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THE EFFECT OF SODIUM CHLORIDE ON COMPRESSIBILITY BEHAVIOUR OF PURE KAOLINITE AND NATURAL SOIL

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ABSTRACT

Clayey materials are often used as liner material in landfills. In some cases, natural soils containing clay minerals are used as cheaper alternatives. The Seawater intrusion in landfill located nearby coastal area might affect the stability and performance of clay liner system located at the bottom of the landfill. The effect of the seawater to the compressibility of the clay liner is still not well understood. This study focused on the effects of saltwater on the plasticity as well as the compressibility characteristics of a natural soil (KB soil) and commercially available FM-C kaolin. Double-oedometer tests were employed by applying increasing vertical stress on initially saturated slurried specimens. The specimens were allowed to inundate under 0.5 M sodium chloride (NaCl) solution. Both the plasticity and the compressibility behavior of FM-C kaolin and KB soils were affected by NaCl solutions. A much higher water contents and void ratios were attained by FM-C kaolin as compared to KB soil, primarily due to the amount of clay fractions available. However, the differences were found to be minimal. Based on the findings of this study, the use of natural soil may be useful in replacing commercially available kaolinite as cost effective alternatives material in landfill liner systems.

ABSTRAK

Bahan bertanah liat sering digunakan sebagai bahan pelapik di tapak pelupusan. Dalam beberapa kes, tanah semulajadi mengandungi mineral tanah liat digunakan sebagai alternatif yang lebih murah. Kemasukan air laut di kawasan tapak pelupusan sampah yang terletak di pantai yang berdekatan mungkin menjejaskan kestabilan dan prestasi sistem pelapik tanah liat yang terletak di bawah tapak pelupusan. Kesan air laut terhadap kebolehmampatan pelapik tanah liat masih tidak jelas. Kajian ini tertumpu kepada kesan air laut terhadap keplastikan serta ciri-ciri kebolehmampatan tanah semulajadi (tanah KB) dan FM-C kaolin yang boleh diperolehi secara komersil. Ujian *Double-oedometer* telah dijalankan dengan mengenakan tekanan menegak yang semakin meningkat ke atas spesimen yang pada mulanya tepu dengan air. Kedua-dua spesimen telah dipenuhi dengan 0.5 M natrium klorida (NaCl). Keplastikan dan tingkah laku kebolehmampatan FM-C kaolin dan tanah KB terjejas oleh larutan NaCl. Kaolin FM-C mengandungi kandungan air dan nisbah lompang yang lebih tinggi berbanding dengan tanah KB, terutamanya disebabkan oleh jumlah pecahan tanah liat yang ada. Walau bagaimanapun, perbezaan antara kedua-dua tanah telah didapati sedikit. Berdasarkan penemuan kajian ini, penggunaan tanah semulajadi mungkin berguna dalam menggantikan kaolinit yang boleh didapati secara komersial sebagai bahan untuk sistem pelapik di tapak pelupusan dengan alternatif kos yang efektif.

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LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
HDPE	High-density polyethylene
FKASA	Faculty of Civil Engineering and Earth Resources
KB	Kuantan Brick
PL	Plastic limit
LL	Liquid limit
PI	Plasticity index
XRD	X-ray diffraction

LIST OF SYMBOLS

NaCl	Sodium Chloride
Na^+	Sodium ion
Cl^-	Chloride ion
$Al_2(OH)_4$	Aluminium hydroxide
H_2O	Water
G_s	Specific gravity
w	Water content
A	Area
M	Initial mass
M_s	Dry mass
e	Void Ratio
ρ_w	Density of water

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CHAPTER 1

INTRODUCTION

1.1 Background

Clay is type of soil having fine particles of less than 0.002mm in diameter (Das, 2007). The behaviour of clay (i.e. swelling and shrinkage) is affected due to changes in the water content (Sudjianto, 2003). At high water content, the voids between particles are completely filled with water and caused clays to have low permeability. In this case, the ability of the soils to transmit fluid such as water and air through the particles is very low (Donahue, 1983).

Clay is widely used as a component in landfill liner systems (Hughes et al, 2005). Due to its low permeability, clay functions as a retarder for the migration of wastes and leachate in landfills. Natural soil containing kaolinite mineral are also used as cheaper alternatives for landfill liners. There are several prerequisite requirements for the selection of backfill material as shown in Figure 1.1. The requirements include coefficient of permeability of 1×10^{-9} m/s or less, minimum clay content of 10%, minimum fines content more than 30%, plasticity index more than 10% and less than 65%, liquid limit less than 90% and maximum particle size of 75mm (O'Sullivan and Quigley, 2002). Any material that passed all these requirements can be used in substitute to clayey material as backfill material.

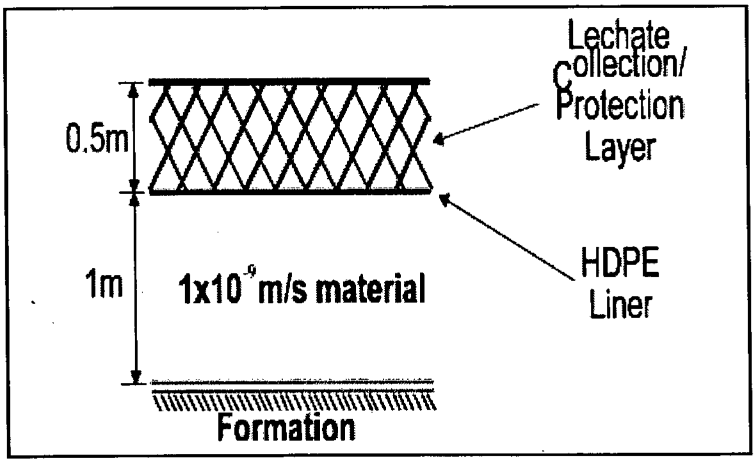

Figure 1.1: Backfill Material

Some landfills are constructed near coastal areas. For instance, the most well known landfill constructed near coastal area is Pulau Burung landfill in Penang Island. During high tides, salt water intrusion would occur and the landfill liner systems would have the potential of interaction with seawater. Seawater contains mixtures of various chemical concentrations (Pidwirny and M. 2006). Various studies in the past have shown that, the behaviour of clay material is affected by the present of various cation concentrations (Olson and Mesri, 1970). Hence, the behaviour of the clay liner and the stability of the liner would be at stake.

The effect of seawater on the compressibility behaviour of clays is not well understood. Therefore, the study of the effect of seawater on the compressibility behaviour of clayey material need to conducted in order to assess the performance of liner systems, particularly for landfill that is constructed near coastal areas. In this study, experimental investigation on the compressibility of commercially available kaolin and natural soil containing kaolinite mineral are conducted. It is hoped that the study can be used as a guide for the design criteria of landfill liner near coastal areas.

1.2 Problem Statement

Intrusion of seawater might affect the stability and performance of clay liner systems. The effects of seawater on the compressibility behaviour of clays and soil containing kaolinite mineral have not been clearly brought out. Although seawater predominantly contained Na^+ and Cl^- ions, the use of NaCl solution in substitute of seawater might not be appropriate, as seawater contained mixtures of various chemical concentrations.

1.3 Research Objectives

The objectives of the study are:

i. To determine the effect of NaCl solution on the compressibility behavior of natural soil containing kaolinite mineral and commercially available kaolinite.

ii. To determine the effect of soil type on the compressibility behaviour of soils

1.4 Scope of Research

The scopes of this study include the following aspects:

i. Laboratory investigation conducted on two (2) different soils.
ii. The use of a solution with specific chemical composition and concentration (i.e. seawater and NaCl solution)
iii. Compressibility behaviour in Oedometer under increasing vertical stresses using NaCl solution

1.5 Significance of Research

If the compressibility of naturally available kaolinite soil and pure kaolinite are found to be similar, thus the use of locally available kaolinite may be useful as cost effective alternatives liners.

1.6 Thesis Overview

The thesis is divided into five consecutive chapters. The summary of each chapters are presented in the following manner.

In chapter 2, the literature reviews that related the study are presented. This chapter explains about the application of clay as a liner, clay mineralogy which consists of kaolinite group, illite group and montmorillonite group, soil-water interaction the compressibility behavior and the oedometer test.

In chapter 3, represent the material properties and the methods that are used to conduct the study. This chapter consists of two sections that is material properties which is discuss the material used to conduct the study and the laboratory test which starting by specific gravity followed by water content, particle size analysis, x-ray diffraction, atterberg limit and the main test oedometer test.

In chapter 4, the result and analysis of the study are presented. The soil properties which divided in two section; physicochemical properties and consistency limit, and followed by the compressibility behaviour are presented in this chapter.

Finally in chapter 5, the conclusion of the study is presented. The finding will be concluded and summarized in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Clay is one type of soil which can be found in the earth's surface. It is formed by weathering and erosion of sedimentary rocks or volcanic ash. According to American Association of State Highway and Transportation Officials (AASHTO) the particle size of clay is less than 0.002 mm.

Clay particles are like plates or needles and are negatively charged (Sivakugan, 2001). The amount of charge present within clay would determine their plasticity characteristics (Goldman and Greenfield, 1990). Clays having much higher specific surface area and higher cation exchange capacity would absorb more water and in turn exhibit much higher volume change behaviour (Sivakugan, 2001). When immersed in water, clays often form colloidal suspensions; however, clay particles flocculate and settle quickly in saline water (Columbia University, 2007).

Besides that, clay has low permeability due to small grain size with large surface areas, which result in increased friction (Fetter, 1994). The permeability of soil is the property that describes the resistance to the flow of liquid through soil

(Lee, 1990). Scott (1980) and Vickers (1978) said, the permeability of clay is increase or decrease according to change in arrangement of particles which is affect the void ratio of clay. The decreases of void ratio will lowest the permeability of clay. Therefore, clay can be compacted in order to reduce its permeability which is suitable to be a landfill liner material.

2.2 Application of Clay as Landfill Liner

One of the uses of clay is to be used as a landfill liner. Landfill liners are designed and constructed to create a barrier between the waste and the environment. Liners also prevent the movement of leachate and allow leachate to be collected and treated (Hughes et al, 2003). This is done to prevent the uncontrolled release of leachate into the environment (Hughes et al., 2005). Figure 2.1 and Figure 2.2 show the clay liner at the bottom of landfill body. Clay liners at the bottom of landfill body play a very important part in the whole multi barrier system for retaining pollutants.

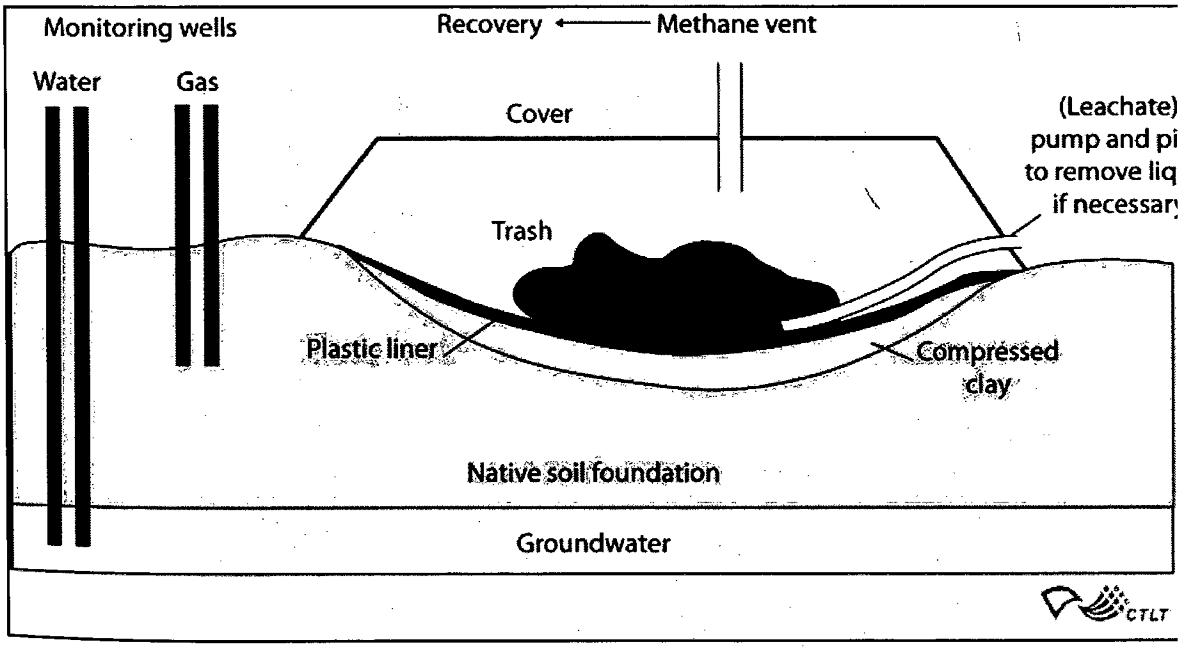

Figure 2.1: Landfill diagram

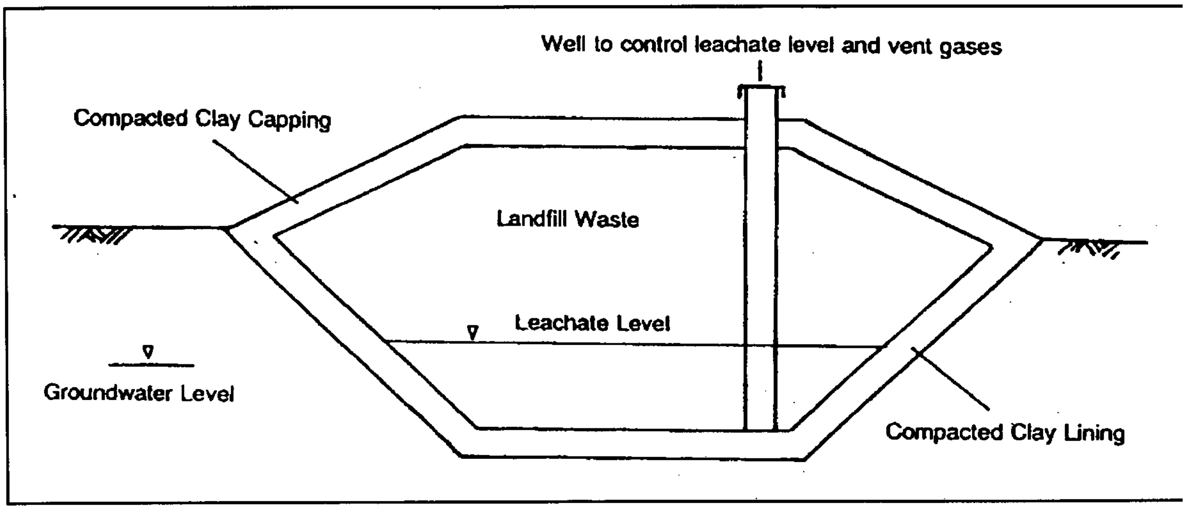

Figure 2.2: Typically Landfill cell

Generally, soil containing kaolinite mineral is also used as landfill liner. Because based on the tests carried out were as recommended by the Environment Agency and all criteria and minimum requirements were satisfied. The plasticity index of the material is only just above the regulatory limit and the most important parameter has been satisfied (Elliott, 1997).

Liner is maybe one or more layers of clay or a synthetic flexible membrane or a combination of these. The liner effectively creates a bathtub in the ground. If the bottom liner fails, wastes will migrate directly into the environment. There are three types of liners: clay, plastic, and composite (Environmental Research Foundation, 2003).

Clay liners are constructed as a simple liner that is two- to five-feet thick. In composite and double liners, the compacted clay layers are usually between two- and five-feet thick, depending on the characteristics of the underlying geology and the type of liner to be installed. Regulations specify that the clay used can only allow water to penetrate at a rate of less than 1.2 inches per year. The effectiveness of clay liners can be reduced by fractures induced by freeze-thaw cycles, drying out, and the presence of some chemicals (Hughes et al, 2003).

2.3 Clay Mineralogy

Clay minerals are complex aluminium silicates composed of two basic units; silica tetrahedron and alumina tetrahedron. The tetrahedron has oxygen atoms at the corners, and silicon in the centre. Octahedron has six oxygen or hydroxyl atoms in the corners, and an aluminium or magnesium ion at the centre (Sivakugan, 2001).

Clays can be divided into three general groups based on their crystalline arrangement. The three important clay minerals are kaolinite, montmorillonite and Illite. The clay mineral present in a soil reflects the weathering and deposition history of the site. For residual soils where the clay has come from the local rock, basalt will weather to predominantly Illite or Montmorillonite, whereas the feldspar of granite weathers to a Kaolinite. Clays themselves are not immune from weathering and Montmorillonite will weather to Illite, in turn altering to Kaolinite, then to Bauxite (Sudjianto, 2003).

2.3.1 Kaolinite Group

Kaolinite is formed by the decomposition of orthoclase feldspar. Kaolinite consists of repeating layers of elemental silica-gibbsite sheet. Each layer is about 7.2 Å thick (Das, 2007). Figure 2.3 shows the structure of kaolinite group. The kaolinite clays are 1:1phyllosilicates as shown in Figure 2.4 (Anderson, 1991). The general structure of the kaolinite group is composed of silicate sheets (Si_2O_5) bonded to aluminum oxide/hydroxide layers ($Al_2(OH)_4$) called gibbsite layers. The silicate and gibbsite layers are tightly bonded together with only weak bonding existing between the s-g paired layers (Amethyst Galleries, 2011).Two adjacent layers are held together by hydrogen bonding. Consequently, the structure is fixed and no expansion occurs between layers when the clay is wetted. The effective surface of kaolinite is restricted to its external surface area. The typical kaolinite particle is fairly large about 50 nm thickness and 1-3 nm width in comparison with other clay particles and hexagonal in shape. Because of the strong binding forces between their structural layers, kaolinite particles are not readily broken down into extremely thin plates. Kaolinite exhibits very little shrinkage and swelling (Krzic et al, 2004). In other words, kaolinite does not absorb water and does not expand when it comes in contact with water. The examples of kaolinite group include kaolinite, dickite, nacrite, and halloysite. Kaolinite is the purest of clays, meaning that it varies little in composition. It also does not absorb water and does not expand when it comes in contact with water (Nelson, 2011).

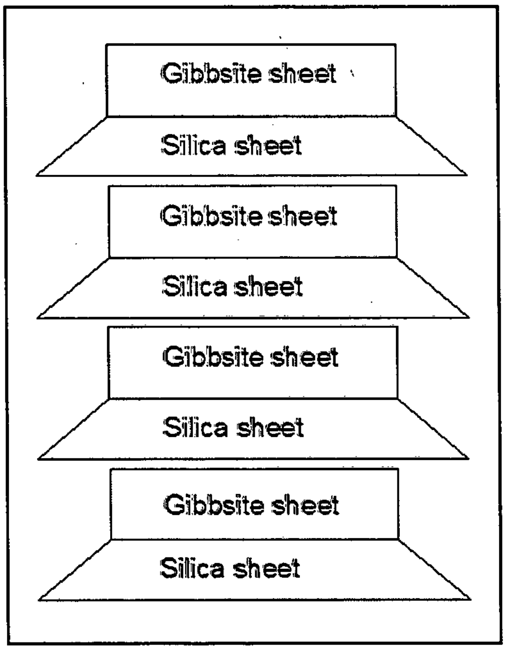

Figure 2.3: Kaolinite Structure

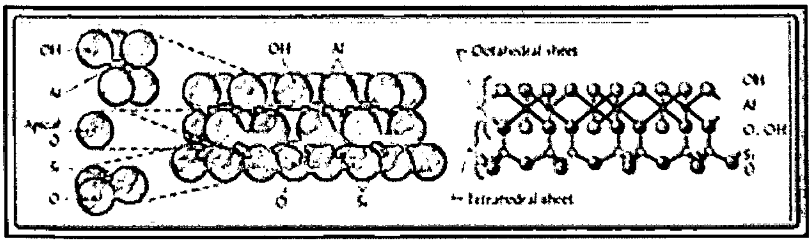

Figure 2.4: 1:1 Phyllosilicates model

2.3.2 Illite Group

Illite structure consists of two silica sheets bonding a gibbsite in the middle. The illite layers are bonded by potassium ions as shown in Figure 2.5. The negative charge to balance the potassium ions comes from the substitution of aluminium for some silicon in the tetra-hedral sheets. Illite is formed by the decomposition of some micas and feldspars which are predominant in marine clays and shales. Illite clays are 2:1 phyllosilicates (Anderson, 1991). Illite particles generally have lateral dimension ranging from 1000 to 5000 Å and thickness from 50 to 500 Å (Das, 2007). Illite is the most common clay mineral, often composing more than 50 percent of the clay mineral suite in the deep sea. Clays in the illite group are hydrous micas, phengite, brammalite, celadonite,and glauconite (Dion et al, 2003).

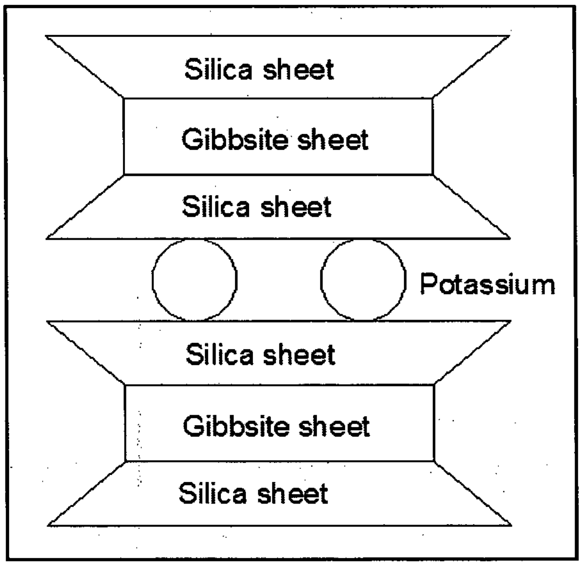

Figure 2.5: Illite Structure

2.3.3 Montmorillonite Group

Montmorillonite structure is similar to illite structure which is consists of gibbsite sheet bonded by two silica sheets as shown in Figure 2.6. The montmorillonite layers are bonded by H_2O and exchangeable cations. Montmorillonite clays are 2:1 phyllosilicates clays, Figure 2.7, which having permanent layer charge because of the isomorphous substitution in either the octahedral sheet (Anderson, 1991). The layers in montmorillonite crystals are loosely held together by very weak oxygen-to-oxygen and cation-to-oxygen bonds. Hence, water molecules and various ions are attracted between layers causing expansion of the crystal. Montmorillonite is characterized by pronounced swelling when wet and shrinkage on drying. A wide cracks commonly form as montmorillonite dominated soils i.e. Vertisols, are dried. Typically, montmorillonite particles are thin-flat disks about 1 to 3 nm of thickness and 500 nm width (Krzic et al, 2004). Montmorillinite is the main constituent of bentonite, derived by weathering of volcanic ash. Montmorillinite can expand by several times its original volume when it comes in contact with water. The interlayer in montmorillonite is not only hydrated, but it is also expansible where the separation between individual montmorillonite sheets varies with the amount of water presenting the soil (Anderson, 1991).

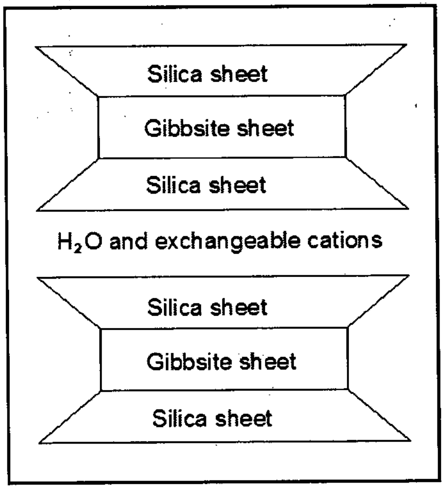

Figure 2.6: Montmorillonite Structure

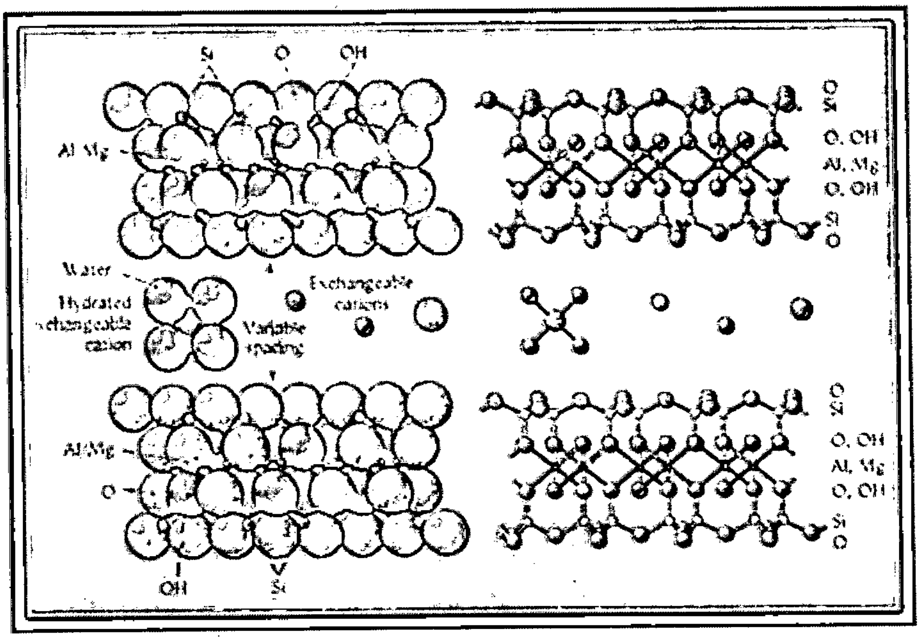

Figure 2.7: 2:1 Phyllosilicatesclays model

2.4 Soil – Water Interaction

The reaction of clay with water is the fundamental importance in the fields of agriculture, engineering and clay technology. In engineering, they are concerned with the consolidation and shear strength of the soil-water mass. A clay mass exists in a series of structural states depending not only on its water content but also on its history. In the dry state the structural status of a clay material can be defined by pore size distribution studies; as swelling takes place the uptake of water can be described in terms of the formation of a gel structure and the film thickness developed by clay particles in repelling one another (Aylmore and Quirk, 1960).

According to Croney and Coleman (1954) and also Holmes (1955), at any given hydrostatic suction it was possible for a clay mass to have a range of different water contents depending on its previous history and also that a disturbed clay mass described a series of hysteresis loops on repeated wetting and drying. This effect of terminal pressure on the decompression curve for clays in the gel state is also well