COMPARISON OF ELECTRO-OSMOSIS AND PREFABRICATED VERTICAL DRAIN FOR KAOLINITE SOIL STABILIZATION

MUHAMMAD LUTFIRRAHMAN SAHDAN

CIVIL ENGINEERING
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by

Muhammad Lutfirrahman Sahdan

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Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved:

Dr. Syed Baharom Azahar Syed Osman
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

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.

Muhammad Lutfirrahman Sahdan

ABSTRACT

Electro-osmosis and Prefabricated Vertical Drain (PVD) with surcharge are two common methods is soil stabilization and this report is the preliminary research done to study the comparison between these methods on Kaolinite soil stabilization. A series of experiments will be conducted during the research period to investigate the effect of electro-osmosis, PVD and electro-osmosis with PVD to the soil water content, shear strength, rate of settlement, Liquid and Plastic Limit,. The experiments will be conducted on disturbed sample in a electro-osmosis box. The controlled parameters in the experiments are voltage applied, electrode distance and duration of experiment conducted. Through this research it shows electro-osmosis is 1.8 and 4.2 times more effective than PVD with surcharge for stabilizing kaolinite soil in term of reducing moisture content and increasing shear stress.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

According to Bergado *et al.* (2003), clay is highly compressible and will consolidate significantly when subjected to loading. The settlement will cause harmful effect on the overlying structures. Base on general nature of clay that are fine in particles size and low permeability, longer period is required for clay to achieve its primary consolidation. In order to stabilize the soil in this condition, water should be removed from the soil and promote the consolidation process to occur. The Author suggested two methods that will be involved in this research that are electro-osmosis and Prefabricated Vertical Drain (PVD).

Electro-osmotic technology had been used since Casagrande, L. introduced this method in 1930's for soil stabilization that induce water movement in the soil by applying direct current. Several other patents of electro-osmosis for water removal in clayey soils and silty soils and after that widely use for drying saturated soils in heavy construction in Germany, England, the USSR, Canada and Mexico (Adamson, L.G. et *al.*, 1966). From Casagrande, L. continuous research using electro-osmotic, clayey soils can be stabilized effectively.

The prefabricated vertical drain (PVD) with preloading method was considered the most feasible treatment option for the project based on the depth of treatment, cost, time available for. The objective of using the vertical drains with preloading technique is to accelerate the rate of consolidation and to minimize future settlement of the treated area under the future loads. The application of preloading alone may not be feasible with tight construction schedules; hence, a system of PVD is often introduced to achieve accelerated radial drainage and consolidation (B. Indraratna et *al.*, 2005).

1.2 PROBLEM STATEMENT

B. Indraratna believed that the demand for infrastructure development on soft compressible soils continuously increases with the rise in population. Often, rapid development necessitates the utilization of even the poorest of soft clays; and therefore, it is essential to stabilize the existing soft clay foundations prior to construction, in order to avoid excessive and differential settlement.

Different ground improvement techniques are available today. Normal compaction method such as dynamic compaction is less effective for clayey soil. Due to the nature of clay soil that are low permeability, fine clay particle size and high water absorption, certain methods of soils stabilization/consolidation are suitable for kaolinite soil. These soil properties create a unique challenge in stabilizing kaolinite soil.

High water absorption and low permeability are the general views of the factor affecting poor clay consolidation process. High water absorption cause clay store up more water compare to other type of soil. With low permeability, water movement in soil is very limited and slow down consolidation process.

Electro-osmosis and PVD are two proven methods in improving consolidation rate and hence stabilize the soil (Bergado, 2003, B. Indraratna., 2005). In general, both methods try to induce movement of water in the soil and improve consolidation but as the mechanism applied are different; both efficiency of soil stabilization can be evaluated.

1.3 OBJECTIVE AND SCOPE OF STUDY

The main objectives of this research are:

- To conduct literature review on electro-osmosis, Prefabricated Vertical Drain (PVD) with surcharge in soils stabilization.
- To study comparison of electro-osmosis and PVD with surcharge in stabilizing kaolinite soil.
- To study the effectiveness of suggested method in term of moisture content, vane shear strength, rate of settlement and pH

The scope of study of this project is basically to understand the behaviors and characteristics (physical and chemical characteristics) of kaolinite soils. Besides that, the research requires the Author to have fundamental knowledge in electro-osmosis and PVD in order to successfully carry out the research.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Different soil improvement techniques are available today. Every technique should lead to an increase of soil shear strength, a reduction of soil compressibility and a reduction of soil permeability. The choice of soil improvement technique depends on soil characteristics, cost, availability of backfill material and experience in the past.

According to Bergado et *al.* (2003) they can be divided broadly into two categories. The first category includes techniques which require utilization of reinforcements. They are based on stiffening. The second category includes methods which are strengthening the soil by dewatering process and promote consolidation.

2.2 ELECTRO-OSMOSIS

2.2.1 THEORY OF ELECTRO-OSMOSIS

Electro-osmosis is defined as a water movement in the soil capillary as the result of an applied direct current. In 1809, Reuss was the first to discover that water flow could be induced through a capillary by an external electric field (Das, 2008). When a direct current potential is applied to saturated soil, the pore water is induced to flow from positive electrode (anode) to negative electrode (cathode).

According to Wilkins, E.A. (1989), movement of water from anode to cathode is caused by movement cations that are predominant in the clay soil. In common view, as the cations are moving to cathode due to the applied direct current, it will moves water molecules in the same direction. The movement of water can be further explained by Helmholtz-Smoluchowski Theory related with cation exchange at diffuse double layer of clay particle.

The diffuse double layer surrounded the clay particles are due to the Cation Exchange Capacity (CEC). CEC is defined as the degree to which a soil can adsorb and exchange cations. In general clay particles have high CEC compare to other soil particles except organic soils. Layer of Cations in the soil can be adsorbed to the soil particle surface because the surface is negative charge. Once adsorbed, these cations are not easily movable. The attractive forces are significantly very strong near the particle surface but decreases with increasing distance away from the surface. This cause the outer layer of cations is not adsorbed to the surface but movable. In between these layers is the transition that known as the diffuse layer.

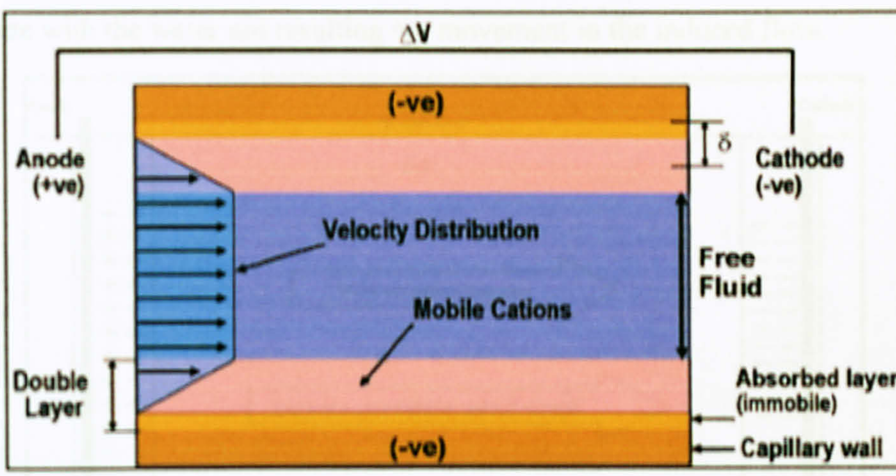


Figure 2.1: Model of Electro-osmosis flow

Water molecule is dipolar because of its molecular shape. It has positive charge at one side and negative charge at another. Because of that, water molecule is also experiences the adsorption to the soil surface. The force of attraction between water and soil decrease with the distance from the surface of the particles. The inner layer of water also known as adsorbed water is negatively charged attached to soil surface, while the outer water layer is knows as free water is positively charged and movable (Das, 2008).

When direct current are applied to the soil, the adsorbed water will be exchange with other trivalent ions such as Al^{3+} and $Fe^{3}+$ ions because it have greater adsorption strength compare to water dipolar molecules. This water molecule then becomes free water and moves along with other cations towards cathodes (Morales E.A).

Athmer (1999) believe that, under the influent of a direct current, the row the row of cations in the diffuse double layer start sliding along toward the cathode. The movement of this boundary layer of cations will drag bulk water with it. As bulk water molecules will promote movement of other water molecules, it will cause the entire cross-section of free pore water to also move in the same direction. When the soil have wider capillaries such in the cohesionless soils, the center portion of void waters will recirculate with the water not resulting net movement in the induced flow.

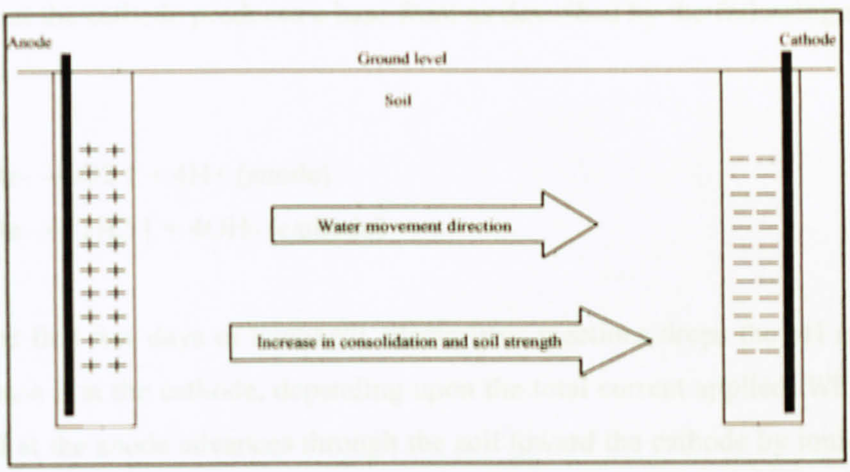


Figure 2.1: Electro-osmosis phenomena in soil

According to Wilkins, E.A. (1989), if the free water is not available at the anode to replenish the pore water, the water content in the soils will decrease starting from anode and progressing toward cathode. Due to this situation, it will create tensile stress in soils that further result in soil consolidation and a subsequent strength increase in soils.

There are a few factor effect the rate of pore water flow through the soil.

i. The amount of applied electric voltage
ii. The chemistry of the soil water system
iii. The size and shape of pores
iv. The relationships between inter granular stress and the pore water tension..
v. The availability of free water at the anode

2.2.2 SECONDARY EFFECT OF ELECTRO-OSMOSIS ON SOIL

Application of direct current through electrodes immersed in water induces electrolysis reactions at the electrodes. Oxidation of water at the anode generates an acid front while reduction at the cathode produces a base front as described by the following electrolysis reactions.

$2H_2O - 4e^- \rightarrow O_2 \uparrow + 4H^+$ (anode)
$4H_2O - 4e^- \rightarrow 2H_2 \uparrow + 4OH^-$ (cathode)

Within the first few days of treatment, electrolysis reactions drops the pH at the anode and increase it at the cathode, depending upon the total current applied. While the acid generated at the anode advances through the soil toward the cathode by ionic migration and electro osmosis, base developed at the cathode initially advances toward the anode by diffusion and ionic migration. However, the counter flow due to electro osmosis retards the back diffusion and migration of the base front. The advance of this front is slower than the advance of the acid front because of the counteracting electro-osmotic flow and also because the ionic mobility of H^+ is higher than OH^- (Asadi A., 2003).

In addition to the movement of water when a direct current voltage difference is applied to saturated soil, the voltage field is also directly resulting in heating the soil. The soil heating will cause lowering pore water viscosity and increase electro-osmosis permeability. The applied current and the induce current will provides resisting heat power to the entire soil mass between the electrodes.

There are also other effects developed from electro-osmosis such as, ion exchange, ion diffusion, difference pH gradient, mineral decomposition, and physical and chemical absorption. Because of these effects contribute to minor change in soil properties, there will be considered in the simplified theory. All those effects mention above will benefit the in term of electro-chemical hardening by increasing the soils strength and lowering plasticity characteristics (Wilkins E.A., 1989).

2.2.3 CALCULATION RELATED TO ELECTRO-OSMOSIS

The quantity of liquid moved in unit time, Q_e, under the influence of potential difference, E, is equal to:

$$Q_e = k_e \, i_e \, A \ \text{cm}^3/\text{sec}$$

Where,

k_e = coefficient of electro-osmosis permeability, cm/sec per volt/cm

i_e = electrical potential gradient

= E/L, volt/cm

L = electrode separation, cm

A = area of flow, cm^2

where, Q is electro-osmotic flow rate, in m^3s^{-1}, ke is coefficient of electro-osmotic conductivity, in m^2Vs^{-1}, ie is applied electrical gradient, in Vm^{-1}, A is gross cross-sectional area perpendicular to water flow, in m^2. In dealing for small capillaries or unsaturated Smoluchowski equation is no longer applicable.

2.3 PREFABRICATED VERTICAL DRAIN (PVD) WITH PRELOADING

2.3.1 HISTORY OF VERTICAL DRAIN

Vertical drain was firstly proposed by D.J. Moran in 1925 for deep soil stabilization. After a few years, the first sand drain was constructed in California. In late 30's, Kjellman start to introduce first prefabricated vertical drain, it was in form of cardboard. Although there were problems related to the cardboard drain, especially its rapid deterioration, it survived half of the century with the technology was been use occasionally in Europe and Japan.

In 1971, Wager improved on the Kjellman cardboard drain by using proved plastic core in the place of the cardboard. It was called Geodrain and utilized Kraft paper filter. The later versions try to utilize non-woven textile for the filters. Now days, Improvement on vertical drain occurs very rapid due to market competitiveness. This cause deceases in cost of the drains and improves installation method. Today, vertical drain can reach up to 60m depth with the rates of 1m/s.

2.3.2 THEORY OF PVD WITH PRELOADING

The objective of using the vertical drains with preloading technique is to accelerate the rate of consolidation and to minimize future settlement. Preloading by placing surcharge loading on top of soft soils will consolidate it and will increases the bearing capacity and reduces the compressibility of weak ground.

For preloading, the surcharge loading is placed on designed location and depth with initial expectation of required deformation can be achieved for final construction. According to Atkinson (1982), Preloading is only effective in causing settlement if the applied surcharge loads significantly exceeds pre-consolidated pressure of it foundation. The presence of vertical drains also will not to help the consolidation if pre-consolidated pressure is not exceeded.

According to B. Indraratna (2005) Vertical drains is use to accelerate soils consolidation process by removing the pores water in the soil. This will significantly reduce the settlement of time of the embankment over the soft soils to allow consolidation complete in reasonable time with minimal post-construction settlement. As consolidation take place, soil bearing capacity increases and improve soil strength. Vertical drain also will decrease the amount of surcharge material needed to achieved settlement in a given period but this amount should be less than the amount required to exceed pre-consolidated pressure.

As the mechanism of vertical drain is to remove pores water from soil, it only accelerates primary consolidation. In primary consolidation, consolidating pressure increase as the pores water pressure. As the consolidating pressure exceeds the pores water pressure, compression of soil is occurred. Consolidating pressure is initially only contributed from the surcharge load that place over the soil. This consolidating pressure will cause the pores water exited from soil. There is increment in consolidating pressure due to horizontal force by the soils until it will reaches its consolidation pressure when if fully consolidated.

Secondary consolidation causes only very small amounts of water to drain from the soil and as such secondary settlement is not speeded up by vertical drains. Only relatively impermeable soil potentially benefit from vertical drains. Vertical drains are particularly effective where a clay deposit contains thin horizontal sand or silt lenses that so-called micro-layers.(B. Indraratna, 2005)

2.3.3 PROPERTIES OF PREFABRICATED VERTICAL DRAINS

The main properties of vertical drains that need to be specified in a ground improvement project are as follows:

i. Discharge Capacity
   - If discharge capacity is smaller than amount of water to be discharged, well resistance will occur.

ii. Properties of Filter
   - Apparent Opening Size (AOS) – has to be sufficiently small to prevent ingress of clay fine particles.
   - Permeability

iii. Tensile Strengths
   - should have adequate strength to sustain the tensile stresses subjected to it during the installation process

Base on previous application, there are factors affecting the performance of vertical drains are as follows:

i. Consolidation stress.
   - The discharge capacity of vertical drains decreases with increasing consolidation stress. The consolidation stress reduce the cross sectional surface area of the drain by put it under constantly increasing pressure and penetration of the filter into drain groove. (Chai, 1999)

ii. Deformation of drain
   - The consolidation pressure also causes the physical form of the vertical drain to deform or buckle. It causes the drain to become smaller and reduce its efficiency. (Chai, 1999)

iii. Time

- The discharge capacity of the vertical drain may change with time. This will cause by the drain material deformation particularly the filter which will cause the effective cross-section area of the drain to reduce

iv. Clogging of drain

- If the pore of the filter too large, it will allow fine soil particles to ingress and clogging the drain. (Chai, 1999)

v. Hydraulic gradient

- The discharge capacity measured varies with different hydraulic gradients and is smaller when a higher hydraulic gradient is used. (Chai, 1999)

vi. Temperature

- The higher the temperature, the lower viscosity, the faster the flow and the larger the discharge capacity. (Chai, 1999)

CHAPTER 3

METHODOLOGY

3.1 PROJECT IDENTIFICATION

For this research requires to conduct successfully, it require the Author to be fully understand the whole electro-osmosis and Prefabricated vertical Drain (PVD) concept and familiarized with the equipment during the laboratory experiment with electro-osmosis cell. Therefore, below are the methodologies which will be taken throughout this project:

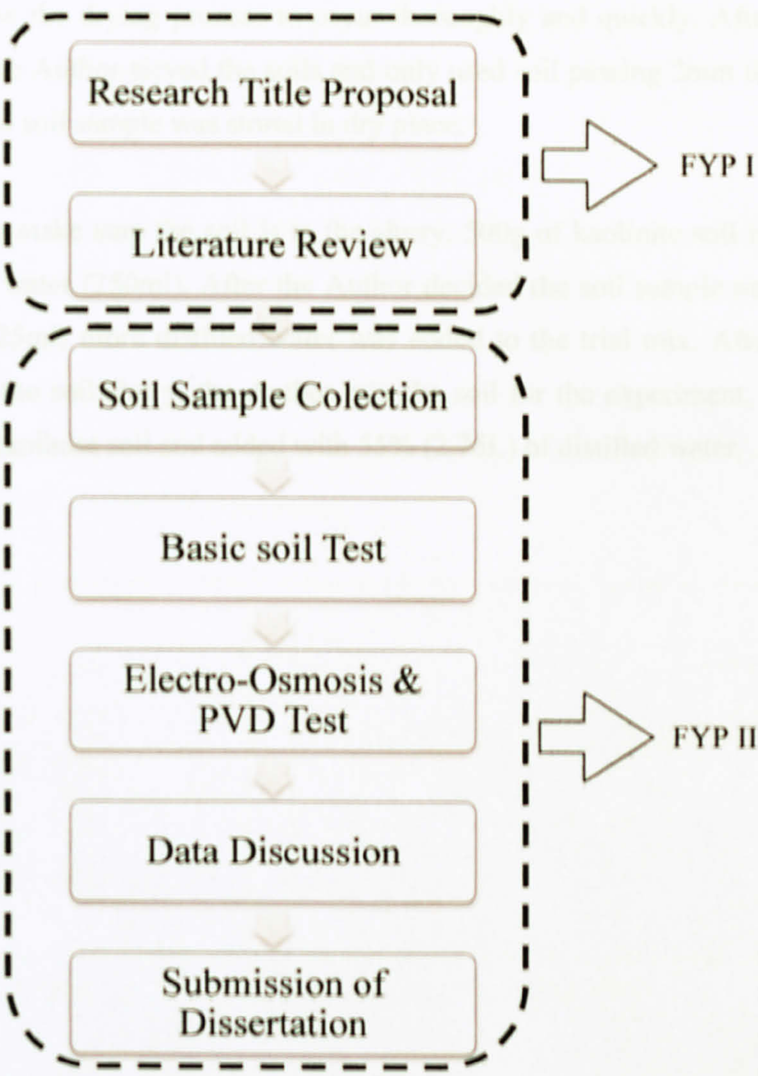


Figure 3.1: Research plan flow chart

3.2 SAMPLE PREPARATION

As advised by Mr. Azmi, Deputy Director of Jabatan Mineral dan Galian Perak, the Author found the location for kaolinite sample. It is around 20 minutes from Ipoh and it is on the hill side of the main road to Cameron Highland. Base on Mr Azmi, this is site for primary clay residual.

After the Author gather the required kaolinite soil for the research, the soil is transported to laboratory. The sample is oven-dried for 24 hours. The soil is crushed in to small piece to allow the drying process to occur thoroughly and quickly. After the soil was oven-dried, the Author sieved the soils and only used soil passing 2mm for the experiment. The sieved soil sample was stored in dry place.

Trial mix was done to make sure the soil is in the slurry. 500g of kaolinite soil is mix with 50% of distilled water (250ml). After the Author decided the soil sample need to be more slurry, 5% (25ml) more distilled water was added to the trial mix. After the Author satisfied with the soil slurry, the Author mix the soil for the experiment. Each box requires 10kg of kaolinite soil and added with 55% (2.75L) of distilled water.

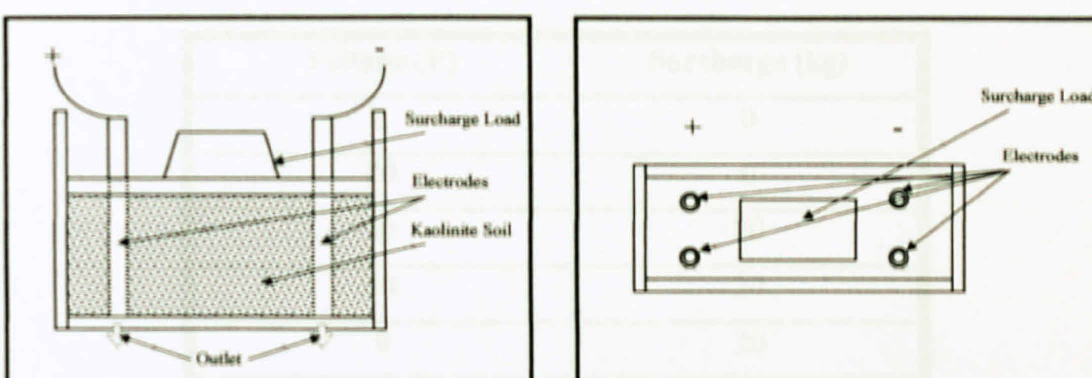
3.2 LABORATORY SESSION

For Final Year Project I (FYP I), the author require to conduct basic soil characteristic test that include moisture content, specific gravity, Particle Size Distribution (PSD), Plastic and Liquid Limits, pH, Vane Shear Strength, Conductivity, XRD.

During the laboratory experiment for FYP II, this research requires the Author to conduct tests on suggested methods. We will be using 30"x 12"x 17" box test for this experiment. The suggested soil modification methods are as below:

a) Electro-osmosis
b) Prefabricated Vertical Drain
c) Control set

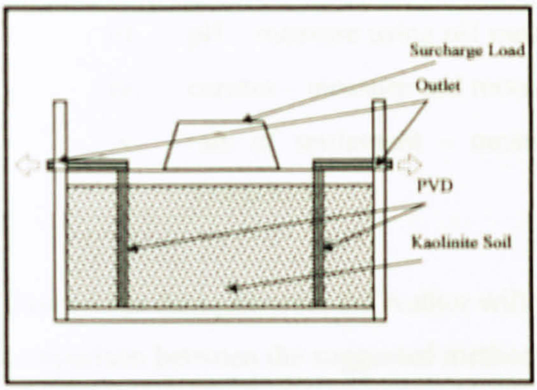
For electro-osmosis box test, soil was treated for 7 days. Direct current was supplied by DC power supply. 4 copper pipe electrodes with 31mm diameter were inserted at specific location as mention in Figure 3.2. Four water outlets are provided at the bottom of each electrode to allow the transported water flow out the box. Surcharge load is applied on top box cover when required. Below are the sketch diagrams of the box test use by the Author for electro-osmosis experiment.



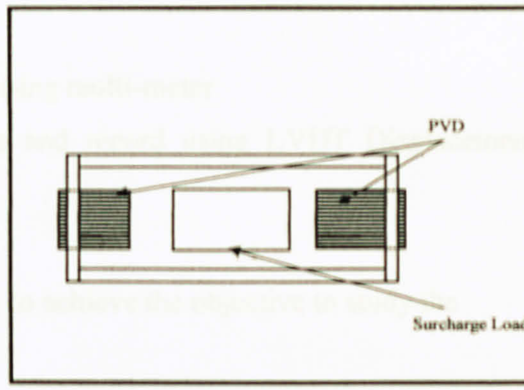
a) Front view b) Top View

Figure 3.2: Sketch diagrams of the box test for electro-osmosis

For PVD box test, soil was treated for 7 days. Surcharge load is applied to the soil by putting weight on top of the cover at center position. Two PVD with 100mm width and 9mm thickness are inserted to the soil. Water outlets are provided at the side of each box, above the box cover level to allow the transported water flow out the box. . Below are the sketch diagrams of the box test use by the Author for PVD experiment.



a) Front view



b) Top View

Figure 3.3: Sketch diagrams of the box test for Prefabricated Vertical Drain (PVD)

During FYP II, the Author planned to run 5 experiments. For electro-osmosis, copper electrodes will be used. All the experiments planned are as below:

Voltage (V)	Surcharge (kg)
0	0
20	0
20	20
40	20
0	20
0	40

The Author conducted a few other tests to observe the change in parameters of the soil tested. 5 Soil samples were taken from the treated soil for testing as mention in Figure 3.4. The parameters are:

i. shear strength – measure using vane shear apparatus
ii. moisture content –calculate using Oven-Drying Method
iii. pH – measure using pH meter
iv. current – measure and record using multi-meter
v. rate of settlement – measure and record using LVDT Displacement Transducer

Base on the data gathered, the Author will try to achieve the objective to study the comparison between the suggested methods.

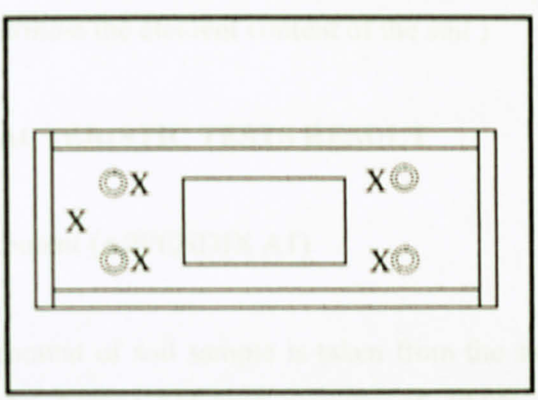


Figure 3.4: Soil sample is taken for testing at points marked X (top view)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

For FYP I, the Author require to run tests on the kaolinite soils to studies it soils characteristic. All the soil characteristic tests are as listed below:

i. Moisture content (APPENDIX A1)
ii. Specific gravity (APPENDIX A2)
iii. Particle Size Distribution (APPENDIX A3 & A4)
iv. Plastic and Liquid Limits (APPENDIX A5 & A6)
v. pH
vi. vane shear strength
vii. Conductivity
viii. XRD (Determine the mineral content of the soil)
ix. XRF (Determine the element content of the soil)

4.2 SOIL CHARACTERISTIC TESTS RESULT

i. Moisture content (APPENDIX A1)

Moisture content of soil sample is taken from the soil sample in-situ. From the test, the Author obtained average of 30.0% moisture content. The average moisture content for kaolinite soils is 29.5% (F. G. Bell) and our sample moisture content is near to the average value.

ii. Specific gravity (APPENDIX A2)

Specific gravity is ratio of mass of soil to mass of equal volume of water. To obtain this, the Author use oven-dried sample and measure it using Pycnometer. According to Bowles, 1978, specific gravity of inorganic clay is in 2.70-2.80G. Specific gravity of our kaolinite sample is 2.72G.

iii. Particle Size Distribution (APPENDIX A3 & A4)

In order to analyze the sample Particle Size Distribution, the sample has to undergo sieve analysis. The oven-dried sample is undergone sieve with opining range from 2mm to 63μm. For Clay soil type, the sample should have 35% soil distribution in passing 63μm. In our soil sample, the author obtained only 7% of passing 63μm.

The source of error is cause by the soil is not fully crushed and still in bulky shape. Because of the sample is fine grained, improved result will be obtained if the PSD test is combined Hydrometer test.

iv. Plastic and Liquid Limits (APPENDIX A5 & A6)

Plastics Limit and Liquid limits for the sample is 38.7% and 51% respectively. Plastic index is 12.3. Base on this Plastic Limit and Liquid Limit, it is clay with low plasticity.

4.3 ELECTRO-OSMOSIS AND PVD TESTS RESULT AND DISCUSSION

After soil undergone the suggested treatment, 5 soil samples were be taken from a certain locations using sample tube. Points are labeled with P1-P5. For Electro-osmosis test, soil samples for P1-P4 are taken next to the electrodes and P5 is at outer area. P1 and P3 soil samples are taken at the anode while P2 and P4 soil samples are taken at the cathode. For PVD test and control test sample, the location of the oints is the same with points taken in Electro-osmosis test. The 5 points are as mention in Figure 5.1 below:-

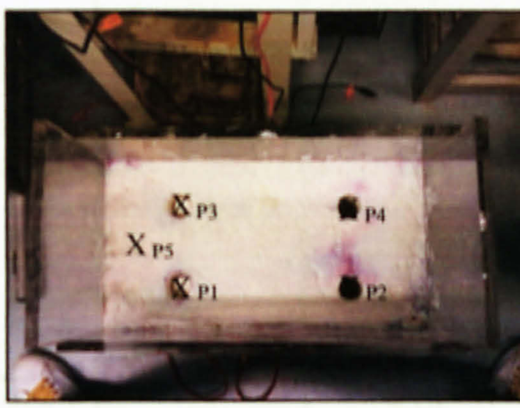


Figure 4.1: Soil sample is taken for testing at points marked X

4.3.1 Moisture Content

Moisture content can be calculated by measuring the weight of the saturated samples and the weight of the sample after oven-dried. Moisture content can be calculated by using this formulae;

$$w = \frac{(m_2 - m_3)}{(m_3 - m_1)} \times 100$$

Where;

m_1 = mass of container (g)

m_2 = mass of container and wet soil (g)

m_3 = mass of container and dry soil (g)

The moisture content for all samples and average moisture content are recorded in table 4.1 below

Experiment	Sample Point	Moisture Content (%)	Average Moisture Content (%)
E-O with 40v,2.5kPa	P1	33.4	36.3
	P2	38.7	
	P3	33.4	
	P4	35.8	
	P5	40.1	
E-O with 20v,2.5kPa	P1	40.5	41.5
	P2	42.6	
	P3	38.6	
	P4	41.6	
	P5	44.1	
E-O with 20v,0kPa	P1	44.2	43.2
	P2	43.5	
	P3	42.5	
	P4	43.1	
	P5	42.8	
PVD with 5.0kPA	P1	45.4	44.2
	P2	43.2	
	P3	44.2	
	P4	42.2	
	P5	45.9	
PVD with 2.5kPA	P1	49.3	48.7
	P2	48.6	
	P3	49.8	
	P4	48.7	
	P5	47.1	
Control Set	P1	53.8	53.5
	P2	52.6	
	P3	54.2	
	P4	53.2	
	P5	53.5	

Table 4.1: Moisture content for all samples and average moisture content

One of the viewpoints to compare the effectiveness of Electro-osmosis and Prefabricated Vertical Drain in soil stabilization/consolidation is by comparing its shear strength. This is because consolidation process is directly related to dewatering process from the soil.

Base on figure 4.2 below, we can observed an average of 32.1%, 22.4% and 19.2% moisture content reductions in electro-osmosis treatments while 17.4% and 9% moisture content reductions in PVD as all the comparison was made to control set. In general, moisture content reductions are 24.6% and 13.2% for electro-osmosis and PVD respectively. This show that electro-osmosis is 1.8 times more efficient in soil consolidation process in term of water reduction.

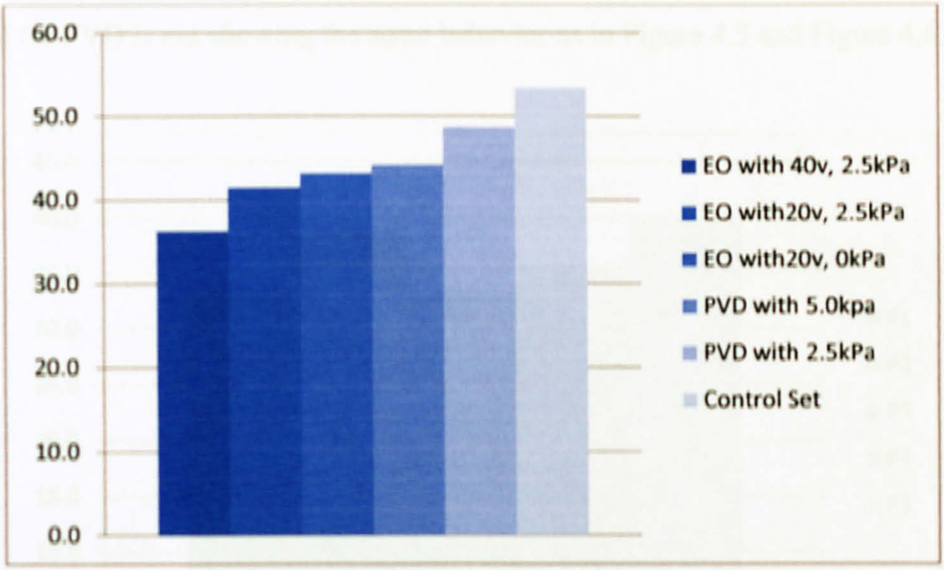


Figure 4.2: Average moisture content (%)

Electro-osmosis without surcharge is reducing more moisture content compare to both PVD tests. This shows Electro-osmosis is more effective compare to PVD in term of moisture content reduction. Although the difference between the methods is not significant, through a few improvements such as increase in treatment time and current applied, electro-osmosis will performs well in actual treatment. The usage of surcharge load in PVD is less preferable because of its cost and supply availability made electro-osmosis the better choice.

For all electro-osmosis tests, there are similarities in moisture content result as can view in Figure 4.3 and Figure 4.4 below for example. Moisture content for P1 and P3 which is at anode are lower compare to moisture content at P2, P4 and P5. This shows water near anode area is moving away to cathode due to direct current applied. Moisture content for PVD is not showing the same behavior as in Figure 4.5 and Figure 4.6.

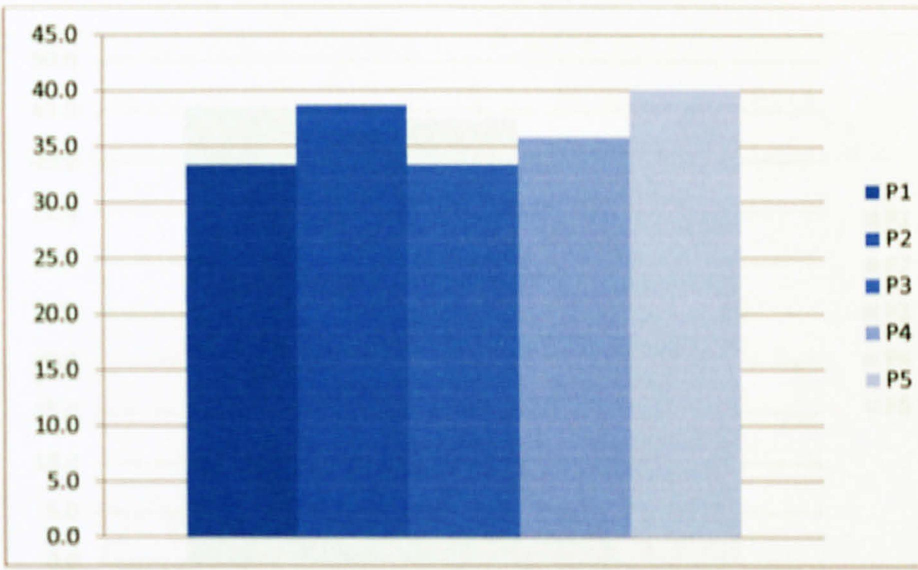


Figure 4.3: Moisture content for Electro-Osmosis with 40v, 2.5kPa surcharge

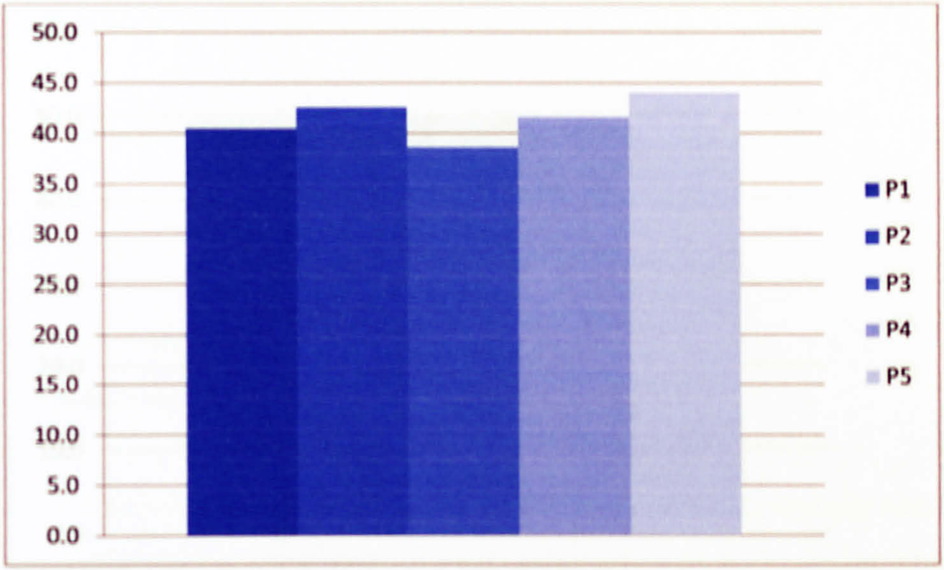


Figure 4.4: Moisture content for Electro-Osmosis with 20v, 2.5kPa surcharge

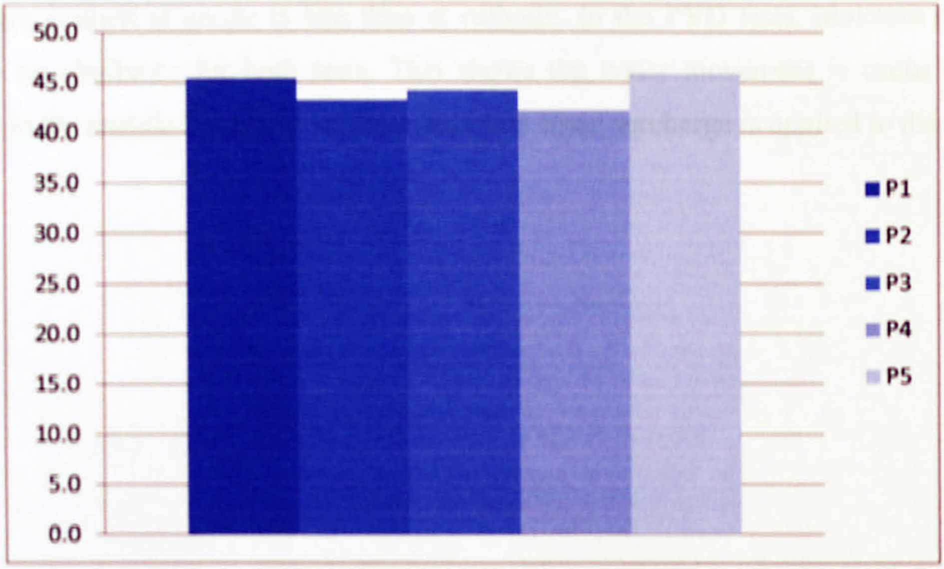


Figure 4.5: Moisture content for PVD with 5.0kPa surcharge

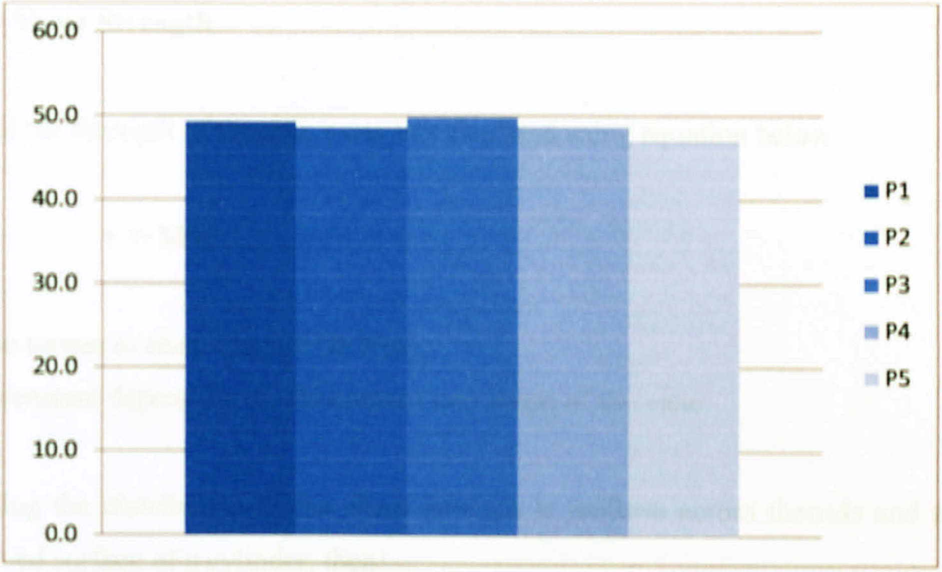


Figure 4.6: Moisture content for PVD with 5.0kPa surcharge

The similarities in electro-osmosis test show the mechanism of electro-osmosis working in test. After a period of time, movement of water from anode to cathode cause the moisture content at anode is less than at cathode. In the PVD tests, moisture content shows no similarity for both tests. This shows the water movement is occur on the whole in the sample but not in uniform direction when surcharge is applied to the soil.

4.3.2 Shear Strength

Vane Shear Strength of the soil, τ can be calculated using equation below

$$\tau = M/K$$

where;

M is the torque to shear the soil (in Nm).

K is a constant depending on dimensions and shape of the vane.

Assuming the distribution of the shear strength is uniform across theends and around the curved surface of a cylinder, then:

$$K = \pi D^2 H/2 \times (1 + D/3H) \times 10^{-6}$$

where

D is the overall width of vane measured to 0.1 mm (in mm).

H is the height of vane measured to 0.1 mm (in mm).

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

The shear strength for all samples and average shear strength are recorded in table 4.1 below;

Experiment	Sample Point	Shear Strength (kN/m^2)	Average Shear Strength (kN/m^2)
E-O with 40v,2.5kPa	P1	11.3	10.26
	P2	9.5	
	P3	11.9	
	P4	9.7	
	P5	8.9	
E-O with 20v,2.5kPa	P1	10.5	9.28
	P2	8.6	
	P3	10.8	
	P4	8.9	
	P5	7.6	
E-O with 20v,0kPa	P1	9.1	7.92
	P2	6.9	
	P3	9.6	
	P4	7.0	
	P5	7.0	
PVD with 5.0kPA	P1	7.8	8.12
	P2	8.6	
	P3	7.8	
	P4	8.4	
	P5	8.0	
PVD with 2.5kPA	P1	7.5	7.54
	P2	7.4	
	P3	7.4	
	P4	7.6	
	P5	7.8	
Control Set	P1	7.5	7.18
	P2	7.2	
	P3	7.1	
	P4	7.2	
	P5	6.9	

Table 4.2: Shear strength for all samples and average shear strength

Increase in shear strength can be observed in all soil samples. Base on figure 4.4 below, we can observed an average of 42.9%, 29.2% and 13.9% shear strength increment in electro-osmosis treatments while 10.3% and 5% shear strength increment in PVD as all the comparison was made to control set. In general, shear strength increment are 28.6% and 7.7% for electro-osmosis and PVD respectively. This show that electro-osmosis is 3.7 times more efficient in soil consolidation process in term of shear strength increment.

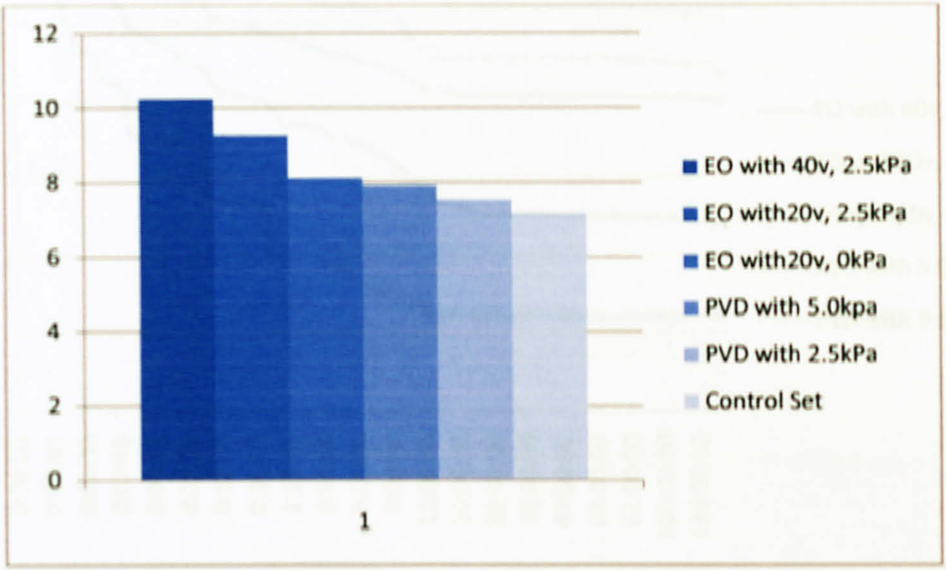


Figure 4.7: Average Shear Strength (kN/m^2)

By observing moisture content and shear strength of the treated soil sample, the author distinguishes the relationship between these two elements. Increment of shear strength is corresponding to the reduction of moisture content.

Although the increase in shear strength is quite small, it shows the soil is consolidating. Given more time and increase in direct current applied, the Author believes it can further improve the result.

4.3.4 Settlement

Settlements of the soil in the tests were measured using LVDT settlement transducer and recorded in the computer. Data of soil settlement is shows in Figure 4.8 below:-

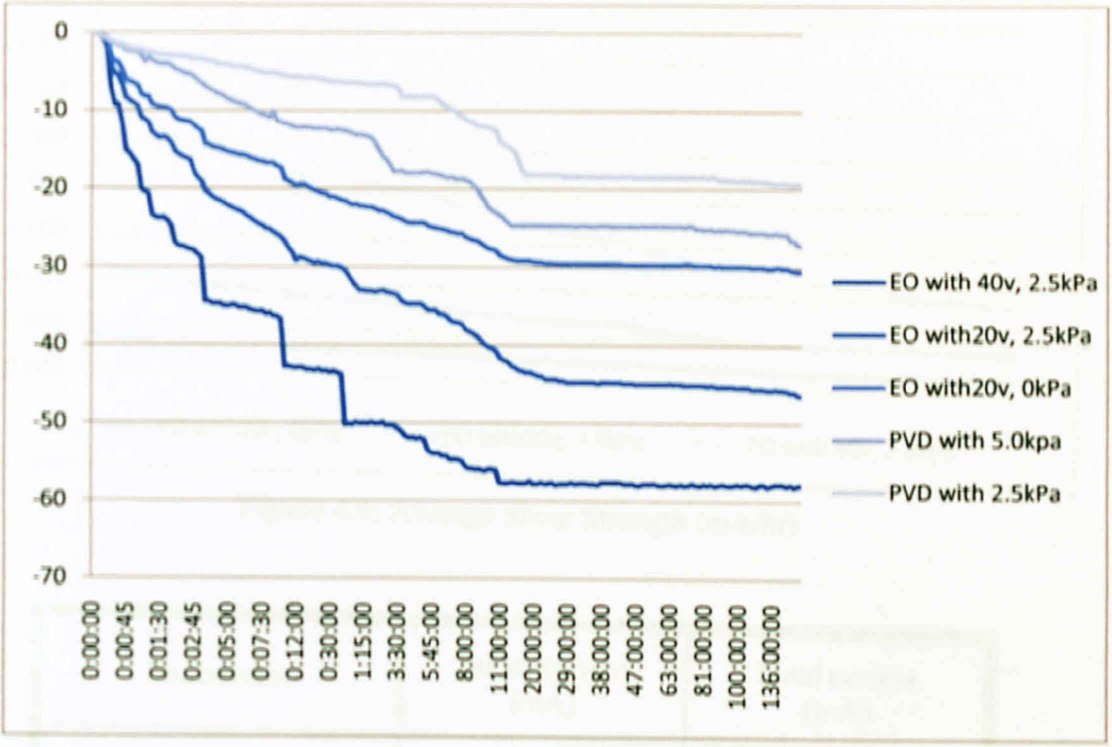


Figure 4.8: Settlement of soil (mm) with respect to time

Soil settlements show Electro-osmosis are perform better compare to PVD is kaolinite soil stabilization. Significant different can be viewed for both methods especially at initial stage of the settlement. Settlement for electro-osmosis tests occur rapidly while settlement in PVD test occurred slowly.

Settlement occurred once the surcharge was applied to the samples. The rate of consolidation will increase if the surcharge loads applied are increased. The largest load applied to the sample will show greatest settlement.

4.3.5 Current

The result for current is only applicable for electro-osmosis test. This will show the efficiency of electro-osmosis in soil stabilization/consolidation.

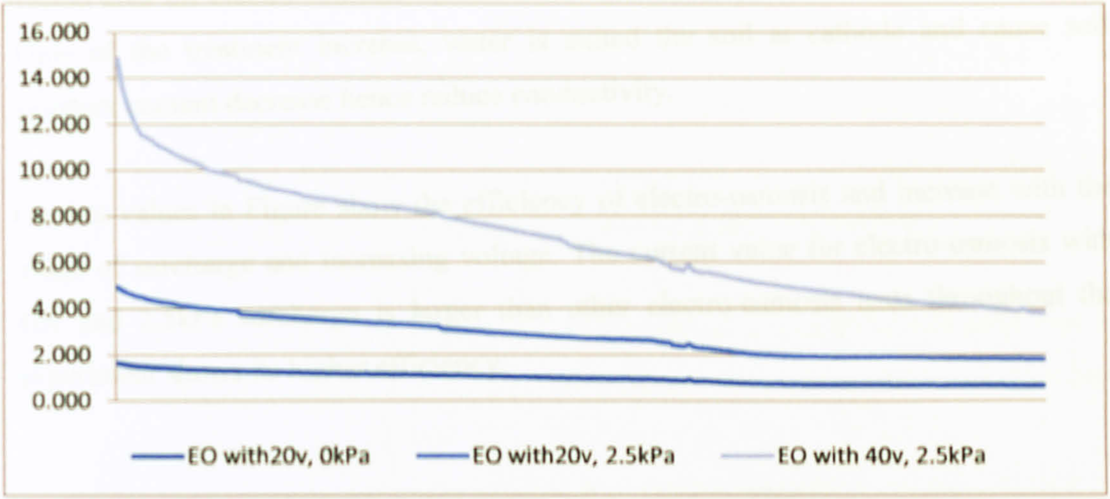


Figure 4.9: Average Shear Strength (mA/hr)

Experiment	Initial current (mA)	Final current (mA)
E-O with 40v,2.5kPa	9.940	2.023
E-O with 20v,2.5kPa	3.273	1.133
E-O with 20v,0kPa	1.659	0.671

Table 4.3: Initial and final current measurement for Electro-osmosis experiment

In electro-osmosis test, current values were measured and recorded using multi-meter. From Figure 4.9 above, the value of current is decreasing with respect to time. This show the conductivity of the soil decrease is because of the reduction of water content in the soil. In Electro-osmosis, water will be the body that transmits current along the treated area for electro-osmosis to occur and cause water movement to cathode. When Time of the treatment increase, water is exited the soil at cathode and cause soil moisture content decrease hence reduce conductivity.

Current values in Figure show the efficiency of electro-osmosis and increase with the usage of surcharge and increasing voltage. The current value for electro-osmosis with 40v and 2.5kPa surcharge is larger than other electro-osmosis tests throughout the experiment shows its higher efficiency.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1. Conclusions

The Author successfully conducted a research on comparison of electro-osmosis and Prefabricated Vertical Drain (PVD) in term of stabilizing kaolinite soil. Research include to study the effectiveness n term of moisture content, vane shear strength, rate of settlement and pH. The following are the conclusion that can be drawn:

1. Electro-osmosis is 1.8 and 4.2 times more effective than PVD with surcharge for stabilizing kaolinite soil in term of reducing moisture content and increasing shear stress.
2. Rate of settlement is improved at higher voltage gradient.
3. Moisture content reductions are 32.1% and 17.4% for electro-osmosis and PVD respectively.
4. Shear strength increment are 42.9% and 10.3% for electro-osmosis and PVD respectively.

5.2. Recommendations

As for improvement to the research, the Author lists the recommendation that can be done for the further research.

1. Combination of electro-osmosis and PVD methods will further improve soil stabilization/consolidation.
2. Use different type of electrode with higher conductivity in electro-osmosis such as Aluminium
3. Allow more time for the electro-osmosis and PVD treatment to occur
4. Use higher voltage for electro-osmosis

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11. Final Year Project Guidelines

APPENDIX

Settlement Measurement Data

Time	EO with 40v, 2.5kPa	EO with20v, 2.5kPa	EO with20v, 0kPa	PVD with 5.0kpa	PVD with 2.5kPa
0:00:00	0	0	0	0	0
0:00:05	2	0	-1	-1	-1
0:00:10	0	-4	-1	-2	-5
0:00:15	-6	-9	-5	-5	-6
0:00:20	-21	-17	-10	-7	-8
0:00:25	-72	-43	-30	-13	-11
0:00:30	-92	-52	-37	-15	-12
0:00:35	-92	-54	-38	-17	-14
0:00:40	-116	-66	-47	-19	-15
0:00:45	-151	-83	-60	-23	-18
0:00:50	-155	-87	-62	-24	-20
0:00:55	-162	-90	-64	-25	-21
0:01:00	-169	-94	-67	-26	-22
0:01:05	-201	-109	-79	-30	-22
0:01:10	-204	-112	-82	-38	-25
0:01:15	-206	-115	-82	-32	-25
0:01:20	-234	-128	-92	-36	-26
0:01:25	-237	-132	-94	-38	-27
0:01:30	-238	-135	-96	-40	-29
0:01:35	-237	-134	-96	-40	-29
0:01:40	-241	-136	-97	-40	-29
0:01:45	-248	-142	-100	-43	-30
0:01:50	-269	-153	-109	-47	-30
0:01:55	-273	-156	-112	-48	-30
0:02:00	-274	-159	-113	-51	-31
0:02:15	-276	-161	-114	-53	-31
0:02:30	-278	-163	-115	-53	-32
0:02:45	-279	-179	-119	-57	-34
0:03:00	-284	-186	-123	-61	-34
1:03:00	-288	-191	-126	-64	-34
2:03:00	-344	-203	-143	-69	-35
3:03:00	-344	-207	-144	-72	-37
0:04:00	-347	-211	-147	-75	-37
0:04:15	-347	-214	-148	-78	-40
0:04:30	-347	-216	-149	-79	-41
0:04:45	-350	-219	-151	-82	-41
0:05:00	-350	-222	-153	-85	-41
0:05:15	-349	-224	-154	-87	-43

0:05:30	-349	-227	-155	-89	-44
0:05:45	-352	-229	-157	-91	-44
0:06:00	-352	-231	-157	-92	-44
0:06:15	-352	-235	-158	-94	-45
0:06:30	-355	-238	-161	-98	-47
0:06:45	-356	-242	-162	-100	-48
0:07:00	-357	-245	-164	-103	-50
0:07:30	-356	-247	-165	-105	-51
0:08:00	-360	-251	-167	-107	-52
0:08:30	-359	-252	-167	-109	-52
0:09:00	-362	-255	-167	-101	-52
0:09:30	-363	-258	-171	-113	-52
0:10:00	-366	-261	-173	-115	-54
0:10:30	-428	-267	-188	-117	-55
0:11:00	-428	-276	-191	-118	-56
0:11:30	-429	-281	-193	-120	-57
0:12:00	-430	-292	-197	-122	-57
0:12:30	-429	-288	-195	-122	-56
0:13:00	-430	-289	-195	-121	-58
0:13:30	-432	-291	-197	-122	-58
0:14:00	-432	-293	-200	-122	-58
0:14:30	-433	-295	-202	-123	-58
0:15:00	-431	-294	-204	-123	-59
0:20:00	-434	-296	-206	-123	-60
0:25:00	-433	-296	-207	-123	-61
0:30:00	-435	-298	-211	-125	-62
0:35:00	-434	-299	-211	-125	-63
0:40:00	-436	-299	-213	-124	-62
0:45:00	-438	-301	-215	-125	-63
0:50:00	-502	-305	-216	-126	-64
0:55:00	-501	-312	-219	-127	-64
1:00:00	-502	-319	-221	-129	-64
1:05:00	-499	-325	-220	-131	-64
1:10:00	-501	-330	-223	-131	-65
1:15:00	-500	-330	-223	-132	-65
1:30:00	-501	-331	-224	-133	-66
1:45:00	-499	-331	-224	-135	-66
2:00:00	-501	-332	-226	-142	-66
2:15:00	-501	-331	-229	-151	-66
2:30:00	-499	-330	-229	-159	-65
2:45:00	-503	-332	-231	-162	-66

3:00:00	-503	-333	-233	-169	-67
3:15:00	-503	-334	-236	-178	-68
3:30:00	-507	-336	-237	-178	-71
3:45:00	-510	-343	-239	-177	-82
4:00:00	-516	-346	-242	-180	-82
4:15:00	-519	-347	-244	-180	-82
4:30:00	-518	-347	-244	-180	-82
4:45:00	-520	-347	-244	-180	-82
5:00:00	-519	-347	-243	-180	-82
5:15:00	-521	-350	-244	-179	-81
5:30:00	-535	-355	-248	-179	-82
5:45:00	-538	-355	-249	-180	-82
6:00:00	-539	-355	-250	-181	-83
6:15:00	-539	-360	-251	-182	-87
6:30:00	-542	-360	-252	-184	-92
6:45:00	-542	-363	-253	-186	-95
7:00:00	-547	-368	-255	-185	-98
7:15:00	-546	-370	-256	-187	-100
7:30:00	-547	-371	-257	-188	-105
7:45:00	-549	-373	-257	-187	-107
8:00:00	-555	-380	-261	-189	-111
8:15:00	-558	-382	-263	-191	-113
8:30:00	-558	-385	-265	-195	-115
8:45:00	-559	-388	-266	-200	-119
9:00:00	-559	-393	-269	-208	-119
9:15:00	-561	-399	-273	-216	-120
9:30:00	-559	-402	-276	-224	-121
9:45:00	-559	-404	-277	-228	-123
10:00:00	-560	-407	-279	-231	-126
11:00:00	-576	-416	-285	-234	-139
12:00:00	-577	-419	-287	-238	-143
13:00:00	-577	-421	-289	-243	-145
14:00:00	-576	-426	-290	-247	-149
15:00:00	-576	-429	-291	-247	-153
16:00:00	-577	-432	-292	-247	-166
17:00:00	-577	-433	-292	-247	-178
18:00:00	-577	-435	-292	-247	-182
19:00:00	-574	-435	-292	-247	-182
20:00:00	-578	-437	-293	-247	-182
21:00:00	-578	-439	-294	-247	-182
22:00:00	-576	-440	-294	-247	-182

23:00:00	-578	-443	-295	-247	-182
24:00:00	-577	-444	-295	-247	-182
25:00:00	-576	-444	-295	-247	-182
26:00:00	-579	-444	-296	-247	-182
27:00:00	-578	-446	-296	-247	-182
28:00:00	-578	-446	-296	-247	-184
29:00:00	-578	-448	-296	-247	-184
30:00:00	-576	-448	-296	-247	-184
31:00:00	-578	-448	-296	-248	-184
32:00:00	-577	-448	-296	-247	-184
33:00:00	-577	-448	-296	-247	-184
34:00:00	-577	-448	-296	-247	-184
35:00:00	-578	-448	-296	-248	-184
36:00:00	-578	-448	-296	-248	-184
37:00:00	-579	-449	-296	-247	-185
38:00:00	-576	-448	-296	-247	-184
39:00:00	-576	-448	-296	-247	-184
40:00:00	-576	-448	-296	-247	-184
41:00:00	-576	-448	-296	-248	-185
42:00:00	-576	-448	-296	-248	-185
43:00:00	-576	-448	-296	-248	-184
44:00:00	-578	-449	-297	-248	-184
45:00:00	-578	-449	-297	-248	-184
46:00:00	-577	-449	-297	-248	-184
47:00:00	-579	-450	-297	-248	-185
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49:00:00	-578	-450	-297	-247	-185
51:00:00	-578	-450	-297	-248	-185
53:00:00	-578	-450	-297	-248	-185
55:00:00	-577	-450	-297	-247	-185
57:00:00	-579	-450	-297	-248	-185
59:00:00	-580	-450	-297	-248	-185
61:00:00	-579	-450	-297	-247	-184
63:00:00	-578	-449	-297	-248	-185
65:00:00	-579	-450	-297	-248	-185
67:00:00	-580	-450	-297	-248	-184
69:00:00	-578	-450	-297	-248	-185
71:00:00	-580	-451	-296	-249	-185
73:00:00	-579	-451	-296	-247	-184
75:00:00	-577	-451	-297	-248	-185
77:00:00	-579	-451	-298	-251	-185

79:00:00	-580	-451	-298	-251	-185
81:00:00	-578	-451	-298	-252	-185
83:00:00	-579	-452	-298	-252	-186
85:00:00	-578	-451	-298	-252	-184
87:00:00	-580	-452	-299	-253	-185
89:00:00	-579	-453	-298	-252	-188
91:00:00	-578	-453	-299	-253	-188
93:00:00	-579	-453	-299	-252	-189
95:00:00	-580	-453	-299	-253	-189
97:00:00	-579	-453	-299	-253	-189
100:00:00	-578	-454	-299	-254	-190
104:00:00	-579	-454	-299	-254	-189
108:00:00	-578	-454	-299	-254	-190
112:00:00	-578	-454	-299	-255	-189
116:00:00	-580	-456	-300	-256	-190
120:00:00	-581	-456	-300	-256	-190
124:00:00	-578	-456	-300	-256	-191
128:00:00	-578	-456	-300	-256	-191
132:00:00	-581	-457	-301	-257	-191
136:00:00	-579	-457	-301	-257	-192
140:00:00	-578	-456	-300	-256	-193
144:00:00	-578	-457	-300	-257	-193
148:00:00	-578	-457	-301	-258	-193
152:00:00	-580	-458	-301	-258	-193
156:00:00	-578	-460	-303	-265	-194
160:00:00	-581	-460	-304	-266	-194
164:00:00	-579	-463	-305	-271	-193
168:00:00	-579	-464	-305	-272	-194

Current Measurement Data

Time	Control Set	EO with20v, 0kPa	EO with20v, 2.5kPa	EO with 40v, 2.5kPa	PVD with 5.0kpa	PVD with 2.5kPa
0:00:00	0.000	1.659	3.273	9.940	0.000	0.000
0:00:05	0.000	1.615	3.184	8.784	0.000	0.000
0:00:10	0.000	1.579	3.110	8.162	0.000	0.000
0:00:15	0.000	1.551	3.072	7.714	0.000	0.000
0:00:20	0.000	1.526	3.017	7.286	0.000	0.000
0:00:25	0.000	1.508	2.987	7.058	0.000	0.000
0:00:30	0.000	1.493	2.946	7.020	0.000	0.000
0:00:35	0.000	1.477	2.914	6.934	0.000	0.000
0:00:40	0.000	1.463	2.886	6.822	0.000	0.000
0:00:45	0.000	1.452	2.856	6.731	0.000	0.000
0:00:50	0.000	1.440	2.841	6.636	0.000	0.000
0:00:55	0.000	1.430	2.821	6.550	0.000	0.000
0:01:00	0.000	1.414	2.790	6.469	0.000	0.000
0:01:05	0.000	1.400	2.762	6.414	0.000	0.000
0:01:10	0.000	1.390	2.742	6.360	0.000	0.000
0:01:15	0.000	1.380	2.723	6.309	0.000	0.000
0:01:20	0.000	1.370	2.703	6.249	0.000	0.000
0:01:25	0.000	1.360	2.683	6.179	0.000	0.000
0:01:30	0.000	1.356	2.675	6.042	0.000	0.000
0:01:35	0.000	1.344	2.652	6.002	0.000	0.000
0:01:40	0.000	1.337	2.638	5.975	0.000	0.000
0:01:45	0.000	1.331	2.626	5.940	0.000	0.000
0:01:50	0.000	1.326	2.616	5.920	0.000	0.000
0:01:55	0.000	1.321	2.606	5.874	0.000	0.000
0:02:00	0.000	1.316	2.596	5.845	0.000	0.000
0:02:15	0.000	1.311	2.457	5.821	0.000	0.000
0:02:30	0.000	1.305	2.446	5.795	0.000	0.000
0:02:45	0.000	1.299	2.434	5.759	0.000	0.000
0:03:00	0.000	1.293	2.423	5.725	0.000	0.000
0:03:15	0.000	1.288	2.414	5.671	0.000	0.000
0:03:30	0.000	1.283	2.404	5.606	0.000	0.000
0:03:45	0.000	1.278	2.395	5.570	0.000	0.000
0:04:00	0.000	1.272	2.384	5.540	0.000	0.000
0:04:15	0.000	1.267	2.374	5.500	0.000	0.000
0:04:30	0.000	1.262	2.365	5.479	0.000	0.000
0:04:45	0.000	1.257	2.356	5.450	0.000	0.000
0:05:00	0.000	1.252	2.346	5.419	0.000	0.000
0:05:15	0.000	1.247	2.337	5.377	0.000	0.000

0:05:30	0.000	1.242	2.328	5.309	0.000	0.000
0:05:45	0.000	1.237	2.318	5.302	0.000	0.000
0:06:00	0.000	1.232	2.309	5.274	0.000	0.000
0:06:15	0.000	1.228	2.301	5.244	0.000	0.000
0:06:30	0.000	1.224	2.294	5.239	0.000	0.000
0:06:45	0.000	1.219	2.284	5.224	0.000	0.000
0:07:00	0.000	1.214	2.275	5.200	0.000	0.000
0:07:30	0.000	1.208	2.264	5.180	0.000	0.000
0:08:00	0.000	1.204	2.256	5.169	0.000	0.000
0:08:30	0.000	1.199	2.247	5.156	0.000	0.000
0:09:00	0.000	1.195	2.239	5.127	0.000	0.000
0:09:30	0.000	1.190	2.230	5.110	0.000	0.000
0:10:00	0.000	1.186	2.223	5.101	0.000	0.000
0:10:30	0.000	1.181	2.213	5.072	0.000	0.000
0:11:00	0.000	1.177	2.206	5.056	0.000	0.000
0:11:30	0.000	1.174	2.200	5.041	0.000	0.000
0:12:00	0.000	1.170	2.193	5.029	0.000	0.000
0:12:30	0.000	1.167	2.187	5.036	0.000	0.000
0:13:00	0.000	1.163	2.179	5.035	0.000	0.000
0:13:30	0.000	1.159	2.172	5.029	0.000	0.000
0:14:00	0.000	1.156	2.166	5.019	0.000	0.000
0:14:30	0.000	1.152	2.159	5.000	0.000	0.000
0:15:00	0.000	1.147	2.149	4.978	0.000	0.000
0:20:00	0.000	1.143	2.142	4.961	0.000	0.000
0:25:00	0.000	1.138	2.133	4.943	0.000	0.000
0:30:00	0.000	1.134	2.125	4.929	0.000	0.000
0:35:00	0.000	1.129	2.116	4.901	0.000	0.000
0:40:00	0.000	1.124	2.106	4.879	0.000	0.000
0:45:00	0.000	1.118	2.007	4.857	0.000	0.000
0:50:00	0.000	1.112	1.996	4.829	0.000	0.000
0:55:00	0.000	1.107	1.987	4.801	0.000	0.000
1:00:00	0.000	1.103	1.980	4.768	0.000	0.000
1:05:00	0.000	1.098	1.971	4.742	0.000	0.000
1:10:00	0.000	1.094	1.964	4.714	0.000	0.000
1:15:00	0.000	1.088	1.953	4.685	0.000	0.000
1:30:00	0.000	1.083	1.944	4.653	0.000	0.000
1:45:00	0.000	1.078	1.935	4.626	0.000	0.000
2:00:00	0.000	1.072	1.924	4.601	0.000	0.000
2:15:00	0.000	1.067	1.915	4.577	0.000	0.000
2:30:00	0.000	1.061	1.904	4.552	0.000	0.000
2:45:00	0.000	1.057	1.897	4.533	0.000	0.000

3:00:00	0.000	1.051	1.887	4.507	0.000	0.000
3:15:00	0.000	1.046	1.878	4.477	0.000	0.000
3:30:00	0.000	1.041	1.869	4.448	0.000	0.000
3:45:00	0.000	1.035	1.858	4.425	0.000	0.000
4:00:00	0.000	1.030	1.849	4.395	0.000	0.000
4:15:00	0.000	1.025	1.840	4.369	0.000	0.000
4:30:00	0.000	1.020	1.831	4.337	0.000	0.000
4:45:00	0.000	1.015	1.822	4.313	0.000	0.000
5:00:00	0.000	1.011	1.815	4.282	0.000	0.000
5:15:00	0.000	1.006	1.806	4.257	0.000	0.000
5:30:00	0.000	1.001	1.797	4.235	0.000	0.000
5:45:00	0.000	0.997	1.790	4.217	0.000	0.000
6:00:00	0.000	0.993	1.782	4.087	0.000	0.000
6:15:00	0.000	0.988	1.773	3.973	0.000	0.000
6:30:00	0.000	0.983	1.764	3.931	0.000	0.000
6:45:00	0.000	0.979	1.757	3.903	0.000	0.000
7:00:00	0.000	0.975	1.750	3.875	0.000	0.000
7:15:00	0.000	0.971	1.743	3.851	0.000	0.000
7:30:00	0.000	0.968	1.738	3.831	0.000	0.000
7:45:00	0.000	0.965	1.732	3.810	0.000	0.000
8:00:00	0.000	0.962	1.727	3.786	0.000	0.000
8:15:00	0.000	0.959	1.721	3.766	0.000	0.000
8:30:00	0.000	0.956	1.716	3.744	0.000	0.000
8:45:00	0.000	0.954	1.712	3.720	0.000	0.000
9:00:00	0.000	0.952	1.709	3.696	0.000	0.000
9:15:00	0.000	0.949	1.703	3.674	0.000	0.000
9:30:00	0.000	0.946	1.698	3.647	0.000	0.000
9:45:00	0.000	0.943	1.693	3.623	0.000	0.000
10:00:00	0.000	0.940	1.687	3.603	0.000	0.000
11:00:00	0.000	0.938	1.684	3.585	0.000	0.000
12:00:00	0.000	0.928	1.666	3.539	0.000	0.000
13:00:00	0.000	0.917	1.646	3.484	0.000	0.000
14:00:00	0.000	0.908	1.630	3.416	0.000	0.000
15:00:00	0.000	0.899	1.614	3.344	0.000	0.000
16:00:00	0.000	0.890	1.519	3.313	0.000	0.000
17:00:00	0.000	0.881	1.504	3.313	0.000	0.000
18:00:00	0.000	0.872	1.489	3.287	0.000	0.000
19:00:00	0.000	0.908	1.550	3.416	0.000	0.000
20:00:00	0.000	0.865	1.477	3.284	0.000	0.000
21:00:00	0.000	0.852	1.454	3.261	0.000	0.000
22:00:00	0.000	0.845	1.442	3.261	0.000	0.000

23:00:00	0.000	0.842	1.437	3.268	0.000	0.000
24:00:00	0.000	0.833	1.422	3.255	0.000	0.000
25:00:00	0.000	0.821	1.401	3.237	0.000	0.000
26:00:00	0.000	0.810	1.383	3.225	0.000	0.000
27:00:00	0.000	0.799	1.364	3.207	0.000	0.000
28:00:00	0.000	0.788	1.345	3.189	0.000	0.000
29:00:00	0.000	0.778	1.328	3.176	0.000	0.000
30:00:00	0.000	0.769	1.313	3.156	0.000	0.000
31:00:00	0.000	0.761	1.299	3.144	0.000	0.000
32:00:00	0.000	0.755	1.289	3.118	0.000	0.000
33:00:00	0.000	0.750	1.280	3.092	0.000	0.000
34:00:00	0.000	0.747	1.275	3.074	0.000	0.000
35:00:00	0.000	0.743	1.268	3.051	0.000	0.000
36:00:00	0.000	0.739	1.261	3.042	0.000	0.000
37:00:00	0.000	0.735	1.255	3.015	0.000	0.000
38:00:00	0.000	0.732	1.250	2.988	0.000	0.000
39:00:00	0.000	0.728	1.243	2.961	0.000	0.000
40:00:00	0.000	0.726	1.239	2.945	0.000	0.000
41:00:00	0.000	0.723	1.234	2.917	0.000	0.000
42:00:00	0.000	0.720	1.229	2.900	0.000	0.000
43:00:00	0.000	0.718	1.226	2.883	0.000	0.000
44:00:00	0.000	0.716	1.222	2.864	0.000	0.000
45:00:00	0.000	0.714	1.219	2.844	0.000	0.000
46:00:00	0.000	0.713	1.217	2.816	0.000	0.000
47:00:00	0.000	0.712	1.215	2.793	0.000	0.000
48:00:00	0.000	0.710	1.212	2.769	0.000	0.000
49:00:00	0.000	0.708	1.209	2.751	0.000	0.000
51:00:00	0.000	0.707	1.207	2.733	0.000	0.000
53:00:00	0.000	0.707	1.207	2.716	0.000	0.000
55:00:00	0.000	0.707	1.207	2.704	0.000	0.000
57:00:00	0.000	0.707	1.207	2.667	0.000	0.000
59:00:00	0.000	0.707	1.207	2.639	0.000	0.000
61:00:00	0.000	0.707	1.206	2.603	0.000	0.000
63:00:00	0.000	0.707	1.206	2.577	0.000	0.000
65:00:00	0.000	0.707	1.207	2.548	0.000	0.000
67:00:00	0.000	0.706	1.205	2.523	0.000	0.000
69:00:00	0.000	0.706	1.205	2.495	0.000	0.000
71:00:00	0.000	0.705	1.203	2.478	0.000	0.000
73:00:00	0.000	0.704	1.202	2.457	0.000	0.000
75:00:00	0.000	0.703	1.200	2.438	0.000	0.000
77:00:00	0.000	0.702	1.198	2.423	0.000	0.000

79:00:00	0.000	0.700	1.195	2.403	0.000	0.000
81:00:00	0.000	0.698	1.191	2.387	0.000	0.000
83:00:00	0.000	0.698	1.191	2.366	0.000	0.000
85:00:00	0.000	0.696	1.188	2.350	0.000	0.000
87:00:00	0.000	0.694	1.172	2.339	0.000	0.000
89:00:00	0.000	0.692	1.169	2.330	0.000	0.000
91:00:00	0.000	0.690	1.165	2.326	0.000	0.000
93:00:00	0.000	0.689	1.164	2.319	0.000	0.000
95:00:00	0.000	0.688	1.162	2.312	0.000	0.000
97:00:00	0.000	0.686	1.159	2.307	0.000	0.000
100:00:00	0.000	0.685	1.157	2.305	0.000	0.000
104:00:00	0.000	0.684	1.155	2.301	0.000	0.000
108:00:00	0.000	0.682	1.152	2.294	0.000	0.000
112:00:00	0.000	0.681	1.150	2.281	0.000	0.000
116:00:00	0.000	0.680	1.149	2.263	0.000	0.000
120:00:00	0.000	0.679	1.147	2.242	0.000	0.000
124:00:00	0.000	0.679	1.147	2.222	0.000	0.000
128:00:00	0.000	0.679	1.146	2.201	0.000	0.000
132:00:00	0.000	0.679	1.146	2.181	0.000	0.000
136:00:00	0.000	0.678	1.145	2.160	0.000	0.000
140:00:00	0.000	0.677	1.143	2.140	0.000	0.000
144:00:00	0.000	0.676	1.142	2.117	0.000	0.000
148:00:00	0.000	0.676	1.142	2.099	0.000	0.000
152:00:00	0.000	0.675	1.140	2.187	0.000	0.000
156:00:00	0.000	0.673	1.137	2.071	0.000	0.000
160:00:00	0.000	0.672	1.135	2.053	0.000	0.000
164:00:00	0.000	0.672	1.134	2.036	0.000	0.000
168:00:00	0.000	0.671	1.133	2.023	0.000	0.000