CORRELATION BETWEEN ELECTRICAL RESISTIVITY AND SOIL WATER CONTENT

by

Khyruzihan Bin Azhar

Dissertation submitted in partial fulfilment of requirements for the Bachelor of Engineering (Honours) Civil Engineering

JUNE 2010

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

CORRELATION BETWEEN ELECTRICAL RESISTIVITY AND SOIL WATER CONTENT

by

Khyruzihan Bin Azhar

A project dissertation submitted to the
Civil Engineering Department
Universiti Teknologi PETRONAS
in partial fulfillment of the requirement for the
BACHELOR OF ENGINEERING (Honours)
(CIVIL ENGINEERING)

Approved by,

....

(Dr. Syed Baharom Azahar Syed Osman)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

June 2010

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.

(KHYRUZIHAN BIN AZHAR)

ABSTRACT

The slope stability analysis are performed to assess the safe and economic design of a human-made or natural slopes such as embankments, road cuts, open-pit mining, excavations, landfills in equilibrium conditions. These studies are to solve the problem for determine the factor of safety (FOS) of the soil stability analysis without conduct any soil investigation or soil exploration where it is costly and time-consuming. The long term objective of this whole research is to implement a quick method of assessing the FOS in slopes by replacing the conventional soil parameters such as cohesion and internal angle of friction with electrical parameters such as electrical resistivity. The laboratory test using basic multimeter were conducted by testing on soil sample with different Particle Size Distribution (PSD) of soil and with different soil water content. Results from the laboratory test of the electrical resistivity indicated that they were consistencies in the correlation between the resistivity and soil properties. It shows that the electrical resistivity decreases when the increment water content in soil sample. The changes in electrical resistivity and varying water content can easily predicted the type of soil and can be determine the strength of the soil because water content in soil will change the soil formation; the water will either absorbed or expelled from the soil mass, which eventually affects to the shear strength of the soils.

ACKNOWLEDGEMENT

I would like to give myself appreciation for giving the opportunity to complete my final project in terms of studying and understanding the Correlation between Electrical Resistivity and Soil Water Content. This study has been crucial to me as this Final Year Project Paper is requirement for me to graduate.

Therefore, I would like to thanks Dr. Syed Baharom Azahar Syed Osman for his guidance and useful information he has given to me. Secondly, I like to thank all the executives at KAOLIN (MALAYSIA) SDN BHD and other organizations and persons involved for this study.

Besides that, I would like to thank all my fellow friends for their help and support that I really needed to complete of this Final Year Project Paper. I also like to express our gratitude to the Librarians of Universiti Teknologi PETRONAS (UTP) who assist me in finding some references materials in order to complete our project.

Finally yet importantly, to our family, for their continuous support and encouragement to me to complete this project and my bachelor study.

Thank You.

KHYRUZIHAN BIN AZHAR (11036)
Bachelor of Engineering (Honours) Civil Engineering
Universiti Teknologi PETRONAS (UTP)
June 2010

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND NOMENCLATURES

FOS Factor of safety

PSD Particle Size Distribution

SI Soil Investigation

CHAPTER 1

INTRODUCTION

1.1 Background

The slope stability analysis are performed to assess the safe and economic design of a human-made or natural slopes such as embankments, road cuts, open-pit mining, excavations, landfills in equilibrium conditions. Term slope stability may be defined as the resistance of inclined surface to failure by sliding or collapsing. The main objectives of slope stability analysis are finding endangered areas, investigation of potential failure mechanisms, determination of the slope sensitivity to different triggering mechanisms, designing of optimal slopes with regard to safety, reliability and economics, designing possible remedial measures with barriers and stabilization.

Successfully design of the slope requires geological information and site characteristics especially properties of soil or rock mass, slope geometry, groundwater conditions, alternation of materials by faulting, joint or discontinuity systems, movements and tension in joints, earthquake activity and others. Choice of correct analysis technique depends on both site conditions and the potential mode of failure, with careful consideration being given to the varying strengths, weaknesses and limitations inherent in each methodology.

One of the essential aspects to identify risk in slopes is to determine/calculate the factor of safety (FOS) which will indicate the stability of a certain slope. In the process of obtaining the FOS, among the crucial soil parameters to be obtained before calculating FOS are cohesion (c), internal frictional angle (Φ), unit weight of soil (γ) etc. Since most of slope failures are mainly due to infiltrations, the moisture/pore water pressure also contributes to the FOS value. All these parameters are obtained for example through borehole sampling.

1.2 Problem Statement

In general practice, soil investigation (SI) incorporating borehole sampling perhaps will produce the most reliable value of the relevant soil parameters for the purpose of actual calculation on FOS in slopes. However, borehole sampling is in general time consuming and very expensive. Conventional methods of soil analysis mostly require disturbing soil, removing soil samples and analyzing them in laboratory where else electrical geophysical methods of soil properties such as electrical resistivity and conductivity directly from soil surface to any depth without soil disturbance.

The general approach behind this quick assessment system is to eliminate the usage of physical soil parameters such as cohesion (c), internal frictional angle (Φ), and unit weight (γ) as is currently being practice for the calculation of FOS and replace these physical parameters with their correlated electrical parameters such as resistivity, conductivity, voltage etc.

1.3 Objectives

To address the discussed problems, the objectives of these studies are:

1.3.1 To establish relationships between electrical resistivity and soil water content with different particle size distribution (PSD) of soil such as sand, silt and clay.

1.3.2 To determine the soil shear strength parameters such as cohesion (c), and internal frictional angle (Φ) for each PSD of the soil depending on water content in the soil.

1.4 Scope of Study

This research covers the following aspect:

1.4.1 Electrical conductivity, resistivity and potential activity in each different PSD of soil by testing the soil sample in the laboratory.

1.4.2 Relationship between water content and each PSD of the soil.

CHAPTER 2

LITERATURE REVIEW

2.1 Soil Properties and Electrical Resistivity

Engineering properties of geomaterials are very important for civil engineers because almost everything they build; tunnels, bridges, dams and others are in, on or with soils or rocks. For geotechnical engineers, the strength, the stress-deformation behaviour and the fluid flow properties of earth materials are of primary concern and form the conventional framework of the geotechnical discipline. Conventional techniques for the determination of these engineering properties can be generally divided into three categories; laboratory tests, in-situ tests and geophysical methods. Of these, geophysical methods have been least developed as regards to their suitability for specific quantification of soil properties. Laboratory tests have the advantages of directly measuring the specified engineering properties under controlled boundary conditions and different environmental conditions. However, soil samples are usually disturbed during the drilling and sampling processes, which may make the measured engineering properties, deviate from their actual values.

Natural geomaterials whose skeletons form the primary structure to supports loadings consists of various solid mineral particles with diverse size, shape and arrangement, while multiple phases of pore fluids fill in their voids, such as air, water and solutions. Many kinds of electrical fields and potentials are often simultaneously observed in natural soil; thus, it is difficult to know what mechanism is responsible for their formation. Electrical conductivity and resistivity of soils have been investigated in a large number of studies, which can be divided into three groups.

The first group includes laboratory studies of electrical conductivity and dielectric constant of different dispersed media (including soils) with electromagnetic waves. These studies help to develop relationship between electrical parameters, quantitative and qualitative compositions of electrolytic solutions. The relationships were enhanced by the studies of soil electrical parameters with constant electrical field. For some diluted soil solutions and groundwater, the methods are developed to calculate electrical conductivity from the solution compositions.

The second group of studies is devoted to laboratory measurements of surface electrical conductivity. The surface electrical conductivity is a major parameter describing structure of electrical double layer and its ion composition. There is only limited special research with experimental measurements of surface electrical conductivity in soils.

The third group of studies includes measurements of electrical conductivity of soils, rocks, and sediments in situ with various geophysical methods.

In the literature the various models proposed to describe relationships between electrical parameters and soil water content, temperature, or salt content. Electrical conductivity and resistivity are usually measured as electrical parameters in laboratory and field conditions. Relationships between soil water content and electrical parameters were measured in field and laboratory conditions and mostly curvilinear models were obtained. Curvilinear relationships were also proposed between electrical resistivity and temperature. The researcher has been experiment and had proved that exponential relationship between electrical resistivity, soil temperature, and water content based on a series of experiments.

The assessment of soil water content variations more and more leans on geophysical methods that are non invasive and that allow a high spatial sampling. Among the different methods, Direct Current (DC) electrical imaging is moving forward. DC Electrical resistivity shows indeed strong seasonal variations that principally depend on soil water content variations. Although there are many studies between electrical resistivity and water content of agricultural soils, on geotechnical or engineering soils there are little attentions.

Electrical current in soils is mainly electrolytic, based on the displacement of ions in pore water, and is therefore greater with the presence of dissolved salts. Thus, electrical current in soils depends on the amount of water in the pores and on its quality. In most studies concerning the water content, the electrical conductivity of the solution is assumed to remain relatively constant to be neglected against its variation related to water content variation. Prior to field surveys, preliminary calibration of the volumetric water content related to the electrical resistivity is usually performed in the laboratory. Figure 2.1 shows examples of laboratory calibration between the electrical resistivity and the volumetric water content. The electrical resistivity decreases when the water content increases. It can also be seen that for water content below 15 percent, the electrical resistivity rapidly decreases with increasing water content. The relationship between the electrical resistivity and the water content has firstly been studied mainly in the field of petroleum research.

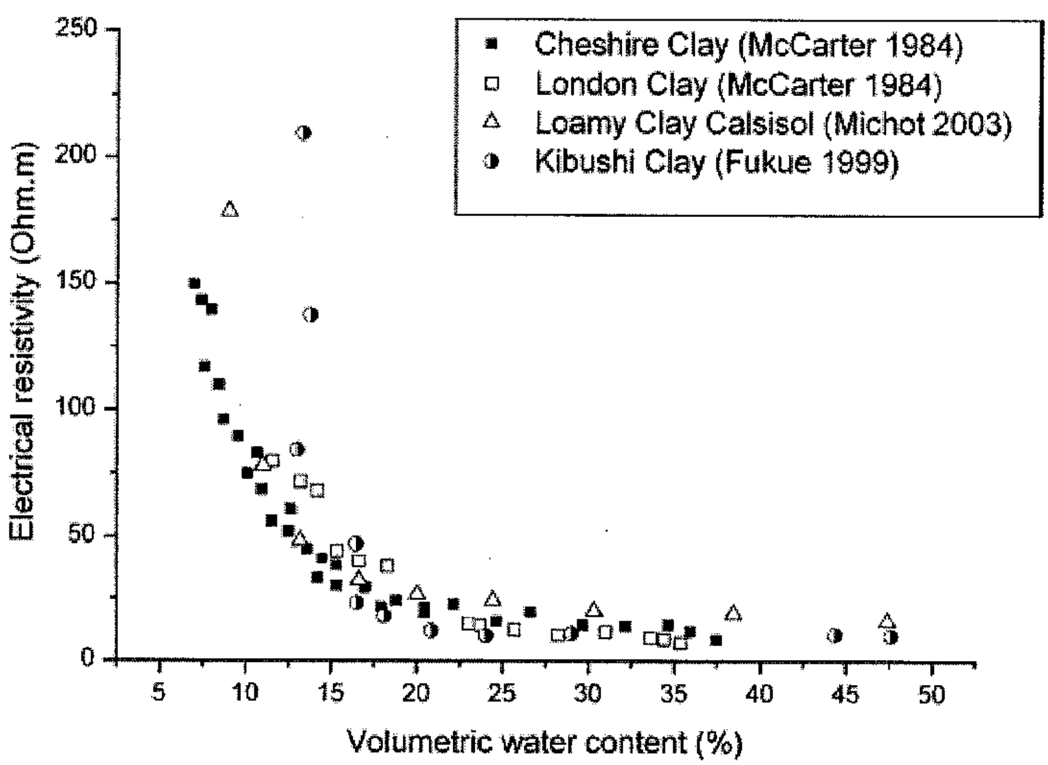


Figure 2.1: Relationship between the volumetric water content and the electrical resistivity for different soil types

2.2 Electrical Resistivity Measurement

Soil resistivity data is the key factor in designing a grounding system for a specific performance objective. All soil conducts electrical current, with some soils having good electrical conductivity while the majority has poor electrical conductivity. The resistivity of soil varies widely throughout the world and changes dramatically within small areas. Soil resistivity is mainly influenced by the type of soil (clay, shale, etc.), moisture content, the amount of electrolytes (minerals and dissolved salts) and finally, temperature.

When designing a grounding system for a specific performance objective, it is necessary to accurately measure the soil resistivity of the site where the ground is to be installed. Grounding system design is an engineering process that removes the guesswork and "art" out of grounding. It allows grounding to be done "right, the first time". The result is a cost savings by avoiding change orders and ground "enhancements."

The best method for testing soil resistivity is the Wenner Four Point method. It uses a 4-pole digital ground resistance meter, probes, and conductors.

It requires inserting four probes into the test area. The probes are installed in a straight line and equally spaced (Figure 2.2). The probes establish an electrical contact with the earth.

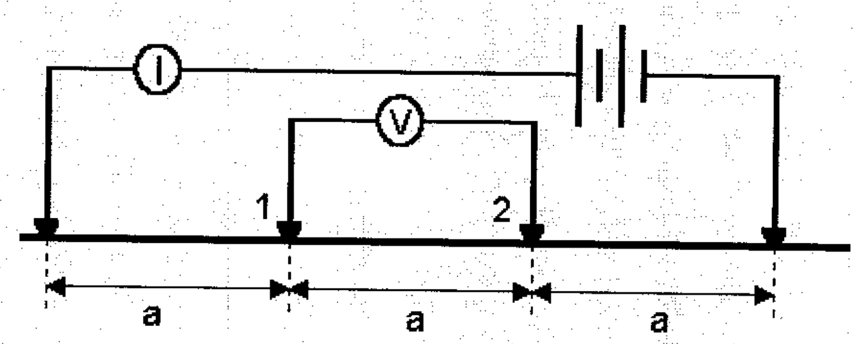


Figure 2.2: Principle of operation

The four pole test meter injects a constant current through the ground via the tester and the outer two probes. The current flowing through the earth (a resistive material) develops a voltage/potential difference. This voltage drop resulting from the current flow is then measured between the two inner probes.

The meter then knows the amount of current that is flowing through the earth and the voltage drop across the two center probes. With this information the meter uses ohms law (R=V/I) to calculate and display the resistance in ohms.

This displayed resistance value is in ohms and must be converted to ohms-meter, which are the units of measure for soil resistivity. Ohms-meter is the resistance of a volume of earth that is one meter by one meter by one meter, or one cubic meter.

To convert from the displayed ohms to ohms-meter, the meter reading is multiplied by 2 and the result multiplied times the probe spacing. The following shows the calculation in a formula.

ρ (ohms-m) = 2 x R x A

ρ = soil resistivity in ohm-m (Ωm)

2 is constant

R = digital readout in ohms (Ω).

A = distance between electrodes in meter.

2.3 Factors Affecting the Electrical Resistivity of Soil

For most common minerals forming soils and rocks, the resistivity is high in a dry condition and therefore in general the resistivity of soils and rocks depends on the amount and type of water in pore spaces and fractures. Connection between cavities and fracture is also an important factor in the final value of resistivity.

However, the basic mechanism affecting conductivity in moist soils and water bearing rocks occurs as result of the movement of ions and the ability to transmit ions is governed by the electrical resistivity which is a basic property of all materials. Besides being dependent to the amount and type of water and porosity, electrical resistivity also depend on other properties such as type of material, particle shape and orientation, mineralogy, amount of clay content and electrical resistivity of the fluid. The presence of clay minerals strongly affects the resistivity of sediments and weathered rocks. This is due to the fact that clay minerals are electrically conductive particles having the ability to absorb and release ions and water molecules on its surface through an ion exchange process.

Therefore, it is worthwhile to mention here that in clean sands and gravels, electrical conduction occurs primarily in the pores while in clayed soils and clay-bearing rocks electrical conduction occurs in the pores and on the surfaces of electrically charged particles. Others factors which indirectly affects the electrical resistivity are frequency of the current, geometry, spacing and type of electrodes used. Temperature also plays an important role in the electrical resistivity of soil in the sense that increasing the temperature increased the mobility of the ions and this decreases the electrical resistivity of soil.

The statement above exhibit the complexities in correlating resistivity with different factors associated with the soil, rocks, and pore fluid. However, one could start off with the variations of resistivity with some common types of material found in many tables as an initial assistance in determining what material one is working with. An example is given in Table 2.1 below.

Material	Ohm Meter (Ωm)
Clay and marl	1 to 100
Loam	5 to 50
Top soil	50 to 100
Clayey soils	100 to 500
Sandy soils	500 to 5000
Typical mine water	1 to 10
Typical surface water	5 to 50
Shale	10 to 80
Limestones	80 to 1000
Sandstones	50 to 8000
Coal	500 to 5000

Table 2.1: Variations of resistivity with some common materials

2.4 The Role of Water

Although water is not always directly involved as the transporting medium in mass-wasting processes, it does play an important role.

Water can be adsorbed or aborted by minerals in the soil. Adsorption causes the electronically polar water molecule to attach itself to the surface of the minerals. Absorption causes the minerals to take the water molecules into their structure. By adding water in this fashion, the weight of the soil or rock is increased. Furthermore, if adsorption occurs then the surface frictional contact between mineral grains could be lost resulting in a loss of cohesion, thus reducing the strength of the soil.

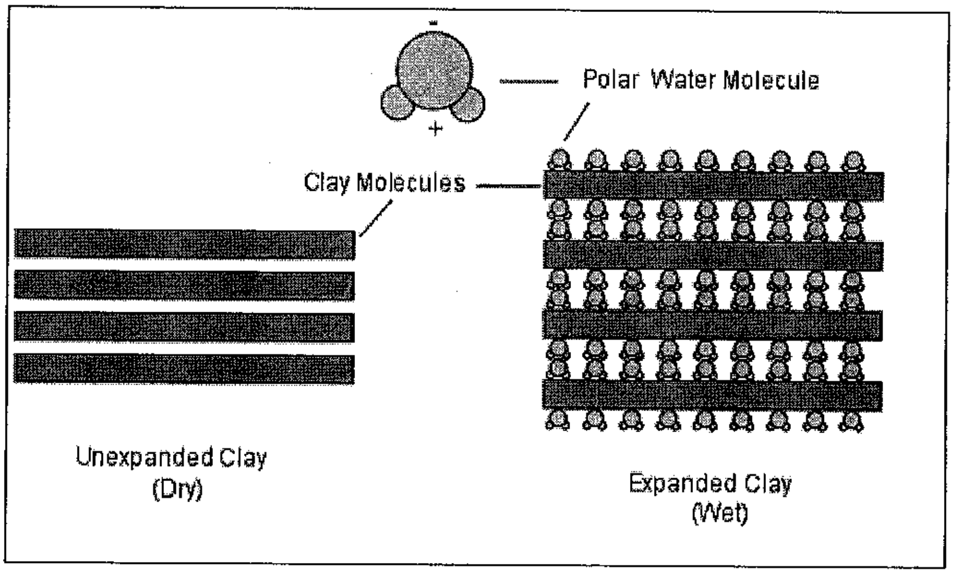


Figure 2.3: Comparison water adsorption between dry clay and wet clay

In general, wet clays have lower strength than dry clays, and thus adsorption of water leads to reduced strength of clay-rich soils.

CHAPTER 3

METHODOLOGY

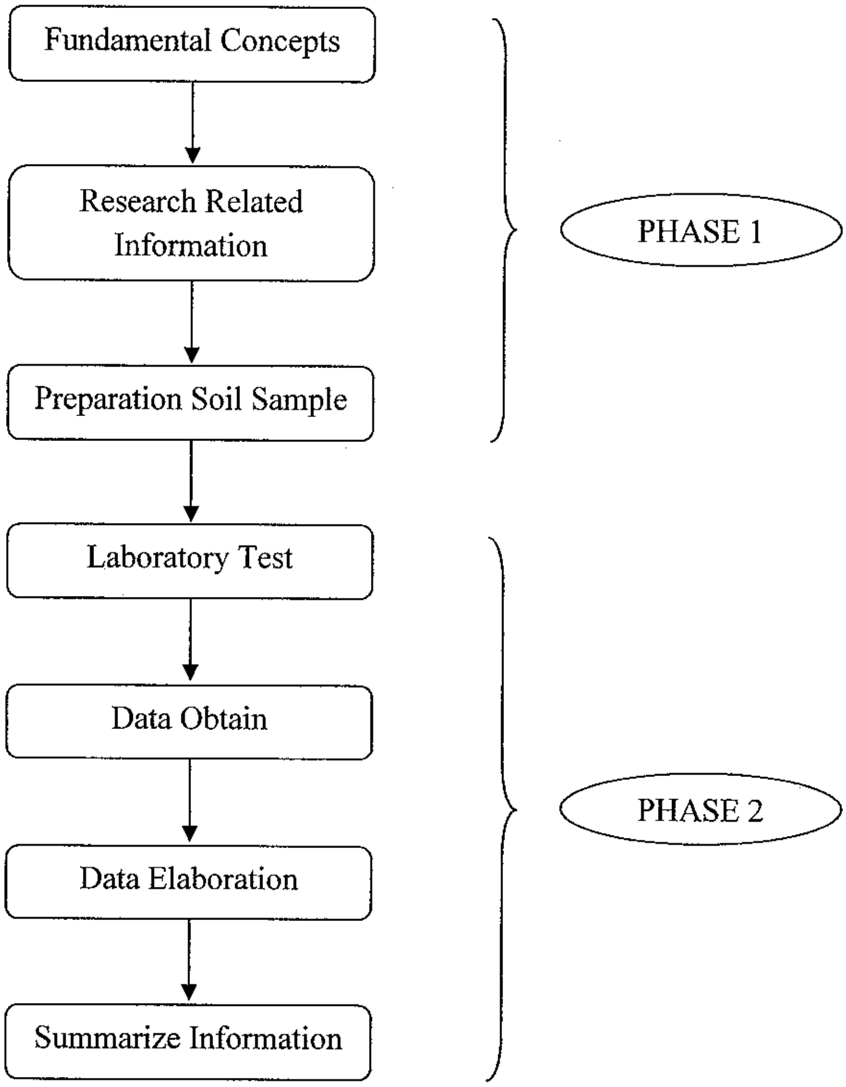


Figure 3.1: Flow Chart of research methodology

These studies will be divide into two main phases which are phase one and phase two.

For the phase one, this research will concentrate on research information details such as the fundamental concepts of these studies, find the related information and research especially the journals and paper works for the electrical resistivity in the soil and includes preparation of soil sample for the laboratory test. The soil will be tested on three soil sample, there are; pure sand, pure silt and pure clay. The soil sample must be totally pure soil without mix with any type of soil.

The second phase of these studies will more on laboratory works test. These will be conduct in the soil laboratory with special instruments and equipments for testing the soil sample about electrical resistivity with the soil water content. The laboratory works will be tested three times for each particle size distribution of the soil with different water content. The shear strength parameter of the soil sample will be determined to correlate with the electrical resistivity in soil sample. The data will be elaborate to find the correlation about the electrical resistivity with the soil water content. At the end of these studies, the result will be summarizing to come out with the relationship of the between electrical resistivity with particle size distribution of the soil and soil shear strength parameters.

3.1 Laboratory Works Test

These laboratory work test will be conduct as Wenner Four Point Test Method. This method covers the determination of resistivity of water or soil using a soil resistance meter and soil box.

While for determination of soil shear strength parameters, the method will be conducting is Direct Shear Box Test. From there the cohesion (c) and internal frictional angle (Φ) of the soil sample can be determined.

3.2 Electrical Resistivity Testing Procedures

3.2.1 Apparatus

- Four terminal probes.
- Null balancing ohmmeter or multimeter capable of four wire resistance measurements from one to one million ohms.
- Four insulated wire conductors
- Soil box
- Measuring tape

3.2.2 Preparation of Soil Sampling

The soil samples will be put into the oven for 24 hours to ensure the soil sample totally dried and free from water content. After 24 hours, the soil will be taken out from the oven and expose to the room temperature for 15 minutes. The soil sample will be weight approximately 5000g for each test.

The 5000g of the soil sample will be added with distilled water depends on water content need to be determined. The soil sample will be mix up with the distilled water by using soil mixture (Figure 3.2) to ensure it will be mix perfectly.

Figure 3.2: Laboratory soil mixture

3.2.3 Equipment Setup

Rinse the soil box with deionised water before starting test. The wire will be connected to the resistance meter to the soil box. A standard soil box will have four probes at either end or a pair of electrode pins spaced out between the probes (Figure 3.3). The current source from the ohmmeter is connected to the outer probes, and the potential is measured between the pins.

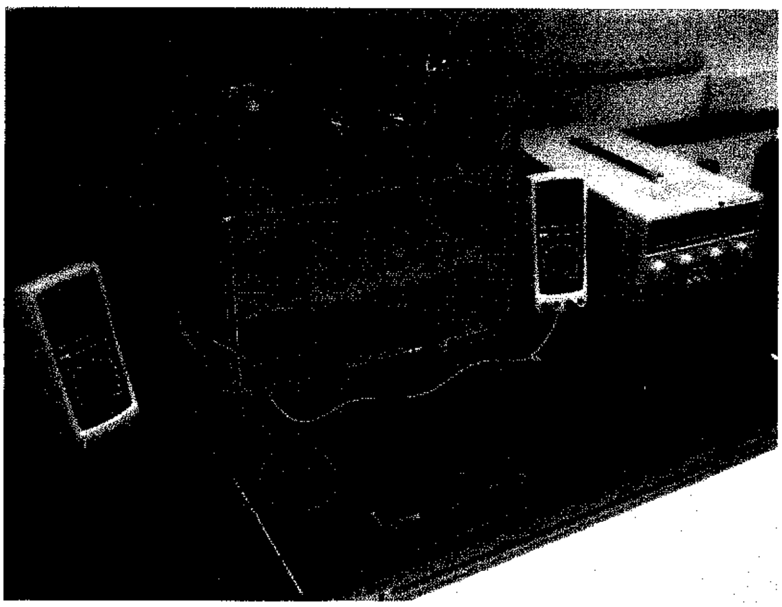


Figure 3.3: Equipments Setup for Laboratory Work Test of Soil Resistivity

3.2.4 Determining Resistivity of Soil

Place sample (5000 grams approximately) in a soil box. Fill soil box to top taking care to leave no voids and striking excess off top of box. Fill level must be more than the distance between the probes. This is the resistivity or the resistivity of the soil in its present condition. Fill soil box and obtain resistivity. The same process are repeated until the resistivity stops dropping or starts to rise again. The result for the test will be the lowest (minimum) resistivity obtained during this process. Report results in ohm (Ω).

3.2.5 Sample Integrity

The soil box will wash with distilled water after each sample to avoid contamination between samples. Use clean tools for gathering samples and never transport or store samples in open containers.

3.3 Determination Soil Shear Strength Parameters

After testing the electrical resistivity of the soil sample, the soil sample will be taken out from the soil box and put into the pan. The soil sample will be testing on shear strength parameters by Direct Shear Box Test Method. The procedures of the testing method will be conducted as same as British Standard procedures. Figure 3.4 shows the equipments of Direct Shear Box Test.

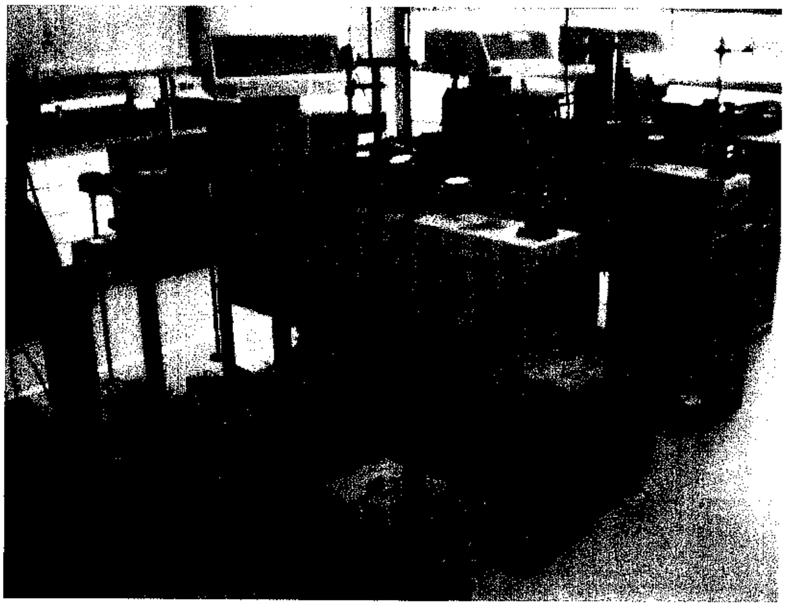


Figure 3.4: Direct Shear Box Test

CHAPTER 4

RESULT AND DISCUSSION

In this chapter, the result will be analyzing by discussion of differences particle size distribution of soil sample that can be categorized as sand, silt, and clay. The discussion will be started with basic soil properties of the soil sample till parallel with electrical resistivity and soil shear strength parameters.

In this chapter, the results of each PSD have been discussed by category of SAND, SILT and CLAY for easy understanding. The discussion has includes the soil the soil formation due to the increment of water content and the influences of water content in the soil sample on the changes of the electrical resistivity.

4.1 SAND

4.1.1 Basic soil properties of sand

- Particle Size Distribution (PSD) : 0.063 mm – 0.2 mm
- Specific Gravity (SG) : 2.6
- pH : 4.41

4.1.2 Electrical resistivity result of sand

Results from the electrical resistivity tests for sand conducted at the laboratory lab are tabulated in Table 4.1.

Electrical Resistivity, ρ (Ωm)	850	516	329
Water Content (%)	15	20	25
Cohesion, c (kN/m²)	2.561	12.670	8.077
Friction angle, Φ (°)	10	8	9

Table 4.1: Electrical resistivity results for sand

Table 4.1 shown the result of electrical resistivity for sand was clear decreases with increment percentage of water contents. The soil sample sand shown the value of electrical resistivity was between the ranges of 300 Ωm to 900 Ωm. Referred to the Table 2.1, the description of the soil generally falls within clayey – sandy soil type which confirmed the classification or description of soil as given earlier. The percentage increment of water content in the sand, actually the cohesion will be lost, thus reducing the strength of the soil because absorption causes the minerals take the water molecules into their structure where by adding the water, then the weight of the sand will increased. So, if adsorption occurs, the surface frictional contact between minerals grains could be lost.

In order to look at the possible correlation of electrical resistivity obtained and the various soil parameters, the results of the electrical resistivity can be referred to the plotting graph. Graph and plotting for electrical resistivity versus water content, cohesion and friction angle are given in Figures 4.1, 4.2, and 4.3.

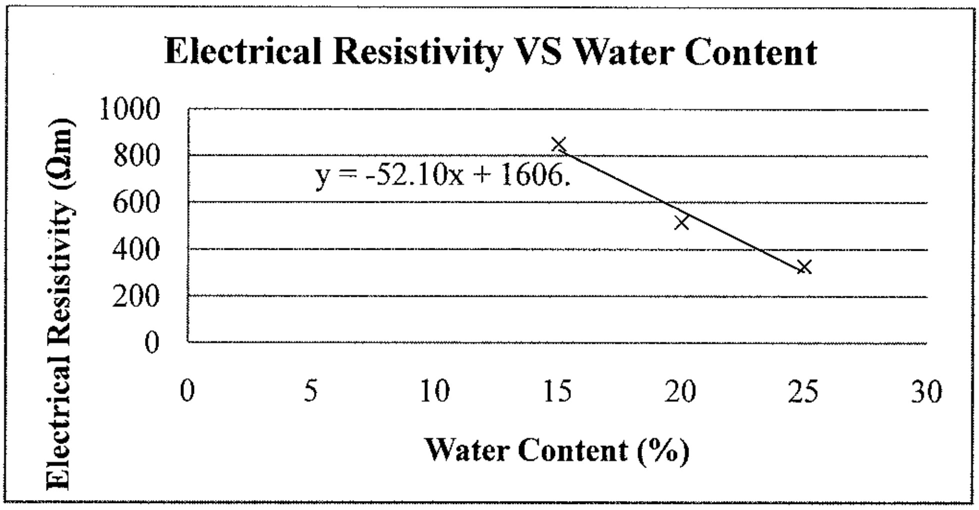


Figure 4.1: Electrical Resistivity VS Water Content

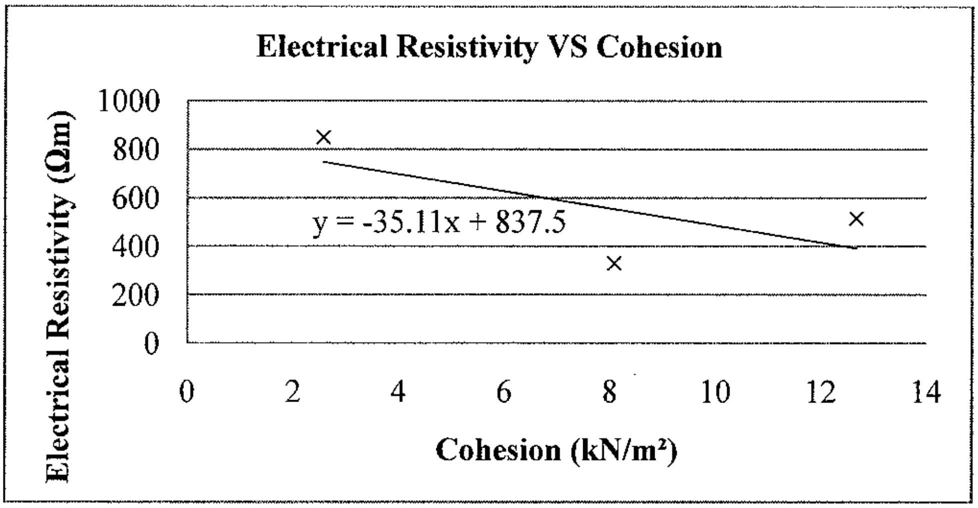


Figure 4.2: Electrical Resistivity VS Cohesion of the soil (SAND)

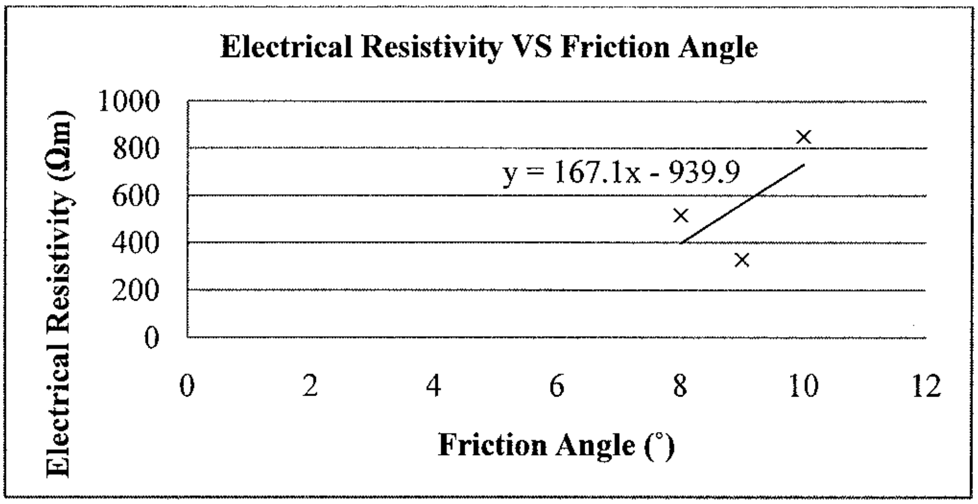


Figure 4.3: Electrical Resistivity VS Internal Frictional Angle

Figure 4.1 showed that the electrical resistivity decreases with increasing water content. The decreasing of the electrical resistivity it's obviously because the higher content of sandy material in the soil sample.

Figure 4.2 indicated that when the electrical resistivity is decreasing, the cohesion of the soil will be increased too. It shows that the cohesion of the soil sample increased as well as increasing of the water content in soil sample.

However, the result for the internal frictional angle of the soil sample was different, where the angle of friction will be increased when the electrical resistivity is increasing as shown in Figure 4.3.

The correlation of this soil sample (sand) can correlated each other's between electrical resistivity with water content in the soil and soil shear strength parameters by referring to the Figure 4.4.

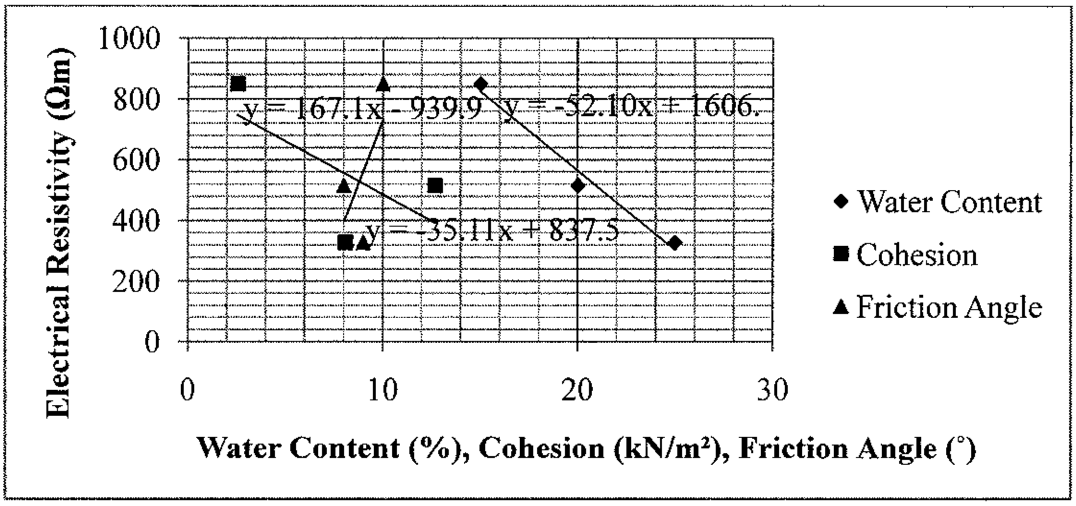


Figure 4.4: Correlation Electrical Resistivity in the soil with Water Content, Cohesion and Friction Angle

By superimposing all the plotting in one graph having the same scale in the x-axis as shown in Figure 4.4, correlation between the various soil parameters with the resistivity could be seen clearly. Hence, for certain value of resistivity, the corresponding water content, cohesion, and internal frictional angle could be very well predicted.

4.2 SILT

4.2.1 Basic soil properties of silt

- Particle Size Distribution (PSD) : 0.002 mm – 0.063 mm
- Specific Gravity (SG) : 2.6
- Liquid Limit (LL) : 36.4%
- Plastic Limit (PL) : 30.1%
- Plasticity Index (PI) : 6.3%
- pH : 4.33

4.2.2 Electrical resistivity result of silt

Results from the electrical resistivity tests for sand that has been conducted at the laboratory lab were tabulated in Table 4.2.

Electrical Resistivity ρ (Ωm)	258	101	59
Water Content (%)	10	20	30
Cohesion, c (kN/m²)	22.060	3.940	5.253
Friction angle, Φ (°)	7	8	11

Table 4.2: Electrical resistivity for silt

For the soil sample silt, the result of electrical resistivity is not so much different with the result of sand electrical resistivity. The electrical resistivity will be decreases when the water content of the soil increases. The range of the electrical resistivity is from 50 Ωm to 300 Ωm. By referring to the Table 2.1, the description of the soil will be considered top-clayey soil which it means as silt. The soil content can be described of distribution between sand and clay.

To correlate the electrical resistivity of the soil and others shear strength parameters, the correlation can be referred to the plotting graph. It's shown the plotting electrical resistivity for the soil sample versus with soil water content, cohesion, and angle of friction as shown in Figure 4.5, Figure 4.6, and Figure 4.7 below.

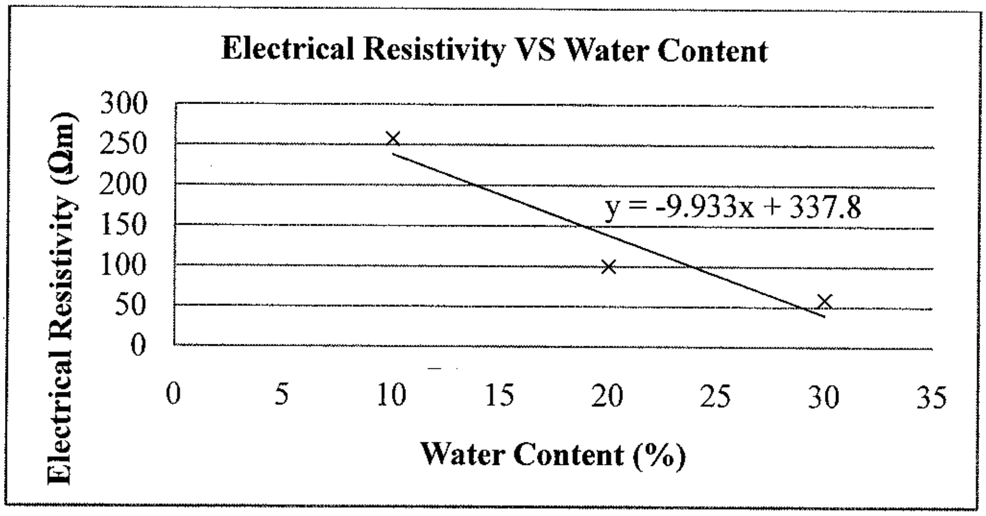


Figure 4.5: Electrical Resistivity VS Water Content

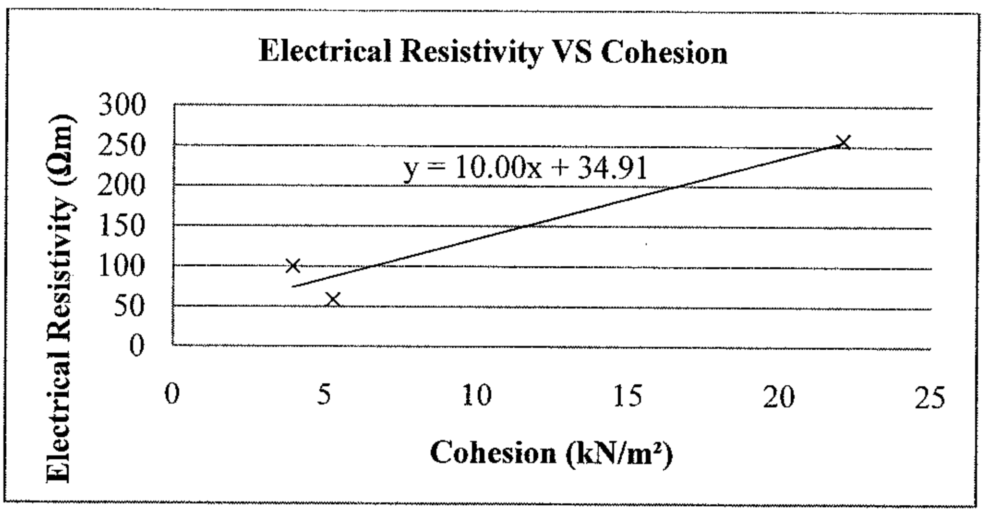


Figure 4.6: Electrical Resistivity VS Cohesion of the soil (Silt)

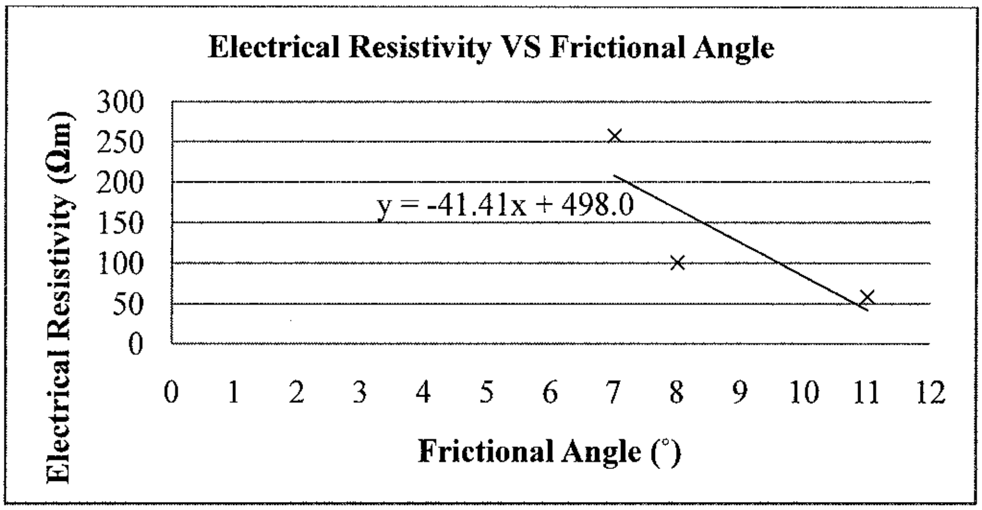


Figure 4.7: Electrical Resistivity VS Internal Frictional Angle

Figure 4.5 indicated that the increasing of water content in soil sample the electrical resistivity will shown decreasing. It is because connections between the particles of the silt are more compact and the soil will absorb more water. When the absorption occurs, the resistant in the soil will be decreased. So, the range of the electrical resistivity will be small.

Between correlation cohesion of the soil sample and the electrical resistivity, Figure 4.6 determines that cohesion of the soil will be increase when the electrical resistivity is increasing.

For the internal frictional angle, refer to Figure 4.7, the increasing of friction angle decreasing the electrical resistivity. The observation can be described same as the analysis between electrical resistivity and soil water content.

The correlation of this soil sample (silt) can correlated each other's between electrical resistivity with water content in the soil and soil shear strength parameters by referring to the Figure 4.8.

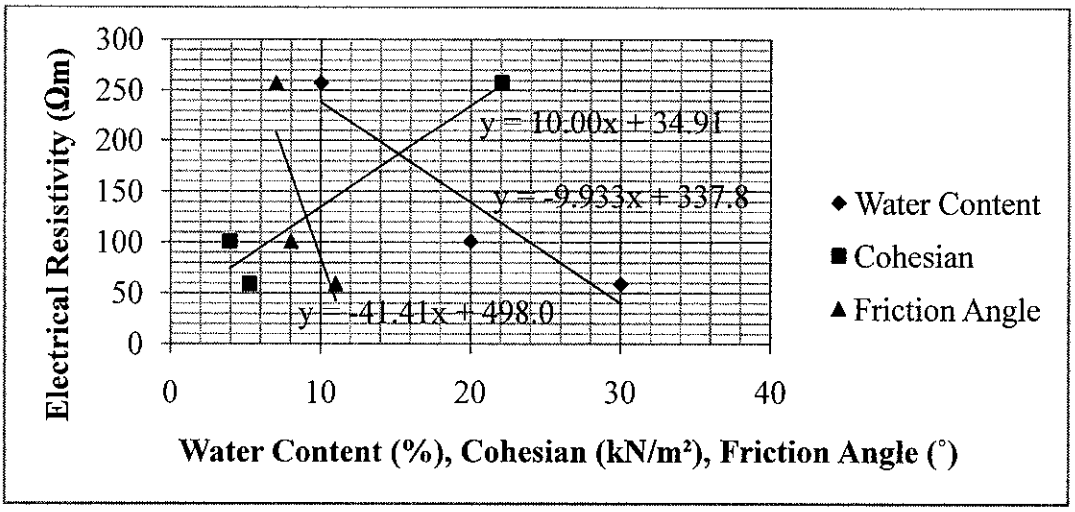


Figure 4.8: Correlation Electrical Resistivity in the soil with Water Content, Cohesion and Friction Angle

By superimposing all the plotting in one graph having the same scale in the x-axis as shown in Figure 4.8, correlation between the various soil parameters with the resistivity could be seen clearly. Hence, for certain value of resistivity, the corresponding water content, cohesion, and internal frictional angle could be very well predicted.

4.3 CLAY

4.3.1 Basic soil properties of clay

- Particle Size Distribution (PSD) : <0.002 mm
- Specific Gravity (SG) : 2.6
- Liquid Limit (LL) : 66.0%
- Plastic Limit (PL) : 35.1%
- Plasticity Index (PI) : 30.9%
- pH : 3.53

4.3.2 Electrical resistivity result of clay

Results from the electrical resistivity tests for sand that has been conducted at the laboratory lab are tabulated in Table 4.3.

Electrical Resistivity ρ (Ωm)	10	7	6
Water Content (%)	30	40	50
Cohesion, c (kN/m²)	30.200	4.334	0.722
Friction angle, Φ (°)	5	7	8

Table 4.3: Electrical resistivity for clay

From the result given in Table 4.3, the electrical resistivity for clay shown clearly decreasing same as well as with the others soil sample sand and silt when the water content is increases. But the electrical resistivity of the clay was obviously small where the range between 1 Ωm to 10 Ωm. Refer to Table 2.1, it falls in category loam or clay and marl. So from the electrical resistivity test it will be considered as clay. Clay soils can be classified into four conditions according to the amount of water content. They are solid, semisolid, plastic and lastly liquid. The continuous increasing of water content will change solid clays soil to semisolid, followed by plastic and liquid. This processes are not only the changing of the condition of clay soils, it also weakens the cohesion value of the soil.

In order to look at the possible correlation of electrical resistivity obtained and the various soil parameters, the results of the electrical resistivity can be referred to the plotting graph. Graph and plotting for electrical resistivity versus water content, cohesion and friction angle are given in Figures 4.9, 4.10, and 4.11.

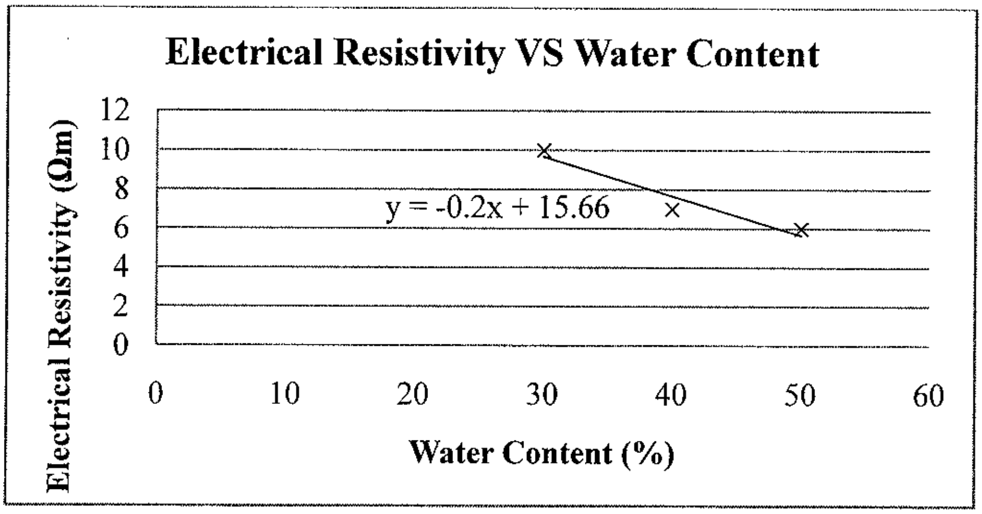


Figure 4.9: Electrical Resistivity VS Water Content

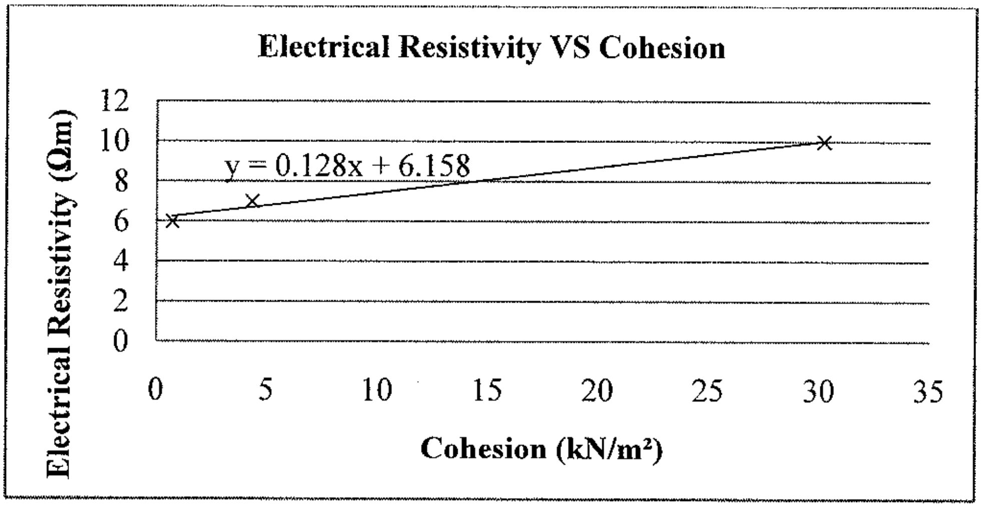


Figure 4.10: Electrical Resistivity VS Cohesion of the soil (Clay)

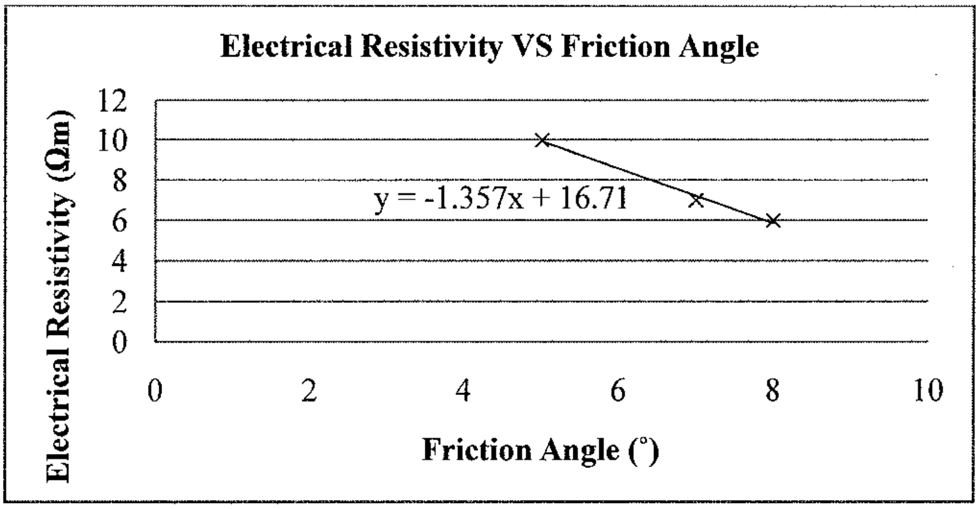


Figure 4.11: Electrical Resistivity VS Internal Frictional Angle

For clay, the result of electrical resistivity with soil water content and others shear strength parameters exactly same trend of results observed in Figure 4.9, Figure 4.10, and Figure 4.11. This same trend to some extend validates the results and correlation obtained from soil sample silt.

The combination of the correlation of the electrical resistivity with soil water content and soil shear strength parameters have been plot in graph in Figure 4.12. The plotting graph is using the same scale at x-axis as below.

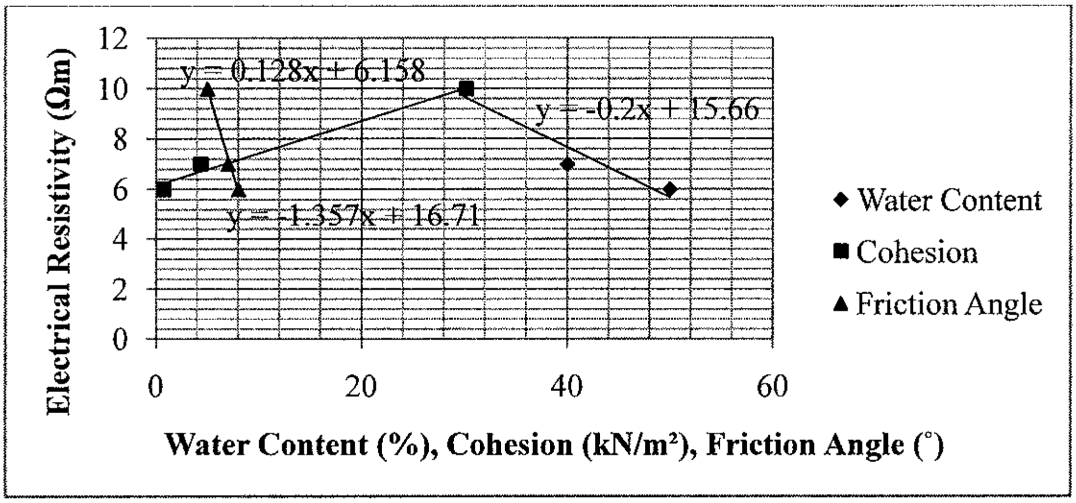


Figure 4.12: Correlation Electrical Resistivity in the soil with Water Content, Cohesion and Friction Angle

By superimposing all the plotting in one graph having the same scale in the x-axis as shown in Figure 4.12, correlation between the various soil parameters with the resistivity could be seen clearly. Hence, for certain value of resistivity, the corresponding water content, cohesion, and internal frictional angle could be very well predicted.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Laboratory electrical resistivity test using basic multimeter have been successfully conducted to obtain preliminary correlations between electrical resistivity and some soil parameters such as water content, cohesion and internal frictional angel. The change in electrical resistivity with varying moisture content could predict the type of soil. The types of soil can be predicted by determination of electrical resistivity and soil water content because the soil water content will change the soil formation; the water will either absorbed or expelled from the soil mass, which eventually affects to the shear strength of the soils.

Within the limitation of this research at this point of time, it is sufficient to say that crude correlations were established between resistivity, ρ, and some selected soil parameters as given in the results. The trend for all the soil testing in laboratory results shows some similarities and behaves as follows given in Table 5.1.

PARAMETERS	ELECTRICAL RESISTIVITY
Water Content, ↑	ρ, ↓
Cohesion, ↑	ρ, ↑
Frictional Angel, ↑	ρ, ↓

Table 5.1: Trend of Results of Sand, Silt, and Clay

5.2 Recommendation

Again, it should be noted here that more laboratory test should be conducted in order to achieved more accuracy and to precise correlations which eventually would enable electrical parameters to replace in computing FOS of soil.

The following recommendations are proposed for further study:

5.2.1 The laboratory electrical resistivity test should have more than three different percentage of water content for each soil types.

5.2.2 Determination of the shear strength of the soil, the soil samples should be obtained with different methods of laboratory strength test for comparison purposes. The tests can be considered are Triaxial Shear Test and Unconfined Compressive Strength Test

5.2.3 The sandbox test procedure should be developed with standard procedure so that the result of the laboratory electrical resistivity tests will be more accuracy and established.

REFERENCES

Pozdyakov, A. and Pozdynakov, L. 2002. Electrical fields and soil properties.

Cristine L. S. Morgan, Richard P. Wolkowski, and John M. Norman. 1998. IS IT USEFUL TO MEASURE SOIL ELECTRICAL CONDUCTIVITY?

Okan, T., and Ferhat, O. 2000. RELATIONSHIP OF ELECTRICAL RESISTIVITY AND GEOTECHNICAL PARAMETERS.

Ferhat, O., Okan, T., and Metin, A. 2009. Correlation between electrical resistivity and soil-water content: Istanbul and Golcuk.

Samoullan, A., Cousin, I., Tabbagh, A., Bruand, A., and Richard, G. 2004. Electrical resistivity survey in soil science: a review.

Stephen A. Nelson. 2009. Factors that Influence Slope Stability.

Baharom, S., and Zahir, Z. 2008. Correlation of Electrical Resistivity with Some Soil Properties in Predicting Factor of Safety in Slopes Using Simple Multimeter.

APPENDIX A

Calculation of Electrical Resistivity

ELECTRICAL RESISTIVITY TEST (SAND)

Water Content (15%)

Volt Supply (V)	TEST 1 100 V	TEST 2 200 V	TEST 3 300 V	AVERAGE
Current (A)	0.0076	0.0108	0.0116	0.0100
Volt (V)	43.000	59.400	64.900	55.767

Resistant, R (Ω) = V/I
= 5577

Electrical Resistivity, ρ (Ωm) = 2aR
= 850

Water Content (20%)

Volt Supply (V)	TEST 1 100 V	TEST 2 200 V	TEST 3 300 V	AVERAGE
Current (A)	0.0073	0.0143	0.0210	0.0142
Volt (V)	24.170	48.160	71.770	48.033

Resistant, R (Ω) = V/I
= 3383

Electrical Resistivity, ρ (Ωm) = 2aR
= 516

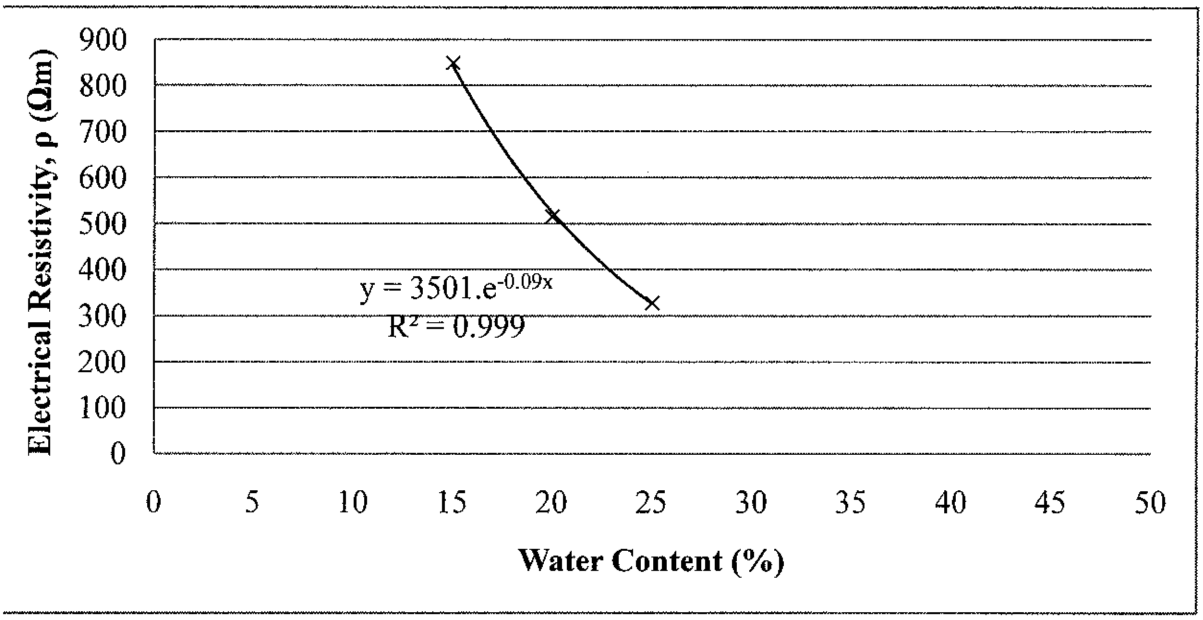
Water Content (25%)

Volt Supply (V)	TEST 1 100 V	TEST 2 200 V	TEST 3 300 V	AVERAGE
Current (A)	0.0113	0.0222	0.0330	0.0222
Volt (V)	24.060	47.900	71.530	47.830

Resistant, R (Ω) = V/I
= 2158

Electrical Resistivity, ρ (Ωm) = 2aR
= 329

Water Content (%)	15	20	25
Electrical Resistivity ρ (Ωm)	850	516	329



:LECTRICAL RESISTIVITY TEST (SILT)

Vater Content (10%)

Volt Supply (V)	TEST 1 100 V	TEST 2 200 V	TEST 3 300 V	AVERAGE
Current (A)	0.0048	0.0096	0.0154	0.0099
Volt (V)	7.900	15.950	26.538	16.796

Resistant, R (Ω) = V/I
= 1691

Electrical Resistivity, ρ (Ωm) = 2aR
= 258

Vater Content (20%)

Volt Supply (V)	TEST 1 100 V	TEST 2 200 V	TEST 3 300 V	AVERAGE
Current (A)	0.0150	0.0283	0.0498	0.0310
Volt (V)	9.520	18.910	33.100	20.510

Resistant, R (Ω) = V/I
= 661

Electrical Resistivity, ρ (Ωm) = $2\pi RL$
= 101

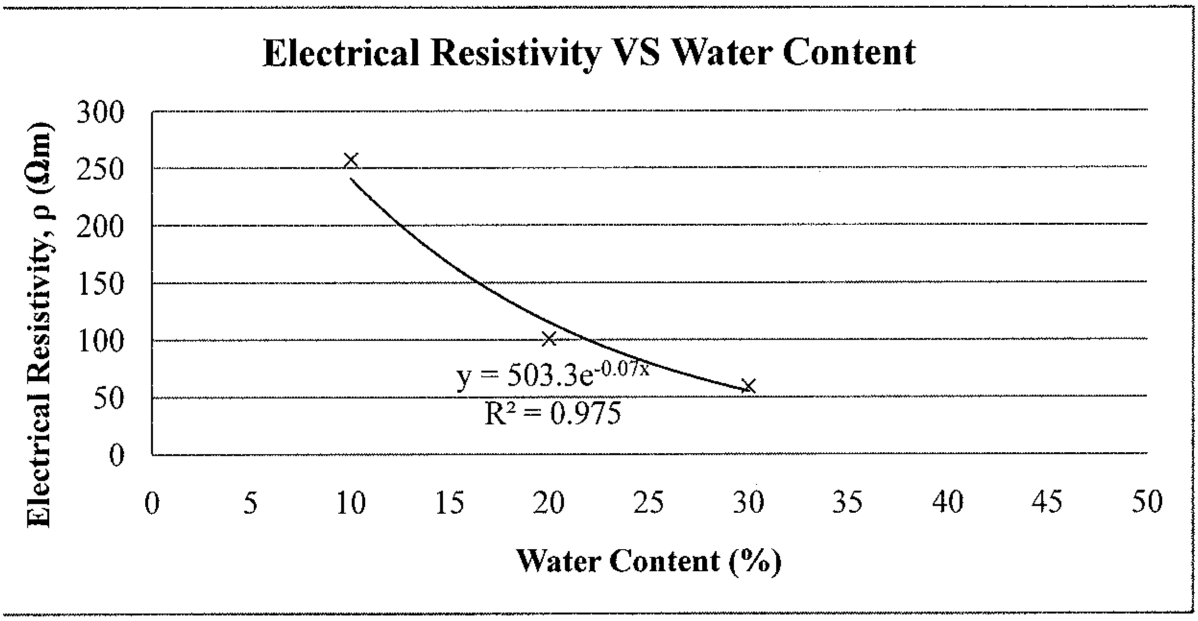
Vater Content (30%)

Volt Supply (V)	TEST 1 100 V	TEST 2 200 V	TEST 3 300 V	AVERAGE
Current (A)	0.0670	0.1308	0.1996	0.1325
Volt (V)	25.345	50.858	77.700	51.301

Resistant, R (Ω) = V/I
= 387

Electrical Resistivity, ρ (Ωm) = $2\pi RL$
= 59

Water Content (%)	10	20	30
Electrical Resistivity ρ (Ωm)	258	101	59



:LECTRICAL RESISTIVITY TEST (CLAY)

Vater Content (30%)

Volt Supply (V)	TEST 1 100 V	TEST 2 200 V	TEST 3 300 V	AVERAGE
Current (A)	0.3258	0.7227	1.0771	0.7085
Volt (V)	20.857	45.550	66.500	44.302

Resistant, R (Ω) = V/I
= 63

Electrical Resistivity, ρ (Ωm) = 2aR
= 10

Vater Content (40%)

Volt Supply (V)	TEST 1 100 V	TEST 2 200 V	TEST 3 300 V	AVERAGE
Current (A)	0.4030	0.9555	1.0728	0.8104
Volt (V)	20.000	46.476	51.340	39.272

Resistant, R (Ω) = V/I
= 48

Electrical Resistivity, ρ (Ωm) = 2aR
= 7

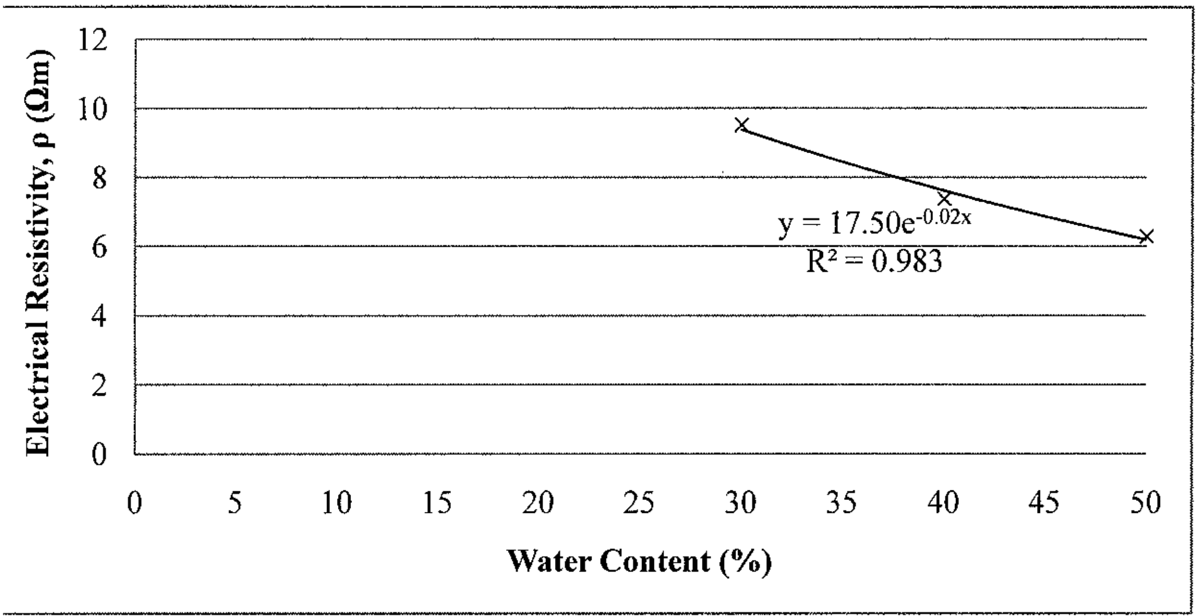
Vater Content (50%)

Volt Supply (V)	TEST 1 100 V	TEST 2 200 V	TEST 3 300 V	AVERAGE
Current (A)	0.6076	0.9175	1.0752	0.8668
Volt (V)	25.998	37.550	43.718	35.755

Resistant, R (Ω) = V/I
= 41

Electrical Resistivity, ρ (Ωm) = 2aR
= 6

Water Content (%)	30	40	50
Electrical Resistivity ρ (Ωm)	10	7	6



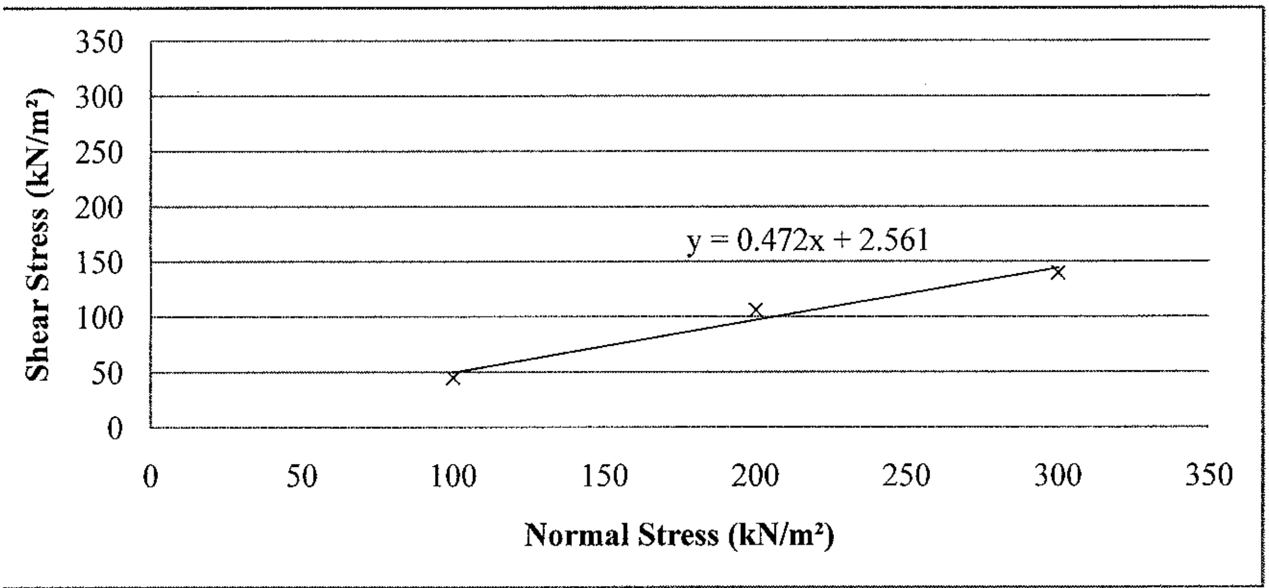
APPENDIX B

Result of Direct Shear Box Test

◆IRECT SHEAR BOX TEST (SAND)

◆Vater Content (15%)

◆Normal Stress (kN/m²)	100	200	300
Shear Stress (kN/m²)	45.310	106.183	139.870

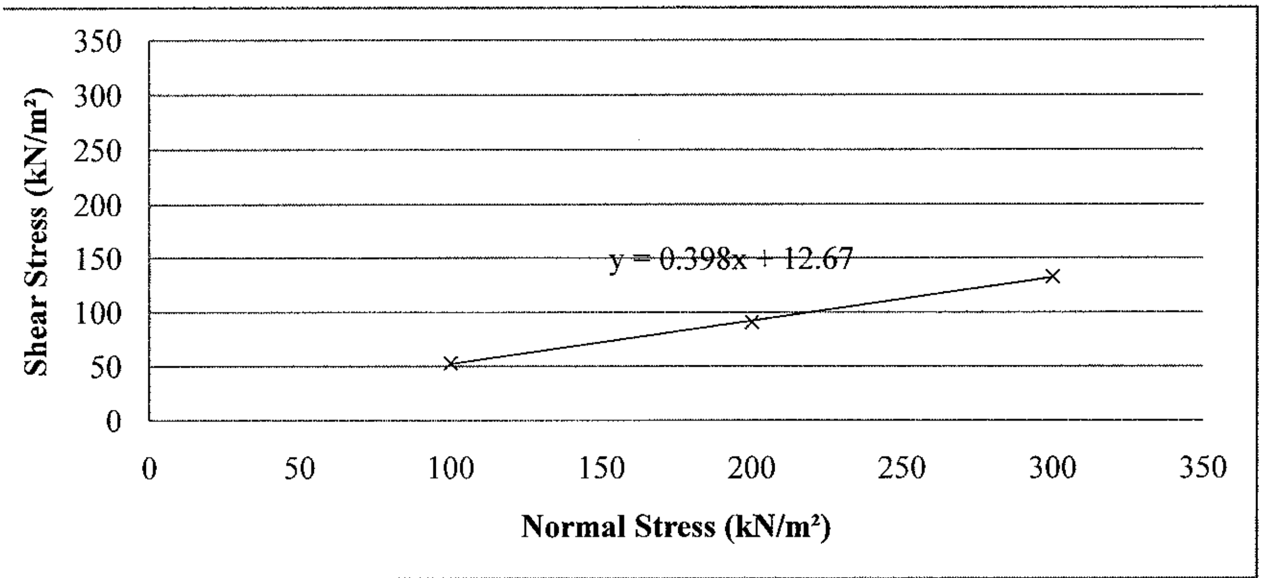


Cohesion, c (kN/m²) = 2.561

Friction angle, Φ = 10°

◆Vater Content (20%)

◆Normal Stress (kN/m²)	100	200	300
Shear Stress (kN/m²)	53.190	91.211	132.975

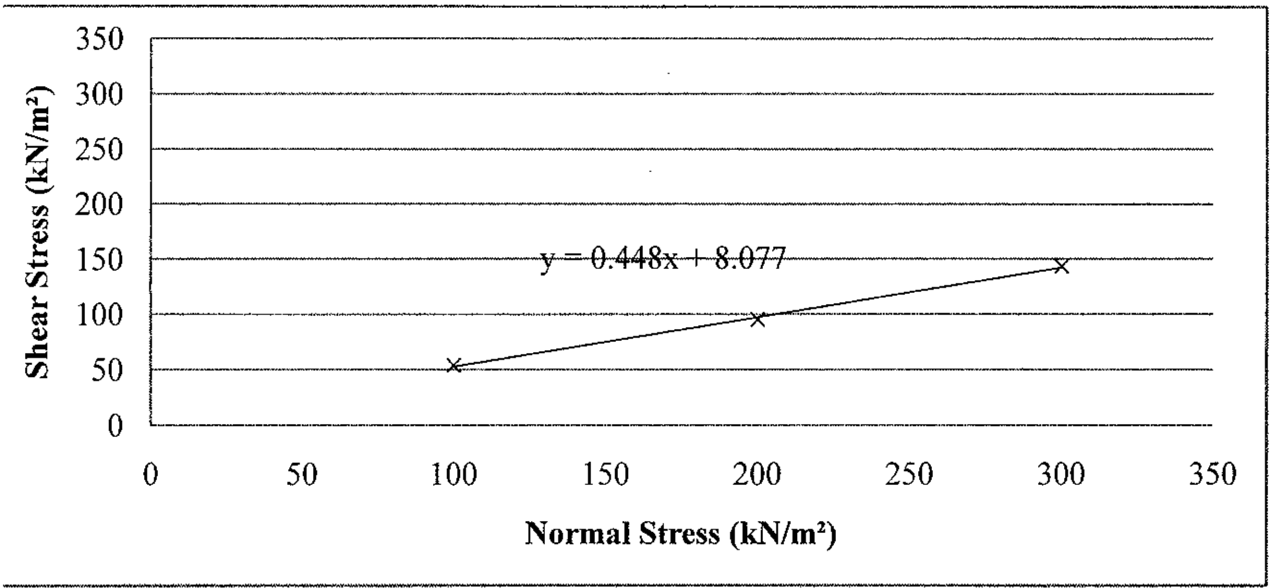


Cohesion, c (kN/m²) = 12.670

Friction angle, Φ = 8°

Vater Content (25%)

Normal Stress (kN/m²)	100	200	300
Shear Stress (kN/m²)	53.978	95.545	143.613



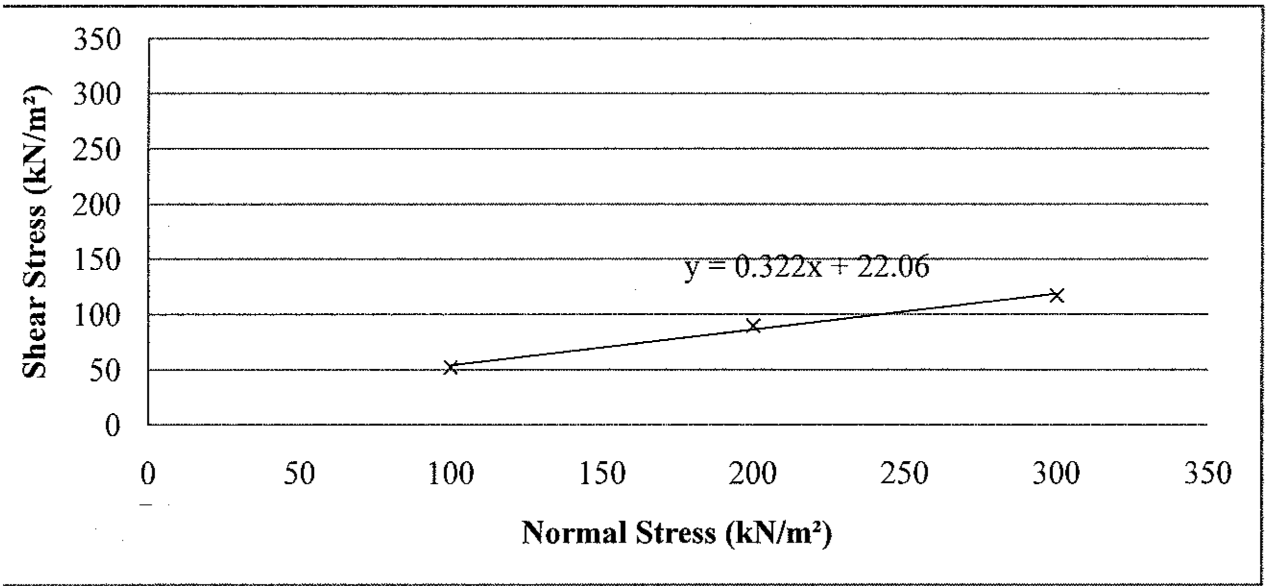
Cohesion, c (kN/m²) = 8.077

Friction angle, Φ = 9°

IRECT SHEAR BOX TEST (SILT)

Vater Content (10%)

Normal Stress (kN/m²)	100	200	300
Shear Stress (kN/m²)	52.599	89.832	117.018

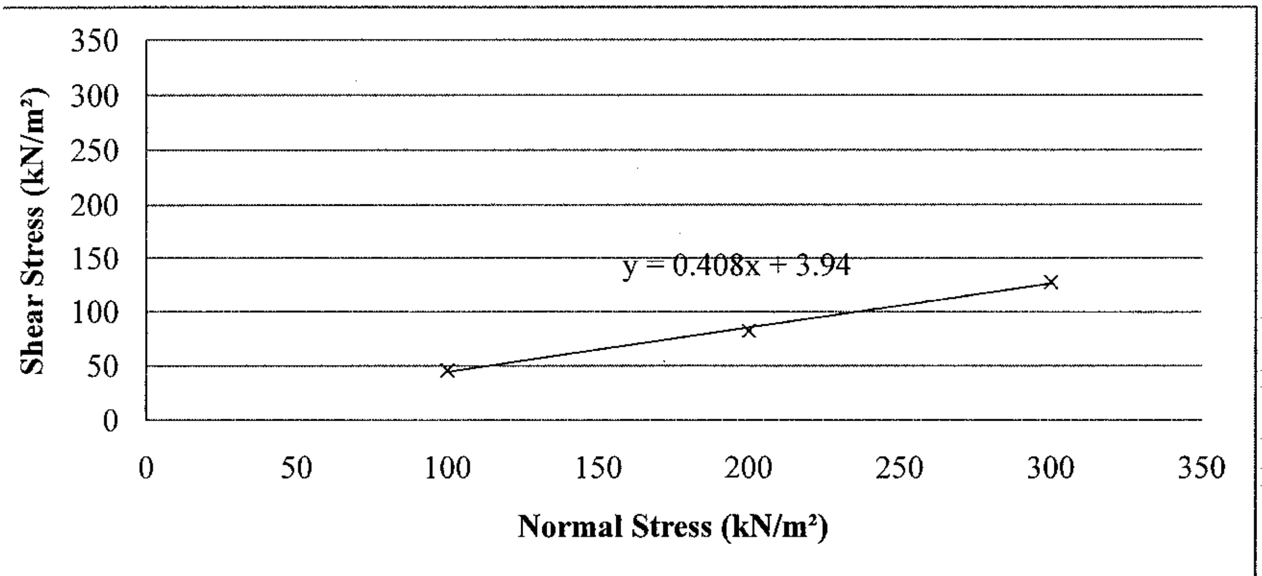


Cohesion, c (kN/m²) = 22.060

Friction angle, Φ = 7˚

Vater Content (20%)

Normal Stress (kN/m²)	100	200	300
Shear Stress (kN/m²)	46.295	82.740	128.050

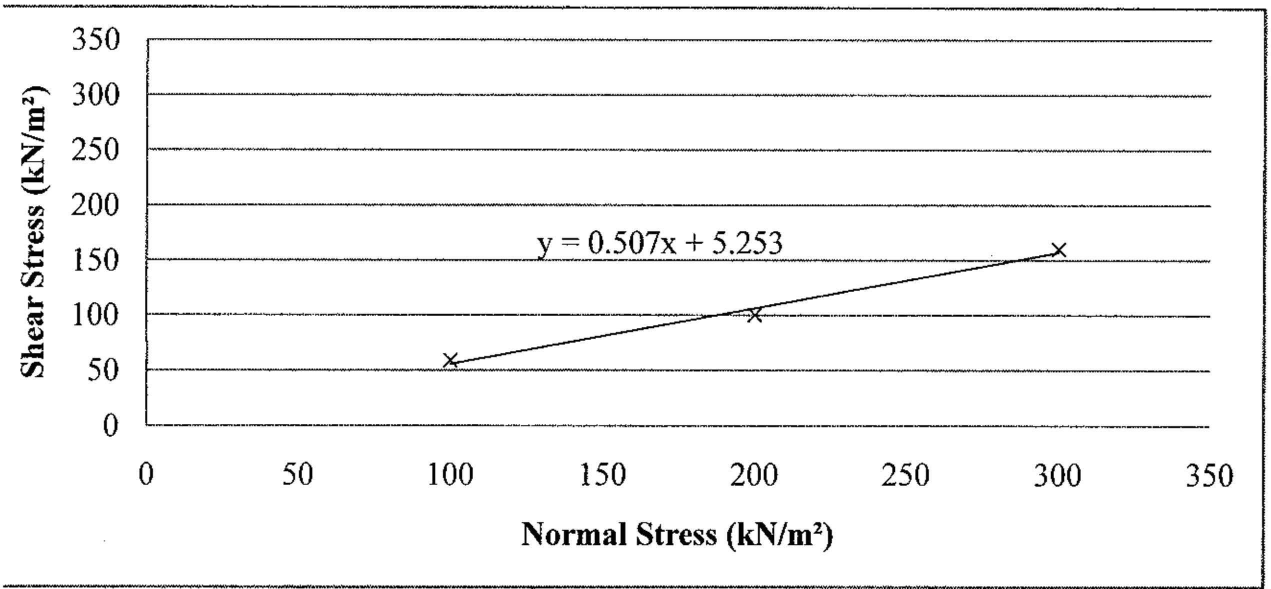


Cohesion, c (kN/m²) = 3.940

Friction angle, Φ = 8˚

Vater Content (30%)

Normal Stress (kN/m²)	100	200	300
Shear Stress (kN/m²)	59.100	100.470	160.555



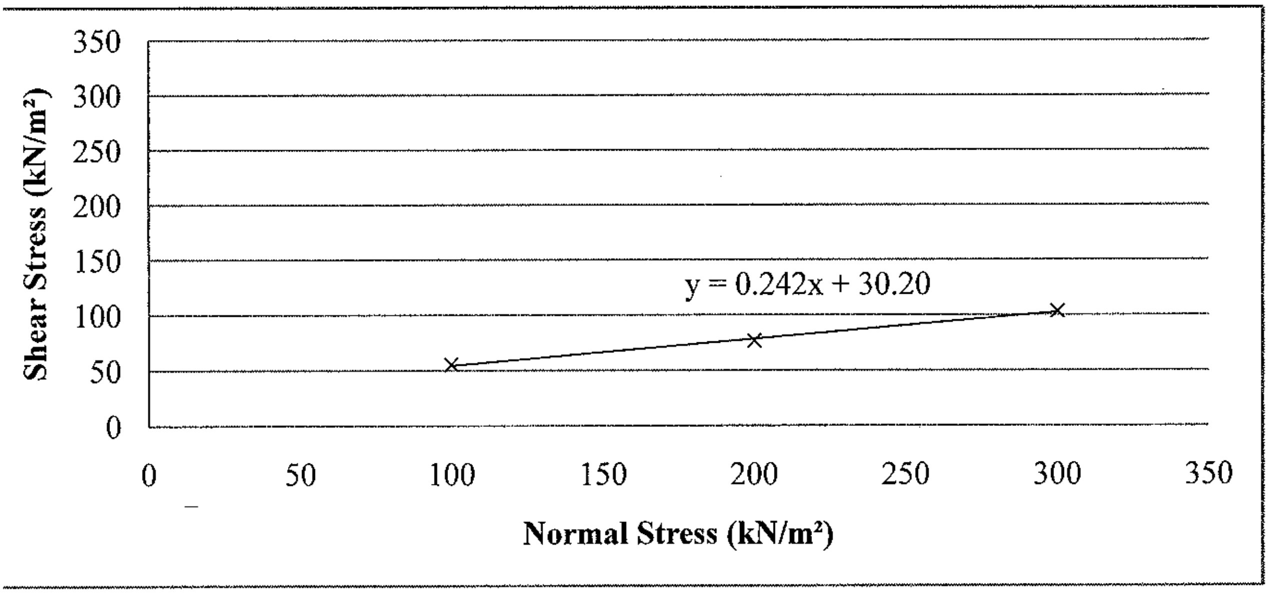
Cohesion, c (kN/m²) = 5.253

Friction angle, Φ = 11°

IRECT SHEAR BOX TEST (CLAY)

Vater Content (30%)

Normal Stress (kN/m²)	100	200	300
Shear Stress (kN/m²)	55.357	76.830	103.819

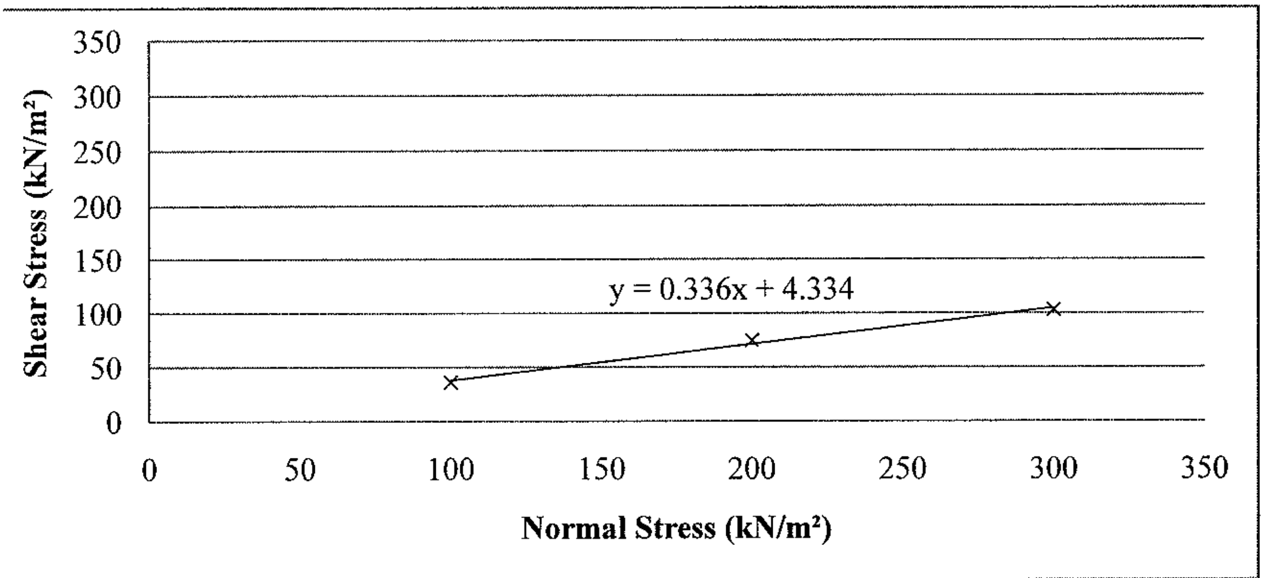


Cohesion, c (kN/m²) = 30.2

Friction angle, Φ = 5

Vater Content (40%)

Normal Stress (kN/m²)	100	200	300
Shear Stress (kN/m²)	36.248	75.254	103.622

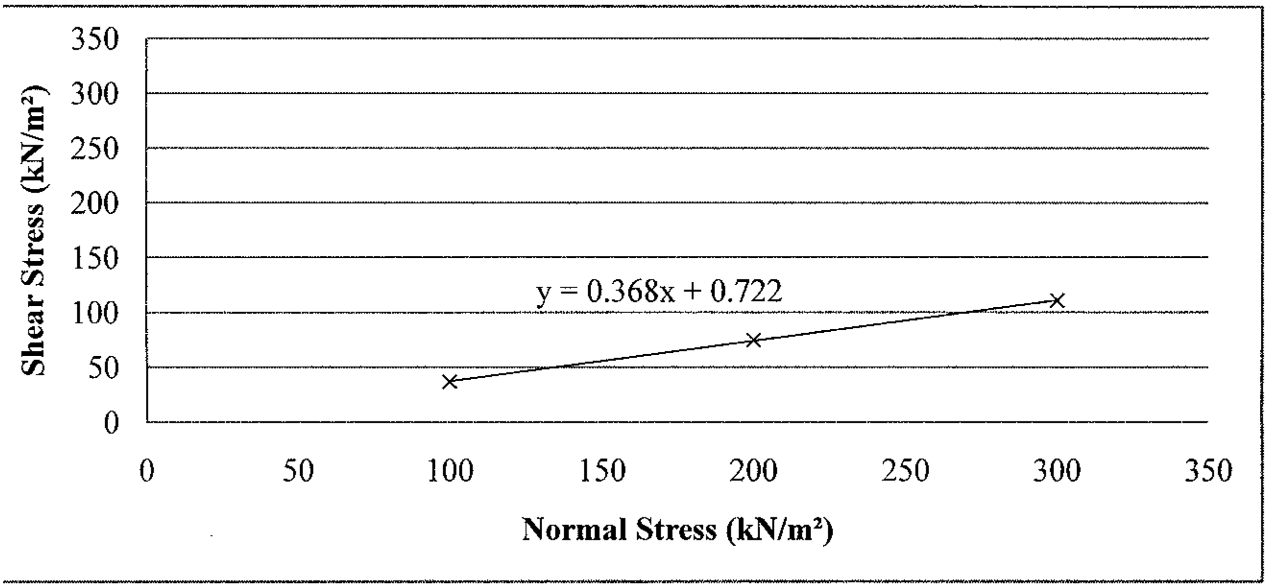


Cohesion, c (kN/m²) = 4.334

Friction angle, Φ = 7

/ater Content (50%)

ɴormal Stress (kN/m²)	100	200	300
Shear Stress (kN/m²)	37.233	75.057	110.911



Cohesion, c (kN/m²) = 0.722

Friction angle, Φ = 8

APPENDIX C

Specification of Minerals

KAOLIN (MALAYSIA) SDN. BHD. (8909-T)
(Since 1970)

MS ISO 9001 REG. NO. AR2749

SM-CR-S50	
REV . 0	

SPECIFICATION OF

REFINED KAOLIN/BROWN CLAY

GRADE : L2B20

Physical Properties

Moisture content	:	Below 5.0%
60 Mesh Residue	:	Below 20.0%

Chemical Composition

Alumina	(Al_2O_3)	:	15.0 - 25.0%
Silica	(SiO_2)	:	55.0 - 65.0%
Iron Oxide	(Fe_2O_3)	:	Below 5.0%
Potash	(K_2O)	:	Below 4.0%
Magnesia	(MgO)	:	Below 4.0%
Sodium	(Na_2O)	:	Below 3.0%
Calcium	(CaO)	:	Below 15.0%
Loss on Ignition @ 1025 °C		:	8.0 - 18.0%

Head Office / Warehouse :
No. 5 & 7, Jalan TPP 5/17, Taman Perindustrian Puchong, 47100 Puchong, Selangor Darul Ehsan, Malaysia.
Tel: 603-8061 0099 Fax: 603-8061 0033

KAOLIN (MALAYSIA) SDN. BHD. (8909-T)
(Since 1970)

MS ISO 9001 REG. NO. AR2749

SM-CR-S16	
REV. 4	

SPECIFICATION OF MINERALS

GRADE : K200

Physical Properties

Moisture content	:	Below 2.0%
60 Mesh Residue	:	Below 1.0%

Chemical Composition

Kaolinite	(Alumina Silicate)	:	90.0 - 96.0%
Iron Oxide	(Fe_2O_3)	:	Below 1.0%
Potash	(K_2O)	:	Below 3.0%
Magnesia	(MgO)	:	Below 0.5%
Loss on Ignition @ 1025 °C		:	2.0 - 6.0%

Head Office / Warehouse :
No. 5 & 7, Jalan TPP 5/17, Taman Perindustrian Puchong, 47100 Puchong, Selangor Darul Ehsan, Malaysia.
Tel: 603-8061 0099 Fax: 603-8061 0033

KAOLIN (MALAYSIA) SDN. BHD. (8909-T)
(Since 1970)

MS ISO 9001 REG. NO. AR2749

SM-CR-S06	
REV . 4	

SPECIFICATION OF MINERALS

GRADE : KM 80

Physical Properties

Moisture content	:	Below 2.5%
Viscosity (30% Solution)	:	2000 – 3000 cp
pH (30% Solution)	:	3.5 - 5.5
325 Mesh Residue	:	Below 0.5%
Average Particle Size	:	1.0 – 3.0μ

Chemical Composition

Alumina	(Al_2O_3)	:	33.0 - 38.0%
Silica	(SiO_2)	:	38.0 - 47.0%
Iron Oxide	(Fe_2O_3)	:	Below 0.5%
Potash	(K_2O)	:	Below 2.0%
Magnesia	(MgO)	:	Below 0.5%
Titanium	(TiO_2)	:	Below 0.5%
Calcium	(CaO)	:	Below 0.5%
Sodium	(Na_2O)	:	Below 0.5%
Loss on Ignition @ 1025 °C		:	14.0 - 20.0%

Head Office / Warehouse :
No. 5 & 7, Jalan TPP 5/17, Taman Perindustrian Puchong, 47100 Puchong, Selangor Darul Ehsan, Malaysia.
Tel: 603-8061 0099 Fax: 603-8061 0033