Chapter 1. Introduction to soil mechanics

1.1 Purpose of Soil Mechanics

Structures use the soil as an element of the infrastructure that transfers the overall load of the structure to a layer of soil that is sufficiently stable and resistant. As a result, the success of the structure depends on the success of the foundation design. Depending on the type of structure and its design method, the soil can serve as a support base for the entire structure, such as a road, tunnel, gravity dam, retaining wall, airport, or just as a point of support for a few elements, such as a building, bridge, or arch dam, etc. Soil mechanics is the science that encompasses all the knowledge and techniques that allow:

- To identify the characteristics that govern the mechanical behavior of the soil.
- The analysis of the soil-structure interaction.
- The proper construction of underground structures.

By way of indication, soil mechanics deals with issues related to various foundations, retaining structures, embankments and earth structures, slope and embankment stability, roads, runways, tunnels, mines, etc.

1.1.1 Disciplines of Soil Mechanics :

To achieve the objectives mentioned above, several disciplines will be required:

a- Site Geology: The study of site geology is of great importance. Indeed, it allows for the identification of different soil layers, their thicknesses, their dips, as well as the potential presence of groundwater. On the other hand, the geological study of the existing layers provides qualitative descriptions of the soil, answers some questions related to the deposition history, and helps guide preliminary investigations.

b- Physico-Chemical Characteristics: The study of the physical and chemical characteristics of soils has proven to be highly useful for predicting or interpreting soil behavior. The majority of these properties are determined through laboratory or field tests.

c- Hydraulic Study: The presence of water in the various layers plays a predominant role in soil behavior. Determining the stabilization level and studying the flow regime allows for the selection of pumping and dewatering equipment, as well as addressing phenomena such as quicksand. Determining the chemical nature of groundwater helps predict the waterproofing methods for buried structures.

d- Mechanical Characteristics: The analysis of the mechanical behavior of soils relies on the conclusions drawn from the previous disciplines, as well as on laboratory or field tests. This discipline enables the determination of soil strength and bearing capacity, and consequently, the selection of the foundation type and the dimensions of buried elements. Finally, it allows for the quantitative prediction of soil deformation or settlement under the load of the structure.

e- Theoretical Research and Numerical Modeling: To understand complex physical phenomena, several theories have been developed. These theories describe problems using rigorous mathematical models, the resolution of which relies on increasingly advanced computational and numerical techniques, occupying a significant portion of current research in this field.

f- Design and Implementation: These are the techniques acquired for the design and construction of buried structures. They take into account the cost analysis of various possible solutions.

In addition to expertise, the current regulations must be followed step by step to ensure safety conditions, both during construction and throughout the operation of the structure.

1.1.2 History of Soil Mechanics :

The evolution of soil mechanics can be traced through its emergence as a distinct science and the development of its major theories (see the table below).

Tab.1.1: Soil Mechanics Through Its Major Theories.

Century	Author	Theory
18th	Coulomb	Shear strength
19th	Collin	Failure in Clay Slopes
	Darcy	Flow of water through sand
	Rankine	Earth pressure on retaining walls
	Gregory	Horizontal drainage, compacted embankment with buttress to stabilize the slope of railway trenches
20th	Atterberg	Consistency limits of clay.
	Terzaghi	Principle of Effective Stress
	Casagrande	Soil Classification and Shear Strength

1.1.3 Can We Build with This Soil ?

It is not reasonable to answer this question immediately. It is preferable to adopt an approach guided by successive questions:

- What are we going to build ? A dam, a dike? A road, a track? A boundary wall?
- A single-story house or a multi-story building ?
- Where are we going to build? In a dry or rainy region ?
- How are we going to build? What techniques or expertise are available ?

Because soils have multiple uses:

- **They can be used as construction materials**

Example: Adobe, fired or stabilized earth bricks, earth dams and dikes, earthen pavements...

It is therefore necessary to choose, considering the borrow areas and the nature of the structure, the type of soil that is suitable, select the construction method, and possibly plan for construction quality control.

- **They can serve as a foundation support for buildings, civil engineering structures, and embankments**

Here, the focus is on selecting a type of foundation in the broad sense, taking into account the loads to be supported, the mechanical properties of the supporting soil, the groundwater level, etc.

In particular, it is essential to predict the magnitude of settlements and ensure that they are compatible with the proper functioning of the structure.

This highlights the importance of geotechnics, which focuses on the study of the mechanical behavior of soils, independent of practical usage conditions. Soil investigation will enable the engineer or technician to determine whether a soil can be used for a specific structure.

1.2 Definitions of Soils

In geotechnical studies, materials existing on the Earth's surface are classified into two main categories:

- **Rocks**: Aggregates of mineral grains bound by strong and permanent cohesive forces, even after prolonged immersion in water ⇒ Rock Mechanics.
- **Soils**: A soil is a heterogeneous assembly of particles or crystals with highly variable properties: size, shape, physicochemical properties, etc., which can be separated under the effect of relatively weak mechanical actions ⇒ Soil Mechanics.
- **Transitional materials between soils and rocks** are called ISSR (Indurated Soils and Soft Rocks).
  - ✓ Soils are loose, porous, heterogeneous, and often anisotropic materials.
  - ✓ The materials, whether mineral or organic, are generally in the form of grains or particles with highly variable shapes and sizes.

1.2.1 Constituent Elements of a Soil

A soil is a mixture of solid elements forming the solid skeleton, water that may or may not circulate between the particles, and air or gas. It is therefore generally composed of three phases:

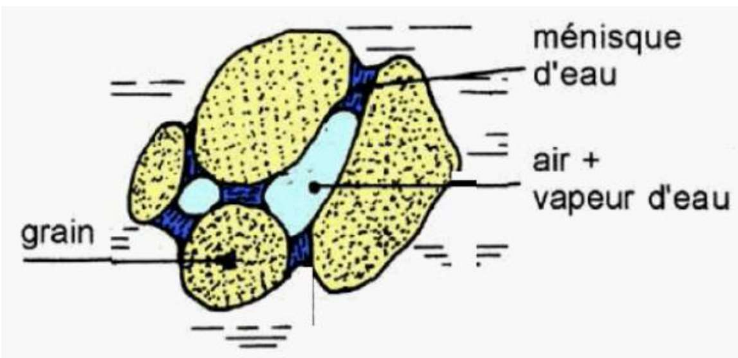

Fig. 1.1: Constituents of a Soil

Soil = solid phase + liquid phase + gaseous phase

Between the grains of the skeleton, the voids can be filled with water, gas, or both.
The gas contained in the voids between the particles is generally air when the soil is dry or a mixture of air and water vapor when the soil is moist (the most common case).
Water can partially or completely fill the voids between the grains and may be mobile (flowing more or less rapidly). When water fills all the voids, the soil is said to be saturated. In temperate regions, most in-situ soils at a few meters depth are saturated.
When there is no water, the soil is said to be dry.
The comprehensive study of unsaturated soils, which constitute a three-phase medium, is highly complex.

1.3 Origin and Formation of Soils

Soils have two main origins:

1.3.1 Disintegration of Rocks:

Through mechanical and physicochemical weathering under the influence of natural agents:

- **Cracking due to decompression, thermal shocks, or freezing**,
- **Mechanical attack (impacts and friction)** during natural transport processes such as gravitational, glacial, fluvial, marine, or aeolian movement,
- **Chemical attack** caused by the circulation of aggressive waters (acidic or alkaline).

1.3.2 Decomposition of Living Organisms:

From plants (peat) or animals (chalk).
Additionally, soils can be classified into:

- **Residual soils**, resulting from the in-situ weathering of rocks,
- **Transported soils**, formed from the deposition of weathered materials previously moved by a physical transport agent.

It is the transported soils that pose the most challenging problems for engineers designing structures.
Finally, depending on their formation and deposition conditions, soils may contain organic matter in varying proportions.

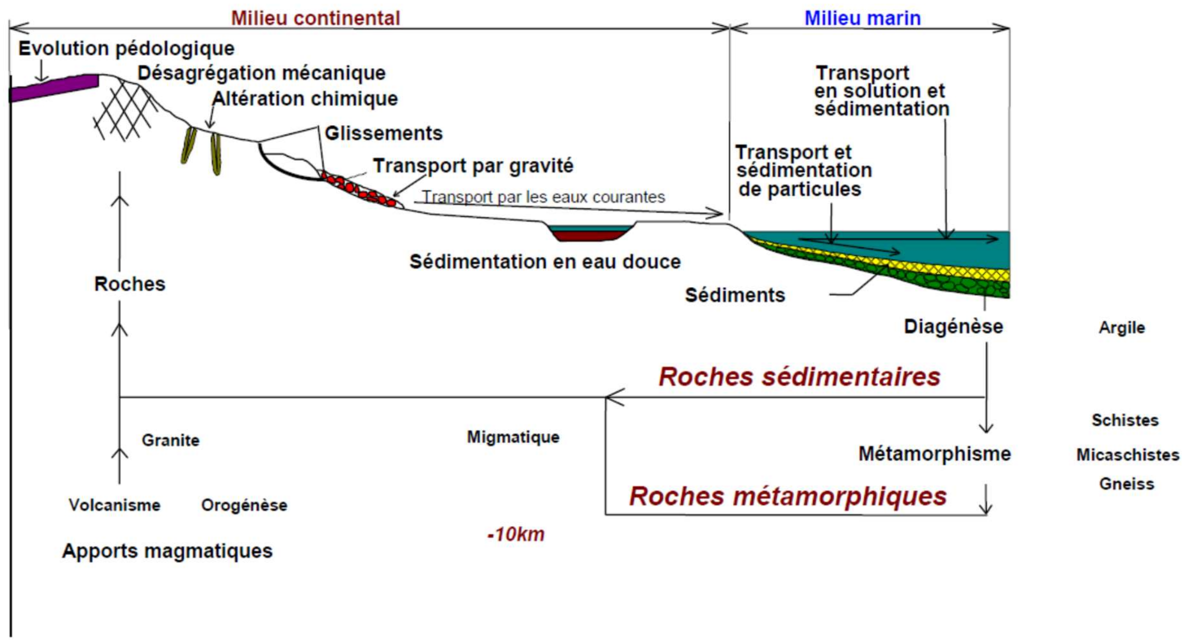

Fig 1.2 Origin of soils.

It is important to note that mechanical or physical processes of rock evolution cannot reduce the size of grains below 10 to 20 µm, as the mechanical effects caused by impacts or friction, related to the mass of the grains, diminish rapidly with their volume. Below this threshold, other processes, such as chemical weathering, become more significant in further reducing particle size.

Below this size, the fragmentation of grains continues primarily through chemical weathering, which leads to the destruction of some of the mineral's chemical bonds. This process is accompanied by a rapid increase in the surface area of the grains exposed to chemical attack.

1.4 Structure of Soils (Granular Soils and Fine Soils)

Soil is a material composed of particles. The sizes of these particles can be uniform or varied, ranging from pebbles of 10 cm down to fine particles of less than a micron.

1.4.1 Main Physical Characteristics of Soil Particles

The main physical characteristics of soil particles are:

- **Size**
- **Shape**
- **Specific surface area**

These characteristics influence the hydraulic and mechanical properties of the soil.

a- Size of Particles

The size of particles is measured by an equivalent diameter. The equivalent diameter of a particle is equal to the minimum square opening of the sieve through which the particle can pass. The equivalent diameter is determined using square-mesh sieves employed in sieve analysis for particle size distribution.

b- Shape of Particles

Although there is an infinite variety of shapes, two main types are commonly recognized:

- **Bulky shape (The voluminous form)**
- **Flaky shape (The lamellar form)**

  ✓ **Bulky Shape**: The bulky shape typically characterizes gravel, sand, and silt particles. The equivalent diameter of bulky particles is generally greater than 0.001 mm. Most bulky particles are roughly spherical and have edges that are more or less rounded or angular. (Fig. 1.3)

Rounded **Sub-rounded** **Angular** **Sub-angular**

Fig. 1.3: Some Typical Shapes of Coarse Grains

Flaky Shape: When the ratio of its length to its thickness is greater than 10, a particle is considered to have a flaky shape. This shape is particularly characteristic of clay particles.

c- Specific Surface Area

By definition, the specific surface area (Sp), also called "massic area," represents the total surface area (As) per unit mass (M) and is generally expressed in m^2/kg. Sp = $\frac{Surface}{mass}$ ($\frac{m^2}{Kg}$).

It can also be expressed as surface area per unit volume, i.e., in (**m^2/m^3** = m^{-1}) : Sp = $\frac{Surface}{Volume}$ ($\frac{mm^2}{mm^3} = \frac{1}{mm^{-1}}$).

Table 1.2 presents the average value of the specific surface area of particles for different types of soils.

Type of soils	**Equivalent diameter (mm)**	**Typical thickness (µm)***	**Average Specific Surface Area (m^2/kg)**
Sand	1 to 2		1.5
Sand	0.25 to 0.5		6
Silt	0.002 to 0.05		82.5
Clay : -Kaolinite -Illite -montmorillonite	 0.0003 to 0.002 0.0001 to 0.002 0.0001 to 0.001	 50 to 100 30 3	 15000 90000 800000
***1ηm = 10-6 mm**			

1.4.2 Soil Types

Soils are usually classified based on the size of their particles.

In soil mechanics, the simples classification divides soils into two main categories:

- Coarse-grained soils
- Fine-grained soils

a- Coarse-Grained Soils

stones and blocks, or rockfill, have an equivalent diameter greater than 80 mm. They are characterized by very high permeability.

Gravel and sand consist of rock particles with an equivalent diameter ranging from 0.08 mm to 80 mm. In general, they exhibit good permeability.

b- Fine-Grained Soils

Silt is composed of fine rock particles with an equivalent diameter ranging from 0.002 mm to 0.08 mm, whose shape can be observed under a magnifying glass or an optical microscope.

Clay consists of crystalline particles resulting from the chemical decomposition of rock constituents. Most of these are aluminum, magnesium, or iron silicates, with atoms arranged in highly regular geometric structures. Their equivalent diameter varies approximately from 1 nm to 0.002 mm, requiring more advanced techniques (such as SEM) to observe these particles.

Each clay mineral is formed by the stacking of microscopic crystals (sheets). These sheets themselves consist of crystalline units known as fundamental structures.

These structures lie in a single plane, which is why the sheets have a very large surface area compared to their thickness. The thickness of the sheets and fundamental structures is estimated to be around 0.5 nm (5×10^{-7} mm).

There are two fundamental structures:

- The tetrahedral fundamental structure
- The octahedral fundamental structure

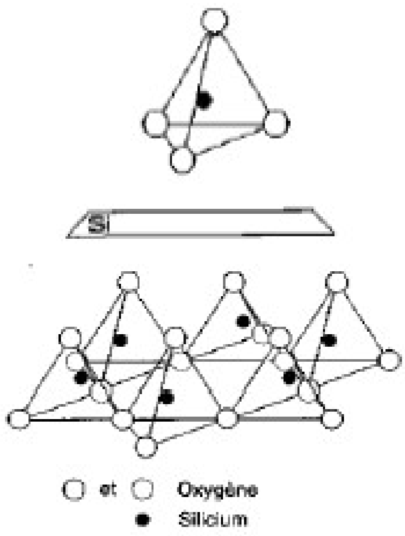

Fig 1. 4 Diagram of a Tetrahedral Sheet

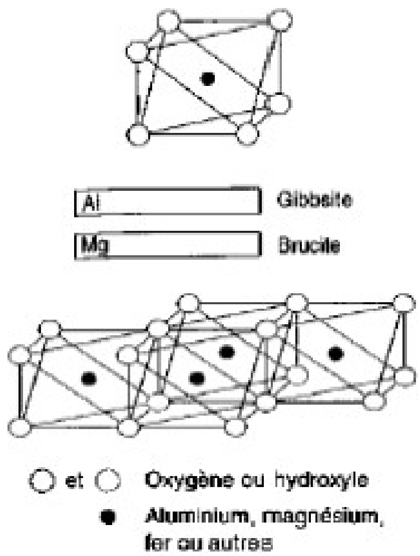

Fig.1.5 Diagram of an Octahedral Sheet:

There are three main families of clay minerals:

- **Kaolinite:** This type of clay is the least hazardous for engineers.
- **Montmorillonite:** Prone to significant swelling or shrinkage depending on water content variations.
- **Illite:**

Elementary layer of a kaolinite particle

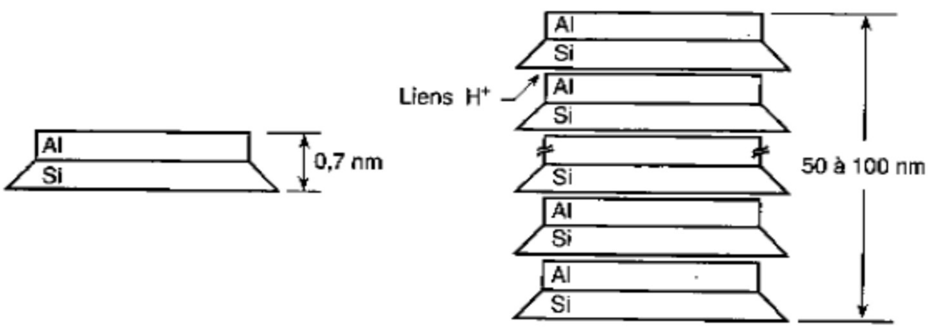

Fig. 1.6: Schematic Representation of Kaolinite.

Elementary layer of a montmorillonite particle

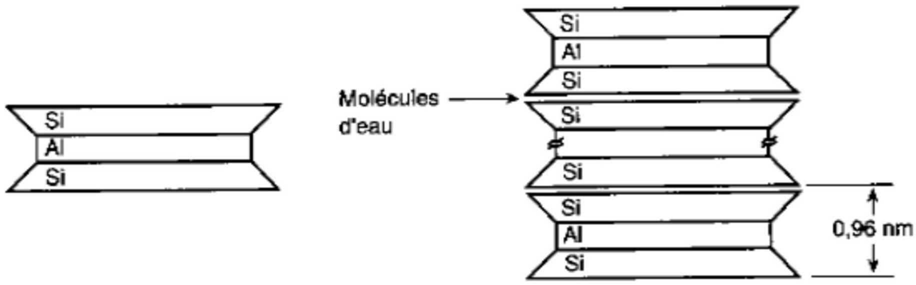

Fig. 1.7: Schematic Representation of montmorillonite

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Elementary layer of a l'illite particle

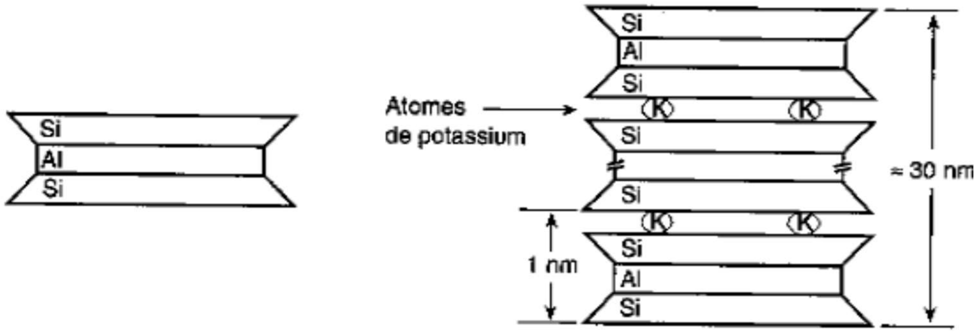
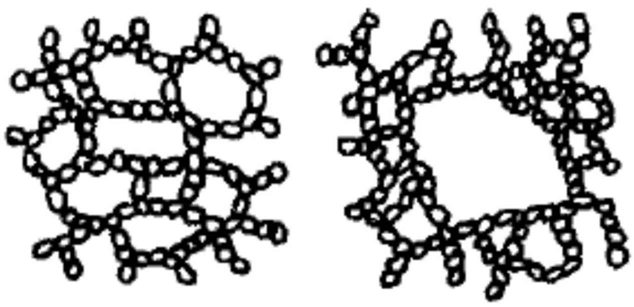


Fig. 1.8: Schematic Representation of l'illite

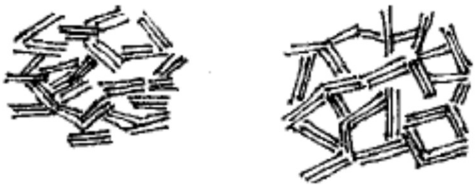
In clays, honeycomb and flocculent structures can be found, which are less resistant (Fig. 1.9).



Honeycomb Structure Flocculent Structure

Fig. 1.9: Arrangement of Fine-Grained Soils

Soils of this type present significant challenges, such as swelling and settlement. The plate-like clay particles can arrange themselves in various ways (Fig. 1.10).

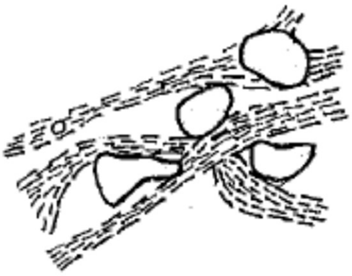


Arrangement of Clay Platelets **Arrangement of Clay Platelet Aggregates**

Interlacking of Clay Clusters

Fig. 1.10: Different Arrangements of Clay Platelets.

When the soil contains grains of varying sizes (coarse or fine), the arrangements diversify between aggregates, clusters, and matrices (Fig. 1.6).



-Matrix of Clay Particles **-Interlacing of Clay Clusters with Silt Inclusions** **-Silt -Sand Grains**

Silt Platelets and Sand Grains -Matrix of Granular Particles -Partially Discernible Matrix Between Particles

Fig. 1.11: Arrangement of Solid Particles of Different Sizes.

c- Organic Soils:

They contain a high percentage of organic matter.

- **MO < 3%:** Inorganic soil
- **3% < MO < 10%:** Slightly organic soil
- **10% < MO < 30%:** Moderately organic soil