PHENOMENAL EFFECT OF ELECTROOSMOTIC TREATMENT ON KAOLINITE SOIL USING DIFFERENT TYPES OF ELECTRODES

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by

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the requirements for the
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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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January 2009

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Mohamad Zulfaqar bin Matnor

ABSTRACT

This report basically discusses the interim research done and basic understanding of the chosen topic, which is **Phenomenal Effect of Electroosmotic Treatment on Kaolinite Soil Using Different Types of Electrodes**. The objective of the project is to determine the effect of electroosmosis treatment whether this method can stabilize the Kaolinite clay or vice versa using medium electroosmotic box with a dimension of 15"x 8"x 9". The reason of using the box is to ensure the application of electroosmotic is almost equivalent to the real sites situation. Copper, aluminium and steel are the electrodes used in this treatment. The basic properties of the in-situ kaolinite clay are obtained by basic engineering test. Electroosmotic treatment that has been carried out show that the increased in shear strength, reduction in moisture content, and changed in pH value of kaolinite soil. Result also shows that different types of electrodes and varies voltage applied in this treatment give different effectiveness in stabilizing the Kaolinite clay.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

According to *Casagrande* (1984), soil can be classified into three types which are coarse grain soils (gravel, sand), fine grained soils (silt, clay, organic silts and clay) and fibrous soils (peat). In this project, kaolinite soil which is a fine grained soil is chosen as a case study that the student needs to study the effects of electroosmosis on kaolinite soil.

Electroosmosis is one of the methods to stabilize soil which is categorized under chemical modification. There are several methods of soil stabilization which are mechanical modification, hydraulic modification, physical and chemical modification and inclusion and confinement modification. The purpose of soil stabilization is to improve strength of the existing soil to enhance its load bearing capacity. Besides, soil stabilization is needed to reduce soil settlement and accelerate consolidation. A test will be conducted to determine whether electroosmosis method has an effect on kaolinite soil strength.

The introduction of an electrical gradient into the soil stabilization mainly by removal of the water has its beginning 70 years ago. Electroosmosis has started in the early 1930's by *Casagrande* in stabilizing clays. A direct current (DC) electrical field application to a wet clayey soil resulted in reduction in its moisture content and increased of shear strength. According to *Casagrande* practice, a small reduction in moisture content could produce significant increase in soil strength.

1.2 PROBLEM STATEMENT

It has been a major problem for engineers and contractors when dealing with soft soil. There have been a lot failures and losses due to existence of soft soil. It is also very hard for the engineers to stabilize these soils especially where existence of fine grained soil such as clay soil is very dominant.

The existence of fine grained soil such as clay and silt is a problem since clay soil is a very fine particle. In general, clay soil has a very low permeability since it consists of very fine particles. This is due to the limited pore water and contaminant movement in fine soils. Certain clay has the ability to absorb and kept water in it which at certain moisture content, this clay soil can becomes very slurry. When water is absorbed, clays will often expand as the water fills the spaces between the stacked silicate layers. Due to the absorption of water, the specific gravity of clays is highly variable and is lowered with increased water content. This directly reduced the load bearing capacity and causes a failure to any structure above it.

Malaysia is predominant with Laterite and Kaolinite clay. Generally, a slope which is predominant with kaolinite clay will prune to fail first compared with a slope having a predominant of laterite clay. This shows that kaolinite clay shear strength is lower than laterite clay.

1.3 OBJECTIVE AND SCOPE OF STUDY

The main objectives of this research are:

- To study the effect of electroosmosis on the shear strength of kaolinite soil.
- To determine the changes in moisture content and pH of kaolinite soil after electroosmosis.
- To study the effect of different electrodes on electroosmotic treatment.

This project requires the student to understand and study the concept and principle of electroosmosis before proceed to the experiment. Since this project will be studied in the two semesters, the scope of the work has been summarized as shown below:

<u>Semester I (Last semester)</u>

- Literature review and theories.
- Looking for the source of kaolinite soil for testing.
- Soil classification by determine the properties of kaolinite soil such as pH, strength, moisture content, Liquid Limit, Plastic Limit and etc.

<u>Semester II (This semester)</u>

- Start collecting all the data such as moisture content, shear strength and pH (testing will be done by using a different values of voltage).

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Stabilization of fine grained soils (silt, clay, organic silts and clay) continues to provide challenge in soil stabilization arena. The limited pore water and contaminant movement in fine soils gives problems for soil stabilization process. Processes like pump-and-treat, soil vapor extraction, in-situ oxidation and even thermal processes are usually inadequate for removing contaminants from fine grain soils. Generally these processes rely on diffusion of the chemicals through clays and silts into regions of higher permeability where they are transported to capture or treatment wells. Diffusion through soil can be very slow. But there is a solution for this problem which is electroosmosis.

2.2 KAOLINITE SOIL

According to F. G. Bell, there are a few physical and chemical properties of Kaolinite soil. The important **physical properties** are:

Liquid limit - 75%
Plastic limit - 42%
Plasticity Index - 33%
Activity - 0.35
Unconfined compressive strength - 350 kPa
Modulus of elasticity - 35 MPa
Optimum moisture content - 29.5%

Chemical properties:

SiO_2 - 47%
Al2O3 - 38.3%
Alkali (K2O, Na2O) - 0.8%
Fe2O3 - 0.5%
Cation exchange capacity - 2 – 16 meq/100g
pH at 10% solid - 5.0 ± 0.5

2.3 ELECTROOSMOSIS

Electroosmosis has started in the early 1930's by *Casagrande* in stabilizing clays. A direct current (DC) electrical field application to a wet clayey soil resulted in reduction in its moisture content and increased of shear strength. Electroosmosis is the movement of liquid containing ions through a porous media by applying a direct current (DC) field. In other words, electroosmotic treatment of soil stabilization can be understood as transporting water from anode to cathode. In fact, there are three basic distinct electrokinetic processes occur when two electrodes are embedded in a fine grained soil such as clay and silt that are connected to opposite polarities on a direct current supply. These three basic distinct of electrokinetic are as follows:

1. Electroosmosis – water transferred in the capillaries of the soil where the movement is primarily generated in the diffuse moisture film. The principle mechanism in electroosmosis is the migrating ions, where the anions move to anode, a positive electrode and cations moves to cathode which is a negative electrode. These ions exert a viscous force on the water surrounding them as they moves towards their respective electrodes.

2. Electrophoresis – in solid-liquid mixture with an electric potential gradient, migration of colloid occurs where discrete particles are transported through water. Negatively charged clay particles will migrate toward the anode in a clay-water system that are applied with direct current.

3. Electromigration – movement of charged ions towards the oppositely charged electrodes relative to solution. Cations, positive ions will attract to a cathode, negative electrode and anions, negative ions to an anode, positive electrode. Electromigration of ions is the major cause of current conduction in a porous medium with certain concentrated aqueous solution of electrolytes.

According to Helmholtz-Smoluchowski, based on the diffused of double layer system, "The inner wall of the double layer which is relatively thin compared to the outer wall is consists of negatively charged ions strongly attached to the wall. The outer wall consists of moveable positive ions. These mobile positive ions will move from anode to cathode and dragged along with them the free water molecules causing a general movement of water to cathode".

According to *D. R. Casagrande and L. Casagrande, 1985,* "The principal reason that electroosmosis is highly effective in reducing the water content of many fine-grained soils is that the electroosmotic coefficient of permeability, *ke,* is usually 100 to 1000 times greater than the common coefficient of hydraulic permeability, *k.* This tremendous difference in permeability is due to the fact that hydraulic and electroosmotic seepage is the result of different forces and mechanisms. Ordinary seepage is caused by a hydraulic pressure gradient, such as a gravity head of water or excess pore-water pressure in unconsolidated soils. However, seepage under the influence of an electric potential is the result of pore water being "pulled" along by the movement of ions toward one of the electrodes (usually, but not always, toward the cathode)".

To simplify, in electroosmotic flow, virtually all the pore water moves except for the very thin rigidly attached part of the double layer. The water flows at a constant velocity irrespective of the pore size. Where else different process happen in hydraulic flow, where the entire double layer remain stationary.

According to *D. R. Casagrande and L. Casagrande, 1985,* "The dewatering process leads to consolidation and consequent strength increase. During the normal (gravity) consolidation process, water is squeezed out of the voids in the soil. However, consolidation during electroosmosis is the result of water being removed from the soil, which makes the cause and effect are reversed from the normal consolidation process. Consolidation and strength increase continue until the intergranular stresses are in equilibrium with the tension that develops in the pore water during electroosmosis".

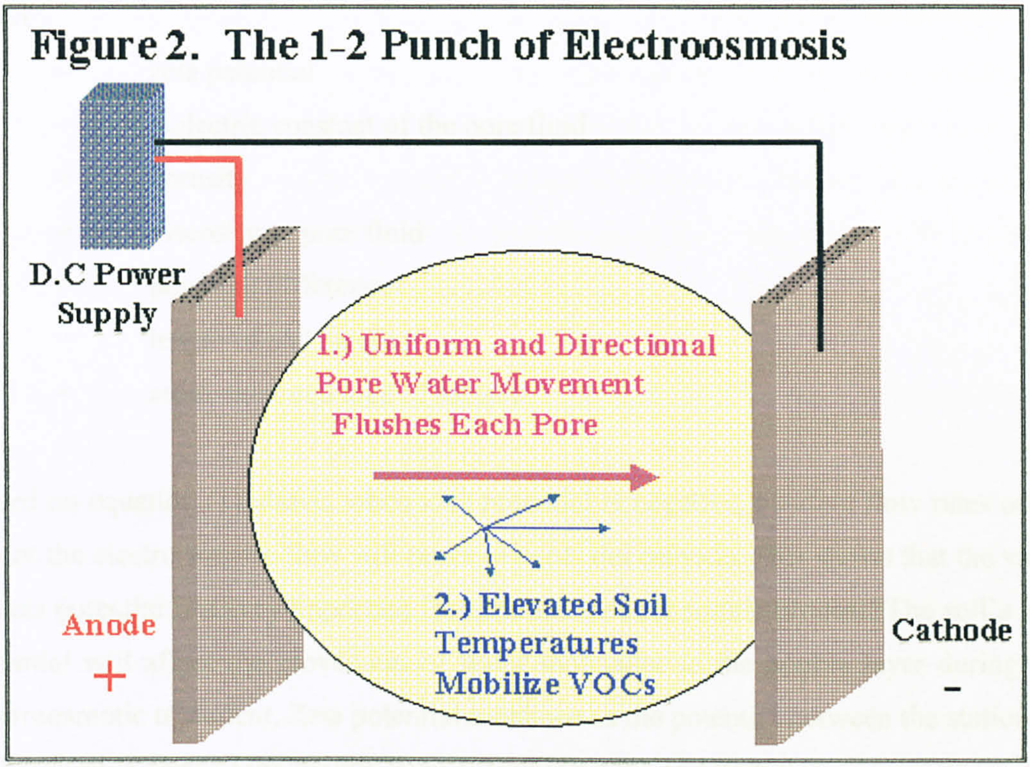

Figure 2.1: The punch of electroosmotic treatment

In a soil region, the driving parameters for electroosmosis are the electric field intensity and surface (Zeta) potential. The mineral particles that give rise to negative charge when in contact with ionic solution is called Zeta potential which arises for many reasons, including chemical and physical adsorption within the soil and lattice imperfections.

The Helmholt-Smoluchowski's equation below described in which the electroosmotic flow rate resulting from the movement of solvated ions concentrated outside the stationary layer when a packed bed soil particles is saturated with an electrolyte and exposed to voltage or current.

$$q_{co} = \frac{\zeta D}{\eta} n \left[\frac{\Delta E}{\Delta L}\right] A \text{ ....(1)}$$

where;

ζ = zeta potential

D = dielectric constant of the pore fluid

n = porosity

η = viscosity of pore fluid

ΔE = potential difference

ΔL = length of soil sample

A = cross-sectional area of sample

Based on equation (1) above, when zeta potential is negative, positive flow rates occur where the electroosmotic flow will move towards the cathode. This shows that the value of zeta potential is a very important factor in the electroosmotic process. The soil's zeta potential will affect the movement of water molecules in the double layer during the electroosmotic treatment. Zeta potential s defined as the potential between the stationary and moveable parts of the double layer surrounding the soil particles.

Two benefits of electroosmosis test when it is properly being applied. First is the uniform pore water movement due to the direct current application. As said by *D. R. Casagrande and L. Casagrande, 1985,* the size of pore of the soil is not important anymore when it comes up to electroosmosis. Electroosmosis process gives a uniform pore water movement in most types of soil when been applied with this method. This process results in soil consolidation.

Secondly, electroosmosis also produced heating on the soil due to the applied direct current. The soil warming will not only increase the electroosmotic permeability by lowering the viscosity of the pore water. The applied DC voltage and induced current provide resistive heating power to the entire soil mass between the electrodes particularly near the anodes. Soils that are more electrically conductive will draw more current at a given voltage and generate more heat. The anodic end gradually became so desiccated that the soil attained the strength of a soft rock. Figure 2.1 shows the punch of electroosmotic treatment.

The electroosmotic efficiency (flow/voltage ratio) by using zeta potential results in bentonite is insensitive to pH and ionic strength variations. The zeta potential of kaolinite, however, was found to be quite sensitive to pH which equally to the electroosmotic efficiency. Zeta potential results also indicate that the electroosmotic efficiency as well as the direction of electroosmosis in Kaolinite soil will be impacted dramatically by the presence of metal cations.

During the electroosmosis process, oxidation and reduction take place at the electrodes as the electrons are transferred in and out of the system. This results in ion exchange, ion diffusion, pH gradients, desiccation by heat generation at the electrodes, mineral decomposition, physical and chemical adsorption and fabric changes (Gray and Mitchell, 1697: Thomas and Lentz, 1990: and Mitchell, 1993). These two factors will influence the effectiveness of the on going electroosmotic process. In simple words, the characteristic and properties of the soil will changes after been treated with electroosmotic method. Some of the changes give benefits and some give retardation.

During the electroosmotic treatment, due to the applied direct current via electrodes embedded in slurry soil, oxidation and reduction occur where anode will experience oxidation and cathode experience reduction process. Oxygen and hydrogen are produce during the electrolysis of water at anode and cathode in which can be represented by the following equations:

At the anode:

$$2\,H_20 - 4e^- \rightarrow 4\,H^+ + O_2 \uparrow \qquad (2)$$

At the cathode:

$$2\,H_20 + 2e^- \rightarrow 2\,OH^- + H_2 \uparrow \qquad (3)$$

Based on equation (2) and (3), changes in pH will occur at anode and cathode. An acid front (area with decreased pH) will develop at the anode, while base front (area with increased pH) develops at the cathode. A higher pH actually increases the pore water movement with electroosmosis. The electroosmotic flow will slow down if the acid build-up at the anode due to the accumulation of protons on the soil surface. Because proton is too small, they do not "drag" much water along as they move toward the cathode. However, if the pH is extremely low, a reverse flow will occur which mean the water will move to anode. To solve the problem, used of recycled flow water which mean by collecting the water at cathode since the pH is high, and put it back in at the anode. This will provide an acceptable pH of the anode.

According to Bergado et al, 1996, "Ion exchange and flocculation also occur in electroosmotic treatment. The change in soil structure is a consequence of cations exchange caused by the dissociated bivalent or trivalent ions in the pore water replacing such monovalent ions that are initially and normally attracted to the negatively charged clay particles. Highly metallic ions such as Fe^{3+} will replace the weaker one that attached on the surface of clay particles. The crowding of Fe^{3+} ions onto the surface of clay particles brings about flocculation". The double layer or the moisture film on the fine clay particle will become thinner due to this process. The ion exchange capacity is still highly depends on the pH of the soil water and the type of clay mineral in the soil.

Electroosmosis method can also be used to remove organic contaminants from fine-grained soils. This has been done in the companion research to remove benzene, toluene, trichloroethylene (TCE), and m-xylene from saturated Kaolin Clay. (Bruellet al. 1991). Contaminant flushing from soil is done by injecting clean water at pipe anodes. Pore water is displaced and contaminated water removed at pipe anodes. This technique is method contaminant flushing using clean water from fine-grained soils that have low hydraulic conductivities.

According to Emilio M. Morales, MSCE, regarding on the electroosmosis, the phenomenon of this treatment is caused by the accumulation of counter ions in a thin liquid (Debye) double layer next to the solid's surface and the accumulation of the not electric charge on the solid's surface that is in contact with an electrolyte solution. Electrolyte solution is considered as neutral when away from solid's surface. The counter ions in the Debye layer are attached to the oppositely charged electrode and drag the liquid along only with the presence of external electric field. In simple word, the electric field presence will creates a body force that induces fluid motion.

Another technique is by using a sacrificial anode made of steel. Iron will oxidize preferentially over water limiting the generation of H^+. The limitation of H^+ and the oxidation over water help to maintain a near neutral pH at the anode and result in stable long-term electroosmotic flow rates. For example, Lasagna^{TM}, an electroosmosis based remediation process in use at the Paducah Gaseous Diffusion Plant in Kentucky makes use of these measures. Cathode water flows by gravity back to the anodes for recharge and steel plates are used as electrodes. Sufficient iron is available to continue operation longer than the expected two-year operation time.

Other stabilization method such as convective systems like pump-and-treat, vapor extraction, surfactant flushing or in-situ oxidation cannot match the effectiveness of electroosmotic treatment in treating soils with silts or clays present. This is because that these types of systems favor the higher permeability zones. Table 1 shows the Comparison of Treatment Technologies with electroosmosis.

Remediation Process	**Transport in Soil**	**Heating Pattern**
SVE	Preferential/non-uniform	None
Pump and Treat	Preferential/non-uniform	None
Steam Stripping	Preferential/non-uniform	Non-uniform
Surfactant Flushing	Preferential/non-uniform	None
In-Situ Chemical Oxidation	Preferential/non-uniform	Non-uniform (low)
6-Phase or RF Soil Heating	None	Uniform
Electroosmosis	**Uniform**	**Uniform**

Table 2.1: Comparison of Treatment Technologies with Electroosmosis

CHAPTER 3

METHODOLOGY

3.1 PROJECT IDENTIFICATION

Planning has been made in order to make sure all activities are in arrangement. This planning is include from the first steps which is the topic selection before proceed the other steps. The methodology will show how the project will be carried out from the first steps to the final step of the project. The methodology of this project is shown in a flowchart in **Figure 3.1**.

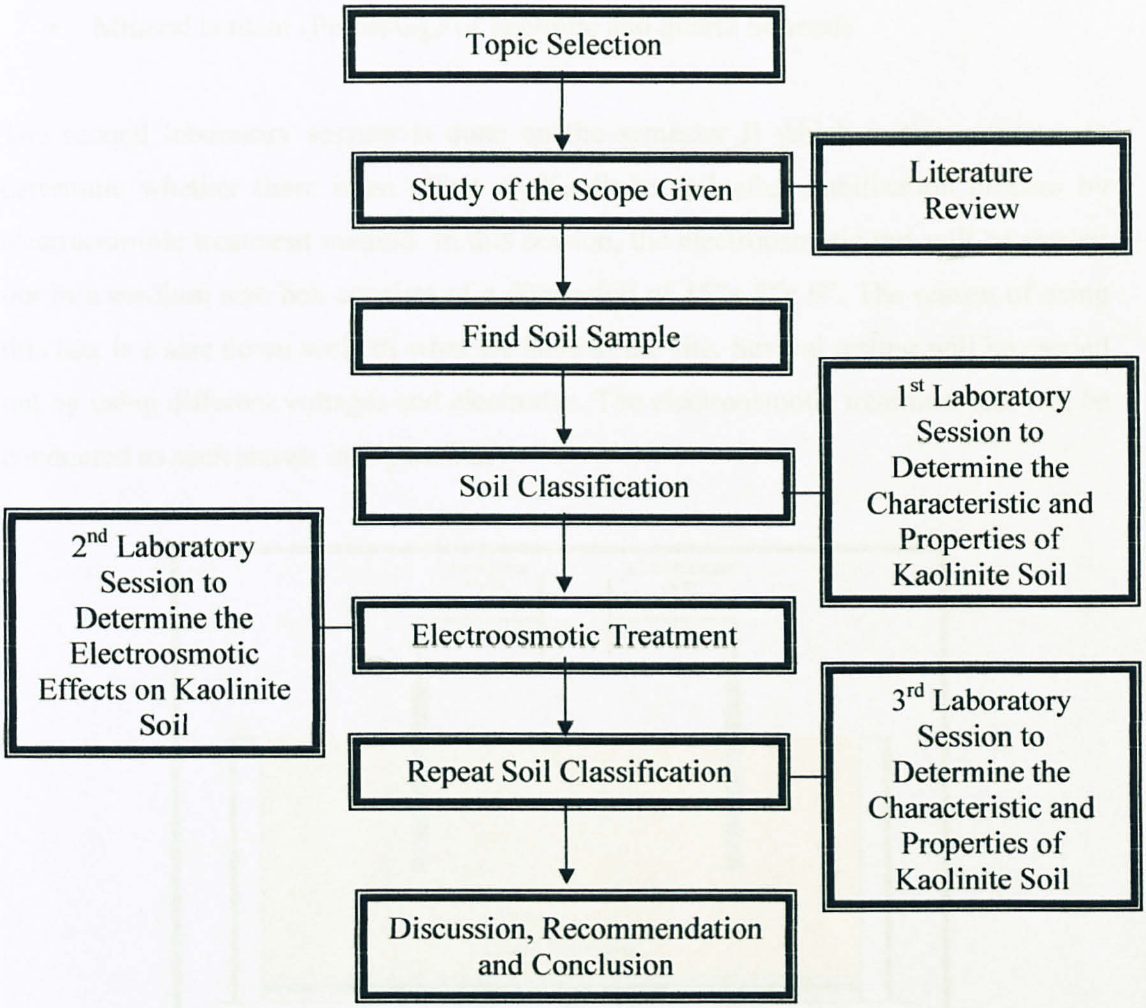

Figure 3.1: Flowchart of FYP

3.2 LABORATORY SESSION

There are three laboratory session will be carried as shown in Figure 3.1. The first laboratory session is done on the semester I. This laboratory session is carried out to determine the characteristics of Kaolinite clay. This laboratory session is to determine on the physical characteristic and chemical properties of Kaolinite clay such as below:

- Moisture content
- Specific gravity
- Particle size distribution
- Plastic index
- Mineral content (Percentage of kaolinite and quartz mineral)

The second laboratory session is done on the semester II which is this semester to determine whether there is an effect on Kaolinite soil after stabilization process by electroosmotic treatment method. In this session, the electroosmotic test will be carried out in a medium size box consists of a dimension of 15"x 8"x 9". The reason of using this box is a size down scale of what we have at the site. Several testing will be carried out by using different voltages and electrodes. The electroosmotic treatment test will be conducted as such shown in Figure 3.2.

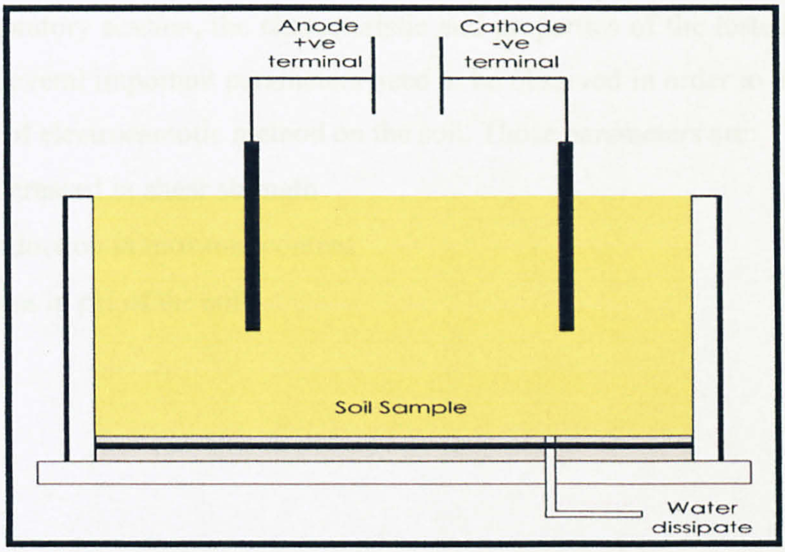

Figure 3.2: Electroosmotic treatment test diagram

The testing will be divided into three parts which are using copper electrodes, aluminium electrodes and steel electrodes with varies voltage. Table 3.1 shows the value of voltage and electrodes used for testing.

Test	Electrode	Voltage (V)
1	Copper	20
2	Copper	40
3	Aluminium	20
4	Aluminium	40
5	Steel	20
6	Steel	40
7	none	none

Table 3.1: Testing in Kaolinite soil

The last test will be the control in which to compare the soil that has been tested with electroosmotic process with the soil that is not subjected to any kind of soil stabilization method. From here, we will determine whether electroosmotic process really affect the soil strength and its moisture content of kaolinite soil. Changes in pH will also be observed in this case.

The third laboratory session, the characteristic and properties of the tested soil will be determined. Several important parameters need to be observed in order to determine the effectiveness of electroosmotic method on the soil. Those parameters are:

- The increased in shear strength
- The reduction in moisture content
- Changes in pH of the soil.

3.2.1 Box Fabrication

This is the most important part in the testing since without this electroosmotic box, the testing cannot be done. Perspex is used as the material to make this equipment in order to sustain the load or pressure from the soil without buckling or cracks. With it transparency, it will ease the user to see the sample inside during the testing. The box will have the dimension of 15"x 8"x 9".

Another important material needed for the completion of the electroosmotic box is the geotextile. A layer of geotextile is placed at the bottom of the electroosmotic box. This material is used in order to make sure that the water discharge out from the box does not contain any kaolinite particle.

Varies type of electrodes that will be used for testing is prepared. There will be copper, aluminium and steel electrode used in the testing. The dimension of each type of electrode is equal which is 8 inch in length and 1 1/4 inch in diameter. This is to determine which type of electrode gives the most affect in electroosmotic process.

3.2.2 Soil Preparation

Kaolinite soil sample is a primary soil that obtained from a slope beside Simpang Pulai highway, Perak. This site area was chosen as a main source of Kaolinite soil since it is easy to get and rich with kaolinite mineral. The place was selected by Mr. Azmi, Deputy Director of Jabatan Mineral dan Galian Perak. After took the sample at Simpang Pulai, the Kaolinite soil was carefully wrapped with the plastic bag and tied in order to maintain the moisture content and kept in a closed bin before kept in the laboratory. The site area of the in-situ soil taken is as shown in Figure 3.3.

Figure 3.3: Site area of Kaolinite soil sample

Before a testing done on the kaolinite soil, the sample is fully dried in the oven with the temperature of 105°C for the soil characteristic testing. After the soil sample is fully dried, it is crushed into a powder form. The sample will be sieve passing 2.00mm to make sure that it is in a powder form. For every testing, the amounts of water and kaolinite soil are the same.

Weight of soil = 10.00 kg

Weight of water = 5.50 kg

The soils and water are mixed together using the mixer for 15 minutes. After that, it will be wrapped up in a bucket and leave it for 24 hours in order for the soil to be in homogeneous state. Note that, the sample preparation used distilled water since it is free from ion, microorganisms and other content compare to fresh water which might affects the testing process.

3.2.3 Electroosmotic Treatment

Without voltage:

The control test is run without applying any voltage to the samples. This experiment will act as the control for all the experiment that has been done. This is purposely done to observe the rate of consolidation of kaolinite itself. The most important parameter to be observed from here will be kaolinite soil moisture content and strength after seven days.

After the fabrication of electroosmotic box is done and the mixed sample is ready, the sample then transferred into the electroosmotic box. During the transferred process, a glass rod is used to make sure that the sample is compacted and filled every void in the box. Then, the sample is ready to be test. The sample will be stop after reach 7 days and be tested for its moisture content, pH and shear strength.

Specific placed in the box area will be taken the sample using the auger sampling tube as shown in Figure 3.4. Five different spots are taken the sample which then will be tested for its shear strength, moisture content and pH. The shear strength of the sample will be determined using Vane method. This method covers the measurements of the shear strength of a sample without disturbing the soil. For this sample, spring number 3 was used.

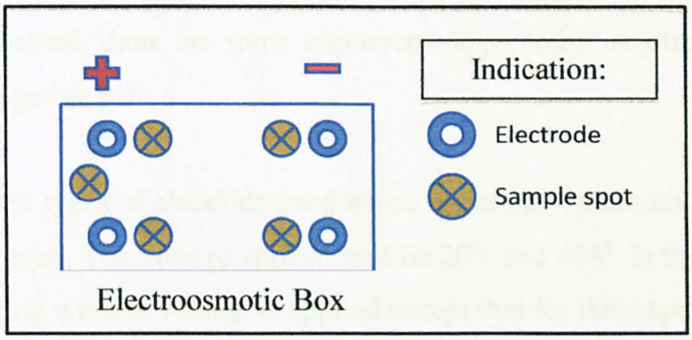

Figure 3.4: Plan view of electroosmotic box

For moisture content, sample in every sampling tube will be divided into three equivalent parts. This is to determine the variation in each small portion according to its location. This is shown in Figure 3.5 below:

Figure 3.5: The sample divided into three equivalent parts

For pH determination, every one of the three small portions in the sampling tube will be tested. The pH test will be conducted as followed as the British Standard manual. 30g of sample will be mixed with 75ml of distilled water and leave it for at least of 8 hours before testing.

With voltage:

For the first six test which is namely; test 1, test 2, test 3, test 4, test 5, and test 6 is the important test since from these tests, the result obtain is a proof whether by using the electroosmotic method, there are some improvement on soil's moisture content, shear strength and changed in pH.

There will be three types of electrode used which are copper, aluminium and steel with same dimension each. The voltage applied will be 20V and 40V. In this case, the same procedure as testing without voltage is applied except that for this experiment there will be electrode and voltage applied. Every experiment, four electrodes will be used to cover the box area. For this part, value of current need to be observed as additional parameters beside moisture content, shear strength and pH. The current will be recorded using the digital miliammeter or logger. The current will recorded manually as follows:

- For the first 2 minutes, the current will be recorded every 5 seconds.
- For the next 5 minutes, the current will be recorded every 15 seconds.
- For the next 8 minutes, the current will be recorded every 30 seconds.
- For the next 1 hour, the current will be recorded every 5 minutes.

The testing will be stopped after reach 7 days. The same procedure as without voltage is applied to the sample to determine the important parameter; shear strength, moisture content and pH. This test will also compare the affect of different electrode in electroosmotic process.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

The sample of each of electroosmotic testing will be tested for its moisture content, shear strength and pH. Every electroosmotic test will have at least three of kaolinite soil sample taken at specific spot as shown in Figure 3.4. This data will be collected in order to compare the affect of each type of electrodes and the significant different of applying electroosmosis test to the soil.

In-situ kaolinite soil sample are taken in order to determine its characteristics and properties. Several basic tests had been done to determine the soil classification. The tests result for the in-situ sample is as such below:

- Moisture content : 30%
- Specific gravity : 2.72 Mg/m^3
- Plastic Limit : 38.7%
- Liquid Limit : 50%
- Plastic Index : 11.3%

The results of the kaolinite soil characteristics and properties are shown in Appendix 1. Several properties of kaolinite soil such as pH, XRD test and shear strength is still in progress.

4.2 RESULTS

Moisture Content

There are seven tests done which include with and without voltage but using different type of electrodes. For each test, three soil sample taken using sampling tube at different spots will be tested for its moisture content. For every sampling tube, the soil sample is divided into three small portions of samples to be taken its moisture content. The most bottom part of every small portion in the sampling tube will be labeled with number 1. All together will be 9 small portions of kaolinite sample. The formulae used to calculate the moisture content (w) is:

$$\text{Moisture content, w (\%)} \quad = \quad \frac{(m2-m3)}{(m3-m1)} \text{ x } 100$$

where;

m1 = mass of the container (g)
m2 = mass of container and wet soil (g)
m3 = mass of container and dry soil (g)

The result in Table 4.1 below shows the moisture content calculated for test 1 to test 7 with varies voltage and electrode types.

Test	Electrode	Voltage	Container	Moisture content (%)	Moisture content (%)
1	Copper	20V	1(1)	49.92	50.51
			1(2)	51.70	
			1(3)	49.92	
			2(1)	50.27	51.48
			2(2)	51.38	
			2(3)	52.79	
2	Copper	40V	1(1)	46.18	46.22
			1(2)	46.52	
			1(3)	45.97	
			2(1)	46.84	47.31
			2(2)	47.81	
			2(3)	47.29	
3	Aluminium	20V	1(1)	47.62	48.30
			1(2)	48.23	
			1(3)	49.04	
			2(1)	47.22	48.96
			2(2)	48.75	
			2(3)	50.91	
4	Aluminium	40V	1(1)	44.08	41.88
			1(2)	44.63	
			1(3)	36.94	
			2(1)	45.21	46.10
			2(2)	46.54	
			2(3)	46.55	
5	Steel	20V	1(1)	49.44	49.76
			1(2)	49.70	
			1(3)	50.14	
			2(1)	50.16	51.67
			2(2)	52.48	
			2(3)	52.37	

6	Steel	40V	1(1)	43.32	44.53
			1(2)	44.95	
			1(3)	45.32	
			2(1)	45.82	46.14
			2(2)	46.50	
			2(3)	46.11	
7	Control	0V	1(1)	50.92	51.82
			1(2)	52.02	
			1(3)	52.52	
			2(1)	50.51	51.55
			2(2)	51.69	
			2(3)	52.45	

Table 4.1: Results of moisture content for test 1 to test 7

From the table, container 1 is taken from the sampling tube that is having a sample from the anode area where else for container 2 having a sample from cathode area. An average value of moisture content is calculated for each of the sample area.

The details value needed to calculate the moisture content is shown in the Appendix II. Those values included mass of container, mass of container with wet soil and dry soil.

Vane Shear Strength

The value of torque applied to shear the soil is calculated by using the formula shown below:

$$\text{Torque, } M \text{ (N.mm)} = K\theta_f$$

The value of K (in mm^3) is given by the following equation, which assumes that the distribution of shear stress is uniform around the perimeter and across the ends of the cylinder of soil at failure.

$$K = \pi D^2[\,(H/2) + (D/6)\,]$$

Where;

D = overall width of the vane measured to 0.1mm (mm)

H = length of the vane measured to 0.1mm (mm)

*The value of K for the vane 12.7mm wide and 12.7mm long is 4290*mm^3

The value of the vane shear strength of the soil can be calculated using the equation below:

$$\text{Vane shear strength, } \tau_v = (M/4.29) \text{ kN/m}^2$$

For every test, vane shear strength is calculated in order to compare those values. Table 4.2 shows the value of torque and vane shear strength of sample for test 1 to test 7.

Test	Electrode	Voltage (V)	Sample	Torque, M (Nm)	Vane shear strength,τ_v (kN/m2)
1	Copper	20	1	31.54	7.353
			2	30.97	7.219
2	Copper	40	1	44.24	10.313
			2	41.61	9.701
3	Aluminium	20	1	36.56	8.521
			2	35.73	8.329
4	Aluminium	40	1	59.71	13.919
			2	57.93	13.503
5	Steel	20	1	32.39	7.549
			2	31.50	7.342
6	Steel	40	1	50.79	11.838
			2	45.31	10.561
7	Control	0	1	30.54	7.119
			2	30.11	7.018

Table 4.2: Vane shear strength for test 1 to test 7

Value of pH

The result shown in Table 4.3 is the value of pH of each test after been treated by electroosmotic method except for test 7. Test 7 is a control test where no electroosmotic treatment is applied on the soil. This is to see the changes in pH value after electroosmotic treatment is applied to the soil.

Test	Electrode	Voltage (V)	Area	pH
1	Copper	20	Anode	4.44
			Cathode	4.49
2	Copper	40	Anode	4.42
			Cathode	4.70
3	Aluminium	20	Anode	4.40
			Cathode	4.51

4	Aluminium	40	Anode	4.32
			Cathode	4.79
5	Steel	20	Anode	4.41
			Cathode	4.51
6	Steel	40	Anode	4.39
			Cathode	4.76
7	Control	-	Anode	4.46
			Cathode	4.47

Table 4.3: pH value for test 1 to test 2

Current

The readings for the currents for those six samples when two different voltages applied on three different electrodes are shown in the Appendix II. Results shown in the table 4.4 is the reading of the initial value of current when voltage applied and final value of current before the tests were stop.

Test	Electrode	Voltage	Initial current (mA)	Final current (mA)
1	Copper	20	2.133	0.681
2	Copper	40	4.324	0.971
3	Aluminium	20	14.101	0.844
4	Aluminium	40	15.316	1.099
5	Steel	20	4.727	0.949
6	Steel	40	0.949	1.058

Table 4.4: Current value for test 1 to test 7

4.3 DISCUSSION

A total of four charts were plotted to show the relationship between moisture content and voltage applied using each of electrodes. The chart shown in Figure 4.1 shows the relationship between moisture content and voltage applied with copper electrode. As the voltage increased, the value of moisture content decreased.

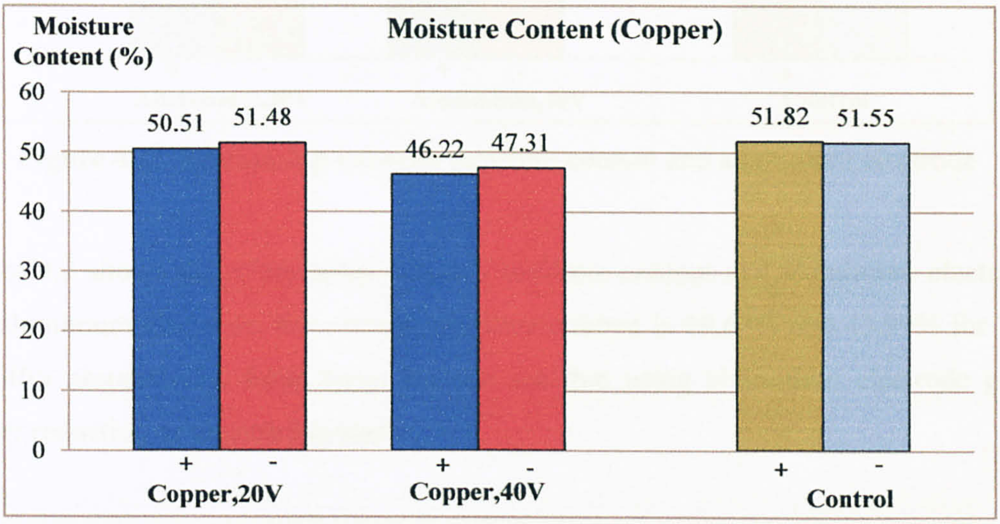

Figure 4.1: Relationship between moisture content and copper electrode

From figure 4.1, we can see that the copper electrode that is applied with 20V of voltage has a result of higher moisture content compared with 40V of voltage. For copper electrode, the average moisture content is 51% and 46.77% for 20V and 40V respectively. While for control test, where no voltage and electrode are applied, has the highest value of moisture content which is an average of 51.69%.

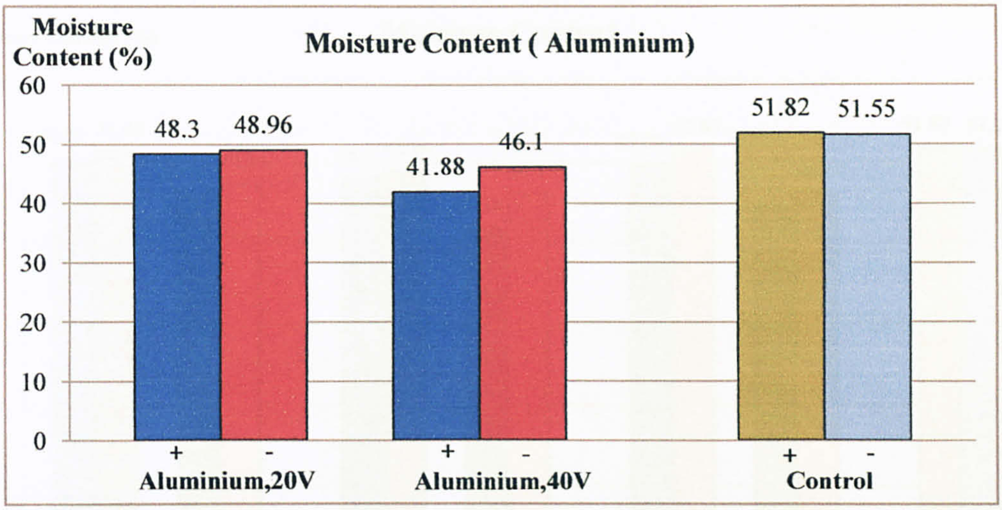

Figure 4.2: Relationship between moisture content and aluminium electrode

Figure 4.2 shows the relationship between moisture content and aluminium electrode. For aluminium electrode, the average moisture content is 48.63% and 43.99% for 20V and 40V respectively. From here, we can see that using aluminium electrode gives higher reduction in moisture content.

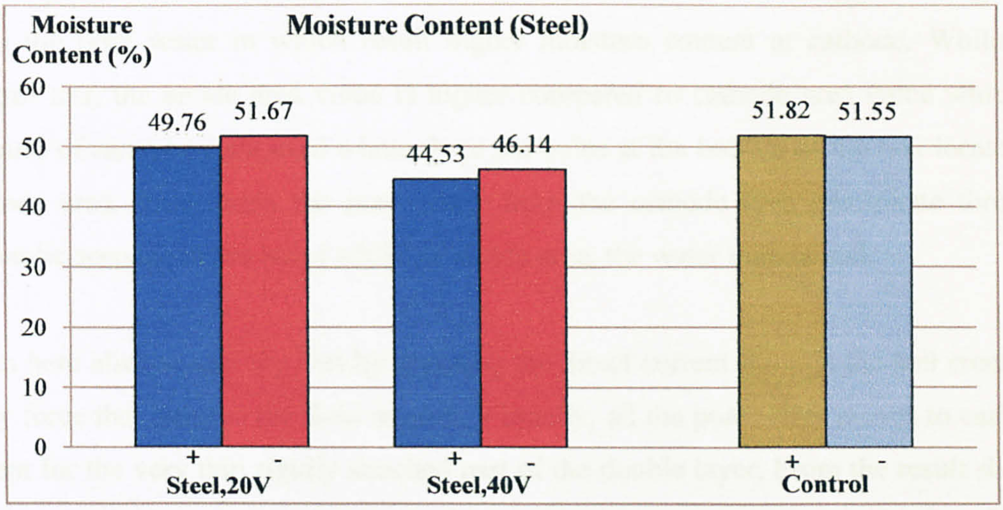

Figure 4.3: Relationship between moisture content and steel electrode

The chart shown in Figure 4.3 shows the relationship between moisture content and steel electrode. As for steel electrode, the average moisture content is 50.72% and 45.34% for 20V and 40V respectively.

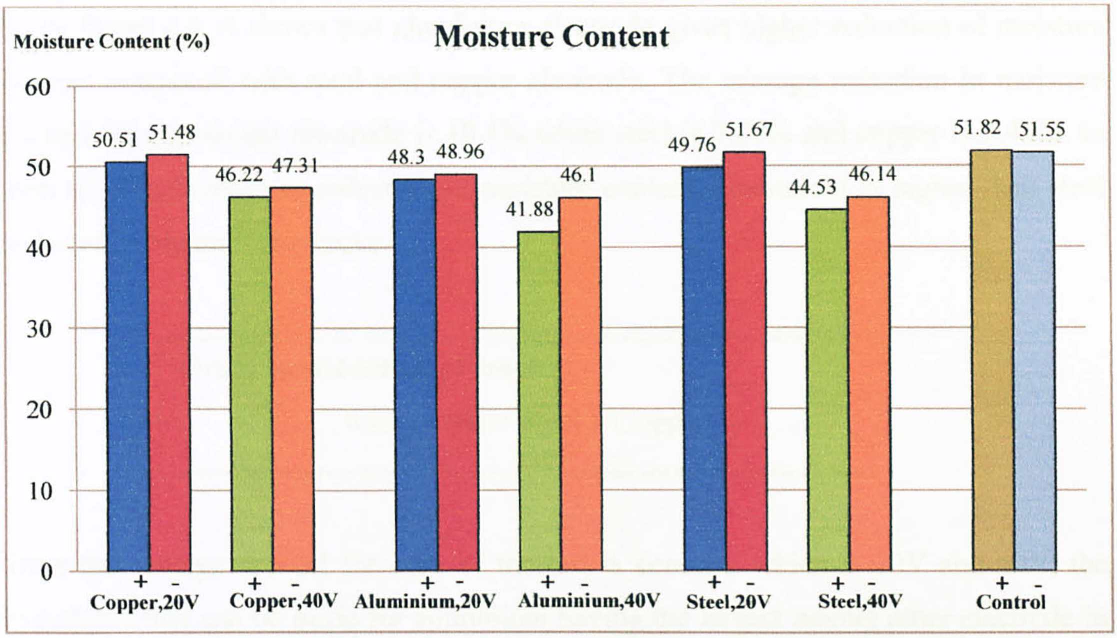

Figure 4.4: Chart of Moisture content for each of electrodes

From Figure 4.4, we can see that the sample at cathode has a higher moisture content compared to the anode area for each sample except for control. This shows that the mobile positive ion in the soil when moving towards the cathode "dragged" along with them the pore water in which result higher moisture content at cathode. While for control test, the anode area value is higher compared to cathode area value which is because of same box are used where there are holes at the bottom of the box located at cathode area. This cause the pore water from the cathode area precipitate through hydraulic seepage to the holes while for anode area, the water maintained.

From here also we can say that by applying the direct current through the soil creates a body force that induces the fluid motion. Virtually, all the pore water moves to cathode except for the very thin rigidly attached part of the double layer. From the result shown in Figure 4.4, the control test has the highest moisture content due to the fact that it depends only on the hydraulic flows such as gravity in reducing the moisture content. This mean that all the double layer remain stationary.

From figure 4.4, it shows that aluminium electrode gives higher reduction of moisture content compared with steel and copper electrode. The average reduction in moisture content for aluminium electrode is 10.4% while steel is 7.07% and copper is 5.41%. In term of effectiveness in reduction of moisture content, aluminium is higher than steel and steel is higher than copper.

Order in reduction of water:

Aluminium > Steel > Copper

Since the voltage applied for each of the test is constant which is 20V and 40V, the hypothesis that can be made for aluminium having the largest among other electrode in term of reduction in water is its high in conductivity through the soil. From figure 4.12, we can see that aluminium has the highest value of current with an average of 14.709mA. On the other hand, we can say that aluminium has higher conductivity compared with steel and copper. Theoretically, current is a function of the soil electrical conductivity according to Ohm's law and soils that are more electrically conductive will draw more current at a given voltage and generate more heat. The heat that been drawn out using aluminium electrode is higher compared with other electrode in which it increases the electroosmotic permeability by lowering the viscosity of pore water.

Vane shear strength

The value of shear strength calculated show that the strength of kaolinite soil sample increasing when applied with electroosmotic treatment. Also, the vane shear strength of the anode area is higher than that in cathode area for each of electroosmosis tests.

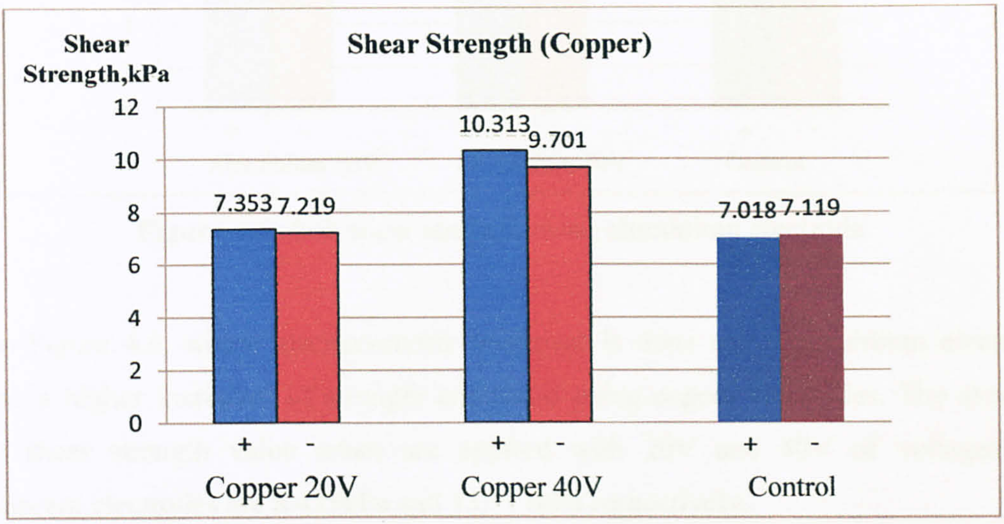

Figure 4.5: Soil shear strength using copper electrode

Figure 4.5 shows the vane shear strength for the samples which testing is using copper electrodes that are applied with 20V and 40V of voltage. The value of vane shear strength increased with the increased of voltage. From here, we can see that the control test, where no voltage is applied that depends on hydraulic seepage for its consolidation obtained an average value of 7.069kPa for vane shear strength while the copper which are applied with 20V and 40V of voltage obtained an average value of 7.286kPa and 10.007kPa respectively.

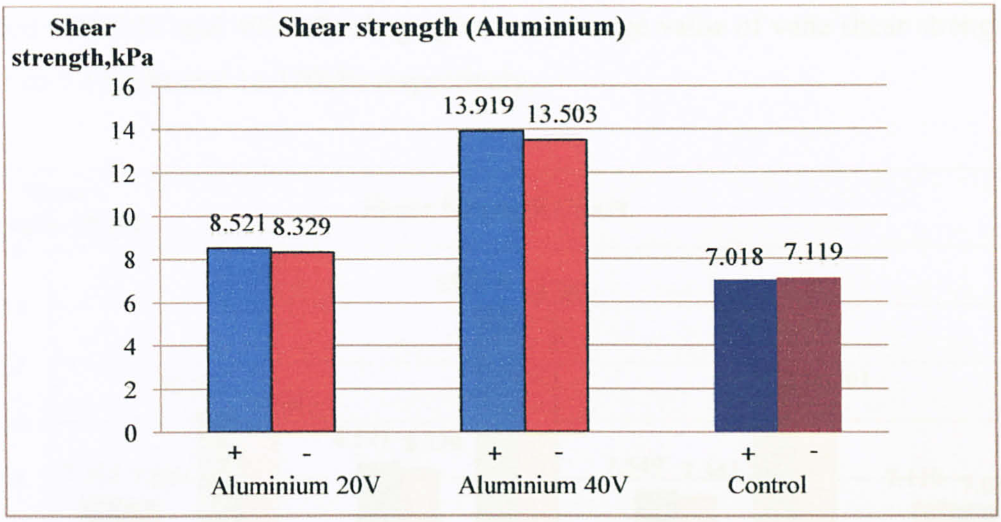

Figure 4.6: Soil shear strength using aluminium electrode

From Figure 4.6, where electroosmotic treatment is done using aluminium electrode shows a higher increased of strength compared using copper electrodes. The average vane shear strength value when are applied with 20V and 40V of voltages for aluminium electrodes are 8.425kPa and 13.711kPa respectively.

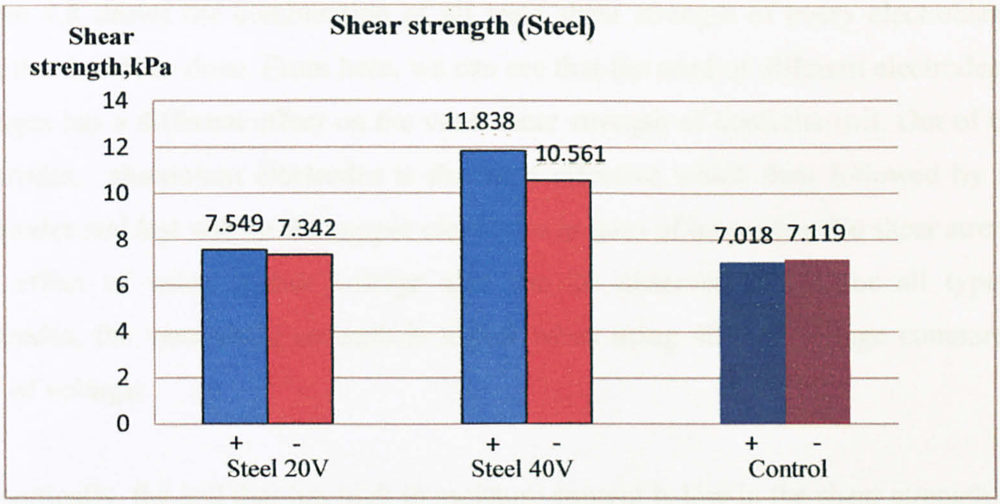

Figure 4.7: Soil shear strength using steel electrode

Figure 4.7 shows the relationship between soil vane shear strength and steel electrode with different voltage used. From here, we can see that using steel as an electrode applied with 20V and 40V of voltage gives an average value of vane shear strength as mush as 7.446kPa and 11.120kPa respectively.

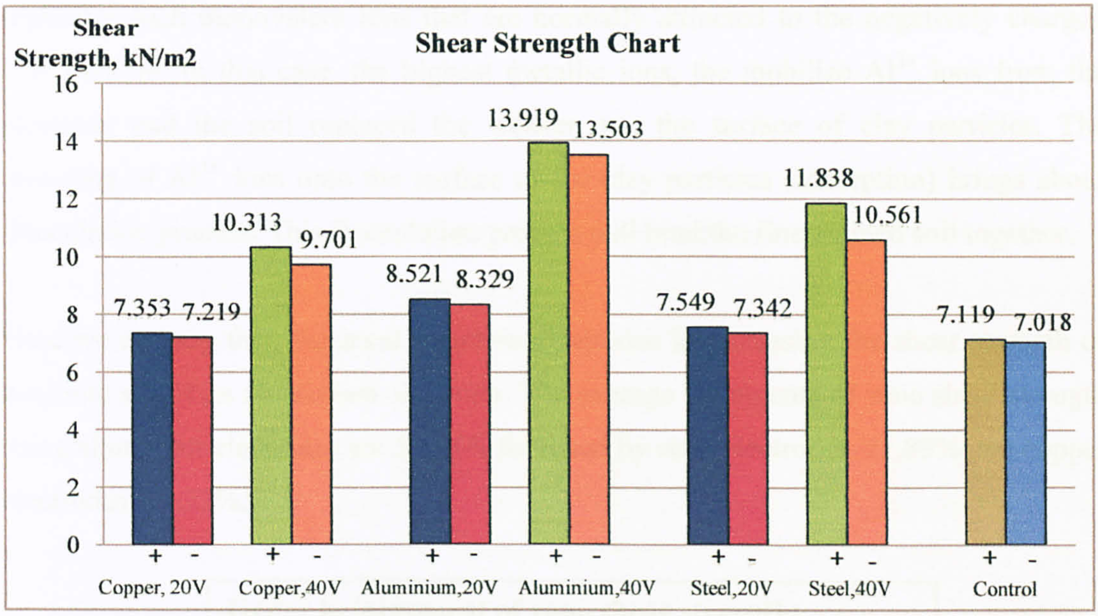

Figure 4.8: Chart of soil shear strength for each electrode

Figure 4.8 shows the combination of all vane shear strength of every electroosmosis tests that has been done. From here, we can see that the used of different electrodes and voltages has a different effect on the vane shear strength of kaolinite soil. Out of these electrodes, aluminium electrodes is the most effective which then followed by steel electrodes and last will be the copper electrodes in term of increasing the shear strength. The effect of using higher voltage also can be observed where for all types of electrodes, the vane shear strength is higher when using 40V of voltage compares to 20V of voltage.

Theoretically, the soil that has high in moisture content is low in the shear strength. The simple way, shear strength is indirectly proportional with moisture content. From the discussion of moisture content, aluminium is the highest in term of reduction in moisture content. This reduction in moisture content results in the increasing in effective stress and a corresponding increase in shear strength of kaolinite soil.

Here, we can also make a hypothesis that flocculation occur due to the ion exchange. From the literature review, mentioned that the change in soil structure is a consequence of cations exchange caused by the dissociated trivalent or bivalent ions in the pore water replacing such monovalent ions that are normally attracted to the negatively charged clay particle. In this case, the highest metallic ions, the mobilize Al^{3+} ions from the electrode and the soil replaced the weaker one the surface of clay particles. The crowding of Al^{3+} ions onto the surface of the clay particles (adsorption) brings about flocculation process. This flocculation process will bind the fine grained soil together.

Here we can say that, the most effective electrodes in increasing the shear strength of kaolinite soil is an aluminium electrode. The average increments of vane shear strength using aluminum electrodes are 56.57% followed by steel electrodes, 31.89% and copper electrodes, 22.32%.

Order in increment of vane shear strength:

Aluminium > Steel > Copper

pH Value

From Table 4.3, there is little bit changes in term of the pH value of the soil after the electroosmotic treatment done onto the soil compared with the control test. Here, we can see that every sample of pH value at anode area is lower compared to the one at cathode area.

From the control test, we can see there is no changes in term oh pH value since there are no reaction occurs during this period. If we compared the anode value for control test and others, there is a little bit reduction in pH where else at cathode, a little bit of increment of pH happened.

Here, we can make a hypothesis from which this phenomenon is cause by the electrolysis of the pore water and the electrode reactions. Theoretically, in electrolysis of pore water, oxidation and reduction occurs at anode and cathode respectively when a direct current is applied to the soils. The following reaction occurs as below:

At the anode:

$$2\ H_20 - 4e^- \rightarrow 4\ H^+ + O_2 \uparrow$$

At the cathode:

$$2\ H_20 + 2e^- \rightarrow 2\ OH^- + H_2 \uparrow$$

From the result, we can see that due to the results of ions are not removed or neutralized, an acid front and base front developed. At anode, hydrogen ions dominantly collected because of the oxidation process occurred causing a decreased in pH while at cathode, hydroxide ions are dominantly collected because of reduction process occurred causing an increased in pH of the soil.

For electrode reaction, based on the corrosion theory, it is known that oxidation of the hydroxide forming oxygen occurs at anode owing to the loss of electrons while reduction of hydrogen from water occurs at the cathode. The reaction is as such below:

Oxidation at anode:

$$Al \rightarrow Al^{2+} + 2e^-$$

Reduction at the cathode:

$$O_2 + 2H_2O + 4e^- \rightarrow 4(OH)^-$$

Therefore during the process of migration of ions

$$Al^{2+} + 2(OH)^- \rightarrow Al(OH)_2$$

At anode, the aluminium corrodes into its oxide and the oxidation of hydroxide ions form oxygen. This reaction results in liberation of oxygen and the production of hydrogen ions. Meanwhile at cathode, reduction of hydrogen from water occurs which result in an increase in the concentration of hydroxide ions. The increase in the hydrogen ions lowers the pH of the soil at anode and the increase in hydroxide is indicated by the increase in the pH value of the cathode.

Current

The initial value of current depends on the voltage applied and the conductivity of the electrodes. There is a direct relationship between current and voltage where the current will be higher if the voltage applied is higher. From the graph below, we can see that current reduces with the increased of time.

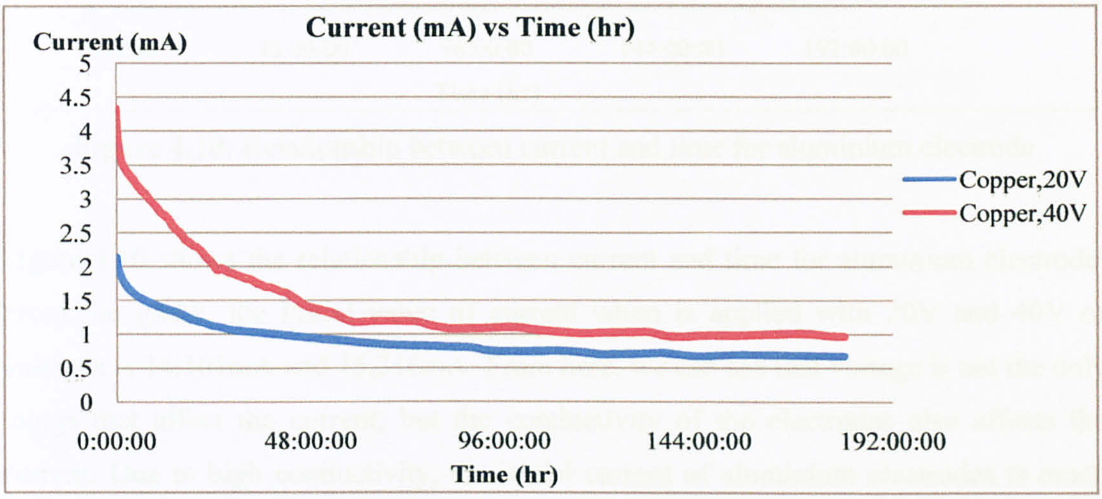

Figure 4.9: Relationship between current and time for copper electrode

Figure 4.9 shows the relationship between current and time for copper electrode. The initial value of current when is applied with 20V of voltage is 2.133mA. The initial value of current is higher when applied with 40V of voltage that is 4.324mA which is double to the current when 20V of voltage is applied. The final values of currents are almost the same after being tested for 7 days. The final value of current for copper electrodes after being tested with 20V and 40V of voltages are 0.681mA and 0.971mA.

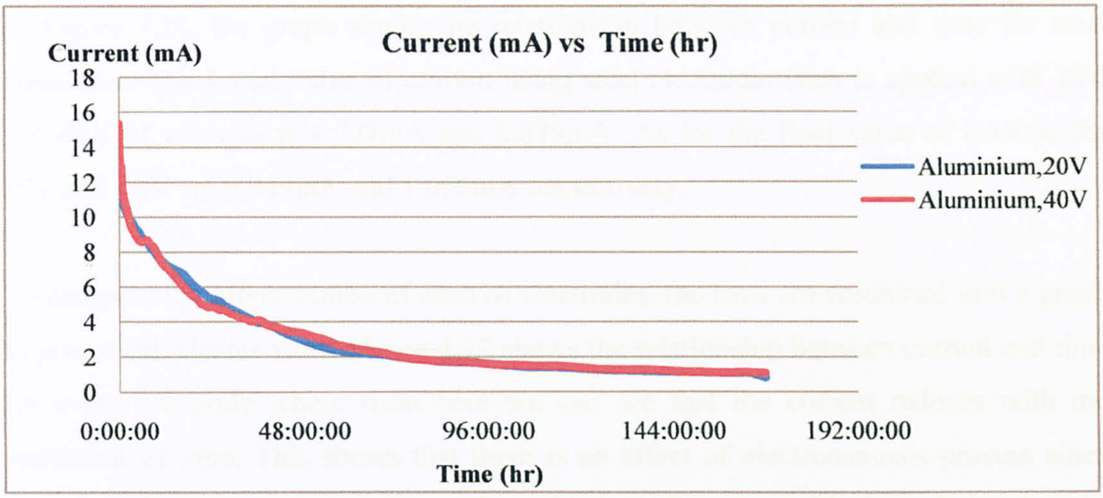

Figure 4.10: Relationship between current and time for aluminium electrode

Figure 4.10 shows the relationship between current and time for aluminium electrode. From the graph, the initial value of current when is applied with 20V and 40V of voltages is 14.101mA and 15.316mA. From here, we can see that voltage is not the only things that affect the current, but the conductivity of the electrodes also affects the current. Due to high conductivity, the initial current of aluminium electrodes is much higher compared to copper electrodes. The final value of current for copper electrodes after being tested with 20V and 40V of voltages are 0.844mA and 1.099mA.

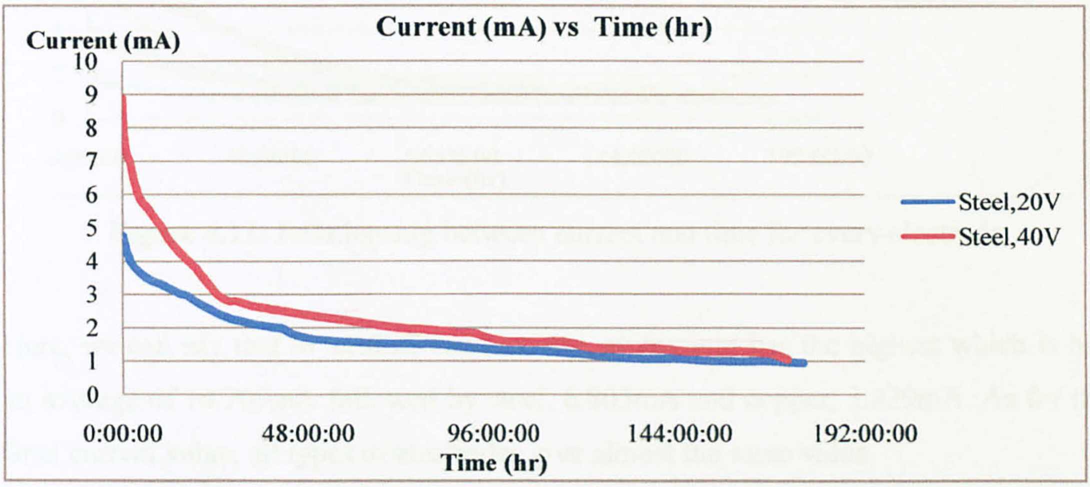

Figure 4.11: Relationship between current and time for steel electrode

In Figure 4.11, the graph shows the relationship between current and time for steel electrodes. The initial value of current using steel electrode when is applied with 20V and 40V of voltages is 4.727mA and 8.879mA. As for the final value of current, for 20V and 40V are 0.949mA and 1.058mA respectively.

To compare the effectiveness of each of electrodes, the tests are combined into a graph to give much clearer view. Figure 4.12 shows the relationship between current and time for every electrode where from here we can see that the current reduces with the increment of time. This shows that there is an effect of electroosmosis process since there is reduction of current. Here, the reduction of current with time shows that the water content in the soil is reducing since electroosmotic treatment used water to complete the circuit.

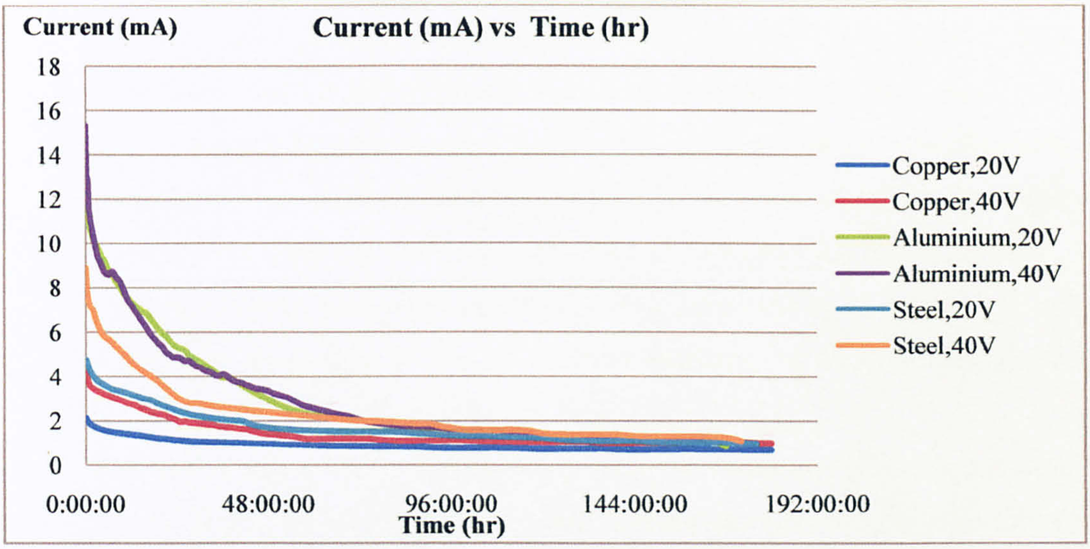

Figure 4.12: Relationship between current and time for every electrode

Here, we can say that in term of conductivity, aluminium has the highest which is has an average of 14.709mA followed by steel, 6.803mA and copper, 3.229mA. As for the final current value, all types of electrodes give almost the same value.

Electroosmosis process depends on dewatering process to strengthen the soil. This dewatering process depends on the Cation Exchange Capacity (CEC). The cations exchange is caused by the dissociated trivalent or bivalent ions in the pore water replacing such monovalent ions that are normally attracted to the negatively charged clay particle. In this case, the highest metallic ions, the mobilize Al^{3+} ions from the electrode and the soil replaced the weaker one the surface of clay particles. The crowding of Al^{3+} ions onto the surface of the clay particles (adsorption) brings about flocculation process. Higher current reading shows that the CEC process is higher by using aluminium electrodes.

Order in conductivity:

Aluminium > Steel > Copper

CHAPTER 5

CONCLUSION

The study on electroosmotic treatment was carried out on kaolinite clay. The study focused on the used electroosmosis process to enhance the vane shear strength of the soil using different types of electrodes which are aluminium, copper and steel electrode. The properties of kaolinite soil especially moisture content; shear strength; and pH were measured before and after the electroosmosis experiments. Analyses of changes in these properties provided important information about electroosmosis method for soil improvement.

Based on the results, the following conclusions are drawn:

(1) Electroosmotic treatment enhanced the shear strength of kaolinite soil. Different electrodes used gives different increment in shear strength. The increase of shear strength at anode is due to the electroosmosis process where pore water t anode area is dragged by the positive ion when moving to the cathode which results in reduction of moisture content. Aluminium is the most effective electrodes in term of increasing the vane shear strength of kaolinite soil which followed by steel and copper electrode respectively. The increment of shear strength using aluminium electrodes is 95.55%, a steel electrode is 66.29% and a copper electrode is 44.87%.

(2) The soil shear strength is depending with the reduction of moisture content. Aluminium with the highest increased of shear strength has the corresponding decrease in the soil water content of approximately 23.73% while using steel and copper electrode has a decrease of moisture content of 16.37% and 12.12% respectively

(3) The strengthening effect is directly associated with the applied electric field intensity. Higher voltage applied for electroosmotic treatment will results higher increased of shear strength and higher reduction of moisture content.

(4) Different types of electrodes with different conductivity effect the electroosmotic treatment. The study shows that aluminium with higher electrical

conductivity compared with steel and copper electrodes gives higher increased in term of soil shear strength and higher reduction in term of moisture content.

(5) The application of an electric field to kaolinite soil generated a pH gradient across the electrodes. At anode, the pH decreased while at cathode increased. This is due to the oxidation and reduction process occurs at each of the respective electrodes, anode and cathode.

In general, the results of the tests led to the conclusion that electroosmotic treatment of kaolinite soil is an effective method of enhancing its vane shear strength.

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7. Final Year Project Guidelines

Appendix I

(In-situ soil characteristic and properties)

Appendix 1 - In-situ soil characteristic and properties

Moisture Content

The result in the table 4.2.1 below shows the moisture content calculated for the in-situ soil sample.

Test method from BS 1377: Part 2: 1990: 3.2

Container No:		**1**	**2**	**3**	**4**
Mass of wet soil + container	(g)	44.72	44.95	41.87	33.97
Mass of dry soil + container	(g)	39.03	38.80	36.48	30.94
Mass of container	(g)	19.79	19.97	18.83	19.85
Mass of moisture	(g)	5.69	6.15	5.39	3.03
Mass of dry soil	(g)	19.24	18.83	17.65	11.09
Moisture content	(%)	29.6	32.7	30.5	27.3

Table A1: Results of moisture content for in-situ soil sample

The average moisture content for the sample Kaolinite soil taken is 30%. The kaolinite soil moisture content that had been obtained by F. G Bell is almost the same to moisture content of the soil sample. Thus, moisture content will be used as the basic result for physical properties of this Kaolinite soil.

Specific Gravity

The test is to determine the value of particle density of soils by using the small pyknometer method. This test is conducted accordingly with BS 1337: Part 2: 1990: 8.2. Basically there are three methods that can determine the specific gravity of soil which are the gas jar method, small pyknometer and large pyknometer. Small pyknometer is used for soil that consists of clay silt and sand-sized particles. The formulae used to calculate the specific gravity, ρ_s is:

$$\text{Specific gravity, } \rho_s = \frac{(m2-m1)}{(m4-m1)-(m3-m2)}$$

where;

m1 is mass of pyknometer + cap assembly (g)

m2 is mass of pyknometer + cap + soil (g)

m3 is mass of pyknometer + cap+ soil + water (g)

m4 is mass of pyknometer + cap+ water (g)

The result in the table 4.2.2 below shows the specific gravity calculated for the in-situ soil sample.

Mass of jar + gas jar + plate + soil + water	m3	1798 g
Mass of jar + gas jar + plate + soil	m2	936.5 g
Mass of jar + gas jar + plate + water	m4	1545 g
Mass of jar + gas jar + plate	m1	536.5 g
Mass of soil	m2-m1	400 g
Mass of water in full jar	m4-m1	1008.5 g
Mass of water used	m3-m2	861.5 g
Volume of soil particles		147 ML
Particle Density		2.72 Mg/m^3

Table A2: Result of specific gravity test on soil sample

The value of the particle density is 2.72 Mg/m^3. This result is shows that the soil sample is a clay sample since the specific gravity of a clay soil is a range from 2.7 -3.0 Mg/m^3.

<u>Particle Size Distribution (Sieve Analysis)</u>

There are two methods of sieving which are wet and dry sieving. The wet sieving is the definite method applicable to essentially cohesionless soils. Dry sieving is suitable only for soils that containing insignificant quantities of silt and clay. As for the soil sample, the dry sieving is selected to determine the soil sample particle size distribution. For silt and clay soil, the requirement is to pass the 63μm. The result of the sieve analysis test is as shown in Table 4.2.3.

BS Test Sieve	Mass retained (g)	Percentage retained	Cumulative percentage passing
2 mm	0.15	0.10	
1.18 mm	0.92	0.92	100
600 μm	3.71	3.71	99
425 μm	3.25	3.25	95
300 μm	30.37	30.37	92
212 μm	24.50	24.50	62
150 μm	7.35	7.35	38
63 μm	24.62	24.62	31
Passing 63 μm	6.70	6.70	7

Table A3: Result of sieve analysis on soil sample

From the result obtain, a graph of the particle size distribution is drawn onto the log graph. The graph of the particle size distribution is shown in Figure 4.2.1 in Appendix 1.

From the graph shown in Figure 4.2.1, the particle sizes are mostly categorized under the sand type of soil. This result cannot be taken since the objective of this project is a treatment on Kaolinite clay soils. The result that should be obtained is in the range of 40-50 percent passes 63μm. The inaccurate result could be caused by:

a) Improper crushing on the soil sample.
b) The soil sample contains other contaminant such as quartz stone.
c) The soil sample is not fully dried

To conclude, the result of particle sizes distribution test is unsuitable and considered failed because could not achieve the target of range 40-50% passes 63μm. This test will definitely will be repeated again until the requirement of a clay soil is fulfilled.

Plastic Limit (PL)

For plastic limit test, the soil is determined according to BS 1337: Part 2: 4.3/4.4. Plastic limit (PL) is the empirically established moisture content at which a soil becomes too dry to be plastic. It is used together with the liquid limit to determine the plasticity index which when plotted against the liquid limit on the plasticity chart provides means of classifying cohesive soils. The result for plastic limit is as shown in Table 4.2.4 below.

PLASTIC LIMIT	**Test no.**	**1**	**2**	**3**	**4**	**Mean**
Mass of wet soil + container	g	24.84	24.66	27.69	25.51	
Mass of dry soil + container	g	23.51	23.28	25.82	24.16	
Mass of container	g	19.80	19.71	21.00	20.07	
Mass of moisture	g	1.43	1.38	1.87	1.35	
Mass of dry soil	g	3.71	3.57	4.82	3.49	
Moisture content	%	38.5	38.70	38.8	38.7	38.7

Table A4: Results of Plastic Limit test on soil sample.

From the result obtain, the difference of value between each of moisture content is less than 0.5% which shows that the result is not failed. Several problems could occur during the test that can contribute for the inaccuracy and failure of the result. There are:

a) Too much water been added up to the soils.
b) Improper technique of rolling.
c) Inaccurate weighing of soil.
d) Improper sieve analysis method.

To conclude, the result for plastic limit is 38.7%. The test will be repeated again to have a rigid value. One test will certainly is not enough to make the result to be the basic properties of the soil.

Liquid Limit (LL)

The test is done by using cone penetrometer according to BS 1337: Part 2: 1990:4.3/4.4. The liquid limit is the empirically established moisture content at which a soil passes from the liquid limit state to the plastic state. The result of liquid limit test is as shown in Table 4.2.5.

LIQUID LIMIT Test no.	**1**			**2**		
Initial dial gauge reading mm	0	0	0	0	0	0
Final dial gauge reading mm	14.9	14.6	15.1	22.2	22.5	21.9
Average penetration mm	14.8			22.2		
Mass of wet soil + container g	29.16			30.57		
Mass of dry soil + container g	26.17			26.91		
Mass of container g	19.8			19.7		
Mass of moisture g	2.99			3.66		
Mass of dry soil g	6.37			7.21		
Moisture content %	46.9			50.76		
LIQUID LIMIT Test no.	**3**			**4**		
Initial dial gauge reading mm	0	0	0	0	0	0
Final dial gauge reading mm	24.1	24.1	25	27.8	26.9	27.5
Average penetration mm	24.4			27.4		
Mass of wet soil + container g	31.63			38.83		
Mass of dry soil + container g	27.55			31.82		
Mass of container g	19.8			19.04		
Mass of moisture g	4.08			7.01		
Mass of dry soil g	7.75			12.78		
Moisture content %	52.65			54.85		

Table A5: Result of Liquid Limit test on soil sample

From Table 4.2.5, a graph of penetration of cone (mm) versus moisture content (%) is plotted to find the liquid limit (LL) of the soil. The soil LL is moisture content corresponding to a cone penetration of 20mm. The graph of liquid limit is as shown in Figure 4.2.2 below.

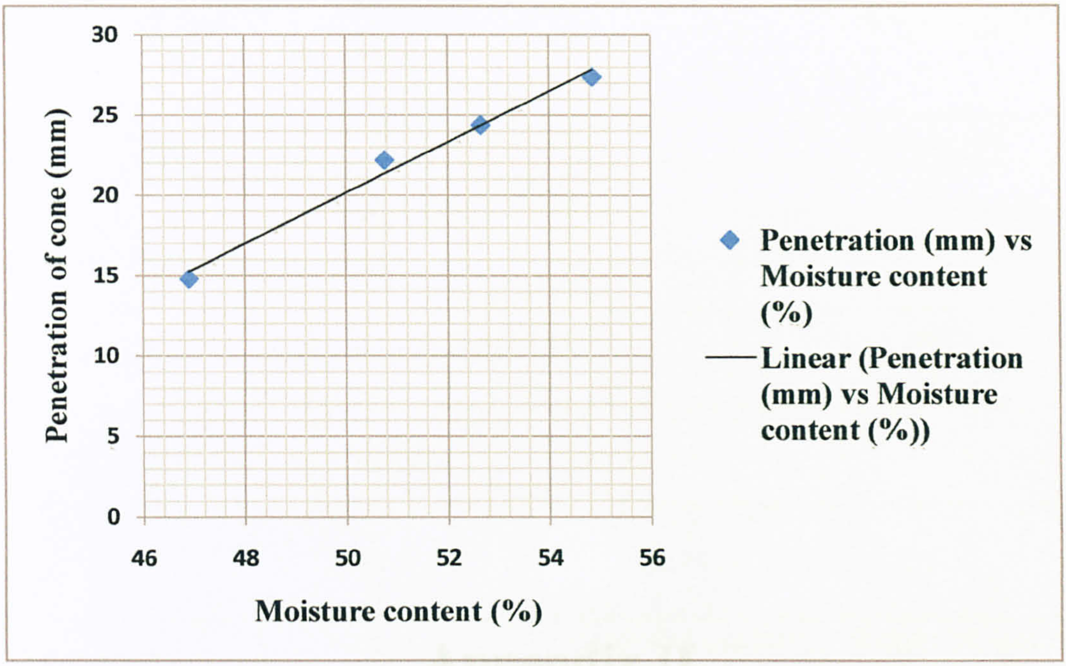

Figure A1: Graph of penetration of cone (mm) versus moisture content (%)

From the graph 4.2.2, the value of liquid limit is 50. To calculate the plasticity index, Ip, plastic limit value is needed. Since the value of plastic limit test is 38.7%, the Ip can be calculated. The formulae to calculate Ip is given as:

$$Ip = LL - PL$$
$$Ip = 50 - 38.7$$
$$Ip = 11.3$$

The plasticity index of the soil is 11.3. This value will be put into the Plasticity Chart for the Classification of Fine Soils. Figure 4.2.3 shows the plasticity Chart for the classification of fine soils in Appendix 2. The result that been obtain from the Plasticity Chart is the soil classification of the soil sample. The soil sample is classified as silt with intermediate plasticity. It is silt because the value is below the A-line.

The test result is suitable but several tests regarding on liquid limit will be conducted in the future to have a better and solid result of liquid limit. One test will certainly is not enough to make the result to be the basic properties of the soil.

Appendix II

(Data collection and calculation)

Moisture content

Test	Electrode	Voltage (V)
1	Copper	20
2	Copper	40
3	Aluminium	20
4	Aluminium	40
5	Steel	20
6	Steel	40
7	none	none

Test	Container	Weight of Container (g)	Weight of container + wet soil (g)	Weight of container + dry soil (g)
1	1(1)	18.3	83.4	61.7
	1(2)	20.7	70.2	53.3
	1(3)	20.5	64.9	50.1
	2(1)	18.6	83.2	61.6
	2(2)	20.7	68.3	52.1
	2(3)	20.9	70.0	53.0
2	1(1)	29.4	82.6	66.0
	1(2)	29.7	98.0	76.3
	1(3)	19.9	76.2	58.5
	2(1)	21.4	79.8	61.2
	2(2)	20.9	89.3	66.9
	2(3)	19.9	79.6	60.4
3	1(1)	20.3	76.1	58.1
	1(2)	20.3	74.7	57
	1(3)	19	81.3	60.8
	2(1)	19.4	75.2	57.3
	2(2)	19.8	67.4	51.8
	2(3)	19.3	68.8	52.1

Test	Container	Weight of Container (g)	Weight of container + wet soil (g)	Weight of container + dry soil (g)
4	1(1)	20.1	73.3	57
	1(2)	29.8	85.9	68.6
	1(3)	29.7	89.8	71.4
	2(1)	21.1	77.2	59.7
	2(2)	19.9	87.1	65.7
	2(3)	21.7	75.3	58.3
5	1(1)	18.3	81.2	60.4
	1(2)	20.6	75.6	57.3
	1(3)	20.5	74.1	56.2
	2(1)	18.6	80.3	59.7
	2(2)	20.7	74.1	55.7
	2(3)	20.9	69.1	52.5
6	1(1)	29.7	95.5	75.6
	1(2)	19.3	84.1	64
	1(3)	29.7	87.9	69.7
	2(1)	29.7	94.2	73.9
	2(2)	19.8	81.9	62.2
	2(3)	21.2	86.6	65.9
7	1(1)	20.6	69.8	53.2
	1(2)	20.9	73.5	55.5
	1(3)	23.5	77.8	59.1
	2(1)	29.5	88.8	68.9
	2(2)	18.7	72.4	54.1
	2(3)	23.1	72.8	55.7

Calculation:

$$\text{Moisture content, w (\%)} = \frac{(m2-m3)}{(m3-m1)} \times 100$$

where;

m1 = mass of the container (g)

m2 = mass of container and wet soil (g)

m3 = mass of container and dry soil (g)

Input the data of container 1(1) for test 1;

m1 = 18.3 g

m2 = 83.4 g

m3 = 61.7 g

$$\text{Moisture content, w (\%)} = \frac{(83.4-61.7)}{(61.7-18.3)} \times 100$$

$$= 49.92\%$$

Vane shear strength

For example taking test 4, aluminium 40V:

Deflection of spring (inner) = 42 °
Rotation of vane (outer) = 9 °
Spring rotation = 51 °
Calibration factor (inner – outer) = 33 °
Spring No. 3 was used.

The torque, M (KN/m^2) was obtained from calibration chart.

Table 1: Calibration chart

Torque		Spring No.			
Kg.cm	Nm	1	2	3	4
0.25	0.025	8	10	14	21
0.50	0.049	16	19	27	39
0.75	0.074	23	29	41	58
1.00	0.098	31	39	55	78
1.25	0.123	40	49	69	98
1.50	0.147	48	60	82	118
1.75	0.172	56	69	95	139
2.00	0.196	65	79	108	160
2.25	0.221	72	90	122	179
2.50	0.245	81	100	135	199
2.75	0.270	89	110	150	
3.00	0.295	98	120	161	
3.25	0.319	105	129	175	

By interpolation, the torque, M for 33 ° was obtained.

$$(41 - 33) / (74 - M) = (41 - 27) / (74 - 49)$$

$$M = 59.71 \text{ kN/m}^2$$

Therefore, the vane shear strength was calculated as,

$$Tv = M / k \qquad (\text{KN/m}^2)$$

Where

$$K = \Pi D^2 [(H/2) + (D/6)]$$

K value is 4.29 for vane with H=12.7mm and D=12.7mm.

By assuming the vane K= 4.29 m^3 , therefore

$$\text{Vane shear strength, } Tv = (59.71) / 4.29$$

$$= 13.92 \text{ kN/ m}^2$$

Table 2: Typical Value.

Term	Undrained Shear strength (Kpa)	Visual identification
Very soft	<12.5	Exudes between fingers
Soft	12.5 – 25	Easily molded with fingers and indented considerably with thumb.
Firm	25 – 50	Can be molded with moderate pressure of fingers and indented with moderate pressure.
Stiff	50 – 100	Molded with difficulty by fingers, can be indented by strong pressure of the thumb only a small mount
Very stiff	100 - 200	Can be indented to little more then a fingerprint with strong pressure of the thumb.