THE EFFECT OF SEAWATER AND SODIUM CHLORIDE ON THE COMPRESSIBILITY BEHAVIOUR OF CLAY SOIL

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ABSTRACT

Clayey materials are widely used as a landfills liners and landfill covers due to its low permeability. In some cases, natural soil containing clay minerals are also used. There are number of landfills in Malaysia located near the sea or coastal area such as Pulau Burung Sanitary Landfill and Kota Bharu Municipal Council Landfill. The behaviour of clay liner and their interaction with seawater is not known since the related study is limited in the literature. This study was conducted in order to determine the compressibility behaviour of a natural soil (KB soil) by using seawater and sodium chloride (NaCl) solution. The compressibility behaviour of the soil was obtained by conducting double-oedometer tests. In addition, the effect of seawater and NaCl solution on the physical properties of KB soil also was identified. The results indicated that the pressure-void ratio relationships were slightly lower using seawater as compared to NaCl solution. However, the differences in the void ratios were only marginal. Similarly, the pressure-water contents relationship using NaCl solution was slightly higher than that of seawater at the same amount of vertical pressure applied. It was noted that, the plasticity and the compressibility characteristics of KB soil showed similar trend using both seawater and NaCl solution.

ABSTRAK

Bahan bertanah liat digunakan secara meluas sebagai pelapik tapak pelupusan sampah dan penutup tapak pelupusan disebabkan oleh kebolehtelapan yang rendah. Dalam beberapa kes, tanah semulajadi yang mengandungi mineral tanah liat juga digunakan. Terdapat beberapa tapak pelupusan di Malaysia yang terletak berhampiran kawasan laut atau pantai seperti tapak pelupusan sanitari Pulau Burung dan tapak pelupusan Majlis Perbandaran Kota Bharu. Tingkah laku pelapik tanah liat dan interaksinya dengan air laut tidak diketahui kerana kajian yang berkaitan dengannya adalah terhad di dalam literatur. Kajian ini dijalankan untuk menentukan tingkah laku kebolehmampatan tanah semulajadi (tanah KB) dengan menggunakan air laut dan larutan natrium klorida (NaCl). Tingkah laku kebolehmampatan tanah telah diperolehi dengan menjalankan ujikaji double-oedometer. Di samping itu, kesan air laut dan larutan NaCl ke atas ciri-ciri fizikal tanah KB juga telah dikenal pasti. Hasil kajian menunjukkan bahawa hubungan di antara tekanan dan nisbah lompang adalah sedikit rendah dengan menggunakan air laut apabila dibanding dengan larutan NaCl. Walau bagaimanapun, perbezaan nisbah lompang hanyalah sedikit. Begitu juga dengan hubungan di antara tekanan dan kandungan air menggunakan larutan NaCl adalah sedikit lebih tinggi berbanding air laut pada nilai tekanan menegak yang sama dikenakan. Didapati bahawa, ciri-ciri keplastikan dan kebolehmampatan tanah KB menunjukkan trend yang sama dengan menggunakan kedua-dua air laut dan larutan NaCl.

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Å	-	Angstrom
Cl-	-	Chloride ion
CaCl	-	Calcium chloride
Cc	-	Compression index
CL	-	Low plasticity
e	-	Void ratio
g/L	-	Gram per litre
g/mol	-	gram per litre
kPa	-	kilopascal
LL	-	Liquid limit
m	-	Meter
M	-	Mol
mm	-	Millimetre
mol/L	-	Mol per litre
m/sec	-	meter per second
m_v	-	Coefficient of volume compressibility
Na+	-	Sodium ion
NaCl	-	Sodium Cloride
p	-	Pressure
PI	-	Plasticity index
PL	-	Plastic limit
w_i	-	Initial water content
µm	-	micro meter
ε	-	Strain

LIST OF ABBREVIATIONS

UMP	-	Universiti Malaysia Pahang
et al.	-	Latin phrase *et alia*, which means "and others"
USCS	-	Unified Soil Classification System
MIT	-	Massachusetts Institute of Technology
BS	-	British standard
etc.	-	Latin phrase et cetera which means "and the rest"
MSW	-	Municipal solid waste
GCL	-	Geosynthetic clay liner

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CHAPTER 1

INTRODUCTION

1.1 Study Background

Waste disposal has become one of the most serious of modern environmental problems in developed and developing countries all over the world (Arasan & Yetimoglu, 2007). This is due to the rapid growth of population and rapid industrial evolution. The average per capita generation of waste is estimated to be about 0.85 kg/cap/day (Local Government Department, 2003). So, waste generated in Peninsular Malaysia is estimated about 17,000 tons per day. One of the preferred methods of dealing with this kind of environmental problem is to dispose the waste directly in sanitary landfills (Arasan & Yetimoglu, 2007).

The landfill liners and covers can be constructed from clayey materials such as natural clay and geosynthetic material. The function of clay liner is to retard the migration of waste and leachate from polluting the ground water (Lee & Jones-Lee, 1992). Clayey materials are widely used as a landfills liners and landfill covers, due to its low permeability (Arasan & Yetimoglu, 2007). Clays exhibit volume change behaviour when subjected to wetting and drying processes (Fang & Daniels, 2006). Storm water infiltration and groundwater interaction may affect the performance of the liner material. Thus, studies relating to the drying and volume change behaviour of clays enable long-term assessment of stability of the liners.

In certain areas, landfill are constructed in close approximate to the sea such as Pulau Burung Sanitary Landfill at Pulau Pinang and Kota Bharu Municipal Council Landfill located near Pantai Sabak. Intrusion of seawater into the landfill especially during high tide may well affect the performance of the liners material. Studies in the past indicated that the volume change behaviour (i.e. compressibility) of clays varied with the salts concentration as well as type of cations present within a solution (Mishra *et al.*, 2005).

Generally, single salt solutions are used in geotechnical testing (Petrov & Rowe, 1997; Cocka, 2000). As such that, sodium chloride (NaCl) solution is used in substitute of seawater due to the fact that, seawater contained majority of sodium (Na+) and chloride (Cl-) ions (Petrov and Rowe, 1997). However, seawater contains mixture of various cations with different type and concentrations (Wikipedia, 2012). Studies on the effect of seawater on the compressibility behaviour of clays are scarce. It is proposed in this study, that the compressibility behaviour of clayey soil when tested with seawater and NaCl solution using standard oedometer cell.

1.2 Problem Statement

There are number of landfills in Malaysia located near the sea or coastal area. The behaviour of clay liner and their interaction with seawater is not known. Thus, it is crucial to study the clay behaviour and the interaction with seawater for the assessment and design of liner at these areas. The effects of seawater and NaCl solution on the compressibility behaviour of soil are studied.

1.3 Objectives of Study

The objectives of this study are:

i. To determine the effect of seawater and NaCl solution on the physical properties of clay

ii. To determine the compressibility behaviour of clay soil by using seawater and NaCl solution.

1.4 Scope of Study

The scope of the study is to determine the effect of seawater and NaCl on the compressibility behaviour of natural soil containing clay mineral. The natural soil sample from Kuantan area is considered in this study. Only experimental investigation is considered and laboratory tests were conducted in UMP Geotechnical Laboratory. The compressibility behaviour was determined from the oedometer test.

1.5 Significance of Study

This study will provide new data for the researchers and engineers to evaluate the effect of seawater on the compressibility behaviour of clayey soils and design criteria for landfill liners in close approximate to the sea. If the compressibility behaviour of clay using NaCl solution and seawater are found to be similar, therefore NaCl solution can be used to replace seawater for the oedometer testing.

1.6 Thesis Overview

This thesis consists of five (5) chapters. The relevant literature is reviewed in chapter 2. This chapter briefly explained about the use of clay as a barrier system /landfill liner, clay mineralogy (kaolinite groups, montmorillonite groups and illite groups), soil – water interaction, composition of seawater, compressibility behaviour and also the oedometer test.

In chapter 3, the material properties and the methods used in this study are presented. This chapter consist of two sections. The first section discusses about the material properties where the brief explanation about the material used are presented. The second section explain about the laboratory tests conducted in this study which is specific gravity, water content, particle size analysis, x-ray diffraction, atterberg limit and the main test oedometer test.

In chapter 4, the result and analysis obtained from the study are presented. The physical properties which are consist of physicochemical properties and consistency limit are presented first, followed by the result of compressibility behaviour which is obtained from the oedometer test.

The final conclusions are presented in chapter 5 based on the finding obtained from the study.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Clay material has a wide application in industries such as in agricultural, engineering and construction, environmental remediation, geology and many other applications (Murray, 2007). Clay has been used as a fill structure such as embankments, dams, quarry tips, mounds or levelled areas (Reeves *et al.*, 2006). In the construction of earth dams, clay is used as an impermeable barrier for water retaining element. Clay soil also use in the construction of landfill for waste disposal. Generally, clay used as a liner in solid waste disposal landfill will be compacted in order to achieve the low permeability value as stipulated by the Department of Environment which is less than 1×10^{-9} m/sec.

Clay is used as a liner due to its low hydraulic conductivity and possesses good contaminant absorption or attenuation properties (Khuan, 2010). The major property of clay is the ability to adsorb water between the layers. Clay particles are negatively charged and attract positively charged ions and water molecules (Russell *et al.*, 2007). This is why the landfills and hazardous waste containment areas are often lined with pure clay (Johnson, 2001).

2.2 Clay as a Barrier System /Landfill Liner

Landfill liners are designed and constructed to create a barrier between the waste and the environment. It is also functioned to protect the groundwater and surface water from contamination by the escape of contaminant from waste disposal (Rowe *et al.*, 2004). Clayey soil is one of the materials that have traditionally been used for the barrier layer. The clayey barriers vary from thin bentonite liners (1 – 3 cm thick), to compacted clayey liners (0.9 – 3 m thick), and to natural undisturbed clayey barriers up to 30 or 40 m thick (Rowe *et al.*, 2004).

There are four critical elements in a landfill namely a bottom liner, a leachate collection system, a cover, and the natural hydrogeologic setting. Normally, clay barrier are laid at the bottom layer of the landfill. The bottom liner of a landfill plays an important role to prevent contamination of the soil, groundwater and surface water. If the bottom liner fails, wastes will migrate directly into the environment. The clay liner will be compacted during the construction of the landfill. The purpose of compacting the clay liner is to decrease the hydraulic conductivity and thus to improve the performance of the clay liner (Christensen, 2011). Figure 1 shows the main components of a common sanitary landfill.

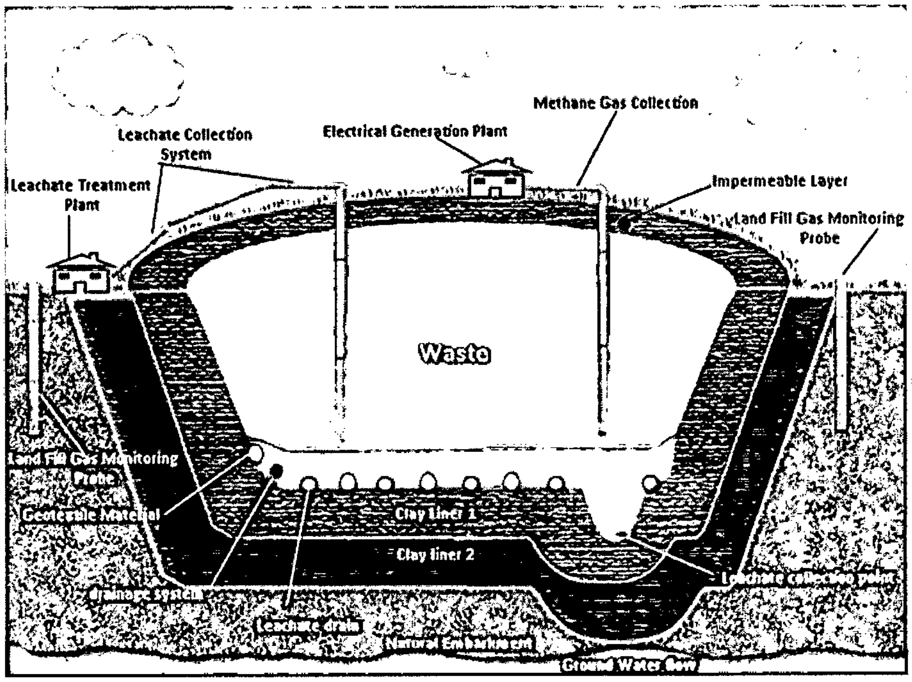

Figure 2: Primary components of a typical modern sanitary landfill

The main components of landfill are:

- Bottom liner system - separates trash and subsequent leachate from groundwater
- Cells (old and new) - where the trash is stored within the landfill
- Storm water drainage system - collects rain water that falls on the landfill
- Leachate collection system - collects water that has percolated through the landfill itself and contains contaminating substances (leachate)
- Methane collection system - collects methane gas that is formed during the breakdown of trash
- Covering or cap - seals off the top of the landfill
- Groundwater monitoring stations — Stations are set up to directly access and test the groundwater around the landfill for presence of leachate chemicals.

2.3 Clay Mineralogy

The definitions of clays are varied. According to Unified Soil Classification System (USCS), clay can be defined as the soil fraction that has particles equal to finer than 0.002 mm (or 2 μm). There are two more soil classification system commonly used which is the international classification system and the Massachusetts Institute of Technology (MIT) classification system. Both the international classification system and MIT classification system define the clay by the 2 μm criterion (Leong, 2005). Clays can be divided into three general groups on the basis of their crystalline arrangement. The three most common clay minerals are kaolinite, montmorillonite and illite which are divided into different groups as shown in Table 2.1.

Table 2.1: Classification of clay minerals (Adapted from Gunduz, 2008)

	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	$K_y(Al_4Fe_2.Mg_4.Mg_6)Si_{8-y}$ $Al_y(OH)_4O_{20}$

According to Table 2.1, kaolinite can be classified into two groups (i.e. kaolinite and halloysite). The structural formula of both kaolinite and halloysite consists of silica alumina and hydroxide. However, differences in the amount of oxygen bond differ between these two minerals. Montmorillonite consists of silica alumina, hydroxide and hydrogen bond. While, the structural formula of illite mineral is similar to montmorillonite but the illite layers are bonded by potassium ions.

2.3.1 Kaolinite Groups

The kaolinite groups of minerals are the most stable of the groups of minerals. The kaolinite mineral is formed by the stacking of the crystalline layers of about 7Å thick one above the other with the base of the silica sheet bonding to hydroxyls of the gibbsite sheet by hydrogen bonds. The kaolinite crystals consist of many sheet stacking that are difficult to dislodge. The mineral is stable and water cannot enter between the sheets to expand the unit cells (Murthy, 2003).

Kaolinite is called 1:1 clay minerals because it is made up of layer of one tetrahedral sheet and one octahedral sheet. The kaolinite structure is represented in

Figure 2.2. Within the octahedral layer, there are generally aluminum atoms and within the tetrahedral layer the cations are silicon. The hydrogen bonding holds sheets tightly together. The chemical formula of kaolinite group is $Al_4O_{10}Si_4(OH)_8$ (Mitchell & Soga, 2005).

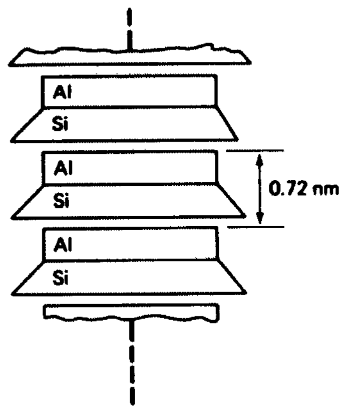

Figure 2.2: Kaolinite structure (Adapted from Mitchell & Soga, 2005)

2.3.2 Montmorillonite Groups

Montmorillonite is a 2:1 mineral and consists of two sheets of silica tetrahedra on either side of a gibbsite sheet. The thickness of the silica-gibbsite-silica layer is about 10Å. Hence, for a montmorillonite that has not experienced any cation substitution or exchange, the chemical formula would be $(OH)_8Si_8Al_4O_{20}(H_2O)_n$, where n = number of layers. Sodium (Na) montmorillonite is a common form of the clay within bentonite (Mitchell & Soga, 2005). The montmorillonite structure is represented in Figure 2.3.

The bonding between the layers for montmorillonite minerals is very weak, so large quantities of water can easily enter and separate them, thus causing the clay to swell (Gunduz, 2008). The soils containing a considerable amount of montmorillonite minerals will exhibit high swelling and shrinkage characteristics (Murthy, 2003).

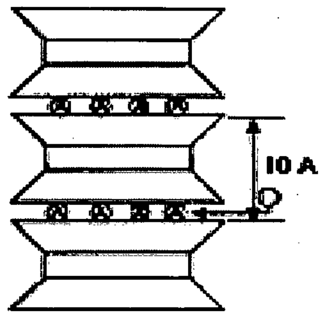

Figure 2.3: Montmorillonite structure (Adapted from Mitchell & Soga, 2005)

2.3.3 Illite Groups

The illite group of minerals has the same structural arrangement as the montmorillonite group. Illite has a 2:1 structure and consists of a gibbsite sheet between two silica tetrahedral sheets with the layers bounded together by potassium cations in the interlayer region as shown in Figure 4. The chemical formula of illite is $(K,H_2O)_2Si_8(Al,Mg,Fe)_{4.6}O_{20}(OH)_4$. The octahedral cations are aluminium, magnesium or iron, and the tetrahedral cations can be aluminium or silicon (Mitchell & Soga, 2005).

The swelling potential of the illite minerals is not very good compared to the montorillonite minerals due to the presence of potassium as the bonding materials between the layers (Murthy, 2003). Besides the bonding between the layers for illite minerals are not as strong as in kaolinite which has more space for water to enter between the elemental layers (Gunduz, 2008).

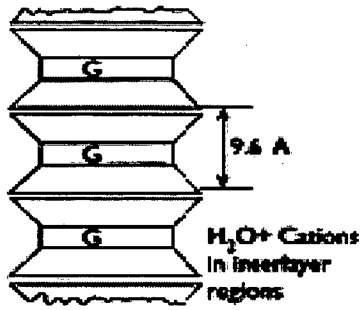

Figure 2.4: Illite structure (Adapted from Mitchell & Soga, 2005)

2.4 Soil – Water Interaction

Soil is a medium that stores and moves water. The interaction between water molecules and soil particle is made by a force of hydrogen combination and van der waals forces. Basically, the interaction between a liquid (water) and a solid (soil) can occur only at the solid's surface (Fang & Daniels, 2006). Clays consist of negatively charged alumina silicate layers kept together by cations. The most characteristic property of clay is their ability to adsorb water between the layers, resulting in strong repulsive forces and clay expansion (Hensen & Smit, 2002).

Clays are strongly influenced by the presence of water because of their high surface activity. The clay – water interactions are caused by:

1. The water held on to the clay particle by hydrogen bonding in which the hydrogen of the water of the water molecule attracted to the oxygen or hydroxyl units on the surface of the particle.
2. The water molecules are electrostatically attracted to the surface of the clay particle.
3. The hydrated exchangeable cations present in water are electrostatically attracted to the clay surface.

There are five descriptive terms describe the progressive interactions that can occur in a clay-water system namely hydration, dispersion/ disaggregation, flocculation, deflocculation and aggregation (Wikipedia, 2011). Hydration occurs as clay packets absorb water and swell. Dispersion/ disaggregation cause clay platelets to break apart and disperse into the water due to loss of attractive forces as water forces the platelets farther apart. When mechanical shearing stops and platelets previously dispersed come together due to the attractive force of surface charges on the platelets, the flocculation will be begins.

While, deflocculation will occurs by addition of chemical deflocculant to flocculated mud causing the positive edge charges are covered and attraction forces are greatly reduced. Last but not least is aggregation. A result of ionic or thermal conditions alters the hydrational layer around clay platelets, removes the deflocculant from positive edge charges and allows platelets to assume a face-to-face structure (Wikipedia, 2011).

The mechanism of soil-water interaction is complex and its behaviour is not only dependent on soil types but is also related to the current and past environmental conditions and stress histories (Fang & Daniels, 2006). However, there are a few approach was introduced by some researchers to explain the mechanism of soil-water interaction such as mechanical (kinetic energy) approach and physicochemical concept introduced by Terzaghi (1943) and Winterkorn (1942) respectively (Fang & Daniels, 2006).

Fang and Daniels (2006) mentioned that Winterkorn (1942) using a physicochemical concept to explain the mechanics of reacting water with a dry cohesive clay, postulated that a dry soil system is held together by a remaining adhesive water film. Winterkorn concluded that two phenomena must be considered and analyzed:

1. The penetration of water into the soil mass and,
2. The action of the water on the cementing films resulting in a lowering and possible destruction of the cohesion of the soil.

While, Terzaghi (1943) using mechanical (kinetic energy) approach to explain that when a dried soil is rapidly immersed in water, the outer portions of the soil become saturated and air is trapped in the inner portions. The pressure in the air produces a tension in the solid skeleton that is likely to cause failure of soil of soil in tension. This process is known as slaking (Fang & Daniels, 2006).

2.5 Composition of Seawater

Seawater is an extremely complex solution, its composition being determined by equilibrium between rates of addition and loss of solutes, evaporation and the addition of fresh water (Tait & Dipper, 1998). Seawater contains more dissolved ions than all types of freshwater. The main salt ions in seawater are presented in table below.

Table 2.2: The main salt ions in seawater

chemical ion	valence	concentration ppm, mg/kg	part of salinity %	molecular weight	mmol/kg
Chloride Cl	-1	19345	55.03	35.453	546
Sodium Na	+1	10752	30.59	22.990	468
Sulfate SO4	-2	2701	7.68	96.062	28.1
Magnesium Mg	+2	1295	3.68	24.305	53.3
Calcium Ca	+2	416	1.18	40.078	10.4
Potassium K	+1	390	1.11	39.098	9.97
Bicarbonate HCO3	-1	145	0.41	61.016	2.34
Bromide Br	-1	66	0.19	79.904	0.83
Borate BO3	-3	27	0.08	58.808	0.46
Strontium Sr	+2	13	0.04	87.620	0.091
Fluoride F	-1	1	0.003	18.998	0.068