MEASURING AND MODELING THE SHRINKAGE CHARACTERISTICS OF PLASTIC CLAYS

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ABSTRACT

Clayey soils are generally used as liner material in landfill to prevent ground water pollution. The swelling and shrinkage soils are affected the change in the water content. Significant shrinkage caused by loss of pore water in clays may cause enormous damage to liner systems. This study presents the shrinkage behaviour of KB soil and MX80 bentonite from saturated condition under zero applied stress. Duplicate specimens were prepared at different water contents and the volumes of the soils were experimentally measured using wax method. The shrinkage characteristic curves (SSCC) were then established. In addition, continuous SSCC were also established using Kea model and compared with the experimental SSCC. The SSCC enabled the determination of shrinkage limits and the air entry value (AEV). Furthermore, the void ratios at consistency limits were identified. The void ratios obtained for KB soil in term of liquid limit (e_{LL}), plastic limit (e_{PL}), shrinkage limit (e_{SL}); and at air entry (e_{AEV}) are 1.16, 0.88, 0.59 and 0.94 respectively. Meanwhile, the void ratios (e) obtained for MX80 bentonite in term of liquid limit (e_{LL}), plastic limit (e_{PL}), shrinkage limit (e_{SL}); and at air entry (e_{AEV}) are 12.24, 1.76, 0.34 and 0.40, respectively. Kea model can be used to establish a continuous shrinkage path of soil having two shrinkage phases with some limitations. Furthermore, it was noted that, the fitting parameters (i.e. the slope parameter depending on the air entry value (β) and slope of the saturation line (φ)) were found to be different for different soil of different physical properties and different mineral compositions.

ABSTRAK

Tanah liat biasanya digunakan sebagai bahan pelapik di tapak pelupusan sampah untuk mencegah pencemaran air bawah tanah. Tanah bengkak dan pengecutan dipengaruhi oleh perubahan dalam kandungan air. Pengecutan ketara yang disebabkan oleh kehilangan air liang di dalam tanah liat boleh menyebabkan kerosakan besar kepada sistem pelapik. Kajian ini membentangkan kelakuan pengecutan tanah KB dan MX80 bentonit yang digunakan; dari keadaan tepu di bawah tekanan sifar. Spesimen pendua telah disediakan pada kandungan air yang berbeza dan isipadu tanah eksperimen diukur dengan menggunakan kaedah lilin. Lengkung cirian pengecutan (SSCC) kemudiannya ditubuhkan. Di samping itu, SSCC berterusan juga telah ditubuhkan menggunakan model Kea dan dibandingkan dengan SSCC eksperimen. SSCC membolehkan penentuan had pengecutan dan nilai kemasukan udara (AEV). Tambahan pula, nisbah lompang pada had yang konsisten telah dikenal pasti. Nisbah lompang yang diperolehi bagi tanah KB dalam tempoh had cecair (e_{LL}), had plastik (e_{PL}), had pengecutan (e_{SL}); dan pada kemasukan udara (e_{AEV}) adalah 1.16, 0.88, 0.59 dan 0.94 masing-masing. Sementara itu, nisbah lompang (e) yang diperolehi untuk bentonit MX80 dalam tempoh had cecair (e_{LL}), had plastik (e_{PL}), had pengecutan (e_{SL}); dan pada kemasukan (e_{AEV}) adalah 12.24, 1.76, 0.34 dan 0.40, masing-masing . Model Kea boleh digunakan untuk mewujudkan laluan pengecutan berterusan tanah yang mempunyai dua fasa pengecutan dengan beberapa had. Tambahan pula, ianya dinyatakan bahawa, parameter yang sesuai (iaitu parameter cerun bergantung kepada nilai kemasukan udara (β) dan kecerunan garis tepu (φ)) telah didapati berbeza bagi tanah yang berlainan sifat yang berbeza fizikal dan komposisi mineral yang berbeza .

TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURE

LIST OF SYMBOL

e	-	Void ratio
e_{AEV}	-	Void ratio at Air Entry Value
e_{LL}	-	Void ratio at Liquid Limit
e_{PL}	-	Void ratio at Plastic Limit
e_{SL}	-	Void ratio at Shrinkage Limit
e_o	-	Initial void ratio
Gs	-	Specific gravity
k	-	Hydraulic conductivity
Sr	-	Degree of saturation
w	-	Water content
w_i	-	Initial water content
β	-	Slope parameter depending on the air entry value
φ	-	Slope of the saturation line
ρ_d	-	Dry density

LIST OF ABBREVIATION

AEV	-	Air entry value
ASTM	-	American Society for Testing and Materials
BS	-	British Standard
GCL	-	Geosynthetic clay liners
KB	-	Kuantan Brick
LL	-	Liquid limit
PI	-	Plasticity index
PL	-	Plastic limit
SL	-	Shrinkage limit
SSCC	-	Soil shrinkage characteristic curve

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

Waste materials are generated daily in the form of solid, sludge, liquid, or gas (Bouzza & Van Impe, 1998). Increasing number of population for a developing country like Malaysia will inevitably produce more wastes that need to be disposed. Disposal of these wastes need to be carried out in a proper way to ensure the safety of the environment. One of the methods of waste disposal is by permanent disposal at landfill sites (Ayomoha *et al.,* 2008). A proper landfill should be able to contained waste at the same time preventing the migration of pollutants into the environment. In order to obtain the best waste disposal practices, waste characterization must be undertaken prior to designing a landfill.

Landfill is built up with layers of solid waste and covered with soil or bottom liner to prevent ground water pollution. A landfill is designed in order to minimize public health and environmental impacts. The main feature of a sanitary landfill is that a liner is designed at the bottom of the landfill (Bagchi, 2004). According to Qian *et al.*, (2002), liner system in landfill acts as a barrier against the advective and diffusive transport of leachate. In addition, liner system in landfill consists of multiple barrier and drainage layers (Qian *et al.*, 2002). Clayey soils are widely used as liner material for landfills. Clayey soil is used as liner material due to its low hydraulic conductivity (k) and sorptive properties (Oweis and Khera, 1998). In some cases, geosynthetic clay liners (GCL) containing bentonite and geotextile are used (Sharma and Reddy, 2004). Furthermore, the use of natural soil containing kaolinite minerals is used as cheaper alternatives.

Clay exhibits swelling and shrinkage behaviour when subjected to wetting and drying processes (Hsai-Yang and Daniels, 2006). In landfills, clay liners received water when in contact with groundwater or stormwater that infiltrate into the landfill which in turn caused the liners to swell. On the other hand, upon drying, soil containing clay mineral undergoes shrinkage process and reduction in volume with water content changes. Shrinkage behaviour of clays can cause damage to structures built on or with clays (Sivapullaiah *et al.*, 1986).

During the dry periods, clayey soil will shrink and form cracks (Sivapullaiah *et al.*, 1986). Significant shrinkage and the excessive formation of cracks cause problems to the landfill. Thus, shrinkage behaviour is important for long-term assessment of engineering behaviour of clays. It is very important to determine the shrinkage behaviour of soil. Studies relating to shrinkage behaviour of soils have been shown to be useful in the assessment of stability of clay barriers (Tang *et al.*, 2008). In order to determine the shrinkage characteristic of clays soil, volume measurement of soil during drying is required. Generally, duplicate soil specimens are prepared and tested in the laboratory for this purpose. However, this process is tedious and time consuming (Head, 2006).

Literature suggested that, the use of several soil parameters can be used to establish the soil shrinkage characteristic curve according to Chertkov, (2000). By using parameters such as water content and specific gravity, the entire shrinkage curves at any given water content can be establish for a given soil. Various researchers in the past have proposed models such as, ModGG model, ModC model, OH model, TD model, Gea model, Bea model, Kea model, MM2 model and MM1 model can be used to establish the soil shrinkage characteristic curve (Cornelis *et al.,* 2006). As the shrinkage curve of soils is generally nonlinear in nature, a number of equations are used to establish the entire shrinkage curve. A model proposed by Kim *et al.* (1992) however, uses a simple equation which combined an exponential and liner functions which gave best fits to experimental data (Cornelis *et al.,* 2006)

In this study, wax method was used to measure the volume change behaviour of soil during drying from initially saturated condition under zero applied stress. The use of wax as a coating material enabled the volume of soil specimens to be measured. Multiple specimens were prepared at various water contents to establish the shrinkage curves. The result obtained experimentally was later compared with the curve established using Kea model.

1.2 PROBLEM STATEMENT

Clayey soils are generally used as liner material of landfill in purpose to prevent the waste water from infiltrating groundwater and pollute the environment. Due to this fact, it is important to measure the shrinkage characteristic of natural clay soil and the stability of liner system. It is also important to ensure the applicability of natural soil to be use as landfill liner.

1.3 OBJECTIVES

Based on the problem statement above, several objectives need to be achieved in this study. The objectives are:

I. To measure the shrinkage characteristics of natural clay soil (i.e. Kuantan Brick soil) and MX80 bentonite by using the wax method.

II. To establish the shrinkage characteristics of natural clay soil in Kuantan Brick and MX80 bentonite by using currently available shrinkage model.

III. To compare the result from both experimental and characteristic curve obtained from that of model.

1.4 SCOPE AND LIMITATION

The shrinkage characteristics of two soils with different mineral compositions and properties are used. Natural clay soil taken from Kuantan Brick at Kuantan, Pahang and MX80 bentonite obtained from Wyoming are considered in this study. The shrinkage behaviours of the clays during drying are measured experimentally from initially saturated slurried condition under zero applied stress using wax method. A single shrinkage model is then used to establish the entire shrinkage curve of both soils.

1.5 THESIS OVERVIEW

The thesis is divided into five consecutive chapters.

In chapter 2, detailed literature reviews concerning the study undertaken are presented. This chapter briefly explained about liner system that applying on the landfill. Followed then, the briefly explanation of the clay liner used as a liner material on landfill site. More explanation about the mineral's group (i.e. kaolinite, illite and bentonite) containing in the clays is presented. In this chapter also present about the interaction between water and clays minerals, followed by the shrinkage behaviour of the soils. Next is explanation about volume measurement to determine the shrinkage characteristic of soils. Lastly, this chapter presented about the proposed model to establish the shrinkage characteristic curve of soils.

In chapter 3, the material properties and the methods used in this study are presented. At the beginning, the methods used to determine the physical properties are presented such as the specific gravity, particle size distribution, initial water content, liquid limit and plastic limit; then followed by the determination of the mineralogical properties of soils by using X-ray diffraction. After that, the briefly explained on the method used to measure the volume change behaviours of soils during drying and the proposed model that used to establish the shrinkage characteristic curve also presented.

In chapter 4, the results obtained from the experimental and theoretical are discussed and presented. The physical properties and the mineralogical properties (i.e. the specific gravity, particle size distribution test, initial water content, Atterberg limits and the mineral composition) are presented first. Then followed by presented the results obtained from volume measurement test (i.e. shrinkage curves, shrinkage limit, void ratios at consistency limits and AEV determination). Besides, the establishing of the shrinkage paths for both soils from available model is also presented.

In chapter 5, the conclusions based on the findings of this study are presented.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to provide a review of past research efforts related with the measuring of the shrinkage characteristic of clays. A review of other relevant research studies is also provided. Substantial literature has been studied on application of landfill liner, clay minerals, shrinkage behaviour, volume measurement and model. The review is organized chronologically to offer insight to how past research efforts have laid the groundwork for the present research effort.

Waste can be classified into mineral, industrial, hazardous and municipal solid waste. Basically organic wastes contain materials which originated from living organisms. According to Kreith, municipal waste produced from the residential, commercial and institutional sources. The composition of the municipal waste is affluence from the society and economic status of the country (Kreith, 1994).

According to Theng, most of the solid waste disposal sites in Malaysia are either open dumps or controlled tipping. There is limited area to placing the waste for the site of controlled tipping. The pollution levels from these sites are expected to be high especially the contamination of soil, air, surface and underground water. All these pollutions can give effects to human being (Theng *et al.*, 2004)

The materials used in the landfill design are very important to research in order to meet several geotechnical design criteria that are acceptable to the public. According to J. Martin, impermeable clay soils can avoid the seepage of landfill leachate, thus make it more often to establish the landfill sites. In the UK, several large sites receiving municipal households waste from London have been sited on Oxford clay (J. Martin and Stephens, 2006).

According to Camp *et al.* (2010), normally landfills come with a cover barrier that includes a compacted clay liner. However, this barrier encounters numerous problems, especially those related to the in situ implementation and the differential settlement. This can cause stress in the clay layer that leads to the development of cracks. Moreover, it is necessary to maintain the physical and mechanical characteristics of the clayey soil and its waterproofing properties at required level such as the permeability of the soil is lower than the 10^{-9} m s^{-1} (Camp *et al.*, 2010).

2.2 LANDFILL (LINER SYSTEM)

According to William, landfill can be classified into 3 classes based on the types of waste that are hazardous waste, designated waste and municipal waste (Williams, 2006). However the majority of landfill being used today is dealing with municipal waste. Municipal solid waste landfill designed and operated to minimize public health and environmental impacts.

According to Kerry *et al.* (2005), the modern landfills are highly engineered containment systems, designed to minimize the impact of solid waste on the environment and human health. In modern landfills, the waste is contained by a liner system. The primary purpose of the liner system is to isolate the landfill contents from the environment and therefore, to protect the soil and ground water from pollution originating in the landfill (Kerry *et al.*, 2005). The Figure 2.1 shown the landfill is installed with liner to protect from leachate into soil.

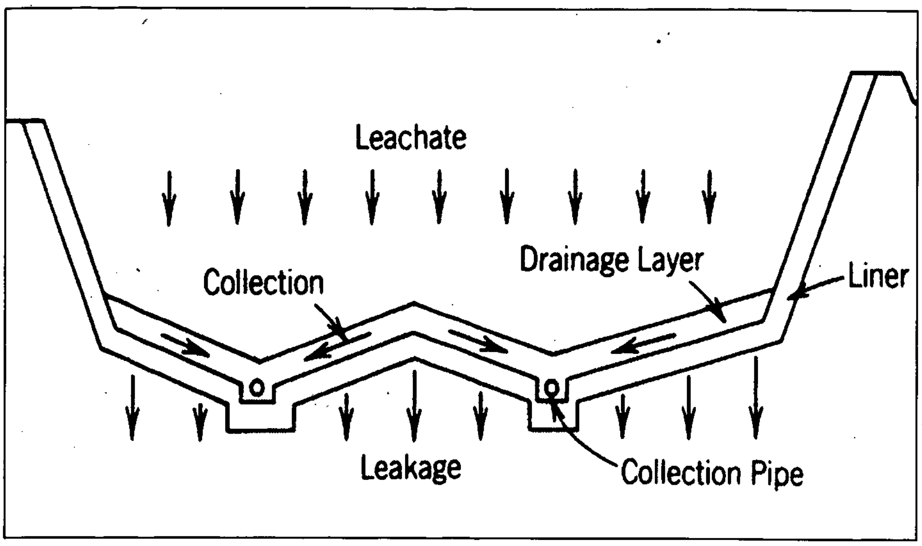

Figure 2.1: Installation liner on landfill

Landfill liners are designed and constructed to create a barrier between the waste and the environment and to drain the leachate to collection and treatment facilities. There are different types of materials that have used to construct the landfill liners and final covers fall into three categories that are the clayey soil, synthetic membranes or other artificially manufactured materials and amended soil or other admixtures (Bagchi, 2004). This is done to prevent the uncontrolled release of leachate into the environment.

2.2.1 CLAY LINER

The liner components are very important to study before design the landfill. According to Kerry *et al.* (2005), clay is used to protect the ground water from landfill contaminants and can only allow water to penetrate at a rate of less than 1.2 inches per year specified by regulations. Besides, clays compacted at higher moisture contents are more effective barriers to contaminants compare that compacted at lower moisture contents (Kerry *et al.*, 2005).

According to Oweis and Khera, generally clays acting on reducing hydraulic conductivity of soils used in the construction of liners and slurry walls for containment of new or existing waste disposal facilities. In general, typical type of clay liners is the soil which can classified as clay with high plasticity, clay with low plasticity, and sandy clay. In liner construction clay is compacted wet-of-optimum and the field moisture content is typically higher than the shrinkage and plastic limits (Oweis and Khera, 1998). According to Koerner and Daniel, clay with low plasticity index and high shrinkage limit is preferable (Koerner and Daniel, 1997).

According to Bagchi, clay that is used in the construction of compacted clay liner should have the following specifications that are liquid limit is between 20 percent and 30 percent, plasticity index is between 10 percent and 20 percent and clay fraction is 0.002 mm or less (Bagchi, 2004). Figure 2.2 show the clay liner as the liner landfill.

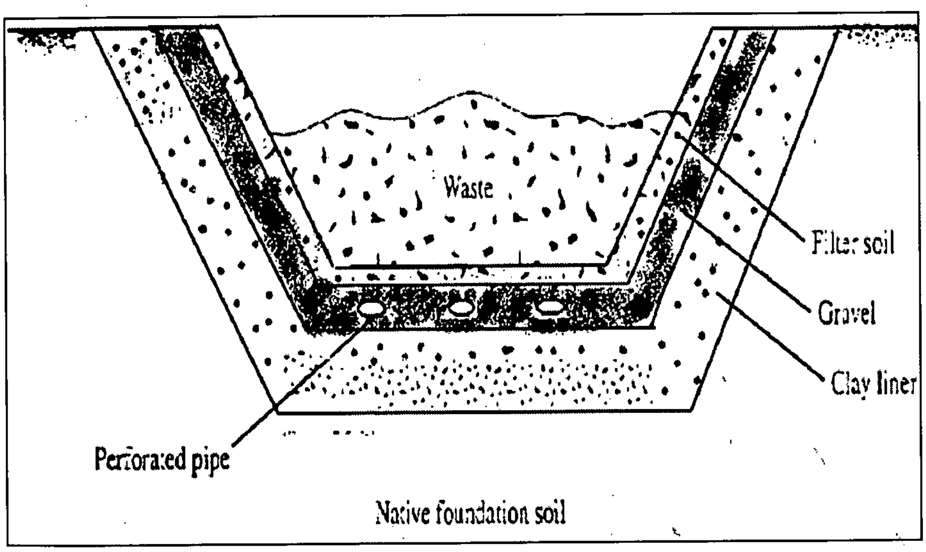

Figure 2.2: Clay liner as liner material in landfill

2.3 CLAYS

Fine-grained soils, such as fine silts and clays, are usually found in deeper water. This is due to the fact that as currents dissipate only fine-grained soils are carried further into a deposition basin or deepwater flow channel. Sands without silts or clays are also susceptible to grain flows, but occur only locally in areas with relatively steep slopes (Middleton, 1970). A soil is consider as a fine-grained soil when the soil passes 50 percent or more by weight of the particles finer than the No. 200 sieve (Naresh C. Samtani, 2006).

Commonly, clayey soil used as lining nonhazardous waste landfills. According to Bagchi, clay can be defined as the soil that is made up of millions of tiny particles, that has particles equal to or finer than 0.002mm (Bagchi, 2004). According to Whitlow, clay is a particle that having sizes below 2μm and can feel that it is slightly abrasive but not gritty and also feel greasy (Whitlow, 2001).

According to Singer and Munns, the surface of clay soil is said to be surface active which means that much happen on their surface. The surface of the clay soils can absorb and holds water, organic compounds, toxic ions and also plant nutrients ion (Singer and Munns, 2006). Alternatively, some clay is more prone to loss of strength due to sensitivity. These clays are relatively strong in their natural, undisturbed state, but can quickly change to a liquid mass when disturbed (Sultan, *et al.,* 2004).

Clay minerals are complex aluminium silicates composed of two basic units that are silica tetrahedron and alumina octahedron. Each tetrahedron unit consists of four oxygen atoms surrounding a silicon atom meanwhile the octahedral units consist of six hydroxyls surrounding an aluminium atom. There are three important clay minerals that are kaolinite, illite and montmorillonite (Das, 2006).

2.3.1 Kaolinite Mineral

Kaolinites be likely to develop in areas that having relatively high precipitation but good drainage that enables the leaching of Magnesium (Mg), Calcium (Ca) and Ferrum (Fe) cations (Mitchell and Soga, 2011). The kaolinite group are known as 1:1 clay minerals because they consists of repeating layers of one silica tetrahedron sheet and one alumina octahedron sheet. They consists of a several layers of the basic layer is about 0.72 nm thick that extends indefinitely in the other two directions. These basic layers are held together by strong hydrogen bonds between the hydroxyls of the octahedral sheet and the oxygen of the tetrahedral sheet (Robert *et al.,* 2011). The Figure 2.3 shows the schematic diagram of the structure of kaolinite.

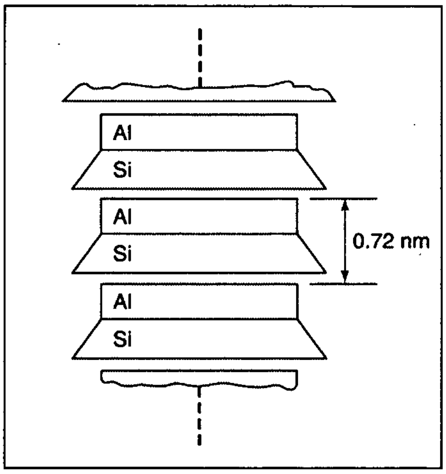

Figure 2.3: Schematic diagram of kaolinite structure

2.3.2 Illite Mineral

Illite group has a 2:1 structure due to its minerals composed of two silica sheets and one alumina sheet in between. The illite interlayer's are bonded together with a potassium ion. These potassium ions (K^+) are strongly bonds the layers together because the diameter of K^+ atom is almost exactly same with the diameter of hexagonal hole in the silica sheet thus it's just fills the hole. Besides, there is some isomorphous substitution of aluminium for silicon in the silica sheet (Robert *et al.*, 2011). The Figure 2.4 shows the schematic diagram of the structure of illite.

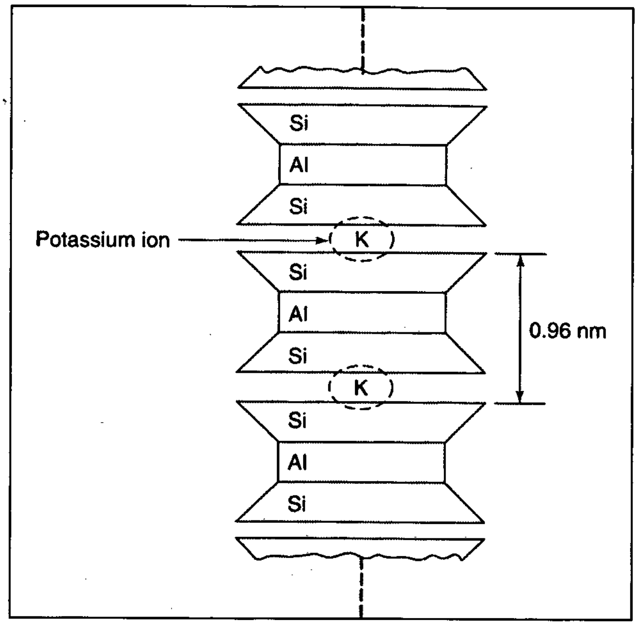

Figure 2.4: Schematic diagram of illite structure

2.3.3 Montmorillonite Mineral

In montmorillonite group, these minerals composed of two silica sheets and one alumina sheet in between. Thus it also called as 2:1 clay minerals same as Illite group. A single layer formed by the tips of the silica share oxygens and hydroxyls with the alumina sheet. The layer thickness of each is about 0.96 nm and the layers extend indefinitely in the other two directions (Robert *et al.*, 2011). According to Handy and Spangler (2007), the dominant clay mineral in most bentonite is montmorillonite. Bentonite is the entire layers of volcanic ash that converted into white, sticky and highly expansive clay by chemical weathering (Handy and Spangler, 2007). The Figure 2.5 shows the schematic diagram of the structure of montmorillonite.