CHAPTER 04

Soil Structure and Clay Minerals

4.1 Introduction

The coarse grained soils generally contain the minerals quartz and feldspar. These minerals are strong and electrically inert. The behaviour of such soils does not depend upon the nature of mineral present; on the other hand, behaviour of fine grained soils depends on large extent on the nature and minerals present. The most significant properties of clay depends upon the type of minerals. The crystalline mineral whose surface activity is high are clay minerals. These clay minerals impart cohesion and plasticity. So the study of clay minerals is essential for understanding the behaviour of clayey solids.

4.2 Clay Minerals

The clay minerals are hydrous aluminium silicate with other metallic ions in a sheet like structure. Their particles are very small in size, very flaky in shape and thus have considerable surface area. These clay minerals are evolved mainly from the chemical weathering of certain rock minerals.

4.3 Structure of Clay Minerals

Clay minerals are composed of two basic structural units.

(i) Tetrahedral unit (ii) Octahedral unit

(i) **Tetrahedral Unit:** The tetrahedral unit comprises of a central silicon atom surrounded by four oxygen atoms positioned at the vertices of the tetrahedron.

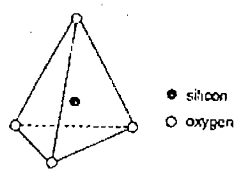

Fig. 4.1 Single tetrahedral unit

The tetrahedral units are combined with each other such that each oxygen atom at the base of tetrahedron lies in same plane and is being shared between two tetrahedron units. This combination of tetrahedral units is called silica sheet.

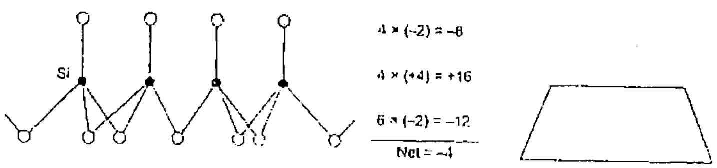

Fig. 4.2 Symbolic representation of silica sheet

In above silica sheet, each of the oxygen ion at the base is common to two adjacent units. The sharing of charges leaves three negative charges at the base per tetrahedral unit. This, alongwith the two negative charges at the apex, makes a total of five negative charges to four positive charges of silicon ion. Thus, there is a net charge of –1 per unit.

(ii) **Octahedral unit:** The octahedral unit comprises a central ion of either aluminium, magnesium or iron surrounded by six hydroxyl ions.

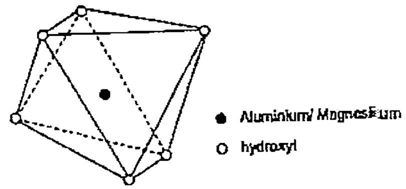

Fig. 4.3 Single octahedral unit

The octahedral sheet is a combination of octahedral units. If the atom at the centre is Aluminium, the resulting sheet is called Gibbsite sheet. If magnesium is the central atom, the sheet is called the Brucite sheet. If iron is the central atom, the sheet is called Ferrite sheet.

Each hydroxyl ion in Gibbsite sheet is being shared between 3 octahedral units. Therefore, net charge present over Gibbsite is –1.

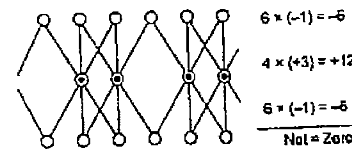

Fig. 4.4 Diffused double layer

4.4 Isomorphous Substitution

It is possible that one atom in a basic unit may be replaced by another atom. The process is known as isomorphous substitution. For example, one silicon ion in a tetrahedral unit substituted may lead to increase in negative charge on the particle which affect the physical properties of mineral.

4.5 Types of Clay Minerals

Clayey soils are made of three basic minerals

(i) Kaolinite mineral

(ii) Montmorillonite mineral

(iii) Illite mineral

(i) **Kaolinite Minerals:** Kaolinite minerals are made of an aluminium sheet (gibbsite sheet, Gi) combined with a silica sheet (Si). The structural units join together by hydrogen bond, which develops between the oxygen of Silica sheet and the hydroxyls of Alumina sheet. Since hydrogen bond is strongest bond, Kaolinite mineral is quite stable. Thus soils consisting kaolinite mineral do not show much change in volume due to moisture variation. The most common example of kaolinite mineral is china clay. The surface area of the Kaolinite particles per unit mass is about 15 m^2/g. The surface area per unit mass is defined as specific surface.

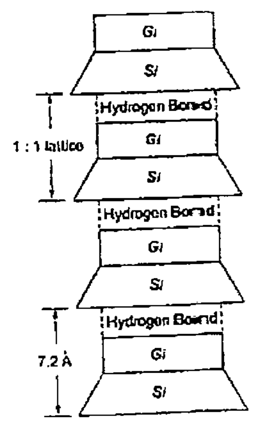

Fig. 4.5 Kaolinite Mineral

(ii) **Montmorillonite Minerals:** Montmorillonite mineral is a three layer sheet mineral. Basic three layer sheet units are formed by keeping one silica sheet (Si) on the top and bottom of gibbsite sheet (Gi).

Isomorphous substitution of magnesium or iron for the aluminium in the gibbsite sheet is common. It attracts water to form a water layer between two connecting basic units. The bonding between basic units is by water forces and exchangeable ion linkage. The bonding of these sheets is very weak, and water may enter between the units. Thus mineral has significant affinity for water, and results in expansion and swelling. Bentonite and Black cotton soils contains montmorillonite mineral in large proportion.

Specific surface of montmorillionite is about 200-800 m^2/g.

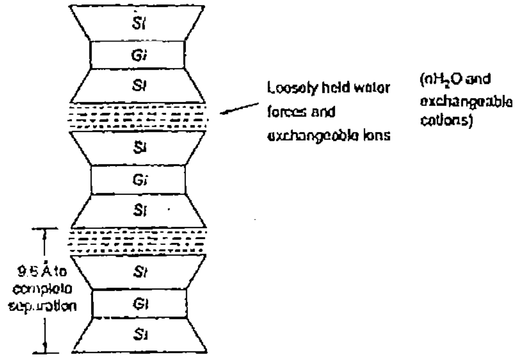

Fig. 4.6 Montmorillonite mineral

(iii) Illite Minerals

Illite is also a three-layer sheet mineral. It consists of basic three layer sheet unit similar to montmorillonite. There is also a substantial amount of isomorphous substitution of silicon by aluminium in silica sheet. Consequently, the mineral has a larger negative charge than that in montmorillonite. The basic units are bonded by non-exchangeable potassium (K^+) ions, which is stronger than the bond in montmorillonite. Thus illite swells less than montmorillonite. However swelling is more than in kaolinite.

The specific surface is 50-100 m^2/g.

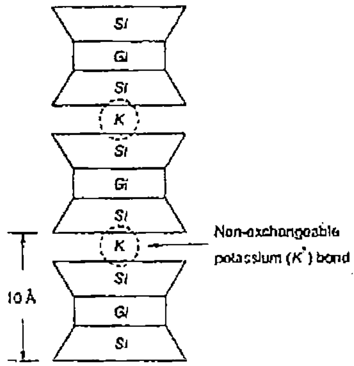

Fig. 4.7 Illite mineral

4.6 Clay Water Relationship

Clay soils are normally associated with water and their properties are greatly influenced by the presence of water. Whereas, there is no impact of structural water on granular soils except for reduction in void due to submergence. The surface of clay particles carry negative charges. The edges of a clay particle may have a positive or a negative charge. Because of net negative surface charges, the clay particles repel each other, but edge to surface attraction may occur. Generally clay particles attract cations (positive ions).

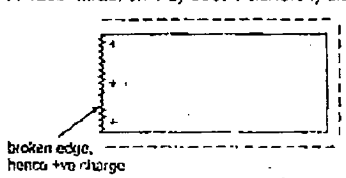

Fig. 4.8 Clay particle

Fig. 4.9 Water molecule

The water immediately surrounding a clay mineral is a dipolar molecule thus treated as a bar magnet. Further to balance the negative charge near the surface layer of clay molecule, cations from water molecule are attracted. This attraction decreases with distance from the surface. Hence there is no attraction on pore water.

The distance from the surface of the particle to the limit of attraction is termed as Diffuse double layer. The water contained between the diffuse layer and adjacent to the surface of clay is termed as Rigid layer.

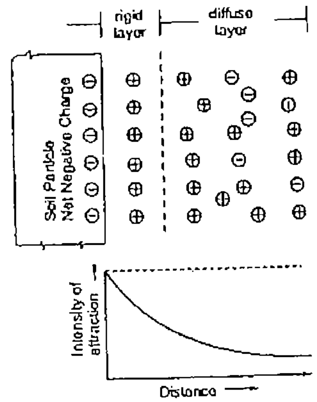

Fig. 4.10 Diffuse Double Layer

NOTE

The surface of clay particles carry a negative charge. This results from any one of the combination of the following factors:

(i) isomorphous substitution
(ii) surface dissociation of OH^-
(iii) absence of cation in the crystal lattice
(iv) adsorption of anion
(v) presence of organic matter

4.7 Clay Particle Interaction

The clay particle interact through the adsorbed water layers. Therefore, factors such as the nature of ions present, their concentration and size and other environmental conditions influence the soil structure found in natural clay deposits.

The clay particles in aqueous environment may mutually attract or repulse. If the total potential energy between the particle decreases as they approach each other, there is attraction between them in which case the particle 'Flocculate'. If the approaching particles increase the energy of the system, they move apart or 'Disperse'.

Particles generally flocculate essentially in the edge to face configuration.

Dispersion of particles will be mostly in the face to face configuration.

The tendency to flocculate increase with increases of one or more of the following:

(i) Concentration of the electrolyte
(ii) Valency of the ion
(iii) Temperature

Tendency to Flocculate increase with decreases of one or more of the following:

(i) Dielectric constant of the medium
(ii) Size of the ion
(iii) pH
(iv) Anion adsorption

The dispersed clay with basic face to face arrangement of platelets has a lower void ratio than the flocculated clay, which has an appreciably large proportion of voids.

4.8 Soil Structure

Soil structure is a more generalized term, applicable to all types of soil. This includes:

(i) Particle gradation
(ii) Compactness

(iii) Interparticle forces and bonding agents
(iv) Geometric and skeletal arrangement of particles

There are various factors that affect the structure of coarse grained soils:
(i) Particle size distribution
(ii) Gravity

There are various factors that affect the structure of clay soils:
(i) Type of clay mineral
(ii) Surface forces

4.9 Types of Soil Structures

4.9.1 Single Grained Structure

In granular soils, the ratio of volume to the surface area is large, so that mass derived (i.e. gravity) forces are dominant and surface-derived electric forces are negligible. These are found in soils having size greater than 0.02 mm. Single-grained structures are formed when the soil grains settle out independently due to gravity force. Examples - gravel and coarse sand

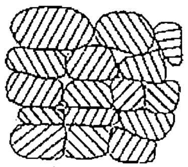

Fig. 4.11 (a) Single grained structure

4.9.2 Honeycomb Structures

This type of structures are found in soil having size between 0.02 mm to 0.002 mm. Gravity and surface electric (adhesive) forces, both are responsible for their formation. These structures enclose large volume of voids. When structure is unbroken, these soils have ability to bear large loads, but once the structure is broken, load carrying capacity is lost and show large deformation. Examples - fine sand and silts.

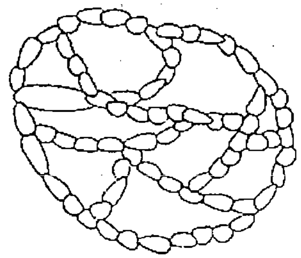

Fig. 4.11 (b) Honey comb structure

4.9.3 Flocculated and Dispersed Structures

These are found in the soils having size less than 0.002 mm. The structure of a fine-grained cohesive soil can be described fully with the understanding of inter particle forces and the geometrical arrangement of particles.

The fine particles are of flaky or plate like shaped. They have large surface area and therefore surface electric force become dominant. The clay particles have a negative charge on the surface and positive charge on edges. Particles joined edge-to-edge or edge-to-surface results in a flocculated structure. This soils structure have high volume of voids.

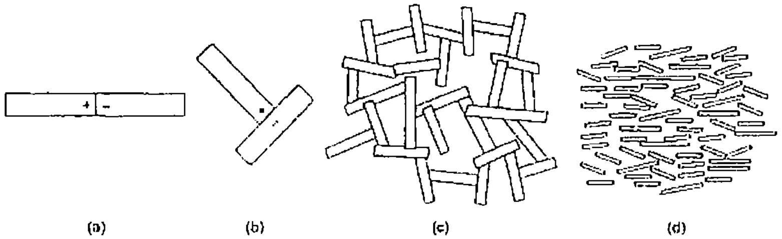

Fig. 4.12 *(a)* Edge-to-edge *(b)* Edge-to-surface *(c)* Flocculated structure *(d)* Dispersed structures

Dispersed structures develops in clays that have been remoulded. When ... remoulded by nature or man, converts its edge-to-edge or edge-to-surface orientation into surface-to-surface orientation, this results in a dispersed structure.

4.9.4 Structure of a Composite Soil

Composite soils are mixture of coarse grain and fine soils.

(a) Coarse Grained Skeleton: Coarse grained skeleton is a composite structure which is formed when soil contain both coarse grain and fine grain particles.

Coarse grain particles form a frame work or skeleton. The space between these skeleton is filled by fine grain particles called binders. These types of soils are less compressible.

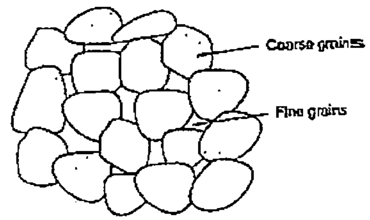

Fig. 4.13 Coarse grain skeleton

(b) Clay-matrix Structure: Clay-matrix structure is also a composite structure which is formed when soil contain both fine grain and coarse grain soils. However, in this case the amount of fine particles is very large as compared to coarse particles. The clay forms a matrix in which coarse grain appear floating without touching each other. Such soils are relatively more compressible.

Summary

- Interparticle forces acting between particles depends upon the surface area, its character and environment.
- In the formation of coarse soils gravity forces are dominant where as surface electric charge are dominant in formation of clays.
- Clay minerals are made of Silica and Gibbsite sheets.
- The three important clay minerals are
  (i) Kaolinite mineral
  (ii) Montmorillonite mineral
  (iii) Illite mineral
- Flocculated and dispersed structure are the two basic structures of clay.
- Single grain and honey comb structure are the two structure of sand.

Objective Brain Teasers

Q.1 The description of 'sandy silty clay' signifies that
(a) the soil contains unequal proportions of the three constituents, in the order sand > silt > clay
(b) the soil contains equal proportions of sand, silt and clay
(c) the soil contains unequal proportions of sand, silt and clay
(d) the soil contains unequal proportions of the three constituents such that clay > silt > sand

Q.2 The correct sequence of plasticity of minerals in soil in an increasing order is
(a) silica, kaolinite, illite, montmorillonite
(b) kaolinite, silica, illite, montmorillonite
(c) silica, kaolinite, montmorillonite, illite
(d) kaolinite, silica, montmorillonite, illite

Q.3 Among the clay minerals, the one having the maximum swelling tendency is
(a) Kaolinite (b) Illite
(c) Montmorillonite (d) Halloysite

Q.4 Among the following types of water, which one is chemically combined in the crystal structure of the soil mineral and can be removed only by breaking the crystal structure?
(a) Capillary water
(b) Adsorbed water
(c) Hygroscopic water
(d) Structural water

Q.5 Honey-combed structure is found in
(a) Gravels
(b) Coarse sands
(c) Fine sands and silts
(d) Clay

Q.6 Which one of the following is the most active clay material?
(a) Na-illite
(b) Na-kaolinite
(c) Na-montmorillonite
(d) Ca-montmorillonite

Q.7 The plasticity characteristics of clay are due to
(a) Adsorbed water
(b) Free water
(c) Capillary water
(d) None of the above

Answers

1. (d) 2. (a) 3. (c) 4. (d) 5. (c)
6. (c) 7. (a)

Hints and Explanations:

2. (a)
Silica has least plasticity while Montmorillonite has highest plasticity.

3. (c)
Montmorillonite has highest swelling characteristics and kaolinite has lowest swelling characteristics