Assistant Prof. Dr.Khitam Abdulhussein Saeed
Al-Mustansiriyah University
Faculty of Civil Engineering
Water Resources Engineering Department

SOIL MECHANICS

CHAPTER ONE

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Third

Stage Students

Undergraduate students (3th stage students)
Faculty of Engineering
Mustansiriyah University
Water Resources Engineering Department

CHAPTER ONE

SOIL BEHAVIOUR & SOIL FORMATION

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1. INTRODUCTION

Civil and ***environmental*** engineering includes the **conception, analysis**, **design**, **construction**, **operation**, and **maintenance** of a diversity of structures, **facilities**, and **systems**. All are built on, in, or with **soil or rock**. The properties and behavior of these materials have major **influences** on the **success**, **economy**, and **safety** of the work.

Soils and their **interactions** with the **environment** are major considerations. **Furthermore**, detailed understanding of the behavior of **earth materials** is essential for mining, for energy resources development and recovery, and for scientific studies in virtually all the geosciences. To deal properly with the earth materials associated with any problem and project ***requires*** **knowledge**, **understanding**, and **appreciation** of the importance of geology, materials science, materials testing, and mechanics. ***Geotechnical engineering*** is concerned with all of these. ***Environmental concerns***—especially those related to **groundwater**, the **safe disposal** and **containment of wastes**, and the cleanup of contaminated sites.

1.1 <u>The Earth's Crust</u>

The continental crust covers 29 percent of Earth's surface. The elemental compositions of the whole Earth and the crust are indicated in Fig. 1. There are more than 100 elements, but 90 percent of Earth consists of **iron**, **oxygen, silicon, and magnesium.** Less iron is found in the **crust** than in the **core** because its **higher density causes it to sink**. **Silicon, aluminum, calcium, potassium, and sodium** are ***more abundant*** in the **crust** than in **the core** because they are ***lighter elements***. ***Oxygen i***s the only anion that has an abundance of more than 1 percent by weight; however, it is very abundant by volume.

Silicon, aluminum, magnesium, and oxygen are the most commonly observed elements in soils.

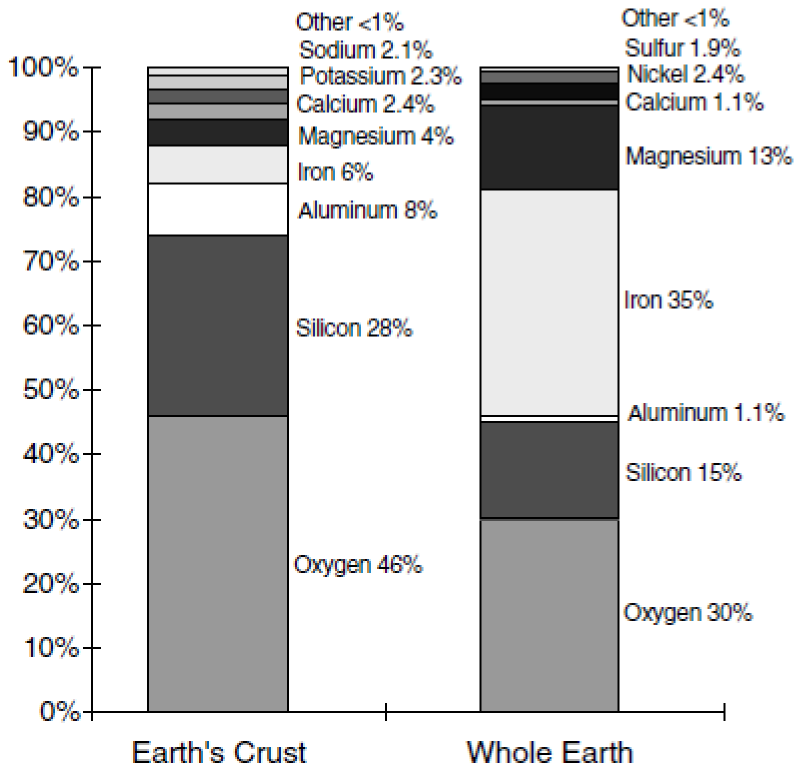


Fig.1 Elemental composition of the whole Earth and the crust (percent by weight)

1.2 Geologic Cycle and Geological

The surface of Earth is acted on by four basic processes that proceed in a never-ending cycle, as indicated in Fig. 2. ***Denudation*** includes all of those processes that act to wear down land masses. These include landslides, debris flows, avalanche transport, wind abrasion, and overland flows such as rivers and streams. ***Weathering*** includes all of the destructive mechanical and chemical processes that break down existing rock masses in situ. Erosion initiates the

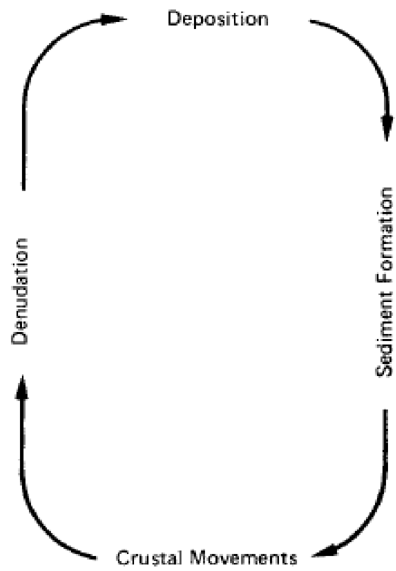


Fig. 2: Geological Cycle

transportation of weathering products by various agents from one region to another—generally from high areas to low. Weathering and erosion convert rocks into sediment and form soil. ***Deposition*** involves the accumulation of sediments transported previously from some other area.

1.3 Soil Formation

Soil is defined as sediments or other accumulation of mineral particles produced by the physical or chemical disintegration of rock, plus the air, water, organic matter, and other substances that may be included. Soil is typically a non-homogeneous, porous, and earthen material whose engineering behavior is influenced by changes in moisture content and density. To understand and appreciate the characteristics of any soil deposit require an understanding of what the material is and how it reached its present state. This requires consideration of rock and soil weathering, the erosion and transportation of soil materials, depositional processes, and postdepositional changes in sediments.

1.3.1 Weathering

In situ, weathering processes lead to a sequence of horizons within soil. Weathering of rocks and soils is a destructive process whereby debris of various sizes, compositions, and shapes is formed. The new compositions are usually more stable than the old and involve a decrease in the internal energy of the materials.

A variety of physical, chemical, and biological processes act to break down rock masses. Physical processes reduce particle size, increase surface area, and increase bulk volume. Chemical and biological processes can cause complete changes in both physical and chemical properties.

1.3.1.1 Physical Processes of Weathering

Physical weathering processes cause in situ breakdown without chemical change. All type of actions that cause a disintegration of the parent rocks by physical means such as, gravity, wind and water. The product of this type is rounded, sub rounded or granular, its products called coarse grained soil e.g. (gravel and sand) they present in nature in a single grain structure(which are cohesion less and they have the same properties of the parent rock) .

1.3.1. 2 Chemical Processes of Weathering

All types of chemical reactions that occur between the minerals of the rock and the environment (air, water ---et.) and will end up by disintegration of parent rock into fine grain particles; these products have different properties from the parent rock. Chemical weathering transforms one mineral to another or completely dissolves the mineral. Practically all chemical weathering processes depend on the presence of water. Hydration, that is, the surface adsorption of water, is the forerunner of all the more complex chemical reactions, many of which proceed simultaneously. Its products called coarse grained soil e.g. (silt and clay), which are cohesive materials, and its properties do not reflect the same properties of the parent rocks.

1.4 Soil Origin

The origin of soil can be broken down to two basic types: **residual, and transported**. The properties of each of one as follow:

Residual soil

1- Is caused by the weathering (decomposition) of rock by chemical or physical action.

2- Residual soils may be very thick in areas of intense weathering such as the tropics, or they may be thin or absent in areas of rapid erosion such as steep slopes.

3- They are usually clayey, and their properties are related to climate and other factors prevalent at the location of the soil.

4- Residual soils are usually preferred to support foundations, as they tend to have better, more predictable engineering properties.

Transported or deposited soils

1- They are derived by the movement of soil from one location to the other by natural means such as wind, water, ice, and gravity.

2- The character of the resulting deposit often reflects the modes of transportation and deposition and the source material for example deposits by water include alluvial floodplains, coastal plains, and beaches, deposits by wind include sand dunes and loess, and deposits by melting ice include glacial till and outwash.

3- Each of these materials has behavioral characteristics dependent on geological origin, and the geological name, such as loess, conveys much useful information.

4- Transported soils – particularly by wind or water – are often of poor quality in terms of engineering properties.

2. SOIL MINERALOGY

Soil is composed of solid particles, liquid, and gas and ranges from very soft, organic deposits through less compressible clays and sands to soft rock. The solid particles vary in size from large boulders to minute particles that are visible only with the aid of the electron microscope. A soil may contain virtually any element contained in Earth's crust; however, by far the most abundant are oxygen, silicon, hydrogen, and aluminum. These elements, along with calcium, sodium, potassium, magnesium, and carbon, comprise over 99 percent of the solid mass of soils worldwide.

Mineralogy is the primary factor controlling the size, shape, and properties of soil particles. These same factors determine the possible ranges of physical and chemical properties of any given soil; therefore, a priori knowledge of what minerals are in a soil provides intuitive insight as to its behavior.

Commonly defined particle size ranges are shown in Fig. 3. The divisions between gravel, sand, silt, and clay sizes are convenient. Particles smaller than about 200 mesh sieve size (0.074 mm), which is the boundary between sand and silt sizes, cannot be seen by the naked eye. **Clay** can refer both to a size and to a class of minerals. **As a size term**, it refers to all constituents of a soil smaller than a particular size, usually 0.002 mm (2µm) in engineering classifications.

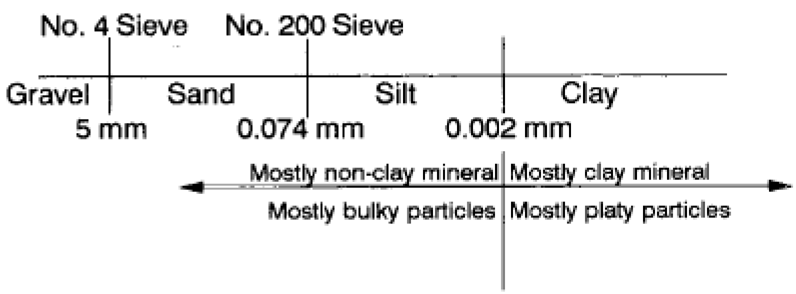


Figure 3: Particle size ranges in soils

4. Soil Composition and Engineering Properties

The engineering properties of a soil depend on the composite effects of several interacting factors. These factors may be divided into two groups: **compositional factors and environmental factors**. Compositional factors determine the potential range of values for any property. They include:

1. Types of minerals
2. Amount of each mineral
3. Types of adsorbed cations
4. Shapes and size distribution of particles
5. Pore water composition
6. Type and amount of other constituents, such as organic matter, silica, alumina, and iron oxide

While, Environmental factors determine the actual value of any property. They include:

1. Water content
2. Density
3. Confining pressure
4. Temperature
5. Fabric
6. Availability of water

Soils are classified as **coarse grained**, granular, and **cohesionless** if the amount of gravel and sand exceeds 50 percent by weight or **fine grained** and **cohesive** if the amount of fines (silt and clay-size material) exceeds 50 percent.

5. Clay Behavior

In geotechnical and environmental fields, an engineer will works with soil, which consist of the entire thickness of the earth's crust. From the geotechnical engineering viewpoint, clay is a kind of cohesive soil, which is very weak, and its strength will decrease by influence of climate or the water content in the soil. Clay can refer both to a size and to a class of minerals. **As a size term**, it refers to all constituents of a soil smaller than a particular size, usually 0.002 mm (2µm) in engineering classifications. **As a mineral term**, it refers to specific clay minerals that are distinguished by

(1) small particle size
(2) a net negative electrical charge
(3) plasticity when mixed with water
(4) high weathering resistance.

Clay minerals are primarily hydrous aluminum silicates. Not all clay particles are smaller than 2 µm, and not all **non-clay** particles are coarser than 2µm; however, the amount of clay mineral in a soil is often closely approximated by the amount of material finer than 2 µm. Thus, it is useful to use the terms clay size and clay mineral content to avoid confusion. A further important difference between clay and nonclay minerals is that the non-clays are composed primarily of bulky particles; whereas, the particles of most of the clay minerals are platy, and in a few cases they are needle shaped or tubular.

5.1 Classification of Clay Mineral

Clay minerals which are found in soils related to the mineral family called **phyllosilicate** that their structures are formed from groupings of two basic units, the **silicon tetrahedron** and **the alumina octahedron**. The tetrahedral and octahedral sheets are the main structural components of these minerals. In a sheet of silica, each silicon atom with a positive charge of four is connected to four oxygen atoms with negative charge total of eight. Each oxygen atom at the base of the tetrahedron accompanies two silicon atoms as depicted in Figures (5 & 6).

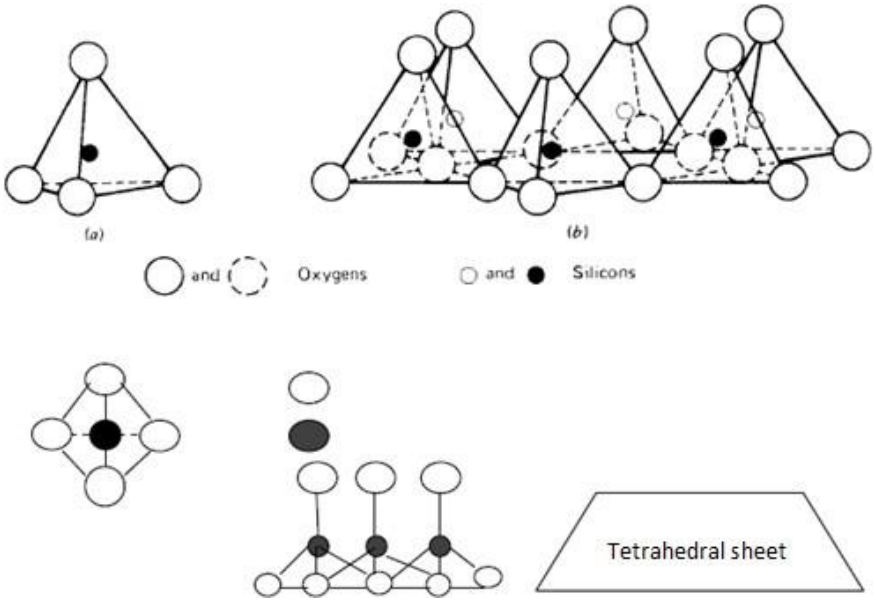


Figure 5: **Tetrahedral Unit**: Consists of four oxygen atoms (or hydroxyls, if needed to balance the structure) and one silicon a tom

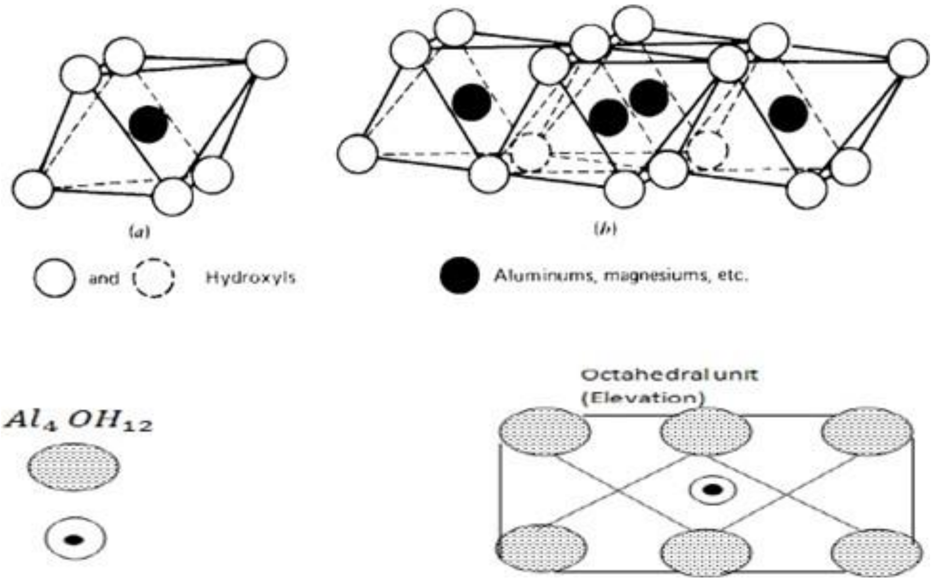


Figure 6: **Octahedral Unit** (consist of six hydroxyl ion at apices of an octahedral enclosing an aluminum ion at the center

Therefore, different clay mineral may be formed by the scheme of stacking of the sheets of these units and the format in which two or three successive layers are held together as shown in Figure (7).

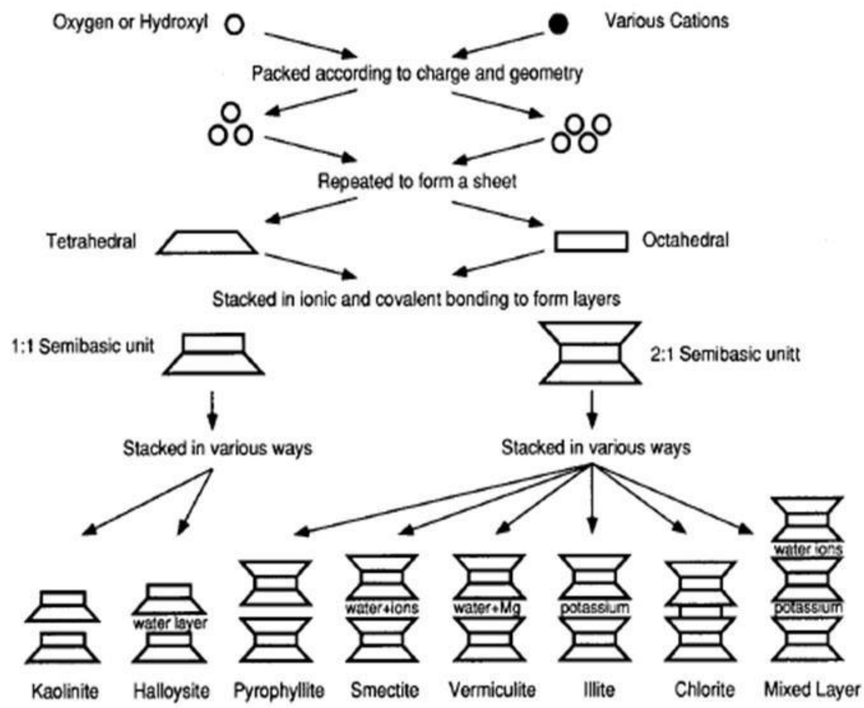


Figure 7: Synthesis pattern for the clay minerals.

5.2 Mineralogical Composition of Clays

The mineralogy of soil is the most important factor can influence the physical and chemical properties of any soil. Clay soils have a wide variety of mineralogical composition. They may include many proportions of different types of clay minerals, particularly **kaolinite, illite and montmorillonite** and non-clay minerals, especially **quartz, orthoclase feldspar, muscovite mica, calcite, dolomite, gypsum, pyrite and / or organic matter.**

Based on these, the clay minerals are categorized into two different groups, i.e., 1:1 and 2:1 type minerals. However, the structure and the detailed characterization of the clay minerals are commonly found in soil deposits described briefly in this section.

1- <u>Kaolinite (1:1 Minerals)</u>

Kaolinite is the most important member of the kaolin group. The structure is composed of a single tetrahedral sheet and a single alumina octahedral sheet as shown in figure (8) below: These layers are bond to other impending layers by hydrogen bonding. Thus, cations and water do not come in between the structural layers of kaolinite

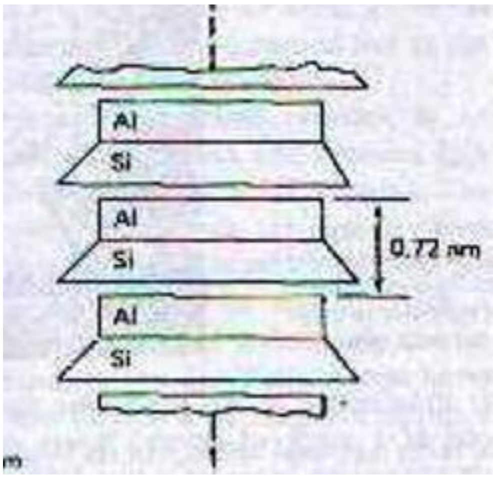


Fig. 8: Diagrammatic sketch of the kaolinite structure

As you can see each particle, kaolinite is constituted by a series of layers of hexagonal shape much like the pages of a book, as shown in Figure (9).

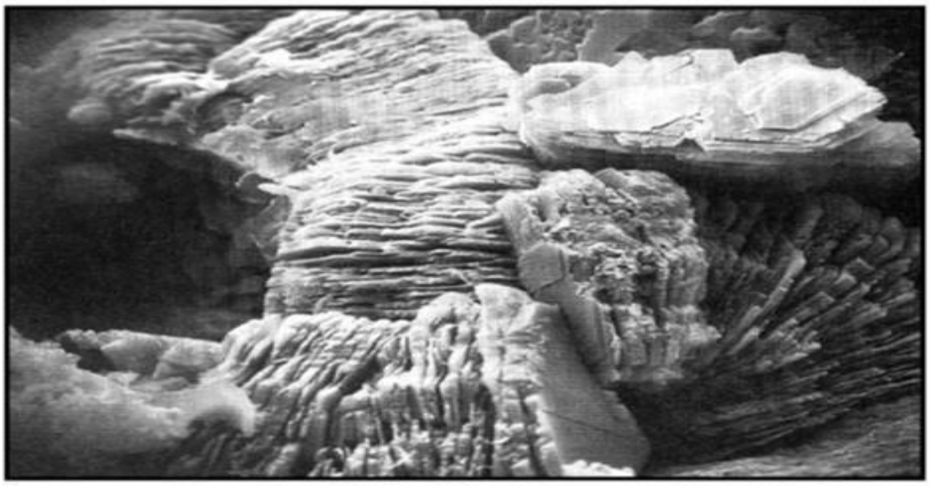


Fig. 9: Photomicrograph of well-crystallized kaolinite

2. <u>Illite (2:1 Smectite Minerals):</u> It is another important constituent of clay soils which have a crystal structure similar to the mica minerals but with less potassium; thus they are chemically much more active than other mica. The crystalline layers of these minerals are classified by a gibbsite octahedral sheet sandwiched between two tetrahedral layers of silica-one at the top and another at the bottom as shown in Figure (10).

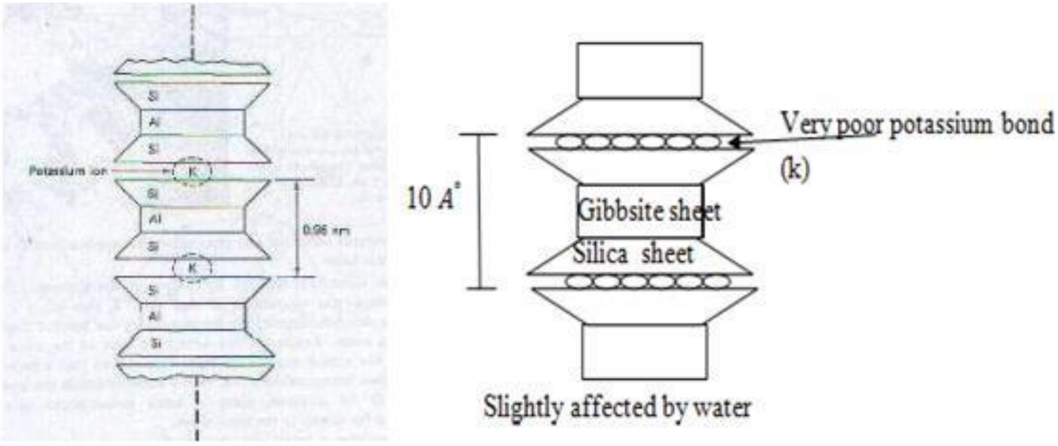


Fig. 10: Diagrammatic sketch of the structure of Illite

It has a basic structure consisting of two silica sheets with a central alumina sheet. There is a potassium bond between the layers. The morphology of these particles is often flaky and thin on the edges as note in the Figure 11.

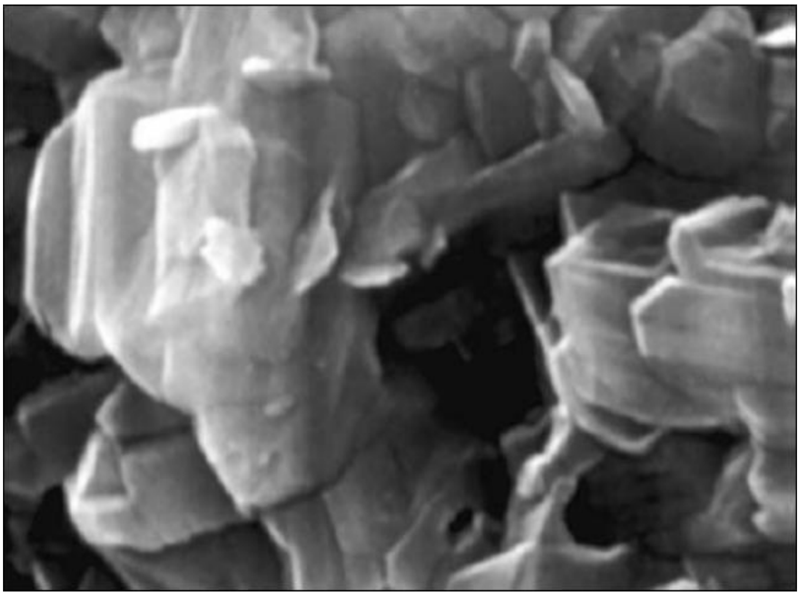


Fig. 11: Electron photomicrograph of Illite

3. Montmorillonite (2:1 Smectite Minerals): it is composed of two silica sheets and one alumina sheet, thus it is called a 2:1 mineral. The structure of montmorillonite is alike to the illite, which is an octahedral sheet gibbsite sandwiched between two silica tetrahedral sheets as shown in Figure (12).

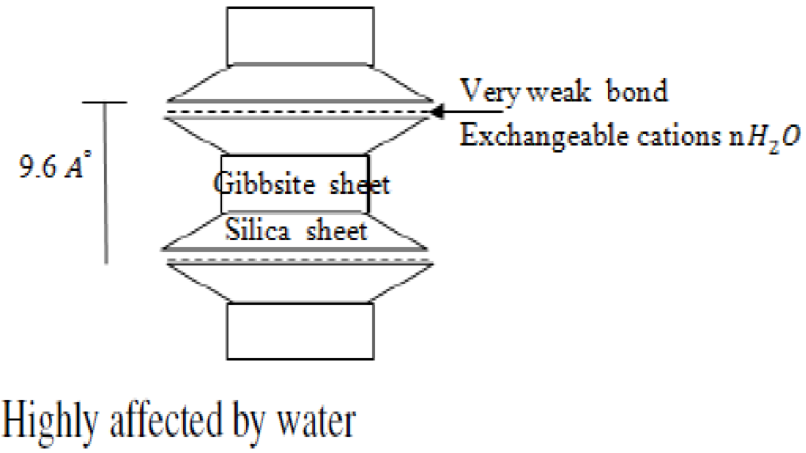


Fig. 12: Schematic diagrams of the structures of Montmorillonite

The small, very thin, and very thin particles of this mineral are shown in Figure 13

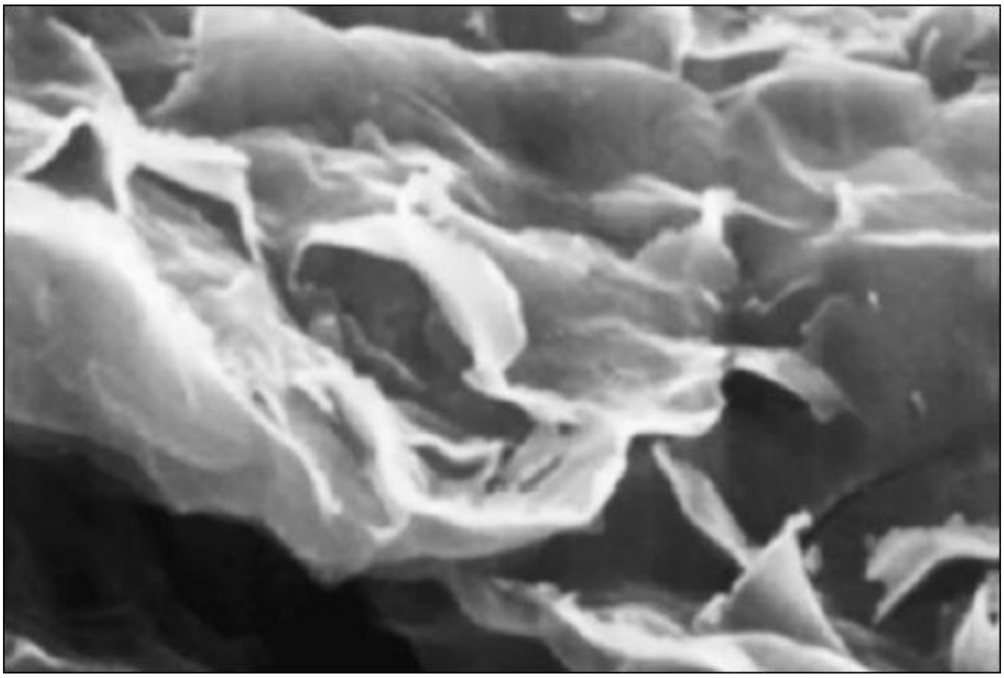


Fig. 13:Electron photomicrograph of Montmorillonite

5.3 Clay-Water Interaction

The clay particles have a high ability for polar liquids and adsorb cations such as water. Since the centers of positive and negative charges of water molecules do not coincide, the molecules behave like dipoles. The negative charge on the surface of the soil particle therefore attracts the positive (hydrogen) end of the water molecules. More than one layer of water molecules sticks on surface with considerable force decrease with increase in the distance of the water molecule from the surface. The electrically attracted water surrounds the clay particle is known as the diffused double-layer of water. The water located within the zone of influence is known as the adsorbed layer as shown in figure 14.

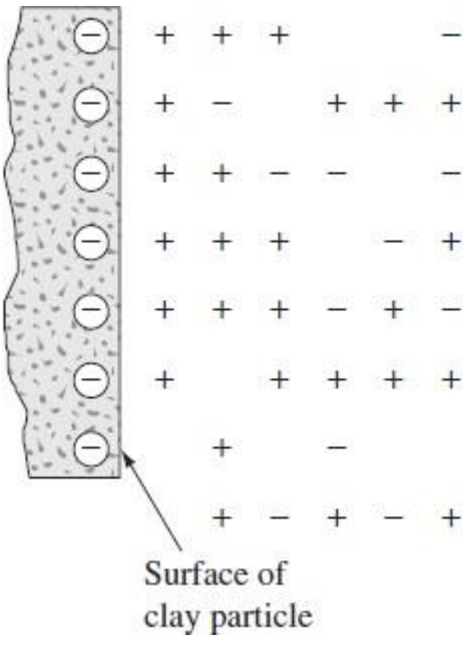


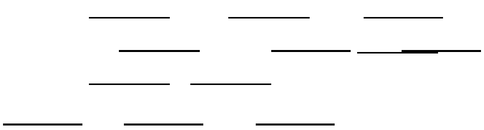
Fig. 14: mechanisms of water adsorption by clay surfaces (hydrogen bonding)

5.3.1 Diffuse double layer

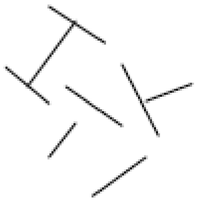
Adsorbed water layer surrounding a soil particle

6- Clay structures

Dispersed structure



Flocculated structure



Lower strength

Permeability is higher permeability is less

Low compressibility higher compressibility

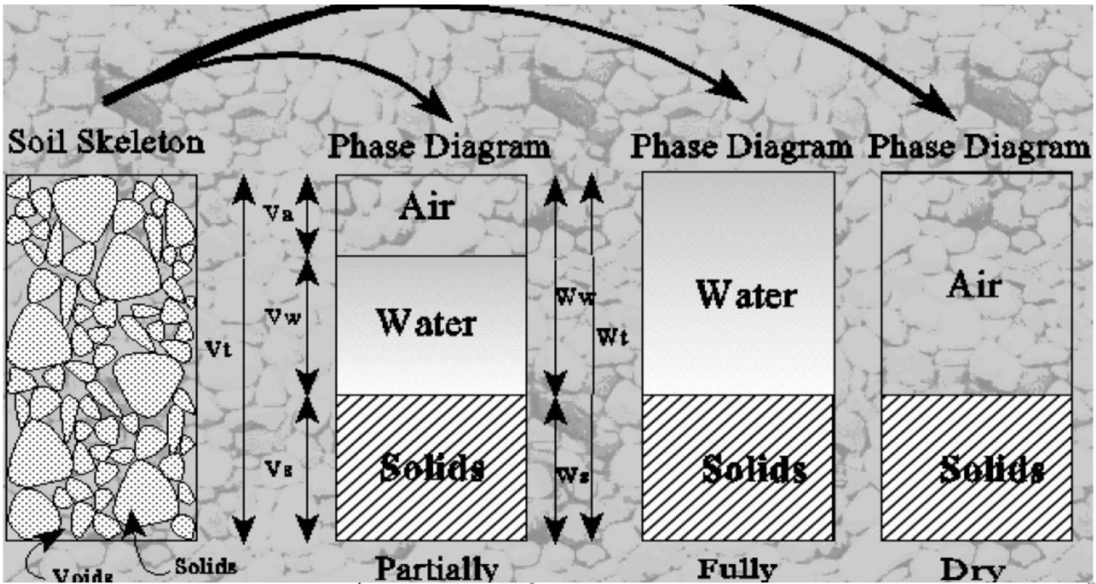
More strength Lower strength

Permeability is higher permeability is less

Low compressibility

7. <u>Soil Volume & Density Relationships</u>

A soil mass is a porous material containing solid particles interspersed with pores or voids. These voids may be filled with air, water, or both as shown in Figure 15. Figure 16 shows a conceptual diagram of relative volumes of air, water, and soil solids in a given volume of soil.



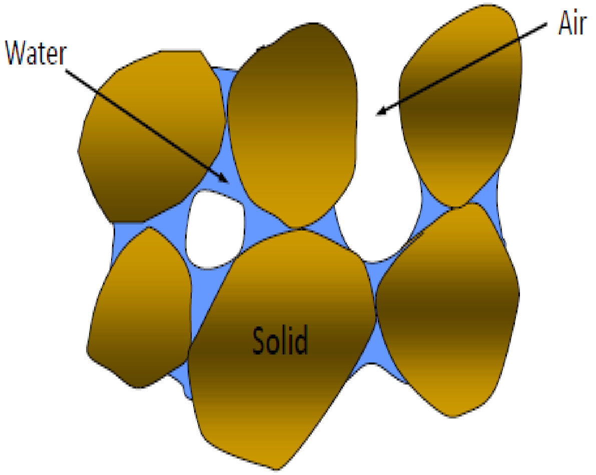
Dry Unit Weight (Dry Density)- γ_d W_s/V_t

Figure 15: Soil Skeleton

γ_t $(W_s + W_w)/V_t$

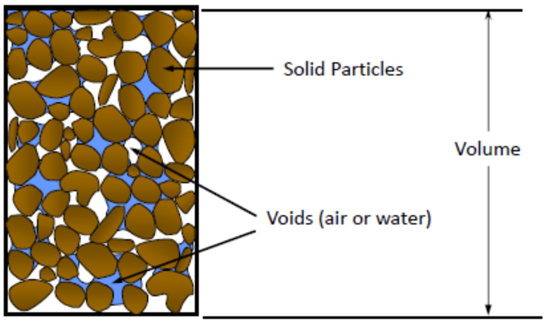
γ_s $(W_s + V_v\gamma_w)V_t$

γ' $\gamma_s - \gamma_w$

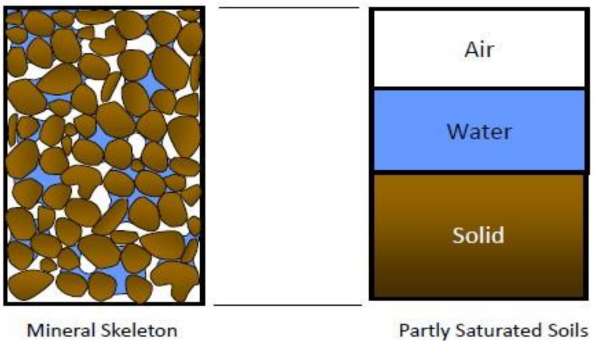


A three – phase material

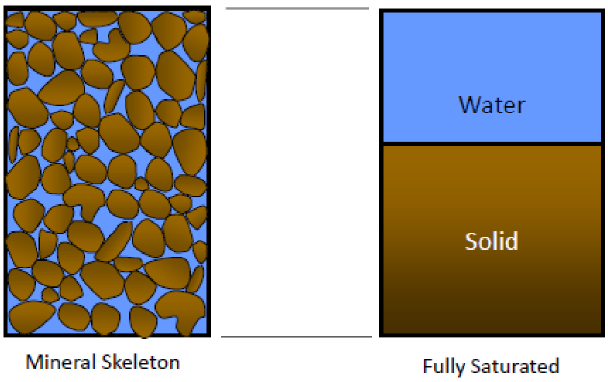
The Mineral Skeleton



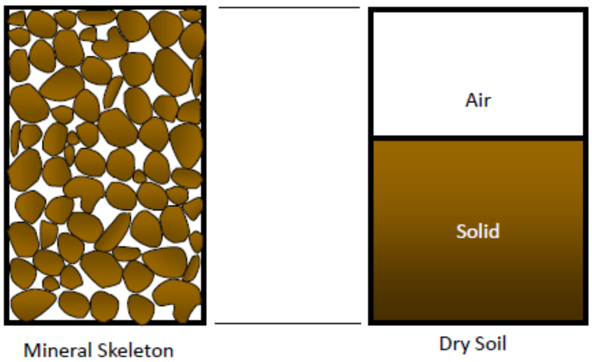
Partly Saturated Soils



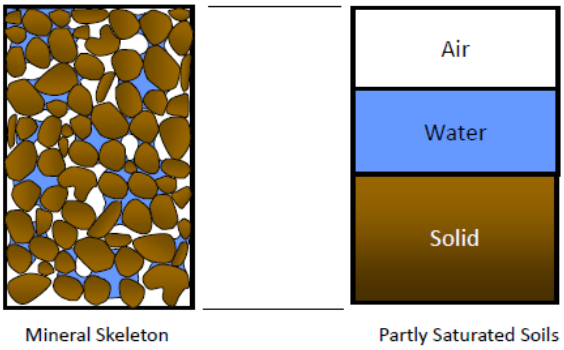
Full Saturated Soils



Dry Soils



Partly Saturated Soils



Density : is the weight of a unit volume of soil. It is more correctly termed the unit weight. Density may be expressed either as a **wet density** (including both soil and water) or as a **dry density** (soil only).

Moisture Content: is the ratio of the weight of water to the weight of soil

Porosity: is the ratio of the volume of voids to the total volume of the soil mass regardless of the amount of air or water contained in the voids.

Void ratio: is the ratio of the volume of voids to the volume of soil particles.

Permeability or hydraulic conductivity :is the property of soil allowing it to transmit water. Its value depends largely on the size and number of the void spaces, which in turn depends on the size, shape, and state of packing of the soil grains.

Basic Relationships

Weight Wt = Ww + Ws

Where:

Wt: total weight of soil

Ws: Weight of solid

Ww:Weight of water

Wa:Weight of air ≈0

Volume Vt = Vv + Vs = Va + Vw+ Vs

Vt: Total Volume

Vv: Volume of Void

Va: Volume of Air

Vw: Volume of water

Vs: Volume of Soild

1- **Unit Weight – Density**

$$\gamma_{soil} = \frac{\text{Total weight}}{\text{Total volume}} = \frac{w_t}{V_t}$$

2- **Water content %**

$$\omega_c\ \% = \frac{w_w}{w_s} * 100 \quad or \quad \omega_c = \frac{m_w}{m_s} * 100$$

3- **Void ratio , e**

$$e = \frac{V_V}{V_S}$$

4- **Porosity (n%)**

$$n\% = \frac{v_v}{v_t} * 100$$

5- **Air content A%**

$$A\% = \frac{v_a}{v_t} * 100$$

6- **Bulk Density (total density), ρ_t**

$$\rho_t = \frac{m_t}{v_t}$$

7- Dry density ,

$$\rho_{dry} = \frac{m_s}{v_t} \qquad (gm/cm^3) \quad or \ (\frac{kg}{m^3})$$

8- **Dry unit weight (γ_{dry})**

$$\gamma_{dry} = \frac{w_s}{v_t} \qquad (kN/m^3)$$

9- **Specific gravity , G_s**

$$G_s = \frac{\rho_s}{\rho_w} = \frac{m_s/v_s}{\rho_w} = \frac{m_s}{v_s * \rho_w}$$

$$G_s = \frac{\gamma_s}{\gamma_w} = \frac{w_s/v_s}{\gamma_w} = \frac{w_s}{v_s * \gamma_w}$$ (its value range between 2.6- 2.85)

10- Solid Density, ρ_s

$$\rho_s = \frac{m_s}{v_s} \quad , \quad \gamma_s = \frac{w_s}{v_s}$$

Some Useful Correlation:

1- $S.e = G_s . \omega_c$

2- $n = \frac{e}{1+e}$

3- $e = \frac{n}{1-n}$

4- $A = n(1-s)$

5- $A = \frac{e - \omega * G_s}{1+e}$

6- $\rho_t = \frac{G_s(1+\omega)}{1+e}\rho_w$ or $\gamma_t = \frac{G_s(1+\omega)}{1+e}\gamma_w$

7- $\rho_t = \frac{G_s + s * e}{1+e}\rho_w$ or $\gamma_t = \frac{G_s + s * e}{1+e}\gamma_w$

8- $\rho_s = \frac{G_s + e}{1+e}\rho_w$ or $\gamma_s = \frac{G_s + e}{1+e}\gamma_w$

9- $\rho_{dry} = \frac{G_s}{1+e}\rho_w$ or $\gamma_d = \frac{G_s}{1+e}\gamma_w$

10- $\rho_{eff.} = \acute{\rho} = \rho_{sat} - \rho_w$

11- $\gamma_{eff} = \acute{\gamma} = \frac{G_s - 1}{1+e}\gamma_w$

Some typical values of void ratio, moisture content in a saturated condition, and dry unit weight for soils in a natural state are given in the following table:

Table 1- Void ratio, Moisture Content, and Dry Unit Weight for some Typical Soi

Type of Soil	Void ratio	Natural moisture content in a saturated state (%)	Dry unit weight ,γ_d (kN/m^3)
Loose uniform sand	0.8	30	14.5
Dense uniform sand	0.45	16	18
Loose angular-grained silty sand	0.65	25	16
Dense angular-grained silty sand	0.4	15	19
Stiff clay	0.6	21	17
Soft clay	0.9-1.4	30-50	11.5-14.5

Note: the weight of one kilogram mass is 9.806 Newton

1 kg = 9.806 N