The Effect of Porosity and Saturation on Electrical Resistivity and Strength of Soil for Clay Size Particle

by

Nur Hernah Syahila Binti Mahamad Rizal

Dissertation submitted in partial fulfillment of

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CERTIFICATION OF APPROVAL

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Approved by,

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(Dr. Syed Baharom Azahar B. Syed Osman)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
September 2013

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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NUR HERNAH SYAHILA BINTI M.RIZAL

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ABSTRACT

In general, the use of electrical resistivity by geotechnical engineers have 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 effects of porosity and saturation on electrical resistivity and strength of soil for clay size particles. It was a study about the effects of porosity and saturation on electrical resistivity of clay with size ranges between 0.5 to 2.5μm.

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 pocket penetrometer test had been done right after the compaction test due to understanding the effects of porosity and saturation on electrical resistivity. The value of electrical parameters such as voltage, current and resistance with corresponding value of soil parameters such as porosity, saturation and cohesion were all recorded.

The results of the tests produced some initial crude relationship between electrical resistivity and the selected parameters. Generally, when porosity increases, resistivity decreases. Also showed when resistivity increased the cohesion increased. On the other hand, some unique trends of behavior were observed for relationship between resistivity and saturation. Overall, results showed the saturation increases, the resistivity value decreases. Hence, more investigation and experiments need to be conducted in order to achieve more precise correlations.

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CHAPTER 1

INTRODUCTION

1.1 Background

Geophysical methods provide information about the physical properties of earth's subsurface. These methods include measuring the response of the subsurface to electromagnetic, electric and seismic energy. Geophysical methods are classified into surface or borehole methods. The surface methods are non-intrusive and is used for obtaining the subsurface data quickly. The borehole measurements require the drilling of a borehole to lower the geophysical measuring device. Hence the borehole measurements are used for obtaining the in situ properties of the subsurface.

The use of geophysical methods in site investigation is gaining notable recognition from the global engineering and construction community. During site investigation, several parameters are investigated by geologist and geotechnical engineers. However, they can only obtain information at certain key locations and interpolate soil conditions area wide. Geophysical methods have the possibility to give an image of the subsurface, as shown in Figure 1.1. Also, with the development of new software for the interpretation of resistivity measurements, 2D and 3D electrical resistivity is extensively used today in shallow geophysical investigation.

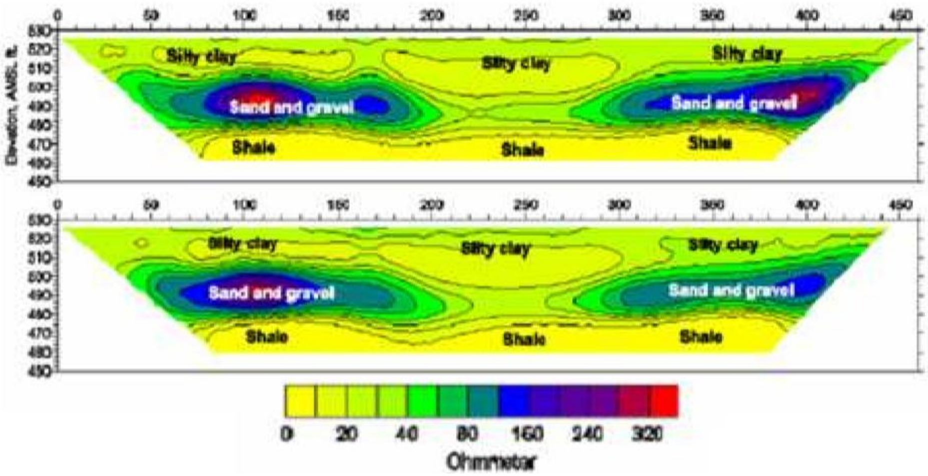


Figure 1.1: The Example of Mapping Stratigraphy, Sand and Gravel Lenses in Clay and Shale Environment

Geologists have been using electrical resistivity to study the properties of rock and subsurface materials successfully. The application of DC current to quantify resistivity was performed by Conard Schlumberger in 1912. It was reported as one of the most successful experimental approach of electrical resistivity survey (Adegboyega and Odeyemi, 2011). In United States, the idea was developed by Frank Wenner in 1915 (Adegboyega and Odeyemi, 2011). After that, the method has undergone by significant improvement in last three decades. To comprehend the heterogeneity and to provide accurate image of subsurface, different electrode combinations and inversion models are being utilized. With the advancement of modern techniques, it is now possible to obtain image of subsurface within a very short time.

Electrical resistivity is a non-destructive method of site investigation. The method is less expensive and subsurface investigation of a large area can be conducted in a short time period. However, soil test borings are traditionally used for subsurface exploration. In addition, Standard Penetration Test (SPT), Cone Penetration Test (CPT), Vane Shear Test, Dilatometer Test and Pressuremeter Test are also widely used in geotechnical investigation. All of these methods provide information of a point at different subsoil depths. Besides, electrical resistivity provides continuous information in vertical and horizontal direction of subsurface. Advantages of electrical resistivity over conventional methods can be summarized below

- Provide continuous image of subsurface.
- Has the ability to cover a large area within a short time period.
- Less expensive.
- Has the ability to determine heterogeneity and high moisture zone.
- Data can be processed in a very short time.

Because of these benefits, the use of electrical resistivity has increased significantly. It is one the most convenient available technique for preliminary subsurface investigation and geo-hazard studies. Therefore, electrical resistivity can be considered as complimentary to soil boring for site investigation and geo-hazard study.

Resistivity is a property possessed by all materials. The electrical resistivity method for determining subsurface conditions utilizes the knowledge that in soil materials, the resistivity values differ sufficiently to permit that property to be used for identification purpose. Because the method is non-destructive and very sensitive, it offers a very attractive tool for describing the subsurface properties without digging (Samouelian, et al., 2005; Kibria and Hossain, 2012; and Samsudin 2002). It has be already applied in various context like landfill, groundwater exploration, agronomical management by identifying areas of excessive compaction or soil horizontal thickness and bedrock depth, and at least assessing the soil hydrological properties.

Turesson, 2006, has mentioned, in earth material, resistivity decrease with increasing water content make it easier for an electrical current to flow through the material. Consequently, nonporous materials (holding little water) will have high resistivity values. Such materials include clean gravel and sand have a relatively high resistivity value. Silts, clays, and coarse grained and also fine grained soil mixtures have comparatively low resistivity values. Soil formation is non-glaciated areas typically have lower resistivity values than soils in glacial areas. Dense rock with few voids, little moisture and negligible amounts of salt with have high resistance (Matsui, et al.,1997). Soft saturated clay will have a low resistance, particularly if any decomposed organic matter or soluble salts are present.

1.2 Problem Statement

The use of electrical resistivity by geotechnical engineers have been increasing all over the world. It is a convenient method to evaluate spatial and temporal variation of moisture and heterogeneity of subsoil. The working principle of this method is based on the conduction phenomenon of soil. However, electrical resistivity provides qualitative information of subsurface. Limited studies have been conducted to obtain geotechnical parameters using resistivity. Quantification of geotechnical properties has become an important issue for rigorous use of resistivity in engineering applications.

The correlation of different geotechnical properties with electrical resistivity will close the gap that currently exists between geophysical engineering and geotechnical engineering. The geotechnical engineers will be able to interpret the geophysical data and utilize the information for their design. Therefore, the development of geotechnical parameters from the electrical resistivity will make this method more effective for subsurface investigation. The presence of moisture changes consistency and strength of soil. Moisture is also important for conduction phenomenon of soil. Conductivity and resistivity also depend on the mineralogy of soil, particle size distribution, Index properties, unit weight, porosity, degree of saturation and other parameters. Proper understanding of the causes of variation of these parameters with resistivity can be helpful for development of correlations.

1.3 Objective of the Current Study

The study was conducted to determine the relationship of geotechnical properties of clay soil with the electrical resistivity. Soil samples were bought and collected from a company called Kaolin Malaysia Sdn Bhd in Kuala Lumpur. It is important to determine the variation of resistivity with different geotechnical parameter's correlation. The specific objectives of the study is presented here:

- To determine the effects of porosity on electrical resistivity and strength of soil for clay size particle.
- To determine the effects of saturation on electrical resistivity and strength of soil for clay size particle.

1.4 The Relevancy of the Project

The electrical resistivity method plays a significant role in the exploration of natural resources like groundwater and mineral deposits. In designing and checking the geotechnical structure, the strength parameter such as cohesive (c) is the important parameter that required beside other parameters like porosity (n) and saturation (S). These soil properties are essential to identify risk in slopes by calculate the factor of safety (FOS) which will indicate the stability of a certain slope. Therefore, rather than conventional method, electrical resistivity is a geophysical method which allow measurement of soil from soil surface to any depth without disturbance with less time consuming.

Feasibility of the Project

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 results of this study can be used for to geological and hydro-geological assessment such as wells location and agricultural activity. 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 such cohesion, porosity, and saturation as is currently being practice for the calculation of bearing capacity and replace these physical parameters with their correlated electrical parameters such resistivity, voltage etc.

CHAPTER 2

LITERATURE REVIEW

2.1 Resistivity

Electrical resistivity measurements are useful for assessing many physical properties of the porous soils including porosity and density of 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.

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

$$\rho = R.\,(A/L)$$

where,	ρ = Electrical Resistivity	R= Resistance of the material
	V= Potential	I = Current
	A= Cross sectional Area	L= Length

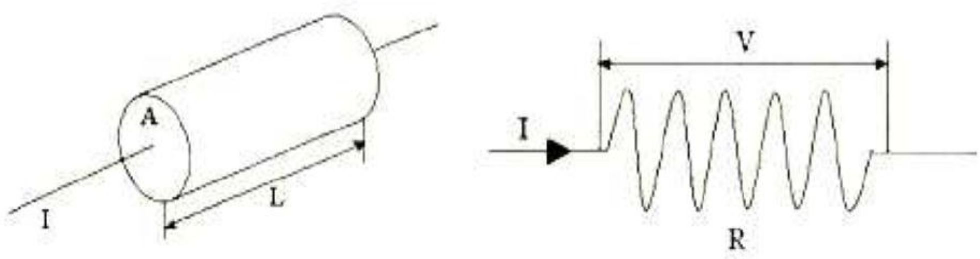


Figure 2.1: The schematics of cylindrical section and flow of current

2.2 Clay Minerals

Clay minerals are formed by chemical weathering of rock forming minerals. They are small colloidal size crystal and chemically known as hydrous aluminosilicates. Clay mineral consists of crystal sheet with repeated atomic structure. There are two fundamental crystal sheets such as tetrahedral or silica and octahedral or alumina. The tetrahedral sheet consists of four oxygen atoms at the corners surrounding a silicon atom. In an octahedral sheet, six oxygen atoms enclose aluminum, magnesium, iron or other atom.

2.3 Factor Affecting Soil Resistivity

2.3.1 Moisture Content

The amount of water present in the soil is one of the most important parameters geotechnical engineer needs to know. It can be defined either weight basis or volume basis. Measurement of moisture content in the weight basis is known as gravimetric moisture content. In the weight basis, the ratio of amount of water present in the void to the amount of solids is known as moisture content. The equation to calculate gravimetric moisture content is expressed as

$$W = \frac{Ww}{Ws}\ x\ 100\%$$

where, Ww = Weight of water

Ws = Weight of solid soil

Several studies showed that moisture content is the most dominating factor which influences electrical resistivity of soil. Electrical conductivity occurs mainly due to the displacement of ions in the pore water. When moisture content increases from air dry to full saturation, adsorbed ions in the solid particles are released. Thus, mobility of electrical charge increases with the increase of moisture.

Free electrical charges cause decrease in electrical resistivity under the application of electric field. It is seen electrical resistivity of soil decreases rapidly with the increase of moisture content more than 15% (Samouelian et al., 2007).

Moisture content and electrical resistivity curve was divided in to various zones based on the different moisture condition in soil. The segments of the curve correspond to the specific water content are adsorbed water, film water, film capillary water, capillary water and gravitational water.

According to the author, electrical resistivity decreases rapidly in the adsorption water zone with the increase of moisture content. Ions of water molecules are immobile in the adsorbed water zone. However, the dipolar water ions create a conductive path for electrical current. Thus electrical resistivity decreases sharply with the increase of moisture in the adsorption zone. In the film water zone Van der Waals' force increases.

As a result electrical resistivity decreases less sharply in the film water zone. When maximum possible thickness of water film is achieved, water goes from film to fissure. In the film capillary water zone relative portion of film water decreases and capillary water increases. Molecular attraction force is higher than the capillary force in this zone. Therefore, electrical resistivity decreases less dramatically in the film capillary and capillary water zone. In the gravitational water zone mobility of electrical charges become independent of movement of water molecule ions. Thus, electrical resistivity is almost independent of water content in this zone.

2.3.2 Geologic Formation and Arrangement of Soil Solids

Generally, soil electrical resistivity exhibits a wide range of value. Soil resistivity is low for coastal soil and high for rocks. Study also demonstrated that soil resistivity is also affected by geological formation. Research conducted by Giao et al., (2002) showed that presence of diatom micro fossils substantially alter the geotechnical properties of clay. This kind of change in structure also affects electrical properties of clay. Robain et al., (1996) presented resistivity variation with the structure of the pedological materials. According to the authors, low and high resistivity values are related to the macro and meso porosity of soil.

Geometry of the pores determines the proportion of the water and air in the soil. Air is considered as dielectric material. If the pores of soil are filled with water then electrical conductivity may change. Usually clay soil is more conductive than sandy soil. However, saturated sandy soil may demonstrate low resistivity than dry compacted clay. Because of these factors, overlapping of resistivity values is observed for different type of soils.

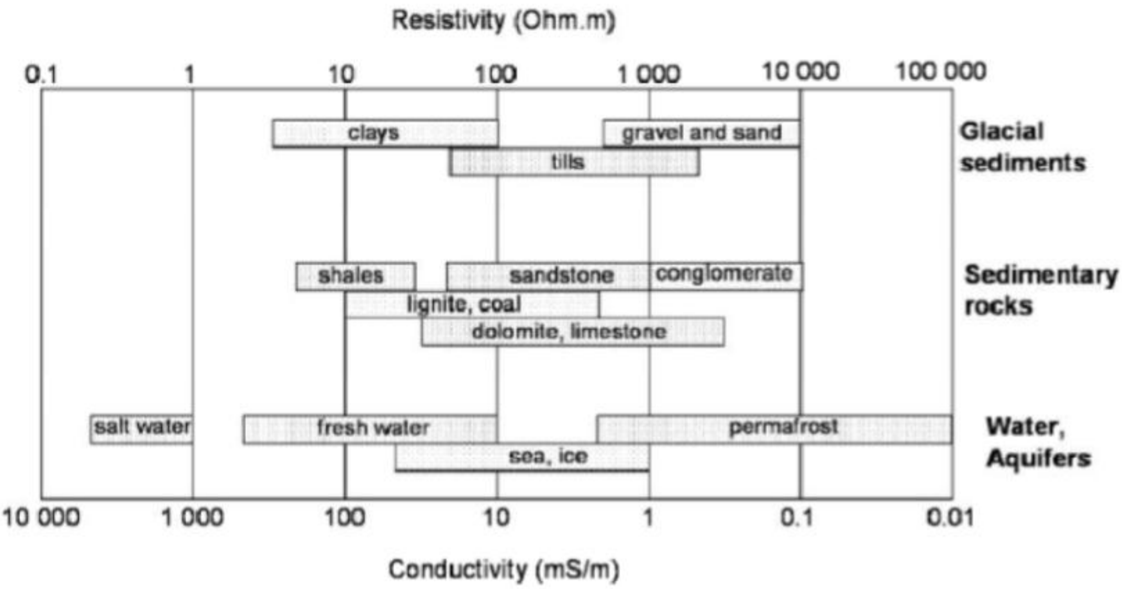


Figure 2.3.2: Typical range of electrical resistivity value of soil

2.3.3 Porosity

The amount of pore space is determined by the arrangement of the soil particles. The proportion of pore space is low when soil particles are very close together (e.g., compacted soil) and is higher when soils have high organic matter. Sandy soils normally have 35-50% pore space, while medium to fine-textured soils have 40-60% pore space. Pore space decreases with soil depth because subsoil tends to be more compacted than topsoil (Turesson, 2006).

The ability of the soil to hold and transmit water and air is impacted by the amount of pore space in the soil and pore size distribution. In research, Samouelian, et al., (2004) stated that the geometry of the pores determines the proportion or air and water according to the water potential. Soil pores can be classified into three main groups depending on the diameter of the individual pore.

Macropores are large diameter pores (≥ 0.1 mm) that tend to be freely draining and are prevalent in coarse textured or sandy soils. Mesopores are medium sized pores (0.03 mm – 0.1 mm) that are common in medium-textured soils or loamy soils. Micropores are small diameter pores (<0.03 mm) that are important for water storage and are abundant in clay soils. It is sometimes helpful to envision soil pore space as a network of tiny tubes of varying diameter. Imagine how the diameters of those tubes would impact the movement of gasses and liquids relative to aeration, drainage, and infiltration (Samouelian, et al., 2004).

Moreover, in the study, Turesson (2005) claimed that the effects of resistivity distortion are seen to considerably greater depth. In saturated zone the water content, which is the porosity when the pores are saturated, varies in certain percentage. Porosity is governed by many factors such as the uniformity of soil, packing and compaction during and after deposition. Packing alone can contribute significantly to the differences in porosity. However, the gradual change from high to low resistivities which inherent to this method makes it difficult to determine an intrinsic value of porosity.

For porosity, which is the amount of void space between soil particles. Infiltration (groundwater movement) and water storage occur in these void spaces. The porosity of soil is the ratio of the volume of pore space to the total volume of material. Porosity also provides some estimate of compaction and the maximum space available for water (at saturation) or air. of soil can be defined as the ratio of weight of soil to the total volume. Porosity can be defined by the phase diagram (Figure 2.3.1) of soil. The expression is

$$n= \frac{Vv}{vt}\ x\ 100\%$$

where, Vv = Volume of voids and Vt = Total volume.

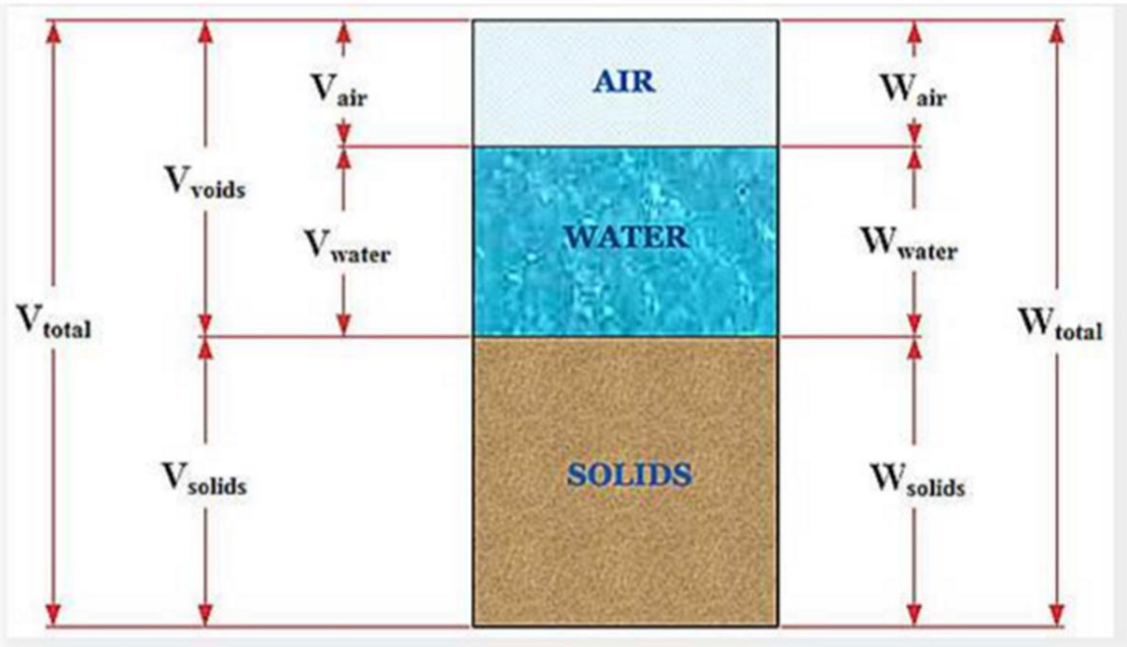


Figure2.3.3: Phase Diagram of soil

2.3.4 Bulk Density and Degree of Saturation

Density is an important geotechnical property which relates volume with mass of soil. Bulk Density of soil can be defined as the ratio of weight of soil to the total volume. It can be defined by the phase diagram of soil. The expression is

$$\gamma = \frac{w}{vt}$$

where, W = Weight of soil mass and Vt = Total volume.

Bulk density is closely related to degree of saturation. It is defined by the ratio of volume of water to the volume of void. It can be given by

$$Sr = \frac{Vw}{Vv}$$

where, Vw = Volume of water and Vv = Volume of void

Research showed that soil resistivity is affected by the change in bulk density and degree of saturation. Increase of bulk density is associated with reduction of pore air in soil. Therefore, the degree of saturation increases. Dissolved ions from the pore water adsorb on the solid surface and affects the formation of double layer in fine grained soil. Therefore, increase of degree of saturation cause proportional decrease of soil resistivity.

However, this relationship is valid above a critical value of degree of saturation. Critical degree of saturation is corresponds to minimum amount of water required to maintain a continuous film of water in soil. An abrupt increase of soil resistivity occurs below critical degree of saturation (Khalil and Monterio Santos, n.d). Moreover, bulk density increases contact between individual particles. Reduction in pore space and closer contacts between the particles allow easy conduction of current. According to the study of Kibria and Hossain (2012), relationship curve of conductivity and degree of saturation was concave upward.

Abu Hassanein et al., (1996) conducted resistivity measurements of four different soils at different initial degree of saturation. It was observed that the electrical resistivity was inversely correlated with initial degree of saturation. It was also noted that initial degree of saturation and electrical resistivity was independent of compactive effort.

2.3.5 Cohesion

The cohesion is a term used in describing the shear strength soils. Its definition is mainly derived from the Mohr-Coulomb failure criterion and it is used to describe the non-frictional part of the shear resistance which is independent of the normal stress. In the stress plane of Shear stress-effective normal stress, the soil cohesion is the intercept on the shear axis of the Mohr-Coulomb shear resistance line .

2.4 Determination of Geotechnical Parameters

2.4.1 Atterberg Limits

Atterberg Limits are moisture content where the soil changes its states and behaviors. With the increase of water content, soil state changes from brittle solid to plastic solid and then to a viscous fluid. The Index properties are widely used by geotechnical engineers to identify the soil behavior in response to moisture. Research has been conducted to identify the relationship between Atterberg Limits and resistivity. Abu Hassanein et al., (1996) evaluated variation of electrical resistivity with Atterberg limits.

Soil samples were compacted at optimum moisture content and dry unit weight using Standard Proctor method. It was observed that soil with higher LL and PI had lower resistivity as presented in Figure 2.4.1. Figure 2.4.1 also shows that decrease of resistivity with the increase of LL and PI tends to be a power function of electrical resistivity. Only exception was found for samples having high coarse fraction. Soils with 47% coarse fraction showed high resistivity. The trend of decreasing resistivity with increase of LL and PI was also consistent with the mineralogy of samples. Clay samples having greater quantity of smectite have higher LL and PI. These soils are more active and exhibit higher surface conductivity. LL and PI of non-swelling clay are strongly influenced by the diffuse double layer. Surface conductivity of the clay depends largely on the diffuse double layer. Therefore, electrical resistivity depends on the Atterberg limits of the soils.

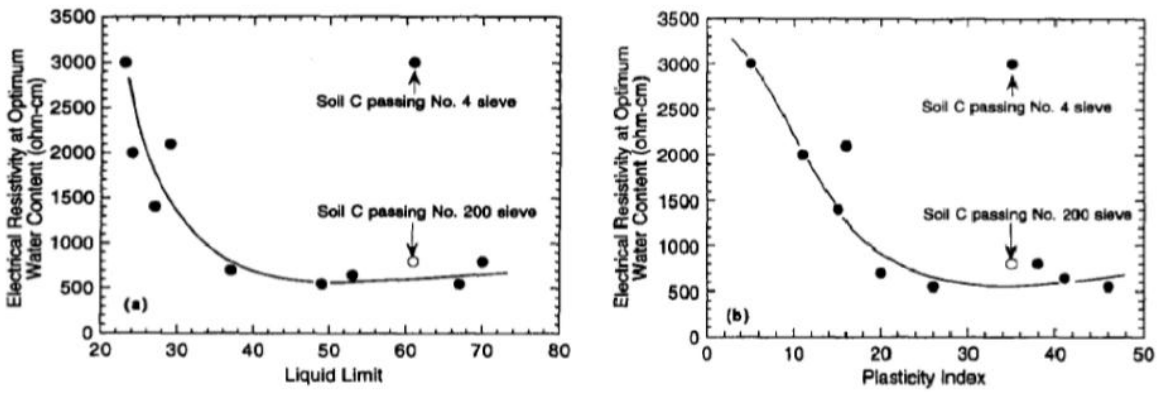


Figure 2.4.1: Relationship between Electrical Resistivity and Atterberg Limit at Optimum Water Content (Abu Hassanein et al., 1996)

2.4.2 Compaction

Compaction is the process of densification of soil by the application of mechanical energy. Generally, compaction is done at specific moisture content to achieve maximum densification of soil. Compaction condition can be determined by Standard Proctor Test. However, different indirect approaches were initiated to observe compaction condition. Several researchers utilized electrical resistivity to evaluate compaction condition. Compaction is associated with the decrease of void ratio and increase of degree of saturation. Good correlations between electrical resistivity and compaction condition were observed in several studies.

Observed resistivity was high when soil was compacted at dry optimum and low when compacted at wet optimum. Resistivity was sensitive of molding water content when water content was below optimum. At wet optimum, resistivity had become almost independent of molding water content. Authors indicated that this relation could be used to evaluate compaction condition of soil. Relationship between resistivity and compaction was discussed in the light of structural change of soil during compaction. At low compactive effort and dry of optimum water content, clay clods are difficult to remold. Interclod pores are also relatively large in this condition. Many pores are filled with dielectric air and inter particle contacts are poor.

Furthermore diffuse double layers are not fully developed. Therefore, soil shows high resistivity. In contrast, when soil is compacted at wet optimum and high compactive effort, clods of clay are easily remolded. At this condition, pores are nearly saturated and smaller in size compare to previous case. Better particle-to-particle contact and formation of bridge between particles improve conductivity. Thus, lower resistivity is attained when compacted at wet optimum water content and high compactive effort (Abu Hassanein et al., 1996). Moreover, study showed that change in compactive effort did not affect resistivity significantly when compacted at wet optimum.

2.5 Resistivity Measurement

Soil resistivity tests can be conducted either in the field or on the collected samples in laboratory. The resistivity test in laboratory is widely used in to identify corrosion potential and contamination of soil. However, field tests are conducted to investigate subsurface, environmental and hydrological condition. Resistivity has the ability to provide a continuous image of subsurface.

2.5.1 Laboratory Measurement of Resistivity

In the laboratory, soil resistivity is conducted by measuring voltage drop across a known resistance which is in series connection with sample. The relationship between the resistance of conductor having regular geometric shape and its resistivity is the basis of laboratory measurement. In general case, two electrode are placed in the end of cylinder and current (I) is measured under applied voltage (V). Sample resistance (R) is obtained from Ohm's Law. Resistivity is determined incorporating the geometric factor such as length (L) and cross sectional area (A) by the following expression

$$\rho = R \ x \ \frac{A}{L}$$

Here, current is carried predominantly by movement of electrons in electrode and ions in pore fluid in the sample. Therefore, charge is carried across interface by electrochemical reaction. If the contact resistance is higher than the resistance of the soil sample then, current cannot pass through the sample. Typical laboratory set up is present below.

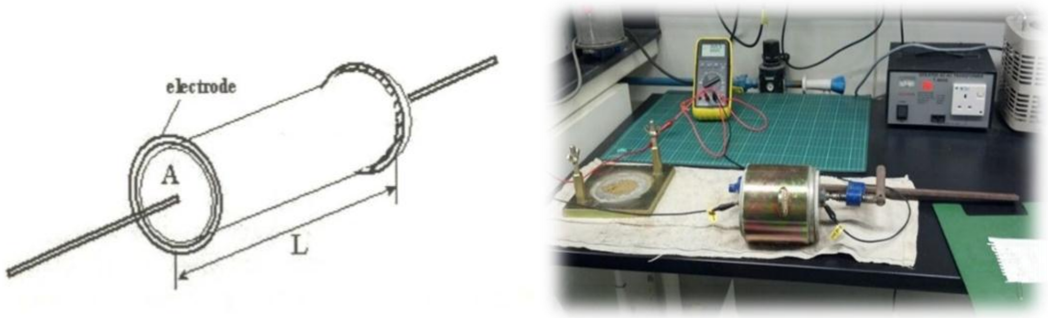
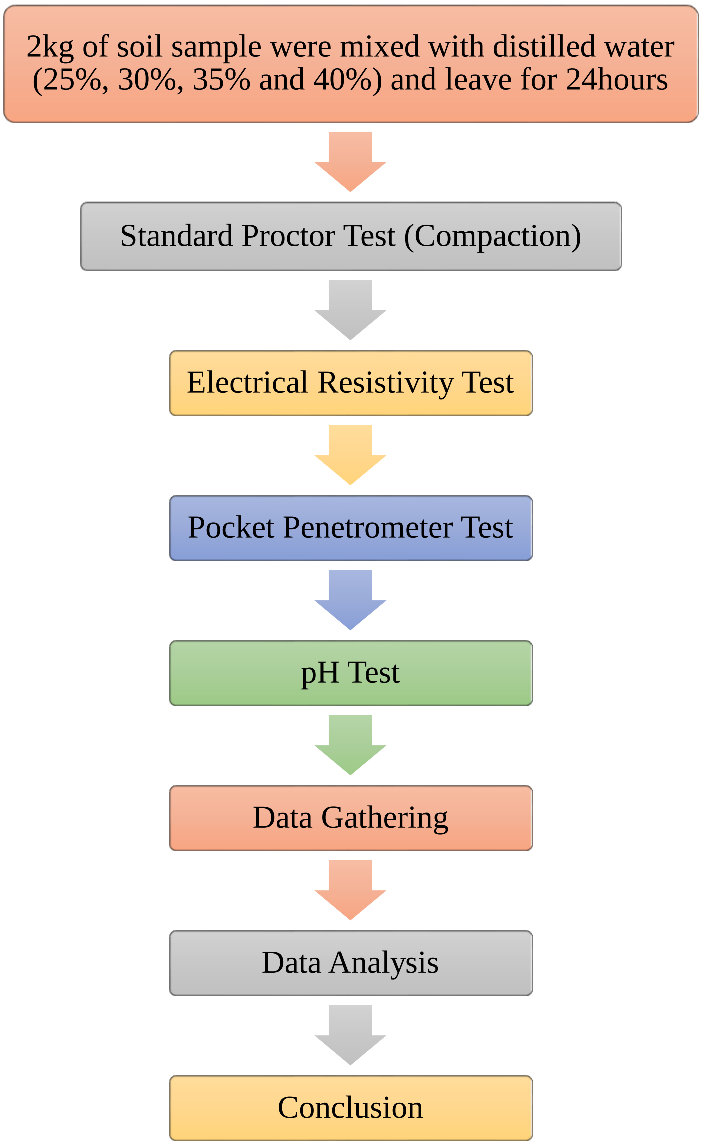


Figure 2.5.2: Laboratory Set Up for Soil Resistivity

CHAPTER 3

METHODOLOGY

The objective of this study is to determine the relationship between geotechnical properties of clayey soil with electrical resistivity. Soil samples 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 shear strength. Electrical resistivity was also measured in the laboratory to determine the correlation of geotechnical properties with the soil resistivity. In general, the research methodology are shown as below.



3.1 Laboratory Testing

3.1.1 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.

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.

Figure 3.1.1 Stake of Sieves

3.1.2 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.

3.1.3 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 labeled 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 call 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).

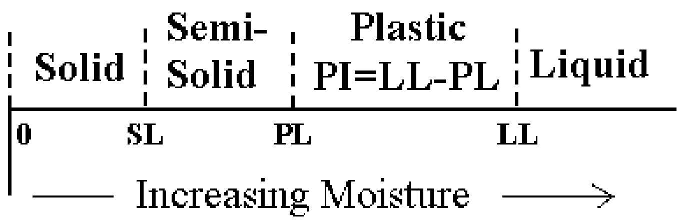


Figure 3.1.3: The PL Test

Apparatus:

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

3.1.4 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:

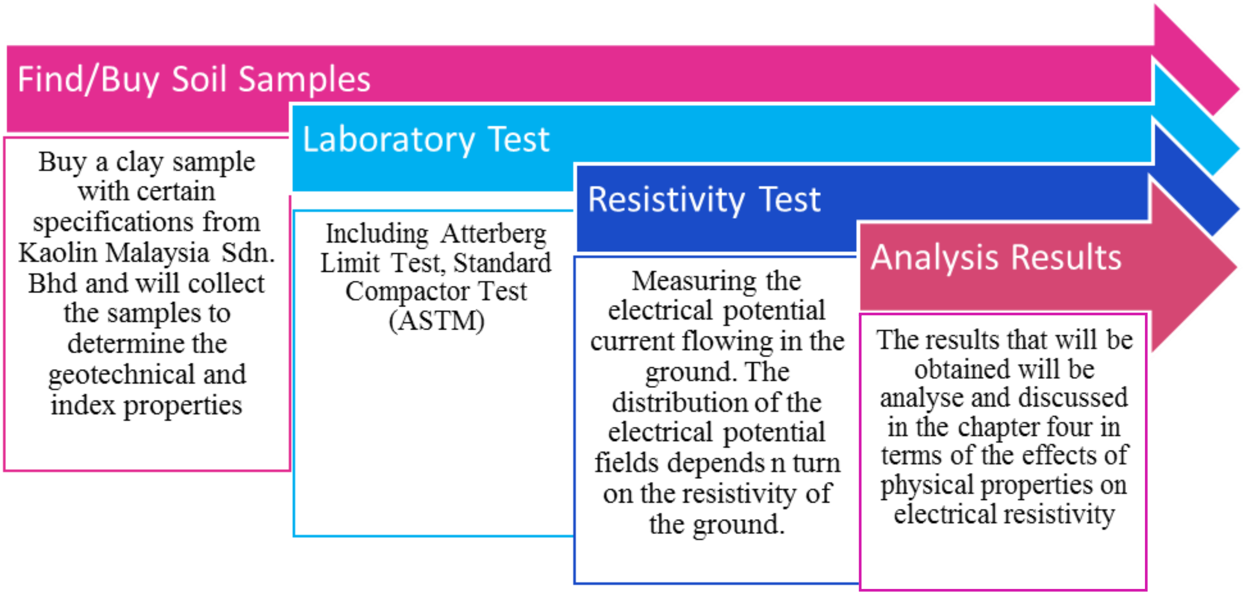
- Soil mixer
- Standard Proctor Hammer
- Two 100mm aluminium electrodes
- 200 volts DC power supply & hand held multimeter

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 shown above.

3.2 Key Milestone



3.3 Gantt Chart

For the time being, the project is running smoothly and following what the author have planned in the Gantt chart schedule and everything is within the time frame. The author have completed all specimens for basic laboratory test and the electrical resistivity test. The author get help each from supervisor and lab technician when facing a problem. For now, frequent meeting with supervisor have enabled the author to track the progress and discuss about the data anlysis and findings about the project.

Final Year Project (FYP) Planning 1

Week Number / **Activities**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Selection of Project Topic														
Briefing														
Preliminary Research Work														
Research on required tools and equipments														
Implement the process of the project														
Searching for the soil samples														
Lab Safety Briefing														
Implement the Preliminary Laboratory Test														
Submission of Extended Proposal Defence														
Implement Laboratory Test														
Proposal Defence														
Continue Lab Work and														
Submission of Interim Draft Report														
Submission of Interim Report														

Table 3.3: Timeline for FYP1

Final Year Project (FYP) Planning 2

Activities \ Week Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Project Work Continues															
Submission of Progress Report															
Project Work Continues															
Pre-SEDEX															
Ir. Idris will asigning the External Examiner															
Submission of Draft Report															
Submission of Dissertation (soft bound)															
Submission of Technical Paper															
Oral Presentation (VIVA)															
Submission of Project Dissertation (hard bound)															

Table 3.4: Timeline for FYP2

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Electrical Resistivity Results

Total of 16 soil samples were tested using compaction test, electrical resistivity test and pocket penetrometer to obtain the effects of porosity, saturation and cohesion on electrical resistivity for clay size particles. The results from were tabulated in table 1 below.

Moisture Content	pH	Blows	Porosity, n	Saturation, S	Resistivity, ρ (Ωm)	Cohesion, c (kPa)
25	3.60	15	0.44	0.81	34.24	350.14
		25	0.40	0.94	31.40	389.05
		35	0.39	0.97	27.30	302.41
		45	0.39	1.02	20.15	384.15
30	3.60	15	0.45	0.96	26.19	113.61
		25	0.45	0.93	22.31	111.97
		35	0.43	1.03	23.77	86.64
		45	0.45	0.95	20.78	128.32
35	3.60	15	0.48	0.95	14.07	22.89
		25	0.48	0.98	13.26	25.34
		35	0.48	0.95	11.77	30.40
		45	0.48	0.95	11.19	35.15
40	3.60	15	0.52	0.96	9.85	9.808
		25	0.53	0.94	7.84	11.44
		35	0.52	0.93	9.69	9.808
		45	0.48	1.15	7.05	9.808

Table 4.1: The results obtained from laboratory experiment

From the results given in table 4.1, it is clear that resistivity of the soil decreases with the higher moisture content and number of blows. For moisture content 25% shows the value of resistivity for ranges 15 blows to 45 blows are from ranges 34.24ohm.m to 20.15ohm.m, where else for moisture content 30% shows the value of resistivity from ranges 26.19ohm.m to 20.78ohm.m, for moisture content 35% shows the value of resistivity from ranges 14.07ohm.m to 11.19ohm.m, and lastly for moisture content 40% shows the value of resistivity from ranges 9.85ohm.m to 7.05ohm.m.

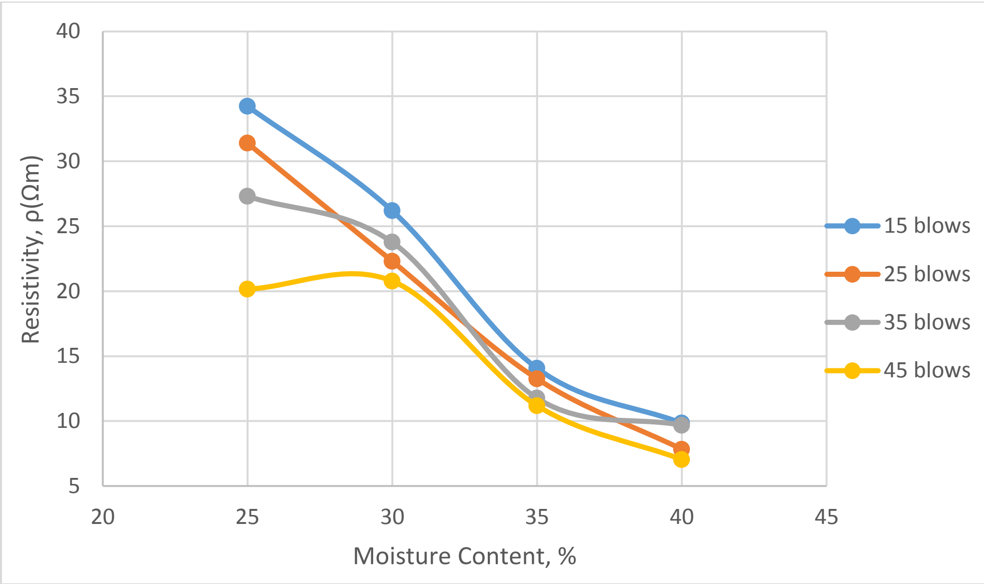


Figure 4.1: Resistivity vs Moisture Content

From the figure 4.1 shows the relationship of resistivity and moisture content. It is clear that resistivity of the soil decreases with the increases of moisture content and number of blows. Several studies showed that moisture content is the most dominating factor which influences electrical resistivity of soil. In clay particles, electrical conductivity occurs mainly due to the displacement of ions in the pore water. When moisture content increases from air dry to full saturation, adsorbed ions in solid particles are released. Thus mobility of electrical charge increase with the increases of moisture content hence, resistivity decreases.

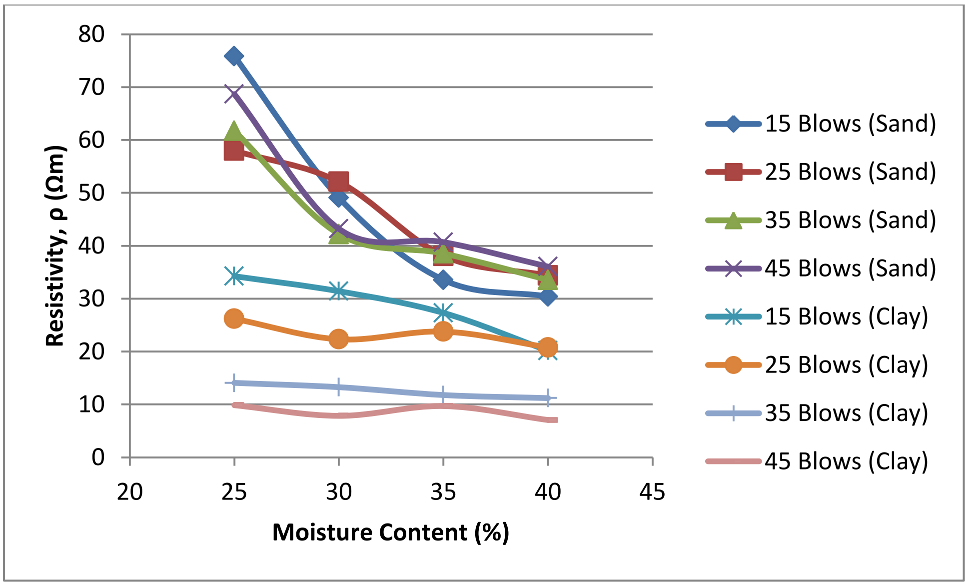


Figure 4.2: Multiple Combined Graphs of Resistivity vs Moisture Content (Clay and Sand)

Graphs shows the combined of clay and sand types of soil. Overall shows that clay soil have low resistivity values. This is due to the arrangement of soil particles for clay which is close together compare to sand. Hence, mobility of electrical charge in clay particles increase with the increases of moisture content, influence the resistivity decreases less that sand.

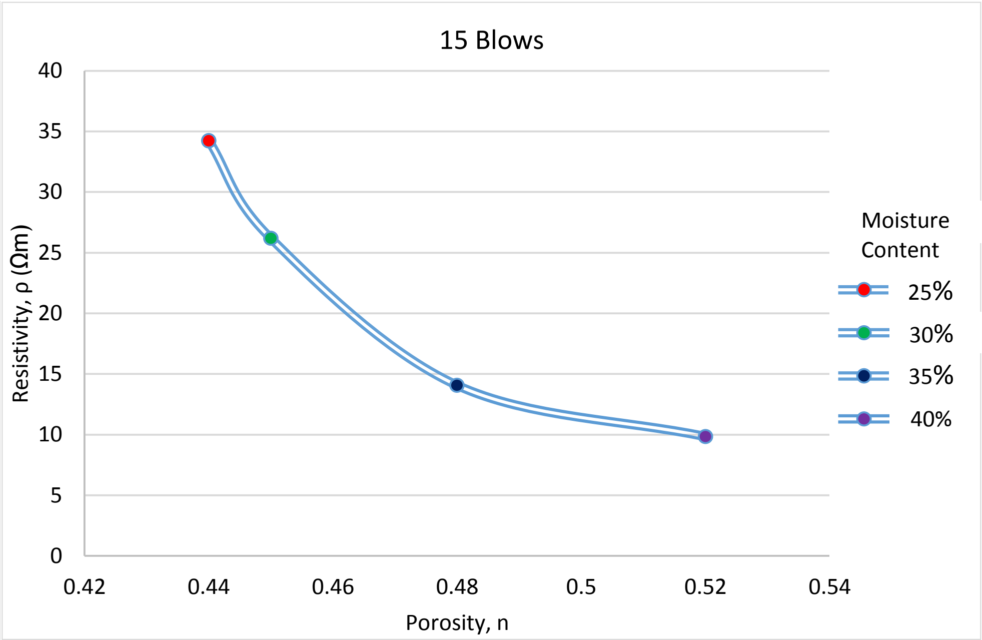


Figure 4.3: Resistivity vs Porosity for 15 Blows

Figure 4.3 shows that as the electrical resistivity decreased with the increase of porosity. Moisture content with 25% shows the highest value of resistivity that inversely proportional to the lowest porosity. With respect to moisture content, the more percentage of moisture content as the resistivity values decreases, the porosity will increase. Enhanced electrical conduction due to the presence of moisture might cause the reduction in resistivity with the increase of moisture content.

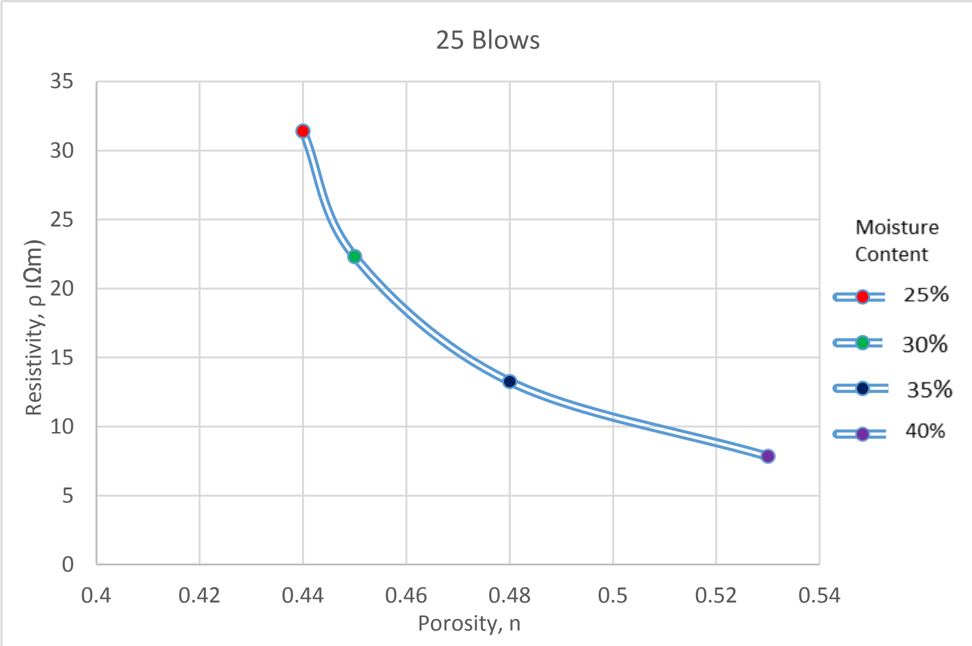


Figure 4.4: Resistivity vs Porosity for 15 Blows

Figure 4.4 shows that as the electrical resistivity decreased with the increase of porosity same behavior as 15 blows. Moisture content with 25% shows the highest value of resistivity value of 31.40ohm.m and the lowest value of resistivity is 7.84ohm.m for 40% moisture content. With respect to moisture content, the more percentage of moisture content as the resistivity values decreases, the porosity will increase.

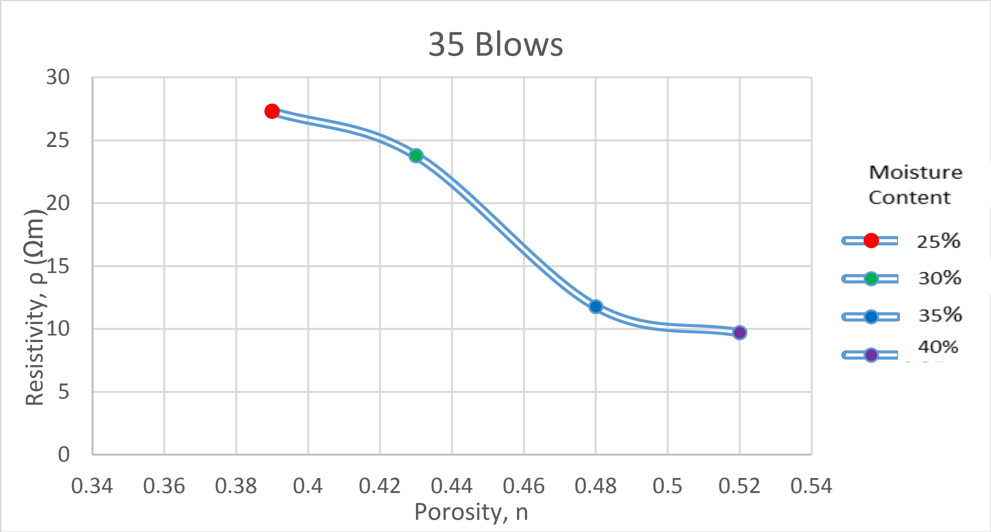


Figure 4.5: Resistivity vs Porosity for 35 Blows

Figure 4.5 shows that moisture content with 40% is the lowest value of resistivity value of 9.69ohm.m with the porosity value of 0.52. There was an optimum value for this graph due to the large gap differences between moisture content 30% and 35%. For moisture content 30% the resistivity value is 23.77ohm.m and for 35% the resistivity values is 11.77ohm.m. These differences gap due to the increase in moisture content which will pushing the particle away and creating bigger void hence increasing the porosity value.

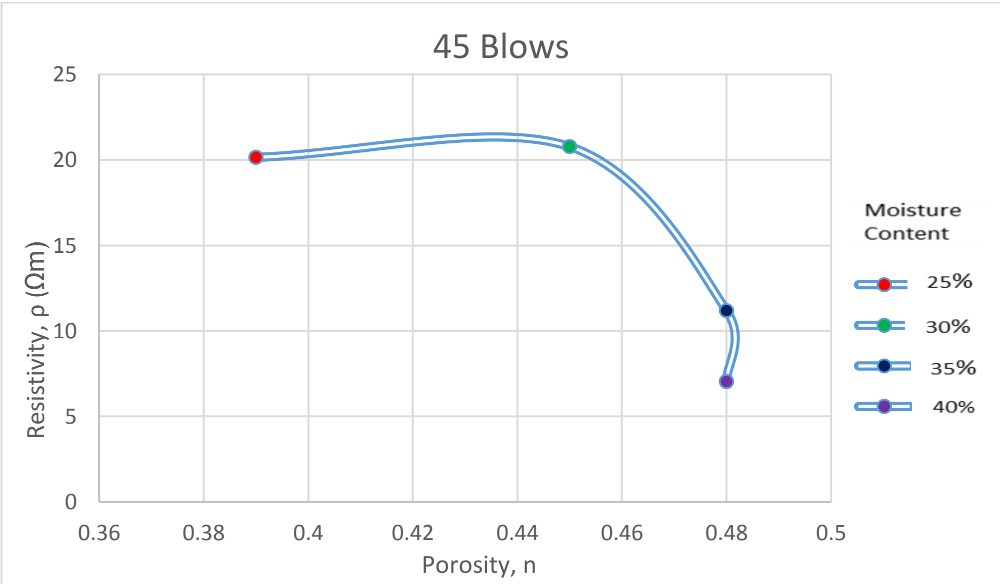


Figure 4.6: Resistivity vs Porosity for 45 Blows

Figure 4.6 shows that highest resistivity value is 20.78ohm.m which for moisture content 30%. This shows that the resistivity value initially increase than will decreases. For 45 blows graph's behavior is dissimilar with others due to its own phenomena for this type of soil. Therefore, more experiments and tests should be done to obtain the exact behavior of this 45blows of resistivity's value. But generally electrical resistivity decreased with the increase of porosity.

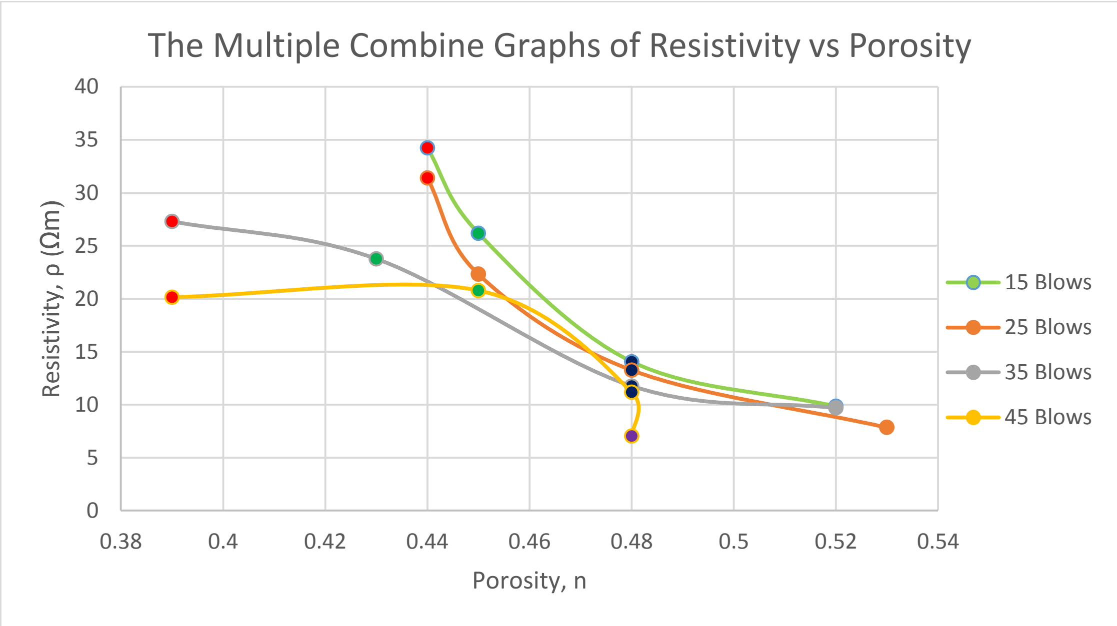


Figure 4.7: The Multiple Combine Graphs of Resistivity vs Porosity

Overall observed, the initial increases in soil resistivity at 25% moisture content might be caused due to the presence of air voids. The reduction in resistivity for the increase of pore space from might be attributed due to the specific surface area. Water film and moisture bridging between the particles might form more easily at 25% moisture content in the soils with small surface area. Therefore, resistivity decreased though there was an increase in pore space due to the pronounce moisture bridging between the particles and this hypothesis was approved by the research done by Abu Hassanein, 1996. The comparison of resistivity with the moisture content showed that soil resistivity was more sensitive to moisture in soil with small surface area. In addition, from the figure 4.6 shows that except for graph 45 blows which in different behavior, other graphs (15, 25, 35 blows) are decreases with respect to the resistivity against porosity graph's form.

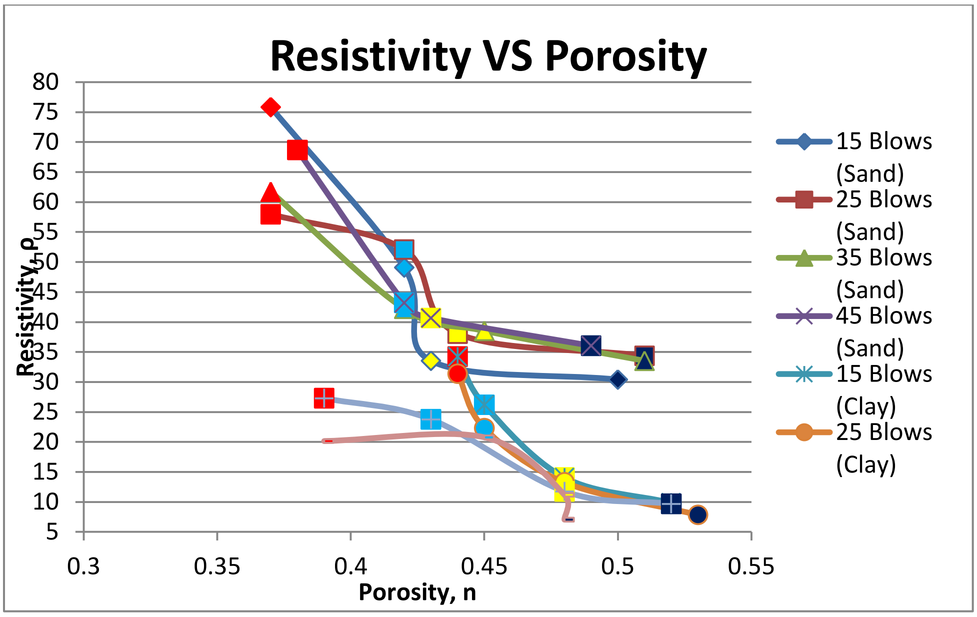


Figure 4.8: The Multiple Combine Graphs of Resistivity vs Porosity (Clay and Sand)

From the graph above shows that the multiple combine graphs of resistivity against porosity for clay and sand types of soil. Briefly, there was different values of porosity between these two types of soil. Sand particles have bigger porosity compared to clay. But from the result due to other factor such as the compative effort that influences the pore space in the between this to types of soil.

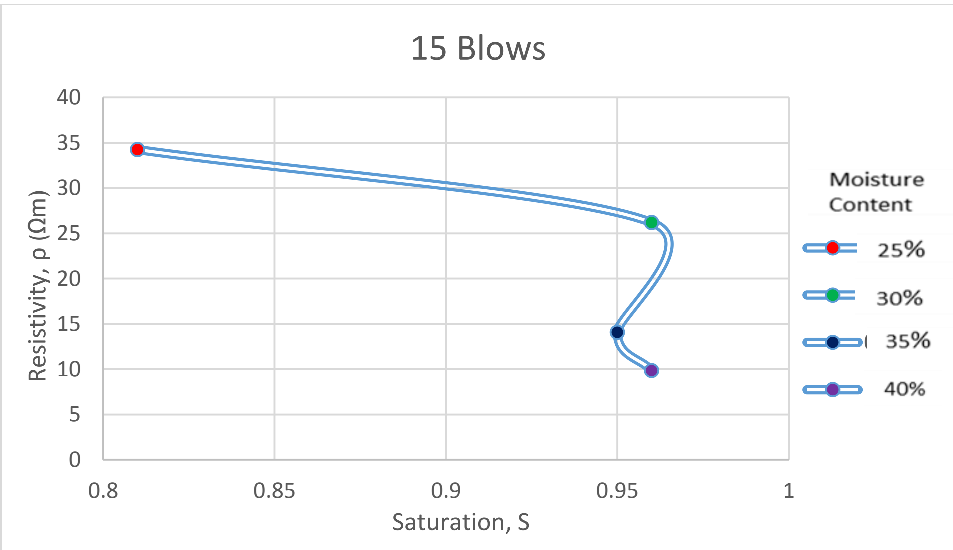


Figure 4.9: Resistivity vs Saturation for 15 Blows

For figure 4.9 shows that soil resistivity decreased from 34.21ohm.m to 9.85ohm.m in an average with the increase of degree of saturation from 0.81 to 1.15 due to elimination of interclod macropores, reorientation of clay particle and remolding of clay clods. However, at low degree of saturation soil with high surface area showed high resistivity.

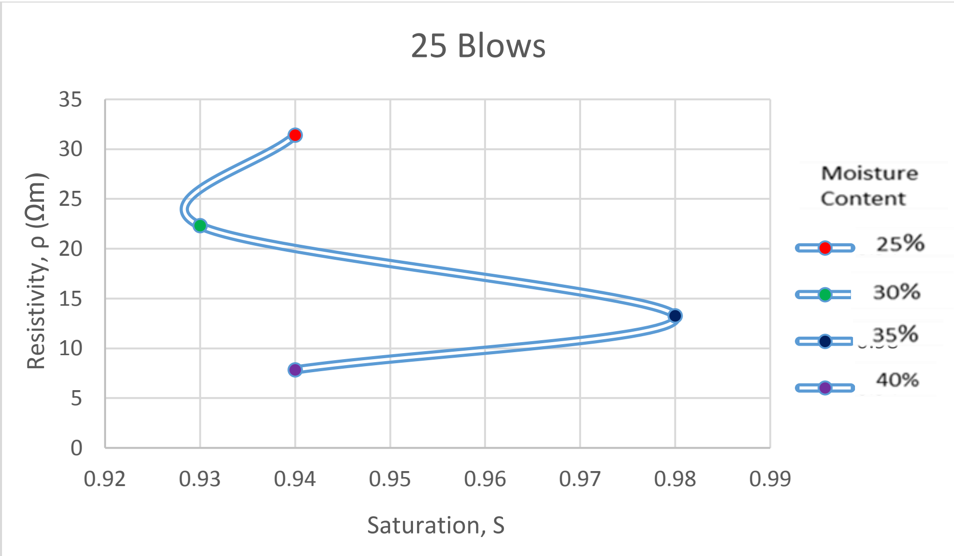


Figure 4.10: Resistivity vs Saturation for 25 Blows

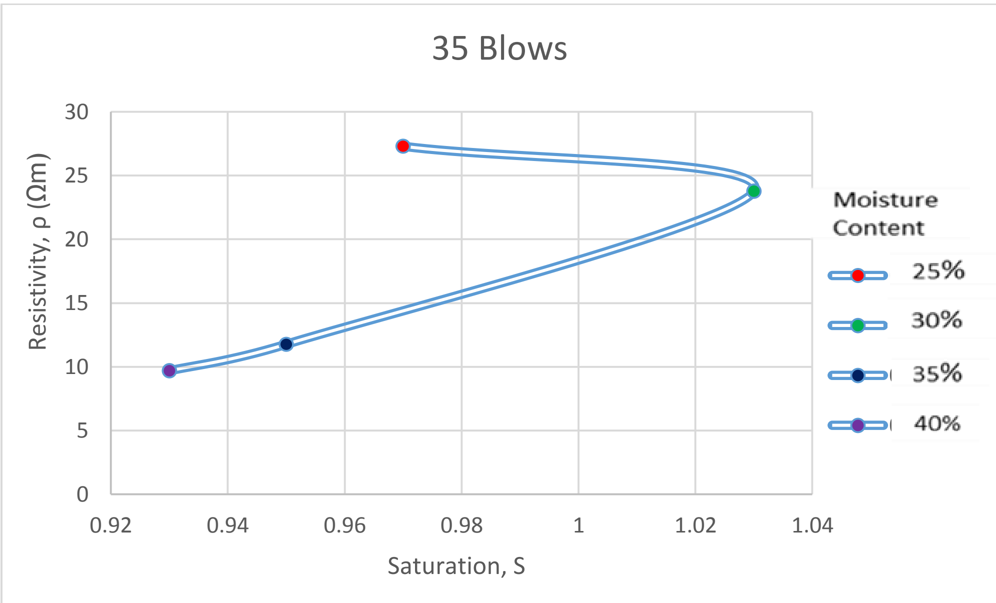


Figure 4.11: Resistivity vs Saturation for 35 Blows

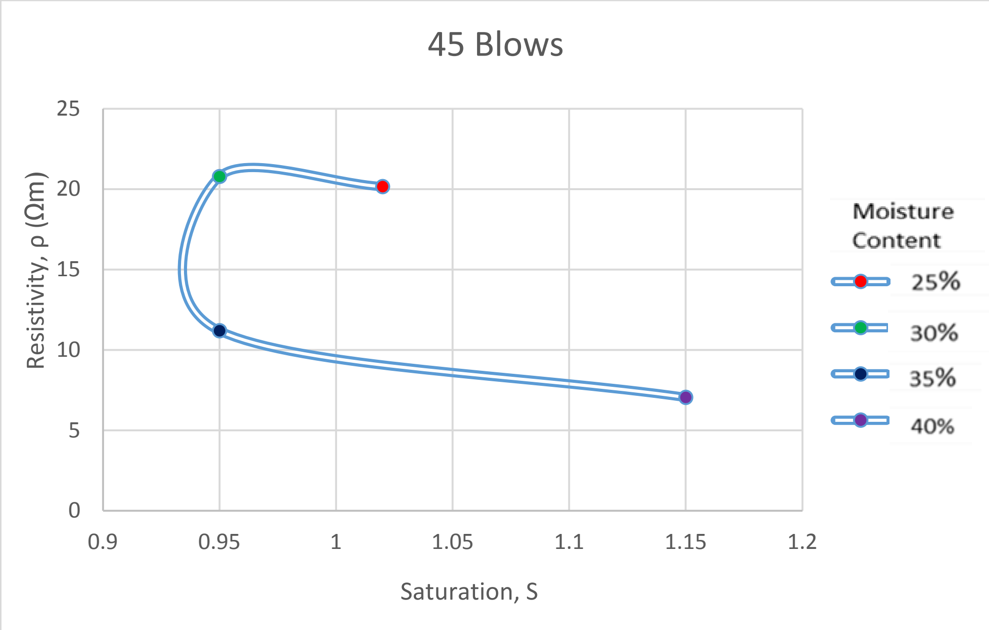


Figure 4.12: Resistivity vs Saturation for 45 Blows

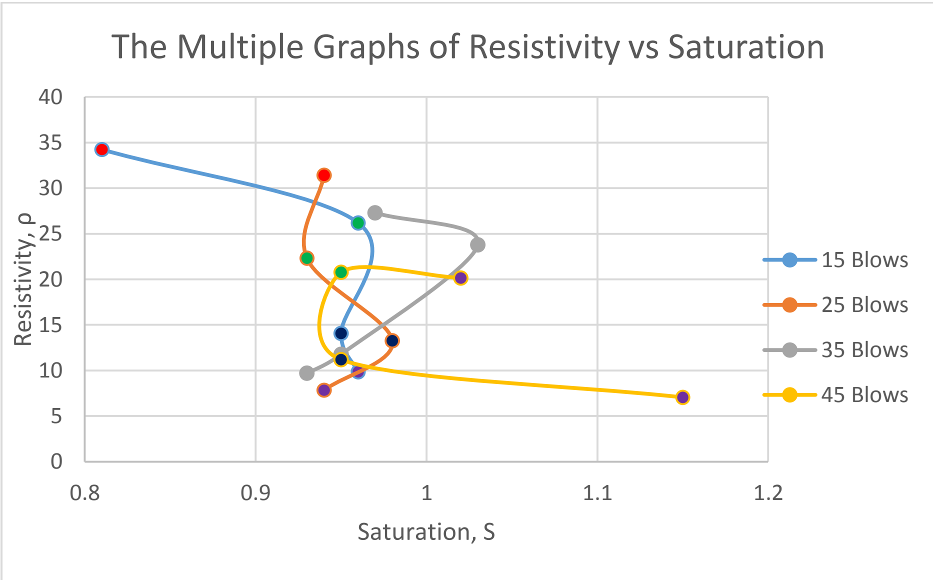


Figure 4.13: The Multiple Combine Graphs of Resistivity vs Saturation

The water content and dry unit weight can be combined to a single geotechnical parameter called degree of saturation Degree of saturation increases with the increase of water content or dry unit weight (Abu Hassanein, 1996). The variations of electrical resistivity with the degree of saturation are presented in figure 4.13 for soil samples 25 blows, figure 4.8 for soil samples 35 blows and figure 4.8 for soil samples 45 blows. The behavior of the graphs were fluctuated and dissimilar. To obtain degree of saturation, specific gravity of 2.58 for clay was assumed. It was that soil resistivity decreased with the increase of degree of saturation. Increase in degree of saturation yields changes in clay clods, reduction in interclod macro voids and orientation of clay particles (Khalil and Santos, n.d). Therefore, briefly observed from the graphs, soil resistivity decreased with the increase in degree of saturation.

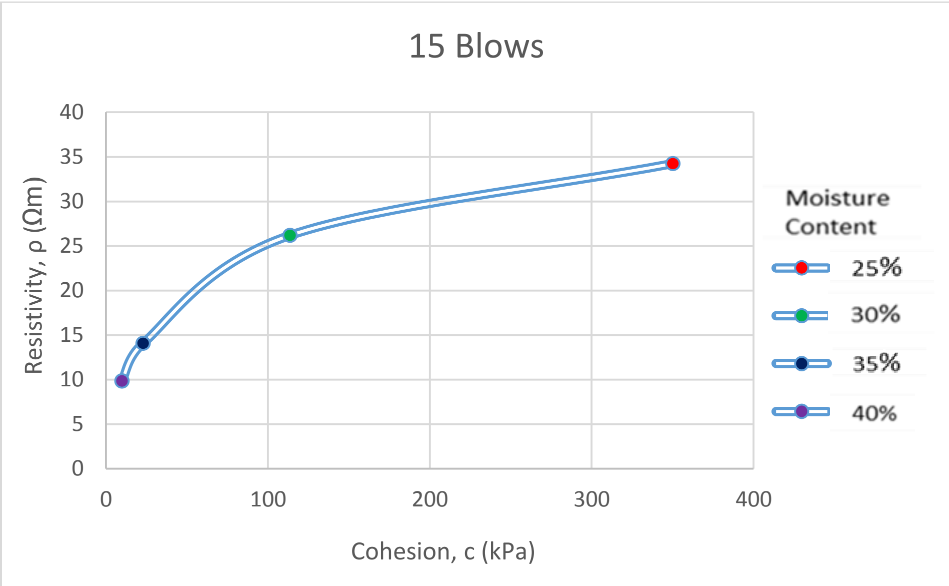


Figure 4.14: Resistivity vs Cohesion for 15 Blows

Figure 4.14 shows that cohesion has weak relationship with the resistivity of the soil. The trend of the curve indicates that the cohesion increases with the increases of electrical resistivity. In addition, compare between differ moisture content, 25% has higher strength compare with 30%, 35% and 40%. Generally, when soil contains more water, the strength will reduce.

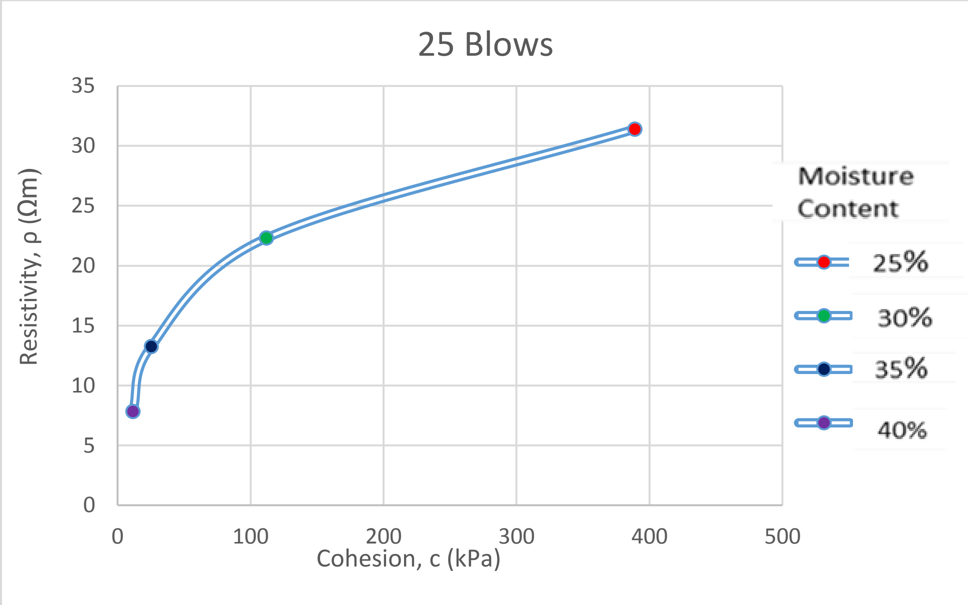


Figure 4.15: Resistivity vs Cohesion for 25 Blows

Figure 4.15 shows the same behavior like 15 blows. When the electrical resistivity increases the cohesion value also increase in terms of different moisture content. The value of cohesion presented in the above graph were all obtained from pocket penetrometer test conducted on the remolded soil samples. The variation of soil resistivity with strength condition can be discussed according to the structural change of soil during compaction. Therefore, moisture content 40% has the lowest strength with 11.44kPa and for moisture content 25% has highest strength which is 389.05kPa.

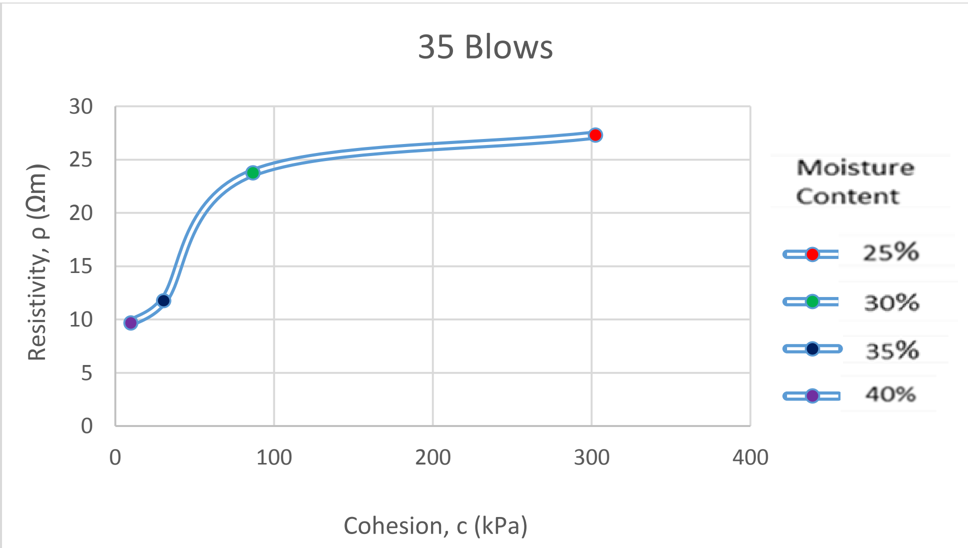


Figure 4.16: Resistivity vs Cohesion for 35 Blows

It is interesting to find out the correlation between cohesion and electrical resistivity for clay soil as shown in Figure 4.11 are also same with other behavior of the graphs. The clay clods are difficult to remold and interclod pores are large when compacted at higher moisture content. The pores are filled with dielectric air at this condition. The contact between the particles is poor because of the presence of distinct clods at low strength. Therefore, resistivity was decreases at higher cohesive soils due to the presence of air filled voids and poor particle-to-particle contact.

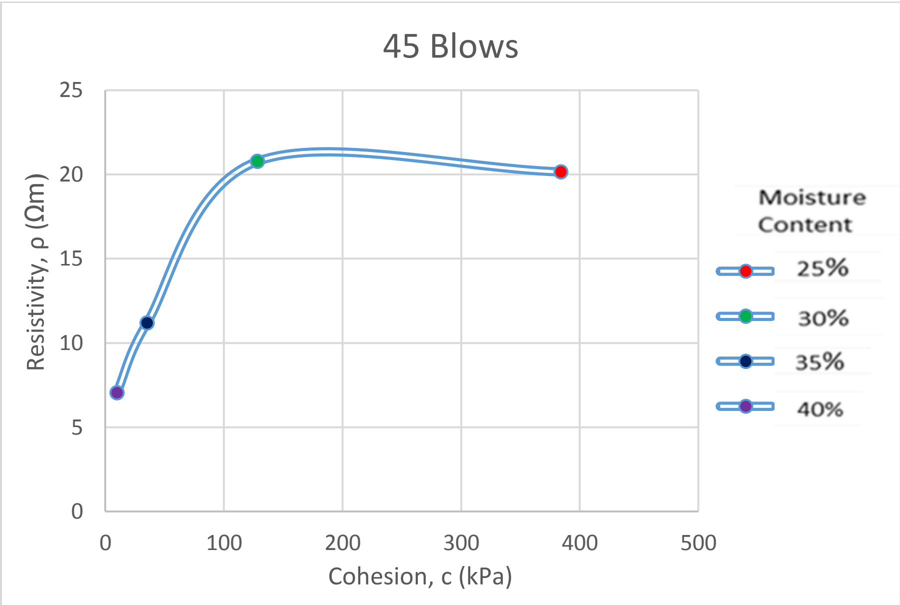


Figure 4.17: Resistivity vs Cohesion for 45 Blows

According to Figure 4.17, soil resistivity decreased from 20.15 to 7.05ohm.m in an average when the sample was compacted at dry of optimum. Therefore, when strength of the soil decreases which has higher moisture content, the electrical resistivity is decreases.

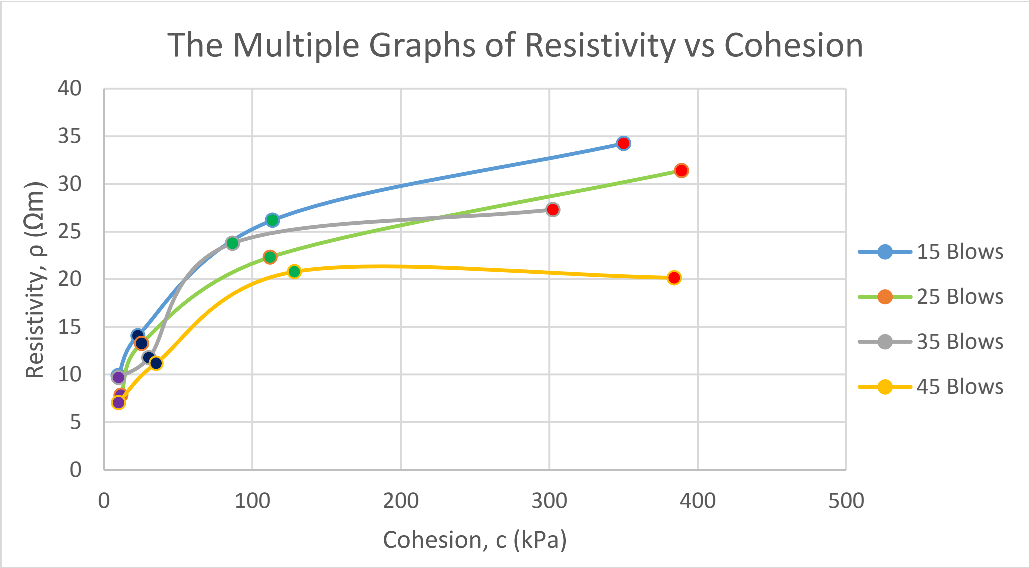


Figure 4.18: The Multiple Combine Graphs of Resistivity vs Cohesion

The combine graphs for all blows are then plotted as shown in Figure 4.18 with the trend of increasing cohesion with increasing electrical resistivity. In addition, from the figure 4.18 shows the trend of all graphs are decreases with respect to the number of blows. 15 blows shows higher curve compare to 25 and 45 number of blows. Except for 35 blows has different trend might be due to its own phenomena for clay type of soil. This paper does not attempt to hypothesize the reasons of such relationship but if what was obtained here is the true representation of the relationship between cohesion and electrical resistivity, then further tests need to be carried out to establish the governing mechanisms. Kibria, G., Hossain, M.S.(2012) point out that the related factors to look for are particle arrangement of fine particles and the reduction of porosity which contribute to the strength of the soil samples and affect the ability in transmission of fluid or ions in the soil which in turn affects the electrical resistivity.

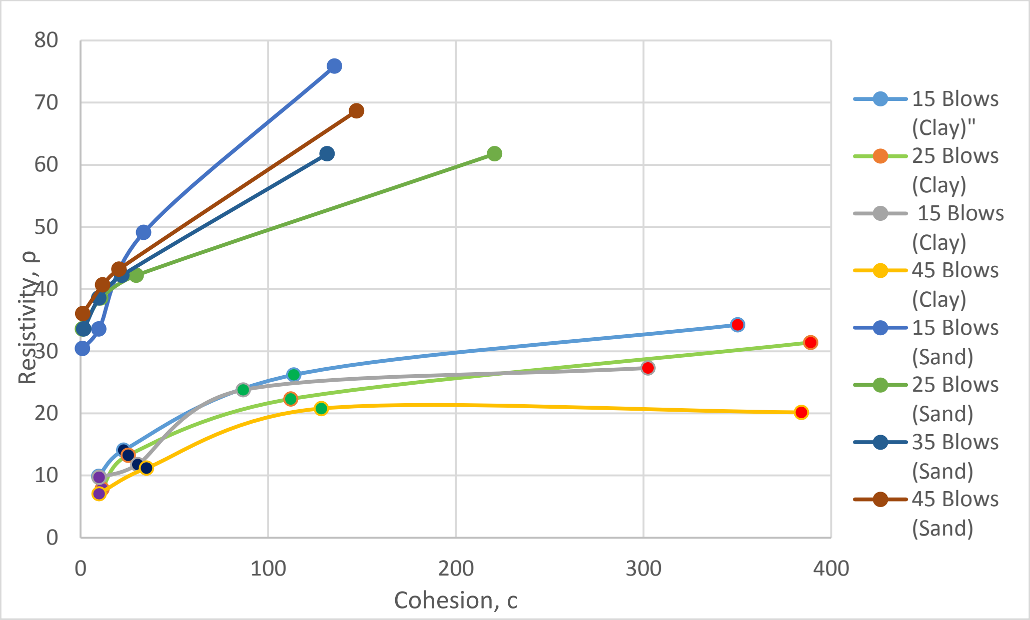


Figure 4.19: The Multiple Combine Graphs of Resistivity vs Cohesion (Clay and Sand)

From the graph above shows that the multiple combine graphs of resistivity against cohesion for clay and sand types of soil. Briefly, there was different values of porosity between these two types of soil. Clay particles have higher cohesion compared to clay. On the other hand, clay has high values of cohesion due to the behavior of clay as cohesive soil and sand as loose sand.

CHAPTER 5

CONCLUSION AND RECEMMENDATION

5.1 Conclusion

The purpose of the study was to determine the effects of porosity and saturation on electrical resistivity and strength of soil for clay particle. Soil samples with particular specification were bought from supplier. Soil resistivity tests were conducted at different condition to identify the relationship with liquid limit, plastic limit, compaction, pH value and moisture content.

Basic laboratory tests and simple electrical resistivity test using basic multimeter were conducted to obtain the correlations between electrical resistivity and some soil parameters. The results showed that when porosity increases, resistivity decreases. Also showed when resistivity increased the cohesion increased. The relationship between resistivity and porosity and resistivity and cohesion showed similarities and behaves which supported the early study done by Abu-Hassanaein, et all. (1996) and Turesson (2005).

On the other hand, for saturation indicated behavior which when the saturation increases, the resistivity value decreases. From the results and graphs analyzed, some unique trends of behavior were observed for relationship between resistivity and saturation. Hence, more investigation and experiments need to be conducted in order to achieve more precise correlations.

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 for Future Study

- 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

1) CALCULATIONS FROM EXPERIMENT DATA

DATE: 26 SEPTEMBER 2013

DIMENSION OF MOULD

Length = 0.116m

Diameter = 0.104m

Radius = 0.052m

Weight of mold + base = 5.04kg

FOR MOISTURE CONTENT = 25%

NO. OF BLOWS = 15

WEIGHT OF EACH LAYERS:

LAYER	WEIGHT (kg)
Layer 1	5.52
Layer 2	6.27
Layer 3	6.78

RESISTIVITY TEST:

VOLT (V)	AMPERE (A)	RESISTANCE	RESISTIVITY (Ωm)
30	0.062	483.87	35.46
60	0.127	472.44	34.62
90	0.202	445.54	32.65
Average			**34.24**

POCKET PENETROMETER TEST:

NO.	TOP (kg/cm^2)	BOTTOM (kg/cm^2)
1	3.30	4.10
2	3.50	3.25
3	4.00	3.25

Weight of mould + base plate + moist compacted soil, w_2	=	6.78 kg
Weight of mould + base, w_1	=	5.04 kg
Weight of moist compacted soil , $w_2 - w_1$	=	6.78 – 5.04
	=	1.74 kg

Obtained Moist Unit Weight:

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

= 1.74 kg / (9.854×10^{-4}) m^3 = 17.66kN/m^3

To find Porosity, *n* using formula unit weight:

γ_B = $G_s \cdot \gamma_w (1-n)(1-w)$

17.66 = (2.58)(9.81)(1-*n*)(1+0.25)

17.66 = (25.31)(1-*n*)(1.25)

0.56 = 1-*n*

n **= 0.44**

To find Saturation, *S*

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

17.66 = (2.58)(9.81)(1-0.44) + (0.44)*S*(9.81)

3.49 = 4.32*S*

S **= 0.81**

2) CALCULATIONS FROM EXPERIMENT DATA

DATE: 24 OCTOBER 2013 (MIXING 23 OCTOBER 2013)

DIMENSION OF MOULD

Length	=	0.116m
Diameter	=	0.104m
Radius	=	0.052m
Weight of mold + base	=	5.04kg

FOR MOISTURE CONTENT	**=**	**40%**
NO. OF BLOWS	**=**	**45**

WEIGHT OF EACH LAYERS:

LAYER	WEIGHT (kg)
Layer 1	5.52
Layer 2	6.41
Layer 3	6.87

RESISTIVITY TEST:

VOLT (V)	AMPERE (A)	RESISTANCE	RESISTIVITY (Ωm)
30	0.339	88.49	6.48
60	0.599	100.17	7.34
90	0.900	100.00	7.33
Average			**7.05**

POCKET PENETROMETER TEST:

NO.	TOP (kg/cm^2)	BOTTOM (kg/cm^2)
1	0.10	0.10
2	0.10	0.10
3	0.10	0.10

Weight of mould + base plate + moist compacted soil, w_2	=	6.87 kg
Weight of mould + base, w_1	=	5.04 kg
Weight of moist compacted soil , w_2 - w_1	=	6.78 – 5.04
	=	1.83 kg

Obtained Moist Unit Weight:

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

= 1.83 kg / (9.854×10^{-4}) m^3 = 18.57kN/m^3

To find Porosity, *n* using formula unit weight:

γ_B = $G_s \cdot \gamma_w (1-n)(1-w)$

18.57 = (2.58)(9.81)(1-*n*)(1+0.40)

18.57 = (35.43)(1-*n*)

0.52 = 1-*n*

n **= 0.48**

To find Saturation, *S*

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

18.57 = (2.58)(9.81)(1-0.48) + (0.48)*S*(9.81)

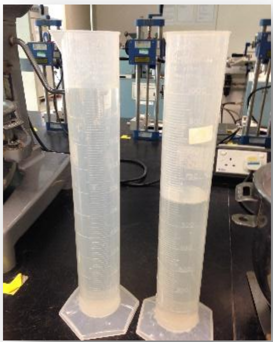
5.41 = 4.71*S*

S **= 1.15**

PHOTO OF MIXING PROCESS

The KM80 soil sampels

The soil sample was weigh before mixing



Mixed the soil samples with distilled water

Mixed them together

Used mixer to mixed the sample

Leaved the sample for 24hours

PHOTO OF COMPACTION TEST

 Sample was compacted layer by layer	 Using a Standard Proctor Hammer
 The 3rd layer was weight	 The apparatus that been used for compaction test

PHOTO OF ELECTRICAL RESISTIVITY TEST

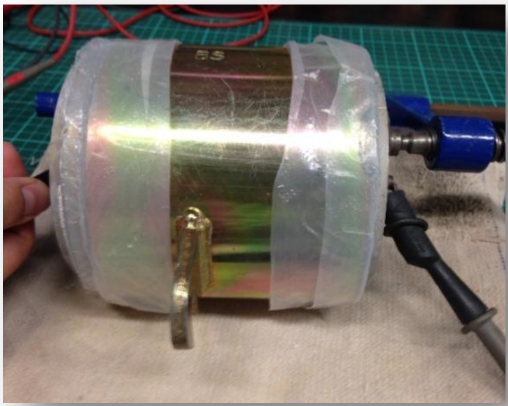
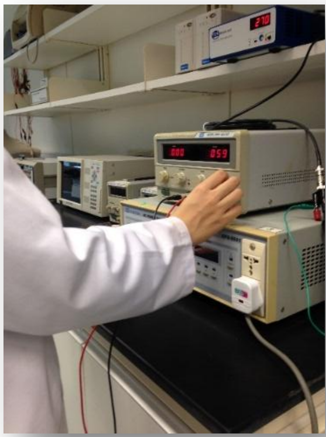
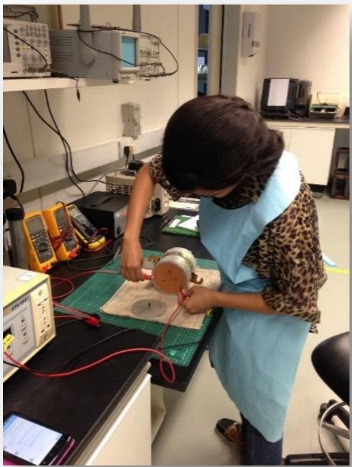
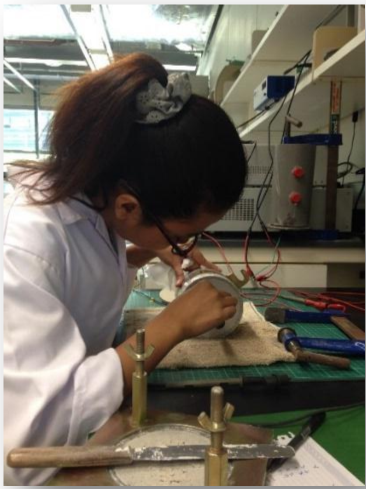
 Sample was connected to the current and voltage	 Different voltage were applied
 Ensure the disc does not touch the surrounded plastic	 The arrangement of the connection for electrical resistivity test

PHOTO OF POCKET PENETROMETER TEST

The pocket penetrometer



Push the pocket penetrometer until the limit line to obtain the reading

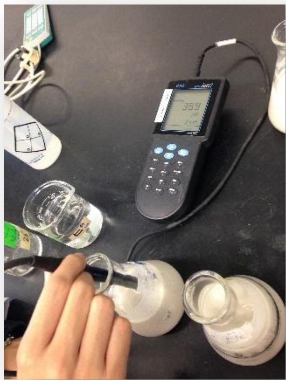
Penetrate for both top and bottom of the samples

PHOTO OF PH TEST

50 gram of samples were mixed with 100mL distilled water

Samples were shake for 24hours

Samples were leaved one hour after shake



pH test reading

EXPERIMENT FINDINGS

MOISTURE CONTENT = 25%




15 blows 25blows 35blows 45blows

MOISTURE CONTENT = 30%




15 blows 25blows 35blows 45blows

MOISTURE CONTENT = 35%

15 blows | 25blows | 35blows | 45blows

MOISTURE CONTENT = 40%

15 blows | 25blows | 35blows | 45blows