Electrokinetic Effects on Kaolin Soil

by

Diyana Binti Muhamad Ali

Dissertation submitted in partial fulfillment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

(Tuan Syed Baharom Syed Azhar)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

Jun 2005

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 reference and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons

DIYANA BINTI MUHAMAD ALI

ABSTRACT

The title for this Final Year Project (FYP) is "**Electrokinetic effects on kaolin soil**". Kaolin soil is a white clay mineral that has relatively low strength. In this Final Year Project, the electroosmosis will be applied to the kaolin soil to improve the characteristics of the soil. It will focus in the strength of the soil.

Electrokinetics is the study of the motion of particles and chemical transformation between two electrodes that result from or produce an electric potential difference (voltage). Electroosmosis involves water transport through a continuous soil particle network from anode to cathode.

Kaolin soil was taken from the Greatpac Sdn. Bhd. Factory, Bidor, Perak. The test that have been conducted in the first semester is the moisture content test, liquid limit, plastic limit, vane shear, sedimentation by hydrometer analysis. This test was conducted to study the physical characteristic of the soil. The result that was obtained from the test shows the same result as others kaolin soil from other place.

There was two type of experiment that had been conducted using different amount of load (10kPa, 20kPa and 30kPa) without applying the current and also applying the different amount current (10mA, 20mA and 30mA) with 20kPa of load. This experiment is to study the result of the electrokinetic effect to the kaolin soil. From the analysis that had been done from the result shows that there were some improvement of strength to the kaolin soil after applying the electrokinetic method. There is not much increase in strength but the experiment proves that there were some findings to the experiments.

ACKNOWLEDGEMENT

Firstly, I would like to extend my appreciation to Tuan Syed Baharom Syed Azhar who has kindly consented to be my UTP Supervisor for my Final Year Project. I would like to thank him for all his supports, ideas and advises. I would like to thank him for his good advises of my final reports. Tuan Syed Baharom also has provided many helpful suggestions during the experiment and revision of the final reports. I also would like to extend my gratitude to Tuan Syed Baharom who has kindly considered and recommended my proposal to perform my Final Year Project under his project tittle and his supervision. My heartfelt thanks also go to En. Zaini, the technician for the Geotechnical Laboratory, for his direction, advises and support throughout my Final Year Project. I would also like to thank him for his kind help and advises during my performance in the laboratory.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

In this project, the kaolin soil is chosen as a case study that the student needs to study the effects of electrokinetic on kaolin soil. Soil consists of voids between the solid particle that consist of air and water. The purpose of the electrokinetic effect is to stabilize the soil. The purposes for soil stabilization are to improve strength of the existing soil, to enhance its load bearing capacity, shear strength and soil waterproofing. There are three types classification of soil that was classified by *Casagrande* (1984), which are coarse grain soils (gravel, sand), fine-grained soils (silt, clay, organic silts and clay) and fibrous soils (peat).

Findings of electrokinetic by Reuss in 1808 was utilized by Casagrande (1951), where he demonstrated that applying a DC electrical field to wet clayey soil resulted in reduction in its moisture content. Accordingly, the effective stress of the soil increased, which in turn increased the shear strength of the soil to such a degree that even steep cuts remained stable. It was indicated from Casagrande's practice that small reductions in moisture content by electroosmosis could produce significant increase in soil strength methods to stabilize a soil.

The mechanical methods that is use to stabilize soil is compaction by roller and deep compaction. During this early period were directed towards removal of water for soil stabilization and were generally concentrated on the dewatering of fine gravel soils by electroosmosis.

1.2 Problem Statement

In general, kaolin is a problematic soil. Kaolin can cause problem in several ways. The main reason of kaolin to be a problematic soil is that it is a type of clay, which shrinks and swells during natural changes in soil moisture. Slight changes in moisture content are sufficient to cause detrimental shrinking and swelling. Kaolin is a soft soil that has low strength. In order to improve the strength of the soil, a study was carried out to stabilize the kaolin soil using electrokinetic by electroosmosis.

Electrokinetic is a transferring of current through the soil to remove the excess water in kaolin soil. The method is conducted by applying different amount of current to the kaolin soil in order to get the optimum result. The purpose of this research is to investigate the effect of the electro kinetic method in stabilizing the kaolin soil for different type of surcharged. The other purpose of the testing is to increase the strength of the soil using electric current that will be applied to the kaolin soil.

1.3 Objectives and Scope of Work

1.3.1 Objectives

In this final year project, the search about electrokinetic's effect on improving the strength of the kaolin soil. The method will be conducted by applying the current to the kaolin soil and remove the pore water pressure in a way to increase the strength of kaolin soil. This purpose is to improve the strength and to stabilize the kaolin soil. The main objectives of this final year project which are;

- To test the electrokinetic's effect by applying the current transmitting through the kaolin soil in order to remove the pore water pressure of the kaolin soil.
- To find the result in the electroosmosis treatment by applying the voltage to the kaolin soil.
- To find the result in the electroosmosis treatment by applying the surcharge to the kaolin soil

- To collect necessary data to improve the strength of the kaolin soil.

1.3.2 Scope of work

The following summarizes the scope of works for two semesters;

- First Semester
  - Literature review and theories about kaolin soil and principle of electrokinetic process.
  - Purchase material from suppliers for equipment and tools for testing.
  - Determine the physical properties of peat soil such as moisture content, Liquid Limit, Plastic Limit, Specific Gravity, Sedimentation by Hydrometer Method and Vane Shear Test.

(Refer Appendix I for the Milestone for the First Semester of 2 Semester Final Year Project)

- Second Semester
  - Fabricating equipment for testing
  - Run the equipment for testing and collect data. (Testing was done using a different value of surcharge and voltage)
  - Analyze the result of Electrokinetic effect to kaolin

(Refer Appendix I for the Milestone for the Second Semester of 2 Semester Final Year Project)

CHAPTER 2
LITERATURE REVIEW AND THEORY

2.1 Kaolin soil

Kaolin is white soft plastic clay composed of well-ordered kaolinite with low iron content. It is made up of a loose aggregation of randomly oriented stacks of kaolinite flakes, smaller packets and sheaves, and individual flakes. Kaolin is the common name for the mineral products comprised totally or substantially of the aluminum silicate clay mineral kaolinite. Milled and air-classified grades of raw kaolin may contain small amounts of related sheet silicates (mica, illite, chlorite, smectite) and quartz. Most of the kaolin used by the coatings industry is water-washed to remove these mineral impurities. [1]

Kaolin is soft and exhibits conchoidal or semiconchoidal fracture; it can be bedded or massive. Most kaolins will slake in water, but some "flint" varieties break into smaller angular fragments only. Depending on kaolin particle size and presence of organic matter, some clay may be very plastic when moist and are usually called "ball clays". The kaolin forms by weathering which results in decomposition of feldspars and other aluminosilicates and removal of fluxing components like alkalies or iron. Post depositional weathering and leaching can produce gibbsitic bauxite. In some deposits, post depositional weathering may improve crystallinity of kaolin particles and increase the size of crystal aggregates.[3]

The residual and hydrothermal occurrences are classed as primary and the sedimentary occurrences as secondary. Primary kaolins are those that have formed in situ, usually by the alteration of crystalline rocks like grinite or gneiss. Secondary kaolins are sedimentary minerals, which were eroded, transported and deposited as beds or lenses associated with other sedimentary rocks. Most of secondary deposits were formed by the deposition of kaolin, which had been formed elsewhere. Kaolin is a white or light, odorless, almost tasteless powder that is practically insoluble in water. It has a color of white, pink or gray and a streak of white. Kaolin has relatively low plasticity when compared to other raw clay types. The problem that usually encountered by kaolin is settlement and sedimentation.

Kaolinite is among the most abundant clay minerals and an important resource for industries. In addition, the mineral has been attracting many clay mineralogists because it shows diverse structural variations related to stacking defects. Kaolinite crystals contain high density of stacking defects. These defects or stacking disorder are formed by mixture of the two kinds of lateral interlayer shifts between adjacent layers. These results provide not only an unambiguous **settlement** for the long controversy of the defect structures in kaolinite, but also a new clue to understand kaolinite-to-dickite transformation mechanism.

The two types are soft kaolin and hard kaolin. Soft and hard kaolins are significantly different in terms of mineralogy, particle shape and size, chemistry and physical properties. Kaolin clay is commonly differentiated as "hard" clay or "soft," according to terminology borrowed from the rubber industry.

- **Hard clay** is relatively poorly crystallized, very fine-grained kaolin, about 0.2 to 0.4 æm median particle size by sedimentation. It provides reinforcement, resulting in hard, uncured compounds.
- **Soft clay** is better-crystallized, coarser kaolin, about 1.3 µm median particle size by sedimentation. It has a low reinforcing effect, resulting in softer uncured compounds.[2]

According to the *Indian Geotechnical Journal, 2002,* there is a few of characteristics of kaolin soil.

PROPERTY	RESULT
Color and physical state	White Powder
Odor	Odorless
Melting Point or Range	1800°C
Specific Gravity (g/cc)	2.5 – 2.6
Solubility In Water	Insoluble
Solubility In Organic Solvent	Insoluble
Density	2.6
Median Particle Sizes (micron)	0.78, 1.1, 1.2 and 3.8
Bulk Density (lb/cu.ft)	14 – 30
Specific Resistivity	35, 000 Ohms/cm
Surface Area (m^2/g)	10 – 29
PH Value	4.9
Moisture Content	44%
Organic Content	Near 0%
Liquid Limit	56%
Plastic Limit	27.4%
Plasticity Index	22.6% (high plasticity)
Cation Exchange Capacity (CEC)	1.0 – 1.6 meg/100g

TABLE 2.1: Characteristics of Kaolin Soil

2.2 Electrokinetic

Electrokinetic phenomena are a relative motion between a charged surface and the bulk solution at its interface. The formation for electrokinetic as an electric double layer at the charged surface of clay particle is responsible for electrokinetic phenomena of interest, namely:

- **Electroosmosis;** movement of water
- **Electrophoresis;** movement of charged soild particles
- **Electromigration;** movement of ions and polar molecules.

Process of electrokinetic is a migration of ion. Cations with positive charges migrate to the cathode. Anions with negative charges move toward anode. [5]

Electrokinetic is a process in which a low-voltage direct-current electric field is applied across a section of soil to move ion. The principle of electrokinetics is similar to a battery. After electrodes (a cathode and anode) are introduced and charged, particles (e.g. ion) are mobilized by the electric current. Ions and water move toward the electrodes. Electrokinetics is most effective in clays because clay particles have a negative surface charge. Electrokinetics is most applicable in low permeability soils. [5]

Electrokinetic analysis provides the means for measuring how the surrounding medium and imposed electric fields interact with extended flat surfaces, channels, pores, particles, and molecular aggregates to produce motion. Such motion has found wide use as a means for separating complex mixtures into their components.

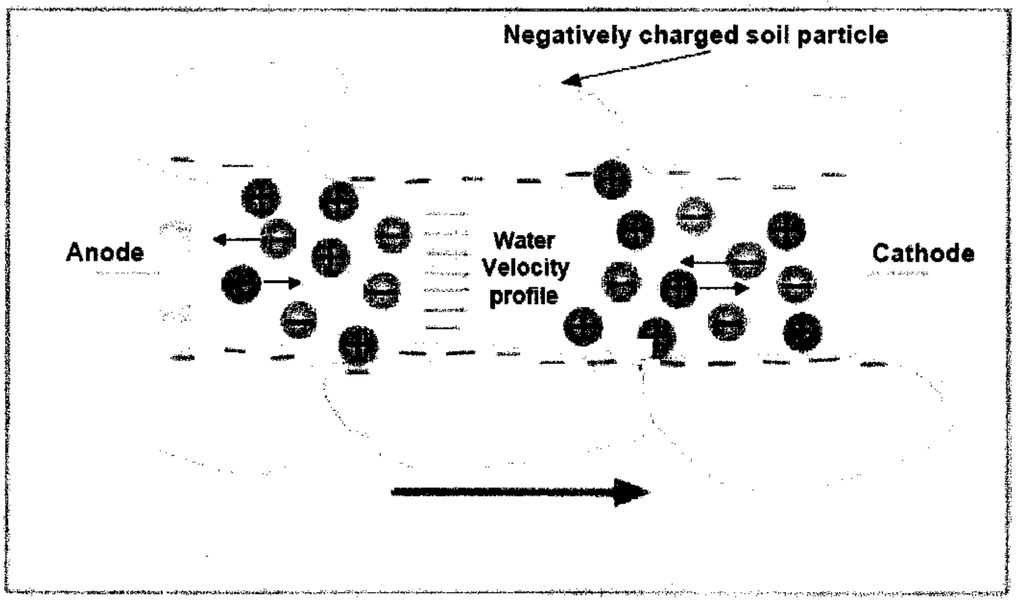

FIGURE 2.1: Schematic representation of electrokinetic process

There is factor that may limit the applicability and effectiveness of this process. Effectiveness is sharply reduced for soil with a moisture content of less than 10%. Maximum effectiveness occurs if the moisture content is between 14 to 18%. Electrokinetics also is most effective in clays because of the negative surface charge of clay particles. Kaolin is a type of clays. However, the surface charge of the clay is altered by charges in the pH of the pore fluid.

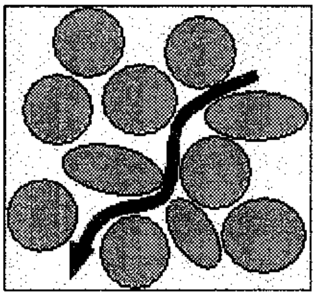

FIGURE 2.2 : Mixture of grain surrounded by pore fluid

Above figure show that soils can be viewed as a mixture of grains surrounded by pore fluid. The pore fluid is a good electrical conductor whereas, by comparison, the soil grains can essentially be considered as insulators. When the electrical conductivity of this mixture is measured, the electrical current primarily flows through the fluid in the pores and can therefore be viewed as mapping the pore structure of the soil. Kaolin slurries were prepared at various pore fluid concentrations of sodium chloride. The slurries were placed in a perspex sedimentation column. To facilitate electrical measurements, the column had pairs of stainless steel square plate electrodes positioned at discrete heights within the column and flush with the sidewalls. The electrical conductivity was monitored hourly at each electrode, giving a concentration profile through the sample as it settled. In the same way that electrical current flows through this pore structure, so too will water or chemicals and therefore electrical conductivity can describe the water flow. Through the Nernst-Einstein relationship, electrical conductivity measurements prior to diffusion can be used to predict the diffusion coefficient. Moreover, the electrical conductivity of the pore fluid in a soil with a stable pore structure will change as a result of the addition of impurity

2.3 Electroosmosis

According to the Khairul Anuar Kassim, Mohd Raihan Taha and Kamarudin Ahmad; electroosmosis involves water transport through a continuous soil particle network, where the movement is primarily generated in the diffuse double layer or soil moisture film. The principle mechanism in electroosmosis is the migrating ions, where the cations migrate to the cathode and the anions move toward the anode. Accordingly, when an electric field (DC) is applied to a clay-water system, the surface or particle is fixed, whereas the mobile diffuse layer moves carrying solution with it. Electroosmosis flow is shown to be independent to the pore size distribution or the presence of macropores. Hence it able the electroosmosis to produce a rapid flow of water in a compact low permeability. It is also learnt that the relative contribution of electroosmosis and ion migration to the total mass transport varies according to soil type, water content, types of ion species, pore fluid concentration of ions and processing condition. [7]

As the electric current is applied to the soil, water in the soil pores flows between the electrodes. When direct current is passed through soil, the aqueous phase will move toward the negative electrode. In addition, ion migration takes place. Cations with positive charges migrate to the cathode. While anions with negative charges moves toward anode. The electric field acts on the charged interface between positive water and the clay surface with fixed charges. The major contribution to surface charge in soils comes from clay particles whose faces can be charge as a result of several mechanisms including isomorphoric substitution, adsorption of charged ions and proton association or dissociation reactions.

Electroosmosis produces a rapid flow of water soils and probably contributes significantly to the decontamination process in clay soils by advection. When a potential difference is applied to across soil to a liquid, the liquid will migrate in the direction determined by the nature of the soil and the liquid. In a porous plug of clay the surface becomes negatively charged when wetted with water. This charge is balanced by the adjoining larger of liquid, which carries a positive space charge. [8]

This process can causes the reduction of volume and reduction of moisture content of the soil. it also increase the shear strength. From the **(Lamont-Black, 2001; Jones et al., 2002) it says that** water flows by electroosmosis from the anode to the cathode thus the area around the anode experiences the greatest reduction in moisture content and improvement in shear strength. In order to minimise moisture content anisotropy, the trial was completed with a phase of polarity reversal in order to draw water away from the electrodes which were acting as anodes in the first phase. Polarity reversal resulted in a much more even distribution of shear strength in the test soil.

This paragraph is quote by J.Q. Shang1 and K.L. Masterson2. The ability to simulate in-situ effective stress conditions experienced by a soil mass during high voltage electrokinetic testing is the primary criterion considered in the design of the apparatus. This requires that the electrokinetic test be conducted in an airtight and pressurized system. Special considerations must be given to the application of total stress, pore pressure, voltage, and configuration of electrodes. Other considerations in the design of the apparatus are pore water pressure and volume change measurement during an electrokinetic test, which are of particular importance in understanding mechanisms involved in an electrokinetic process. The volume change is measured through the water flow in or out of the soil sample; hence, it will indicate the direction of electrokinetics-induced water flow. It is well understood that water flows towards the cathode in a low voltage electrokinetic process using non-insulated electrodes. However, there has been no affirmative experimental evidence regarding the direction of water flow during a high voltage electrokinetic process using insulated electrodes. Therefore, the direction of water flow during a high voltage electrokinetic test is of particular importance in understanding the principles involved. In the process of examining the effects of electrokinetics, one must recognise that the consolidation pressure (effective stress) on the soil sample prior to and during an electrokinetic test inevitably generates primary and secondary consolidation. The effects should be distinguished from electrokinetics-induced effects. Further, since electrokinetic tests and especially high voltage tests usually take more time (up to several months, as shown in the example in the next section), an increase in the soil shear strength due to soil aging could become considerable. To compensate for these effects, a control test is performed with every electrokinetic test under the same consolidation pressure and drainage condition over the same

According to the Khairul Anuar Kassim, Mohd Raihan Taha and Kamarudin Ahmad; Gray and Mitchell (1967) showed experimentally that although the electroosmosis flow increase with increasing water content of most soils, the flow decrease with an increasing electrolyte concentration of the pore fluid. In addition, they observed that the fundamental importance in electroosmosis phenomena is the cation-anion distribution and the water-ion distribution in the soil. The stresses that in clays and other ion exchangers, the positive counter ion require balancing the negative fixed charges on the solid particles are in the majority, and hence they impart more momentum to the water than do the co-ions. So there is a net water transfer in the direction of counter- ion movement.

In addition to water transport between the electrodes, oxidation and reduction take place at the electrodes as electrons are transferred in and out of the system (Gray and Mitchell, 1967; Thomas and Lentz, 1990; and Mitchell, 1993), resulting in ion diffusion, ion exchange, development of osmotic and pH gradients, dessication by heat generation at the electrodes, mineral decomposition, precipitation of salts or secondary minerals, electrolysis, hydrolysis, oxidation, reduction, physical and chemical adsorption and fabric changes (Mitchell, 1993). Some of the changes maybe give the advantages while the others may retard the efficiency of electroosmosis. Electro osmosis provides two benefits when properly applied. First, electroosmosis provides uniform pore water movement in most types of soil. Since the boundary layer movement towards the cathode provides the motive force for the bulk pore water, the size of the pore is not important. Unlike hydraulic conductivity, electroosmotic flow rate is not sensitive to the pore size. Electroosmotic flow rate is primarily a function of applied voltage.

CHAPTER 3

METHODOLOGY/ PROJECT WORK

3.1 Laboratory Testing

To determine the physical characteristics of the kaolin soil obtained from the Bidor, a few tests had been done according to BS 1377. The laboratory test was done during the first semester. The result shows there was not much different from the kaolin from other place. The test that had been done was:

- Moisture content
- Specific gravity
- Atterberg limits
- Sedimentation by the hydrometer method
- Vane shear strength

3.2 Equipment Design, Fabrication and Procedures

3.2.1 Equipment Design and Fabrication

Equipment that had been used during the experiment to the kaolin soil consists of two parts:

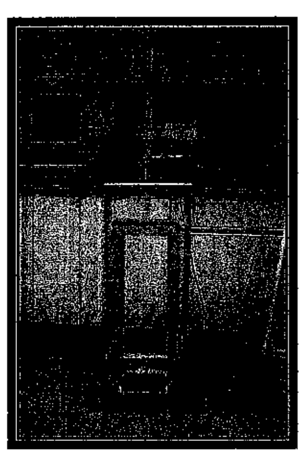

FIGURE 3.2.1.1: Stool

- **Stool** – made of steel, consist of frame that is used to put the load and also used to place the cylinder cell.

FIGURE 3.2.1.2: Cylinder Cell

- **Cylinder cell** – made of Perspex, used to put the kaolin soil and it is cylinder in shape.

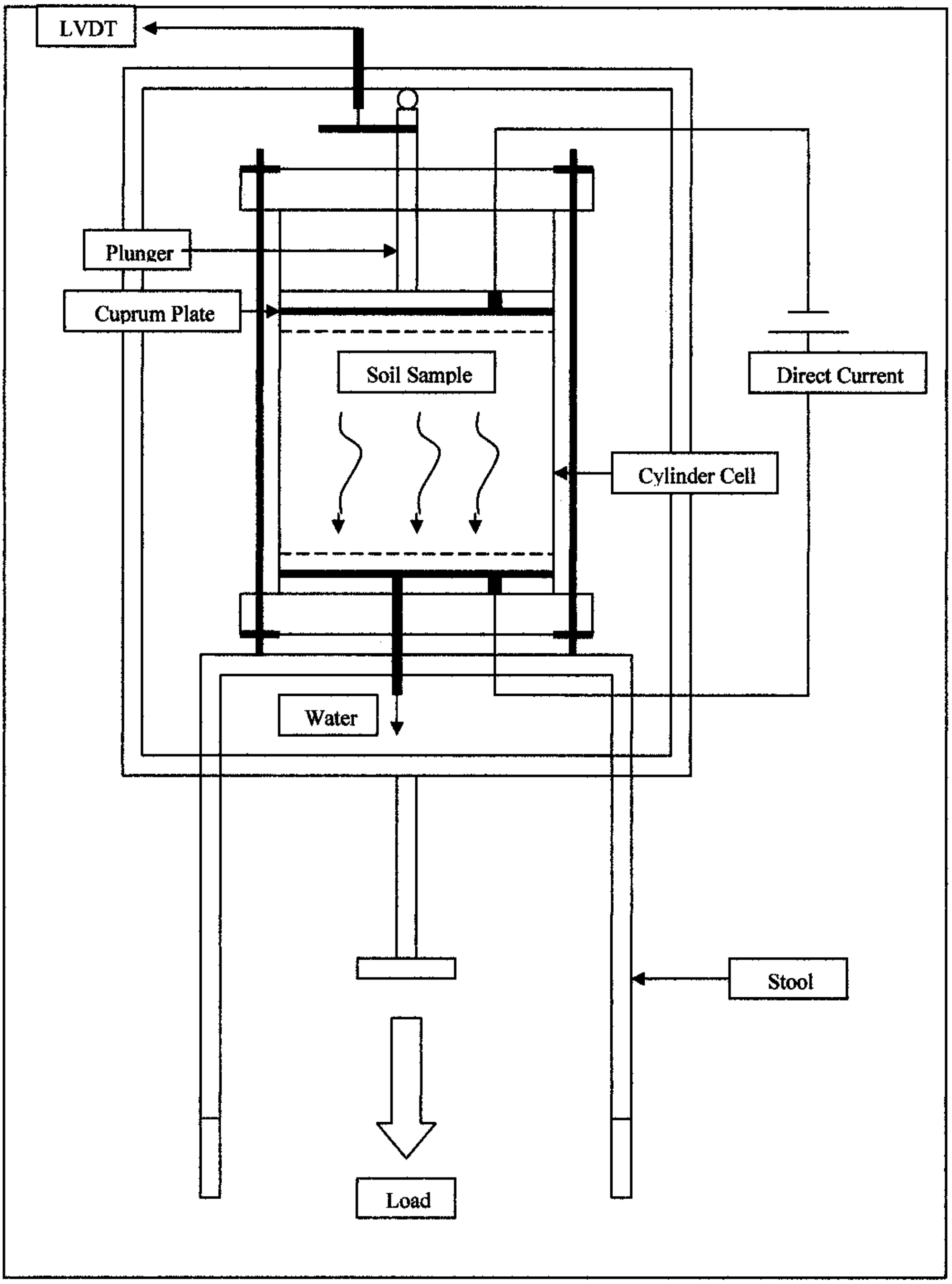

FIGURE 3.2.1.3: Schematic of the tool and cylinder cell.

Figure 3.2.1.3 shows that the schematic picture of the equipment that were used in the experiment to the kaolin soil. The main equipment is the cylinder cell. The kaolin soil that had been dry and added with water is put inside the cell.

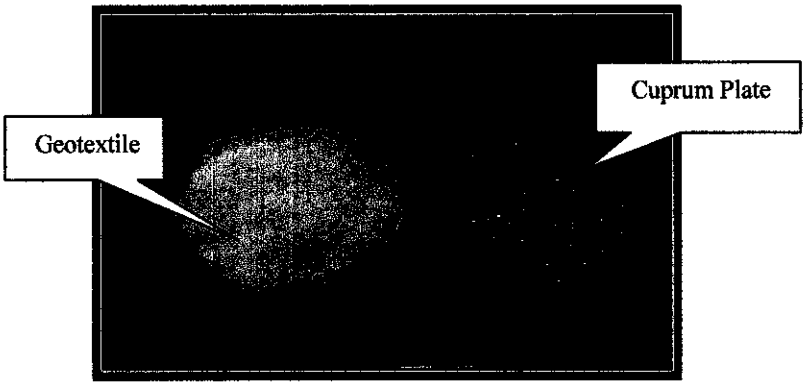

FIGURE 3.2.1.4: Geotextile and Cuprum Plate

Cuprum Plate – the cuprum plate was place at the top and bottom of the soil. The top plate is connected to the plunger by screw. The screw is connected with direct current (anode). The bottom plate was connected to the base by screw. The screw is connected with the direct current (cathode).

Geotextile – geotextile was placed between the plunger and cuprum plate. At the bottom the geotextile was placed between the base and the cuprum plate. Geotextile is used to avoid the soil sample to move up through the hole of the cuprum plate. Due to the load the soil will be compress the soil and the soil will move up through the hole. The geotextile will prevent the soil to move up.

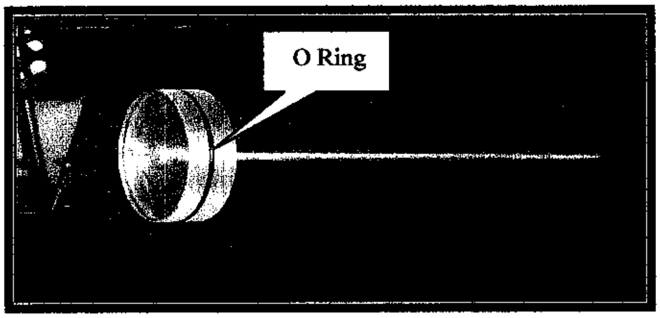

FIGURE 3.2.1.5: Plunger

Plunger – plunger is connected with the load at the bottom of the stool. On the tip of the plunger there is a ball ring so the frame can be place on the ball ring.

The load will pull the plunger downward so the kaolin soil will be compress. At the plunger there was a hole so that the air from the soil that had been compressed can go out. Around the plunger there is an o-ring so that the plunger will move smoothly and also prevent the soil from sipping out at the side. To help the plunger to move smoothly the grist will be applied around the cell.

FIGURE 3.2.1.6: Voltage supplier

Voltage supplier – direct current is connected to the plunger (anode) and the base of the cell (cathode). It is connected by a screw also with the cuprum plate and the geotextile.

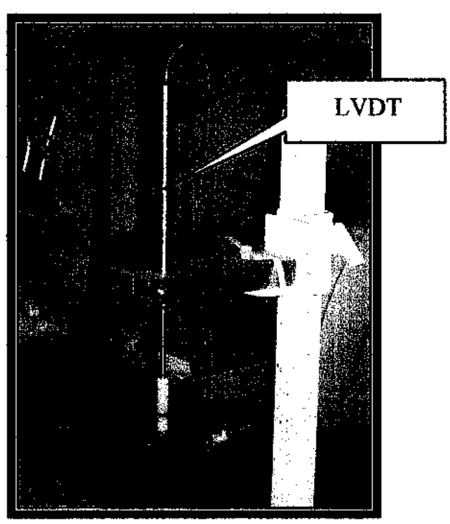

FIGURE 3.2.1.7: LVDT

LVDT – this LVDT also connected with the plunger. The LVDT will be connected to the data logger. This data logger will record the settlement of the soil when the load is applied. The logger can be set so that it can be log at specified time.

Water flow – the arrow of water shows that the way the water will go out. This hole is at the base of the cylinder. Water from the soil that had been compressed will flow through the hole.

3.2.2 Procedures

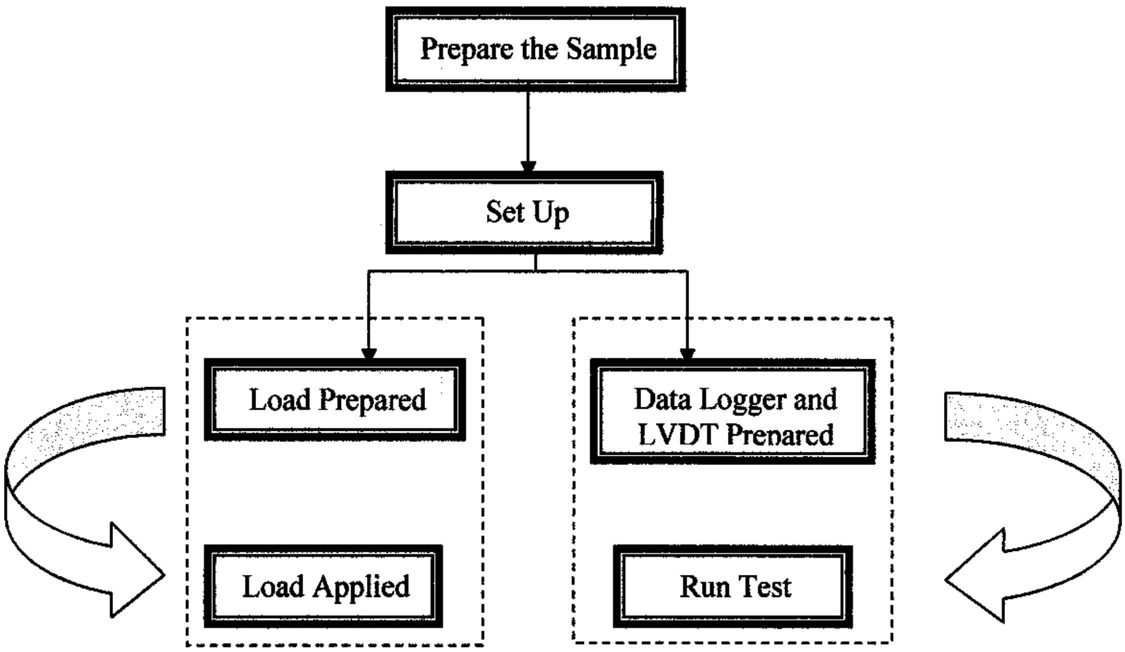

FIGURE 3.2.2.1: Procedure of the experiment

I. Prepare the sample of soil.
II. Put the wet kaolin into the cylinder. There will be the same amount of wet kaolin will be test through out the experiment. So that we will get the consistent reading.

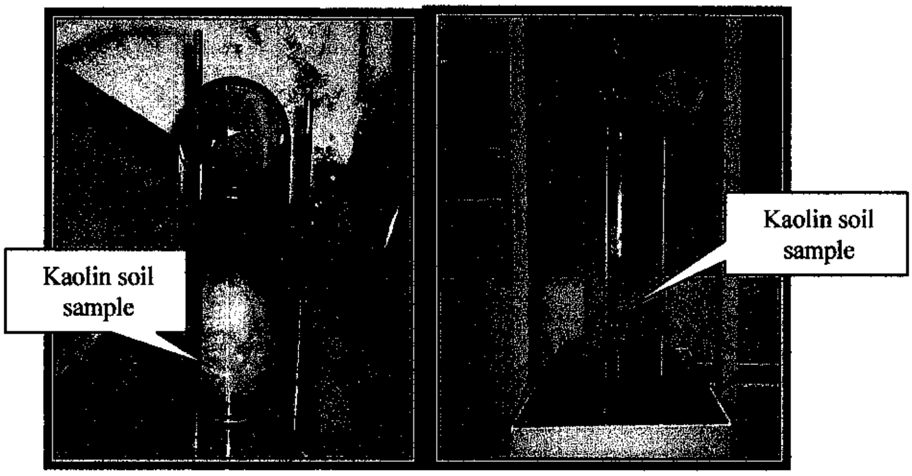

FIGURE 3.2.2.2: Kaolin soil sample in the Perspex cylinde

III. The equipment will be set up before the test will be run. The plunger must be exactly touching the surface soil so that the LVDT will log the correct settlement. The load will be prepared for the test.

IV. The load will be put to the frame of the stool and at the same time the test had to be run. This is because when the load is being applied, the settlement is starting so the data logger will start record the settlement. The water from the soil will be flow through the hole.

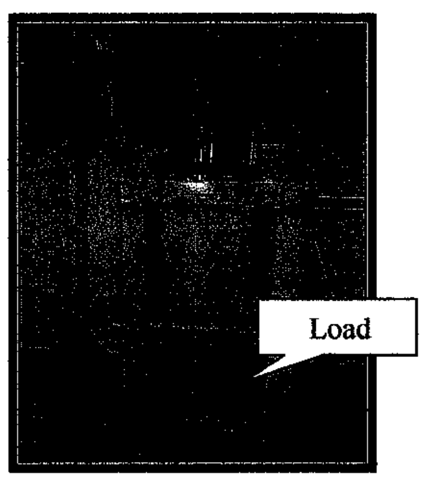

FIGURE 3.2.2.3: Load that been applied

V. During the test, data logger will record the settlement. The test that applied the voltage, the reduction of amperage has to be record.

VI. After the test had stop the moisture content of the sample will be taken. Vane shear strength test was done to know the soil strength.

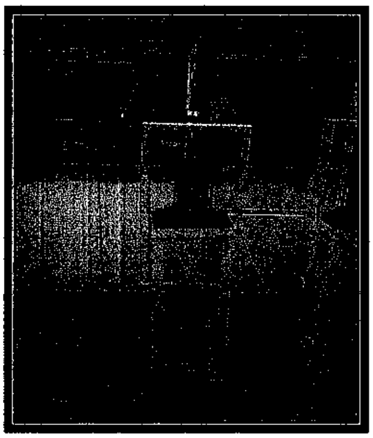

FIGURE 3.2.2.4: Actual equipment that been tested

Figure 3.2.2.1 shows the actual testing that had been done for the kaolin soil. it shows that the load that had been applied to the soil. Picture of the equipment can be refer in the Appendix II

3.3 Sample Preparation

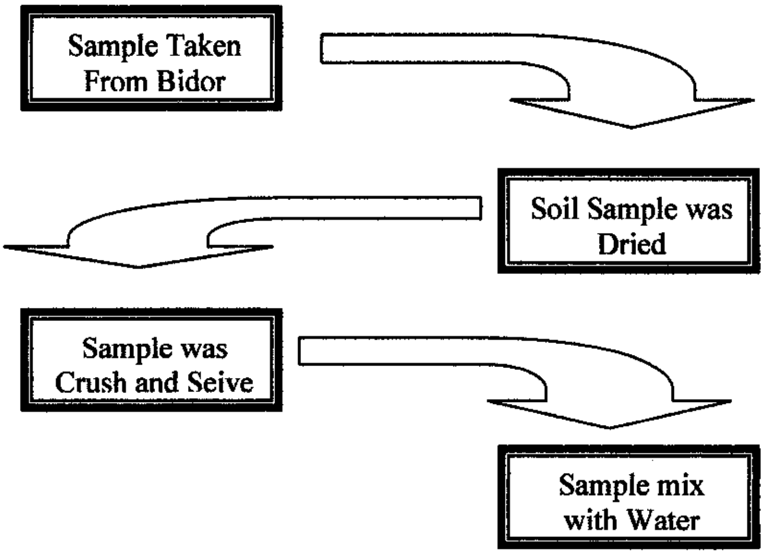

FIGURE 3.3.1: Procedure of preparation of sample

Figure 3.3.1 shows that the procedure that had been conducted for preparation if the sample before the test will be run. There are 6 tests that were conducted in this Final Year Project. Before the experiment can be run the sample had to be prepared. The soil that was obtained from Bidor was dry in the oven for about 24 hours. After that the soil had to be crush into powder and sieve so that there will no stick, small stone and leaves in the sample. The water that been used is a distill water. The distill water was used into the mixture because the water is a means to transmit the current so the distill water contain no other mineral. The water and the soil will be mix. Lastly the wet kaolin soil will be put in the cylinder about 1.05 kilogram.

3.4 Experiments on Kaolin

Ratio of water and soil is 1:1.25

Soil = 750 gram

Liquid Limit = 56%

Water = 56% x 1.25 x 750

= 525 gram

TEST	RATIO WATER AND SOIL	SOIL (GRAM)	WATER (GRAM)	LOAD (KPA)	VOLTAGE (V)	PERIOD (DAYS)
1	1 : 1.25	750	525	10	0	5
2	1 : 1.25	750	525	20	0	5
3	1 : 1.25	750	525	30	0	5
4	1 : 1.25	750	525	20	10	5
5	1 : 1.25	750	525	20	20	5
6	1 : 1.25	750	525	20	30	5

TABLE 3.4.1: Type of Test

Table 3.3.1 shows that the first test until the third test was used the increasing load and without voltage. Forth test until sixth test was used fix load and increasing in voltage.

CHAPTER 4
RESULTS & DISCUSSION

4.1 Results

The result of the test determines whether the project's objectives are met or not. The test was been done according to the BS 1377. There are several parameter that is observed and record in order to ensure the effectiveness of the test.

- Settlement of the soil during the test.
- The strength of the peat soil increased
- Reduction in amperage during electroosmosis treatment
- Variation of moisture content of peat soil tested from anode to cathode

4.1.1 Settlement of soil

The settlement of kaolin soil during the test is recorded. The data logger will log the data at time specified. The test is set in a time frame. The test was conducted according to the time limited for certain experiment. The time specified in the data logger so that the record the settlement at every time that had been specified was :

- First 5 minutes, log every 30 seconds
- Next 49 minutes, log every 60 seconds
- Next 23 hours, log every 20 minutes
- Next 216 hours, log every 1 hour

The test also been conducted according to the sample and it is a time frame. From the observation the kaolin soil shows, that the settlement and other result is stable so we stop the test. The time frame for each of the test was :

- Test 1 = 5 Days
- Test 2 = 5 Days
- Test 3 = 5 Days
- Test 4 = 5 Days
- Test 5 = 5 Days
- Test 6 = 5 Days

The value of settlement each of the test is tabulated in the table as shown in the Appendix III. Some graph had been made in order to analyze the result which are consist of :

- Individual graph time (min) versus settlement (mm)
  Test 1 until Test 6
- Combination of Test 1, 2 and 3 (without voltage)
- Combination of Test 4,5 and 6 (with voltage)
- Combination of Test 1,2,3,4,5 and 6

All the graph are shown in the Appendix III

4.1.2 Shear Strength

Without voltage

Test 1: 7kg = 10kPa

Deflection of spring (θ_f)	=	13°
Rotation of vane	=	82°
Rotation of spring mounting	=	95°

Torque, M (N.mm) = **K θ_f**

Torque, M = K x θ_f

= 0.015 x 13°

$= 0.201 \times 10^3$ Nmm

Vane shear strength = (M/4.29)

= (201/4.29)

= 46.85 kN/m^2

Test 2: 14kg = 20kPa

Deflection of spring (θ_f)	=	23°
Rotation of vane	=	8°
Rotation of spring mounting	=	31°

Torque, M (N.mm) = K θ_f

Torque, M = K x θ_f

= 0.028 x 23°

$= 0.636 \times 10^3$ Nmm

Vane shear strength = (M/4.29)

= (636/4.29)

= 148.25 kN/m^2

Test 3: 21kg = 30kPa

Deflection of spring (θ_f)	=	26.5°
Rotation of vane	=	12.5°
Rotation of spring mounting	=	39°

Torque, M (N.m) = K θ_f

Torque, M = K x θ_f

= 0.032 x 26.5°

$= 0.857 \times 10^3$ Nmm

Vane shear strength = (M/4.29)

= (857/4.29)

= 199.76 kN/m^2

With voltage

Test 4: 10V

Deflection of spring (θ_f)	=	13.5°
Rotation of vane	=	3°
Rotation of spring mounting	=	39°

Torque, M (N.m) = **K θ_f**

Torque, M = K x θ_f

= 0.016 x 13.5°

= 0.217 x 10^3 Nmm

Vane shear strength = (M/4.29)

= (217/4.29)

= 50.58 kN/m^2

Test 5: 20V

Deflection of spring (θ_f)	=	22.5°
Rotation of vane	=	6°
Rotation of spring mounting	=	28.5°

Torque, M (N.m) = **K θ_f**

Torque, M = K x θ_f

= 0.027 x 22.5°

= 0.608 x 10^3 Nmm

Vane shear strength = (M/4.29)

= (608/4.29)

= 141.72 kN/m^2

Test 6: 30V

Deflection of spring (θ_f) = 48.75°

Rotation of vane = 11°

Rotation of spring mounting = 59.75°

Torque, M (N.m) = K θ_f

Torque, M = K x θ_f

= 0.062 x 48.75°

= 3.014 x 10^3 Nmm

Vane shear strength = (M/4.29)

= (301.4/4.29)

= 702.56 kN/m^2

Tabular form of the result of the shear strength and the graph can be obtained in the Appendix IV. Consist of graph:

- Graph pressure versus shear strength (test 1, 2 and 3)
- Graph voltage versus shear strength (test 4, 5 and 6)
- Combination of the graph voltage versus shear strength (test 1, 2, 3, 4, 5 and 6)

4.1.3 Reduction of Amperage

The elektrokinetic test on kaolin soil was test for tested number 4, 5 and 6 with constant load about 20kPa. The amount of the voltage that is used was 10V, 20V and 30V.The result shows that the value of the current is reducing with time. The record of the current reduction is conducted manually. There was a time frame for the reading that had to be taken that was:

First day

- First 60 minutes, record every 5 minutes
- Next 60 minutes, record every 15 minutes
- Remain hours, record every 60 minutes

Second day

- Record every 2 hours

Third day, forth day and fifth day

- Record every 5 hours

TEST	LOAD (KPA)	VOLTAGE	INITIAL	FINAL
4	20	10	0.9	0.38
5	20	20	1.41	0.61
6	20	30	2.05	1.01

TABLE 4.1.3.1: Result of reduction of Amperage

The tabular record of the reduction on amperage and the analysis graph can be referring to the Appendix V

- Individual graph of time versus current
- Combination graph of test 4,5 and 6

4.1.4 Variation of Moisture Content

There are 6 samples of kaolin soil were prepared in each of the test that were conducted in order to get the value of moisture content of the kaolin soil. Every time each of the tests was complete, sample of kaolin is cut slice into 6 slices. The layer was from anode to cathode. The height of the sample is about 90cm and each slice is about 15cm.

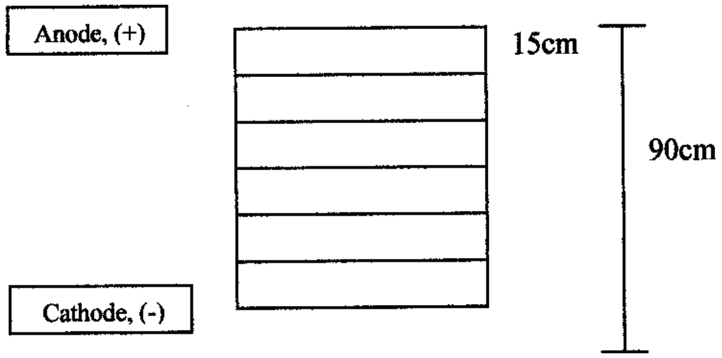

FIGURE 4.1.4.1: Schematic of the sample of soil

The value obtained is tabulated in the table as shown in the Appendix *. The formulae used to calculate the moisture content (w) is;

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

Where;

m_1 = mass of the container (g)

m_2 = mass of container and wet soil (g)

m_3 = mass of container and dry soil (g)

Analysis graph was construct that can be referring to the Appendix VI Consist of:

- Individual graph of moisture content versus distance from anode
- Combination graph from test 1,2 and 3 (without voltage)
- Combination graph from test 4,5 and 6 (with current)
- Combination graph of test 1,2,3,4,5 and 6

4.2 Discussion

4.2.1 Settlement of Soil

Kaolin soil was said as one of the soft soils categories. This is why the settlement is a major problem of the kaolin soil. From the test that had been done, the result of the first test, second test and third test shows different in settlement in from the test forth, test fifth and test sixth. The rate of settlement will become faster if the load or surcharge applied was bigger. The bigger the load applied to the sample, the faster the rate of settlement. The trend of kaolin soil is that the soil will be stable after some period of time, means that the rate of settlement is high in the early part of the test. This is because when the load that had been applied the kaolin will settle with high rate.

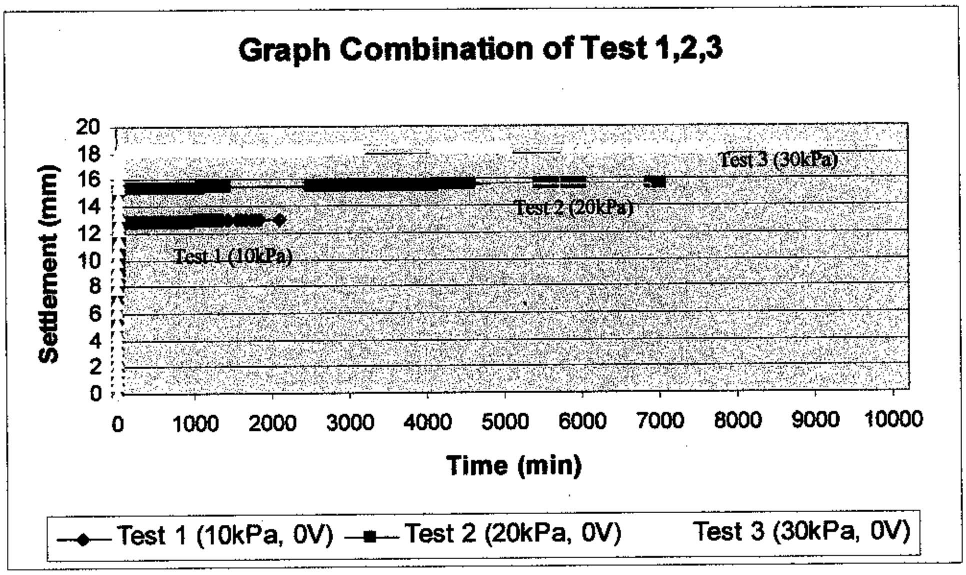

FIGURE 4.2.1.1: Combination of graph Settlement vs Time of Test 1,2 and 3 (without voltage)

Figure 4.2.1.1 shows the trend of graph for the test that did not applied the electrokinetic effect. Test 3 which is the load applied is 30kPa has the higher rate of settlement compare to test 1 and 2 which is the load applied is 10kPa and 20kPa. The first test was applied with 10kPa, second test with 20kPa and third test with 30kPa. From the graph shows that there were some increasing of reduction of settlement when increase in load. The soil samples will settle if the bigger load applied and the soil become more compact and consolidated. This is because the different amount of load that been applied give the different rate of settlement to the kaolin soil. Due to this reason the pore space that is filled with water and air is been compress out. The heavier the load more water and air will be expelled out. The rate of settlement also increases as the load increase. Thus, it enhances higher vane shear strength of the samples. More consolidated the soils, more strength it has.

The settlement for the first test was 12.95mm, second test was about 15.61mm and for the third test were about 18.48mm. Test 3 has a greater rate of settlement compare to test 1 and 2. The individual graphs of the settlement for every test are shown in Appendix III.

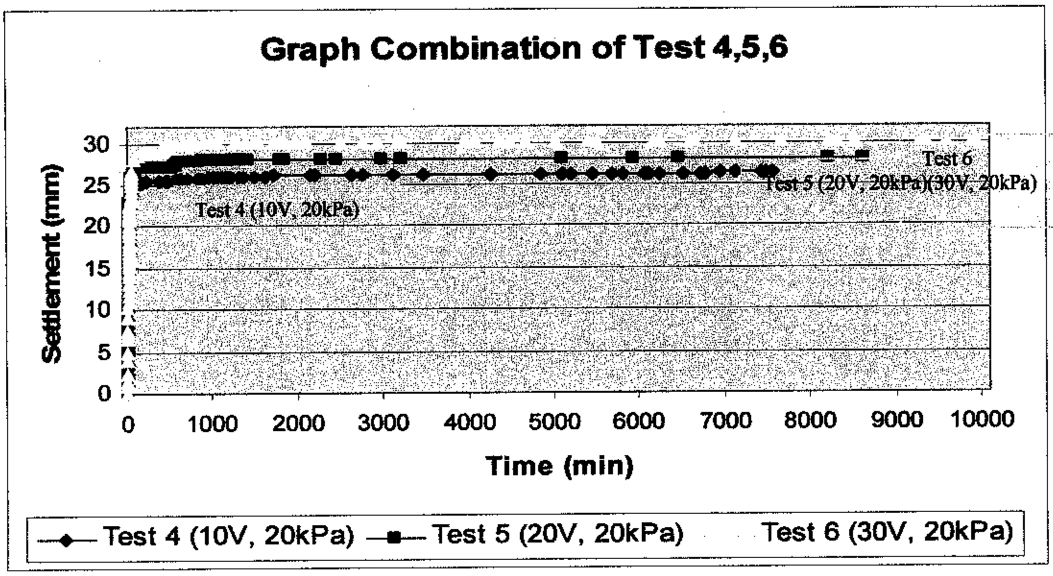

FIGURE 4.2.1.2: Combination of graph from test 4,5 and 6 (with voltage)

Figure 4.2.1.2 shows the settlement of a samples which the test were conducted with electricity. The above graph shows the range of settlement is increasing from the test 4 until to the test 6. We can see that the test 5 and 6 which is individually applied the same load and with different voltage of 20V and 30V. The increasing in voltage cause the range of settlement of the soil also increases. The effect of 20V and 30V to the settlement is not really effective although those voltages give a lot of effects to the shear strength.

The range of settlement for test 4 is about 26.35mm, test 5 is about 28.08mm and test 6 is about 30.21mm. This increase of range of settlement shows that the electrokinetic effect to the soil gives some improvement of the settlement of soil. The increasing of range due to the increasing in the voltage applied. More voltage applied cause the water to move out faster and more. The voltage will conduct the current to mitigate the moving of the water. So the help of the load the soil will be compressed faster.

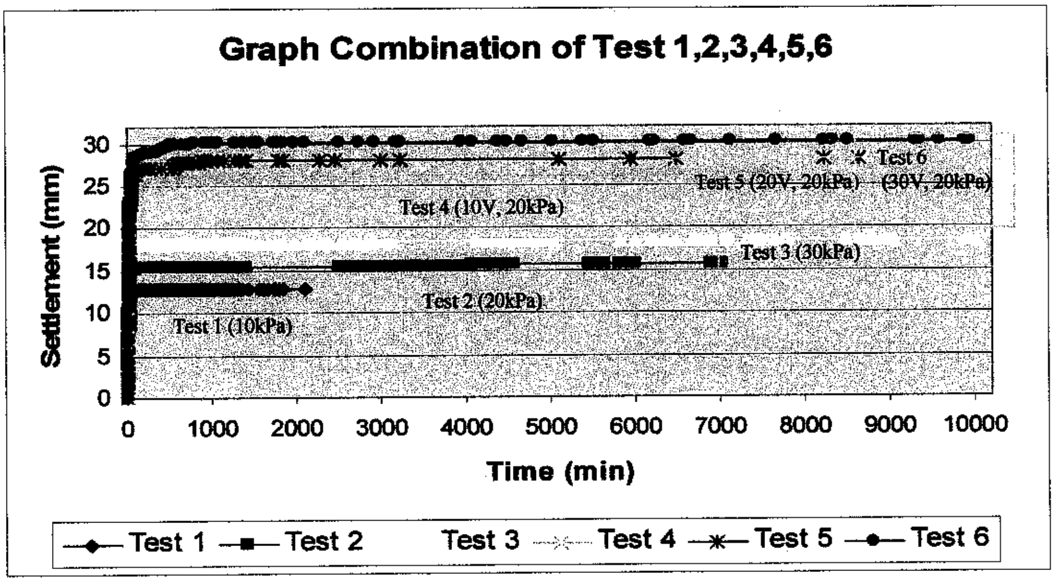

FIGURE 4.2.1.3: Combination of graph from test 1,2,3,4,5 and 6

The combination of the test with voltage and without voltage shows that there was some trend for the test. From the graph, it shows that the increase in the range of settlement. The range of the graph shows that the electrokinetic effect gives some improvement to the settlement of kaolin soil. There were some different in the range of the time of the test were conducted. This is due to the fact that the test was stopped when further settlement was very small.

4.2.2 Shear Strentgh

There are three general ways to induce deformations in solids or semi-solids: tension, compression, and shear. Soil is not capable of resisting tension; it is capable of resisting compression to some extent. In cases of excessive compression, failure usually occurs in the form of shearing along some internal surface within the soil. Structural strength of soil is primarily a function of its shear strength, where shear strength refers to the soils ability to resist sliding along internal, 3-dimensional surfaces within a mass of soil.

The value of shear of each of the test was tabulated in the table below:

Pressure (kPa)	Shear Strength (kN/m^2)
10	46.85
20	148.25
30	199.76

TABLE 4.2.2.1: Shear strength of test of without voltage.

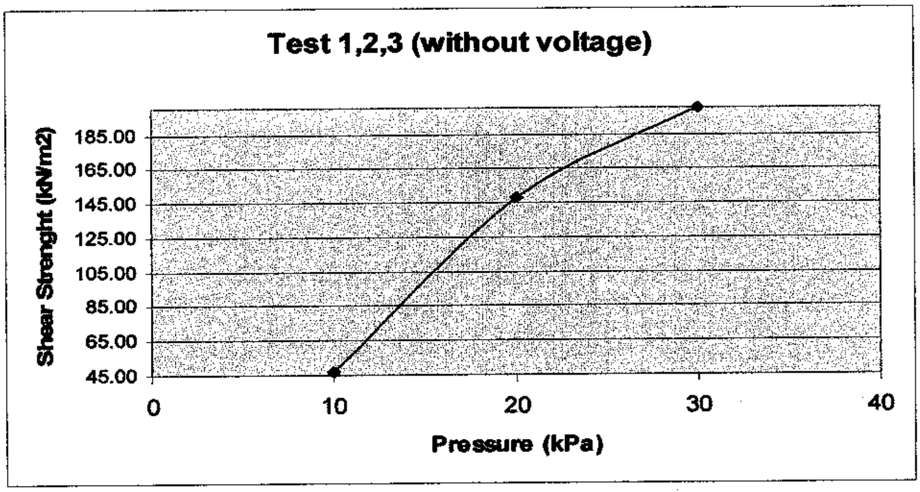

FIGURE 4.2.2.1: Graph of pressure versus shear strength (without voltage)

The graph in Figure 4.2.2.1 is plotted based on the result collected in the vane shear strength test. The load that been applied is increasing this because the shear strength of the soil also increase. This is relating with the settlement of the soil. From the graph, we can see that the shear strength is keep increasing when the value of load is increased. The increase of strength shown is consistence with the load.

Current (V)	Shear Strength (kN/m^2)
10	50.58
20	141.72
30	702.56

TABLE 4.2.2.2: Shear strength of every voltage applied

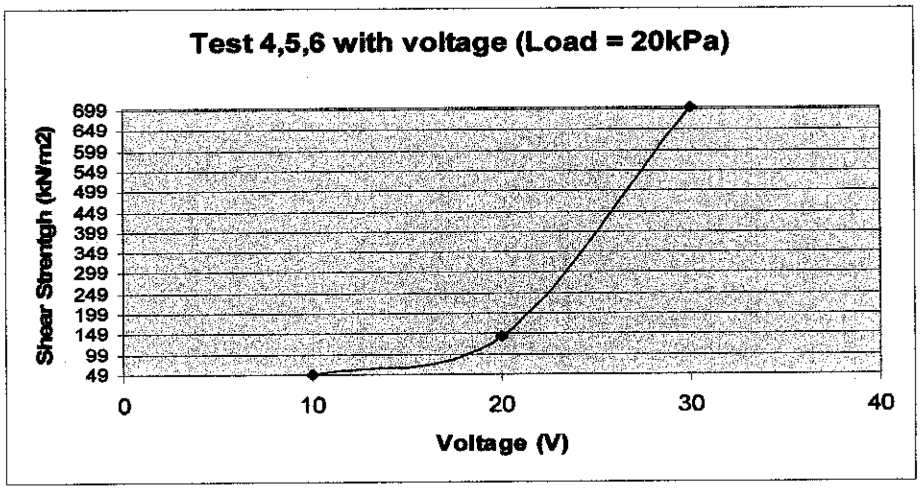

FIGURE 4.2.2.2: Graph voltage versus shear strength

Graph of figure 4.2.2.2 shows that the shear strength is increase as the voltage is increase. The strength of the kaolin soil is increase when the voltage was applied through the soil. As we can see the increasing of the graph is too wide from the 20V and 30V. The different of shear strength is wide. The shear strength at 30V is 702.56 kN/m^2 and for 20V is about 141.72 kN/m^2. This is might be because of the voltage is optimum enough to make the shear strength increase in a wider range. Shear strength of 10V and 20V is not much different.

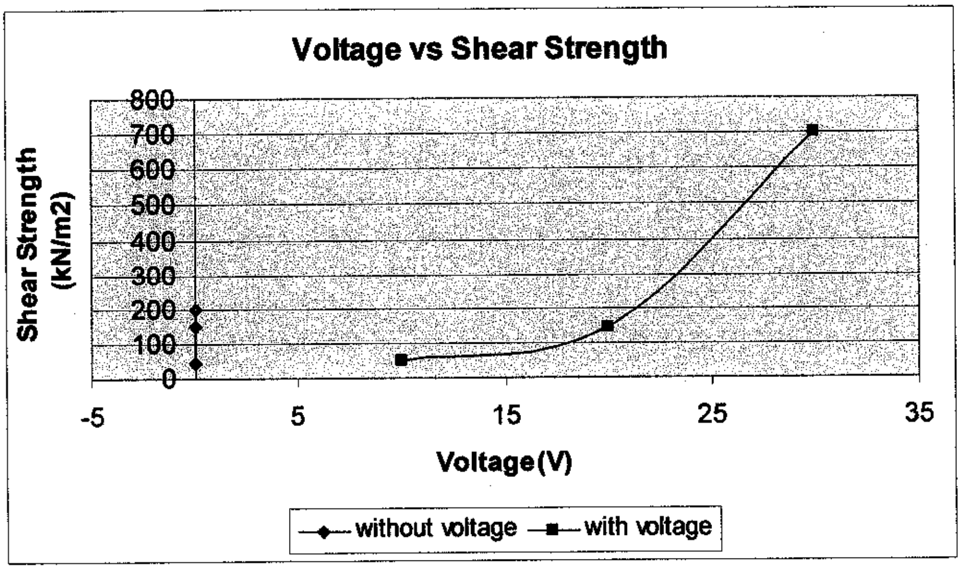

FIGURE 4.2.2.3: Combination of graph without voltage and with voltage.

As we can see from the graph, the increase in shear strength for the test with voltage is obtaining high shear strength. Test 1,2,3,4 and 5 is not much different value of shear strength from each other. For test 6 that is 702.56 kN/m^2, the value having much different from the other value. Comparing the test that did not apply the voltage to the test that was applied a voltage it shows the increment in value. 30V might be the optimum voltage for load of 20kPa to obtain high shear strength.

4.2.3 Reduction of amperage

The voltage about 10V, 20V and 30V is applied to the soil to increase the strength of the soil by applying low intensity direct current through the soil. Current is move through the soil because of the availability of water. As the time increase the water in the soil is decrease. Reduction of water in the soil causes a reduction of amperage through the soil. Amperage is in mA unit. The current reduction was recorded in a tabular form that can be referring in the AppendixVI

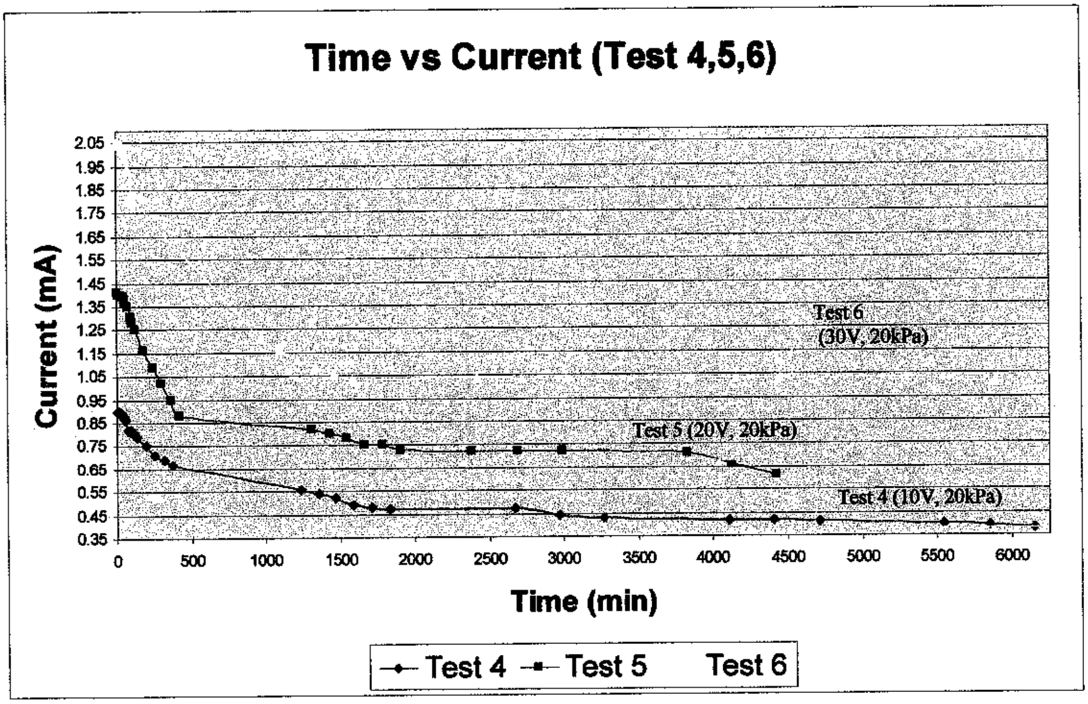

FIGURE 4.2.3.1: Combination of graph time versus current

Figure 4.2.3.1 shows that there was a current reduction against time. The current transmit with the availability of water. After certain time it shows that the value will be stable means that the reduction of current will be slower. This is because the water in the soil is reducing. The test was using a constant value of load that is 20kPa. The time frame is different, for test 4 and 6 the test was conducted for about 5 days and for test 5 the test was conducted for about 4 days. This was because the result shows the stable of value, so we stop the test regarding to the result of the reduction of amperage.

The starting point of current is also different. Test 4 until test 6 shows the increasing of the starting points. This is because the voltage that had been applied also increase with the test. Test four the voltage is about 10V, test five about 20V and test six about 30V, this will cause the starting point of the current is high for test six and lower for test five and four.

The range of the reduction of amperage shows that the result of the voltage applied is showing an improvement to the soil. Larger the range of reduction of the current shows that larger amount of water that had been expelled. This is because the current transmit through water. As the water reduce the current transmit also will be reduce. Test four the range is about 0.52mA, test five ranges about 0.80mA and test six ranges about 1.04mA. This shows an increase in the range of the current reduction with the increase of the voltage applied.

High range of current reduction causes the reduction of the settlement. Wide range of the current cause more the water will be expel, after the water had been expel the void that initially filled with water will be compressed by the load. These will cause the high rate of consolidation. If the reduction of current is fast this will cause the rate of consolidation also will be fast.

The reduction of amperage means the pore space is reduce and the water also reduce. This will cause the moisture content of the soil also will be decrease. This can be shown from the formula which is:

$$V = IR$$

V = Voltage (V)

I = Current (mA)

R = Resistance

If the voltage is increase the current will be decrease and the resistance will be increase. From these formula the higher the voltage that been applied the higher the resistance of the soil. It is means that the strength of the soil also increase with increase in the voltage applied. In test 6 the voltage applied is the highest; 30V, this means that the strength of the soil should be highest than other test. This is prove by the test of the shear strength that test 6 obtain the highest shear strength; 0.703kPa.

4.2.4 Variation of Moisture Content

By following the research or study that has done by other peoples, kaolin soil is said to have higher moisture content. This high water content is the cause of buoyancy and a high pore volume that results in low bulk density and low bearing capacity. When the moisture content very high, the soil and water may flow like a liquid.

Table of moisture content of each of the test that had been done can be seen in the Appendix VI. After each of the test, the sample will be cut into 6 slices, that's from anode to cathode in order to determine the moisture content of the sample. The height is about 90mm and every slice is about 15mm.Each of the slices have to be determine the moisture content, in order to know the pattern of the moisture content. The pattern that is observed is the moisture content from anode to cathode.

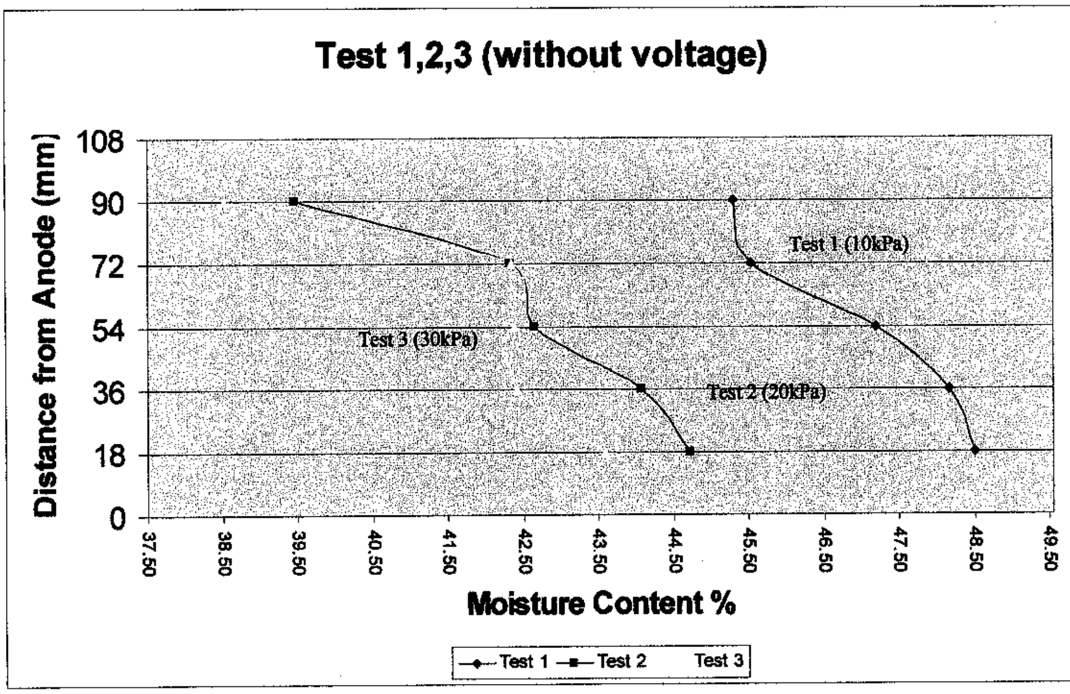

FIGURE 4.2.4.1: Combination of Graph Moisture Content versus Distance from Anode (without voltage)

Figure 4.2.4.1 shows that the combination graphs of moisture content from test 1, 2 and 3. The graph were plotted to show the relationship between moisture content and distance from anode. This test is without applying the voltage. As you can see the graph, the reduction of moisture content is from anode to cathode. The trend of all the three tests is the reduction of range of the moisture content from test one until test three. This occurred because the load that had been applied was increased from test one until test three, that is why the moisture content also decrease with increase of load. The trend also shows that the middle layer of Test 2 and Test 3 is not much different of moisture content and also the last layer from anode is having a wide different of moisture content from the upper layer.

As you can see graph for Test 1 show that the range of the graph is at the highest moisture content from other test. The top layer consists of 48.50% of moisture content and the bottom layer consists of 45.31%. This shows that the decrease in the moisture content from anode to cathode. At the layer of 0 to 36mm from anode the moisture content is not much different, but the moisture content decrease in a wide range from layer of 36mm until 72mm from anode. At the layer 72mm until 90mm the moisture content is not much different. From the graph the sample is consist of high percentage of moisture content at the top of the cell or at anode because of the water is not drain yet. At the middle of the cell the water is drain slowly. The bottom part of the cell shows that the water was drain quickly because the different of moisture content from the 54mm from anode is wide in range.

From graph of Test 2 the moisture content is decrease from anode to cathode. The graph shows that the moisture content at the layer of 90mm from anode means the lowest layer of the cell is different so much from 72mm from anode. The moisture content of 90mm from anode is 39.46% and the layer of 72mm is about 42.33%. This is may be because of the lowest layer of the sample is drain quickly than the upper layer.

Test 3 shows the top and the lowest layer from the anode consist a wide different of moisture content from the middle portion. This may be because of the lowest part drains quickly than the upper part. The top part until the middle the moisture content is not much different.

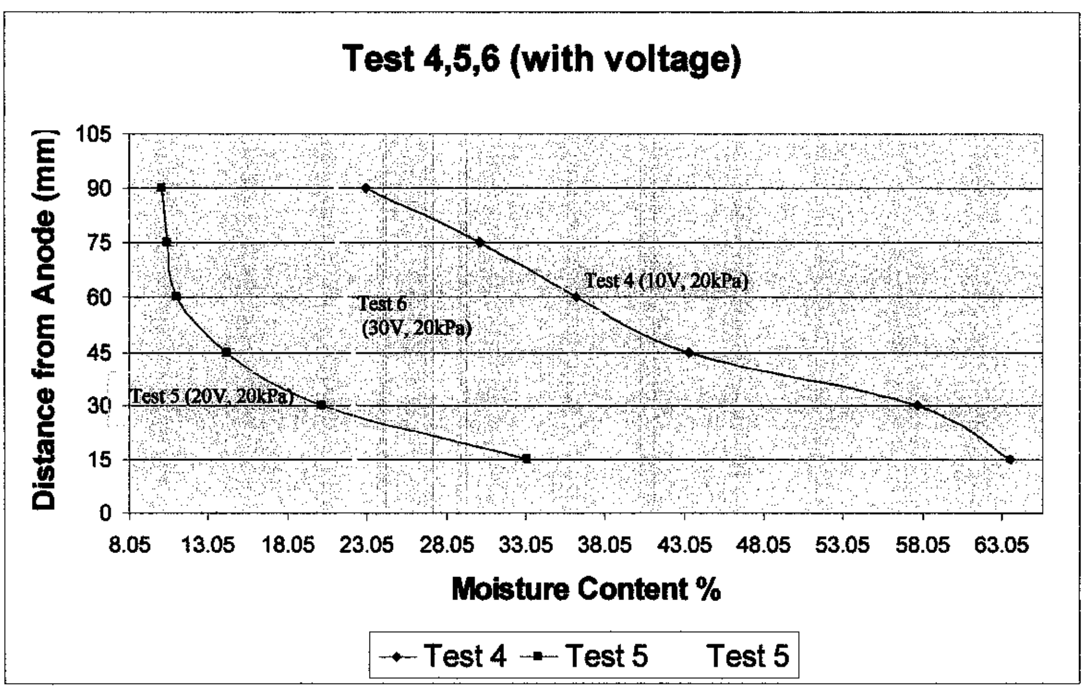

FIGURE 4.2.4.2: Combination of graph from Test 4,5 and 6 (with voltage)

Figure 4.2.4.2 shows a combination of graph from the test that voltage had been applied a voltage through the soil. The graph shows that the reduction of moisture content is the same with the graph of without applying the voltage that is reduction from anode to cathode. Test 4 shows that the moisture content consists in the sample are constant in reduction while Test 5 and 6 there might be some problem. Test 5 shows the top layer consist of 33.17% of moisture content while Test 6 consist of 22.23% of moisture content. There was a decrease in the amount of moisture content.

Test 4 shows that the moisture content is in constant reduction. This is might be because the low permeability of the kaolin soil, that is why the water in the soil drain slowly.

Test 5 shows that the reduction of moisture content is more than the reduction of Test 6. Test 6 shows that the range of the moisture content trough out the sample is so small. The top layer until the lowest layer consist the same amount of moisture content. It shows the reduction from anode to cathode but the reduction is too small. This is might be because of the voltage that had been applied to the sample is the optimum voltage because it cause the moisture content trough out the sample is slightly the same. The water in the soil is drain constantly that the moisture content through out the sample did not have much different.

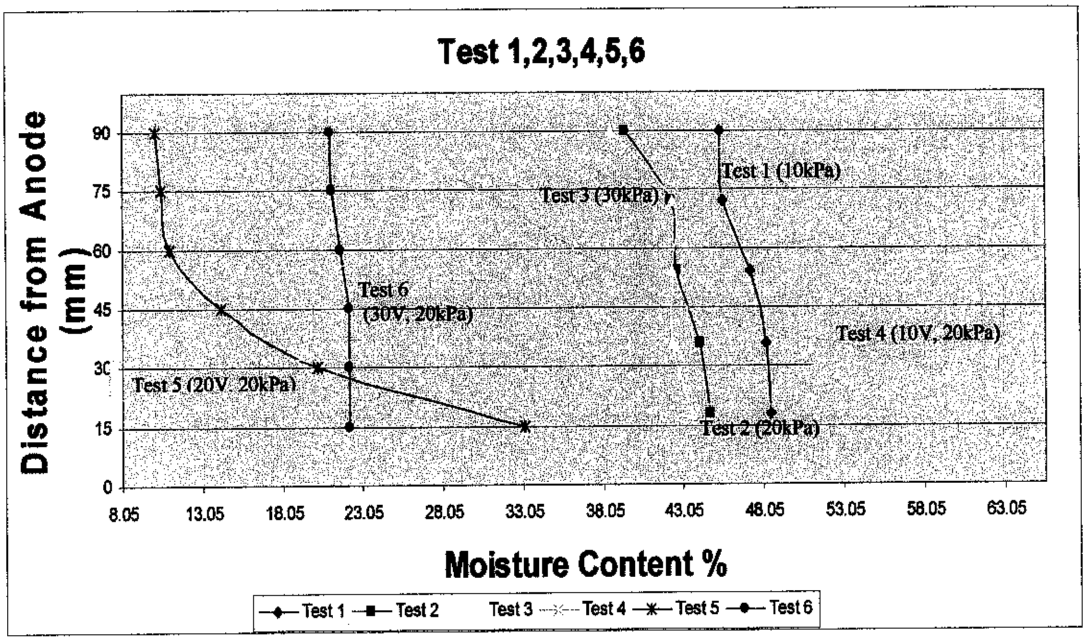

FIGURE 4.2.4.4: Combination of graph Moisture Content versus Distance from Anode.

Figure 4.2.4.4 shows that the combination of graph from test without voltage and with voltage. For test 1, 2 and 3 the load of 10kPa, 20kPa and 30kPa had been applied without voltage. So the range of graph is slightly the same. There were not much different of moisture content trough out layer of the sample. The moisture content from anode until cathode is not much different.

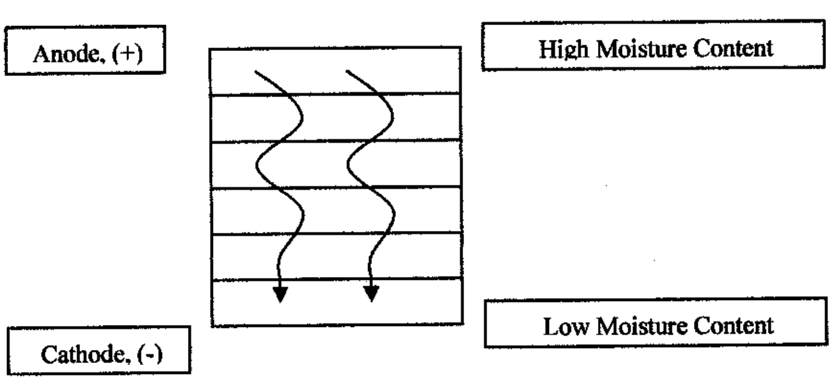

FIGURE 4.2.4.5: Reduction of moisture content from anode to cathode

Figure 4.2.4.5 shows the reduction of the moisture content in every test that had been conducted. The reduction of moisture content on every test shows that the moisture content decreases from anode to cathode.

Test 4, 5 and 6 the load that were using is 20kPa for the entire test and the voltage is 10V, 20V and 30V. The graph shows that the different value from the top of the sample through the lowest layer there were wide range of moisture content. Test 6 shows that the moisture content drops very fast that the different is not much different. From the current reduction Test 6 also shows that the range of reduction is wide. Current reduction and the moisture content reduction are related to each others. Less water in the sample means less reduction of current through out the sample.

The result that obtain may be because of the kaolin behavior. This also might be because of the discrepancies of taking a reading or while doing the test.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

From the experiments done, the effectiveness of electrokinetic effect on kaolin soil was determined. There were 6 tests that had been conducted in this Final Year Project. Test 1, 2 and 3 was applied with 10kPa, 20kPa and 30kPa of load and without voltage. Test 4, 5 and 6 applied 10V, 20V and 30V of voltage through the sample and using the same load that is 20kPa. Comparing the settlement of test with voltage with the test without voltage, where the range of settlement applied with voltage is more. The shear strength of the test that had been applied with voltage shows the effectiveness of the electrokinetic effect. This is because the shear strength increases in wide range. Reduction of amperage means pore space also decrease. When the pore space decrease the water also decreased and causes the reduction in the moisture content of the soil applied with voltage. Reduction of current also related to the increase in resistance of the soil. The strength of the soil will increase as the reduction of current.

As a conclusion, the electrkonetic method gives some improvement to the kaolin soil from the experiment that had been done. There were reduction in current and increase in shear strength and also increase in moisture content from cathode to anode. The moisture content at the top layer which is the anode part consists of high moisture content from other layers. As we can see, the objectives of this study which is to know whether there is an electrokinetic effect on kaolin soil has been achieve since the result show that there is an electrokinetic effect on kaolin especially in the strength of kaolin soil.

The results obtained might be the behavior of the kaolin soil after been applied with the voltage. The result is still subjected to more research and the phenomena are still ambiguous. Beside that, there might be a discrepancies while taking the reading or conducting the test. However, the results of the kaolin soil show some improvement to the characteristic of kaolin soil especially in term of strength. Further findings and testing by using more value of surcharges should be done in order to be more certain regarding the effect the electrokinetic of kaolin soil. Since the voltage applied did not give much effect on the consolidation on kaolin soil, higher voltage can be applied to find the optimum value of voltage to give more impact on the consolidation.

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- Final Year Project Guidelines

APPENDICES

APPENDIX I

Milestone for the First Semester and Second Semester of Final Year Project

1	**Selection of Project Topic** - Topic Assigned To students														
2	**Preliminary Research Work** - Introduction - Objectives - List of referance / literature - Project planning														
3	**Submission of Preliminary Report**														
4	**Project Work** - Referance / literature - Practical / Laboratory Work														
5	**Submission of Progress**														
6	**Project work continue** - Practical / Laboratory Work														
7	**Submission of Interim Report Final Draft**														
8	**Submission of Interim Report**														

Table 1: Milestone for the first semester of final year project

1	**Project work continue** - Practical / Laboratory Work														
2	**Submission of Dessertationt Final Draft**														
3	**Oral Presentation**														
4	**Submission of Project Dessertation**														

Table 2: Milestone for the socond semester of final year project

APPENDIX II

Pictures of the Equipment

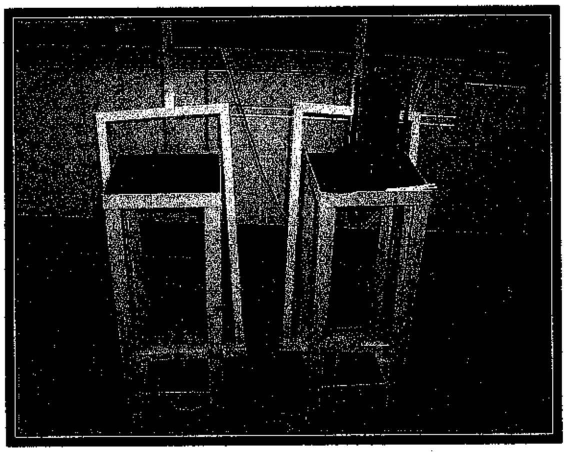


Figure 1: Preparing for the test

Figure 2: Set up the data logger through the computer

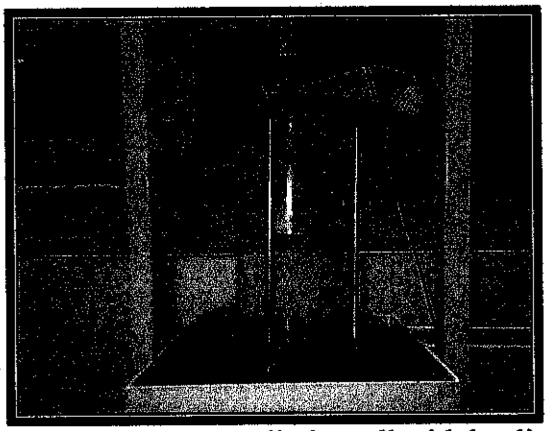


Figure 3: Perspex cylinder cell with kaolin

APPENDIX III

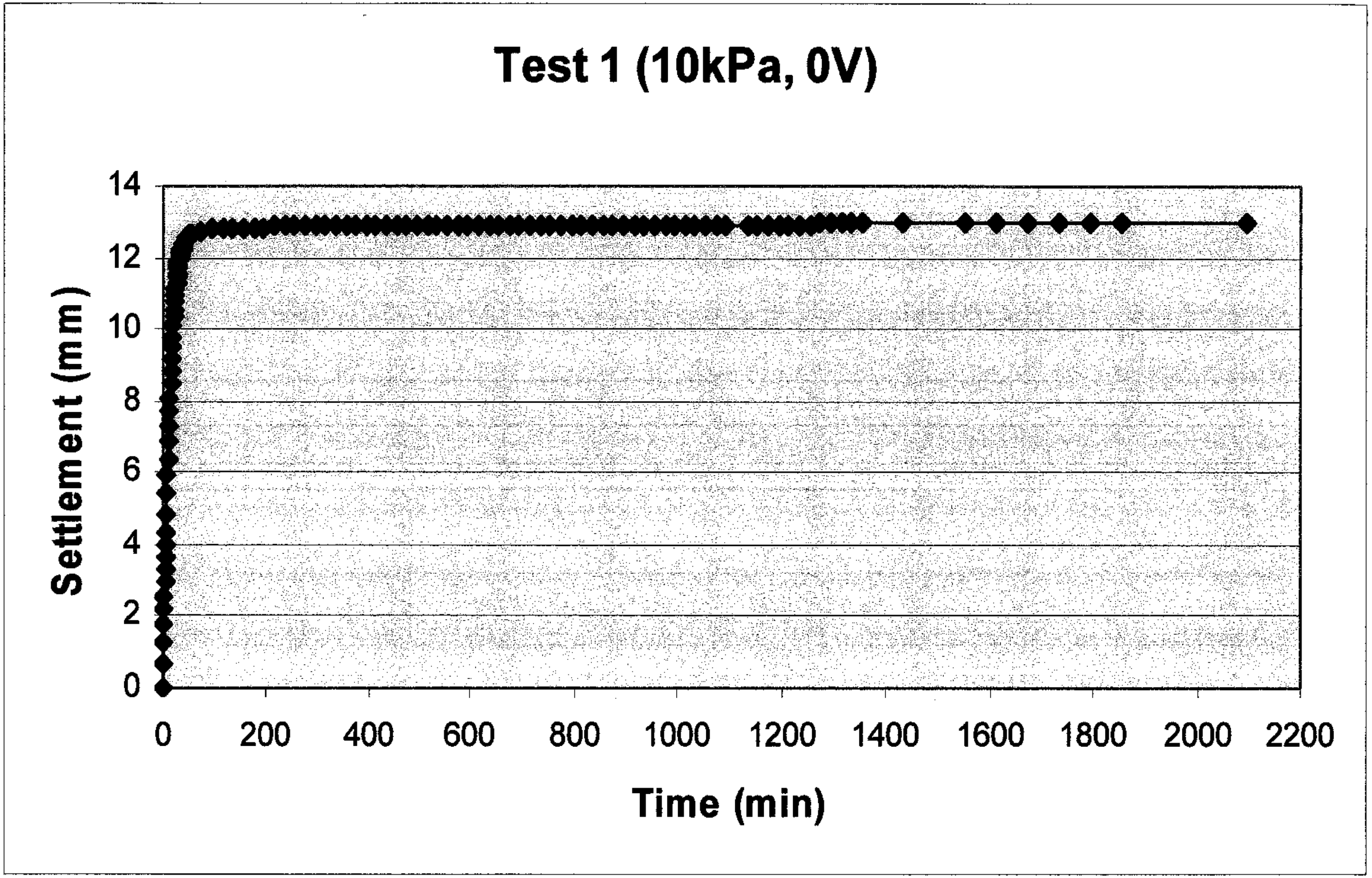
Settlement of soil

- Table of settlement of soil Test 1, 2, 3, 4, 5 and 6
- Individual graph time (min) versus settlement (mm) Test 1 until Test 6
- Combination of Test 1, 2 and 3 (without voltage)
- Combination of Test 4,5 and 6 (with voltage)
- Combination of Test 1,2,3,4,5 and 6

Test 1 (10kPa, 0V)

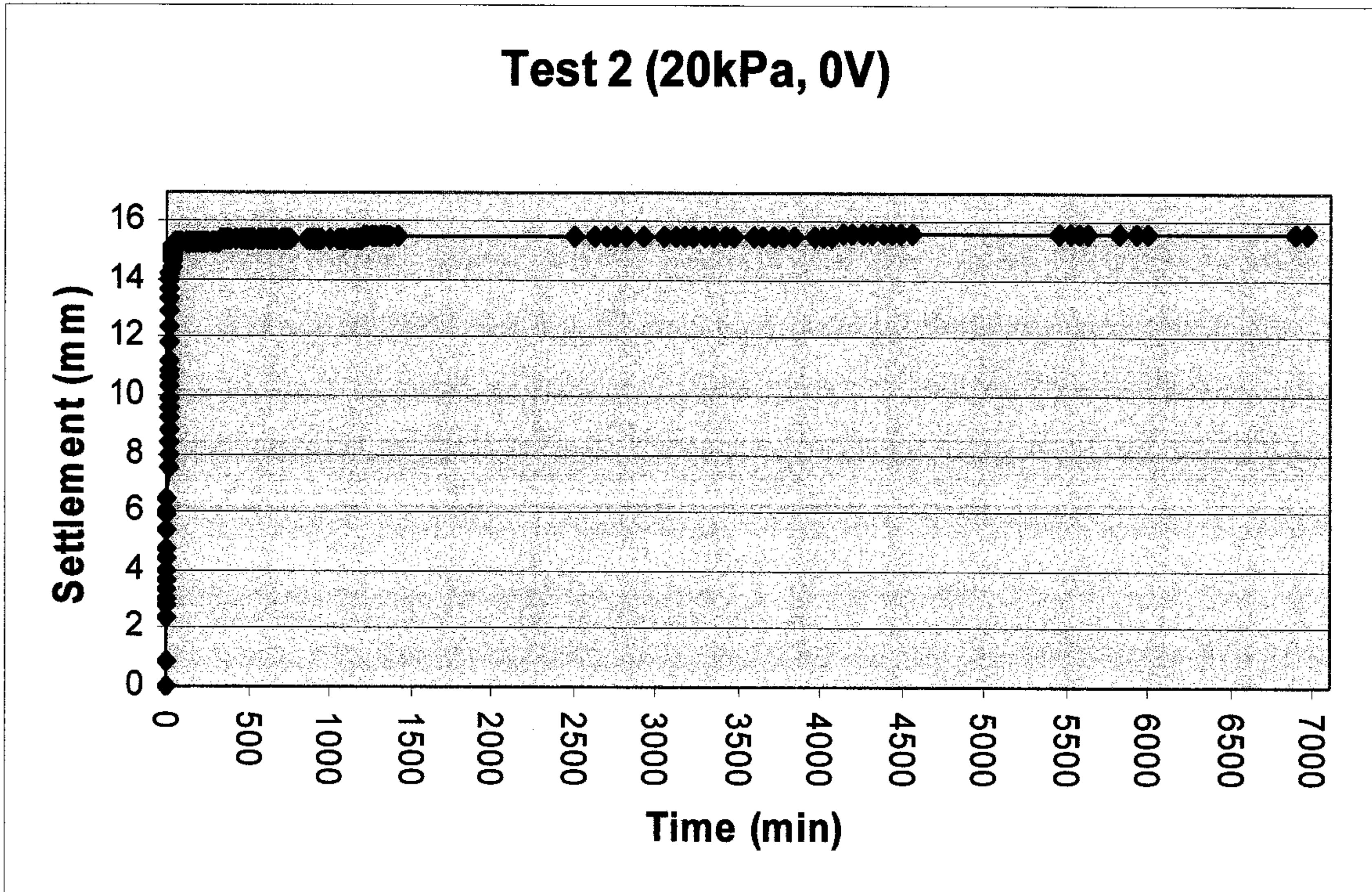
Time secs	Time min	L1 mm	Settlement mm	Time secs	Time min	L1 mm	Settlement mm
0	0.0	41.74	**0**	2340	39.0	29.38	**12.36**
30	0.5	41.02	**0.72**	2400	40.0	29.34	**12.40**
60	1.0	40.48	**1.26**	2460	41.0	29.32	**12.42**
90	1.5	39.99	**1.75**	2520	42.0	29.29	**12.45**
120	2.0	39.55	**2.19**	2580	43.0	29.26	**12.48**
150	2.5	39.16	**2.58**	2640	44.0	29.25	**12.49**
180	3.0	38.76	**2.98**	2700	45.0	29.22	**12.52**
210	3.5	38.41	**3.33**	2760	46.0	29.20	**12.54**
240	4.0	38.08	**3.66**	2820	47.0	29.18	**12.56**
270	4.5	37.76	**3.98**	2880	48.0	29.17	**12.57**
300	5.0	37.45	**4.29**	2940	49.0	29.16	**12.58**
360	6.0	36.90	**4.84**	3000	50.0	29.14	**12.60**
420	7.0	36.35	**5.39**	3060	51.0	29.13	**12.61**
480	8.0	35.83	**5.91**	3120	52.0	29.12	**12.62**
540	9.0	35.35	**6.39**	3180	53.0	29.10	**12.64**
600	10.0	34.89	**6.85**	3240	54.0	29.10	**12.64**
660	11.0	34.46	**7.28**	4440	74.0	28.99	**12.75**
720	12.0	34.04	**7.70**	5640	94.0	28.96	**12.78**
780	13.0	33.64	**8.10**	6840	114.0	28.93	**12.81**
840	14.0	33.26	**8.48**	8040	134.0	28.92	**12.82**
900	15.0	32.90	**8.84**	9240	154.0	28.90	**12.84**
960	16.0	32.56	**9.18**	10440	174.0	28.89	**12.85**
1020	17.0	32.24	**9.50**	11640	194.0	28.89	**12.85**
1080	18.0	31.95	**9.79**	12840	214.0	28.88	**12.86**
1140	19.0	31.67	**10.07**	14040	234.0	28.88	**12.86**
1200	20.0	31.41	**10.33**	15240	254.0	28.88	**12.86**
1260	21.0	31.18	**10.56**	16440	274.0	28.87	**12.87**
1320	22.0	30.97	**10.77**	17640	294.0	28.87	**12.87**
1380	23.0	30.78	**10.96**	18840	314.0	28.87	**12.87**
1440	24.0	30.60	**11.14**	20040	334.0	28.86	**12.88**
1500	25.0	30.44	**11.30**	21240	354.0	28.86	**12.88**
1560	26.0	30.30	**11.44**	22440	374.0	28.86	**12.88**
1620	27.0	30.17	**11.57**	23640	394.0	28.86	**12.88**
1680	28.0	30.06	**11.68**	24840	414.0	28.86	**12.88**
1740	29.0	29.96	**11.78**	26040	434.0	28.86	**12.88**
1800	30.0	29.87	**11.87**	27240	454.0	28.85	**12.89**
1860	31.0	29.79	**11.95**	28440	474.0	28.85	**12.89**
1920	32.0	29.72	**12.02**	29640	494.0	28.85	**12.89**
1980	33.0	29.65	**12.09**	30840	514.0	28.85	**12.89**
2040	34.0	29.59	**12.15**	32040	534.0	28.85	**12.89**
2100	35.0	29.54	**12.20**	33240	554.0	28.84	**12.90**
2160	36.0	29.49	**12.25**	34440	574.0	28.84	**12.90**
2220	37.0	29.44	**12.30**	35640	594.0	28.84	**12.90**
2280	38.0	29.41	**12.33**	36840	614.0	28.84	**12.90**

Time	Time	L1	Settlement
secs	min	mm	mm
38040	634.0	28.84	**12.90**
39240	654.0	28.84	**12.90**
40440	674.0	28.84	**12.90**
41640	694.0	28.84	**12.90**
42840	714.0	28.84	**12.90**
44040	734.0	28.84	**12.90**
45240	754.0	28.84	**12.90**
46440	774.0	28.84	**12.90**
47640	794.0	28.84	**12.90**
48840	814.0	28.84	**12.90**
50040	834.0	28.84	**12.90**
51240	854.0	28.84	**12.90**
52440	874.0	28.84	**12.90**
53640	894.0	28.83	**12.91**
54840	914.0	28.83	**12.91**
56040	934.0	28.83	**12.91**
57240	954.0	28.83	**12.91**
58440	974.0	28.83	**12.91**
59640	994.0	28.82	**12.92**
60840	1014.0	28.82	**12.92**
62040	1034.0	28.82	**12.92**
63240	1054.0	28.82	**12.92**
64440	1074.0	28.81	**12.93**
65640	1094.0	28.81	**12.93**
68040	1134.0	28.81	**12.93**
69240	1154.0	28.81	**12.93**
70440	1174.0	28.81	**12.93**
71640	1194.0	28.81	**12.93**
72840	1214.0	28.81	**12.93**
74040	1234.0	28.81	**12.93**
75240	1254.0	28.81	**12.93**
76440	1274.0	28.80	**12.94**
77640	1294.0	28.80	**12.94**
78840	1314.0	28.80	**12.94**
80040	1334.0	28.80	**12.94**
81240	1354.0	28.80	**12.94**
86040	1434.0	28.80	**12.94**
93240	1554.0	28.80	**12.94**
96840	1614.0	28.80	**12.94**
100440	1674.0	28.80	**12.94**
104040	1734.0	28.80	**12.94**
107640	1794.0	28.80	**12.94**
111240	1854.0	28.79	**12.95**
125640	2094.0	28.79	**12.95**


Test 1 (10kPa, 0V)
Settlement (mm)
14
12
10
8
6
4
2
0
0
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
Time (min)

Test 2 (20kPa, 0V)

Time secs	Time min	L1 mm	Settlement mm	Time secs	Time min	L1 mm	Settlement mm
0	0	51.58	**0.00**	2340	39	23.24	**15.15**
30	0.5	49.13	**0.82**	2400	40	23.23	**15.16**
60	1	47.60	**2.36**	2460	41	23.22	**15.17**
90	1.5	46.35	**2.85**	2520	42	23.22	**15.17**
120	2	45.27	**3.29**	2580	43	23.21	**15.18**
150	2.5	44.29	**3.68**	2640	44	23.19	**15.20**
180	3	43.38	**3.00**	2760	46	23.19	**15.20**
210	3.5	42.54	**4.43**	2820	47	23.18	**15.21**
240	4	41.74	**4.76**	3000	50	23.18	**15.21**
270	4.5	40.98	**4.00**	3060	51	23.17	**15.22**
300	5	40.26	**5.39**	3180	53	23.16	**15.23**
360	6	39.91	**5.94**	3240	54	23.16	**15.23**
420	7	38.65	**6.49**	4440	74	23.13	**15.26**
480	8	37.47	**6.00**	5640	94	23.11	**15.28**
540	9	36.34	**7.49**	6840	114	23.11	**15.28**
600	10	35.24	**7.95**	8040	134	23.09	**15.30**
660	11	34.33	**8.38**	9240	154	23.08	**15.31**
720	12	33.18	**8.80**	10440	174	23.08	**15.31**
780	13	32.18	**9.20**	11640	194	23.08	**15.31**
840	14	31.28	**9.58**	12840	214	23.08	**15.31**
900	15	30.39	**9.94**	14040	234	23.06	**15.33**
960	16	29.53	**10.28**	15240	254	23.06	**15.33**
1020	17	28.72	**10.60**	16440	274	23.06	**15.33**
1080	18	27.95	**10.89**	17640	294	23.06	**15.33**
1140	19	27.22	**11.17**	18840	314	23.06	**15.33**
1200	20	26.57	**11.82**	20040	334	23.05	**15.34**
1260	21	25.98	**12.41**	21240	354	23.04	**15.35**
1320	22	25.49	**12.90**	22440	374	23.04	**15.35**
1380	23	25.04	**13.35**	23640	394	23.04	**15.35**
1440	24	24.68	**13.71**	24840	414	23.03	**15.36**
1500	25	24.37	**14.02**	27240	454	23.03	**15.36**
1560	26	24.14	**14.25**	28440	474	23.03	**15.36**
1620	27	23.94	**14.45**	29640	494	23.03	**15.36**
1680	28	23.78	**14.61**	30840	514	23.02	**15.37**
1740	29	23.66	**14.73**	32040	534	23.02	**15.37**
1800	30	23.57	**14.82**	33240	554	23.02	**15.37**
1860	31	23.50	**14.89**	34440	574	23.02	**15.37**
1920	32	23.43	**14.96**	35640	594	23.02	**15.37**
1980	33	23.38	**15.01**	36840	614	23.02	**15.37**
2040	34	23.35	**15.04**	38040	634	23.02	**15.37**
2100	35	23.32	**15.07**	39240	654	23.01	**15.38**
2160	36	23.30	**15.09**	40440	674	23.01	**15.38**
2220	37	23.27	**15.12**	41640	694	23.01	**15.38**
2280	38	23.25	**15.14**	42840	714	23.00	**15.39**

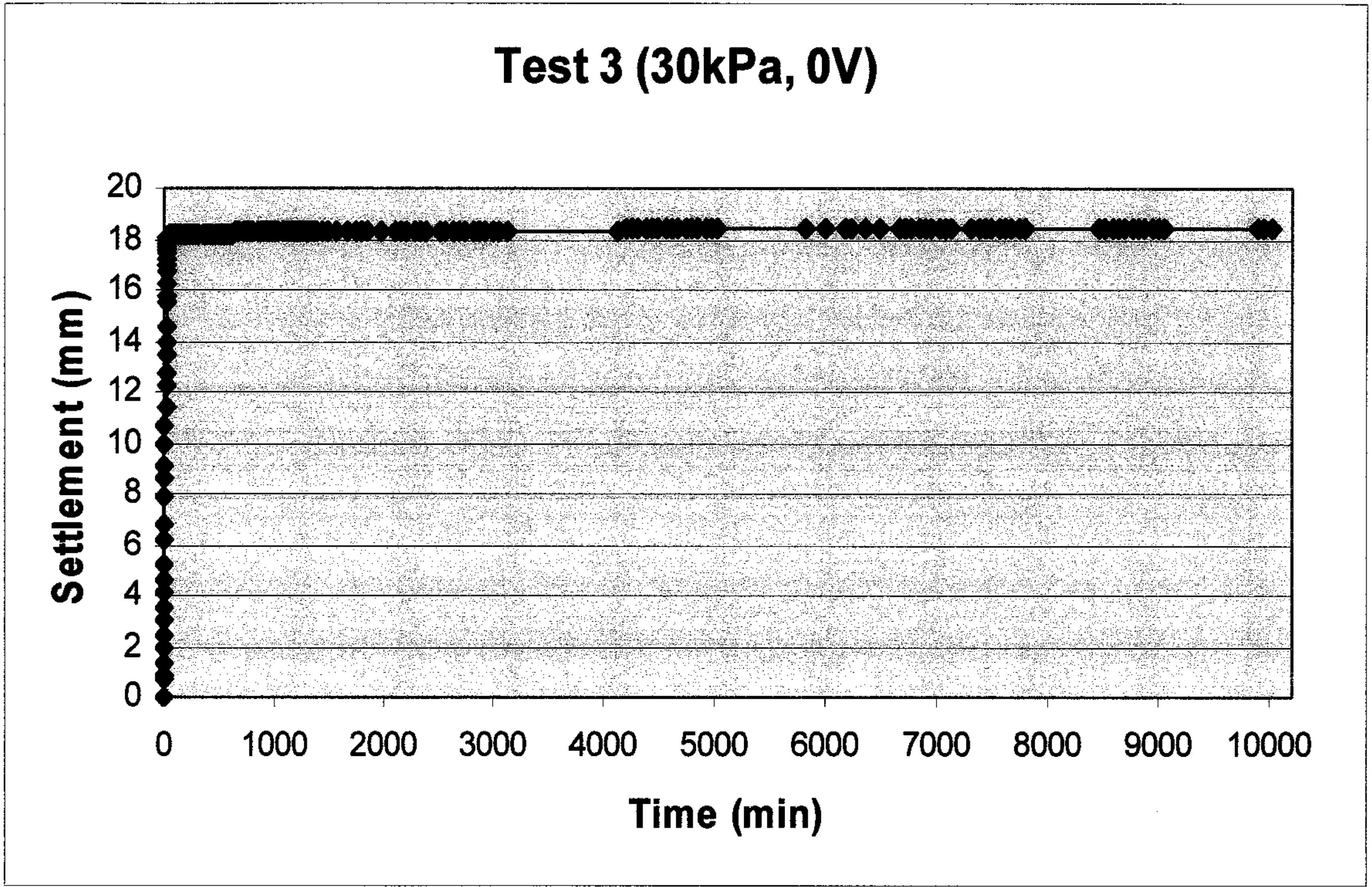

Test 2 (20kPa, 0V)
Settlement (mm)
0
2
4
6
8
10
12
14
16
Time (min)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000

Test 3 (30kPa, 0V)

Time secs	Time min	L1 mm	Settlement mm	Time secs	Time min	L1 mm	Settlement mm
0	0	44.75	**0.00**	2340	39	16.44	**18.13**
30	0.5	42.45	**0.85**	2400	40	16.44	**18.13**
60	1	40.91	**0.74**	2460	41	16.43	**18.14**
90	1.5	39.63	**1.28**	2520	42	16.42	**18.15**
120	2	38.52	**1.89**	2580	43	16.41	**18.16**
150	2.5	37.54	**2.48**	2640	44	16.41	**18.16**
180	3	36.63	**3.03**	2700	45	16.40	**18.17**
210	3.5	35.77	**3.57**	2760	46	16.40	**18.17**
240	4	34.95	**4.07**	2820	47	16.40	**18.17**
270	4.5	34.18	**4.56**	2880	48	16.40	**18.17**
300	5	33.45	**5.21**	2940	49	16.39	**18.18**
360	6	32.08	**6.20**	3000	50	16.39	**18.18**
420	7	30.80	**6.80**	3120	52	16.39	**18.18**
480	8	29.58	**7.83**	3180	53	16.38	**18.19**
540	9	28.42	**8.60**	3240	54	16.38	**18.19**
600	10	27.31	**9.14**	4440	74	16.37	**18.20**
660	11	26.25	**10.00**	5640	94	16.36	**18.21**
720	12	25.24	**10.69**	6840	114	16.36	**18.21**
780	13	24.26	**11.34**	8040	134	16.35	**18.22**
840	14	23.33	**12.29**	9240	154	16.34	**18.23**
900	15	22.43	**12.71**	10440	174	16.34	**18.23**
960	16	21.57	**13.41**	11640	194	16.34	**18.23**
1020	17	20.76	**14.00**	12840	214	16.34	**18.23**
1080	18	20.02	**14.59**	14040	234	16.34	**18.23**
1140	19	19.36	**15.46**	15240	254	16.33	**18.24**
1200	20	18.79	**15.78**	17640	294	16.33	**18.24**
1260	21	18.31	**16.26**	18840	314	16.33	**18.24**
1320	22	17.90	**16.67**	21240	354	16.33	**18.24**
1380	23	17.57	**17.00**	22440	374	16.33	**18.24**
1440	24	17.31	**17.26**	24840	414	16.33	**18.24**
1500	25	17.11	**17.46**	26040	434	16.33	**18.24**
1560	26	16.95	**17.62**	27240	454	16.33	**18.24**
1620	27	16.83	**17.74**	29640	494	16.33	**18.24**
1680	28	16.74	**17.83**	30840	514	16.33	**18.24**
1740	29	16.67	**17.90**	32040	534	16.33	**18.24**
1800	30	16.62	**17.95**	33240	554	16.33	**18.24**
1860	31	16.57	**18.00**	34440	574	16.33	**18.24**
1920	32	16.54	**18.03**	35640	594	16.33	**18.24**
1980	33	16.52	**18.05**	36840	614	16.33	**18.24**
2040	34	16.50	**18.07**	38040	634	16.32	**18.25**
2100	35	16.48	**18.09**	39240	654	16.32	**18.25**
2160	36	16.46	**18.11**	42840	714	16.32	**18.25**
2220	37	16.46	**18.11**	45240	754	16.32	**18.25**
2280	38	16.45	**18.12**	46440	774	16.32	**18.25**

Time	Time	L1	Settlement	Time	Time	L1	Settlement
secs	min	mm	mm	secs	min	mm	mm
47640	794	16.32	**18.25**	165240	2754	16.24	**18.33**
50040	834	16.32	**18.25**	168840	2814	16.24	**18.33**
51240	854	16.32	**18.25**	172440	2874	16.24	**18.33**
52440	874	16.32	**18.25**	176040	2934	16.23	**18.34**
53640	894	16.32	**18.25**	179640	2994	16.23	**18.34**
54840	914	16.32	**18.25**	183240	3054	16.23	**18.34**
56040	934	16.32	**18.25**	186840	3114	16.22	**18.35**
57240	954	16.32	**18.25**	248040	4134	16.21	**18.36**
58440	974	16.32	**18.25**	251640	4194	16.20	**18.37**
59640	994	16.32	**18.25**	255240	4254	16.20	**18.37**
60840	1014	16.31	**18.26**	258840	4314	16.20	**18.37**
64440	1074	16.31	**18.26**	262440	4374	16.20	**18.37**
65640	1094	16.31	**18.26**	266040	4434	16.20	**18.37**
68040	1134	16.31	**18.26**	269640	4494	16.20	**18.37**
69240	1154	16.31	**18.26**	273240	4554	16.20	**18.37**
70440	1174	16.31	**18.26**	276840	4614	16.20	**18.37**
71640	1194	16.29	**18.28**	280440	4674	16.20	**18.37**
72840	1214	16.29	**18.28**	284040	4734	16.20	**18.37**
74040	1234	16.27	**18.30**	287640	4794	16.20	**18.37**
75240	1254	16.27	**18.30**	291240	4854	16.20	**18.37**
77640	1294	16.27	**18.30**	294840	4914	16.20	**18.37**
78840	1314	16.27	**18.30**	298440	4974	16.20	**18.37**
80040	1334	16.27	**18.30**	302040	5034	16.19	**18.38**
81240	1354	16.27	**18.30**	348840	5814	16.19	**18.38**
82440	1374	16.27	**18.30**	359640	5994	16.19	**18.38**
83640	1394	16.26	**18.31**	370440	6174	16.19	**18.38**
86040	1434	16.26	**18.31**	374040	6234	16.19	**18.38**
89640	1494	16.26	**18.31**	381240	6354	16.19	**18.38**
93240	1554	16.26	**18.31**	388440	6474	16.19	**18.38**
100440	1674	16.26	**18.31**	399240	6654	16.19	**18.38**
104040	1734	16.26	**18.31**	402840	6714	16.19	**18.38**
107640	1794	16.26	**18.31**	406440	6774	16.19	**18.38**
111240	1854	16.26	**18.31**	410040	6834	16.19	**18.38**
118440	1974	16.26	**18.31**	413640	6894	16.19	**18.38**
125640	2094	16.26	**18.31**	417240	6954	16.18	**18.39**
129240	2154	16.26	**18.31**	420840	7014	16.16	**18.41**
132840	2214	16.26	**18.31**	424440	7074	16.15	**18.42**
136440	2274	16.26	**18.31**	428040	7134	16.14	**18.43**
140040	2334	16.26	**18.31**	438840	7314	16.14	**18.43**
143640	2394	16.26	**18.31**	442440	7374	16.14	**18.43**
150840	2514	16.26	**18.31**	446040	7434	16.14	**18.43**
154440	2574	16.26	**18.31**	449640	7494	16.14	**18.43**
158040	2634	16.26	**18.31**	453240	7554	16.14	**18.43**
161640	2694	16.25	**18.32**	456840	7614	16.14	**18.43**
				460440	7674	16.14	**18.43**

Time	Time	L1	Settlement
secs	min	mm	mm
464040	7734	16.14	**18.43**
467640	7794	16.14	**18.43**
507240	8454	16.13	**18.44**
510840	8514	16.13	**18.44**
514440	8574	16.13	**18.44**
518040	8634	16.13	**18.44**
521640	8694	16.13	**18.44**
525240	8754	16.13	**18.44**
528840	8814	16.13	**18.44**
532440	8874	16.13	**18.44**
536040	8934	16.10	**18.47**
539640	8994	16.10	**18.47**
543240	9054	16.10	**18.47**
593640	9894	16.09	**18.48**
597240	9954	16.09	**18.48**
600840	10014	16.09	**18.48**

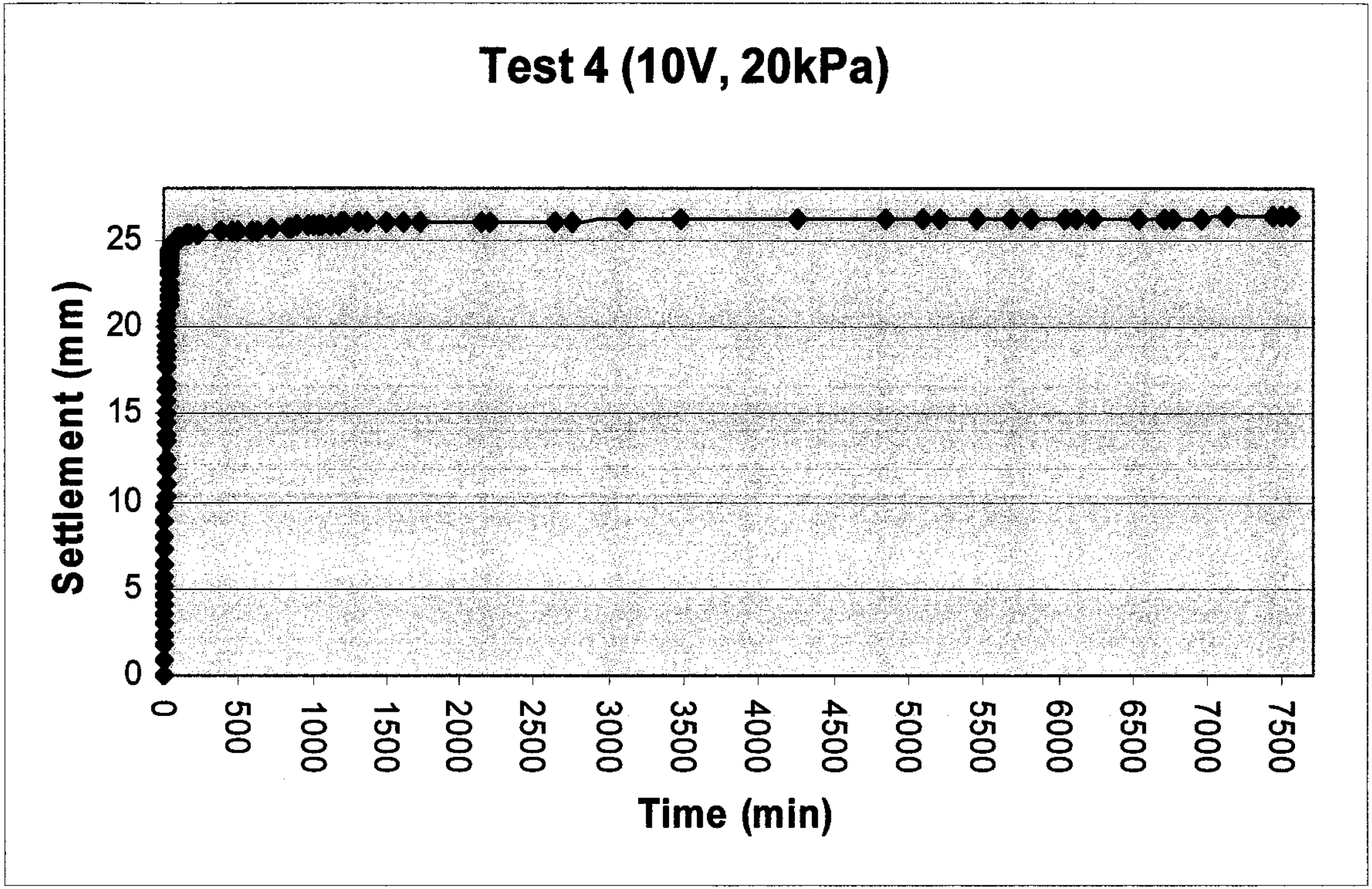


Test 3 (30kPa, 0V)
Settlement (mm)
20
18
16
14
12
10
8
6
4
2
0
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Time (min)

Test 4 (10V, 20kPa)

Time secs	Time min	L1 mm	Settlement mm	Time secs	Time min	L1 mm	Settlement mm
0	0	46.79	**0**	2460	41	22.95	**23.84**
30	0.5	45.84	**0.95**	2520	42	22.86	**23.93**
60	1	44.95	**1.84**	2580	43	22.78	**24.01**
90	1.5	44.41	**2.38**	2640	44	22.72	**24.07**
120	2	43.80	**2.99**	2700	45	22.59	**24.20**
150	2.5	43.21	**3.58**	2760	46	22.27	**24.52**
180	3	42.66	**4.13**	2940	49	22.13	**24.66**
210	3.5	42.12	**4.67**	3180	53	22.02	**24.77**
240	4	41.62	**5.17**	4440	74	22.02	**24.77**
270	4.5	41.13	**5.66**	5640	94	21.61	**25.18**
300	5	40.48	**6.31**	6840	114	21.54	**25.25**
360	6	39.49	**7.30**	9240	154	21.49	**25.30**
420	7	38.89	**7.90**	10440	174	21.47	**25.32**
480	8	37.86	**8.93**	14040	234	21.41	**25.38**
540	9	37.09	**9.70**	22440	374	21.31	**25.48**
600	10	36.55	**10.24**	27240	454	21.27	**25.52**
660	11	35.78	**11.01**	29640	494	21.25	**25.54**
720	12	35.00	**11.79**	35640	594	21.21	**25.58**
780	13	34.35	**12.44**	38040	634	21.20	**25.59**
840	14	33.40	**13.39**	42840	714	21.18	**25.61**
900	15	32.98	**13.81**	50040	834	21.13	**25.66**
960	16	32.28	**14.51**	51240	854	21.09	**25.70**
1020	17	31.70	**15.09**	53640	894	20.99	**25.80**
1080	18	31.10	**15.69**	58440	974	20.90	**25.89**
1140	19	30.23	**16.56**	60840	1014	20.88	**25.91**
1200	20	29.91	**16.88**	63240	1054	20.86	**25.93**
1260	21	29.06	**17.73**	64440	1074	20.85	**25.94**
1320	22	28.51	**18.28**	66840	1114	20.83	**25.96**
1380	23	28.27	**18.52**	70440	1174	20.83	**25.96**
1440	24	27.74	**19.05**	71640	1194	20.80	**25.99**
1500	25	27.28	**19.51**	72840	1214	20.79	**26.00**
1560	26	26.80	**19.99**	78840	1314	20.77	**26.02**
1620	27	26.37	**20.42**	82440	1374	20.77	**26.02**
1680	28	26.00	**20.79**	89640	1494	20.76	**26.03**
1740	29	25.60	**21.19**	96840	1614	20.75	**26.04**
1800	30	25.24	**21.55**	104040	1734	20.72	**26.07**
1860	31	24.93	**21.86**	129240	2154	20.71	**26.08**
1920	32	24.61	**22.18**	132840	2214	20.70	**26.09**
1980	33	24.37	**22.42**	158040	2634	20.67	**26.12**
2040	34	23.82	**22.97**	165240	2754	20.67	**26.12**
2100	35	23.59	**23.20**	186840	3114	20.63	**26.16**
2220	37	23.23	**23.56**	208440	3474	20.63	**26.16**
2340	39	23.21	**23.58**	255240	4254	20.61	**26.18**
2400	40	23.08	**23.71**	291240	4854	20.57	**26.22**

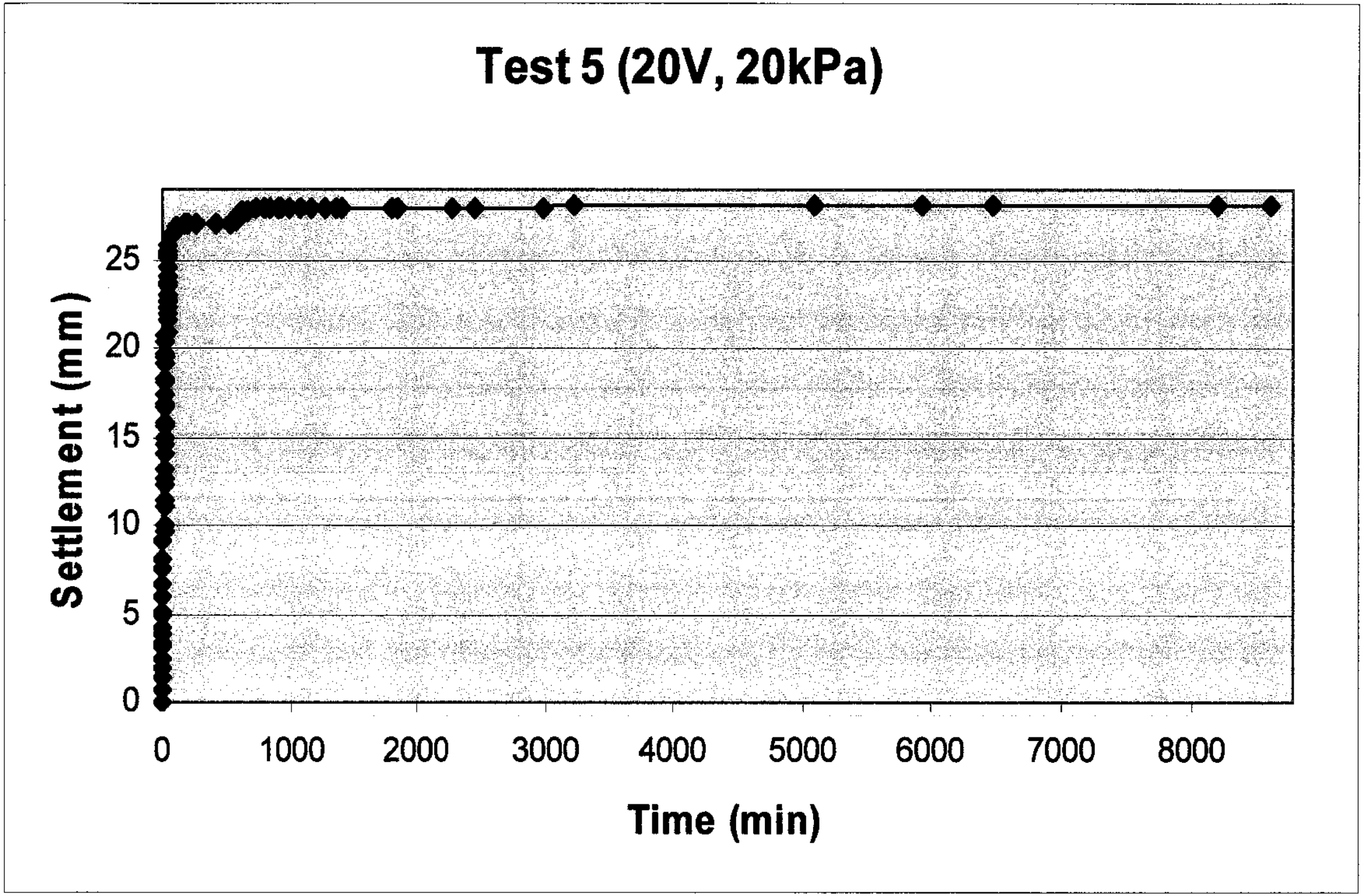
Time	Time	L1	Settlement
secs	min	mm	mm
305640	5094	20.57	**26.22**
312840	5214	20.57	**26.22**
327240	5454	20.56	**26.23**
341640	5694	20.56	**26.23**
348840	5814	20.53	**26.26**
363240	6054	20.53	**26.26**
366840	6114	20.53	**26.26**
374040	6234	20.53	**26.26**
392040	6534	20.53	**26.26**
402840	6714	20.53	**26.26**
406440	6774	20.52	**26.27**
417240	6954	20.49	**26.30**
428040	7134	20.47	**26.32**
446040	7434	20.45	**26.34**
449640	7494	20.45	**26.34**
453240	7554	20.44	**26.35**


Test 4 (10V, 20kPa)
Settlement (mm)
0
5
10
15
20
25
Time (min)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
5500
6000
6500
7000
7500

Test 5 (20V, 20kPa)

Time secs	Time min	L1 mm	Settlement mm	Time secs	Time min	L1 mm	Settlement mm
0	0	38.15	**0**	2340	39	15.18	**22.97**
30	0.5	37.42	**0.73**	2400	40	14.55	**23.60**
60	1	36.83	**1.32**	2520	42	14.35	**23.80**
90	1.5	36.24	**1.91**	2580	43	14.13	**24.02**
120	2	35.74	**2.41**	2640	44	13.61	**24.54**
150	2.5	35.01	**3.14**	2760	46	13.54	**24.61**
180	3	34.76	**3.39**	2820	47	13.06	**25.09**
210	3.5	34.30	**3.85**	2940	49	13.02	**25.13**
240	4	33.90	**4.25**	3000	50	12.95	**25.20**
270	4.5	33.17	**4.98**	3060	51	12.83	**25.32**
300	5	32.99	**5.16**	3120	52	12.74	**25.41**
360	6	32.19	**5.96**	3180	53	12.63	**25.52**
420	7	31.43	**6.72**	3240	54	12.24	**25.91**
480	8	30.52	**7.63**	4440	74	11.78	**26.37**
540	9	30.00	**8.15**	5640	94	11.66	**26.49**
600	10	29.04	**9.11**	6840	114	11.21	**26.94**
660	11	28.40	**9.75**	10440	174	11.12	**27.03**
720	12	28.05	**10.10**	11640	194	11.11	**27.04**
780	13	27.00	**11.15**	15240	254	11.10	**27.05**
840	14	26.66	**11.49**	16440	274	11.08	**27.07**
900	15	25.79	**12.36**	24840	414	11.08	**27.07**
960	16	25.51	**12.64**	32040	534	11.07	**27.08**
1020	17	24.95	**13.20**	33240	554	10.91	**27.24**
1080	18	24.08	**14.07**	34440	574	10.82	**27.33**
1140	19	23.53	**14.62**	35640	594	10.68	**27.47**
1200	20	23.28	**14.87**	36840	614	10.34	**27.81**
1260	21	22.48	**15.67**	39240	654	10.32	**27.83**
1320	22	22.26	**15.89**	42840	714	10.27	**27.88**
1380	23	21.47	**16.68**	47640	794	10.25	**27.90**
1440	24	21.25	**16.90**	50040	834	10.24	**27.91**
1500	25	20.79	**17.36**	53640	894	10.23	**27.92**
1560	26	19.99	**18.16**	54840	914	10.20	**27.95**
1620	27	19.83	**18.32**	59640	994	10.19	**27.96**
1680	28	19.06	**19.09**	64440	1074	10.19	**27.96**
1740	29	18.61	**19.54**	69240	1154	10.19	**27.96**
1800	30	18.48	**19.67**	76440	1274	10.18	**27.97**
1860	31	17.74	**20.41**	81240	1354	10.15	**28.00**
1920	32	17.33	**20.82**	84840	1414	10.15	**28.00**
1980	33	17.23	**20.92**	107640	1794	10.15	**28.00**
2040	34	16.54	**21.61**	111240	1854	10.14	**28.01**
2100	35	16.17	**21.98**	136440	2274	10.14	**28.01**
2160	36	16.14	**22.01**	147240	2454	10.12	**28.03**
2220	37	15.77	**22.38**	179640	2994	10.12	**28.03**
2280	38	15.45	**22.70**	194040	3234	10.11	**28.04**

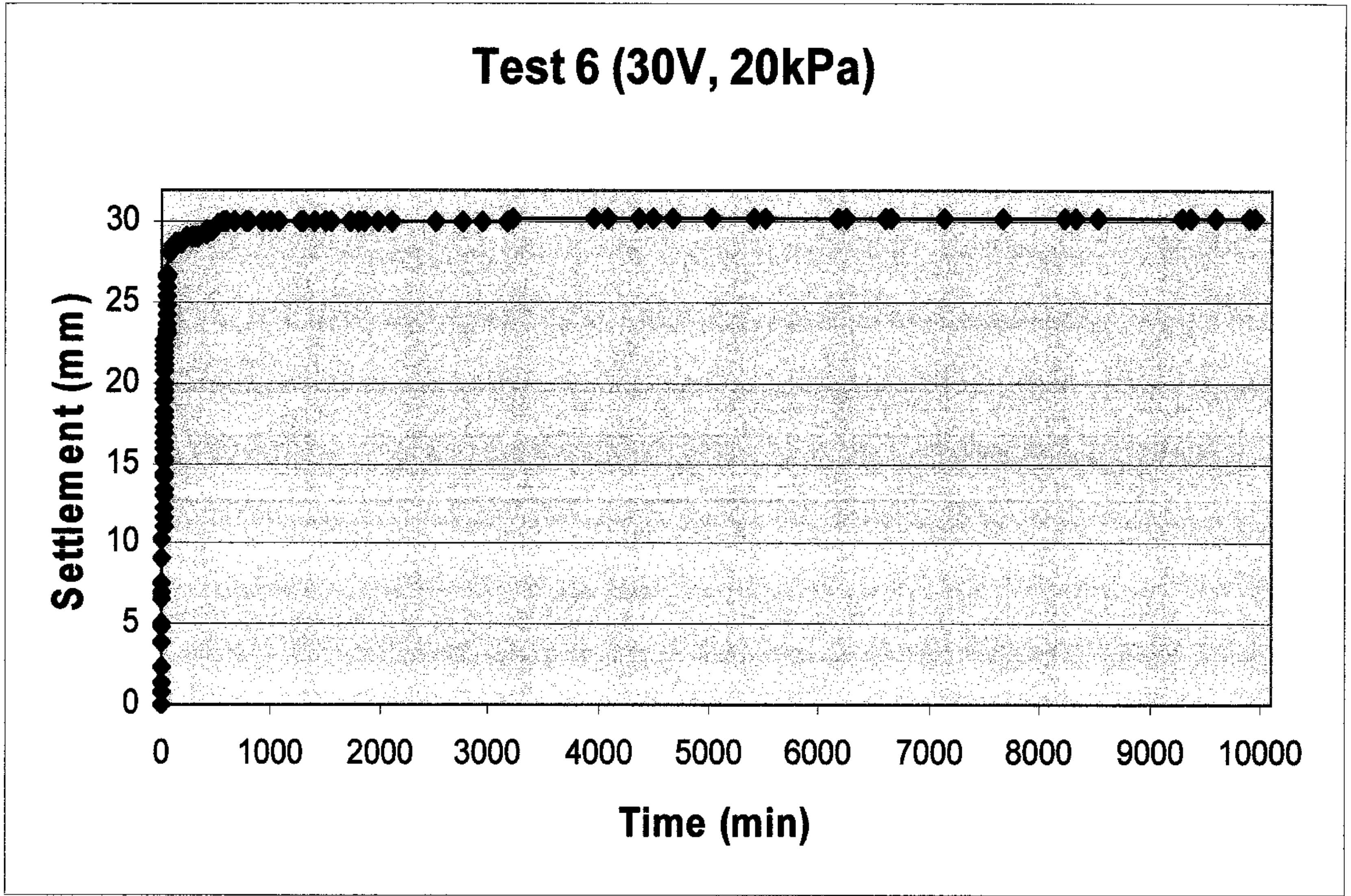
Time	Time	L1	Settlement
secs	min	mm	mm
305640	5094	10.11	**28.04**
356040	5934	10.11	**28.04**
388440	6474	10.09	**28.06**
492840	8214	10.09	**28.06**
518040	8634	10.07	**28.08**


Test 5 (20V, 20kPa)
Settlement (mm)
0
5
10
15
20
25
0
1000
2000
3000
4000
5000
6000
7000
8000
Time (min)

Test 6 (30V, 20kPa)

Time secs	Time min	L1 mm	Settlement mm	Time secs	Time min	L1 mm	Settlement mm
0	0	39.00	**0**	2640	44	14.10	**24.90**
30	0.5	38.13	**0.87**	2760	46	13.56	**25.44**
60	1	37.56	**1.44**	2880	48	13.09	**25.91**
90	1.5	36.60	**2.40**	3000	50	12.99	**26.01**
120	2	35.09	**3.91**	3060	51	12.50	**26.50**
150	2.5	34.18	**4.82**	3180	53	12.48	**26.52**
180	3	33.99	**5.01**	3240	54	12.31	**26.69**
210	3.5	32.50	**6.50**	4440	74	10.91	**28.09**
360	6	32.10	**6.90**	5640	94	10.56	**28.44**
480	8	31.42	**7.58**	6840	114	10.44	**28.56**
600	10	29.83	**9.17**	8040	134	10.39	**28.61**
660	11	29.82	**9.18**	9240	154	10.34	**28.66**
720	12	28.74	**10.26**	10440	174	10.32	**28.68**
780	13	27.91	**11.09**	11640	194	10.02	**28.98**
840	14	27.28	**11.72**	14040	234	9.99	**29.01**
900	15	26.73	**12.27**	16440	274	9.99	**29.01**
960	16	25.95	**13.05**	17640	294	9.99	**29.01**
1020	17	25.67	**13.33**	18840	314	9.98	**29.02**
1080	18	24.89	**14.11**	20040	334	9.98	**29.02**
1140	19	24.62	**14.38**	23640	394	9.74	**29.26**
1200	20	23.88	**15.12**	24840	414	9.61	**29.39**
1260	21	23.62	**15.38**	26040	434	9.51	**29.49**
1320	22	23.16	**15.84**	27240	454	9.44	**29.56**
1380	23	22.66	**16.34**	28440	474	9.40	**29.60**
1440	24	22.19	**16.81**	29640	494	9.39	**29.61**
1500	25	21.70	**17.30**	30840	514	9.06	**29.94**
1560	26	21.23	**17.77**	33240	554	9.03	**29.97**
1620	27	20.77	**18.23**	34440	574	9.03	**29.97**
1680	28	20.07	**18.93**	39240	654	8.99	**30.01**
1740	29	19.62	**19.38**	45240	754	8.99	**30.01**
1800	30	19.45	**19.55**	47640	794	8.96	**30.04**
1860	31	19.02	**19.98**	54840	914	8.94	**30.06**
1920	32	18.32	**20.68**	59640	994	8.93	**30.07**
1980	33	17.93	**21.07**	64440	1074	8.92	**30.08**
2040	34	17.80	**21.20**	76440	1274	8.92	**30.08**
2100	35	17.42	**21.58**	77640	1294	8.90	**30.10**
2160	36	17.03	**21.97**	83640	1394	8.90	**30.10**
2220	37	16.67	**22.33**	89640	1494	8.90	**30.10**
2280	38	16.30	**22.70**	93240	1554	8.89	**30.11**
2340	39	15.96	**23.04**	104040	1734	8.89	**30.11**
2400	40	15.64	**23.36**	107640	1794	8.89	**30.11**
2460	41	15.32	**23.68**	111240	1854	8.89	**30.11**
2520	42	14.70	**24.30**	118440	1974	8.89	**30.11**
2580	43	14.68	**24.32**	125640	2094	8.88	**30.12**

Time	Time	L1	Settlement
secs	min	mm	mm
150840	2514	8.88	**30.12**
165240	2754	8.87	**30.13**
176040	2934	8.85	**30.15**
190440	3174	8.85	**30.15**
194040	3234	8.84	**30.16**
237240	3954	8.84	**30.16**
244440	4074	8.83	**30.17**
262440	4374	8.83	**30.17**
269640	4494	8.83	**30.17**
280440	4674	8.81	**30.19**
302040	5034	8.81	**30.19**
323640	5394	8.81	**30.19**
330840	5514	8.81	**30.19**
370440	6174	8.81	**30.19**
374040	6234	8.81	**30.19**
395640	6594	8.81	**30.19**
399240	6654	8.81	**30.19**
428040	7134	8.79	**30.21**
460440	7674	8.79	**30.21**
492840	8214	8.79	**30.21**
500040	8334	8.79	**30.21**
510840	8514	8.79	**30.21**
557640	9294	8.79	**30.21**
561240	9354	8.79	**30.21**
575640	9594	8.79	**30.21**
593640	9894	8.79	**30.21**
597240	9954	8.79	**30.21**


Test 6 (30V, 20kPa)
Settlement (mm)
0
5
10
15
20
25
30
Time (min)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000

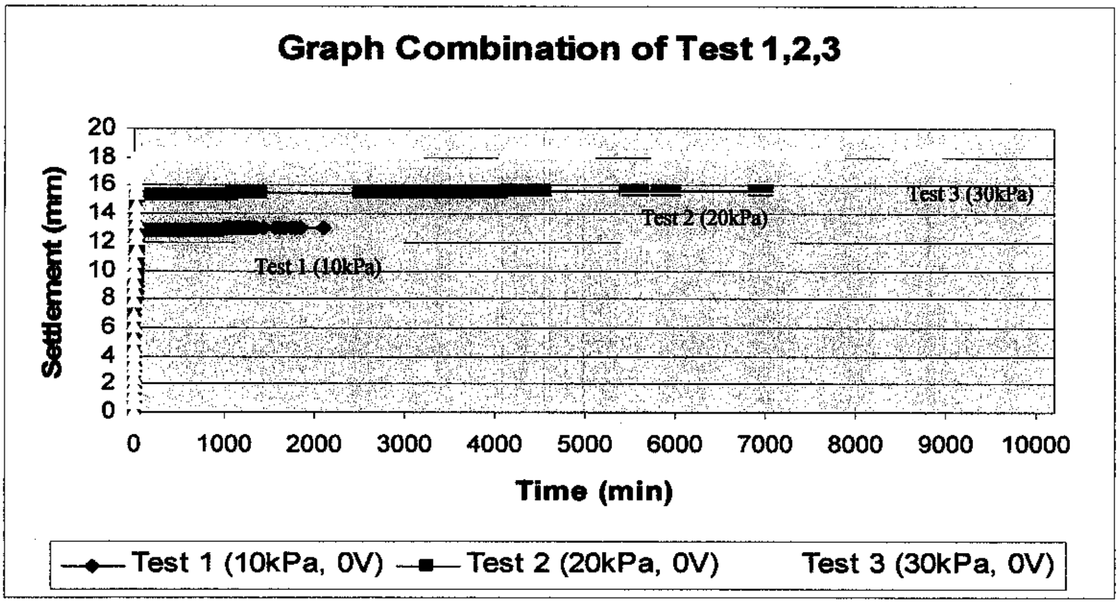


Figure 1: Test 1, 2, 3 (without voltage)

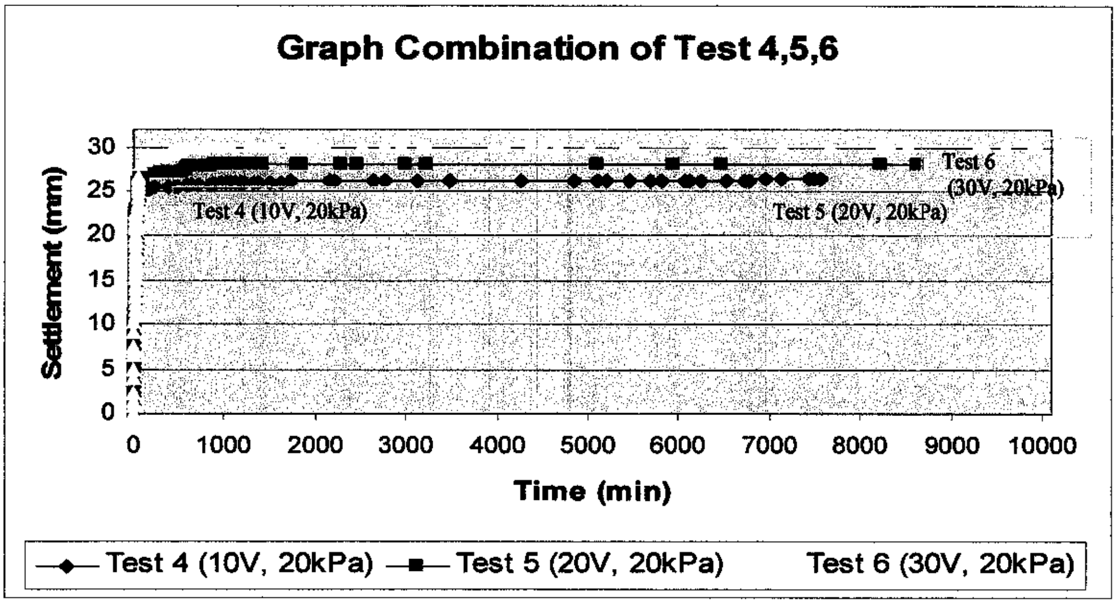


Figure 2: Test 4, 5, 6 (with voltage)

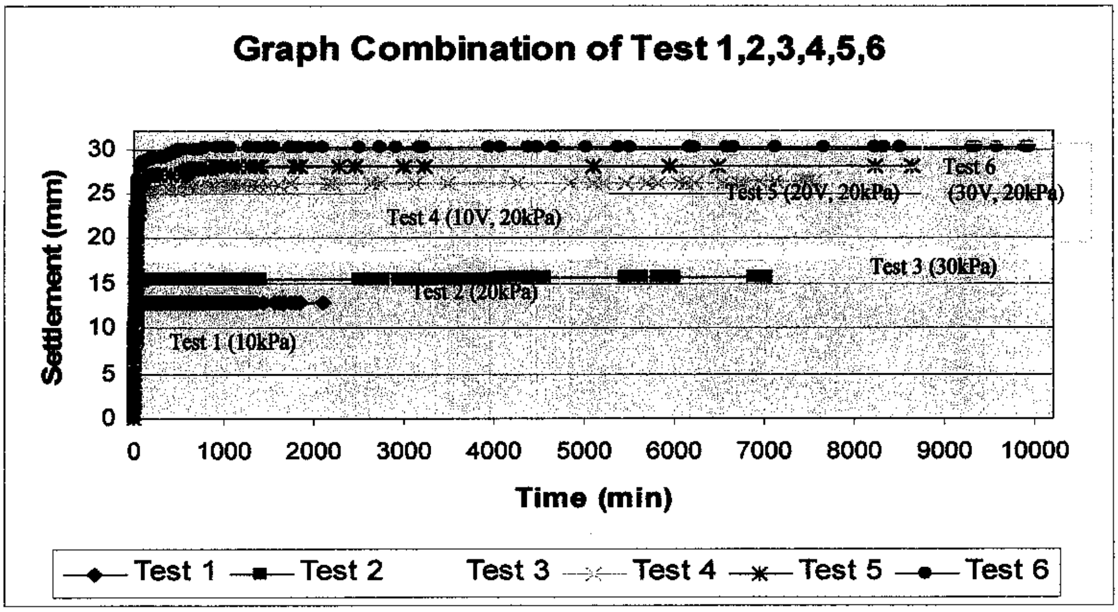


Figure 3: Test 1,2,3,4,5,6 (time vs settlement)

APPENDIX IV

Shear Strength

- Tabular record of the shear strength of every test (Test 1, 2, 3, 4, 5 and 6)
- Graph pressure versus shear strength (test 1, 2 and 3)
- Graph voltage versus shear strength (test 4, 5 and 6)
- Combination of the graph voltage versus shear strength (test 1, 2, 3, 4, 5 and 6)

Pressure (kPa)	Shear Strength (kN/m2)
10	46.85
20	148.25
30	199.760

Table 1: Without Voltage

Current (V)	Shear Strength (kn/m2)
10	50.58
20	141.72
30	702.560

Table 2: With Voltage (Load = 20kPa)

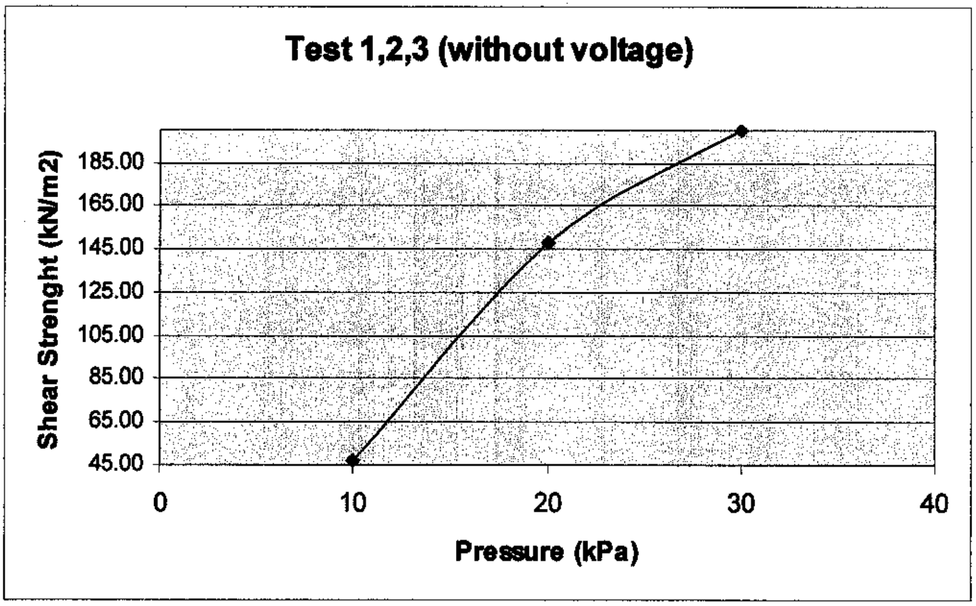


Figure 1: Without Voltage

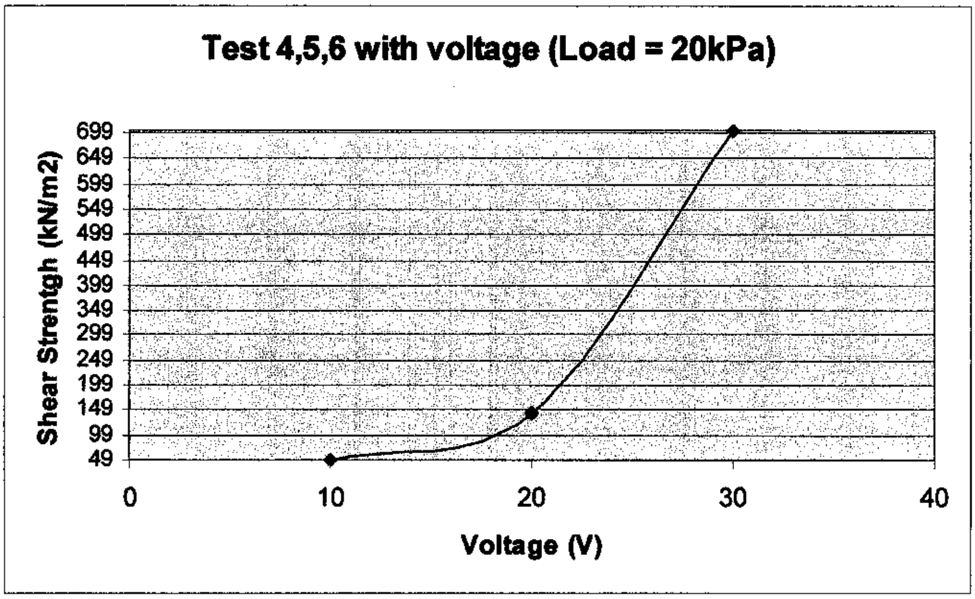


Figure 2: With Voltage (Load = 20kPa)

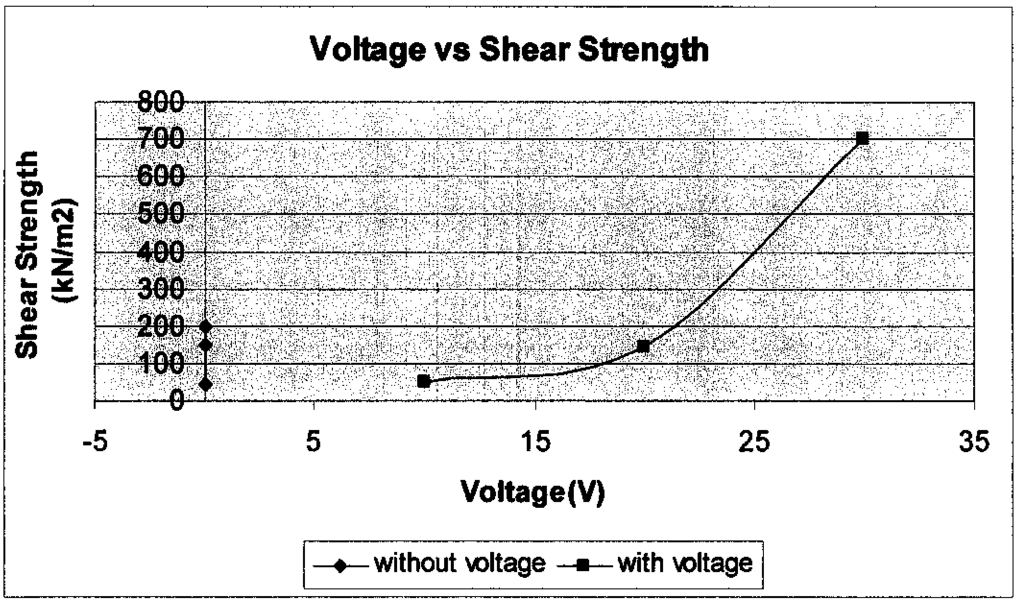


Figure 3: Voltage vs Shear Strength

APPENDIX V

Reduction of Amperage

- Tabular form record of the reduction of the amperage (Test 4, 5 and 6)
- Individual graph of time versus current
- Combination graph of test 4,5 and 6

Mac 2005

st 1 (with electricity)

= 10V

eight = 14kg = 20kPa

tial value data logger = 51.01mm

t Day

ery 5 minutes

Time (hrs)	Current (mA)
12.30 p.m	0.90
12.35 p.m	0.90
12.40 p.m	0.90
12.45 p.m	0.90
12.50 p.m	0.90
12.55 p.m	0.89
1.00 p.m	0.89
1.05 p.m	0.88
1.10 p.m	0.88
1.15 p.m	0.88
1.20 p.m	0.87
1.25 p.m	0.87
1.30 p.m	0.80

Every 15 minutes

Time (hrs)	Current (mA)
1.45 p.m	0.82
2.00 p.m	0.82
2.15 p.m	0.81
2.30 p.m	0.80
2.45 p.m	0.79

Every 1 hour

Time (hrs)	Current (mA)
3.45 p.m	0.75
4.45 p.m	0.71
5.45 p.m	0.69
6.45 p.m	0.67

d Day

Mac 2005

ery 2 hours

Time (hrs)	Current (mA)
9.00 a.m	0.56
11.00 a.m	0.54
1.00 p.m	0.52
3.00 p.m	0.49
5.00 p.m	0.48
7.00 p.m	0.47

i Day

-Apr-05

ery 5 hours

Time (hrs)	Current (mA)
9.00 a.m	0.47
2.00 p.m	0.44
7.00 p.m	0.43

ı Day

:-Apr-05

ery 5 hours

Time (hrs)	Current (mA)
9.00 a.m	0.42
2.00 p.m	0.42
7.00 p.m	0.41

5th Day

3-Apr-05

Every 5 hours

Time (hrs)	Current (mA)
9.00 a.m	0.40
2.00 p.m	0.39
7.00 p.m	0.38

st 2 (5 April 2005)
= 20V
eight = 14kg = 20kPa
tial value data logger = 49.98mm
t Day

ery 5 minutes

Time (hrs)	Current (mA)
11.15 a.m	1.41
11.20 a.m	1.40
11.25 a.m	1.40
11.30 a.m	1.40
11.35 a.m	1.40
11.40 a.m	1.40
11.45 a.m	1.39
11.50 a.m	1.39
11.55 a.m	1.39
12.00 p.m	1.39
12.05 p.m	1.39
12.10 p.m	1.38
12.15 p.m	1.37

Every 15 minutes

Time (hrs)	Current (mA)
12.30 p.m	1.35
12.45 p.m	1.31
1.00 p.m	1.28
1.15 p.m	1.25

Every 1 hour

Time (hrs)	Current (mA)
2.15 p.m	1.16
3.15 p.m	1.09
4.15 p.m	1.02
5.15 p.m	0.95
6.15 p.m	0.88

d Day
-Apr-05

ery 2 hours

Time (hrs)	Current (mA)
9.00 a.m	0.82
11.00 a.m	0.80
1.00 p.m	0.78
3.00 p.m	0.75
5.00 p.m	0.75
7.00 p.m	0.73

l Day
-Apr-05

ery 5 hours

Time (hrs)	Current (mA)
9.00 a.m	0.72
2.00 p.m	0.72
7.00 p.m	0.72

ı Day
-Apr-05

ery 5 hours

Time (hrs)	Current (mA)
9.00 a.m	0.71
2.00 p.m	0.66
7.00 p.m	0.61

st 3 (11 April 2005)
= 30V
eight = 14kg = 20kPa
tial value data logger = 50mm
t Day

ery 5 minutes

Time (hrs)	Current (mA)
4.45 p.m	2.05
4.50 p.m	2.05
4.55 p.m	2.05
5.00 p.m	2.04
5.05 p.m	2.04
5.10 p.m	2.04
5.15 p.m	2.04
5.20 p.m	2.03
5.25 p.m	2.03
5.30 p.m	2.03
5.35 p.m	2.02
5.40 p.m	2.01
5.45 p.m	1.99

Every 15 minutes

Time (hrs)	Current (mA)
6.00 p.m	1.94
6.15 p.m	1.89
6.30 p.m	1.83
6.45 p.m	1.80

d Day
2-Apr-05

ery 2 hours

Time (hrs)	Current (mA)
9.00 a.m	1.21
11.00 a.m	1.16
1.00 p.m	1.12
3.00 p.m	1.09
5.00 p.m	1.06
7.00 p.m	1.03

d Day
3-Apr-05

ery 5 hours

Time (hrs)	Current (mA)
9.00 a.m	1.04
2.00 p.m	1.03
7.00 p.m	1.03

1 Day
I-Apr-05

ery 5 hours

Time (hrs)	Current (mA)
9.00 a.m	1.03
2.00 p.m	1.03
7.00 p.m	1.03

5th Day
15-Apr-05

Every 5 hours

Time (hrs)	Current (mA)
9.00 a.m	1.03
2.00 p.m	1.02
7.00 p.m	1.01

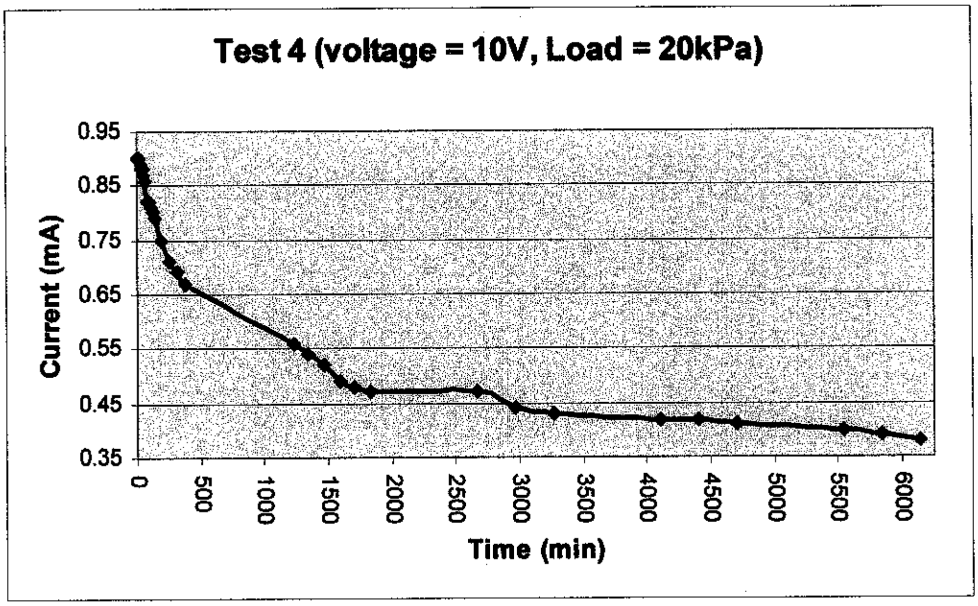


Figure 1: Test 4 (voltage = 10V, Load 20kPa)

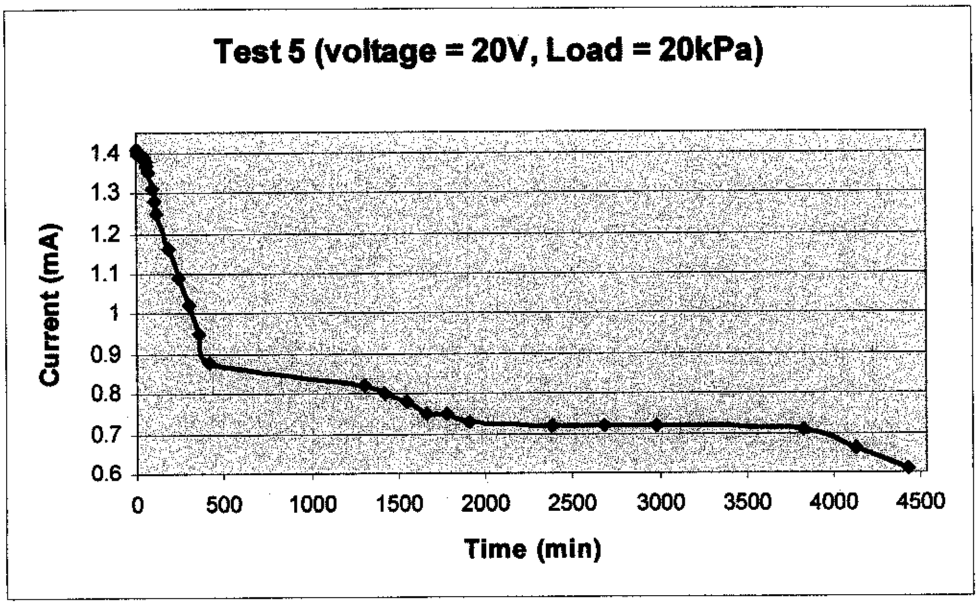


Figure 2: Test 5 (voltage = 20V, Load = 20kPa)

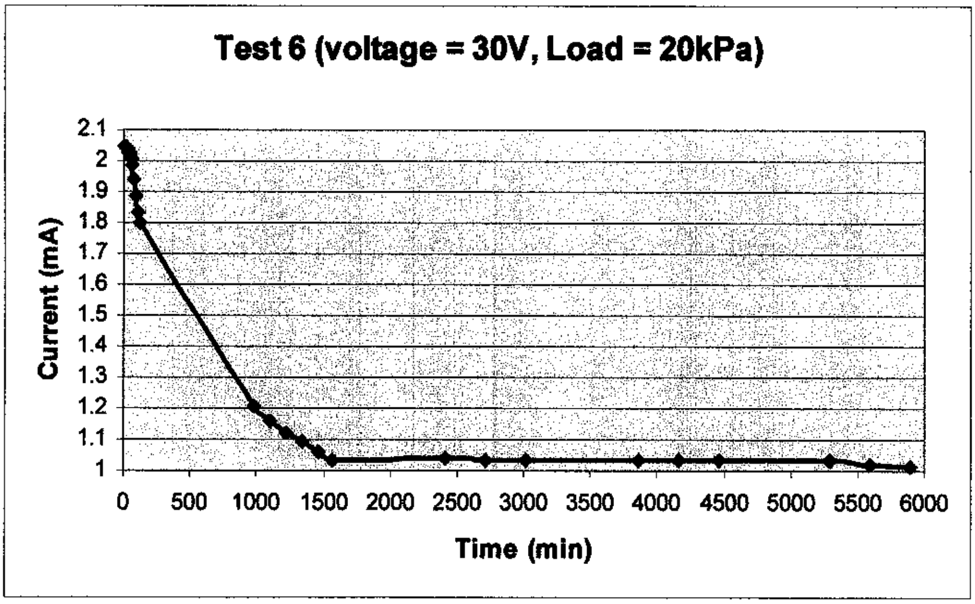


Figure 3: Test 6 (voltage = 30V, Load = 20kPa)

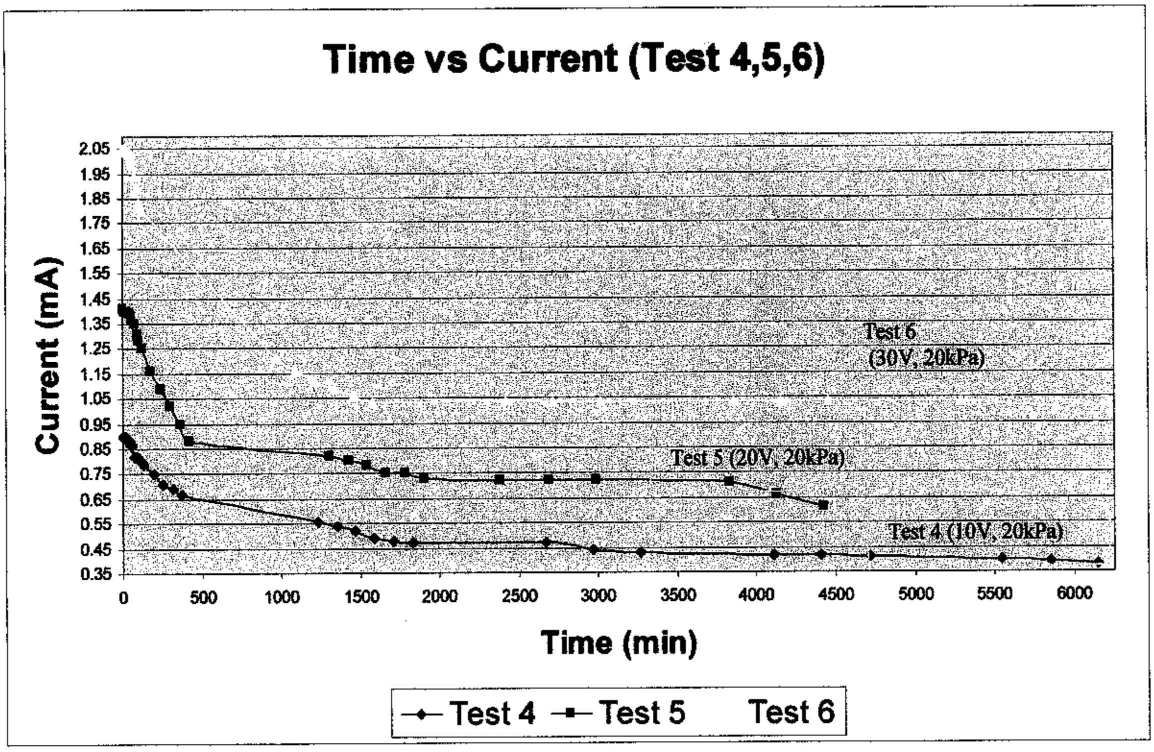


Figure 4: Test 4,5,6 (time vs current)

APPENDIX VI

Variation of Moisture Content

- Tabular record of the moisture content of every test (Test 1, 2, 3, 4, 5 and 6)
- Individual graph of moisture content versus distance from anode
- Combination graph from test 1,2 and 3 (without voltage)
- Combination graph from test 4,5 and 6 (with current)
- Combination graph of test 1,2,3,4,5 and 6

st 1 (without electricity)

= 7kg = 10kPa

5
4
3
2
1

5 = bottom to top of cell

ıss of wet soil + container (m2) g
ıss of dry soil + container (m3) g
ıss of container (m1) g
ıss of moisture (m2 -m3) g
ıss of dry soil (m3 - m1) g
ɔisture content, w = [(m2 - m3) / (m3 - m1)]100

o.	m1	m2	m3	(m2 - m3)	(m3 -m1)	w
8	29.30	48.56	42.27	6.29	12.97	48.50
6	29.39	44.74	39.75	4.99	10.36	48.17
4	29.17	49.88	43.24	6.64	14.07	47.19
2	29.37	94.66	74.23	20.43	44.86	45.54
0	29.07	72.56	59.00	13.56	29.93	45.31

st 2 (without electricity) W = 14kg = 20 kPa

o.	m1	m2	m3	(m2 - m3)	(m3 -m1)	w
8	29.39	62.01	51.93	10.08	22.54	44.72
6	29.30	63.92	53.33	10.59	24.03	44.07
4	29.17	57.87	49.29	8.58	20.12	42.64
2	29.07	60.07	50.85	9.22	21.78	42.33
0	29.37	62.66	53.24	9.42	23.87	39.46

st 3 (without electricity) W = 21kg = 30 kPa

o.	m1	m2	m3	(m2 - m3)	(m3 -m1)	w
8	29.39	52.78	45.68	7.1	16.29	43.59
6	29.07	55.66	47.74	7.92	18.67	42.42
4	29.17	55.14	47.41	7.73	18.24	42.38
2	29.30	51.25	44.72	6.53	15.42	42.35
0	29.37	99.23	79.80	19.43	50.43	38.53

st 4 (with electricity)

= 14kg = 200kPa

5
4
3
2
1

5 = bottom to top of cell

= 10V

ass of wet soil + container (m2) g

ass of dry soil + container (m3) g

ass of container (m1) g

ass of moisture (m2 -m3) g

ass of dry soil (m3 - m1) g

oisture content, w = [(m2 - m3) / (m3 - m1)]100

o.	**m1**	**m2**	**m3**	**(m2 - m3)**	**(m3 -m1)**	**w**
5	29.41	52.49	43.52	8.97	14.11	63.57
0	29.17	42.1	37.37	4.73	8.2	57.68
5	29.41	45.06	40.33	4.73	10.92	43.32
0	29.09	46.89	42.16	4.73	13.07	36.19
5	29.10	49.51	44.78	4.73	15.68	30.17
0	29.38	57.29	52.08	5.21	22.7	22.95

st 5 (with electricity)   V = 20V

o.	**m1**	**m2**	**m3**	**(m2 - m3)**	**(m3 -m1)**	**w**
5	29.4	48.35	43.63	4.72	14.23	33.17
0	29.17	49.4	46	3.4	16.83	20.20
5	29.42	56.73	53.33	3.4	23.91	14.22
0	29.09	65.39	61.79	3.6	32.7	11.01
5	29.11	69.19	65.39	3.8	36.28	10.47
0	29.38	73.21	69.19	4.02	39.81	10.10

st 6 (with electricity)   V = 30V

o.	**m1**	**m2**	**m3**	**(m2 - m3)**	**(m3 -m1)**	**w**
5	29.49	55.59	47.84	7.75	18.35	22.23
0	29.17	51.45	44.84	6.61	15.67	22.18
5	29.1	69.42	57.46	11.96	28.36	22.17
0	29.41	60.43	51.31	9.12	21.9	21.64
5	29.12	63.73	53.64	10.09	24.52	21.15
0	29.38	61.63	52.24	9.39	22.86	21.08

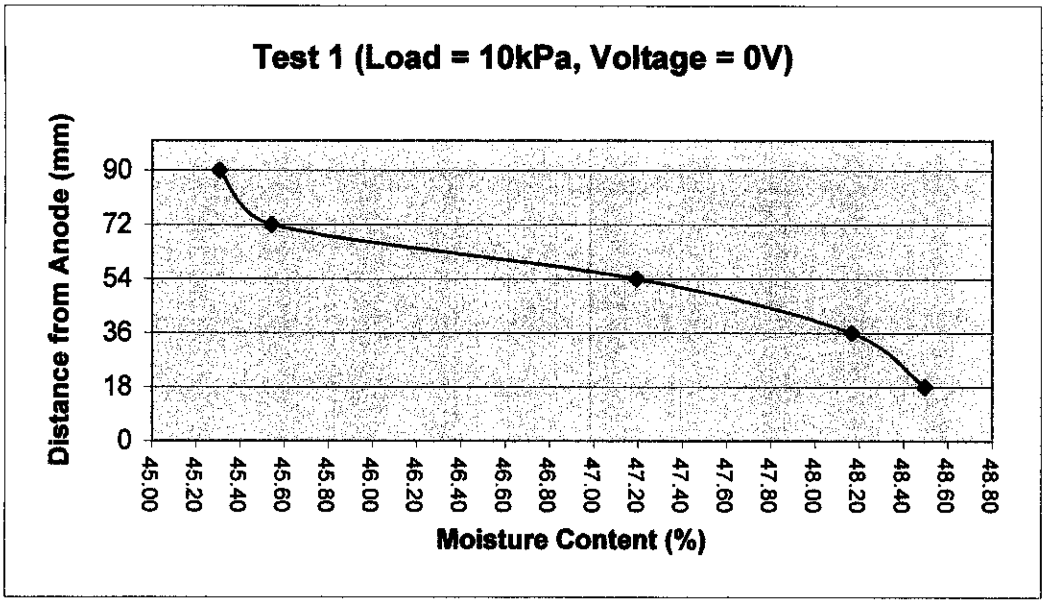


Figure 1: Test 1 (Load = 10kPa, Voltage = 0V)

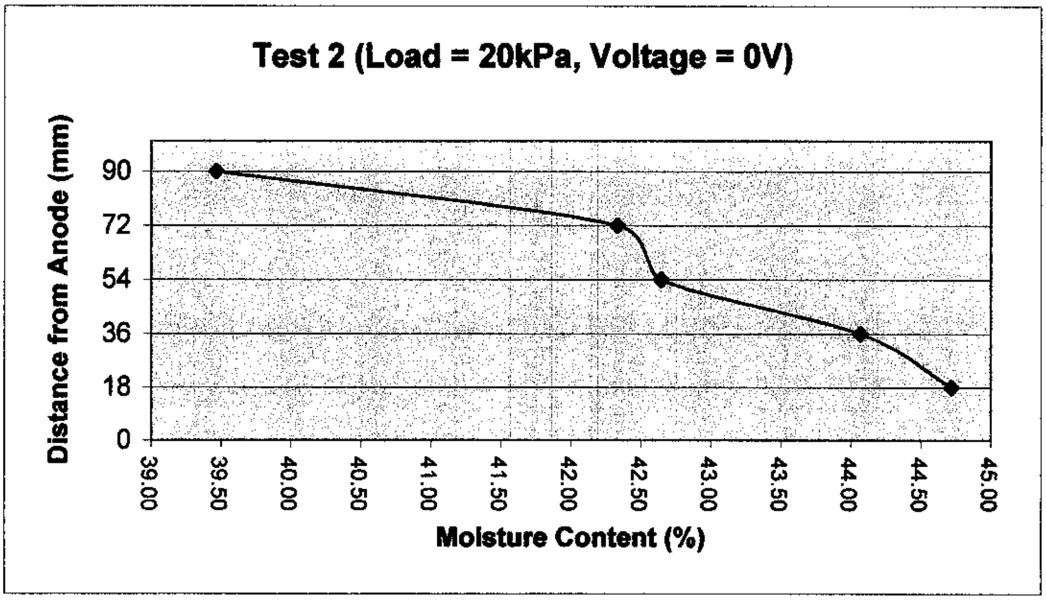


Figure 2: Test 2 (Load = 20kPa, Voltage = 0V)

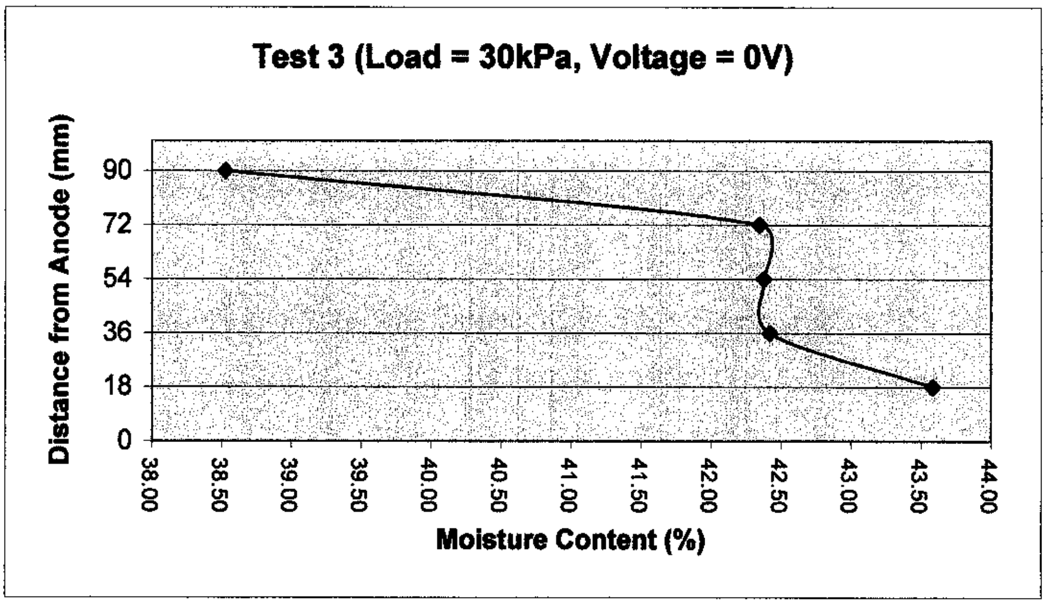


Figure 3: (Load = 30kPa, Voltage = 0V)

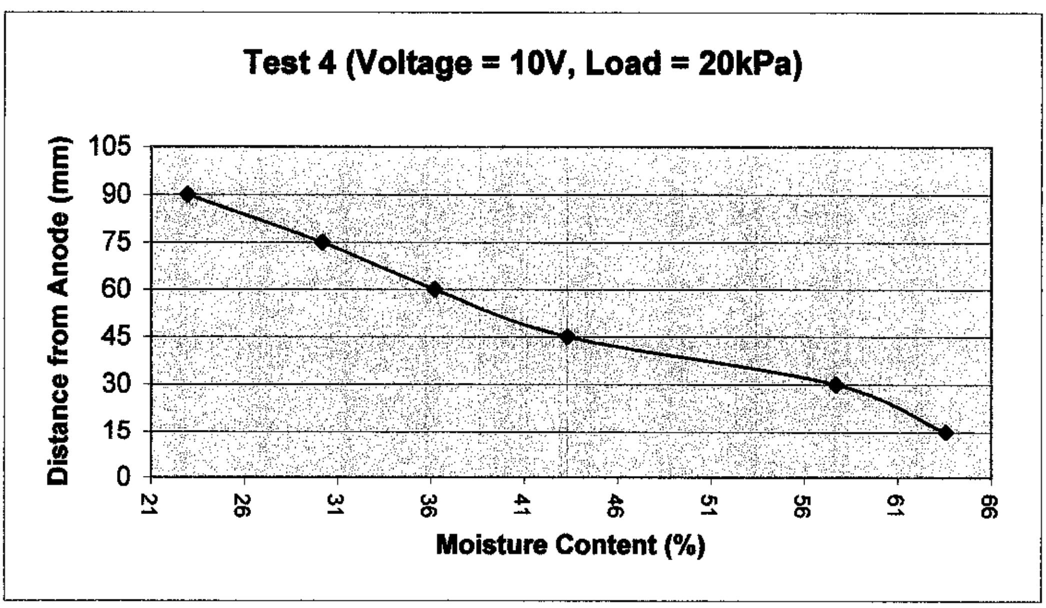


Figure 4: Test 4 (Voltage = 10V, Load = 20kPa)

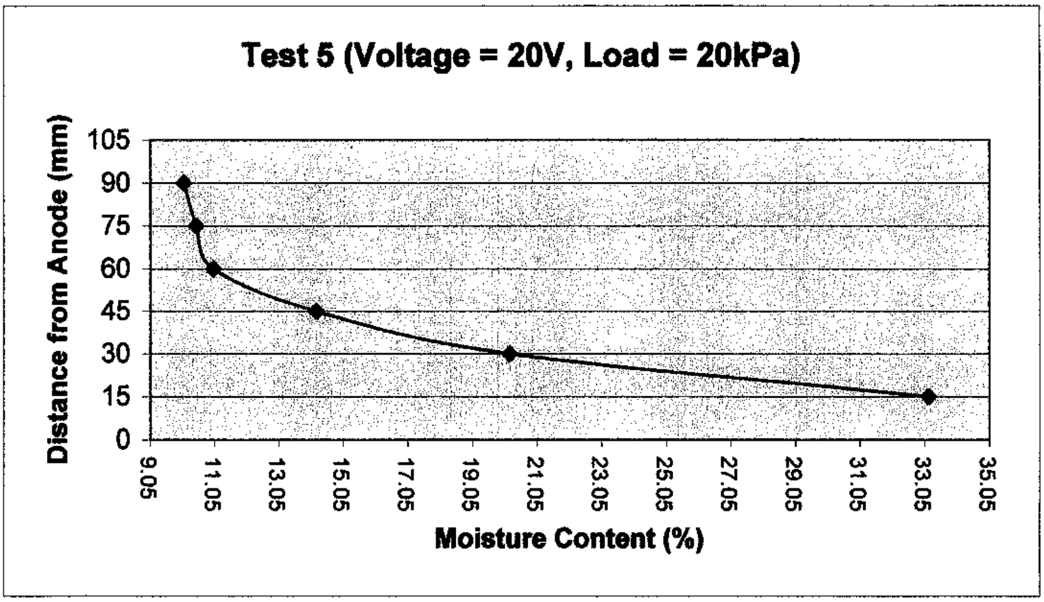


Figure 5: Test 5 (Voltage = 20V, Load = 20kPa)

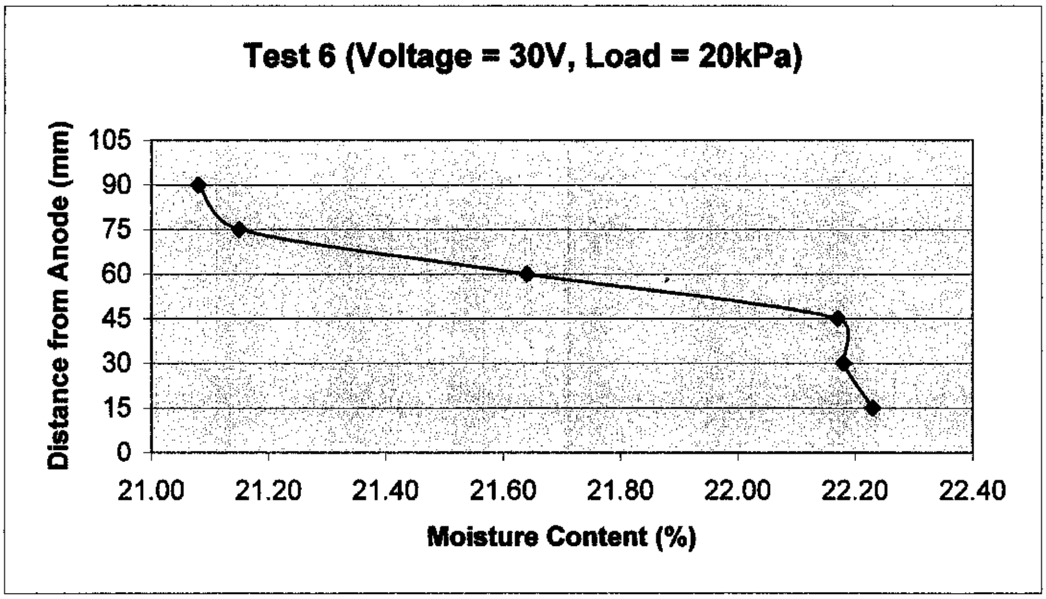


Figure 6: Test 6 (Voltage = 30V, Load = 20kPa)

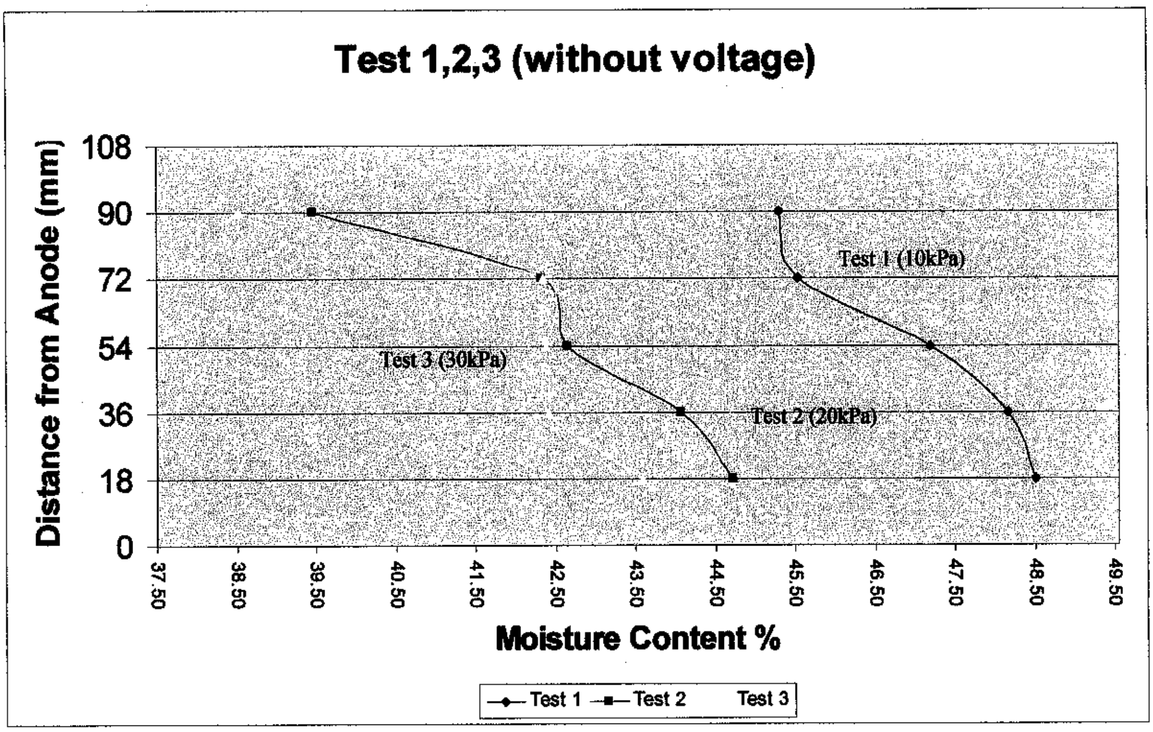


Figure 4: Test 1,2,3 (without voltage)

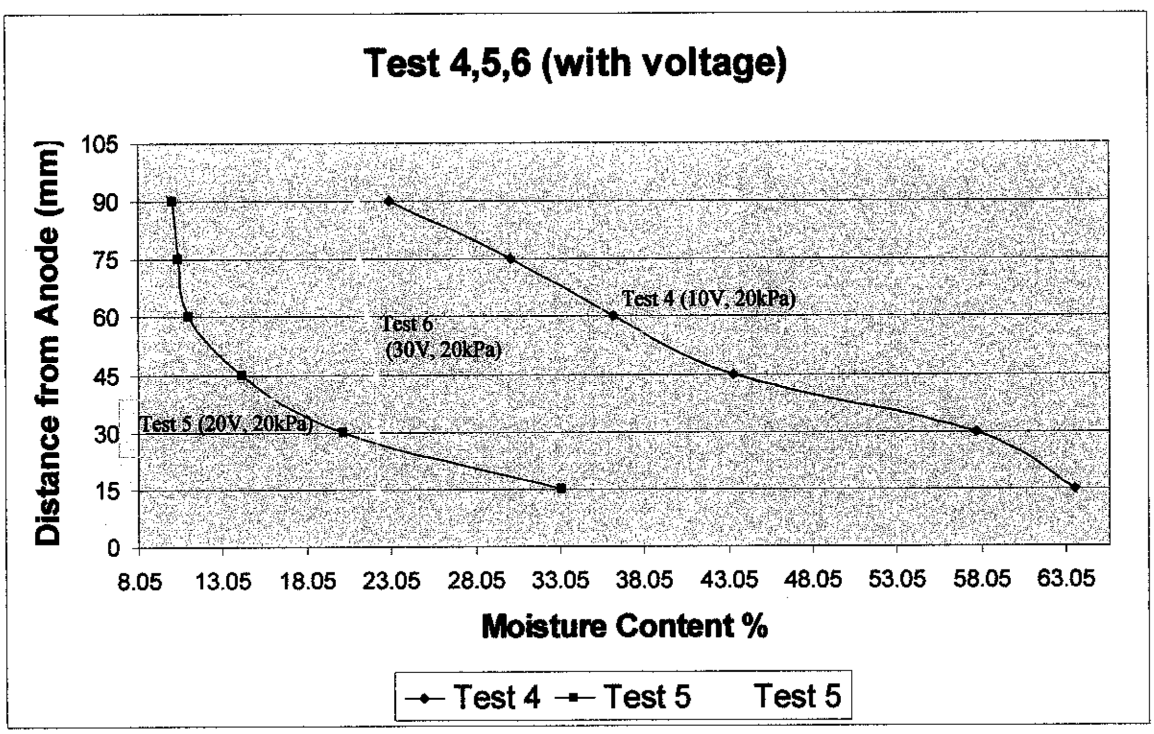


Figure 5: Test 4,5,6 (with voltage)

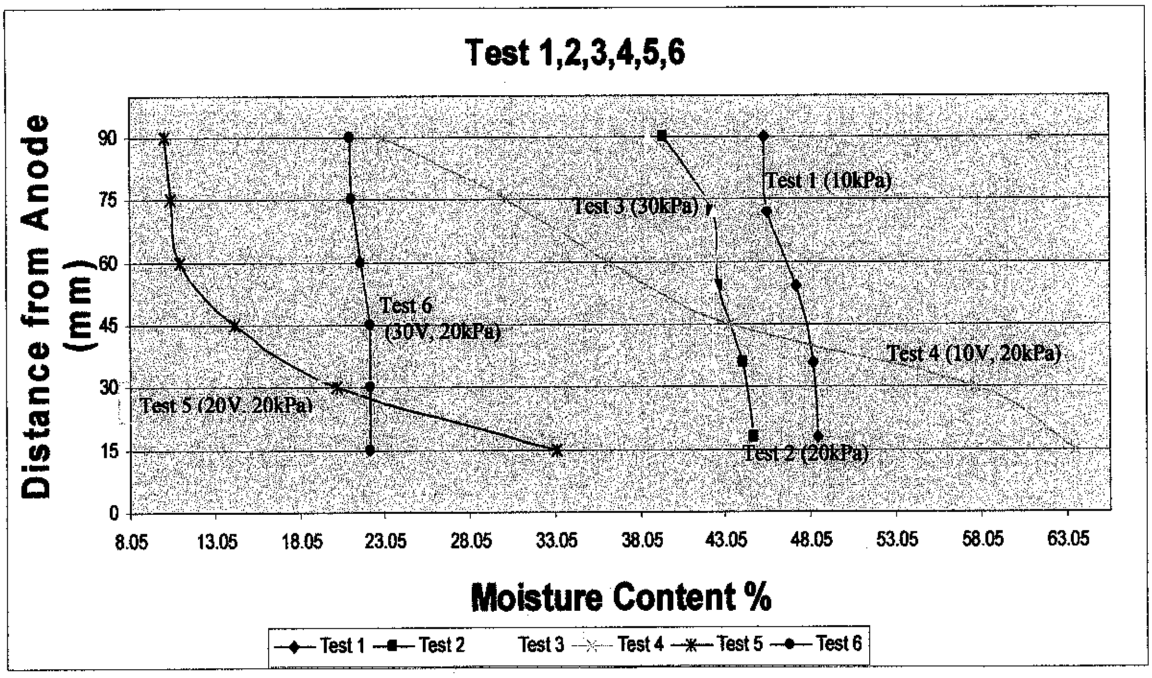


Figure 6: Test 1,2,3,4,5,6

APPENDIX VII

Reference table for shear strength