Chapter-4
Soil Structure and Clay Minerals

Abhash Acharya
M.Sc. In Transportation Engineering
acharyaabhash@gmail.com
abhashacharya.com.np

Soil Structure and Clay Minerals

- Introduction
- Clay Minerals
- Clay Particle Interaction
- Soil Structure and Fabrics

Introduction

- Clay refers to material composed of a mass of small mineral particles which, in association with certain quantities of water, exhibits the property of plasticity.
- According to the clay mineral concept, clay materials are essentially composed of extremely small crystalline particles of one or more members of a small group of minerals that are commonly known as clay minerals.
- Soil structure is usually defined as the arrangement and state of aggregation of soil particles in a soil mass. It influences many soil properties, such as permeability, compressibility and shear strength, etc.

Clay Minerals

- Clay minerals are essentially crystalline in nature though some clay minerals do contain material which is non-crystalline (allophane).
- Two fundamental building blocks are involved in the formation of clay mineral structures as:
  - Tetrahedra unit
  - Octahedral unit
- The combination of two sheets of silica and gibbsite in different arrangements and conditions lead to the formation of different clay minerals.
- In the formation of the sheet silicate minerals, the phenomenon of isomorphous substitution frequently occurs.

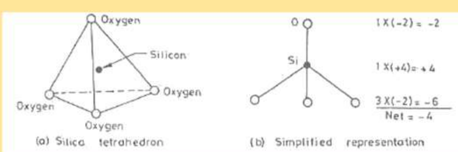
Clay Minerals

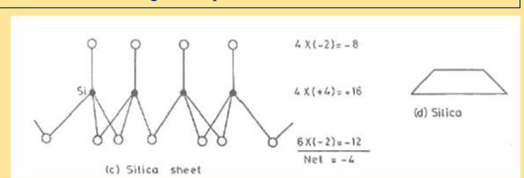
- Isomorphous substitution consists of the substitution of one kind of atom for another, generally by more electropositive ion such as silicon by aluminum.
- Replacement is done by the atom of similar physical size and different atomic number.
- Replacement within the crystal lattice.
- Increases the negative charge on the particle.
- Could bring the distortion on the crystal lattice.

	Name of mineral	Structural formula
I.	Kaolin group	
	1. Kaolinite	$Al_4Si_4O_{10}(OH)_8$
	2. Halloysite	$Al_4Si_4O_6(OH)_{16}$
II.	Montmorillonite group	
	Montmorillonite	$Al_4Si_8O_{20}(OH)_4nH_2O$
III.	Illite group	
	Illite	$K_y(Al_4Fe_2.Mg_4.Mg_6)Si_{8-y}$ $Al_y(OH)_4O_{20}$

Clay Minerals

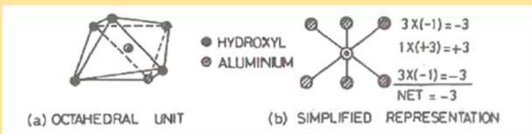
- **Tetrahedral unit** consists of four oxygen atoms at the apices of a tetrahedron enclosing a silicon atom which combines together to form a shell-like structure with all the tips pointing in the same direction. The oxygen at the bases of all the units lie in a common plane.
- Each of the oxygen ions at the base is common to two units.
- The oxygen atoms are negatively charged with two negative charges each and the silicon with four positive charges.
- Each of the three oxygen ions at the base shares its charges with the adjacent tetrahedral unit. The sharing of charges leaves three negative charges at the base per tetrahedra unit and this along with two negative charges at the apex makes a total of 5 negative charges to balance the 4 positive charges of the silicon ion.
- The process of sharing the oxygen ions at the base with neighbouring units leaves a net charge of -1 per unit.

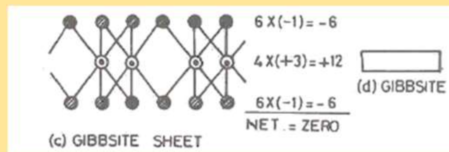




Clay Minerals

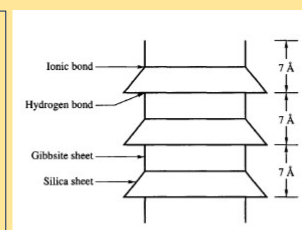
- **Octahedral unit** consists of six hydroxy ions at apices of an octahedral enclosing an aluminum ion at the center.
- Iron or magnesium ions may replace aluminum ions in some units.
- These octahedral units are bound together in a sheet structure with each hydroxyl ion common to three octahedral units. This sheet is sometimes called as gibbsite sheet. The sheet is electrically neutrall.
- Sometimes, magnesium replaces the aluminum atoms in the octahedral units in this case, the octahedral sheet is called a brucite sheet.





Types of Clay Minerals

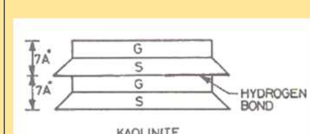
- **Kaolinite**
  - Most common mineral of the kaolin group.
  - Made up of gibbsite sheets(with aluminum atoms at their centers) joined to silica sheets.
  - The structural unit is symbolized by which is about $7A^o$ thick.
  - Successive $7\ A^o$ layers are held together with hydrogen bonds.
  - As the bond is fairly strong, it is extremely difficutl to separate the layers and as a result kaolinite is relatively stable and water is unable to penetrate between the layers, Kaolinite consequently shows relatively little swell on wetting.
  - Platelets carry negative electromagnetic charges on their flat surface which attract thick layers of adsorbed water thereby producing plasticity when mixed with water.
  - In kaolinite mineral, there is small amount of isomorphous substitution.
  - Used in pottery. Eg. China Clay



Structure of kaolinite layer

Lateral dimension: 100 to 1000 A^o.

Specific surface: $15m^2/gm$

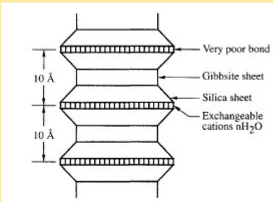


Types of Clay Minerals

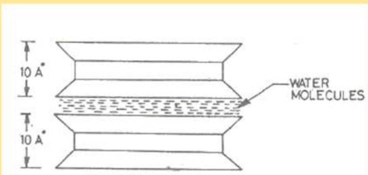
- **Halloysite**
  - Made up of successive layers with the same structural composition as those composing kaolinite. However, the successive units are randomly packed and may be separated by a single molecular layer of water.
  - The dehydration of the interlayers by the removal of the water molecules leads to change in the properties of the mineral.
  - An important structural feature of halloysite is that the particles appear to take tubular forms as opposed to the platy shape of kaolinite.

Types of Clay Minerals

- **Montmorillonite**
  - Most common mineral of the montmorillonite group.
  - The basic structure of each unit is made up of gibbsite sheet (octahedral sheet) sandwiched between two silica sheets.
  - The thickness of each unit is about 10A°.
  - Successive 10A° units are held by weak bonding.
  - Water may enter between the sheets causing the minerals to swell and thus structure can break into 10A° thick structural units.
  - Isomorphous substitution of magnesium and iron for aluminum.
  - Soils containing a considerable amount of montmorillonite will exhibit high swelling and shrinkage characteristics.
  - Lateral dimension: 1000 to 5000 A° with thickness varying from 10 to 50 A°.
  - Specific surface: $800 m^2/gm$



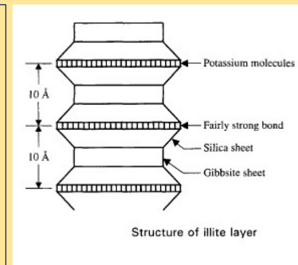
Structure of montmorillonite layer



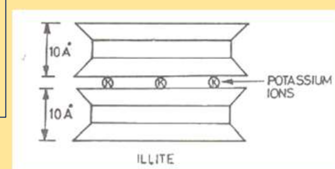
MONTMORILLONITE

Types of Clay Minerals

- **Illite**
  - The basic structural unit of illite is similalr to that of montmorillonite except that some of the silicons are always replaced by aluminum atoms and the resultant charge deficiency is balanced by potassium ions.
  - The potassium ions occur between unit layers.
  - The bond with the non-exchangeable K^+ ions are weaker than the hydrogen bonds, but stronger than the water bond of montmorillonite. Illite, therefore does not swell as much in the presence of water as does montmorillonite.
  - Lateral dimension: 1000 to 5000 A° with thickness varying from 50 to 500 A°.
  - Specific surface: 80m²/gm



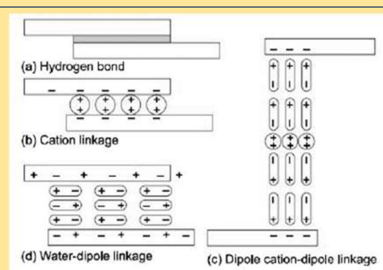
Structure of illite layer



ILLITE

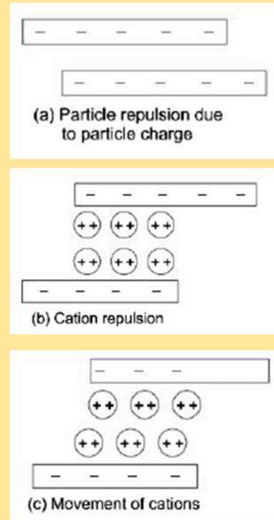
Clay Particle Interaction – Interparticle forces in a soil mass

- Two types of forces exist between soil particles, namely gravitational forces and surface forces.
- Gravitational forces are proportional to mass and are important for coarse-grained soils.
- Surface forces dominates over gravitational forces in the case of clay particles which behaves as colloids..
- When the particles are very close, the surface forces can be attractive or repulsive.
- Vander Wall forces, hydrogen bond, cation linkage, dipole-cation-dipole linkage, water dipole linkage and ionic bond are the possible mechanisms for attractive forces between particle surface.



Clay Particle Interaction – Interparticle forces in a soil mass

- The repulsive forces are particle charge and cation-cation repulsion.
- The repulsive forces between two adjacent particles become effective when they approach each other and their double layers just overlap ad interact.
- When two particles with exchangeable cations are brought close to each other, the cations tend to repel leach other, since they carry like charges. However, this mechanism does not constitute a strong repulsive force between particles, since the mobile cations will move along the particle surface of positions not opposite other cation. The cation charge may also be entirely balanced by the particle charge, so that there is no cation-cation repulsion.
- For a given type of clay in suspension, the net forces between the adjacent particles at a given separation is the algebraic sum of the repulsive and attractive forces acting at that distance..



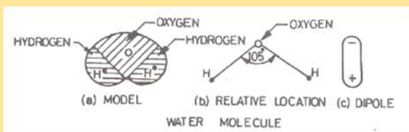
Clay Particle Interaction – Diffuse Double Layer

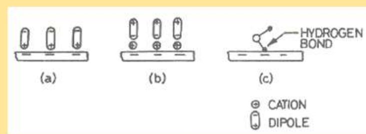
- The behavior of a soil mass depends upon the behavior of the discrete particles composing the mass and the pattern of particle arrangement.
- In all these cases water plays an important part.
- The behavior of the soil mass is profoundly influenced by the inter-particle-water relationships, the ability of the soil particles to adsorb exchangeable cations and the amount of water present.
- Clay particle carry net negative charge.
- Negative charge is due to:
  - Isomorphous substitution
  - Breaking of particles
  - Attraction of anions or removal of cations

Base exchange capacity:
The cations attracted to the negatively charged surface of the soil particles are not strongly attached. These cations can e replaced by other ions and are known as exchangeable ions. The soil particles and the exchangeable ions make the system neutral.
The phenomenon of replacement of cations is called cation exchange or base exchange.

Clay Particle Interaction – Diffuse Double Layer

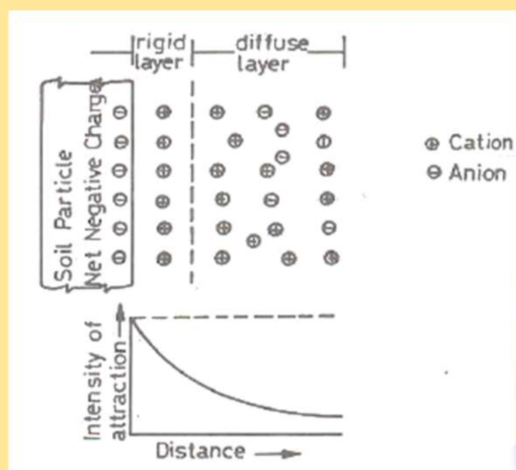
- Soil contains water in different proportion.
- Since the centers of positive and negative charges of water molecules do not coincide, the molecules behave like dipoles.
- The molecule acts as a bar magnet.
- As the faces of clay particles carry a negative charge, there is attraction between the negatively charged faces and the positive ends of dipoles. (a)
- The second mode of attraction between the water dipoles and the clay surface is through cations. Cations are attracted to the soil surface and water dipoles are attached to these cations through their negative charged ends. (b)
- The third possible mode by which the attraction between the water and the clay surface occurs is by sharing of the hydrogen atom in the water molecule by hydrogen bonding between the oxygen atoms in the clay particles and oxygen atoms in the water molecules. (c)





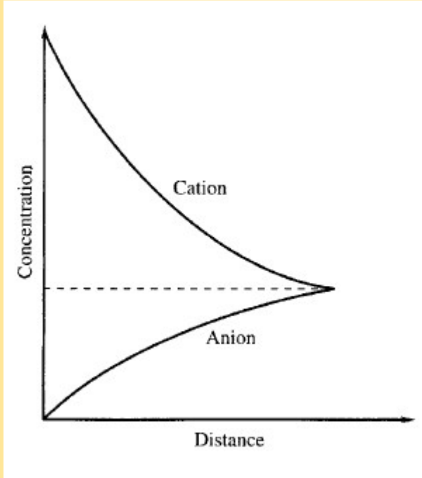
Clay Particle Interaction – Diffuse Double Layer

- The cations attracted to a clay mineral surface also try to move away from the surface because of their thermal energy.
- The net effect of the forces due to attraction and that due to repulsion is that the forces of attraction decrease exponentially with an increase in distance from the clay particles surface.
- The layer extending from the clay particle surface to the limit of attraction is known as the **diffuse double layer.**
- It is believed that immediately surrounding the particle, there is a thin, very tightly held layer of water about 10A^{o} thick. Beyond this thickness there is a second layer, in which water is more mobile. This second layer extends to the limit of attraction, and is known as diffuse double layer.



Clay Particle Interaction – Diffuse Double Layer

- The water held in the diffuse-double layer is known as adsorbed water or oriented water.
- Outside the diffuse double layer, the water is normal, non-oriented.
- The total thickness of the diffuse-double layer is about 400A°.
- The adsorbed water affects the behavior of clay particles when subjected to external stress, since it comes between the particle surface. (Cohesive soils)
- To drive off the adsorbed water, the clay particle must be heated to more than 200°C, which would indicate that the bond between the water molecules and the surface is considerably greater than that between normal water molecules.

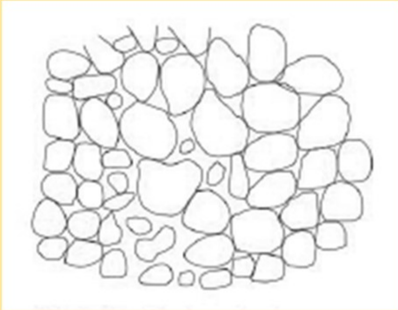


Soil Structure and Fabrics

- Soil structure is usually defined as the arrangement and state of aggregation of soil particles in a soil mass. (Arrangement and forces)
- It influences many soil properties, such as permeability, compressibility and shear strength, etc.
- Soil fabric is a term describe only the geometric arrangement of the mineral particles.
- For coarse grained soil – both are same
- For fine grained soil – different (the geometrical arrangement of the soil particles depend on the force of attraction between the particles).

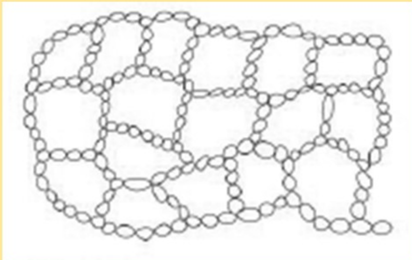
Soil Structure and Fabrics

- **Single grained structure**
  - Coarse-grained soils (diameter > 0.02mm) settle out of suspension in water as individual grains independently of other grains.
  - The major force causing their deposition is gravitational and the surface forces are too small to be of practical importance.
  - The weight of the grains causes them to settle and get particle to particle contact on deposition.
  - May be deposited in a loose state having a high void ratio or in a dense state having a low voids ratio.



Soil Structure and Fabrics

- **Honeycomb structure**
  - Such a structure exists in grains of silts.
  - When such grains settle under gravity, the surface forces also play an equally important role.
  - When particles approach the lower region of suspension, they will be attracted by the particles already deposited as well as the neighbouring particles leading to the formation of arches.
  - The combination of a number of arches leads to the honeycomb structure.
  - The structures so formed has high void ratio and is capable of carrying relatively heavy loads without excessive volume change under static conditions.
  - However, the structures might be broken down with a resulting volume decrease, by driving piles into a deposit of silt having honeycomb structure.



Soil Structure and Fabrics

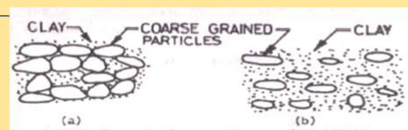
- **Flocculated Structure**
  - Occurs in clay.
  - Formed when there are edge to edge contacts between the platelets.
  - This type of structure is formed if the net electrical forces between adjacent soil particles at the time of deposition are attractive forces.
  - If there is a concentration of dissolved minerals in the water, the tendency of flocculation is increased.
  - High void ratio and light weight but due to strong bonding they are quite strong.
  - Low compressibility, high permeability and high shear strength.

Soil Structure and Fabrics

- **Dispersed structure**
  - Occurs in clays that have been reworked or remoulded.
  - Clay deposits with a flocculent structure when transported to other places by nature or man get remoulded converting the edge to edge orientation to face to face orientation.
  - Formed when the platelets have face to face contact in more or less parallel area.
  - Formed if the net electrical forces between adjacent soil particles at the time of deposition are repulsion.
  - Low shear strength, high compressibility and low permeability.
  - Remoulding causes a loss of strength in cohesive soil. However, the soil regains strength as a result of re-establishing a degree of chemical equilibrium. This phenomenon of regain of strength with the passage of time, with no change in water content, is known as thixotropy.

Soil Structure and Fabrics

- **Composite Structures**
  - Coarse grained skeleton
    - Formed when the soil contains particles of different types.
    - When the amount of bulky, cohesion-less particles is large compared with that of fine grained clayey particles, the bulky grains are in particle to particle contact. These particles form a skeleton.
    - As long as the soil is not disturbed, a coarse grained skeleton can take heavy loads without much deformation.
  - Clay matrix structure
    - Formed when the soil contains particles of different types.
    - Amount of clay particles is very large as compared with bulky coarse-grained particles.
    - The clay forms a matrix in which bulky grains appear floating without touching one another.



Composite Structure (*a*) coarse Graind Skeltion, (*b*) Clay Matrix

Thank You!

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abhashacharya.com.np