THE ABSORPTION AND DESORPTION CHARACTERISTICS OF MANSULI
BENTONITE

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# ABSTRACT

Moisture content of a soil is defined by water content in the specific soil. It is important to know the water content in soil in order to find the characteristics . Due to the type of ions contained, the level of hydration and swelling will varies. This study focus on the determination of absorption and desorption of Mansuli Bentonite clay. Appropriate suction methods, wetting and drying process using Vapour Equilibrium Technique and the second method, Chilled Mirror Device were used in this study. The hysteresis effect in the water potential-water content relation is obtained under wetting and drying process, where hysteresis is the difference in the relationship between the water content of the soil and the corresponding water potential. The compared results of both methods by using soil-water characteristics curve (SWCC) shows that Mansuli Bentonite has a very high soil suction. In general, this study shows that the reading of soil suction of Mansuli Bentonite from both method is almost the same. With different levels of water content, soil suction will varies. The higher water content in Mansuli bentonite result with lower soil suction.

# ABSTRAK

Kandungan lembapan tanah yang ditakrifkan oleh kandungan air dalam tanah tertentu. Ia adalah penting untuk mengetahui kandungan air dalam tanah untuk mencari ciri-ciri. Disebabkan oleh jenis ion yang terkandung, tahap penghidratan dan bengkak akan berbeza-beza. Fokus kajian mengenai penentuan penyerapan dan penyaherapan daripada Mansuli Bentonit tanah liat. Kaedah yang sesuai sedutan, membasahkan dan proses pengeringan menggunakan Teknik Wap keseimbangan dan kaedah kedua, Peranti 'Chilled-mirror' telah digunakan dalam kajian ini. Kesan histerisis dalam air yang berpotensi air berhubung kandungan yang diperoleh di bawah basah dan kering proses, di mana histerisis adalah perbezaan dalam hubungan antara kandungan air tanah dan potensi air yang sepadan. Keputusan berbanding kedua-dua kaedah dengan menggunakan ciri-ciri tanah air lengkung (SWCC) menunjukkan bahawa Mansuli Bentonit mempunyai sedutan tanah yang sangat tinggi. Secara umumnya, kajian ini menunjukkan bahawa bacaan sedutan tanah Mansuli Bentonit dari kedua-dua kaedah adalah hampir sama. Dengan tahap yang berbeza kandungan air, sedutan tanah akan berbeza-beza. Kandungan air yang lebih tinggi dalam Mansuli bentonit menyebabkan dengan sedutan tanah yang lebih rendah.

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$K_2SO_4$        Potassium sulfate

$KNO_3$        Potassium nitrate

NaCl        Sodium chloride

KCl        Potassium chloride

$K_2CO_3$        Potassium carbonate

LiCl        Lithium chloride

# CHAPTER 1

# BACKGROUND

## 1.1    INTRODUCTION

The land surface of the earth was covered by soil mostly, ranging from few centimetres to several metres generally (Rahardjo *et al*; 1993). It contains of inorganic matter such as rocks and minerals, organic matter such as decaying plants and animals, living plants and animal ( microscopic) , water and air (redlund, 199). As the humankind has grown advanced in using raw material on earth, they had done some studies and succesfully classified the types of soil needed for specific application such as construction and agriculture.

About 75% of the earth surface is either clay or will be clay (Bennett, D.R. 1988). For the reason of the nature of clay particles, they form small, sheet-like structure, thus the soil clay structures is very dense with little porosity. Clay is is the earthy material containing particles with a grain size of less than 0.01 mm which give it the characteristic of soft and loose. This is due to the weathering and erosion of rocks that consist of mineral group from the ancient time. Under a fairly limited range of geologic conditions, clay and mineral were composited. The natural process that involves in the process of clay formation are such as soil horizons, continental and marine sediments, geothermal fields, volcanic deposites, and weathering rock formations. Most clay minerals form when rocks are in contact with water, air or steam. (Blat and others, 1980).

Natural clays generally contain a range of clay mineral, the most widely encountered minerals being kaolinite, calcite, illite, dolomite and smectite (Newman, 1987). Smectite has a characterstic in which, they can absorb and adsorb extremely well compared to the other five type of clay. Smectite are called living clay due to the powerful absorption characteristic (Newman, 1987). They also have a high detoxifying ability. (Hillier.S, 1995). Peer linkage of Bentonite is coming from the family of smectite. The absorptive properties of bentonites make them ideal for such diverse uses as a drilling mud, foundry sand bond, absorbents for oil,grease and animalmwaste and carriers for pesticides and fertilizers (Stanley, 1977).

Due to the high ability in asorption, it important for us to find the Soil Water Characteristic Curve (SWCC) of bentonite to ensure their optimum function in certain applications that need us to use bentonite. For this reason, a study focus on Mansuli Bentonite will be done to study the absorbtion and reabsorb of water in this type of clay, in order to find the engineering behaviour, specific unit weight, of Mansuli Bentonite.

## 1.2 PROBLEM STATEMENT

Moisture content of a soil is defined by water content in the specific soil. Behaviour of soils can be determined by having the water content of it. It is important to know the water content in soil in order to identify the characteristic. From experiment, several engineering properties of soil such as strength, compressibility, permeability, atterberg limit by determining the water content of the soil. As the soil textures and structures varies, they hold different amount of water. This varities will allowed them to be used in different applications. Experimental studies on unsaturated soils are costly, time consuming and are difficult to conduct. Knowing the characteristic of soil also can helps in identifying the function of the soil. One of the most important characteristic is soil suction. Due to the vary of suction in different type of bentonite, this study was conducted on mansuli bentonite.

Presently, it has become essentially standard practice in geotechnical engineering to use the Soil Water Characteristic Curve to compute an unsaturated coefficient of permeability when solving saturated and unsaturated flow problems.

The capabilities in absorption of bentonite can be identify using Soil Water Characteristic Curve. In order to come up with Soil Water Characteristic Curve, two variables needed are water content in the unit of percentage and soil suction in the unit of Mega Pascal.

Water movement in unsaturated in Mansuli Bentonite can be identfy using Soil Water Characteristic Curve (SWCC) as it has been used widely. By using SWCC, the characteristic such as shear strength and compressibility can be identified.

## 1.3 OBJECTIVE

There are several objectives to be accomplished through this study.

1. To determine the physical, chemical and mineralogical properties of mansuli bentonite drying and wetting.
2. To establish soil-water content curve (SWCC) for mansuli bentonite.

## 1.4 SCOPE OF STUDY

Mansuli bentonite was the speciment used in this study. To reach the objectives of this project, two analysis and testing will be carried out in the laboratory to get the results. Variables of this project are a water content of the Mansuli Bentonite and soil suction . For vapour equilibrium technique, two sample powder and slurry has been used. Six samples of mansuli bentonitel were slurried after oven-dried for drying while six samples of oven-dried soil has been used for wetting. For chilled mirror device, ten samples of mansuli bentonite with ten different water content has been prepared. Drying and wetting tests was conducted for applied suction of 3.6MPa to 262.75MPa using vapour equilibrium technique and chilled mirror device. These are the two available techniques that has been practiced in this study.

## 1.5 THESIS LAYOUT

This thesis consists of five consecutive chapters. In this chapter 1, it presents the minerology of bentonite, and soil water characteristic curve SWCC. Chapter 2 explain the literature review conducted that are related to this research study.

Chapter 3 is methodology. This chapter contents of methods and procedures for sample reparations, determination of bentonite clay properties (specific gravity, initial water content, soil mineral properties, and determination of drying and wetting behavior in mansuli bentonite.

Chapter 4 consists of results and discussion obtained from the study. This chapter consists of the final results of the study; engineering characteristic of mansuli bentonite (specific unit weight, atterberg limit,) can be identified. The results gained from drying and wetting process will be used to discussed the behaviour in mansuli bentonite. Based on the results, soil water characteristic curve can be form.

Chapter 5 is the conclusion and recommendations. This chapter summarizes the whole purpose of this study, the significance and important of this study for future references.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1    THEORETICAL BACKGROUND

The influential role of clay minerals in soil properties and soil properties and soil behaviour is derived from their particle size and shape, their large specific surface area in contrast to the soil particles of larger dimensions, and their physicochemical activities. The types and proportions of minerals present in clay significantly influence its index properties. Water content in soils effect the amount of liquid limit of soil. The liquid limit LL is the water content above which a disturbed soil starts to flow and to behave as a liquid, and the plastic limit PL is the water content below which disturbed unconfined soil fissures and behaves as a brittle solid. Between these limits the soil is said to behave as a plastic material. The influence of pore fluid composition on clay behaviour has been the subject of considerable interest in clay mineralogy (Low, 1980), soil physics (Barshad, 1952; Sposito, 1981), geotechnical engineering (Bolt, 1956;Mesri and Olson, 1971; Sridharan and Rao, 1973) and environmental engineering (Ye et al., 2014). In fact, clays, whose natural state pore fluid is generally a compound solution, may also be exposed to different aqueous solutions either deliberately or accidentally. The mechanical behaviour may be strongly influenced by physicochemical effects when alt concentrated pore fluids are introduced to clays (Studds et al., 1998; Di Maio et al., 2004; Rao  and Thyagaraj, 2007; Tripathy et al., 2013).

Water content of unsaturated soils are important soil properties in geotechnical engineering. An understanding of the absroption behaviour in unsaturated soils is required for numerous applications in geotechnical and geo-environmental areas such as nuclear waste disposal concepts and mud drilling. Due to the need to identify all the characteristic of soil mentioned above, soil water characteristic curve has been proposed.

## 2.2    BENTONITE

Bentonite terms was first used for clay found in about 1890 in upper cretaceous tuff near Fort Benton, Wyoming. Bentonite is generate frequently from the alteration of volcanic ash, in which smectite dominant predominantly on it. As the smectites are clay minerals, they even build up with individual crystallites where the majority of which are <2μm.

Bentonite is three-layer clay minerals. They built up of two tetrahedral layers and one  octahedral layer. In montmorillonite tetrahedral layers consisting of $[SiO_4]$ - tetrahedrons enclose the $[M(O_5,OH)]$-octahedron layer (M = and mainly Al, Mg, but Fe also often found). The silicate layers have a slight negative charge that is compensated by exchangeable ions in the inter-crystallite region. The charge is so weak that the cations (in natural form, predominantly Calcium, Magnesium and Sodium ions) can be adsorb in this region with their hydrate shell. The extent of hydration produces inter-crystalline swelling. Depending on the nature of their genesis, bentonites contain a variety of accessory minerals in addition to montmorillonite. (Industrial Minerals Association, 2011). Bentonite minerals may include quartz, feldspar, calcite and gypsum. The presence of these minerals can affect the industrial value of a deposit, reducing or increasing its value depending on the application. Bentonite presents strong colloidal properties and its volume increases several times when in contact with water, creating a gelatinous and viscous fluid (Grindrod, 1999). The special properties of bentonite (hydration, swelling, water absorption, viscosity) make it a valuable material for a wide range of uses and applications.

### 2.2.1   Bentonite-Water Interaction

The fundamental property of bentonite is to absorb water and expand. Depending on types of bentonite, some might absorb more and someone might not as the absorption capacity varies. Due to the type of ions contained, the level of hydration and swelling will varies.

For montmorillonite, the total negative charge contributed to the structure by the sum of all the oxide anions is somewhat in excess of the total positive charge contributed by the sum of all the structural cations Silicon, Alluminium, Ferum and Magnesium and imparts a slight overall negative charge to the surfaces of the clay sheets (Yu, 2006). Slight excess negative charge on the sheets was counterbalanced by free-moving (exchangeable) cation that exists between them. These three layers in each sheet comprise individual bentonite platelets which are typically 1 nm in thickness and 0.2-2 microns in diameter. (Grindrod, 1999). Dry platelets of sodium bentonite are most commonly grouped together in a face-to-face arrangement, with exchangeable cations and small amounts of absorbed water in an interlayer region between each platelet. The thickness of the interlayer region is variable depending on the amount of water absorbed between the platelets (Huo, 2002).
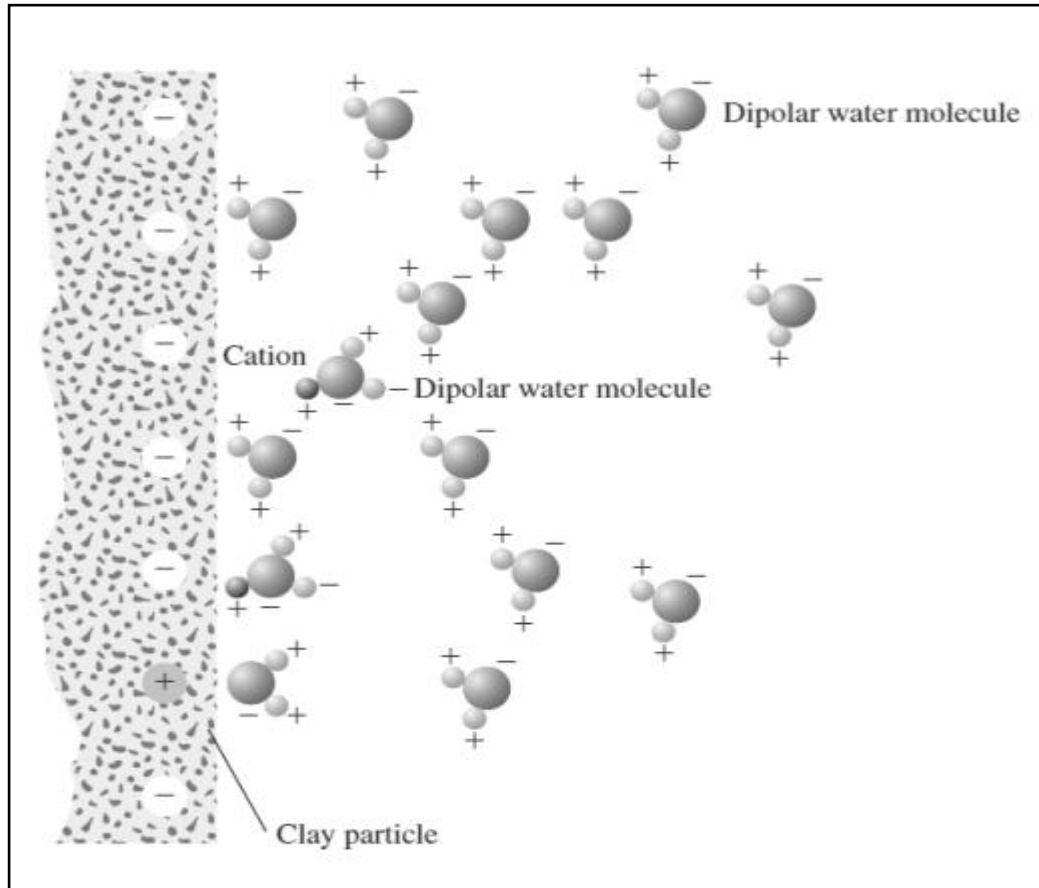
**Figure 2.1 :** Attraction of dipolar molecules in diffuse double layer (Das, 2010)

The plastic properties of the clay soils are due to the orientation of water around the clay particles (Bolchover, 1998). It needs to be well recognized that the presence of clay minerals in a soil aggregate has a great influence on the engineering properties of the soil. The present of moisture in clay influenced the engineering behavior of a soil as the percentage of clay mineral content increases (Ahmer Wadee, 1998).

## 2.3    SOIL SUCTION

Soil suction is the soil exerts the attraction on the water and manifests itself as a tensile hydraulic stress in a saturated piezometer. Water is hard to remove from the void as the size of the void decreases. It can be measured in terms of the partial vapor pressure of the soil water (Richards, 1965) and represents the thermodynamic potential pore water relative to free water, where the free water is defined as water with no dissolved solutes. The use of soil suction in explaining the mechanical behavior of unsaturated soils in relation to engineering problems was introduced by Croney and Coleman (1948). The gradients in suction are the driving forces for water movement in soil, and that components of the total suction could be balanced against each other (Edgar Buckingham, 1920).

### 2.3.1    Matric Suction

The pressure dry soil exerts on the surrounding soil to equalise the water or moisture content in the overall block of soil is called matric suction (Fredlund, 1972). This type of suction conditions is obtained through steady state unsaturated seepage analysis. Due to surface tension, a meniscus forms at the soil-air interface, resulting in decreasing of vapour pressure in the water. When the vapour pressure decreases, it will become more negative in which, the matric suction pressure increses as the radius of curvature of the meniscus decreases. Therefore, the vapour decrease when the degree of saturation decrease.

### 2.3.2    Osmotic Suction

From the electrical conductivity of an extract of the pore fluid, the osmotic suction can be determined. Due to the presence of dissolved ions in water, it will decrease the vapour pressures, relative humidity, in which this will increase the total osmotic suction. Osmotic suction can be significant portion of the total soil suction ( Jkruhn, 1972). However, there is no theoretical procedure for back-calculating to obtain the osmotic suction at lower water content. An inverse linear relationship between cation concentration and volume of water in the soil would be the most reasonable way to do the back-calculating. Osmotic suction arises is because of a reduction in the chemical potential of the pore water in clays due to the presence of

dissolved salt in the pore-fluid. Dissolved salt may originate either from exchangeable ions in the interlayer pore space of clay minerals or from the free pore-fluid. Osmotic swelling and consolidation is attributed to pressures that develop as a result of dissolved salt concentrations between the interlayer pore fluid and the free pore-fluid (Bolt, 1956; Barbour and Fredlund, 1989; Pusch and Yong, 2003; Schanz, 2013) .

## 2.4    SUCTION CONTROL TECHNIQUES

It is quite difficult to measure and control the suction of bentonite. Due to this fact, the evolution of the mechanics of unsaturated soils has not been as advanced as that of saturated soils. Now, there were further research on measuring and controlling suction in unsaturated soils been made for further evolutions. In geotechnical field, several techniques have been invented  in order to find soil suction.   In this paper, measuring and controlling suction of Mansuli Bentonite was measure in two different techniques.

### 2.4.1   Vapour Equilibrium Technique

Vapour equilibrium technique controls total suction. It do not provide direct measurement of the suction applied. Application of suction using sealed glass containers with soil specimens suspended over binary salt solutions is common (Kanno and Wakamatsu 1993: Delage et al. 1998; Saiyouri et al. 2000; Tang et al. 1998; Romero et al. 2001; Leong and Rahardjo 2002). The technique has also been applied to modified testing apparatus to control suction during traditional laboratory testing.

### 2.4.2   Chilled-mirror Dew-point  Technique

This deviced is used to measured the suction of a soil sample by measuring the relative of soil humidity . This deviced provides one of the few truly direct physical measurements of humidity. It is recognized as the most precise method of determining the water vapor content of a gas as it provide direct measurement of suction applied.

## 2.5    SOIL -WATER CHARACTERISTICS CURVE SWCC

The soil water characteristic curve (SWCC) or it also called as soil water retention curve is the basic drainage properties of partially saturated soils by showing the relationship between soil suction and water content. Since many years ago, many experiments had been done in order to find the best way to obtain SWCC. Scientist Brooks and Corey have utilized available SWCC data and come up with empirical equations that fit data point on the fitting equations. Due to the requires of experimental data points, estimation techniques has been proposed. Estimation techniques considers physical properties of soils such as particle size distribution data to estimate SWCC. ( Arya and Paris, 1981; Fredlund ad Wilson, 1997). The slope of soil-water characteristic curve represents the slope of line conncting AEV and RWC. The part of the curve before the AEV value represents the stage where all soil pores are filled with water and hence represents saturated volumetric water content.
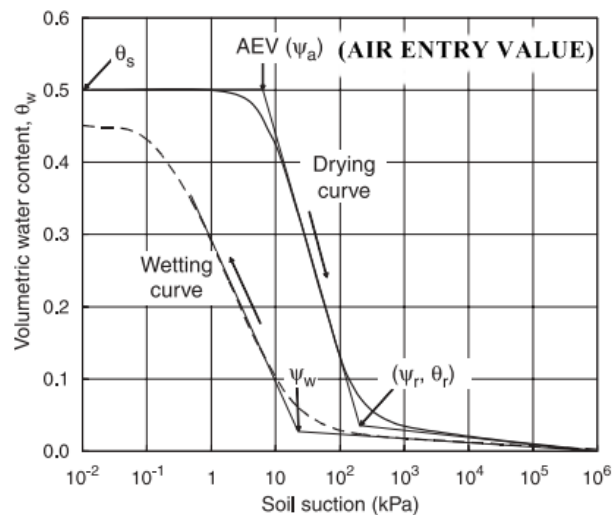


**Figure 2.3** : Idealized soil-water characteristic curves (modified after Fredlund and Xing 1994)

### 2.5.1    Wetting And Drying Curves

The relationship between the water content and suction is known as soil water characteristic curve. Soil water characteristic curve are often expressed in terms of volumetric water content, or degree of saturation, versus suction. Measurements are usually ade of gravimetric water content by weight. This will not allow any changes in volume   due to drying and wetting and can results in errors for soils that shrink and swell by significant amount. If the soil start from saturated state and then subjected into drying, it will follow the primary drying curve. As suction increases, the largest pores will reach their limiting value of suction, and they will start to desaturated. The suction at which this start to occur, when air first enter the soil, is known as the air entry value AET. Beyond the air entry value, the soil will reduce the water content as iner and finer pores progressively desaturated. At a value of suction known as residual suction , with a residual corresponding water content, the soil water characteristic curve may flatten and much smaller change in volumetric water content result from an increase in suction. It is suggested that within the residual zone, beyond the residual suction, water is held as adsorbed water on bentonite particles.

Wetting from oven dried state , the bentonite will follow the primary wetting curve At a point known as water entry value, a significant increase in water content occurs as more pores started to fill. When the suction is reduce to zero, the final volumetric water content ay be lower than the initial water content.
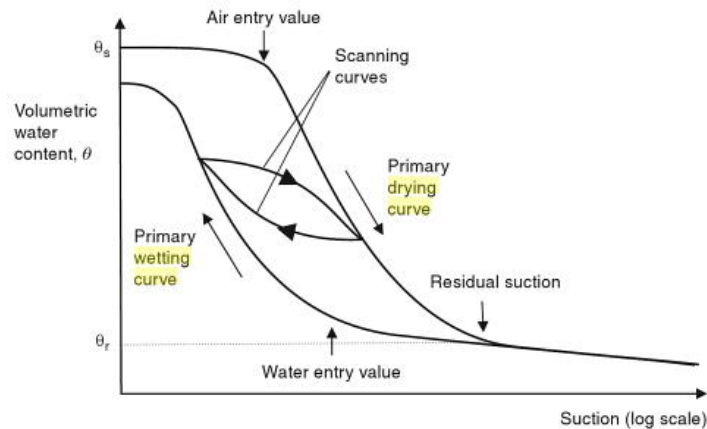
**Figure 2.4** : Idealized soil-water characteristic curves showing primary drying curve and primary wetting curve.

## 2.5.2  Hysteresis

Water content in the soil can be change in two directions, where it can be decreased in the drying process or increased in the wetting process. Because most functional characteristics of the thermodynamic variables in the real process show hysteresis, the hysteresis effect in the water potential-water content relation can be observed for soil. Thus, this relation is non-explicit and the course of hysteresis was determined by the colloidal-porous properties of the soil. The water content in the soil reached in the drying process is always higher than the corresponding water content reached in the wetting process. (Durner and Fluhler, 1996). The magnitude of the hysteresis was measured by the area between the drying and wetting soil water characteristic curve (Walczak R., 1985).

Hysteresis in soil is defined as the difference in the relationship between the water content of the soil and the corresponding water potential obtained under wetting and drying process. This dependency manifests itself through hysteresis (Haines, 1930). This means that water content in the drying (or drainage) branch of water potential − water content relationship − is larger than water content in the