Correlation of Electrical Resistivity with Unconfined Compressive Strength, c_u for Clay Particles

by

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Dissertation submitted in partial fulfilment of

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

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(CIVIL)

Approved by,

____

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2014

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.

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(NURUL ATIQAH BINTI MUSTOFFA ASHUKRI

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First and foremost, I would like express my utmost gratitude to God for the accomplishment of this work. It cannot be done without the help and continuous supports from my project supervisor Dr Syed Baharom Azahar bin Syed Osman who always motivates me to not losing hope. It is an honour to work under his sincere guidance. The completion of this work would not have been possible without his constant inspiration and feedback. He has provided me precious time for series of discussion, valuable guideline, comment and idea as well as his kind assistant.

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ABSTRACT

Precise determination of the engineering properties of the soil such as soil strength is required for a proper design and successful construction of any structures. Conventional method that uses borehole sampling is generally time-consuming and very expensive. Thus, it is desirable to use geophysical method that is more rapid and non-invasive as an alternative. The use of electrical resistivity by geotechnical engineers has been increasing all over the world. It is a convenient method to evaluate spatial and temporal variation of moisture and heterogeneity of subsoil. This research presents the relationship of electrical resistivity with unconfined compressive strength, porosity and saturation of clay size particles. Soil samples were mixed with distilled water and left for 24hours. Electrical resistivity tests using basic multimeter, steels moulds and other related equipment were conducted in the laboratory on KM80 clay soil samples with the variations of numbers of blows and moisture content. The electrical resistivity as well as unconfined compression test had been done right after the compaction test. The value of electrical parameters such as voltage, current and resistance with corresponding value of soil parameters such as unconfined compressive strength, porosity and saturation were all recorded. The results of the tests produced some initial crude relationship between electrical resistivity and the selected parameters. Generally, the relationship between resistivity and unconfined compressive strength is proportional. On the other hand, some unique trends of behavior were observed for relationship between resistivity with porosity and saturation. Overall results showed, as the resistivity in clay increases, the unconfined compressive strength of the soil sample also increases. In order to achieve more precise correlations, more additional investigation and experiments need to be conducted.

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CHAPTER 1

INTRODUCTION

1.1 Background Study

The most important aspect in geotechnical engineering is the stability of the natural and engineered structures. Precise determination of the engineering properties of the soil such as soil strength is required for a proper design and successful construction of any structures. The engineering parameters are usually obtained through conventional method where soil sample is acquired through borehole sampling and sent for laboratory testing for soil analysis. However, conventional method is generally time-consuming and very expensive (Syed & Siddiqui, n.d). Therefore, it is desirable to use geophysical method that is more rapid and non-invasive as an alternative.

Geophysical methods (seismic, electromagnetic, electrical resistivity and magnetic method) provide information about physical properties of earth's subsurface. Geophysical methods have been used for many years in soil characterization. The general principal of geophysical exploration is to non-destructively collect data on the medium under investigation. Among the methods, those based on the electric properties appear predominantly promising because soil materials and properties are strongly correlated and can be measured through the geoelectrical properties. Electrical resistivity survey was initially applied to oil/gas exploration and later found applications in numerous other engineering fields e.g. mining, agriculture, environment, archeology, hydrology and geotechnical engineering.

Electrical resistivity measurements are useful for assessing many physical properties of the soils. Typically, an electrical current is applied to the ground through a pair of electrodes. A second pair of electrodes is then used to measure the resulting voltage. Because various subsurface materials have different resistivity values, measurements at the surface can be used to determine the vertical and lateral variation of underlying materials. Electrical resistivity method provides advantages where it is non-intrusive method of site investigation, less expensive and subsurface investigation can be conducted in a shorter time period. Another advantage is the data obtained from the method, can be processed in a very short time. The use of electrical resistivity method has increased significantly due to the benefits it has compared to the conventional method. It is one of the most suitable available techniques for preliminary subsurface investigation and geo-hazard studies. Thus, electrical resistivity can be considered as complimentary to soil boring for site investigation.

One of the crucial aspects to identify the soil strength in clay is by determining the unconfined compression strength. The soil sample obtained from borehole sampling will then sent for lab testing for the soil properties analysis. Unconfined compression test is done to measure the strength of the soil. The unconfined compression strength value obtained shows the amount of pressure that will cause the soil to collapse. Based on proper correlation between unconfined compression strength and electrical resistivity of soil, the electrical resistivity method can be used to obtain the resistivity value that will define the unconfined compression strength of soil. In this paper, the result obtained from previous laboratory and fieldworks are conducted, compared and presented in order to surface the uncertainties of their research. Recommendations are proposed in order to further improve the whole research in future.

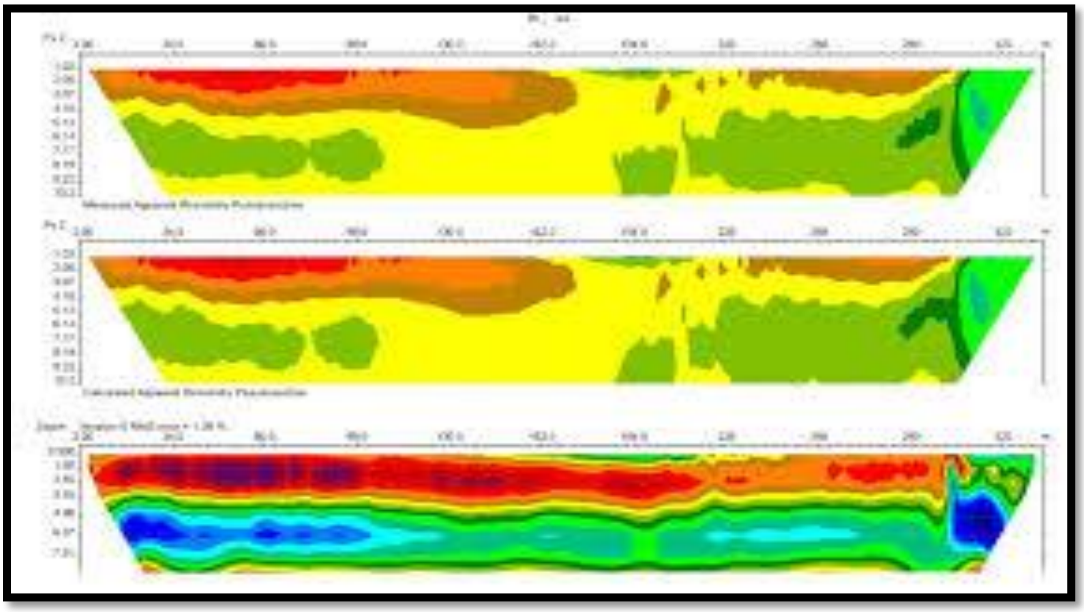

Figure 1.1 Example of Mapping Stratigraphy

1.2 Problem Statement

Soil investigation incorporating bore hole sampling will produce a reliable and relevant value of soil parameters and characteristics which part of the purpose is to understand the soil strength. However, borehole sampling is in general very expensive and time consuming. This method require disturbing soil, removing soil sample and laboratory analysis which shows that it consume a longer time in processing the essential data and conclusion. Electrical resistivity method is a convenient method to be used since the method is more rapid, cost effective and non-destructive. The use of this method in geotechnical engineering has been rapidly increasing worldwide. It evaluates spatial and temporal variation of moisture and heterogeneity of subsoil. Quantification of geotechnical properties has become a significant issue for demanding use of resistivity in engineering application.

Limited number of research has been conducted to obtain geotechnical parameters especially unconfined compressive strength by using resistivity. This has initiated this research to be part of it where it studies on relationship between resistivity and some geotechnical parameters concentrating on the unconfined compressive strength parameter. From the data collection and analysis this study will contribute in producing an accurate correlation of the parameters in future. The current gap between geophysical engineering and geotechnical engineering is able to be reduced significantly with the correlation made. Geotechnical engineers will be capable to interpret the geophysical data and apply it in their design works. Good understanding of the variation of soil parameters with resistivity can be helpful for the development of correlations. Therefore, the development of geotechnical parameters from the electrical resistivity will make this method more effective for subsurface investigation.

1.3 Objectives

The study was aimed to determine the relationship of geotechnical properties of clay with electrical resistivity. Based on the understanding of electrical resistivity and the potential it hold in determining the geotechnical properties, the research is initiated and the following objectives were set:

- To determine the relationship of electrical resistivity with unconfined compression strength for clay size particle.
- To study the relationship of electrical resistivity under controlled variables namely as moisture content and compaction blows with geotechnical parameters such as porosity and saturation.

1.4 Scope of Study

The research covers the experiments performed on laboratory level. Several laboratory tests are conducted to obtain both electrical resistivity and engineering soil characteristic data for relationship analysis. Clay is chosen to be the type of soil to be used as the soil sample in the experiment. Soil sample was bought and collected from a local company; Kaolin Malaysia Sdn. Bhd. This is to ensure a homogenous soil sample is provided for the study. The clay sample were subjected to electrical resistivity test, compaction and unconfined compression test. The index properties such as particle size distribution of the sample are also to be determined in order to know more about the soil characteristics.

1.5 Relevancy of Study

The electrical resistivity method plays a significant role in the exploration of natural resources like groundwater and mineral deposits. In designing and checking of geotechnical structure, the strength parameter such as unconfined compressive strength is an important parameter beside other parameters like porosity and saturation. These soil properties are essential to indicate the stability of a certain slope or any structures. Therefore, rather than using conventional method in obtaining those parameters, electrical resistivity can be used as an alternative. This geophysical method allows measurement of soil from soil surface to any depth without disturbance and less time consuming.

1.6 Feasibility of Study

Electrical resistivity surveys have been used for many decades in geotechnical investigation, mining and hydro geological. More recently, it has been used for environmental surveys. The electrical resistivity method plays a significant role in the exploration of natural resources like groundwater and mineral deposits. Although there are several researchers in the past and recent years has included correlation of electrical resistivity with various parameters. The general approach behind this quick assessment system is to eliminate the usage of physical soil parameters; unconfined compression strength and replace these physical parameters with their correlated electrical parameters such resistivity, voltage etc.

CHAPTER 2

LITERATURE REVIEW

2.1 Electrical Resistivity

In 1912, Schlumberger introduced the idea of using electrical resistivity measurement to study subsurface rock bodies. Oil companies adopt this method to be applied in geology in searching for petroleum reservoirs and outlining geological formations (Samouëlian, Cousin, Tabbagh, Bruand & Richard, 2005). Nowadays, the application of electrical resistivity method in geotechnical engineering is increasing.

Ozcep, Yildirim Asci & Karabulut (2010) define that an electrical resistivity of soil is the measure of its resistance to the passage of current through it. The soil is a three phase heterogonous material consisting solid, liquid and gases. The solid and liquid plays an important role in soil spontaneous electrical phenomena and in behavior of electrical fields, artificially generated in soil. The electric current flows in soil through electrolytic conduction; i.e. as a result of ion movement in pore fluids.

Electrical potential and current relates to the geometrical dimension of the specified region through resistivity. Resistivity is the reciprocal of conductivity. Due to the movement of charges, electrical conduction takes place where charges are displaced from the original equilibrium condition under the application of electric potential. Nevertheless, charge density depends on the applied electric field and resistivity of the material. Definition of resistivity is considering current flow through a cylindrical section. To further define resistivity, assuming a cylindrical section with cross sectional area of A and L, if current flow I is through section resistance R and potential drop across the section is V, then resistivity can be expressed by the following equation:

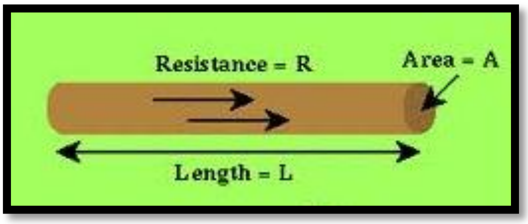

FIGURE 2.1 The schematics of cylindrical section

$$V = IR \qquad \text{(i)}$$

$$\rho = R\left(\frac{A}{L}\right) \qquad \text{(ii)}$$

where,

ρ = *Electrical Resistivity*	*I = Current*
R = Resistance of material	*V= Potential*
A = Cross sectional area	*L = Length*

2.2 Electrical Resistivity and Hydraulic Conductivity

The relationship between electrical resistivity and hydraulic conductivity has been studied but contradictory results have been reported. Direct correlations between electrical resistivity and hydraulic conductivity (i.e., hydraulic conductivity increases as electrical resistivity increases) have been reported for some soils, whereas inverse relationships (i.e., hydraulic conductivity decreases as electrical resistivity increases) have been reported for others. (Abu Hassanein, Benson & Blotz, 1996) Previous research concludes that the relationship between hydraulic conductivity and electrical resistivity is inverse for soils of a particular type. For example, saturated dense clean sands have lower porosity, lower hydraulic conductivity, and greater electrical resistivity than loose clean. Conversely, when a comparison is made between the electrical resistivity and hydraulic conductivity of different types of soils (e.g., clay, sand, silt), the relationship between electrical resistivity and hydraulic conductivity is direct, with coarse grained soils generally having the highest electrical resistivity and highest hydraulic conductivity. The direct relationship between electrical resistivity and hydraulic conductivity for soils of different type is primarily due to changes in surface conductance; that is, surface conductance decreases as soils become increasingly coarse grained. For compacted clays, previous research reports that the relationship between electrical resistivity and hydraulic conductivity is not unique since the same electrical resistivity can be attained for specimens having different structure and hydraulic conductivity. A distinct relationship between electrical resistivity and volumetric water content exists and suggest that this relationship may prove useful in assessing the hydraulic conductivity of compacted soil liners.

2.3 Factors Affecting Resistivity

2.3.1 Nature and arrangement of solid constituents

The electrical resistivity is a function of a number of soil properties, including the nature of the solid constituents (particle size distribution, mineralogy), arrangement of voids (porosity, pore size distribution, connectivity), degree of water saturation (water content), electrical resistivity of the fluid (solute concentration) and temperature. The air medium is an insulator (i.e. infinitively resistive), the water solution resistivity is a function of the ionic concentration, and the resistivity of the solid grains is related to the electrical charges density at the surface of the constituents. These parameters affect the electrical resistivity, but in different ways and to different extents. Electrical resistivity experiments have been performed to establish relationships between the electrical resistivity and each of these soil characteristics.

Turesson (2006) mentioned, in earth material, resistivity decreases with increasing water content make it easier for an electric current to flow through the material. Consequently, non-porous material (holding little water) will have high resistivity values. Silts, clays and coarse grained and also fine grained soil mixtures have comparatively low resistivity values. In the context of soil mapping, electrical resistivity exhibits a large range of values from 1 V m for saline soil to several 105 V m for dry soil overlaying crystalline rocks (Figure 2.2). The electrical conductivity is related to the particle size by the electrical charge density at the surface of the solid constituents. In clay soil, the electrical charges located at the surface of the clay particles lead to greater electrical conductivity than in coarse-textured soils because of the magnitude of the specific surface. The electrical resistivity recorded by Giao et al. (2003) on 25 clay samples collected worldwide ranged from 1 to 12 V m. The geometry of the pores (void distribution and form) determines the proportion of air and water according to the water potential.

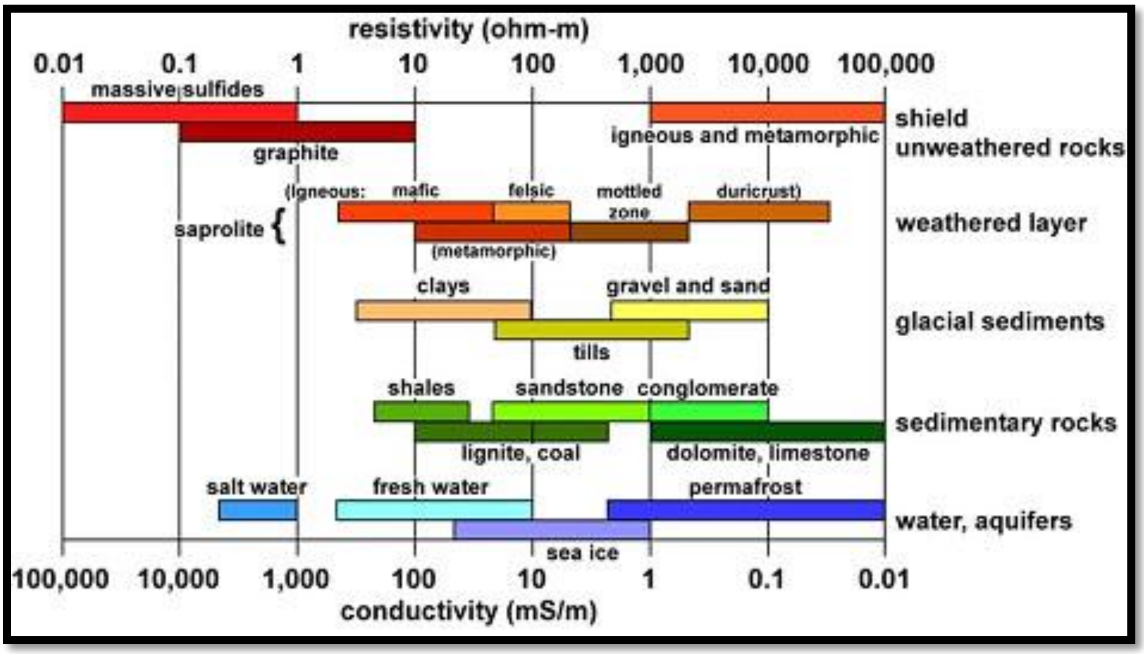

FIGURE 2.3 Typical range of electrical resistivity and conductivity of earth material

2.3.2 Water content

Electrical current in soils is mainly electrolytic, i.e. 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.

2.3.3 Pore fluid composition

Electrical conduction in electrolytic solutions, moist soils, and water-bearing rocks occurs as a result of the movement of ions. The ability to transmit ions is governed by the electrical resistivity, a basic property of all materials. For soils, electrical resistivity depends on many factors such as porosity, electrical resistivity of the pore fluid, composition of the solids, degree of saturation, particle shape and orientation, and pore structure Archie relates the electrical resistivity of saturated soil p to the electrical resistivity of its pore fluid p", by the relationship

$$\rho = \alpha \rho_w n^{-m} \qquad \text{(iii)}$$

where n = porosity; and a and m = constants that depend on the type of soil or rock Eq. (iii), which is generally referred to as Archie's Law shows that the electrical resistivity of saturated soil is sensitive to the porosity, the electrical resistivity of the pore fluid, and characteristics of the solids and the structure of the pores (i.e., different soils with same p", and n may have different a and m*)*. As the resistivity of the pore fluid increases or the porosity decreases, the electrical resistivity of the soil increases. The constant m is usually referred to as the cementation factor and it varies between 1.4 and 2.2 for clean sands and gravel encountered in ground-water aquifers. Electrical conduction in clean sands and gravels occurs primarily in liquid contained in the pores. In clayey soils and clay-bearing rocks, however, electrical conduction occurs in the pores and on the surfaces of electrically charged clay particles. For clays, surface conductance can be a significant factor affecting the bulk electrical resistivity of the soil. Thus, for clays, clay-rich soils, and clay-rich rocks, parallel resistor models were developed to account for conduction through the pore fluid and along the particle surfaces Electrical resistivity also depends on degree of saturation where increasing the degree of saturation results in lower electrical resistivity.

2.4 Previous Research

In order to explore electrical resistivity and its relationship with other soil properties phenomenon, several attempts have been made by many researchers. Water content and electrical resistivity of soil has been successfully correlated by various researchers. The correlation models showed a clear correlation between soil moisture and resistivity. (Pozdnyakova et. al. 2002; Cosenza et. al. 2006; Ozcep et. al. 2010) Cosenza, Marmet, Rejiba, Cui, Tabbagh & Charley (2006) conducted 2D electrical resistivity survey with Wenner electrode configuration to establish qualitative and quantitative correlations between resistivity and CPT values. No clear relationship between cone resistance and resistivity was observed and authors suggested an extensive study to be conducted for more precise correlations. Sudha, Israil, Mittal & Rai (2009) investigated relationship of electrical resistivity and SPT value using 2D electrical resistivity tomography at two different sites in India. The obtained correlations indicated a site-specific relationship between electrical resistivity and N values. Liu, Du, Han & Gu (2008) investigated the electrical resistivity of soil cement-admixture, at varying cement-mixing ratio, water content and curing time. The results show a good correlation of SPT and compressive strength with electrical resistivity of soil-cement admixtures. A thorough study of geotechnical properties and resistivity of clayey soil is conducted by Giao, Chuy, Kim and Tanaka (2002) and found poor correlation between plasticity index, unit weight and organic content.

So far, there is no research work has been carried out to correlate electrical resistivity with strength properties of soil; unconfined compression strength using a simple multimeter. There is only some preliminary work done by Syed & Siddiqui (2011, n.d) discussing on the basic correlation between field electrical resistivity and several properties such as angle of friction, cohesion, bulk density, standard penetration test (SPT) and factor of safety (FOS). The research work results are quite encouraging. Extensive field and laboratory test is suggested to be performed in order to establish more precise correlation. This will eventually enable electrical resistivity to replace physical parameters in computation of unconfined compressive strength and properties of the soil.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

This research aimed to determine the relationship between geotechnical properties of clayey soil with electrical resistivity. Soil samples; clay were bought from the specific supplier. Laboratory testing on the collected samples were conducted to determine soil type, index properties, optimum dry unit weight and moisture content and compressive strength. Electrical resistivity was also measured in the laboratory to determine the correlation of geotechnical properties with the soil resistivity. Figure 3.1 shows the research methodology used for the research.

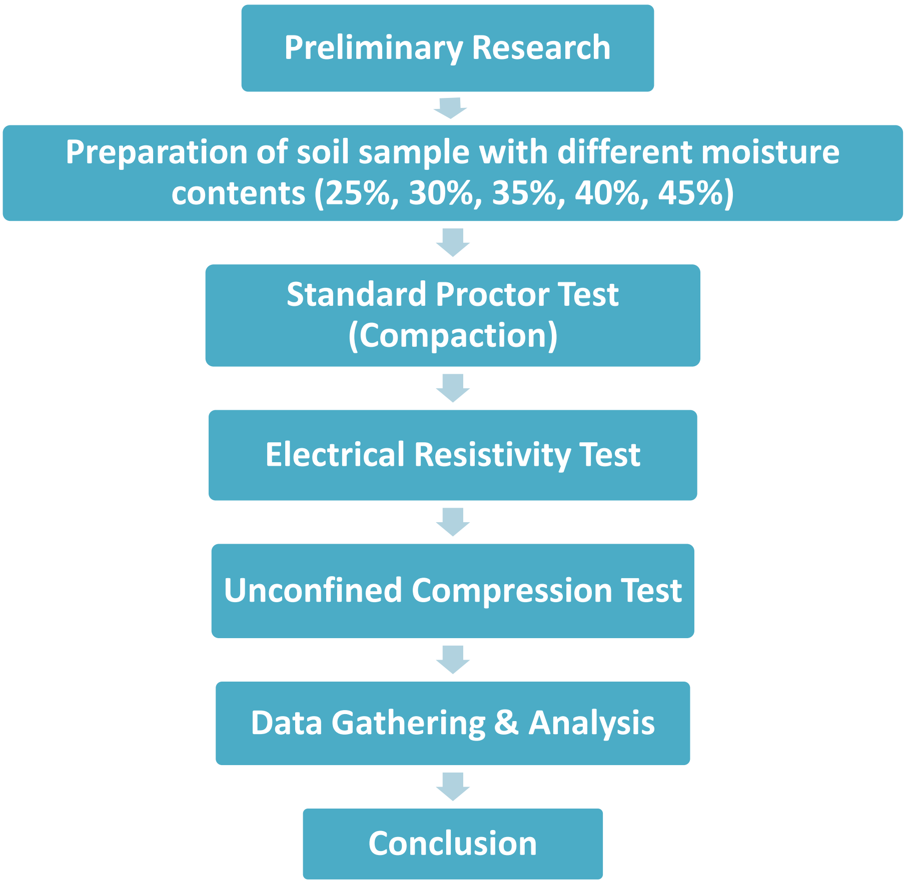

FIGURE 3.1 Research methodology

3.2 Laboratory Testing

The moisture content of the clay sample is set up into five different moisture contents; 25%, 30%, 35%, 40%, 45%). Each moisture contents will have four different numbers of blows ranging from 15, 25, 35 and 45 blows for soil compaction. The laboratory works start up with mixing of 2 kg of the soil according to its moisture content. The sample is kept airtight and left for 24 hours. The compaction together with electrical resistivity test and unconfined compression test is performed on the next day after the mixing process. Plastics are used around the mould to ensure during the electrical resistivity test, the material of the mould would not affect the current reading. For compaction, automated machine is used instead of the drop hammer. This is due to a better compaction and a more homogeneous compaction can be done by the help of the equipment. After compaction, for electrical resistivity test, two circular aluminium disc electrodes were connected to a DC power supply and a multimeter. The voltage is varies between 30V, 60V and 90V is applied to the specimen. The resulting values of current are measured. For unconfined compression test (UCT), soil sample was extruded from the compacted soil in the mould to be tested in UCT. Reading of deformation gauge and force gauge is measured. Then, test for moisture content is performed. All the data are gathered and analyzed. Figure 3.2 shows the electrical resistivity test done on laboratory scale.

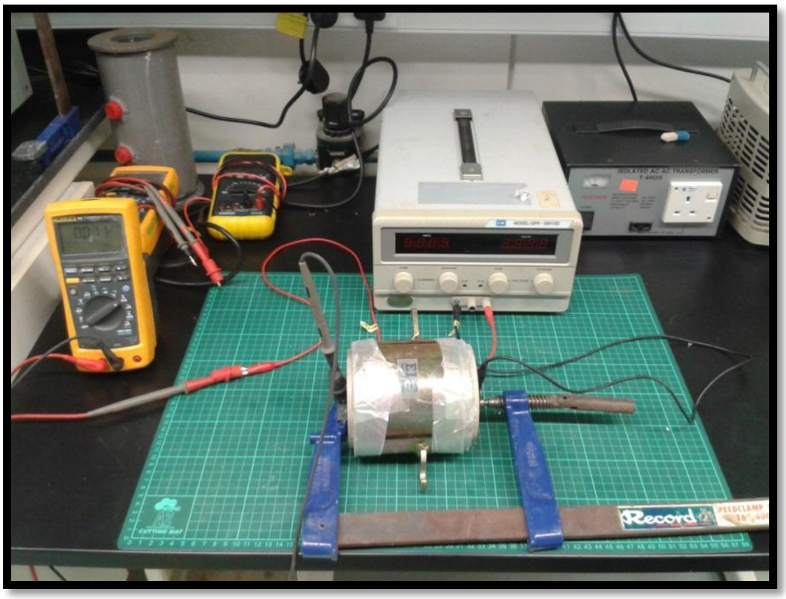

FIGURE 3.2 Electrical resistivity test done on laboratory scale.

3.2.1 Sieve Analysis

Particle size distribution is one of the most important characteristics of soil in engineering implications. This property indicates how the soil would interact with water. Moreover, plasticity, permeability and electric conductivity, consolidation, shear strength and chemical diffusion are dependent on particle size distribution. In this study, sieve analyses were conducted on the collected samples in the laboratory according to ASTM standard D422.Sieve analysis was carried out using 65 gm of air dried samples to determine the particle size distribution Aggregation of the particles was broken by mortar and rubber covered pestle.

FIGURE 3.2.1 Sieve equipment

The grain size distribution was conducted using a set of US standard sieves (No. 4, 10, 20, 40, 60, 100, 200 and pan). A lid was also placed at the top to provide cover of the sample. Weight of each sieve was determined before staking. Stack of sieves were shaken by mechanical sieve shaker. After 5 min the stack of sieves were removed. Combined weight of each sieve and sample was measured. Wet washing was conducted to prevent aggregation of large clumps of fine particles in soil samples retained on sieve No. 200. A bowl was placed under the sieve. Washing of sample was continued until clean water was coming out. Remaining sample was dried in the oven and weight was measured. Figure 3.1.1 showed the stake of sieves used in sieve analysis in geotechnical engineering laboratory of the UTA.

3.2.2 Water Content

Most laboratory tests in soil mechanics require the determination of water content. Water content is usually expressed in percent. Water content is defined as

$$w = \frac{\text{weight of water present in a given soil mass}}{\text{weight of dry soil}}$$

Apparatus:

- Moisture cans which are available in various sizes diameter.
- Oven with temperature control. For drying, the temperature of oven is generally kept between 105°C to 110°C. A higher temperature should be avoided to prevent the burning of organic matter in the soil.
- Scientific balance. The balance should have a readability of 0.01g for specimens having mass of 200g or less. If the specimen has a mass over 200g, the readability should be 0.1g.

3.2.3 Atterberg Limit Test

To obtain Liquid limit and Plastic limit of the soil samples, ASTM standard D4318 method was adopted. Soil Samples passing through No. 40 sieve were used in the test. Moisture cans were labelled and their individual mass was recorded. When a cohesive soil is mixed with an excessive amount of water, it will be in a somewhat liquid state and flow like viscous liquid. However, when this viscous liquid is gradually dried, with the loss of moisture it will pass into a plastic state. With further reduction of moisture, the soil will pass into semisolid and then into a solid state.

The moisture content at which the cohesive soil will pass from a liquid state to a plastic state is named as the liquid limit of the soil. Similarly, the moisture content at which the soils changes from a plastic to semisolid state and from a semisolid state to a solid state are referred to as the plastic limit and the shrinkage limit, respectively. These limits are referred to as the Atterberg Limit (Das, 2010).

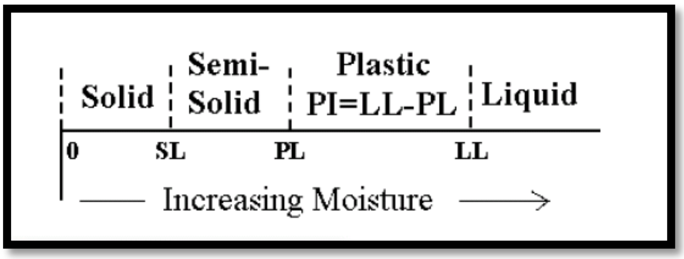

FIGURE 3.2.3 Atterberg Limit

Apparatus:

- Porcelain evaporating dish
- Grooving tool and spatula
- Distilled Water
- Ground Glass Plate
- Penetration Machine
- Scientific Balance

3.2.4 Specific gravity

To obtain specific gravity of the soil sample large pyknometer method according to BS1337 was adopted. The sample was divided into two specimens, each weighing 400g by riffling. It is then put into the oven for drying at 105^{o}C – 110^{o}C. The pyknometer was cleaned, dried and the whole assembly top was weighed to the nearest 0.5g. The jar with the screw-top assembly and the first specimen is weighed to the nearest 0.5g. Water is added to about half fill of jar. The mixture is stirred thoroughly with the glass rod to remove air trapped in the soil. The screw cap assembly is tightened and it is filled with water. The apparatus is leaved for 24 hours at room temperature. The pyknometer is dried outside and weighed. Lastly, the pyknometer is emptied, filled with water completely and is weighed. The experiment is repeated with the second specimen.

Apparatus:

- Pyknometer set
- Electronic balance
- Glass rod

FIGURE 3.2.4 Pyknometer Set

3.2.5 Electrical Resistivity Test

All samples were stored in airtight containers so as to reduce the absorption of moisture. After basic test such above mentioned were conducted to ascertain some basic properties of the soil samples. Following this, samples were then prepared for the second phase tests which were consisted of the electrical resistivity test.

Apparatus:

- Soil mixer
- Standard Proctor Hammer
- Two 100mm aluminium electrodes
- 200 volts DC power supply & hand held multimeter

For every specimen, certain weight of soil such 2kg and 4 kg were mixed with a certain amount of distilled water according to the percentage of moisture content required which ranges between 25% to 40%. Mixing was done by means of a soil mixer and the samples were then left aside for at least 24hour in the mixing bowl wrapped with plastic.

Prior to the compaction process, the internal perimeter of the mould was lined with a thick plastic material for easy removal of the specimen once the mould was disassembled and also during the electrical resistivity test so that the mould which made by steel does not affect the reading. The specimens were then compacted in three equal layers using standard proctor hammer that delivers blows ranging from 15 to 45 blows per layer. The procedure for compaction is the same as prescribed in BS 1377.

Moreover, the mould was disassembled upon completion of compaction and the specimen were placed between two circular aluminium electrodes for the purpose of determination of electrical resistivity using disc electrode method according to BS 1377. The specimens then along with aluminium disc were connected to both positive and negative terminals of a DC power supply and also connected to a multimeter where an initial potential with varying voltage from 30V, 60V and 90V were applied. The resulting values of current in ampere were the recorded. The electrical resistant and resistivity of the samples were calculated using formula.

3.2.6 Unconfined Compression Test

Test specimen is sampled by using 38mm sampling tube with sharp cutting edge. The specimen is then being set up centrally on the lower platen on the unconfined compression test machine. The motor is switched on and the reading at regular interval of 0.2mm strain dial readings is recorded. The loading and recording of the readings is continued until it is certain that failure has occurred. From the readings, stress-strain curve is plotted and value of unconfined compressive strength in kPa is obtained.

Apparatus:

- Unconfined compression test machine
- Apparatus for extruding and trimming of soil specimen

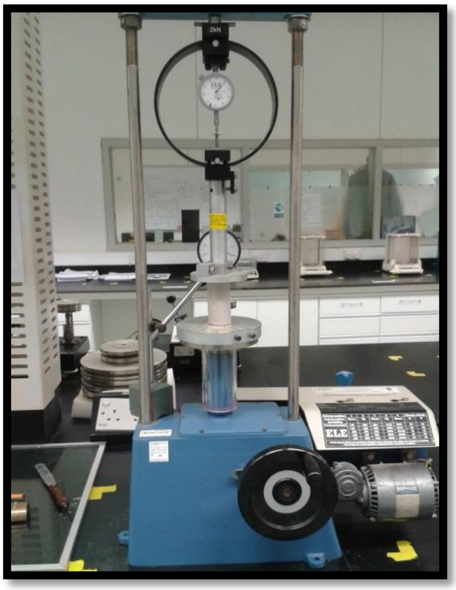

FIGURE 3.2.6 Unconfined Compressive Strength Machine

3.3 Project Timeline

Table 3.3 shows the Gantt chart planned for the project.

TABLE 3.3 Gantt chart

Detail / Week	FYP 1														FYP 2													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Preliminary Research	■	■	■	■	■	■																						
Preparation of Soil Sample										■	■	■	■	■	■	■	■	■	■	■								
Conducting Laboratory Tests										■	■	■	■	■	■	■	■	■	■	■								
Gathering data										■	■	■	■	■	■	■	■	■	■	■								
Analysing data												■	■	■	■	■	■	■	■	■	■	■						
Project Dissertation																					■	■	■	■	■	■	■	■

3.4 Key Project Milestone

Table 3.4 shows the key milestone to be achieved in the project.

TABLE 3.4 Key milestone

Detail / Week	FYP 1														FYP 2													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Completion of Preliminary Research						◆																						
Submission of Extended Proposal						◆																						
Submission of Interim Report														◆														
Completion of Soil Sample Preparation																					◆							
Completion of Laboratory Testing																					◆							
Completion of Data Gathering & Analysis																							◆					
Submission of Project Dissertation																												◆

CHAPTER 4

RESULT AND DISCUSSION

4.1 Correlations of Electrical Resistivity with Geotechnical Parameters

Total of 20 clay samples were tested using compaction test, electrical resistivity test and unconfined compression test to obtain the data for the analysis of correlation between electrical resistivity and geotechnical engineering parameters including unconfined compressive strength. The results were tabulated in Table 4.1.

TABLE 4.1 Results obtained from laboratory experiment

Moisture content	No. of Blows	Porosity (%)	Saturation	Resistivity (Ωm)	Unconfined compressive strength (kPa)
25%	15	0.43	0.85	87.28	375.70
	25	0.42	0.87	49.00	366.90
	35	0.38	1.00	9.85	407.02
	45	0.39	1.00	33.61	446.90
30%	15	0.43	1.00	17.42	195.00
	25	0.45	0.96	16.67	145.44
	35	0.44	1.00	12.82	119.73
	45	0.44	0.97	12.07	97.03
35%	15	0.48	0.98	15.67	41.48
	25	0.47	1.00	10.27	48.44
	35	0.48	0.99	10.60	48.87
	45	0.48	0.98	11.52	46.35
40%	15	0.51	0.97	13.54	25.90
	25	0.52	0.96	11.18	30.70
	35	0.52	0.96	9.10	20.07
	45	0.52	0.95	12.32	30.57
45%	15	0.57	0.87	12.66	17.07
	25	0.62	0.70	12.91	17.32
	35	0.55	0.94	9.81	15.42
	45	0.55	0.93	19.44	15.84

Observation from the above table shows that there is a certain pattern of resistivity as the number of blows increases. For certain moisture content, resistivity increases at first with 15 blows, it then continues to decrease further until the 35 blows. It then changes at 45 blows where resistivity value increases back. This pattern can clearly observed in clay sample with 25% and 40% moisture content whereas the other sets of moisture content shows different patterns. In 30% moisture content, the resistivity is continuingly decreasing while in 35% and 45% moisture content, the resistivity fluctuates as the compaction increases.

Based on the data collected, several graphs has been plotted to analyze the relationship between resistivity and several geotechnical parameters. Several correlations with resistivity are made by varying the geotechnical parameters. These are presented in the graphs below. Conclusion of project is determined according to the analysis of the correlations. For simplicity, unconfined compressive strength will be referred as UCS in the graphs below.

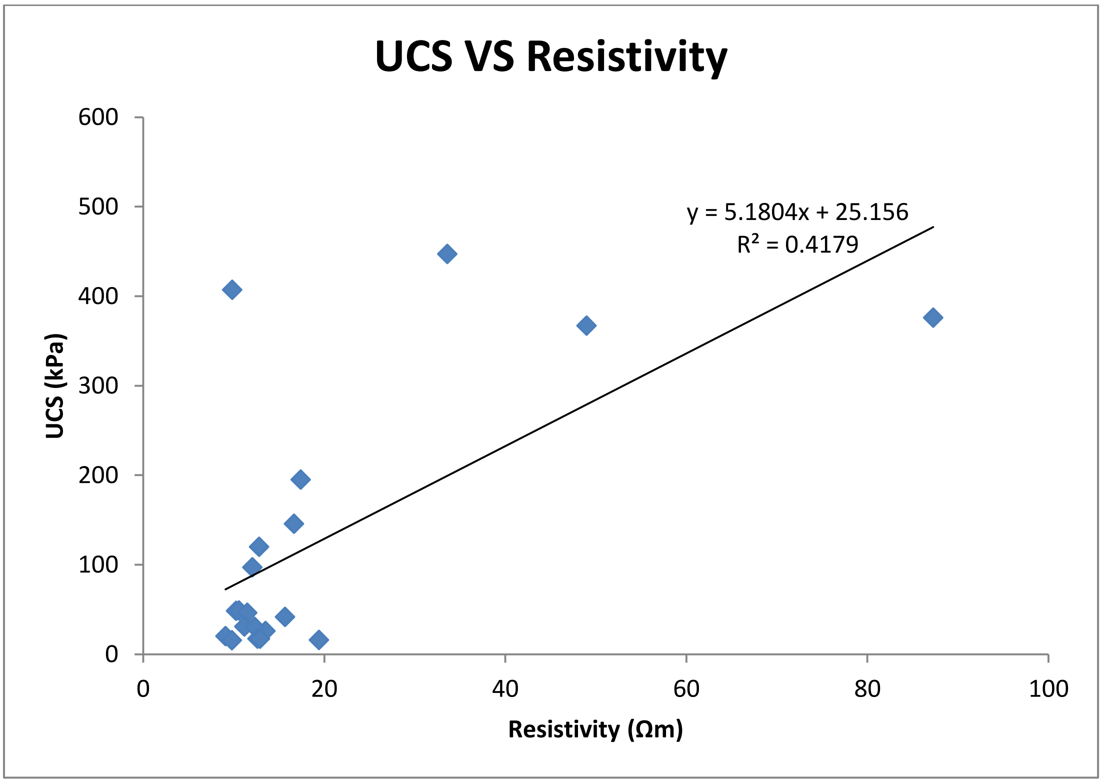

FIGURE 4.1 Unconfined Compressive Strength vs Resistivity Graph

There is crude correlation observed between resistivity and unconfined compressive strength shown in Figure 4.1. Resistivity increases with the increase of unconfined compressive strength. This is supported by Syed and Siddiqui (n.d) study on the correlation of electrical resistivity and SPT value. The obtained correlation shows the same linear relationship. Besides that, another correlation of resistivity with angle of internal friction also displays same result where resistivity increases when angle of internal friction increases. Another observation is that, at 25% moisture content, the points are found to be scattered and far from the trendline. There might be some other factor that contributes to such behaviour. The regression value of 0.42 appears promising for correlation of these two parameters. To get a better and more accurate correlation, more points are needed because what shown in this preliminary research is limited only for final year project.

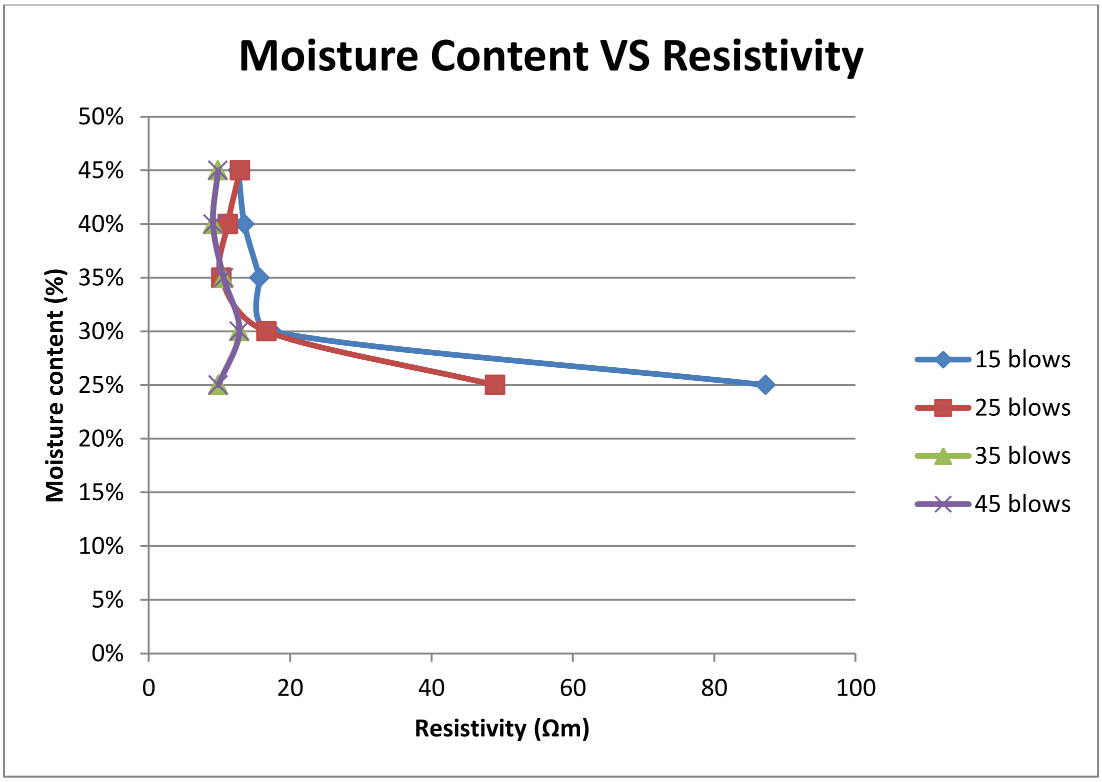

FIGURE 4.2 Moisture Content vs Resistivity Graph

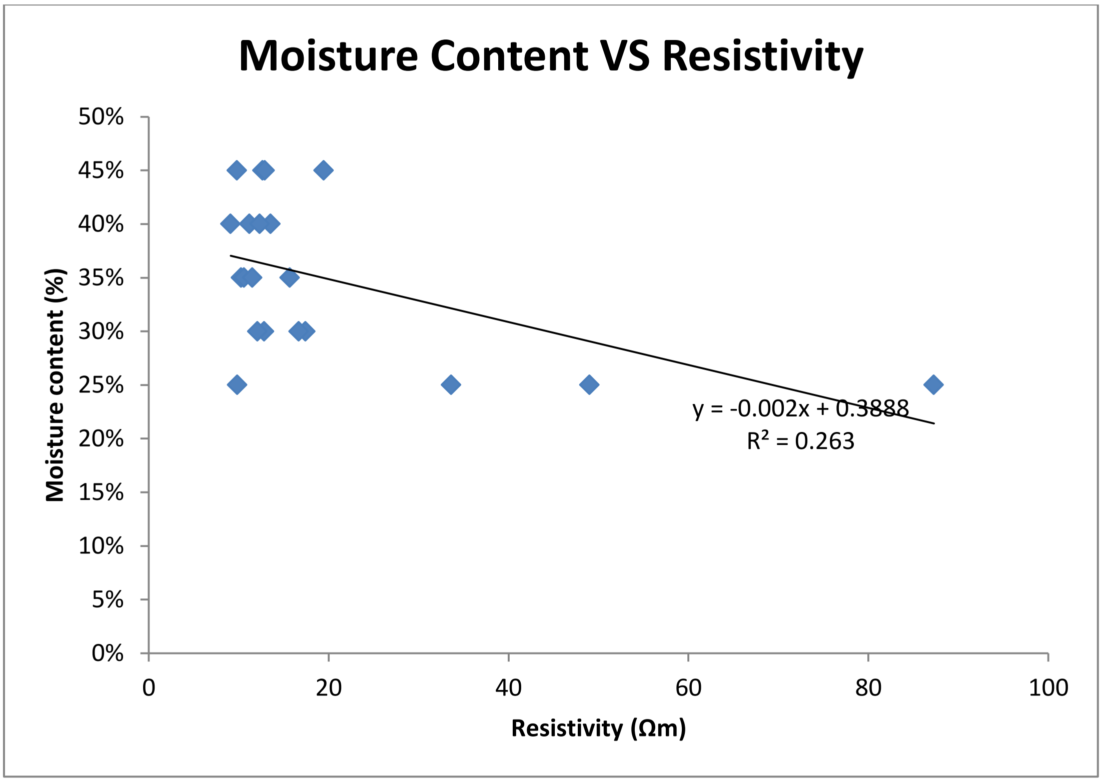

FIGURE 4.3 Moisture Content vs Resistivity Graph

Relationship between resistivity and moisture content of clay for different number of blows is plotted in Figure 4.2. From the obtained result, resistivity decreases when the moisture content increases for 15 and 25 number of blows. This result fulfill the theory from Samouëlian et al. (2005) based on laboratory calibration between the electrical resistivity and the volumetric water content. It states that the electrical resistivity decreases when the water content increases. However, for 35 and 45 blows, the behavior is observed to be different. It seems that in this research, the decrease of resistivity is low for moisture content above 30%. But for moisture content below 30% like the 25% moisture content, the decrease in resistivity is very prominent. A trendline is plotted and shown in Figure 4.3. The regression value, R^2 calculated is 0.26. Theoretically many had found that the correlation between these parameters is strong, but somehow the result from this research shows the correlation is not that strong. This may happen due to either it is a phenomenon for this type of soil or it comes from discrepancies of the laboratory experiment.

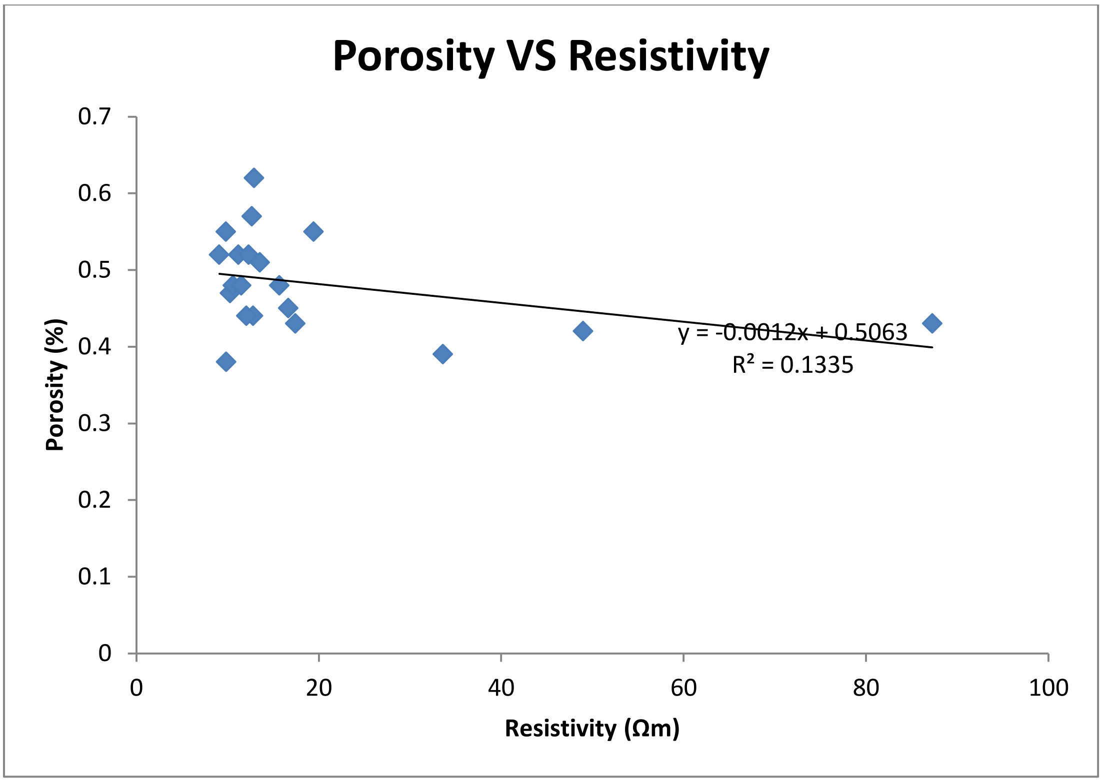

FIGURE 4.4 Porosity vs Resistivity Graph

Relationship between porosity and resistivity is very low whereby theory stated that resistivity increases when porosity decreases. According to Archie's Law, electrical resistivity of saturated soil is sensitive to the porosity, the electrical resistivity of the pore fluid, and characteristics of the solids and the structure of the pores. As the resistivity of the pore fluid increases or the porosity decreases, the electrical resistivity of the soil increases. Figure 4.4 indicates a poor correlation between electrical resistivity and porosity of soil with R^2=0.13. The weak correlation might be due to the void does not become smaller during the compaction. Instead, it stays the same and this result in low difference of porosity as the number of blows increases.

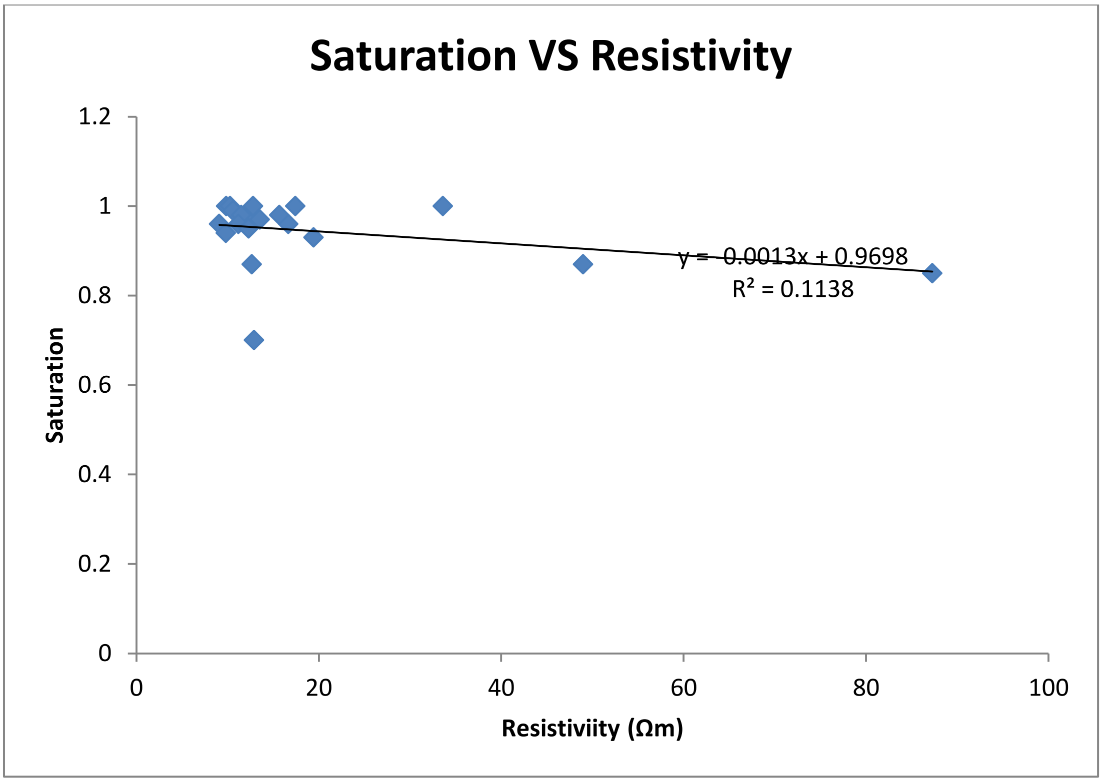

FIGURE 4.5 Saturation vs Resistivity

Figure 4.5 shows a weak correlation between electrical resistivity and saturation of soil. Regression value obtained is R^2=0.11 which is low. By theory, resistivity should become lower when the saturation is rises. This happen is due to the bridging effect. Samouëlian et al. (2005) explained that saturation of soil is considered as a standardize measurement of soil salinity. Estimation of soil salinity by electrical resistivity requires measurements made at the same water content. Thus, the reason of getting low correlation may come from the inconsistencies in measurement of data.

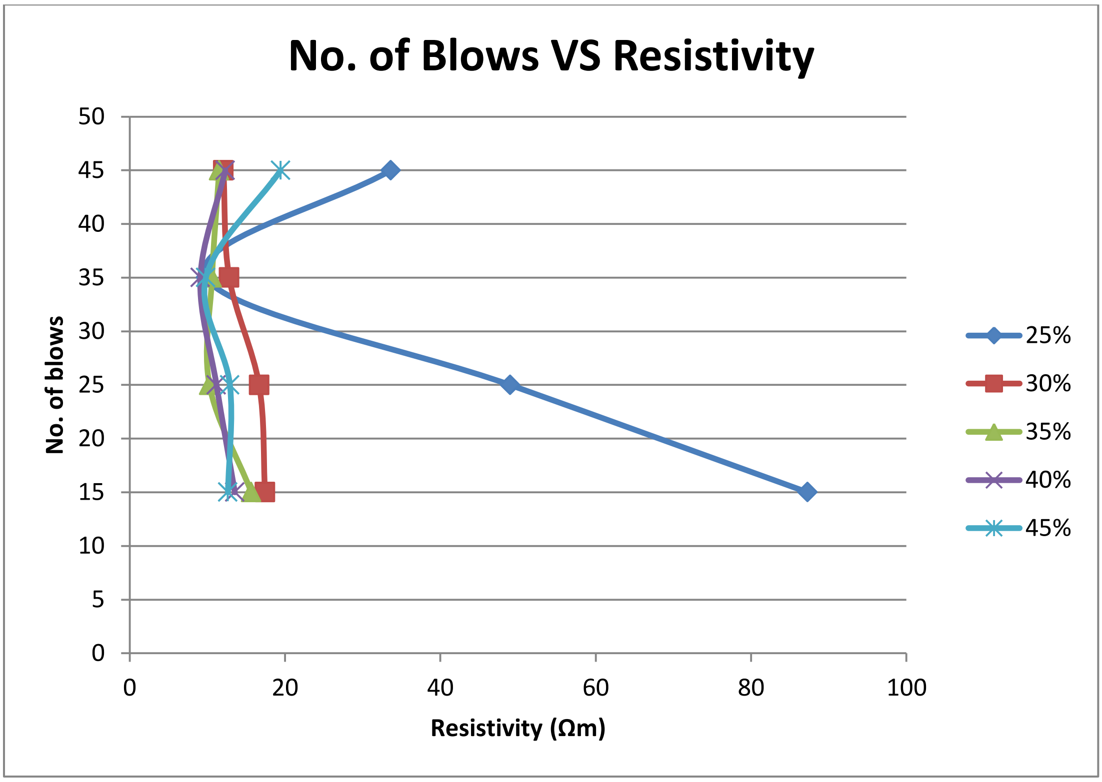

FIGURE 4.6 No. of Blows vs Resistivity

Figure 4.6 shows the relationship of resistivity and number of compaction blows. In 25% moisture content, the distinction between the points is high compared to other moisture content data. No clear trend is observed from the graph above. For moisture content 30% to 45%, the increase of number of blows did not contribute much effect to the resistivity. This might due to void does not become smaller after the compaction and this affect the electrical resistivity.

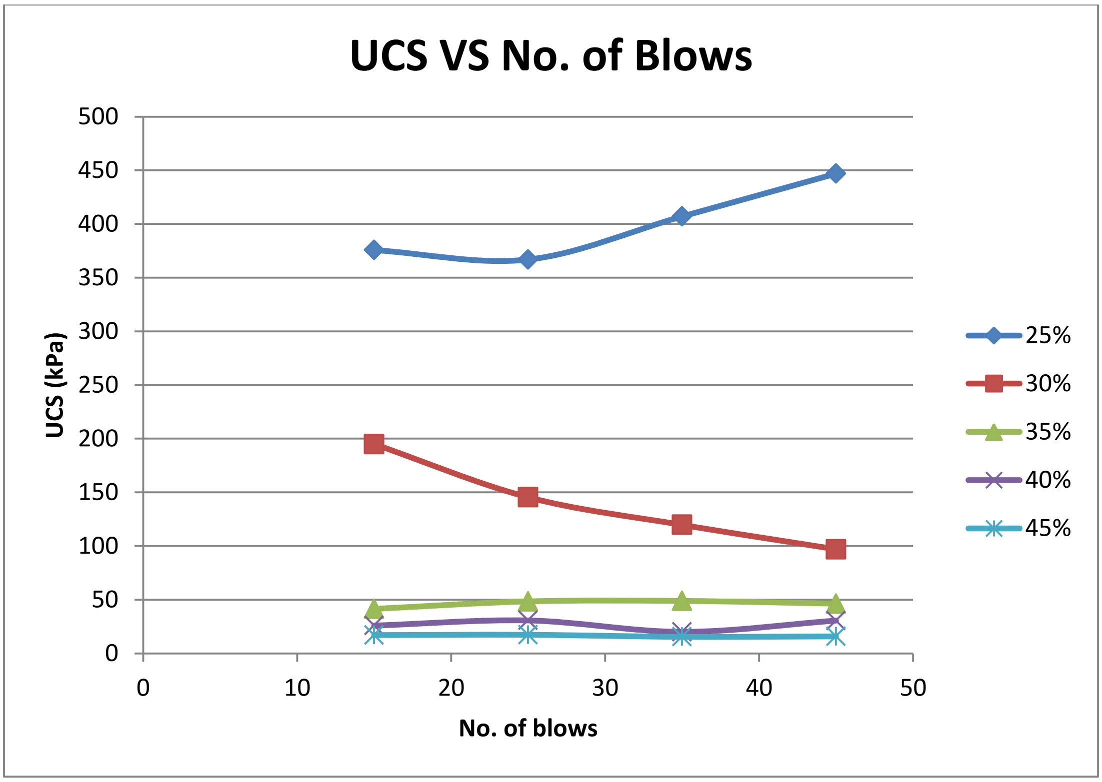

FIGURE 4.7 Unconfined Compressive Strength vs Number of Blows

Increasing number of blows result in increases in strength for 25% moisture content. For 30% moisture content, the unconfined compressive strength decreases. This phenomenon occurs due to the behavior of the clay itself. From observation during conducting the experiment, the soil heaves during the compaction. It continues to behave in such way as the moisture content increases. This can be seen in the result of moisture content 35% to 45%. The unconfined compressive strength is almost the same for increasing number of blows. It shows that the clay does not gaining much strength from the compaction. From the principle of compaction, particle supposed to come close together, and as it is closely packed, the void will be smaller. However, instead of particles become closer, the void is actually filled with water. In the first place, water is used to facilitate the particles to be packed together. With presence of water in soil, the density increases. Thus, instead of particles becoming closer, it is actually becoming looser.

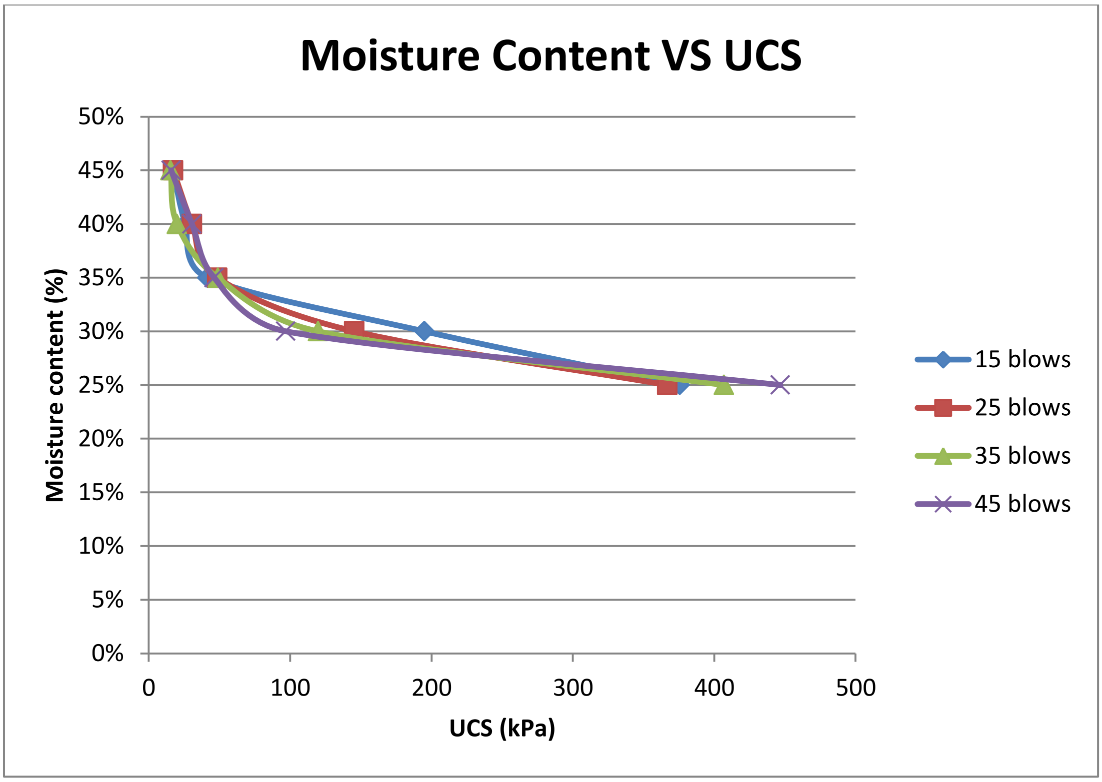

FIGURE 4.8 Moisture Content vs Unconfined Compressive Strength

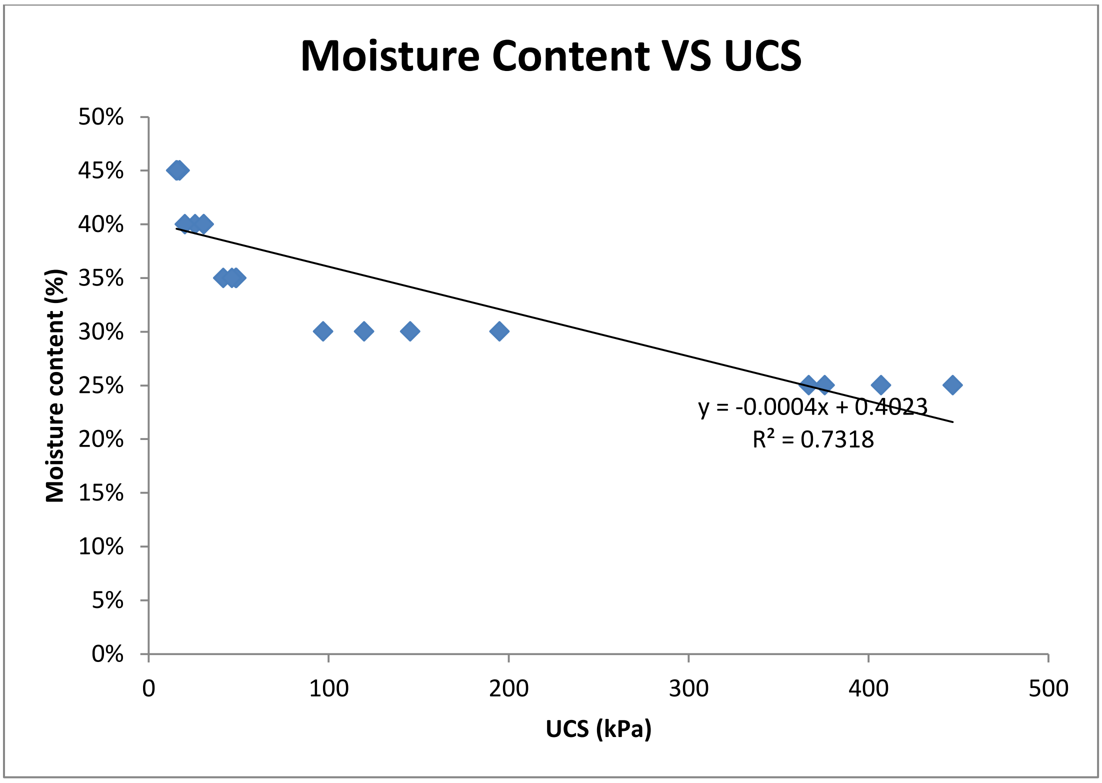

FIGURE 4.9 Moisture Content vs Unconfined Compressive Strength

Figure 4.8 and 4.9 shows a very good correlation between moisture content and unconfined compressive strength with R^2=0.73. From the graph above, the relationship of these two parameters is inversely proportional. As moisture content increases, the unconfined compressive strength of the clay sample decreases. It shows the higher amount of water in soil, the strength of the soil will be lower.

4.2 Soil characteristics

Based on the particle size distribution of the clay sample in Figure 4.1, 64% of the overall particle size is observed as clay size particles. According to American Association of State Highway and Transportation Officials (AASHTO), clay size particle is defined as particle size less than 0.002 mm. Silt is also present in the remaining percentage of soil sample. The distribution shows that the soil sample is predominantly clay. This is supported by the Atterberg limit result. Based on AASHTO classification system, the result shows that the usual type of significant constituent materials is clayey soil and the general subgrade rating is between fair to poor.

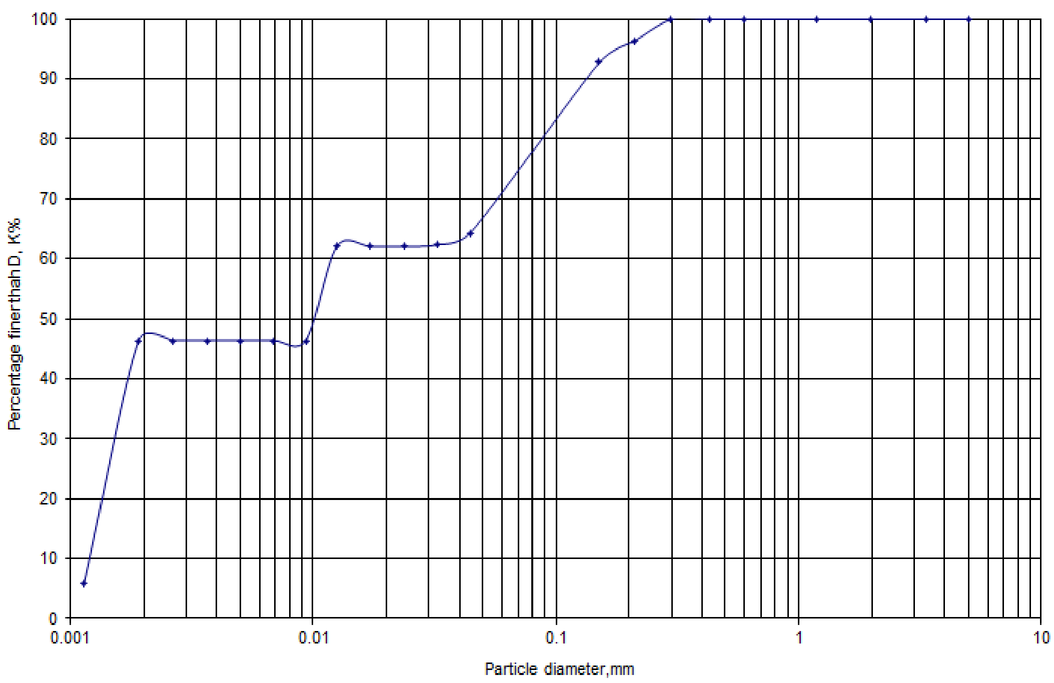

FIGURE 4.10 Particle Size Distribution of Clay

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The purpose of the study was to determine the relationship between electrical resistivity and unconfined compressive strength. Another main objective is to study the relationship of electrical resistivity under controlled variables namely as moisture content and compaction blows with geotechnical parameters such as porosity and saturation of soil for clay particle. Basic laboratory tests, simple electrical resistivity test using basic multimeter and unconfined compression test (UCT) were conducted to obtain the correlations between electrical resistivity and several soil parameters. The laboratory work is continued for other sets of data of 25% to 45% moisture content. The data is expected to be all gathered by week 8 of FYP II. With a continuous work and proper planning, this research is can successfully complete within the timeline.

The results showed when electrical resistivity increases, unconfined compressive strength also increases. Crude correlation between those parameters is obtained with R^2=0.42. The correlation of resistivity with both porosity and saturation result in poor correlation with R^2=0.11 and 0.13 respectively. This might happen due to discrepancies in experiment or it is the behavior of that particular type of soil.

Within the limitation of this research at this point of time, it is sufficient to say that crude correlations were established between resistivity and some selected soil parameters given in the results. The relationship between soil resistivity and different geotechnical parameters has the potential to fill the gap between geotechnical and geophysical engineering site investigations. By developing the correlations of electrical resistivity of soil with geotechnical parameters, electrical resistivity can be used extensively for geotechnical site investigation.

5.2 Recommendation

- The developed relationship between soil resistivity and geotechnical parameters of soil are site specific. More research is required to develop relationship between soil resistivity with geotechnical properties that can be applicable for different place and type of soils.
- Correlation of soil moisture, strength and electrical resistivity can be determined by in-situ testing and laboratory investigation on undisturbed sample.
- More research can be conducted to identify the relationship between saturation and electrical resistivity of soil.
- Statistical analysis can be done to introduce a model. The model of soil resistivity should incorporate all the factors affecting soil resistivity. Moreover, the model should be validated by electrical resistivity results, in-situ test results and laboratory test results

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APPENDICES

Data Collection & Calculation

RESULT – MOISTURE CONTENT 25%

-SET 1-

Date : 21st March 2014

Mixing Date : 20th March 2014

Moisture Content : 25 %

Number of Blows : 15 blows

DIMENSION OF MOULD

Length (mm)	115.4
Diameter (mm)	104.88
Weight of mould + base, w_1 (kg)	5.04
Weight of mould + base + moist compacted soil, w_2 (kg)	6.87
Weight of moist compacted soil, $w_2 – w_1$ (kg)	1.83

RESISTIVITY TEST

Voltage (V)	Current (mA)	Resistance (Ω)	Resistivity (Ωm)
30	0.0345	869.57	65.10
60	0.0702	854.70	63.99
90	0.1032	872.26	65.30
			Avg = 64.79

MOISTURE CONTENT – after compaction

Sample 1

Weight of container (g)	18.9
Weight of container + moist soil (g)	76.5
Weight of container + oven dry soil (g)	64.0

Sample 2

Weight of container (g)	19.0
Weight of container + moist soil (g)	58.3
Weight of container + oven dry soil (g)	49.78

Sample 3

Weight of container (g)	21.0
Weight of container + moist soil (g)	71.8
Weight of container + oven dry soil (g)	60.75

Soil Sample

Weight of container (g)	20.6
Weight of container + moist soil (g)	183.4
Weight of container + oven dry soil (g)	148.82

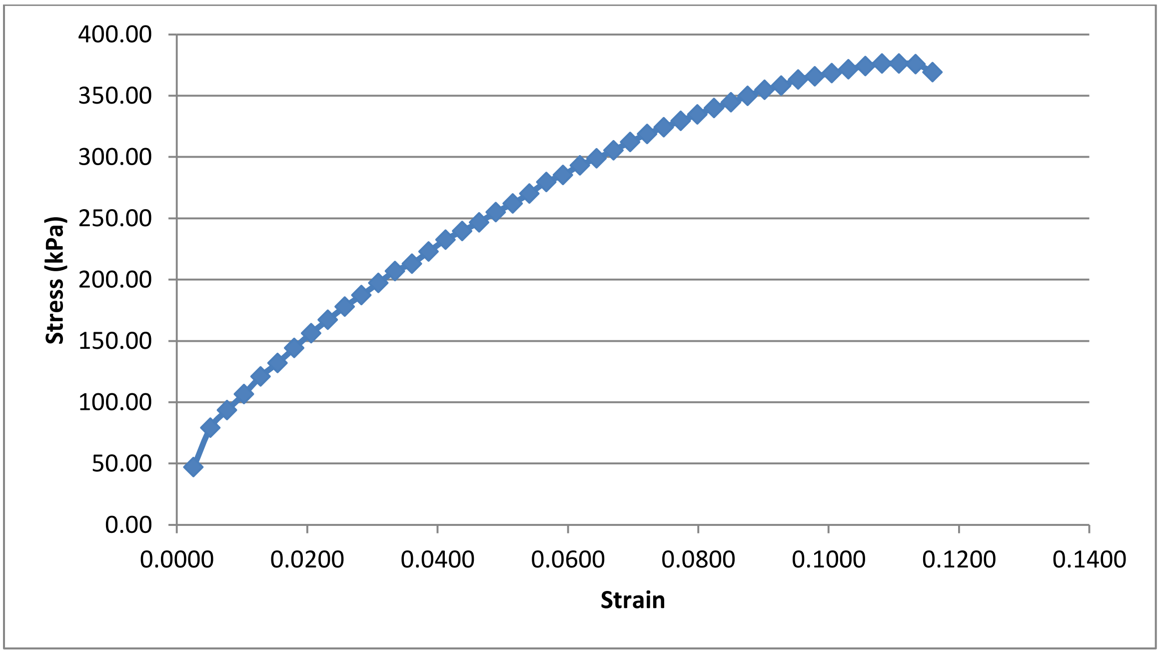
<u>DIMENSION OF SOIL SPECIMEN - UCT</u>

Length (mm)		77.62
Diameter (mm)		38.27
Area (mm^2)		1150.29
Mass (g)	Before UCT	163.19
	After UCT	162.91
q_u (kPa) [from graph]		375.7

<u>UCT - STRESS STRAIN CURVE</u>

Deformation gauge reading	Compression of specimen (mm)	Strain	Force gauge reading, N	Axial force	Corrected area (mm^2)	Axial stress (kPa)
20	0.2	0.0026	35.0	54.3	1153.26	47.04
40	0.4	0.0052	59.0	91.5	1156.25	79.09
60	0.6	0.0077	70.0	108.5	1159.25	93.60
80	0.8	0.0103	80.0	124.0	1162.27	106.69
100	1.0	0.0129	91.0	141.1	1165.30	121.04
120	1.2	0.0155	99.5	154.2	1168.35	132.00
140	1.4	0.0180	109.0	169.0	1171.42	144.23
160	1.6	0.0206	118.5	183.7	1174.50	156.39
180	1.8	0.0232	127.0	196.9	1177.60	167.16
200	2.0	0.0258	135.5	210.0	1180.71	177.88
220	2.2	0.0283	143.0	221.7	1183.84	187.23
240	2.4	0.0309	151.0	234.1	1186.99	197.18
260	2.6	0.0335	159.0	246.5	1190.15	207.07
280	2.8	0.0361	164.0	254.2	1193.34	213.02
300	3.0	0.0386	172.0	266.6	1196.53	222.81
320	3.2	0.0412	180.0	279.0	1199.75	232.55
340	3.4	0.0438	186.0	288.3	1202.98	239.65
360	3.6	0.0464	192.0	297.6	1206.23	246.72
380	3.8	0.0490	199.0	308.5	1209.50	255.02
400	4.0	0.0515	205.0	317.8	1212.79	262.00
420	4.2	0.0541	212.0	328.6	1216.09	270.21
440	4.4	0.0567	220.0	341.0	1219.41	279.64
460	4.6	0.0593	225.0	348.8	1222.75	285.22

480	4.8	0.0618	232.0	359.6	1226.11	293.29
500	5.0	0.0644	237.0	367.4	1229.49	298.78
520	5.2	0.0670	243.0	376.7	1232.88	305.50
540	5.4	0.0696	249.0	386.0	1236.30	312.18
560	5.6	0.0721	255.0	395.3	1239.73	318.82
580	5.8	0.0747	260.0	403.0	1243.18	324.17
600	6.0	0.0773	265.0	410.8	1246.65	329.48
620	6.2	0.0799	270.0	418.5	1250.15	334.76
640	6.4	0.0825	275.0	426.3	1253.66	340.01
660	6.6	0.0850	279.5	433.2	1257.19	344.60
680	6.8	0.0876	284.5	441.0	1260.74	349.78
700	7.0	0.0902	289.5	448.7	1264.31	354.92
720	7.2	0.0928	293.0	454.2	1267.90	358.19
740	7.4	0.0953	298.0	461.9	1271.51	363.27
760	7.6	0.0979	301.0	466.6	1275.14	365.88
780	7.8	0.1005	304.0	471.2	1278.79	368.47
800	8.0	0.1031	307.5	476.6	1282.47	371.65
820	8.2	0.1056	310.5	481.3	1286.16	374.19
840	8.4	0.1082	313.0	485.2	1289.88	376.12
860	8.6	0.1108	314.0	486.7	1293.62	376.23
880	8.8	0.1134	314.5	487.5	1297.38	375.74
900	9.0	0.1159	310.0	480.5	1301.16	369.29



POROSITY & SATURATION CALCULATION:

Moist Unit Weight,γ = $\dfrac{\textit{weight of compacted moist soil}}{\textit{volume of mould}}$

= 1.83 kg / (0.001) m^3

= 18.36 kN/m^3

To find Porosity, n:

γ_B = $G_s \cdot \gamma_w (1-n)(1+w)$

18.36 = (2.58)(9.81)(1-n)(1+0.25)

18.36 = (25.31)(1-n)(1.25)

0.58 = 1-n

n = 0.42

To find Saturation, S:

γ_B = $G_s \cdot \gamma_w (1-n) + nS\, \gamma_w$

18.36 = (2.58)(9.81)(1-0.42) + (0.42)(S)(9.81)

3.68 = 4.12S

S = 0.89

PROPERTIES OF CLAY SAMPLE:

Properties	**Result**
Specific gravity	2.58
Liquid limit	64.0 %
Plastic limit	42.3 %
Plasticity index	21.7 %

Particle Size Analyzer Result:

MALVERN INSTRUMENTS

MASTERSIZER 2000

Result Analysis Report

Sample Name:
Clay

Sample Source & type:
Atikah

Sample bulk lot ref:
123-ABC

SOP Name:
Clay Atikah

Measured by:
Administrator

Result Source:
Measurement

Measured:
Monday, July 14, 2014 9:18:50 AM

Analysed:
Monday, July 14, 2014 9:18:52 AM

Particle Name:
clay

Particle RI:
1.480

Dispersant Name:

Accessory Name:
Scirocco 2000

Absorption:
0.1

Dispersant RI:
1.000

Analysis model:
General purpose

Size range:
0.020 to 2000.000 um

Weighted Residual:
0.367 %

Sensitivity:
Enhanced

Obscuration:
11.64 %

Result Emulation:
Off

Concentration:
0.0009 %Vol

Specific Surface Area:
2.32 m²/g

Span :
5.804

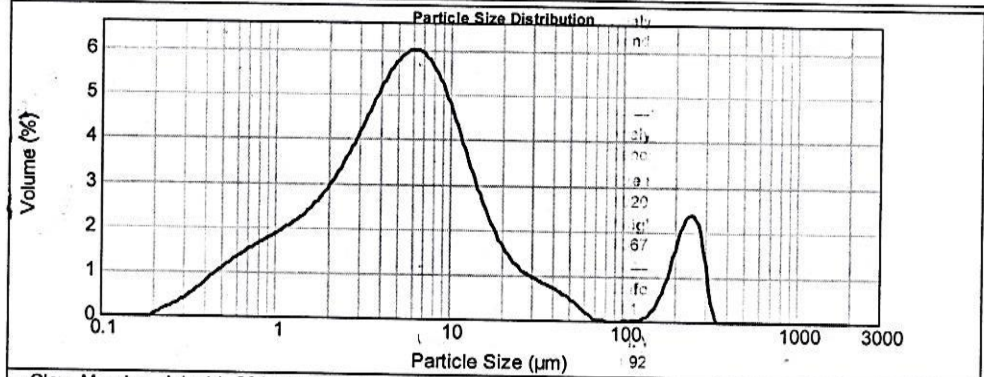
Surface Weighted Mean D[3,2]:
2.586 um

Uniformity:
4.01

Vol. Weighted Mean D[4,3]:
24.920 um

Result units:
Volume

d(0.1): 1.022 um **d(0.5):** 5.553 um **d(0.9):** 33.254 um



Size (μm)	Volume In %
0.010	0.00
0.011	0.00
0.013	0.00
0.015	0.00
0.017	0.00
0.020	0.00
0.023	0.00
0.026	0.00
0.030	0.00
0.035	0.00
0.040	0.00
0.046	0.00
0.052	0.00
0.060	0.00
0.069	0.00
0.079	0.00
0.091	0.00
0.105	

Size (μm)	Volume In %
0.105	0.00
0.120	0.00
0.138	0.00
0.158	0.00
0.182	0.00
0.209	0.13
0.240	0.23
0.275	0.34
0.316	0.48
0.363	0.66
0.417	0.84
0.479	1.01
0.550	1.17
0.631	1.31
0.724	1.45
0.832	1.57
0.955	1.70
1.096	

Size (μm)	Volume In %
1.096	1.83
1.259	1.98
1.445	2.16
1.660	2.39
1.905	2.66
2.188	2.99
2.512	3.37
2.884	3.80
3.311	4.25
3.802	4.69
4.365	5.07
5.012	5.33
5.754	5.44
6.607	5.36
7.586	5.08
8.710	4.63
10.000	4.05
11.482	

Size (μm)	Volume In %
11.482	3.41
13.183	2.77
15.136	2.19
17.378	1.71
19.953	1.35
22.909	1.10
26.303	0.93
30.200	0.81
34.674	0.71
39.811	0.60
45.709	0.46
52.481	0.29
60.256	0.10
69.183	0.01
79.433	0.00
91.201	0.00
104.713	0.00
120.226	

Size (μm)	Volume In %
120.226	0.03
138.038	0.19
158.489	0.58
181.970	1.25
208.930	1.94
239.883	2.13
275.423	1.41
316.228	0.07
363.078	0.00
416.869	0.00
478.630	0.00
549.541	0.00
630.957	0.00
724.436	0.00
831.764	0.00
954.993	0.00
1096.478	0.00
1258.925	

Size (μm)	Volume In %
1258.925	0.00
1445.440	0.00
1659.587	0.00
1905.461	0.00
2187.762	0.00
2511.886	0.00
2884.032	0.00
3311.311	0.00
3801.894	0.00
4365.158	0.00
5011.872	0.00
5754.399	0.00
6606.934	0.00
7585.776	0.00
8709.636	0.00
10000.000	

Operator notes:

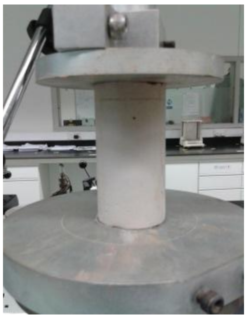
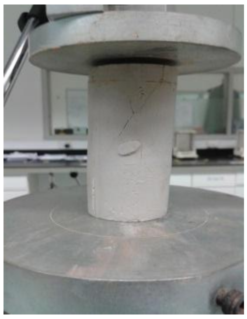
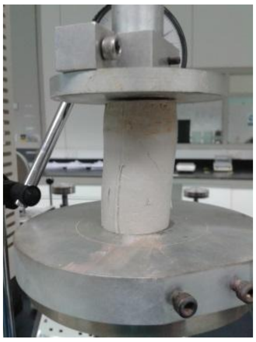
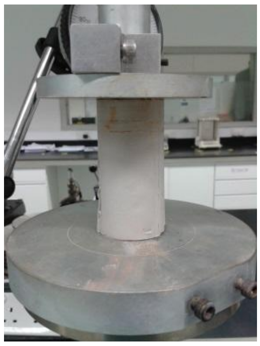
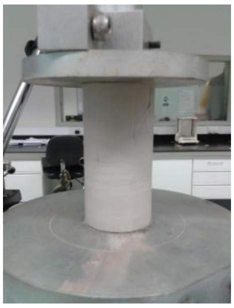
Malvern Instruments Ltd.
Malvern, UK
Tel := +[44] (0) 1684-892456 Fax +[44] (0) 1684-892789

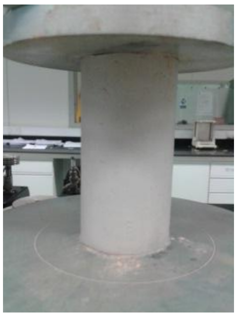
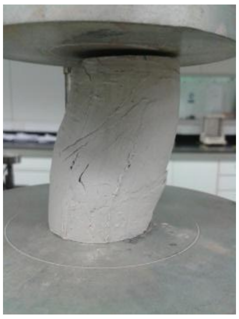
Mastersizer 2000 Ver. 5.54
Serial Number : MAL18486

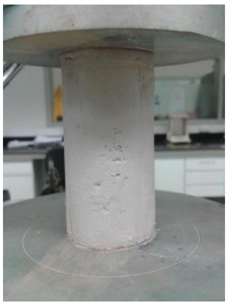
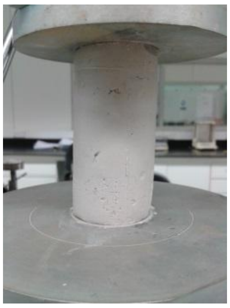
File name: Afikah
Record Number: 1
14 Jul 2014 9:19:07 AM

Photos

Picture of clay specimen before and after unconfined compression test:

Moisture content	No. of blows	Before test	After test
25%	15 blows		
	25 blows		
	35 blows		
	45 blows		

Moisture content	No. of blows	Before test	After test
30%	15 blows		
	25 blows		
	35 blows		
	45 blows		

<table>
<tr><th>Moisture content</th><th>No. of blows</th><th>Before test</th><th>After test</th></tr>
<tr><td rowspan="4">35%</td><td>15 blows</td><td></td><td></td></tr>
<tr><td>25 blows</td><td></td><td></td></tr>
<tr><td>35 blows</td><td></td><td></td></tr>
<tr><td>45 blows</td><td></td><td></td></tr>
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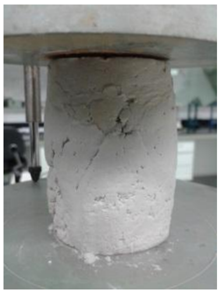
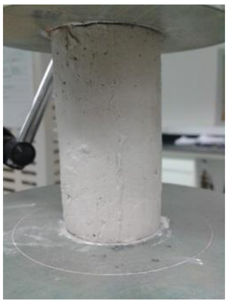
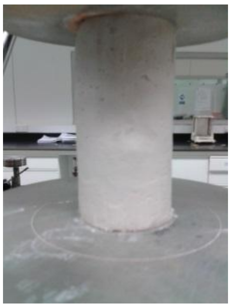
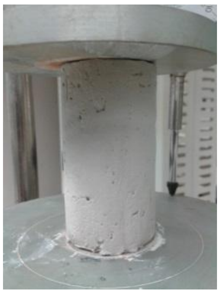
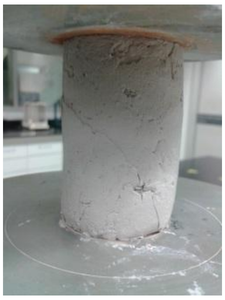
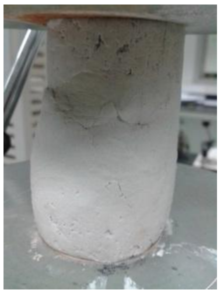
Moisture content	No. of blows	Before test	After test
40%	15 blows		
	25 blows		
	35 blows		
	45 blows		

Moisture content	No. of blows	Before test	After test
45%	15 blows		
	25 blows		
	35 blows		
	45 blows		

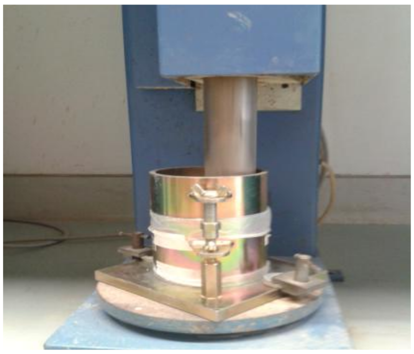
Soil mixing

Cover & leave for 24 hours

Apparatus for compaction

Mould covered with plastic

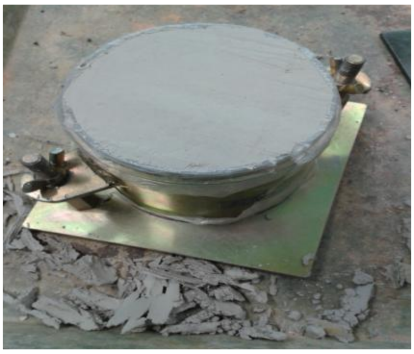
3 layers compaction



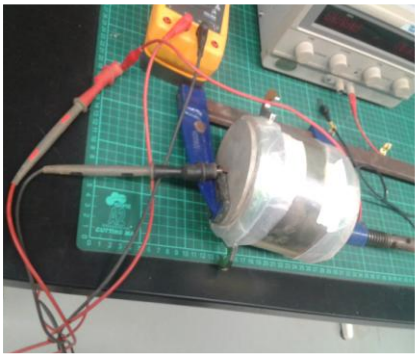
1st layer

2nd layer

3rd layer



Resistivity test

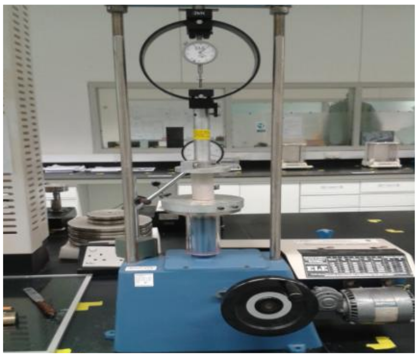


Extrude the soil

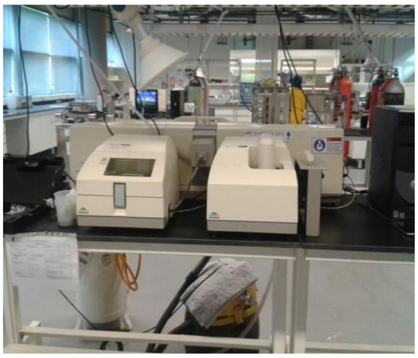
Sampling

Trimming

UCT



Particle size analyzer



Plastic limit test

Liquid limit tets