



AN INVESTIGATION ON THE USE OF OEDOMETER METHOD FOR
DETERMINATION OF LIQUID LIMIT VALUE OF SOIL

VICKRAM ALAKUVENTHAN

*Thesis submitted in partial fulfillment of the requirements
for the award of the degree of
B. ENG (HONS.) CIVIL ENGINEERING

FACULTY OF CIVIL ENGINEERING AND EARTH RESOURCES
UNIVERSITY MALAYSIA PAHANG

JUNE 2014

ABSTRACT

Consistency limits are extensively used in geotechnical engineering practice. These limits are commonly referred to the Atterberg Limits and the limits are the liquid limit, plastic limit and shrinkage limit. Consistency limits is potentially useful as an index property for predicting the behaviour of clay soils. The liquid limit in particular is used in many correlations with engineering properties. It provides a good basis form predicting the soil properties such as deformability, expansion, hydraulic conductivity and strength. Therefore, liquid limit has strong links to underlying mechanical behaviour. However, the determination of the liquid limit by Casagrande Liquid Limit Device and Cone Penetration Method which are in international standards have their own limitation as they requires several points to determine liquid limit of soil as these both methods uses trial and error method. This study presents the investigation on the use of oedometer method as an alternative way to determine the liquid limit of zeolite from saturated slurried condition by using a small consolidation pressure of 0.9 kPa and 6 kPa. Thus by doing this, one can determine the liquid limit by one point determination technique as the equilibrium water content reached from the consolidation will be equivalent or nearer to the liquid limit of soil under the consolidation pressure either 0.9 kPa or 6 kPa. The physical properties of zeolite were determined and the liquid limit of zeolite was determined from cone penetration method. The test results shows that by using a consolidation pressure of 0.9 kPa, the value of liquid limit obtained from oedometer method is much nearer to the value of liquid limit obtained from the cone penetration method and the difference between those values obtained is less than 1%. Meanwhile, the liquid limit value obtained by using consolidation pressure of 6 kPa does not tally and far away from the value of liquid limit obtained from cone penetration method. Hence, by using consolidation pressure of 0.9 kPa, oedometer method can be used to determine the liquid limit of soil and for consolidation pressure of 6 kPa, other methods or different soil should be used and applied for determination of liquid limit value.

ABSTRAK

Had ketekalan adalah luas digunakan di dalam amalan kejuruteraan geoteknikal. Had-had ini biasanya dirujuk kepada had Atterberg dan had tersebut adalah had cecair, had plastik dan had pengecutan. Had ketekalan berpotensi untuk digunakan sebagai hartanah indeks untuk meramalkan kelakuan tanah liat. Had cecair khususnya digunakan dalam banyak korelasi dengan ciri-ciri kejuruteraan. Ia menyediakan satu bentuk asas yang baik meramalkan sifat-sifat tanah seperti kebolehcanggaaan, pengembangan, kekonduksian hidraulik dan kekuatan. Oleh itu, had cecair mempunyai hubungan yang kuat dengan tingkah laku mekanikal asas. Walau bagaimanapun, penentuan had cecair melalui kaedah Casagrande had cecair peranti dan kaedah tusukan kon yang dalam piawaian antarabangsa juga mempunyai had terbatas kerana kedua-dua kaedah memerlukan beberapa perkara untuk menentukan had cecair tanah kerana kedua-dua kaedah ini menggunakan kaedah percubaan dan kesilapan. Oleh iitu, kajian ini membentangkan siasatan terhadap penggunaan kaedah oedometer sebagai kaedah alternatif untuk menentukan had cecair zeolite dari tepu keadaan slurried dengan menggunakan tekanan penyatuan kecil yang bernilai 0.9 kPa dan 6 kPa. Oleh itu dengan melakukan ini, seseorang boleh menentukan had cecair dalam satu teknik penentuan sebagai kandungan air keseimbangan dicapai dari penyatuan ini akan sama atau lebih hampir kepada had cecair tanah di bawah tekanan penyatuan bernilai sama ada 0.9 kPa atau 6 kPa. Sifat-sifat fizikal zeolite telah ditentukan dan had cecair zeolite telah ditentukan melalui kaedah tusukan kon. Keputusan ujian menunjukkan bahawa dengan menggunakan tekanan penyatuan 0.9 kPa, nilai had cecair yang diperolehi daripada kaedah oedometer adalah lebih dekat dengan nilai had cecair yang diperolehi daripada kaedah tusukan kon dan perbezaan antara nilai-nilai yang diperolehi adalah kurang daripada 1%. Manakala, nilai had cecair yang diperolehi dengan menggunakan tekanan penyatuan 6 kPa adalah tidak sama dan jauh daripada nilai had cecair yang diperolehi melalui kaedah tusukan kon. Oleh itu, dengan menggunakan tekanan penyatuan 0.9 kPa, kaedah oedometer boleh digunakan untuk menentukan had cecair tanah dan manakala untuk tekanan penyatuan 6 kPa, kaedah lain atau tanah yang berbeza perlu digunakan dan diaplikasikan untuk penentuan nilai had cecair.

TABLE OF CONTENTS

	PAGE
SUPERVISOR'S DECLARATION	ii
STUDENT'S DECLARATION	iii
DEDICATION	iv
ACKNOWLEDGEMENTS	v
ABSTRACT	vi
ABSTRAK	vii
TABLE OF CONTENTS	viii
LIST OF FIGURES	xi
LIST OF SYMBOLS	xii
LIST OF ABBREVIATIONS	xiii
LIST OF APPENDICES	xiv
CHAPTER 1 INTRODUCTION	
1.1 Background of the Study	1
1.2 Problem Statement	3
1.3 Objectives	4
1.4 Scope of study	4
1.5 Thesis Overview	5
CHAPTER 2 LITERATURE REVIEW	
2.1 Introduction	6
2.2 Applications of clay	6
2.3 Types of clay	
2.3.1 Clays and their composition structure	7
2.4 Zeolite	10
2.5 Clay Soil- Water Interaction	11
2.5.1 Hydrogen Bonding	12
2.5.2 Hydration of Exchangeable Cations	12

2.5.3	Attraction by Osmosis	12
2.5.4	Charged Surface- Dipole Attraction	13
2.5.5	Attraction by London Dispersion Force	13
2.5.6	Capillary Condensation	13
2.6	Consistency of Fine-Grained Soil	
2.6.1	Plastic Limit of Soil	15
2.6.2	Liquid Limit of Soil	16
2.6.3	Importance/ Significance of Liquid Limit	17
2.6.4	Determination of Liquid Limit	
	2.6.4.1 Casagrande Liquid Limit Device Method	18
	2.6.4.2 Cone Penetration Method	19
	2.6.4.3 Oedometer Method	20

CHAPTER 3 METHODOLOGY

3.1	Introduction	22
3.2	Selection of Soil Sample	24
3.3	Determination of Physical Properties of Zeolite	
	3.3.1 Specific Gravity	25
	3.3.2 Particle Size Distribution	25
	3.3.3 Initial Water Content	26
	3.3.4 The Atterberg Limits	26
3.4	Liquid Limit Determination	
	3.4.1 Cone Penetration Test	27
	3.4.2 Oedometer Method	29
	3.4.2.1 Preparation of Slurry Specimen	29
	3.4.2.2 Testing Procedure	29

CHAPTER 4 RESULT AND DATA ANALYSIS

4.1	Introduction	31
4.2	Physical Properties of Zeolite	31
4.2.1	Specific Gravity	31
4.2.2	Fine Analysis	32
4.2.3	Initial Moisture Content	33
4.2.4	Consistency Limits	33
4.3	Liquid Limit by Oedometer Method	34
4.4	Discussion	36

CHAPTER 5 CONCLUSION AND RECOMMENDATION

5.1	Conclusion	37
5.2	Recommendation	38

REFERENCES	39
-------------------	----

APPENDICES A-D	42
-----------------------	----

LIST OF FIGURES

Figure No.	Title	Page
2.1	Basic Unit of Clay Minerals	8
2.2	Structure of Main Clay Minerals	9
2.3	Kaolinite, Illite, Smectite Sheet Structure	10
2.4	Illustration of Atterberg Limits	14
2.5	Casagrande Apparatus For Measuring The Liquid Limit	19
3.1	The Overview of The Experimental Investigation	23
3.0	ELE International Semi-Automated Cone Penetrometer	28
3.1	ELE International Oedometer Test Equipment	33
3.2	Particle Size Distribution Curve of Zeolite	32
3.3	Time-Equilibration Plot Obtained for 0.9 kPa	34
3.4	Time-Equilibration Plot Obtained for 6 kPa	35

LIST OF SYMBOLS

%	Percentage
kPa	kilo Pascal
kg	Kilogram
μm	Micrometer
mm	millimeter
m	meter
ml	milliliter
g	gram
N	Newton
$^{\circ}\text{C}$	Degree of Celcius
s	second

LIST OF ABBREVIATIONS

Fig	Figure
UMP	Universiti Malaysia Pahang
BS	British Standard
ASTM	American Society for Testing and Materials

LIST OF APPENDICES

Appendix	Title	Page
A	Specific Gravity Result	42
B	Fine Analysis Test Result	44
C	Atterberg Limit Test Result	47
D	Oedometer Test Result	50

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF THE STUDY

According to the Das (2010), soil is defined as the uncemented aggregate of mineral grains and decayed organic matter which is solid particles with liquid and gas in the empty spaces between the solid particles. In the Unified Soil Classification System (USCS), mostly soils are divided into two categories, which are coarse-grained soils and fine-grained soils. In coarse-grained soil, they are divided into two major divisions which are gravels and sands meanwhile silts and clays are classified under the fine-grained soils.

Furthermore according to Das (2010), soil consistency provides a means to describe and indicate the degree of firmness of fine-grained soil. The consistency also describes the degree and kind of cohesion and adhesion between soil particles. The consistency of soil can be expressed qualitatively in terms of very soft, soft, stiff, very stiff and hard. The consistency mainly depends on water content and also soil mineral. The water content significantly affects the properties of cohesive soils like silt and clayey soil. The physical properties of fine-grained soil differ greatly at different water content.

According to Sridharan *et al.* (2000), the consistency of soil are commonly referred to the Atterberg Limits. The consistency limits was initially proposed by Atterberg in 1911 for agricultural purposes. It was later adopted by Terzaghi in 1925 for classification of fine-grained soils for engineering purposes. It was Terzaghi who first realised their engineering potential (Seed *et. al*, 1964). The consistency limits are the liquid limit, plastic limit and shrinkage limit. The moisture content at which the transition from solid to semisolid state takes place is defined as the shrinkage limit. The moisture content at the point of transition from semi-solid to plastic state is the plastic limit, and from plastic to liquid state is the liquid limit (Das, 2010). The liquid and plastic limits define the transitions between liquid, plastic and brittle solid soil behaviour (Jefferson & Rogers, 1997). According to Dolinar and Skrabl (2012), as the water content is increased, the consistency of a fine-grained soil changes from the semi-solid state, to the plastic state, and eventually to the liquid state. The plastic limit is the soil's water-content boundary between the semi-solid and the plastic consistency. The liquid limit is the soil's water content where further increases in the amount of water change the consistency from the plastic to the liquid state. The plastic limit and liquid limit are often collectively referred to as the Atterberg Limits. The liquid limit in particular is a key of importance in soil mechanics because they determine, in a simple way, the interaction between the solid and liquid phases in soils, and thus provide the possibility of classifying soils into groups with similar mechanical properties. Perhaps, the liquid limit provides a good basis for predicting other soil properties, such as deformability, expansion, hydraulic conductivity, and strength

The liquid limit of soil is usually determined in two ways which are, Casagrande Liquid Limit Device Method and Cone Penetration Method (Christaras, 1991) Although these methods are standardized and in international standards, these methods requires several points and uses trial and error method to determine the liquid limit of soil. Hence, it can be said the progress of determining the liquid limit of soil using these methods are slow and there is no other well-known or other standardize methods to determine the liquid limit of soil using one point determination technique.

However, Sridharan *et.al* (2000), investigated and found out that the equilibrium water content, which is very near to the liquid limit water content of the soil, can be reached under a small consolidation pressure of 0.9 kPa. Wroth and Wood (1978), on the basis of earlier investigations has indicated that all fine-grained soils tend to equilibrate from the same high initial water-content state to their respective liquid limit water contents at an applied suction of the order of 6 kPa. So, an investigation needs to be done using oedometer method to determine liquid limit value of soil using consolidation pressure of 0.9 kPa and 6 kPa. It is believed that this study will fills an important gap in the literature where the oedometer method can be used as an alternative way to determine the liquid limit of soils in prior to the Casagrande Liquid Limit Device Method and Cone Penetration Method and this will provides a new data and approach for the researchers and engineers to determine liquid limit of soil using oedometer method.

1.2 PROBLEM STATEMENT

In geotechnical engineering practice, consistency limits are used extensively to determine the liquid limit of a fine-grained soil, currently there are two methods which are popular in practice and widely used and accepted as they are in international standards. They are, Casagrande Liquid Limit Device Method and Cone Penetration Method. And there are also many methods to determine the liquid limit of soil. But most of them require trial and error method. The values of liquid limit determined from Casagrande Method and Cone Penetration Method make use of a semi-logarithmic graph as these both methods requires several points to get the liquid limit value. It is clearly seen that the process of determining the liquid limit using these two standardize methods are tedious and cumbersome. However by knowing the pressure at liquid limit, the liquid limit of soil can be determined easily by one point determination. An investigation needs to be done using the oedometer method to determine the value of liquid limit of soil and this value will be checked and compared with liquid limit obtained from cone penetration method.

1.3 OBJECTIVES OF THE STUDY

The objectives of this research can be outlined as follow:

1. To determine the value of liquid limit of zeolite using oedometer method and cone penetrometer method
2. To compare using oedometer method to determine the value of liquid limit of soil with commonly used methods.

1.4 SCOPE OF THE STUDY

The scope of study is to determine the value of liquid limit of soil consisting zeolite as clayey soil using cone penetration method and oedometer method. The zeolite was used as the soil sample and only experimental investigation is considered and the samples are tested in Soil & Geotechnical Laboratory, UMP. The values of liquid limit were determined from the cone penetration method and oedometer method.

1.5 THESIS OVERVIEW

Chapter 2 presents the explanation and the information of clay minerals including its applications in engineering field, clays and their types, zeolite, clay soil-water interaction and consistency limits of fine grained soils and determination of liquid limit methods are presented along with the review of reported studies and related books of various investigator and writer.

Chapter 3 presents the methodology of the whole study are presented and well explained in terms of the determination of physical properties of zeolite and the determination of liquid limit of zeolite using oedometer method.

Chapter 4 presents results and data analysis, the laboratory data obtained is analyzed and the results are presented through the tables and graphical method.

Chapter 5 presents conclusion and recommendation, the results are concluded and checked whether the objectives of this study well achieved or not and recommendation and suggestions are discussed to improve the results obtained.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this chapter, a brief explanation and information of clay minerals including its applications in engineering field, clays and their types, zeolite, clay soil-water interaction and consistency limits of fine grained soils are presented along with the review of reported studies and related books of various investigator and writer. Furthermore, the reviews of studies and investigations about the determination of liquid limit methods are presented at the end of this chapter.

2.2 APPLICATION OF CLAYS

It is well known that clay minerals have many applications and uses in worldwide. However, the most famous of clay minerals application in worldwide and in engineering field is the use of clay minerals as liner system in landfill (Das, 2010). Solution for waste disposal that being used today is landfilling and landfilling is the only waste disposal method that can deal with all kinds of materials in the solid waste stream and it is also the

simplest and cheapest way of disposing solid waste (Choong, 2001). Landfill is designed with liner system to protect groundwater quality from the disposed wastes. The liner system consist of low permeable materials (viz.compacted clay, geo-membrane, geo-synthetic clay liner) and must contain the disposed wastes effectively (Sharma & Reddy, 2004). The essential function of bottom line of the landfill is to provide stability and to support the total waste mass as well as to prevent from pollution of groundwater with the landfill leachate. Leachates consist of water and water soluble compounds in the refuse that accumulates as water moves through landfill. This water maybe from the landfill and contaminate soil and ground water, thus presenting a risk to human health and environmental (Das, 2010).

So, clay can be used as cost effective bottom liners. Clay liners at the landfill body play a very important part in the whole barrier system for retaining pollutants. Porosity of clay is 40-70% and the clay has the property of swelling, plasticity, cohesion and adhesion.

2.3 TYPES OF CLAY

2.3.1 Clays and their composition structure

Clays are important constituent of soils, which evolve mainly from chemical weathering of rock forming minerals, and regarded as fine-grained soils in geotechnical engineering (Aksoy *et. al*, 2008). Weems (1993) stated that clay is a substance which is known as a deposit which is extensively distributed over the surface of the earth. It is found almost everywhere, but differs greatly in purity. Pure clay is a silicate of aluminum and when found in large quantities, it is called kaolin. Das (2007) explained that clay minerals are primarily hydrous aluminum silicates composed of two basic units, silica tetrahedron and alumina octahedron. Each tetrahedron unit consists of four oxygen atoms surrounding a silicon atom. The combination of tetrahedral silica units forms a silica sheet. Three oxygen atoms at the base of each tetrahedron are shared by neighboring tetrahedral. The octahedral

unit consists of six hydroxyls surrounding an aluminum atom and the combination of the octahedral aluminum hydroxyl unit gives an octahedral sheet. These structures are illustrated in Figure 2.1 below.

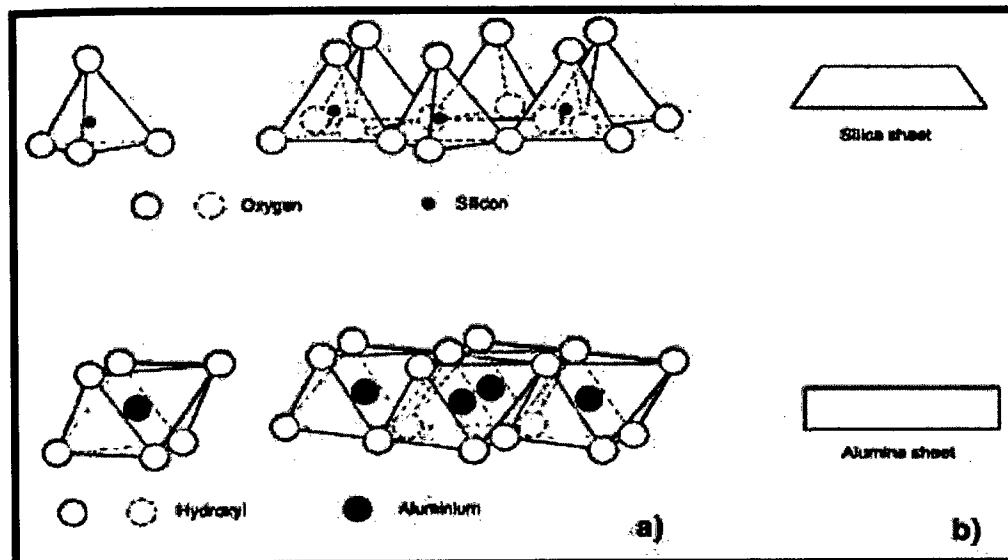


Figure 2.1: Basic units of clay minerals and the silica and alumina sheets

(after Mitchell, 1993)

Wesley (2010) explained that the most well-known clay minerals are kaolinite, montmorillonite, and illite. These have a crystalline structure, the basic units of which are termed as silica tetrahedron and alumina octahedron. These units combine to form special structures, which are usually represented graphically in the form shown in Figure 2.2. The actual clay particles are formed by combinations of these basic sheets, which form multilayered “stacks” as indicated in Figure 2.3, the nature of bonds between the sheets has a very important influence on the properties of the whole particle.

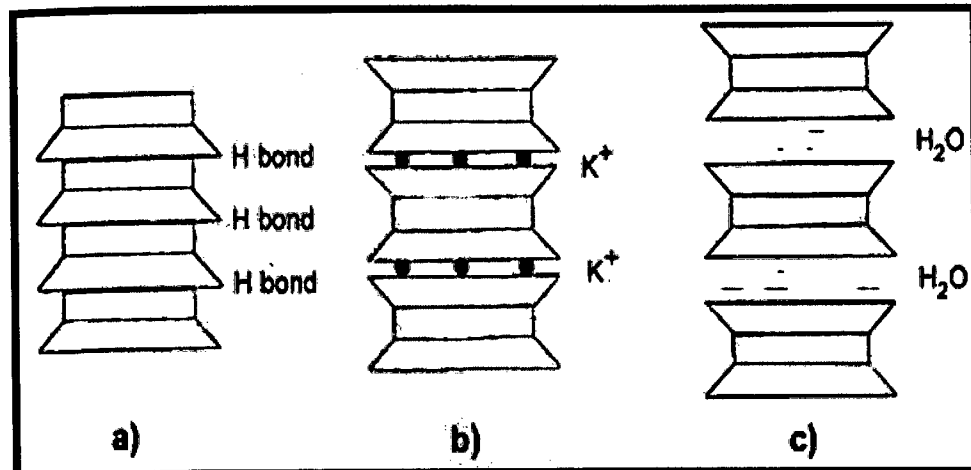


Figure 2.2: Structure of the main clay minerals: (a) kaolinite, (b) illite and (c) montmorillonite, based on combined sheets (after Craig, 1990)

Kaolinite particles have a basic structure consisting of a single sheet of silica tetrahedrons and a single sheet of alumina octahedrons. These combined effects are then held in a stack fairly tightly by hydrogen bonding. Illite particles have a basic structure made up of central alumina sheet combined with silica sheets above and below. The combined sheets are in turn linked together by potassium ions sandwiched between them. This is a fairly weak form of bond. Montmorillonite is made up of the same basic unit as illite but the form of bond between these basic units is different. Water and exchangeable cations provide this bond which is a much weaker bond than that in illite particles.

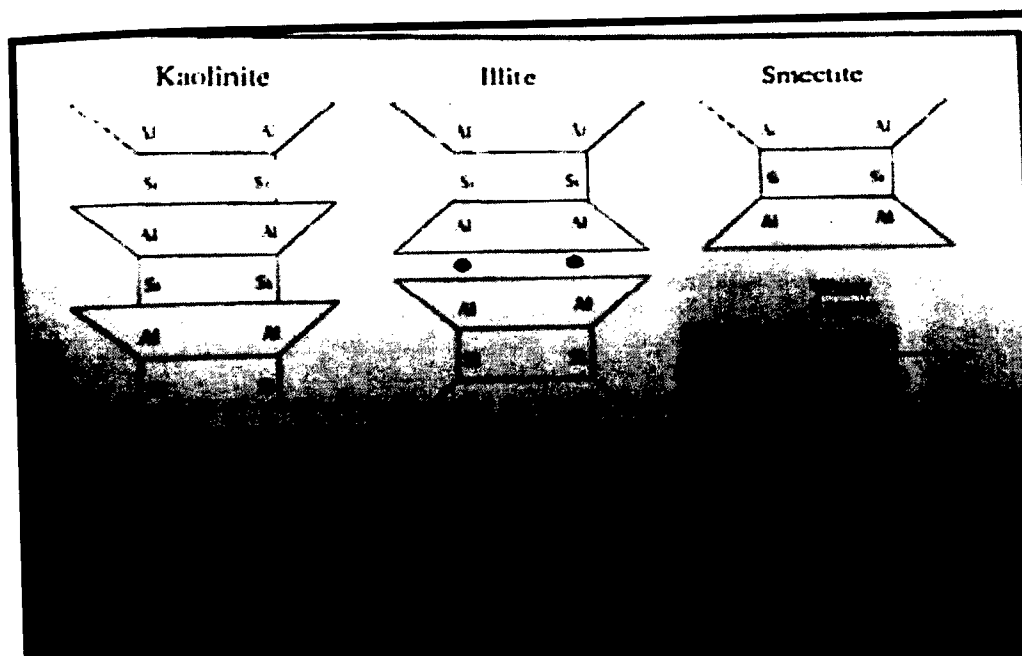


Figure 2.3: Kaolinite, Illite and Smectite Sheet Structure (after Wesley, 2010)

This special structures means that these clay particles are not inert as the rock particles. The term “active” is used to describe clay minerals, meaning that they are capable of swelling and shrinking by taking in water or losing it, depending on the environment surrounding them.

2.4 ZEOLITE

Auerbach *et al.* (2003) describe and explained that the zeolite is microporous crystalline aluminosilicates. Zeolite are found in nature and it was first discovered in 1756 by the mineralogist, Cronstedt. Most zeolite are known to occur in nature of are of lower Si/Al ratios, and sometimes this natural zeolites are found as a large single crystals as though it is very difficult to make large crystals in the laboratory.

From this zeolite, there are many interesting properties which are thermal stability, acidity, adsorption, and ion exchange property. Zeolites are extensively used in primarily three applications which are adsorbents, catalysts, and ion exchange. In adsorbent application, zeolite is used on removal of small polar or polarizable molecules as a purification process and bulk separation. In catalyst application, zeolite is used for synthesis of organic intermediates and fine chemicals which will be used for easy separation formwork, doping with metals for selective oxidation chemistry, and ease of regeneration of catalysts. The major use of zeolite in ion exchange agents is for water softening applications in the detergent industry and substitute use of phosphate. Apart from these applications, the zeolite is also used as an odor removal, plastic additives, fertilizers, soil conditioners, lightweight aggregate and pozzolanic cements and concrete and etc. Zeolite is also used in molecular sieve applications such as separation of oxygen and nitrogen from air and ion exchangers in pollution abatement processes.

However, zeolite has a unique property that the internal surface is highly accessible because of the ion exchange property. This ion exchange property provides a measure of the selectivity of one ion over another. Ion exchange property also provides information regarding phase transformations during exchange because of exclusion of a cation. Because of this unique property, the zeolite is selected and used as the soil specimen in this study.

2.5 CLAY SOIL-WATER INTERACTION

All clays have high affinity to water (Aksoy *et. al*, 2008). Similar observations were also made by Lambe (1949). According to Lambe (1949), water is strongly attracted to soil mineral surfaces particularly to clay. Dried clay adsorb water from the atmosphere even at low relative humidity, many soils swell when given access to water and temperatures above 100°C is needed to remove all the water from a soil. Several possible mechanisms for water adsorption have been proposed (Low, 1961).

2.5.1 Hydrogen Bonding

Surface of soil minerals are composed of a layer of either oxygen or hydroxyl, so hydrogen bonds can form easily with oxygen attracting the positive corners and hydroxyl attracting the negative corners of water molecules . Early concepts of the structure of adsorbed water suggested an ice-like character because of the similarity between the hexagonal symmetry of the oxygen and hydroxyls in clay surfaces and the structure of ice; however, subsequent studies have shown that the structure cannot be that of ice.

2.5.2 Hydration of Exchangeable Cations

Mitchell and Soga (2005) said that because cations are attracted to the negatively charged clay surfaces, so is their water of hydration.

2.5.3 Attraction by Osmosis

Cations concentration increases as negatively charged clay surfaces are approached. This increased concentration means that water molecules tend to diffuse toward the surface in an attempt to equalize concentrations.

2.5.4 Charged Surface-Dipole Attraction

Mitchell and Soga (2005) stated that clay particles can be viewed as negative condenser plates. Water dipoles then orient with their positive poles directed toward the negative surfaces with the degree of orientation decreasing with increasing distance from the surface. However, at the mid-plane between parallel plates, there would be adjacent to each other. Ingles (1968) suggested that because of high hydration number and energy of aluminum in the clay structure, water is so strongly attracted to the surfaces that it interposes itself between the surfaces and the counter ions with the counter ions removed as far as possible from the surface that is to the mid-plane between opposing parallel sheets.

2.5.5 Attraction by London Dispersion Force

Van der Waals attractive forces could bond water molecules to clay surfaces. In phase fluctuations of electron clouds form temporary dipoles and induce displacements in neighboring molecules so that dipole-dipole attraction occurs. Because such bonds would be non-directional, the water structure would be closely packed and more fluid than the H-bonded structure.

2.5.6 Capillary Condensation

A range of pore sizes and distributions usually exists in a soil. The pores may fill with liquid water and water vapor. At saturation less than 100 percent, the water is retained in micro and mini pores through the combine effects of surface tension and attraction to particle surfaces (Mitchell & Soga, 2005)

Atterberg limits are the limits of water content used to define soil behavior. According to the findings of Andrade *et.al* (2010), Albert Atterberg (1846–1916), a Swedish chemist and agricultural scientist, found that plasticity is a particular characteristic of clay. The consistency limits was called as Atterberg limits and it was explained that there is a defined amount of water at which the clay is easily moldable. With lower moisture content, the clay cracks when molded. The Atterberg plastic limit is the lowest water content (expressed in mass percent of the clay dried at 120 °C) at which the clay can be rolled into threads without breaking (Bergaya *et al.*, 2006). The Atterberg liquid limit is the water content at which the clay begins to flow, using Casagrande Liquid Limit Device. The difference between both values is called the plasticity (or plastic) index. The liquid and plastic limits define the transitions between liquid and plastic behavior. Arthur Casagrande standardized the method to determine such limits in soil consisting of clayish and non-clayish materials. These limits can give significant information about the behavior of clay (Jefferson & Rogers, 1998). Illustration of Atterberg limits are shown in Figure 2.4.

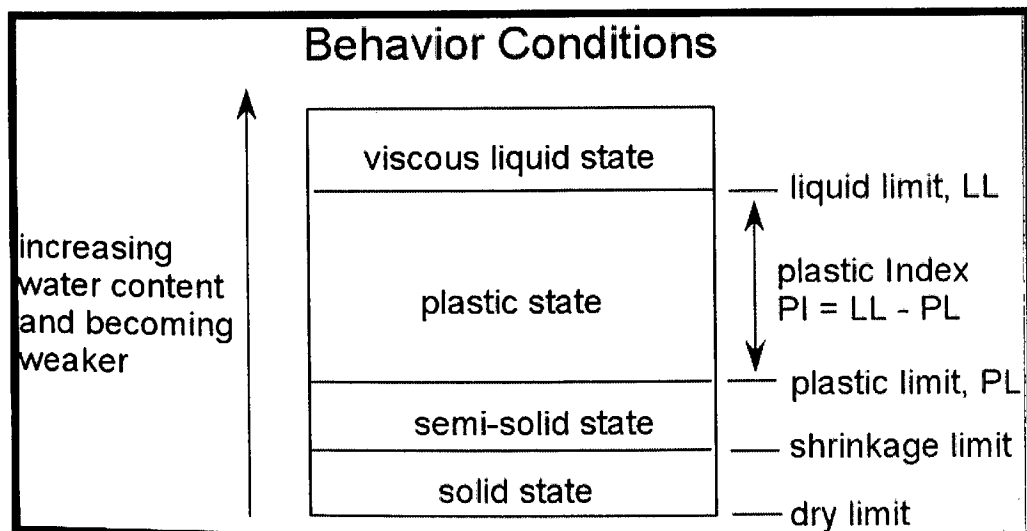


Figure 2.4 : Illustration of Atterberg Limits