coefficient of permeability, consolidation test, direct shear test, unconfined and triaxial test]. Appropriate handouts on each test will be handed to the students ahead of time. Each student is expected to read the handouts before he comes to the lab. The students will work in one group or more depending on the number of the students in class. Every student is expected to turn in a lab report summarizing the work that was performed along with discussion for the results of the experiments. These reports are due by the time of the next experiment. The report has to be word-processed using a computer.

Participation

During the lectures, students will be able to ask questions or be given the opportunity to answer questions posed by the instructor. Each student is expected to participate in these discussions during the lectures. Relevant information from students with practical working experience on a particular topic is encouraged. Sleeping or reading materials or browsing regarding information not relevant to the class is not appropriate.

Cheating

Cheating of any kind on laboratory reports, quizzes or exams will not be tolerated and will result in a grade of zero for the course.

Exams

10 monthly exams will be on given dates later, one exam at the end of each chapter. Quizzes will be sudden dates, that is depend on the decision of the instructor. The final exam will be comprehensive and will be at the time assigned by the department.

Grading

The work during the course will be cover 40% of the grade while the final exam covers the remaining 60%.

Activity	Mark
Instructor Evaluation	2.5 %
Quizzes	2.5 %
Attendance Class	2.5 %
Homework	2.5 %
10 Exams	20 %
Lab Reports	10 %
Final Exam	60 % (will be divided into 50% Theoretical questions and 10% Lab questions)
Total	100 %

Process of Solution and Formatting Answers

The following format must be used to complete each problem requiring substantial numerical calculations:

Given

Concisely list the important information given in the problem. Use appropriate symbols whenever possible.

Required

Concisely summarize the task(s) required to solve the problem. If there is more than one task, designate the tasks using a numerical or alphabetical character as appropriate. For example, if the problem number is numerical (1, 2, 3, etc.) designate the tasks using an alphabetical character (a, b, c, etc.).

Assumptions

List all assumptions needed to solve the problem. If other assumptions could be made in place of any assumption you have make, discuss the logic used to select your assumption rather than the alternative assumptions. Show the solution to the problem in a logical, well-organized, and neat manner. For handwritten solutions, it is highly recommended that you solve the problems first on scratch paper and then transfer the solutions neatly to engineering paper.

Summary of Answers

At the end of each problem, provide a summary of answers for all tasks requiring numerical answers and tasks requiring text answers that can be summarized in three sentences or less. If a task requires a text answer of more than three sentences, a figure or a large table, refer in the summary to the location of the answer by page number and figure or table number. Provide numerical answers with the appropriate number of significant figures.

Chapter One: Definition of Soil

1. Definition of soil
2. Rock cycle
3. Clay Minerals
   a) Kaolinite
   b) Illite
   c) Montmorillonite
4. Particle size of soil
   a) Mechanical analysis
   b) Hydrometer analysis
5. Gradation of soil
6. Particle shape
7. Problems

Chapter Two: Soil Composition

1. Definition of unit weight and density
2. Definitions of soil phases
3. Relations among unit weight, e, w, and Gs
4. Relations among unit weight, n, w, and Gs
5. Consistency of soil
6. Plasticity of soil
7. Stickiness of soil
8. Atterberg's limits
   a) Liquid limit
   b) Plastic limit
   c) Shrinkage limit
9. Plasticity chart
10. Soil structure
    a) Cohesionless soils
    b) Cohesive soils
11. Problems

Chapter Three: Classification of Soil

1. Scales of particle size definition
2. USDA Scale (agriculture)
3. Engineering classification
   a) AASHTO classification
   b) USCS classification

4. Problems

Chapter Four: Soil Compaction

1. Definition of compaction
2. Standard Proctor test
3. Modified Proctor test
4. Factors affecting compaction
5. Field compaction
6. Measurement of field compaction
    a) Relative compaction
    b) Relative density
7. Determination of field unit weight
    a) Sand cone method
    b) Rubber balloon method
    c) Nuclear method
8. Special compaction techniques
    a) Vibroflotation
    b) Dynamic compaction
    c) Blasting
9. Problems

Chapter Five: Flow in Soils

1. Permeability of soil
2. Bernoulli's equation
3. Darcy's law
4. Coefficient of permeability (Hydraulic conductivity)
5. Laboratory determination of hydraulic conductivity
    a) Constant head test
    b) Falling head test
6. Empirical relations for hydraulic conductivity
7. Equivalent permeability in stratified soils
8. Permeability test in field by pumping from wells
    a) Unconfined aquifer
    b) Confined aquifer
9. Laplace equation
10. Flow nets
11. Seepage calculation from a flow net
12. Uplift pressure under hydraulic structures

13. Seepage through an earth dam on an impervious base
14. Problems

Chapter Six: In Situ Stresses

1. Definition of stresses
2. Effective stress principle
3. Stress in saturated soils without seepage
4. Stress in saturated soils with seepage
5. Seepage forces
6. Heaving in soil caused by flow around sheet piles
7. Effective stress in partially saturated soils
8. Capillary rise in soils
9. Problems

Chapter Seven: Stresses in Soil Mass

1. Normal and shear stresses on a plane
2. Mohr circle
3. Pole method
4. Stress caused by a point load
5. Vertical stress caused by a line load
   a) Vertical line load
   b) Horizontal line load
6. Vertical stress caused by a vertical strip load
7. Vertical stress due to an embankment loading
8. Vertical stress below the center of a uniformly loaded circular area
9. Vertical stress at any point below a uniformly loaded circular area
10. Vertical stress caused by a rectangular loaded area
11. Stress isobars
12. Influence chart for vertical pressure
13. Approximate method 2:1
14. Problems

Chapter Eight: Compressibility of Soil

1. Introduction
2. Elastic settlement
3. Consolidation settlement
4. One-dimensional consolidation test

Chapter Nine: Shear Strength of Soil

Chapter Ten: Soil Testing

The Greek alphabet

Greek letters are commonly used as variable names in mathematics and statistics. The purpose of this assignment is to give you some familiarity with the Greek alphabet so that you become more comfortable with use of Greek letters.

Lower case	Upper case	Latin equivalent	Name
α	A	a	alpha
β	B	b	beta
γ	Γ	g	gamma
δ	Δ	d	delta
ϵ or ε	E	e	epsilon
ζ	Z	z	zeta
η	H	ê	eta
θ	Θ	th	theta
ι	I	i	iota
κ	K	k	kappa
λ	Λ	l	lambda
μ	M	m	mu
ν	N	n	nu
ξ	Ξ	ks	xi
o	O	o	omicron
π	Π	p	pi
ρ or ϱ	P	r	rho
σ or ς	Σ	s	sigma
τ	T	t	tau
υ	Y	u	upsilon
ϕ or φ	Φ	f	phi
χ	X	ch	chi
ψ	Ψ	ps	psi
ω	Ω	ô	omega

SI Base Units

The International System of Units (SI) is constructed from seven base units, which are adequate to describe most of the measurements used in science, industry and commerce.

Quantity	Unit Name	Symbol
length	meter	m
mass[3]	kilogram	kg
time	second	s
electric current	ampere	A
thermodynamic temperature	kelvin	K
amount of substance	mole	mol
luminous intensity	candela	cd

SI Prefixes

The units often have prefixes, indicating the power(s) of 10 by which a unit may be multiplied (for example, the prefix kilo in kilometer indicates that the unit kilometer is 1000 times larger than the meter).

Multiplication Factor	Prefix Name	Prefix Symbol
$1\ 000\ 000\ 000\ 000 = 10^{12}$	tera	T
$1\ 000\ 000\ 000 = 10^{9}$	giga	G
$1\ 000\ 000 = 10^{6}$	mega	M
$1\ 000 = 10^{3}$	kilo	k
$100 = 10^{2}$	hecto	h
$10 = 10^{1}$	deka	da
$0.1 = 10^{-1}$	deci	d
$0.01 = 10^{-2}$	centi	c
$0.001 = 10^{-3}$	milli	m
$0.000\ 001 = 10^{-6}$	micro	μ
$0.000\ 000\ 001 = 10^{-9}$	nano	n
$0.000\ 000\ 000\ 001 = 10^{-12}$	pico	p

The following table contains useful conversions between SI units and BS units.

Length:	1 m	$= 3.281$ ft
	1 cm	$= 3.281 \times 10^{-2}$ ft
	1 mm	$= 3.281 \times 10^{-3}$ ft
	1 m	$= 39.37$ in.
	1 cm	$= 0.3937$ in.
	1 mm	$= 0.03937$ in.
Area:	1 m^2	$= 10.764$ ft^2
	1 cm^2	$= 10.764 \times 10^{-4}$ ft^2
	1 mm^2	$= 10.764 \times 10^{-6}$ ft^2
	1 m^2	$= 1550$ $in.^2$
	1 cm^2	$= 0.155$ $in.^2$
	1 mm^2	$= 0.155 \times 10^{-2}$ $in.^2$
Volume:	1 m^3	$= 35.32$ ft^3
	1 cm^3	$= 35.32 \times 10^{-4}$ ft^3
	1 m^3	$= 61{,}023.4$ $in.^3$
	1 cm^3	$= 0.061023$ $in.^3$
Force:	1 N	$= 0.2248$ lb
	1 kN	$= 224.8$ lb
	1 kgf	$= 2.2046$ lb
	1 kN	$= 0.2248$ kip
	1 kN	$= 0.1124$ U.S. ton
	1 metric ton	$= 2204.6$ lb
	1 N/m	$= 0.0685$ lb/ft

Stress:	1 N/m^2	$= 20.885 \times 10^{-3}$ lb/ft^2
	1 kN/m^2	$= 20.885$ lb/ft^2
	1 kN/m^2	$= 0.01044$ U.S. ton/ft^2
	1 kN/m^2	$= 20.885 \times 10^{-3}$ kip/ft^2
	1 kN/m^2	$= 0.145$ $lb/in.^2$
Unit weight:	1 kN/m^3	$= 6.361$ lb/ft^3
	1 kN/m^3	$= 0.003682$ $lb/in.^3$
Moment:	1 N · m	$= 0.7375$ lb-ft
	1 N · m	$= 8.851$ lb-in.
Energy:	1 J	$= 0.7375$ ft-lb
Moment of inertia:	1 mm^4	$= 2.402 \times 10^{-6}$ $in.^4$
	1 m^4	$= 2.402 \times 10^{6}$ $in.^4$
Section modulus:	1 mm^3	$= 6.102 \times 10^{-5}$ $in.^3$
	1 m^3	$= 6.102 \times 10^{4}$ $in.^3$
Hydraulic conductivity:	1 m/min	$= 3.281$ ft/min
	1 cm/min	$= 0.03281$ ft/min
	1 mm/min	$= 0.003281$ ft/min
	1 m/sec	$= 3.281$ ft/sec
	1 mm/sec	$= 0.03281$ ft/sec
	1 m/min	$= 39.37$ in./min
	1 cm/sec	$= 0.3937$ in./sec
	1 mm/sec	$= 0.03937$ in./sec
Coefficient of consolidation:	1 cm^2/sec	$= 0.155$ $in.^2/sec$
	1 m^2/yr	$= 4.915 \times 10^{-5}$ $in.^2/sec$
	1 cm^2/sec	$= 1.0764 \times 10^{-3}$ ft^2/sec

Definition of Soil

1

8. Definition of soil

Soil is defined as the uncemented aggregate of mineral grains and decayed organic matter with liquid and/or gas in the pores between the grains.

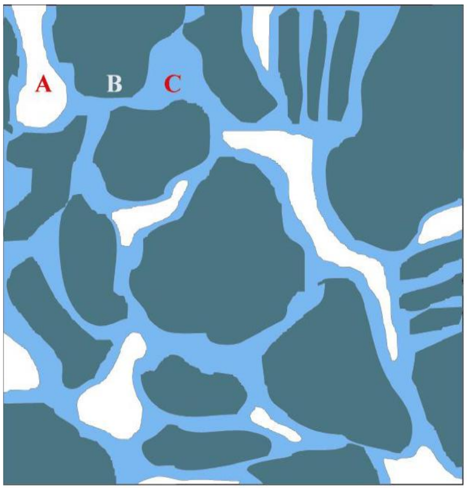


Figure 1.1: (A) gas (mostly air); (B) solid particles (minerals); (C) liquid (water, contaminant liquid).

Engineering Definition of Soil:
Soil is the earth material that can be disaggregated in water by gentle agitation.

Where did soil come from?
Soils are formed by weathering of rocks. The mineral grains that form the solid phase of a soil aggregate are the product of rock weathering.

9. Rock cycle

In Geology, '***Rock***' is defined as the solid material forming the outer rocky shell or crust of the earth. There are three major groups of rocks by its origin:

a) ***Igneous Rocks:*** cooled from a molten state;
b) ***Sedimentary Rocks:*** deposited from fluid medium; e.g., products of weathering of other rocks in water;
c) ***Metamorphic Rocks:*** formed from pre-existing rocks by the action of heat and pressure.

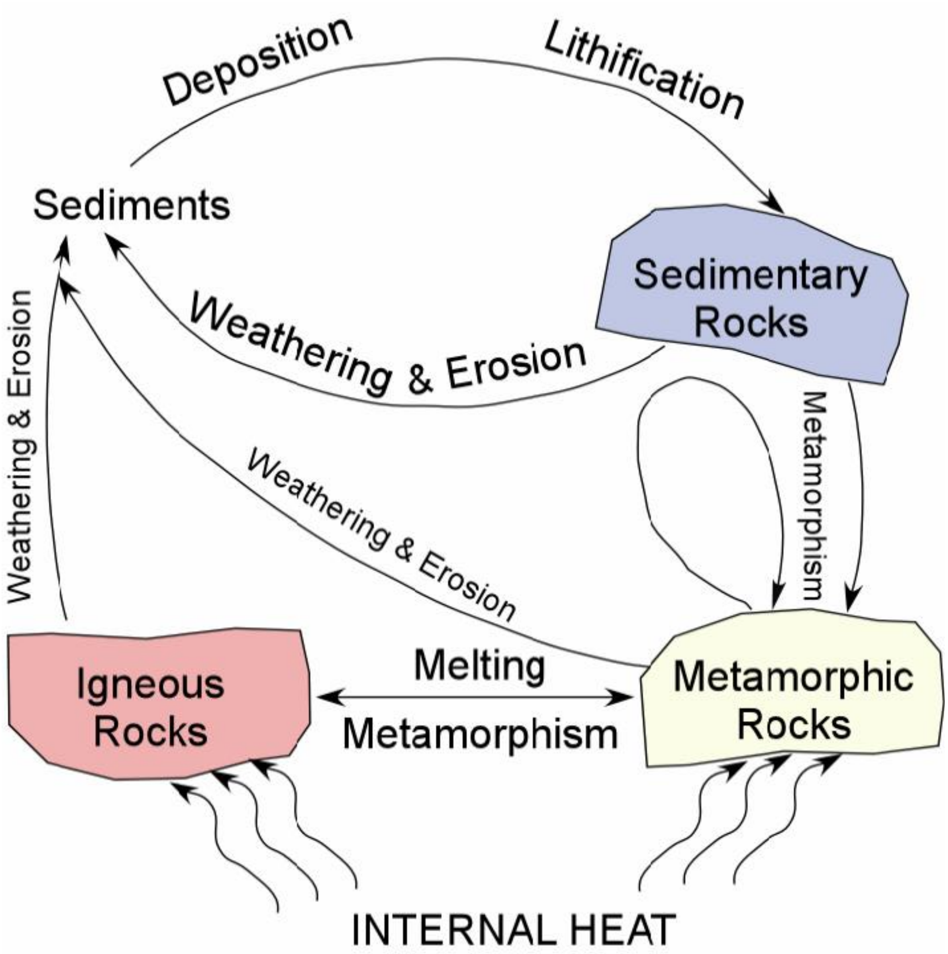


Figure 1.2: Rock cycle.

Apparently, the igneous rock is the one far more essential and intrinsic since the other two types are relative secondary in origin.

Basic Mineralogy of Rocks

Rocks are formed of minerals. What is a mineral?

- **a)** A naturally occurring chemical element or compound;
- **b)** Formed by inorganic processes;
- **c)** An ordered arrangement or pattern for its atoms–crystalline structure;
- **d)** Possesses a definite chemical composition or range of compositions.

- There are more than 2000 naturally occurred minerals have been discovered; only a bit more than 100 is common and used in college mineralogy.
- However, of the 100 common minerals only about 25 are abundant rock-forming minerals.
- The main types of minerals are: metallic minerals; nonmetallic minerals; carbonate minerals; sulfate minerals; sulfide minerals; silicate minerals; oxide minerals; clay minerals.

Table 1.1: Comparison between surface and subsurface conditions.

Subsurface	Surface
High temperature but constant at which minerals reach equilibrium	Low temperature, and highly variable
High confining pressure (stress)	Little or no confining pressure (stress)
Less water or no water	Abundant of water
No oxygen	Abundant of oxygen

- Rock at the surface will undergo changes, these changes are called **Weathering**.

Weathering

Weathering: is the physical breakdown (disintegration) and chemical alteration (decomposition) of rocks to form soil or loose particles at or near Earth's surface.

Mechanical weathering: is the physical disintegration or degradation of rock pieces without a change in composition (size reduction).

Mechanical weathering processes include:

a) Freezing & thawing (frost wedge);
b) Differential expansion and contraction as temperature changes (in deserts or from forest fires), not all parts of a rock or all its minerals expand or contract by the same amount.

Chemical weathering: is decomposition whereby one mineral species is changed into another through various chemical processes. Water plays a major role, through providing oxygen and mobility for moving ions.

Chemical weathering processes include:

a) **Solution (or dissolution):** several common minerals dissolve in water.
b) **Oxidation:** Oxygen combines with iron-bearing silicate minerals causing "rusting".
c) **Hydrolysis:** Hydration-reaction between mineral and water.

The chemical weathering rate depends on Temperature; Amount of surface area; and Availability of water or natural acid.

Table 1.2: Classification of soil according to transportation and deposition.

Name	Description
Glacial soils	formed by transportation and deposition of glaciers;
Alluvial soils	transported by running water and deposited along streams;
Lacustrine soils	formed by deposition in quiet lakes;
Marine soils	formed by deposition in the sea;
Aeolian soils	transported and deposited by wind;
Colluvial soils	formed by movement of soil from its original place by gravity, such as during landslides.

10. Clay Minerals

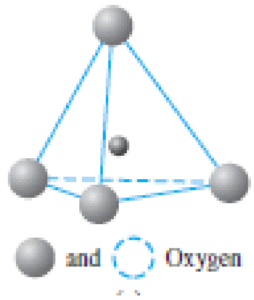
Clay minerals are complex aluminum silicates composed of two basic units:

a) Silica Tetrahedron

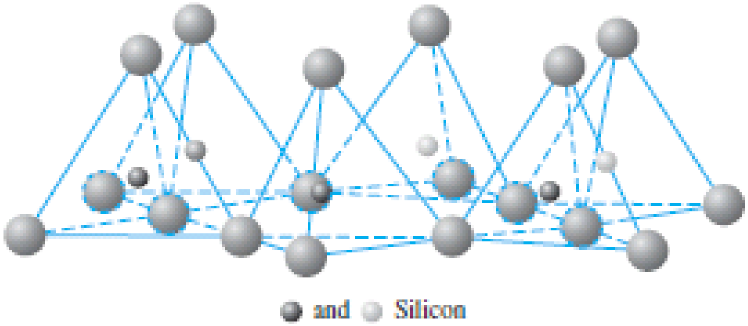
- ❖ Each tetrahedron unit consists of four oxygen atoms surrounding a silicon atom.
- ❖ The combination of tetrahedral silica units gives a silica sheet. Three oxygen atoms at the base of each tetrahedron are shared by neighboring tetrahedra.

b) Alumina Octahedron

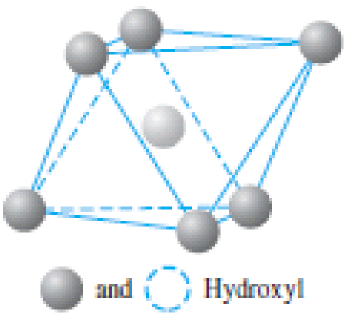
- ❖ The octahedral units consist of six hydroxyls surrounding an aluminum atom.
- ❖ The combination of the octahedral aluminum hydroxyl units gives an octahedral sheet (gibbsite sheet).
- ❖ Sometimes magnesium replaces the aluminum atoms in the octahedral units; in this case, the octahedral sheet is called a brucite sheet.



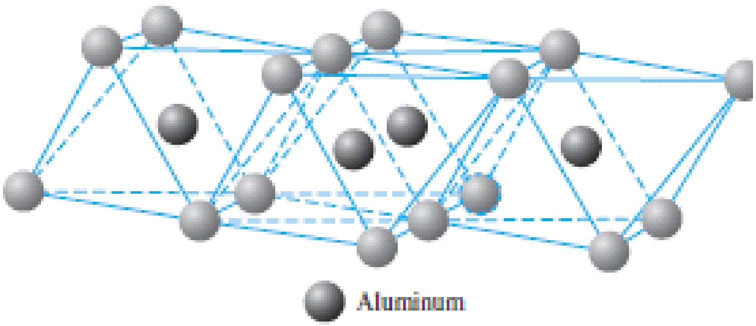
Silica Tetrahedron



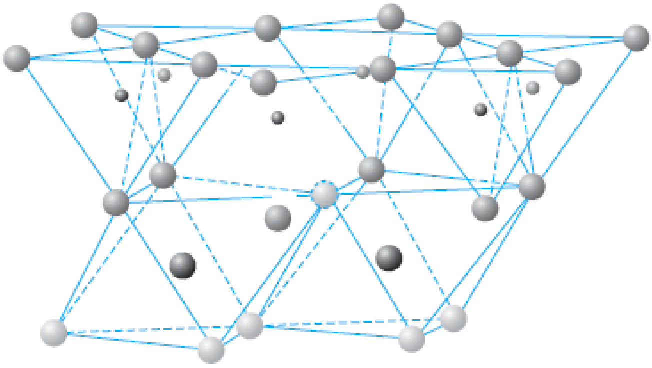
Silica Sheet



Alumina Octahedron



Gibbsite Sheet



Elemental Silica-Gibbsite Sheet

Figure 1.3: Silica sheet and Gibbsite sheet.

The three important clay minerals are:

d) 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**.

e) Illite

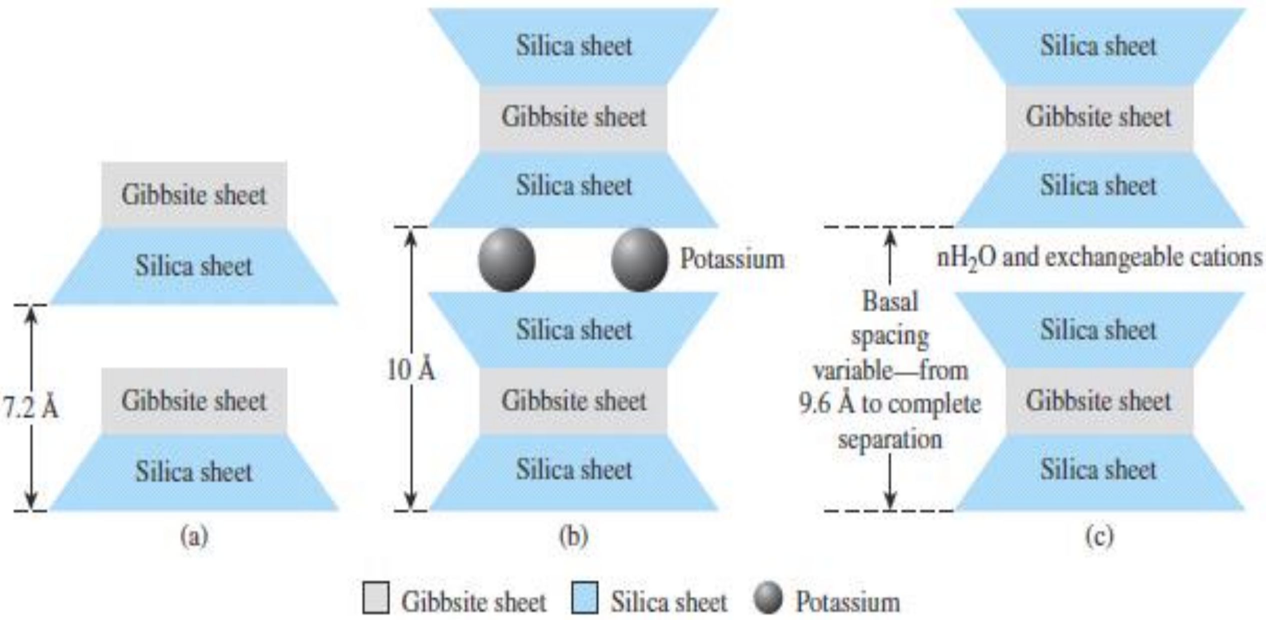
Consists of a gibbsite sheet bonded to two silica sheets-one at the top and another at the bottom. It is sometimes called clay mica.

- ❖ 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**.

f) 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) Kaolonite, (b) Illite, (c) Montmorillonite

Figure 1.4: Clay minerals.

11. Particle size of soil

The description of the grain size distribution of soil particles according to their texture (particle size, shape, and gradation).

Major textural classes include:
Gravel particle size >4.75 mm;
Sand particle size (0.075 –4.75) mm;
Silt particle size (0.005 –0.075) mm;
Clay particle size < 0.005 mm.

Furthermore, **gravel and sand** can be roughly classified as **coarse-grained soils**, while **silt and clay** can be classified as **fine textures soils**.

For engineering purposes, soils can also be divided into **cohesive** (***fine textured soils***) and **non-cohesive** soils (***coarse grained soils***). Cohesive soil contains clay minerals and possesses plasticity.

Particle size determination

- ***Mechanical analysis:*** used for particles sizes > 0.075 mm in diameter;
- ***Hydrometer analysis:*** used for smaller particles (φ < 0.075 mm), analysis is based on Stokes' Law (velocity proportional to diameter).

  - For soils with fine and coarse-grained materials a combined analysis is made using both the sieve and hydrometer procedures.

c) Mechanical analysis

Mechanical analysis (sieving analysis) consists of shaking the soil sample through a set of sieves, the test used for the grain size greater than 0.075 mm (75 microns).

Table 1.3: Standard sieve sizes.

Sieve No.	Sieve opening (mm)
4	4.75
10	2.00
20	0.85
40	0.425
60	0.25
100	0.15
200	0.074

Procedure of sieve analysis

1. The total mass of soil sample (ΣM) used in sieve test;
2. Determine the mass of soil retained on each sieve and the pan at end of test (i.e., M_1, M_2, M_3, ….., Mn, and Mp); (n is the number of sieves)
3. The sum of soil mass retained on each sieve plus the mass in the pan should be equal to the total mass ($\Sigma M = M_1+M_2+M_3+\ldots +Mn+Mp$);
4. Determine the cumulative mass of soil retained above each sieve, for the i^{th} sieve: $\Sigma Mi = M_1+M_2+M_3+\ldots +Mi$;

5. The mass of soil passing the i[th] sieve is ΣM-ΣMi;
6. The percent of soil passing the i[th] sieve (percent finer) is:

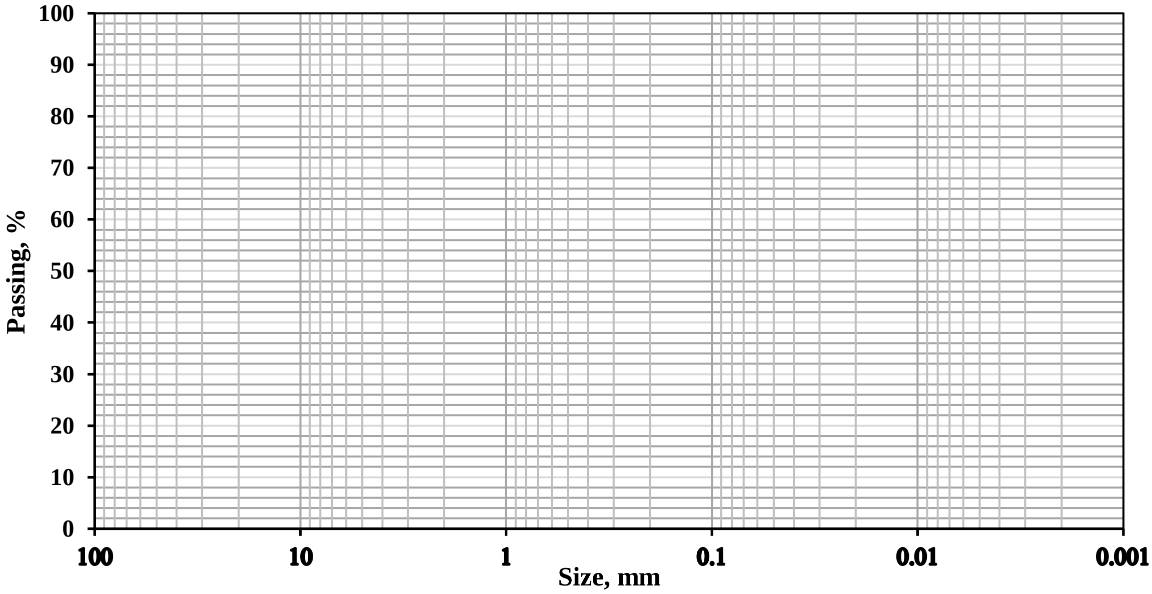
$$F = \frac{\sum M - \sum Mi}{\sum M} X\,100$$

Example 1

If you have a soil sample with a weight of 150 gm, after sieving you get the following result.

Solution

Sieve No.	Sieve Opening, mm	Retained Mass, gm	Accumulated Retained Mass, gm	Passing mass, gm	Percentage Finer, %
4	4.75	30.0			
20	0.85	40.0			
60	0.25	50.0			
100	0.15	20.0			
200	0.074	10.0			
Step		(2) & (3)	(4)	(5)	(6)



d) Hydrometer analysis

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.

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

where
v: velocity of the particle;
ρ_s: density of soil particles;
ρ_w: density of water;
η: viscosity of water;
D: diameter of soil particles.

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

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

With

$$\rho_s = G_s \, \rho_w$$

$$G_s = \frac{\rho_s}{\rho_w} = \frac{\gamma_s}{\gamma_w}$$

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:

Table 1.4: Specific gravity of soil.

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.***

12. Gradation of soil

Gradation is a measure of the distribution of a particular soil sample.

- Larger gradation means a wider particle size distribution and soil can be classified as well graded, poorly graded or gap-graded.

Effective Size, D_{10}

D_{10} represents a grain diameter for which 10% of the sample will be finer than it. Using another word, 10% of the sample by weight is smaller than diameter D_{10}.

Hazen's approximation (an empirical relation between hydraulic conductivity with grain size).

$$k(cm/s) = c\,D_{10}^2$$

Where D10 is in millimeters and c is constant varies from 1.0-1.5.

Uniformity coefficient, Cu

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

Where D_{60} is the diameter for which 60% of the sample is finer than D_{60}.

- *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.*

Coefficient of curvature, Cc (Coefficient of gradation, Cz)

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

- ***A soil is to be well graded if the coefficient of gradation Cc between 1 and 3 and Cu greater than 4 for gravels and 6 for sands.***

Sorting Coefficient S_0

Another parameter for measuring uniformity used mostly by geologists.

$$S_0 = \sqrt{\frac{D_{75}}{D_{25}}}$$

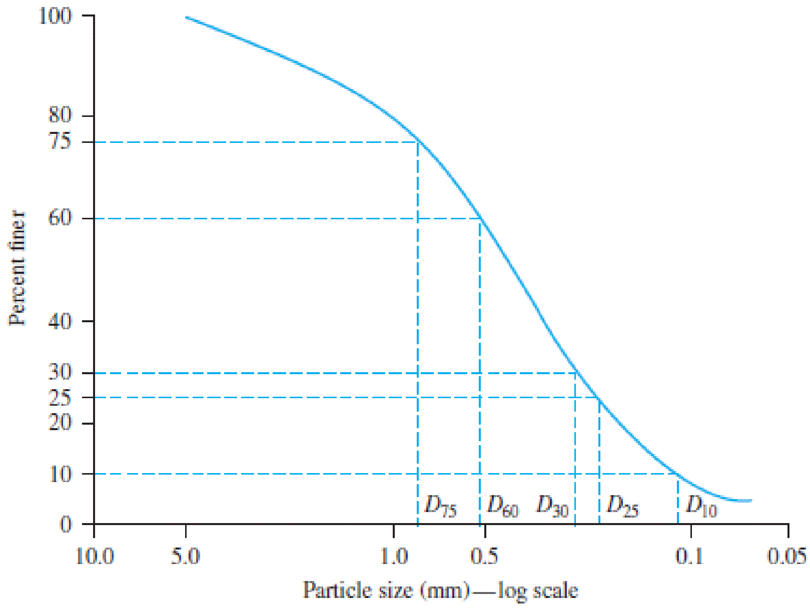


Figure 1.5: Particle size distribution curve.

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

- **Curve I** represents a poorly graded soil (most grains have the same size);
- **Curve II** represents a well graded soil (wide range distribution of the particle sizes);
- **Curve III** represents a gab graded soil (have a combination of two or more uniformly graded fractions).

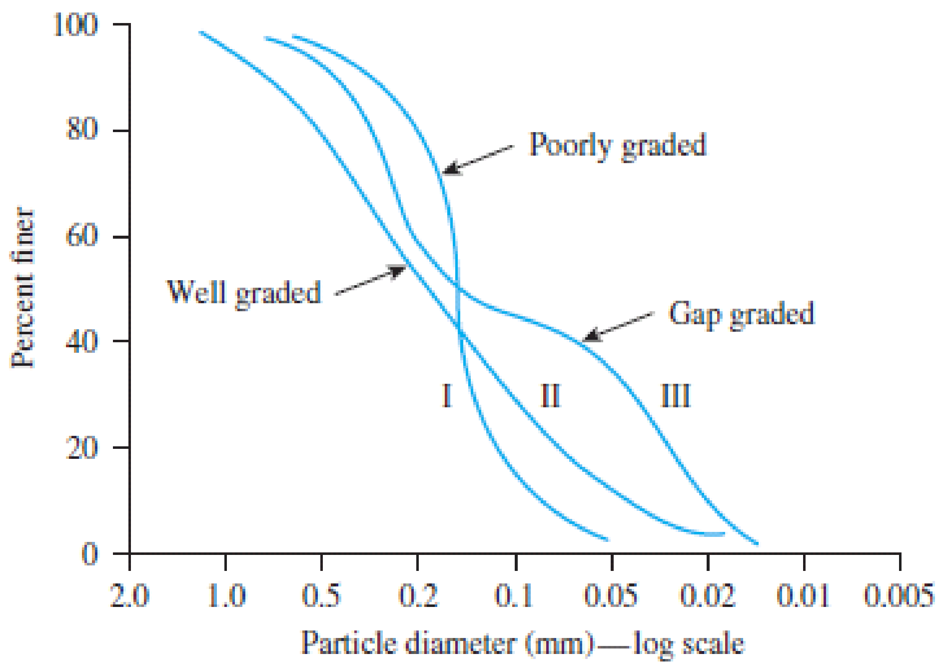


Figure 1.6: Gradation curves of soil.

13. Particle shape

The shape of particles has significant influence on the physical properties of a given soil. The particle shape can be divided into three major categories:

Bulky particles: are mostly formed by mechanical weathering of rock and minerals (angular, sub angular, rounded, and surrounded). The angularity, A, is defined as:

$$A = \frac{\textbf{Average radius of corners and edges}}{\textbf{maximum radius of the inscribed sphere}}$$

The sphericity of bulky particles is defined as:

$$S = \frac{D_e}{L_p}$$

where

De: is the equivalent diameter of the particle$= \sqrt[3]{\frac{6V}{\pi}}$, (volume of sphere);

V: is the volume of particle;
Lp: is the length of particle.

Flaky particles: have very low sphericity--usually 0 .01 or less. These particles are predominantly clay minerals.

Needle-shaped particles: are much less common than the other two particle types. (Coral deposits and attapulgite clays).

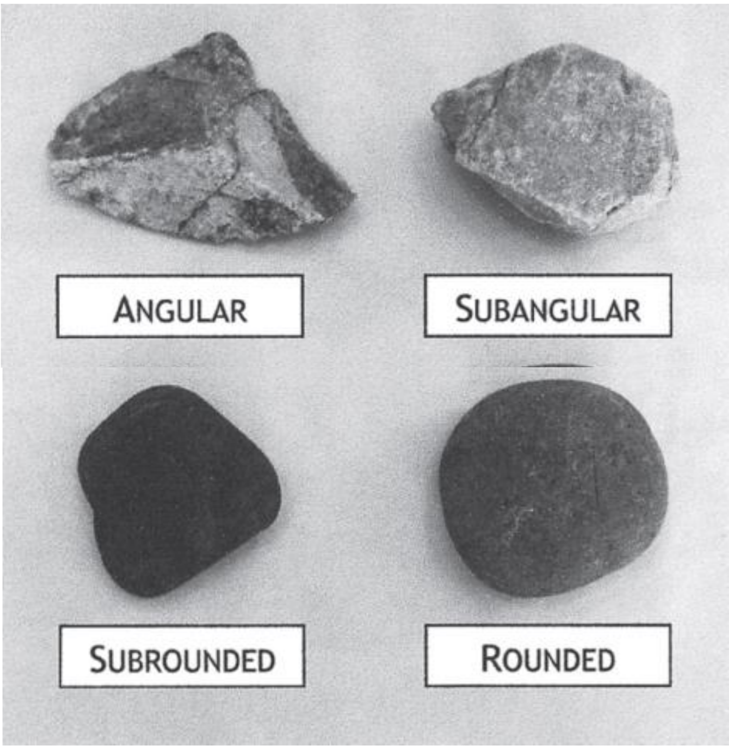


Figure 1.7: Particles shape.

14. Problems

Problem 1.1

Sieve analysis test was conducted on 650 grams of soil. The results are given in Table below. Calculate the % finer and plot the particle-size distribution curve. Extract the amount of coarse-grained soil (particle sizes ≥0.075 mm) and the amount of fine-grained soil (particle sizes ≤0.075 mm). Also, find the D_{10}, Cu, Cz, So and k in cm/sec.

Sieve No.	9.53	4	10	20	40	100	200	Pan
Opening, mm	9.53	4.75	2	0.85	0.425	0.15	0.075	-
Mass retained, gm	0	53	76	73	142	85	120.5	99.8

Solution

Sieve No.	Sieve Opening, mm	Retained Mass, gm	Accumulated Retained Mass, gm	Passing mass, gm	Percentage Finer, %