THE EFFECTS OF POROSITY AND SATURATION ON ELECTRICAL RESISTIVITY AND STRENGTH OF SOIL FOR SAND SIZE PARTICLES

by

NOOR FAIZAH BINTI SANI

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Civil Engineering)

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CERTIFICATION OF APPROVAL

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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 sourced or persons.

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NOOR FAIZAH BINTI SANI

ABSTRACT

Geophysical methods had become increasingly practiced in engineering site characterization as being quicker, more economical, and allow more data to be taken than the present method. Electrical resistivity was conducted by supply generated electric current to the soil and the resulting potential differences are measured. This research presents the effects of porosity and saturation on electrical resistivity and strength of soil for sand size particles. It was a study about the effects of porosity and saturation on electrical resistivity of sand size particles ranges between 0.029mm to 2.00mm. Soil sample was mixed with distilled water and left for 24 hours. The compaction test conducted with different blows in each of moisture content ranged 25% to 40%. Electrical resistivity test as well as pocket penetrometer test had been done right after the compaction test to analyzed and understand the effects of porosity, saturation and cohesion on electrical resistivity. Results show that the effects of porosity on electrical resistivity of sand size particles is when the porosity is high, it means that there is less water in the pore and the resistivity will get higher because water is the good in conductivity. When moisture content is higher, the resistivity will get lower. From test, it shows that there is no specific trend for resistivity against saturation but past studies shows that the lower the saturation, the higher the resistivity. For the cohesion, the lower the moisture content, the higher the resistivity, the higher the cohesion. This showed that the higher the compaction, the stronger the soil will be. The results of this research can be used for geotechnical site investigation by using electrical resistivity.

ACKNOWLEDGEMENT

In this column of an acknowledgment, firstly, I thank Allah S.W.T. for a smooth and successful process of preparing this report. Secondly, I wish to express my sincere gratitude particularly to my supervisor, Dr. Syed Baharom Azahar Bin Syed Osman for patience and kind guidance throughout the period of final year project. Without the attention and dedicated guidance from my supervisor, my final year project would not be successfully completed.

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CHAPTER 1

INTRODUCTION

1.0 BACKGROUND OF STUDY

Every development needs soil investigation to know the soil parameters. Soil investigation (SI) works involve soil boring, laboratory testing, sample acquisition and others which are time-consuming and expensive even though it provides the accurate engineering properties for the soil parameters. By using the geophysical methods such as electrical resistivity which now have become increasingly practiced in engineering site characterization, the soil investigation can be done quicker, more economical, and allow more data to be taken than the present method.

Electrical resistivity was first applied to oil and gas exploration and prospecting of conductive ore bodies, later it found applications in various engineering fields e.g. mining, agriculture, environment, archeology, hydrogeology and geotechnics. There are very limited studies have been carried out to correlate the electrical resistivity and geotechnical parameters of soil.

Electrical resistivity is conducted by supply generated electric current to the soil and the resulting potential differences are measured. Usually, nonporous materials will have high resistivity value. Silts, clays and coarse and fine grained soil mixtures have comparatively low resistivity values. Hence, to understand more about the relationship between geotechnical parameters and resistivity, this research is to study the effects of porosity and saturation on electrical resistivity and strength of soil for sand size particles.

1.1 PROBLEM STATEMENT

The use of electrical resistivity by geotechnical engineers has been increasing worldwide but there are very limited studies have been conducted to obtain geotechnical parameters using resistivity.

Obtaining geotechnical properties has become an important issue in geotechnical engineering. The correlations of different geotechnical properties with electrical resistivity will close the gap currently exists between geophysical and geotechnical testing and therefore geotechnical engineers will be able to interpret the geophysical data and utilize the information for their design.

1.2 OBJECTIVE

The objectives of this project are:-

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

1.3 SCOPE OF STUDY

The study is to determine the relationship of geotechnical properties of sand soil with electrical resistivity. The soil samples (L2B20) were bought and collected from Kaolin Malaysia Sdn. Bhd. in Kuala Lumpur. The test then being carried out by using different moisture content (25%, 30%, 35%, and 40%) and different number of blows (15, 25, 35, and 45) to the soil sample.

The effects of porosity, saturation and strength of soil for sand size particles will be analysed by using compaction test, electrical resistivity test and pocket penetrometer test in the laboratory.

1.4 THE RELEVANCY OF THE PROJECT

Electrical resistivity can be used to help in the exploration of natural resources. The soil parameters such as porosity, saturation and cohesion that obtained from electrical resistivity can also be used to calculate the factor of safety (FOS) which will indicate the stability of a certain slope. Therefore, the method of electrical resistivity is the best solution to find the soil parameters because the result can be obtains directly which shows it is less time consuming.

1.5 FEASIBILITY OF THE PROJECT

In each of every development, the soil investigation must be made in order to obtain the soil characteristics. Due to save time and cost, the method of electrical resistivity is the best solution to find the soil characteristics because the result can be obtains directly. The results of this study can be used for geological and hydro-geological assessment such as wells location and agricultural activity.

To carry out the electrical resistivity survey in the laboratory, first get the soil specimen from the factory according to the specific coding and particle size. For this research, the chosen soil is sand L2B20 with particle size from 0.029mm to 2.00mm. This is to make sure that all the samples have the same criteria. Before conduct the electrical resistivity test, compaction test must be done first to compare the result in different blows.

The laboratory test done in Universiti Teknologi PETRONAS (UTP) at geotechnical laboratory and the equipment to conduct the tests is available and still in good condition. So it will not involve high cost and long time because all the equipment is available. In conclusion, this project achieved within the time frame given based on the scope of study.

CHAPTER 2

LITERATURE REVIEW

2.0ELECTRICAL RESISTIVITY

Electrical resistivity is the best tool to conduct SI because it delineating subsurface properties without soil disturbance (Siddiqui & Syed, n.a.). Besides, it is save time as well as cost. Electrical resistivity survey is a measure of how much the soil resists the flow of electricity. The purpose of electrical resistivity surveys is to determine the resistivity distribution of the sounding soil volume which generated electric currents are supplied to the soil and the resulting potential differences are measured (Samoelian et. al., 2005)

As mentioned by Syed, Fikri & Siddique (n.a.), the electrical resistivity of the soil is determined first by conducting the compaction test. Prior to the compaction process, the internal perimeter of the mold was lined with a thick plastic material for easy removal of the specimen once the mold was dissembled and it will not interrupt the resistivity reading because the mold is made by metal. The specimens were then compacted directly in the round mold in three equal layers using the standard proctor hammer that delivers blows ranging from 15 - 45 blows per layer. The procedure for compaction is the same as prescribed in BS 1377. The mold was disassembled upon completion of compaction and the specimen was placed between two circular aluminium electrodes for the purpose of determination of electrical resistivity using disc electrode method.

The specimens along with the aluminium disc were connected to both the negative and positive terminals of a DC power supply and also connected to multimeter where an initial potential with varying voltages from 30V, 60V, and 90V were applied. The resulting values of current in miliampere were then recorded and calculated using equations.

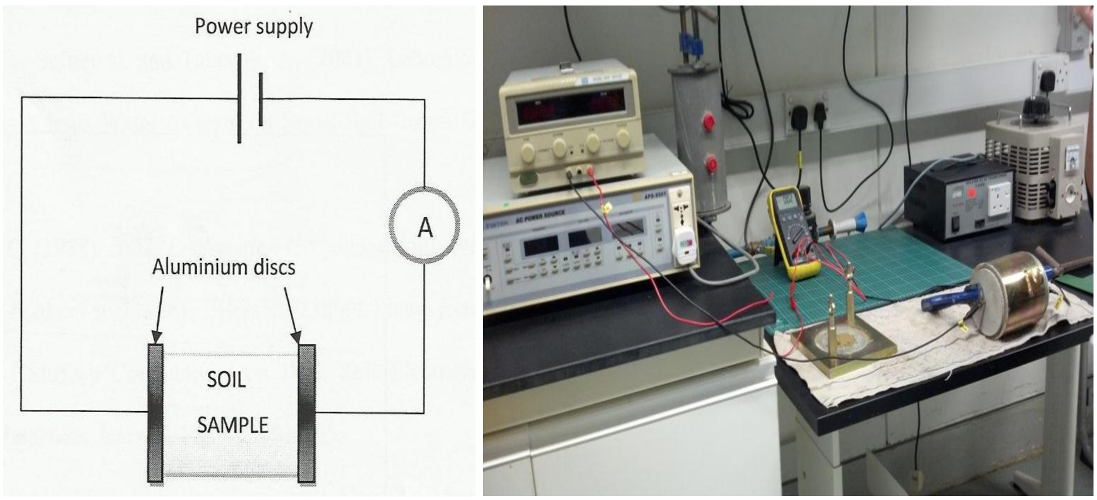


Figure 1: Laboratory electrical resistivity test setup

The resistivity of soil is determined by measuring the resistance through the cylindrical section of the mold. To define the resistivity, measure the sectional area, A and length, L of the mold, if current flow, I through section resistance, R and potential, V drop across the section, then the resistivity can be expressed by the following equation.

$$\boldsymbol{\rho = R. (A/L)}$$

Where, ρ=Electrical resistivity

R=Resistance of the material

V=Potential

I=Current

A=Cross sectional area

L=Length

The resistance, R is calculated by using Ohm's Law as below.

$$R = V/I$$

Where, R=Resistance of the material

V=Potential

I=Current

2.1POROSITY

Porosity of soil is the amount of pore space or open space between soil particles. Porosity of surface soil decreases as particle size increases. This is due to soil aggregate formation in finer textured surface soils when subject to soil biological processes. For sandy soil normally have 35% to 50% pore space, while medium to fine-textured soils have 40% to 60% pore space. Porosity of subsurface soil is lower than in surface soil due to compaction by gravity (Turesson, 2006).

The geometry of the pores determines the proportion or air and water according to the water potential (Samouelian, et al., 2004). Macro pores are larger diameter pores which have more than 0.1mm tend to be freely draining and are prevalent in coarse textured or sandy soils while micro pores are smaller diameter pores which less than 0.03mm that can be abundant in clay soil.

Porosity is governed by many factors such as uniformity of soil compaction during and after deposition and others. The relationship between porosity and electrical resistivity is the higher the porosity, the higher the electrical resistivity (Turesson, 2005). Porosity can be defined by following equation.

$$\text{Porosity} = n = \frac{\text{Volume of voids}}{\text{Total Volume}} = \frac{V_v}{V_t} \times 100\%$$

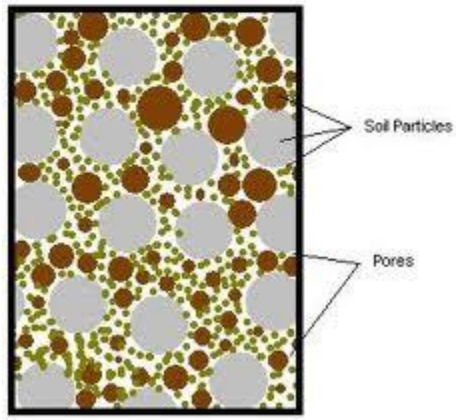


Figure 2: The composition of soil.

2.2SATURATION

Saturation is a condition which all easily drained voids or pores between soil particles are temporarily or permanently filled with water (Biology Online, n.a.). The water content and dry unit weight can combine to a single geotechnical parameter called degree of saturation. The degree of saturation, S is defined as the ratio of the volume of water to the volume of voids. It can be range between 0% for completely dry soil and 100% for a fully saturated soil. Research showed that soil resistivity affected by the change in bulk density and degree of saturation. The degree of saturation increase with the increase of water content or dry unit weight (Kibria and Hossain, 2012). This statement was agreed by Khalil and Santos (n.d.).

However, Abu Hassanaein et al., (1996) observe that the electrical resistivity was inversely correlated with initial degree of saturation and the initial degree of saturation and electrical resistivity was independent of compactive effort. The degree of saturation can be defined by following equation.

$$\text{Degree of Saturation, } S = \frac{\text{Volume of Water}}{\text{Volume of Voids}} = \frac{V_w}{V_v}$$

2.3COHESION

Cohesion is the component of shear strength of a rock or soil that is independent of interparticle friction. In soils, the cohesion is caused by electrostatic forces in stiff over consolidated clays which may be lost through weathering. There can also be apparent cohesion which is caused by negative capillary pressure which is lost upon wetting and pore pressure response during undrained loading which is lost through time. The value of cohesion, C can be obtained by plotting the Mohr circle. In this research, ELE International Pocket Penetrometer will be used to get the cohesion data.

2.4COMPACTION

Soil compaction reduces total pore space of a soil. More importantly it significantly reduces the amount of large pore space, restricting air and water movement into and through the soil (Whiting, 2011). Lower resistivity is attained when compacted at wet optimum water content and high compactive effort (Abu Hassanaein et al., 1996).

2.5MOISTURE CONTENT

Moisture content is amount of water present in the soil. It is an important factor that geotechnical engineer needs to know. Samouelian et al. (2007) research mentioned that electrical resistivity of soil decreases with the increase of moisture content. The following equation is to calculate the moisture content.

$$W = \frac{\text{Weight of water, Ww}}{\text{Weight of solid soil, Ws}} \times 100\%$$

2.6EFFECTS OF SELECTED SOIL PARAMETERS ON ELECTRICAL RESISTIVITY

The research to measure the effects of selected soil parameters such as moisture content, frictional angle, bulk density and standard penetration Test (SPT) on electrical resistivity was conducted by Syed, Fikri and Siddique (n.a.). In their research, the graph of moisture content against the electrical resistivity plotted in Figure 2 below:

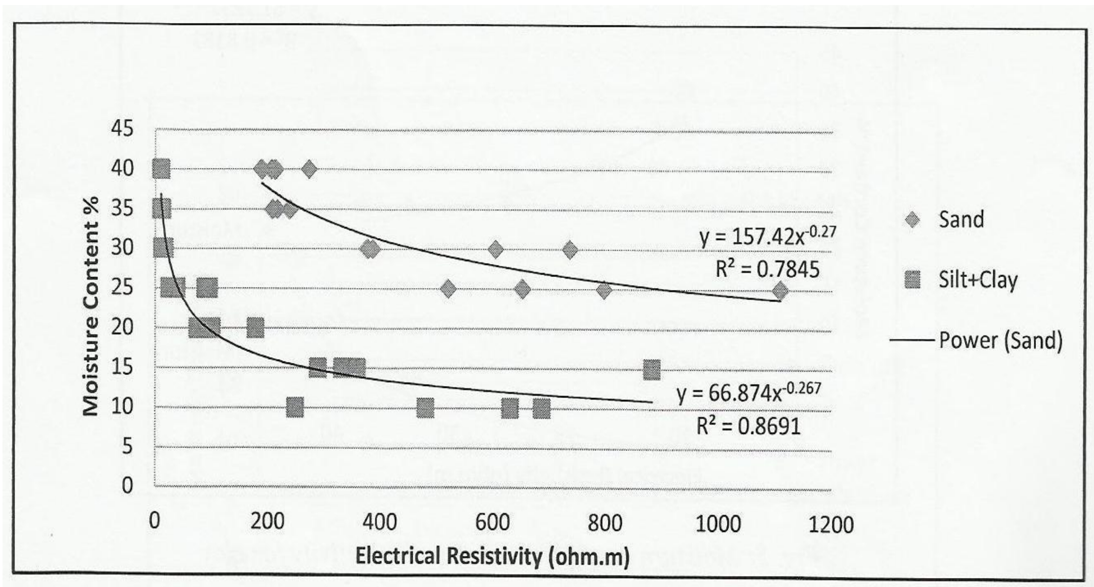


Figure 3: Moisture content vs. electrical resistivity for sand and silt+clay

This shows that at any types of soil, there are strong correlation between moisture content and electrical resistivity. The combined curve for silt and clay result shown above can be concluded that samples with fine grain soils will produce lesser resistivity while the moisture content is increasing.

parameter	parameter
Moisture content, ↓	ρ,↑
Frictional angle, ↑	ρ, ↑
Bulk density, ↑	ρ, ↑
SPT, ↑	ρ, ↑

Table 1: Trend of Result Obtained

Table 1 shows the conclusion of each soil parameters with electrical resistivity parameter which done by Syed and Zuhar (n.a.) after they conducted the electrical resistivity in one of the chosen site in UTP. The relationship between moisture content and electrical resistivity shows that lower moisture content will cause the increment in electrical resistivity. While the relationship for frictional angle, bulk density and SPT shows some similarities which indicate the value of the parameter increase with increase of electrical resistivity.

In Hakamada et.al. (2006) research mentioned that the variation in electrical resistivity as a function of porosity as shown in Figure 4, where the pore size is constant and the electrical resistivity increased with increasing porosity.

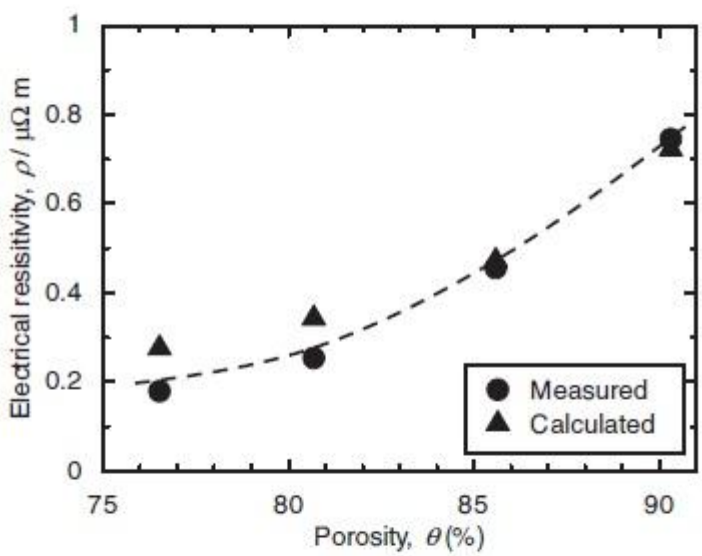


Figure 4: Variation in electrical resistivity as a function of porosity, where pore size is constant (425-500 µm)

2.7FACTORS AFFECTING THE ELECTRICAL RESISTIVITY OF SOIL

There are certain factors that affecting the electrical resistivity of soil. According to Syed & Zuhar (2010), the resistivity is high in a dry condition and in general, the resistivity of soils and rocks depends on the amount and type of water in the pore spaces and fractures. On top of that, Abu-Hassanein et. al. (1996) mention that the temperature also plays an important role in electrical resistivity because the increasing of the temperature will increase the mobility of ions and this decreases the electrical resistivity of soil.

The presence of clay minerals strongly affect the resistivity because the electrical conductive particles having the ability to absorb and release ions and water molecules on its surface through an ion exchange process as mentioned in Parasnis (1986) research.

The variations of resistivity with some common materials are list down in a table by Jackson (1975) as below:

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

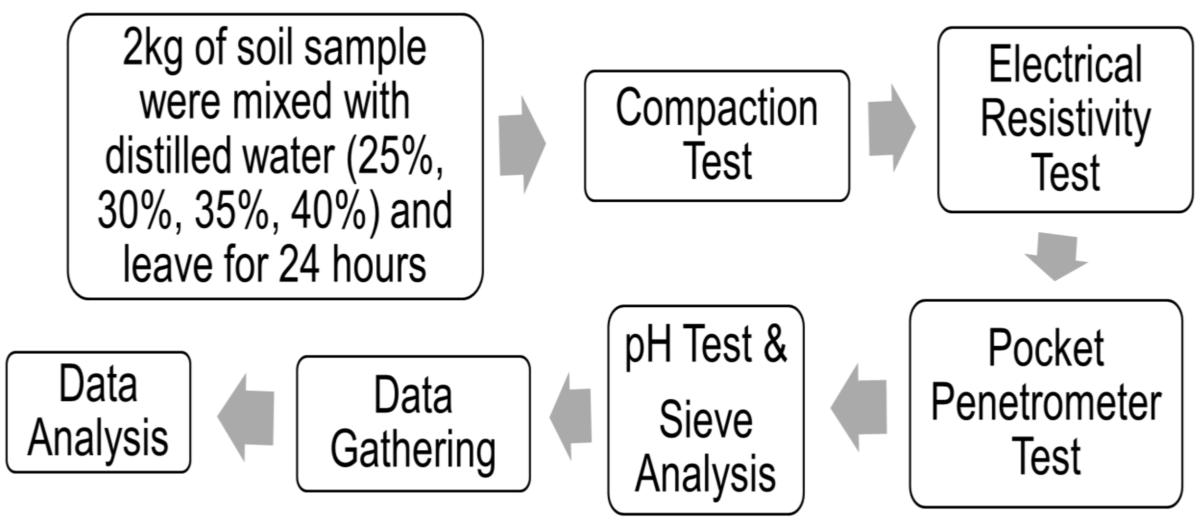
Figure 5: Variations of Resistivity with Some Common Materials

CHAPTER 3

METHODOLOGY

3.0RESEARCH METHODOLOGIES

- The process to find the results of electrical resistivity as well as the laboratory test to analyze this research as below:-



PROJECT ACTIVITIES

1) For every specimen, 2 kg of soil were mixed with a certain amount of distilled water according to the percentage of moisture content required which ranges between 25% - 40%.
2) Mixing was done by means of a soil mixer and the samples were left aside for at least 24 hours in the mixing bowl wrapped with plastic.
3) Prior to the compaction process, the internal perimeter of the mold was lined with a thick plastic material for the resistivity reading is accurate as well as it will be easy to remove the specimen once the mold was dissembled.
4) The specimens were then compacted directly in the round mold in three equal layers using the standard proctor hammer that delivers blows ranging from 15 - 45 blows per layer.
5) The procedure for compaction is the same as prescribed in BS 1377.
6) The mold was disassembled upon completion of compaction and the specimen was placed between two circular aluminum electrodes for the purpose of determination of electrical resistivity using disc electrode method.
7) The specimens along with the aluminum disc were connected to both the negative and positive terminals of a DC power supply and also connected to multimeter where an initial potential with varying voltages from 30V, 60V, and 90V were applied.
8) The resulting values of current in ampere were then recorded and calculated using equations.
9) The specimens were then used for pocket penetration test to get the cohesion.
10) Conduct pH test to know the pH for the soil sample. First, take 3 conical flasks and add 50gram of soil sample with 200 ml of distilled water in each of conical flask. Shake the mixture for 24 hours by using shaker and take the pH reading by using pH meter. Conduct the sieve analysis.
11) Gather all data from electrical resistivity as well as pocket penetration data and the pH test result.
12) Analyze gathered data to get the appropriate result and give a conclusion.

3.2 GANTT CHART AND KEY MILESTONE

Gantt chart below shows the project progress until the end of Final Year Project.

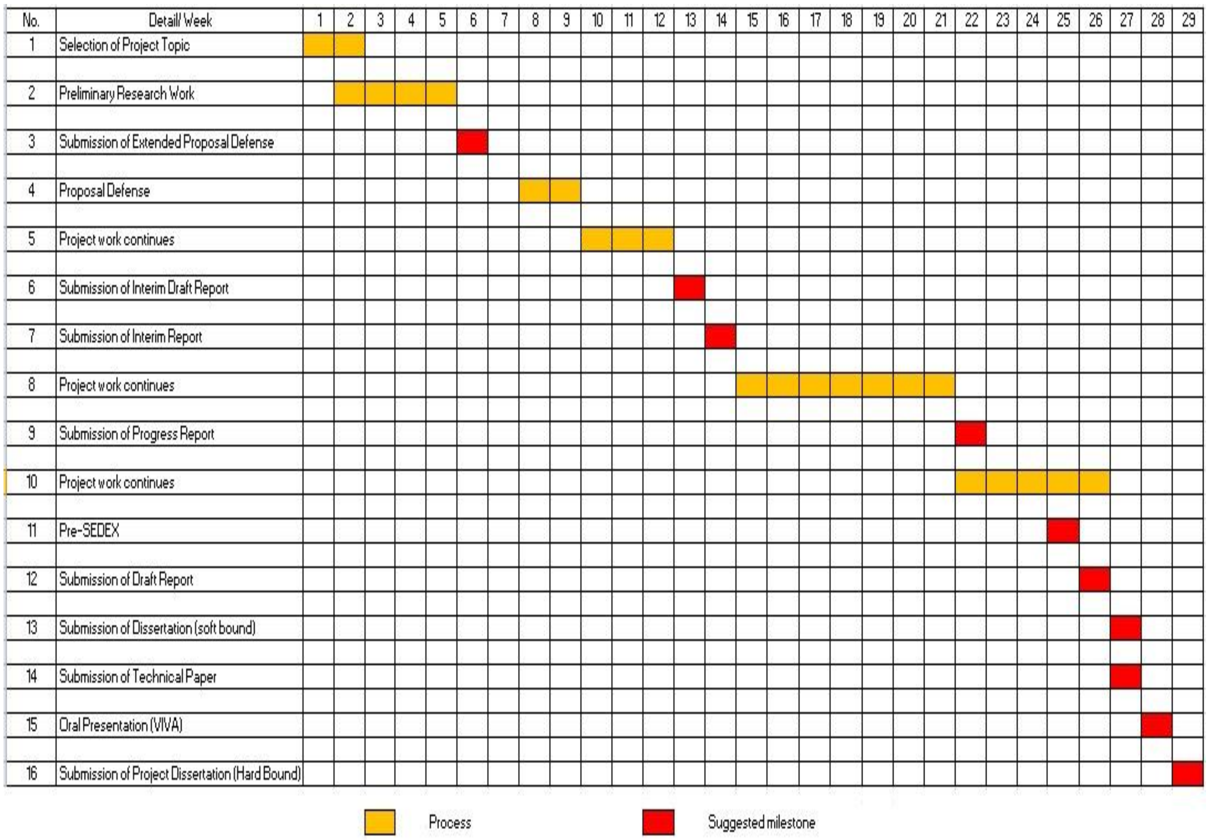


Table 2: Project Timeline

3.1 TOOLS

Electrical resistivity test equipment:

- Two 100mm aluminum electrodes
- 200 volts DC power supply
- Handheld multimeter
- Other basic apparatus

Compaction Test equipment:

- Soil mixer
- Standard cylinder mold
- Standard compaction hammer

Particle Size Distribution equipment:

- Sieve analysis apparatus

pH Test equipment:

- pH meter
- Conical flask
- Distilled water

ELE International Pocket Penetrometer Test

- ELE International Pocket Penetrometer
    - Direct-reading scale in tons/sq. ft. and kg/sq. cm.
    - Ground and polished stainless steel loading piston.
    - Calibrated spring and penetrometer body plated for rust resistance and long life.
    - Convenient belt-loop style carrying case.
    - Optional Adapter Foot for testing very soft materials.
- Specifications

Range.	0.25 to 4.5 tons/sq. ft. (kg/sq. cm).
Scale Divisions	0.25 tons/sq. ft. (kg/sq. cm)
Load Piston	1/4" (6 mm) diam.; stainless steel
Carrying Case	Canvas; belt-loop style
Dimensions	3/4" diam. x 6-3/8" l. (19 x 162 mm).
Weight	Net 7 oz. (198 g)

Table 3: Specifications of ELE International Pocket Penetrometer

Software	Function
Microsoft Office Word	This software is used for report purposes.
Microsoft Office Excel	This software is commonly used for calculation and datasheet. This software also can be used for data sheet purposes.

Table 4: List of software needed

CHAPTER 4

RESULT AND DISCUSSION

4.0RESULTS AND DISCUSSION

A total of 16 soil samples were tested using compaction test, electrical resistivity and pocket penetrometer to get the effects of porosity, saturation and cohesion on electrical resistivity of sand size particles. The results of all the tests from different moisture content and different blows of compaction have been gathered in a table as below.

Moisture Content	pH Value	Blows	Porosity, n	Saturation, S	Resistivity, ρ (Ωm)	Cohesion, c (kPa)
25%	6.69	15	0.37	1.08	75.83	135.35
		25	0.37	1.13	57.97	220.68
		35	0.37	1.08	61.73	131.43
		45	0.38	1.09	68.67	147.12
30%	6.69	15	0.42	1.06	49.09	33.64
		25	0.42	1.03	52.08	29.72
		35	0.42	1.03	42.21	22.07
		45	0.42	1.06	43.20	20.43
35%	6.69	15	0.43	1.17	33.54	9.81
		25	0.44	0.99	38.08	10.79
		35	0.45	0.98	38.53	9.81
		45	0.43	1.17	40.68	11.77
40%	6.69	15	0.50	1.06	30.41	0.98
		25	0.51	1.02	34.38	1.14
		35	0.51	1.02	33.54	1.77
		45	0.49	1.08	36.05	1.18

Table 5: Results of electrical resistivity and pocket penetrometer test.

Based on the result in Table 5, 25% of moisture content has the highest resistivity while 40% of moisture content has the lowest resistivity. These show that higher moisture content has the lower resistivity. This proves that findings from many researchers that moisture content and ionic content in pore fluids are more important than the conductivity of the constituent mineral grain of the soil in governing resistivity of the sample (Kizlo and Kanbergs, 2009).

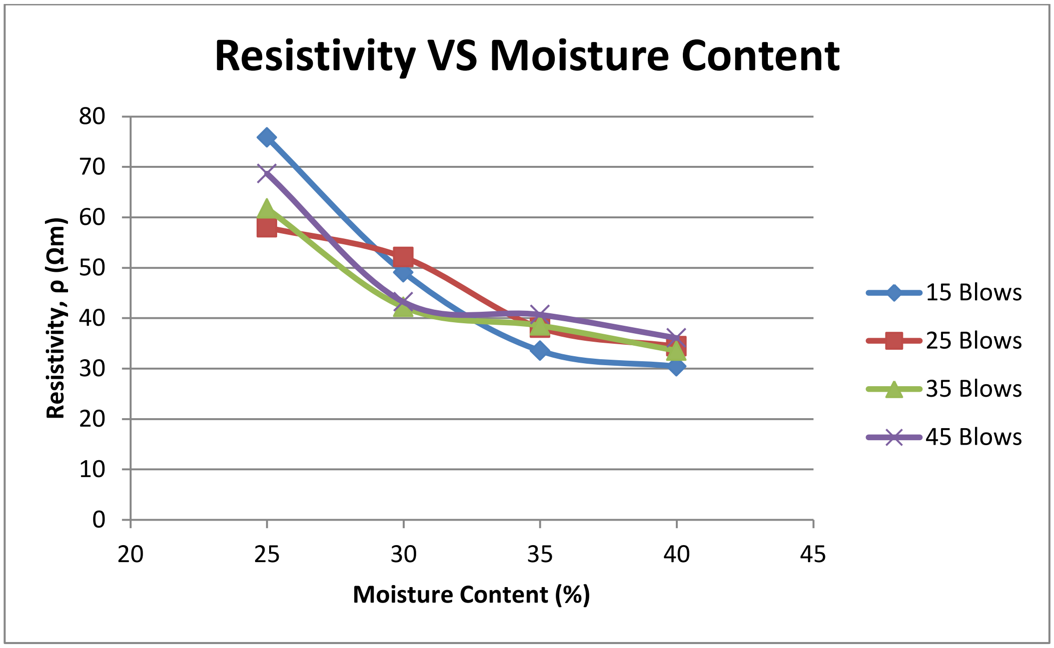


Figure 6: Resistivity vs. moisture content for combination of multiple blows of compaction.

Figure 6 shows the multiple graph of resistivity against moisture content. It is clearly shows that the higher the moisture content, the lower the resistivity. This is because moisture contains water and water is a good conductor. The higher the conductivity, the lower the resistivity.

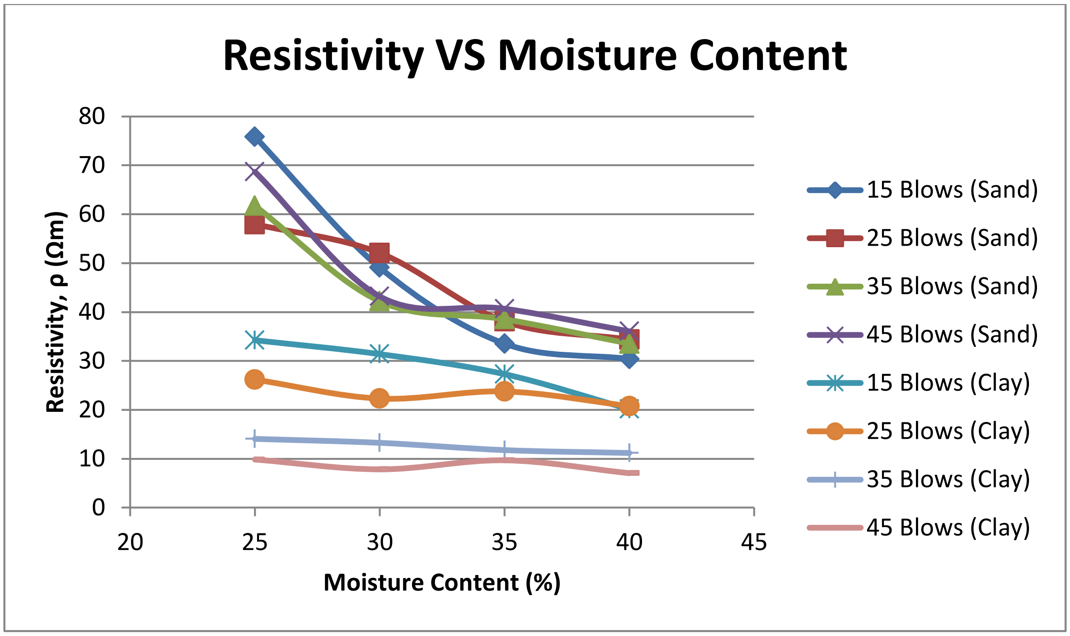


Figure 7: Resistivity vs. moisture content for combination of multiple blows of compaction for sand and clay size particles.

Figure 7 shows the resistivity against moisture content for combination of multiple blows of compaction for sand and clay. The resistivity value for clay size particles was smaller compared to resistivity value for sand size particle. This is due to the arrangements of sand particles which is loose. Hence, it do not allow much water to retained between the soil particles and when the moisture content in the soil particles is low, the resistivity will increase.

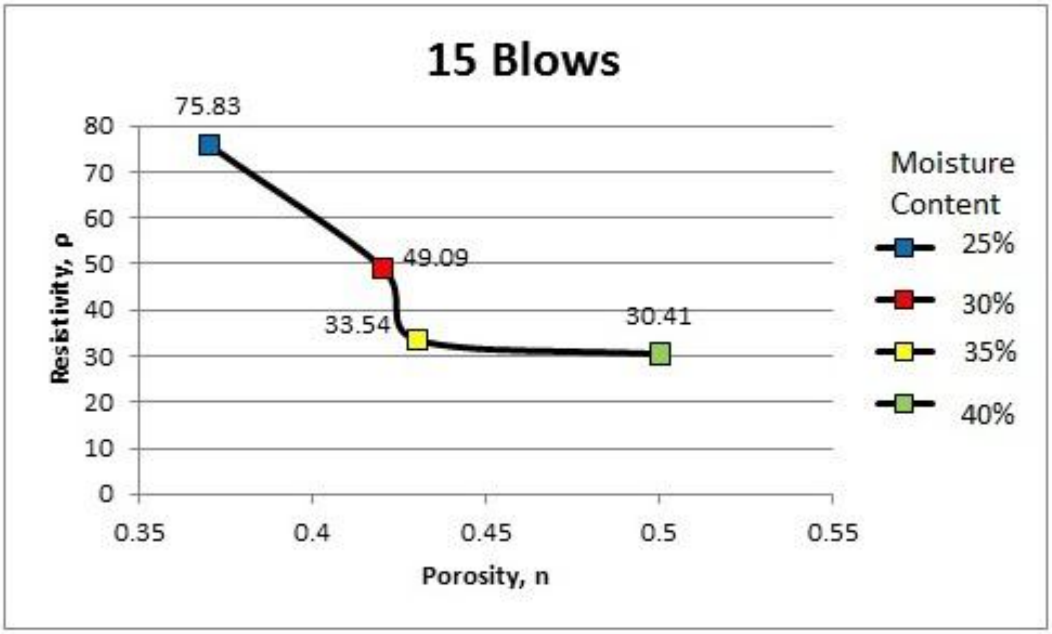


Figure 8: Resistivity vs. porosity for 15 blows of compaction.

Figure 8 shows the graph of resistivity versus porosity for 15 blows of compaction. 25% of moisture content has the lowest porosity which is 0.37 while 40% of moisture content has the highest porosity which is 0.50. This shows that the higher the moisture content, the higher the porosity but have lower resistivity.

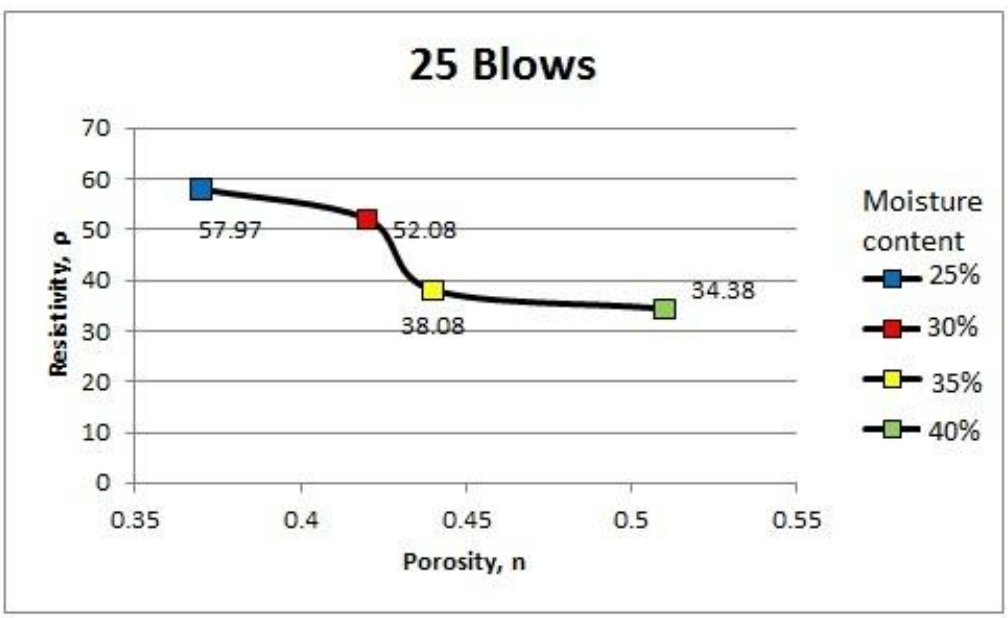


Figure 9: Resistivity vs. porosity for 25 blows of compaction.

Figure 9 shows the graph of resistivity versus porosity for 25 blows of compaction. The result is quite similar with 15 blows of compaction which 25% of moisture content has the lowest porosity which is 0.37 while 40% of moisture content has the highest porosity which is 0.51. This again shows that the higher the moisture content, the higher the porosity. This is due to the water contains in the soil sample push out the particles and make the voids bigger.

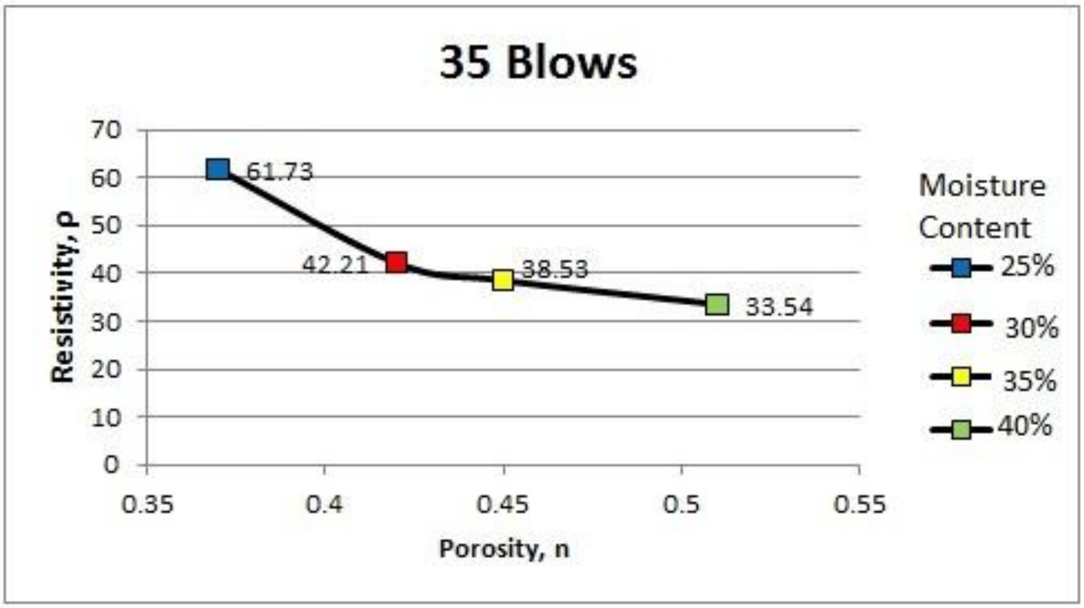


Figure 10: Resistivity vs. porosity for 35 blows of compaction.

Figure 10 shows the graph of resistivity versus porosity for 35 blows of compaction. The result is quite similar with 15 and 25 blows of compaction but have a much gentler curve. 25% of moisture content has the lowest porosity which is 0.37 while 40% of moisture content has the highest porosity which is 0.51. The lower the resistivity, the porosity will get lower because there was less water in the pore and have less ionic content resulting in higher resistivity.

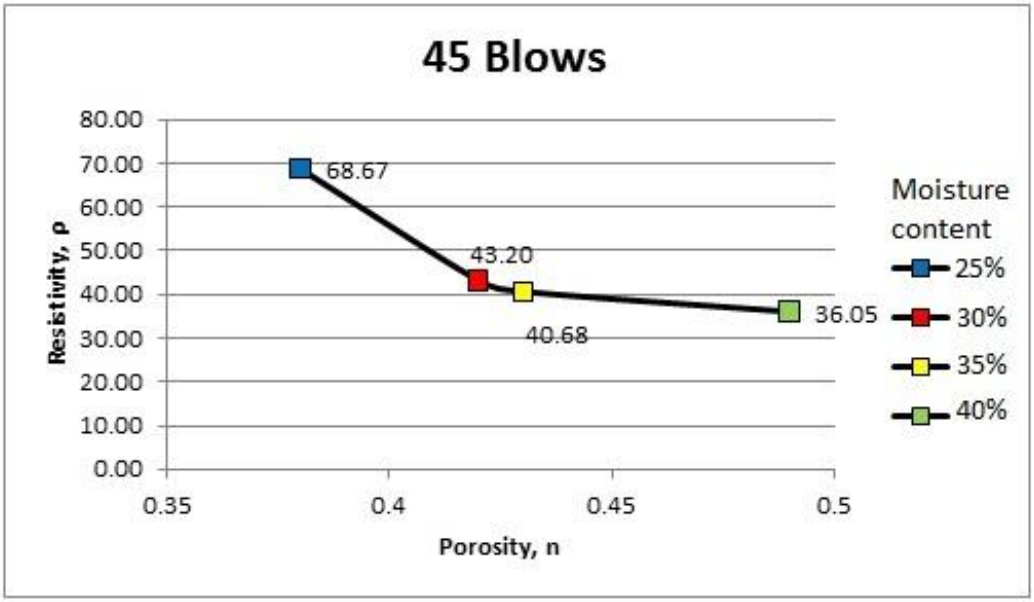


Figure 11: Resistivity vs. porosity for 45 blows of compaction.

Figure 11 shows the graph of resistivity versus porosity for 45 blows of compaction. Again, 25% of moisture content has the lowest porosity which is 0.38 while 40% of moisture content has the highest porosity which is 0.49. The result is also similar with 15, 25 and 35 blows of compaction but the resistivity data between 30% and 35% of moisture content is very near to each other. The porosity of 40% moisture content is decrease from 0.51 from 35 blows of compaction to 0.49 because it has reached the optimum value.

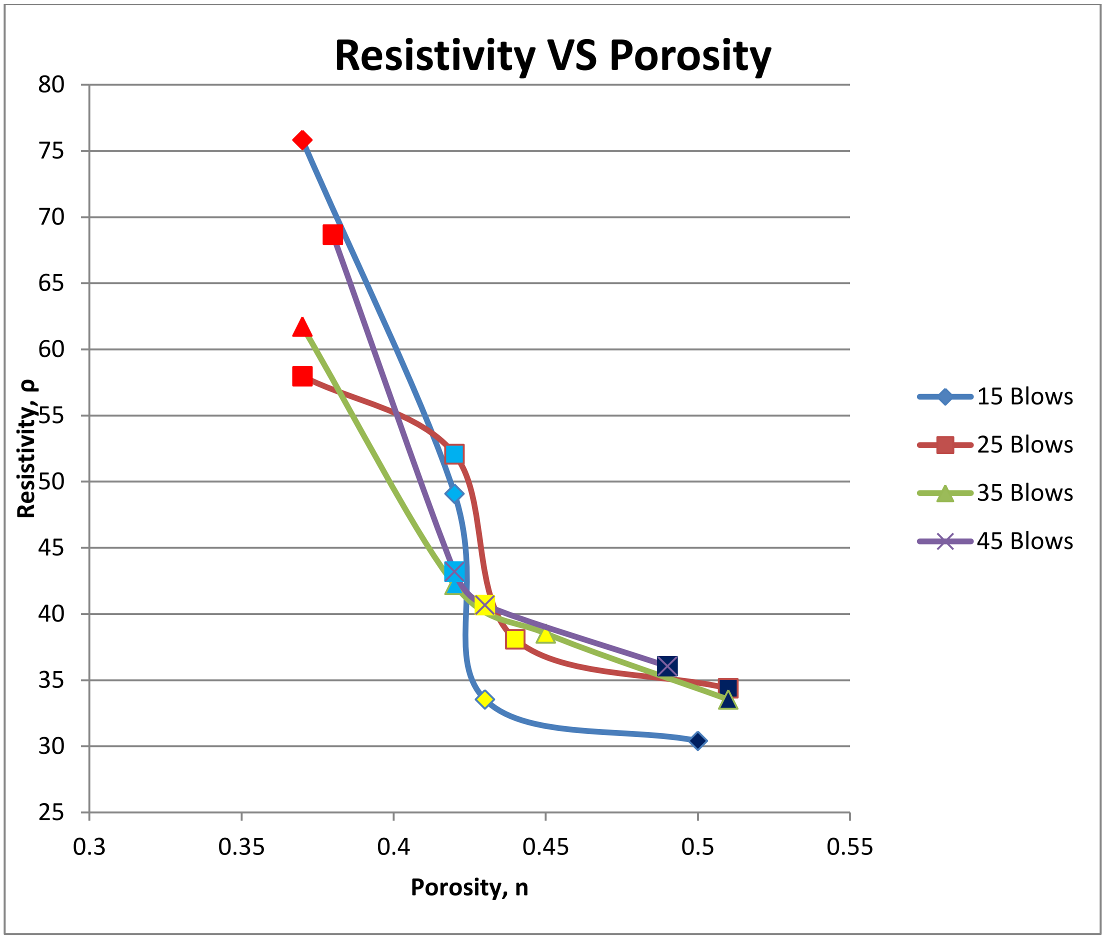


Figure 12: Resistivity vs. porosity for combination of multiple blows of compaction.

Figure 12 shows the graph of resistivity versus porosity for combination of multiple blows of compaction. All shows that the higher the moisture content, the higher the porosity but lower resistivity. The higher the porosity means that the voids or pores is larger and this condition allows moisture to seeps in and increase the moisture content. The higher the moisture content, the higher the resistivity. From Figure 12, for 25 blows of compaction has different trend. It is because of the phenomena of its own and to understand more about this phenomena, more test need to be done in the future.

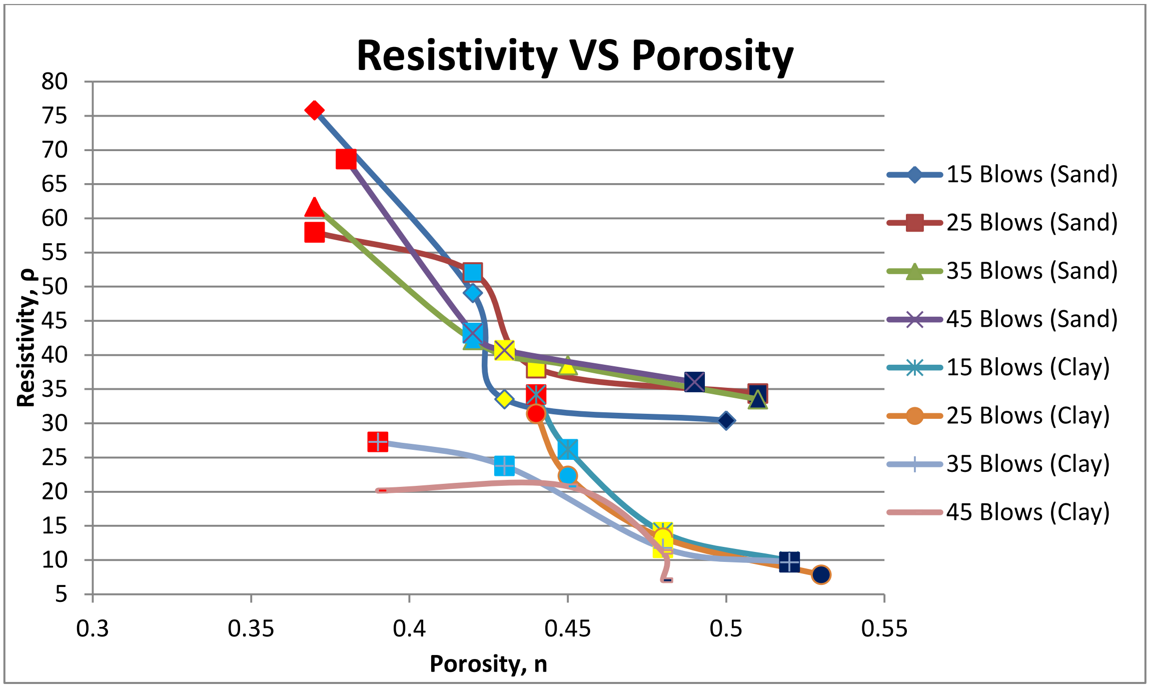


Figure 13: Resistivity vs. porosity for combination of multiple blows of compaction for sand and clay size particles.

Figure 13 shows the graph of resistivity versus porosity for combination of multiple blows of compaction for sand and clay size particles. All shows that the higher the moisture content, the higher the porosity but lower resistivity but for sand size particles, the resistivity value is higher compared with clay size particles. This is due to the sand size particles which have more pores in the arrangement of the particles compared to clay size particles. Hence, this condition allows moisture to seeps in the pores and increases the moisture content. The higher the moisture content, the higher the resistivity.

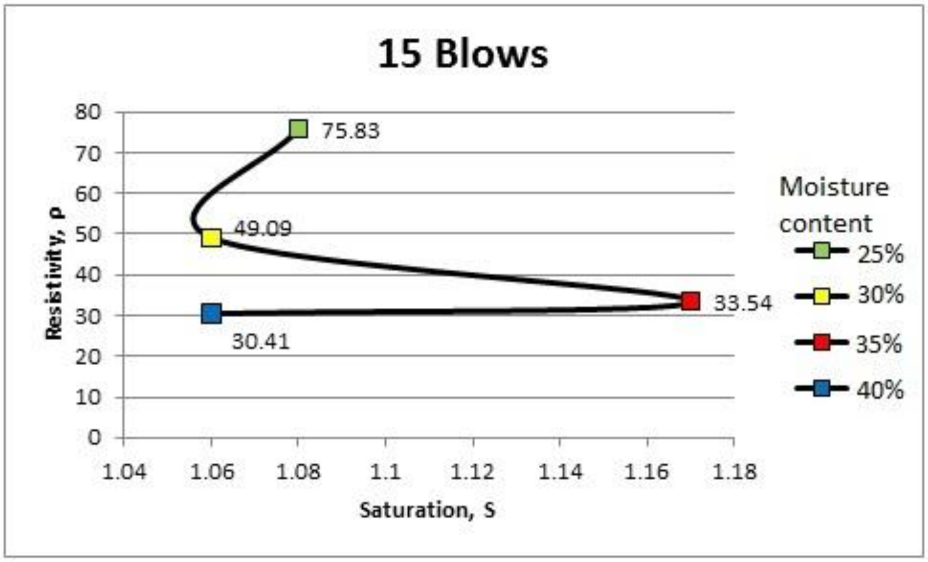


Figure 14: Resistivity vs. saturation for 15 blows of compaction.

Figure 14 shows the graph of resistivity versus saturation for 15 blows of compaction. The result for 25% of moisture content has the highest resistivity which is 75.83 Ωm while 40% of moisture content has the lowest resistivity which is 30.41Ωm. The highest saturation is 1.17 at 35% of moisture content but the lowest saturation is 1.06 at 30% and 40% of moisture content. Even though that the saturation is fluctuated, but the resistivity is still decreased when the moisture content increased.

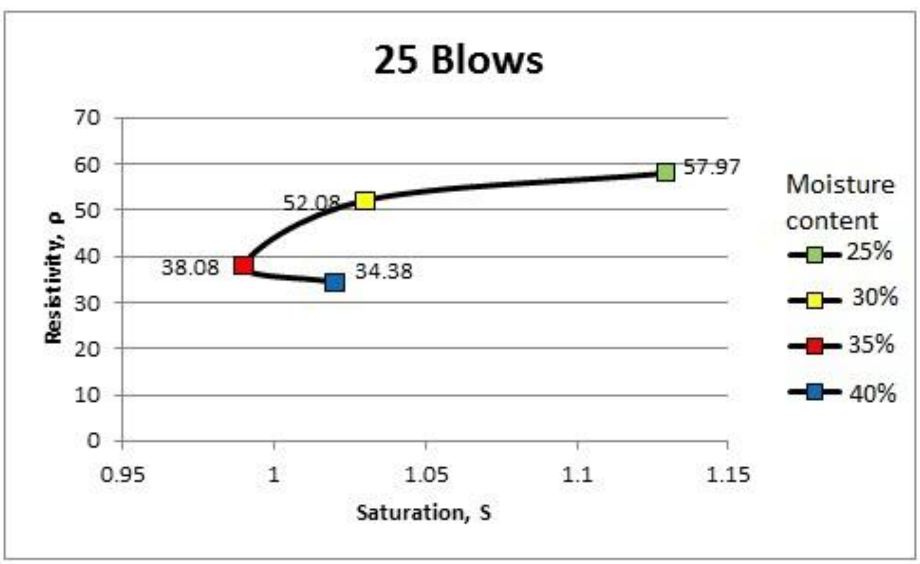


Figure 15: Resistivity vs. saturation for 25 blows of compaction.

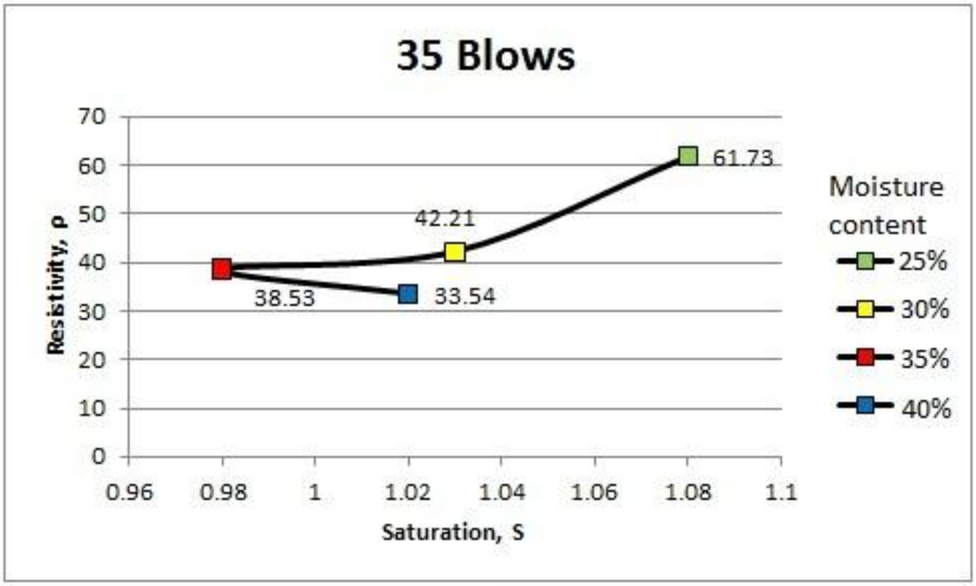


Figure 16: Resistivity vs. saturation for 35 blows of compaction.

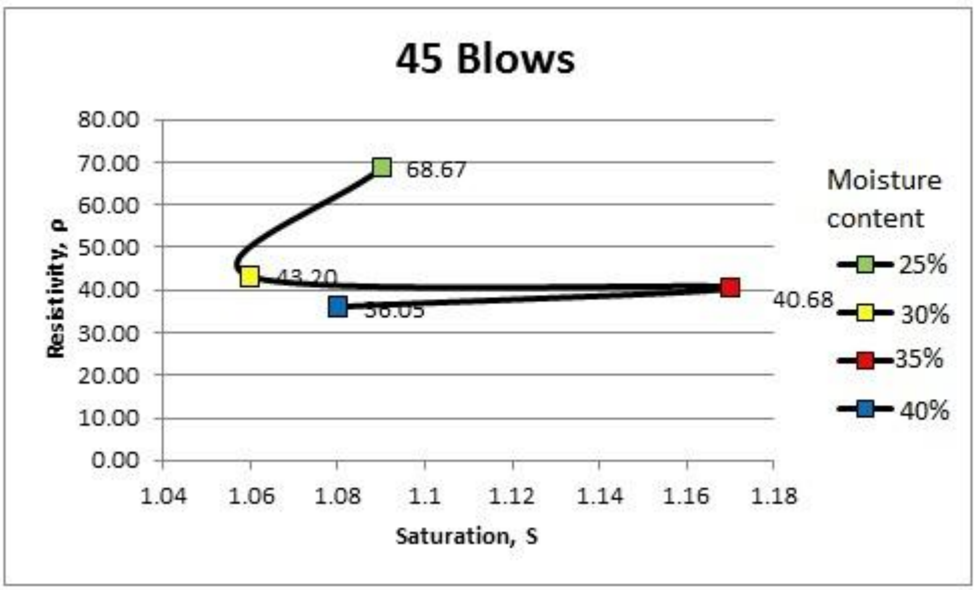


Figure 17: Resistivity vs. saturation for 45 blows of compaction.

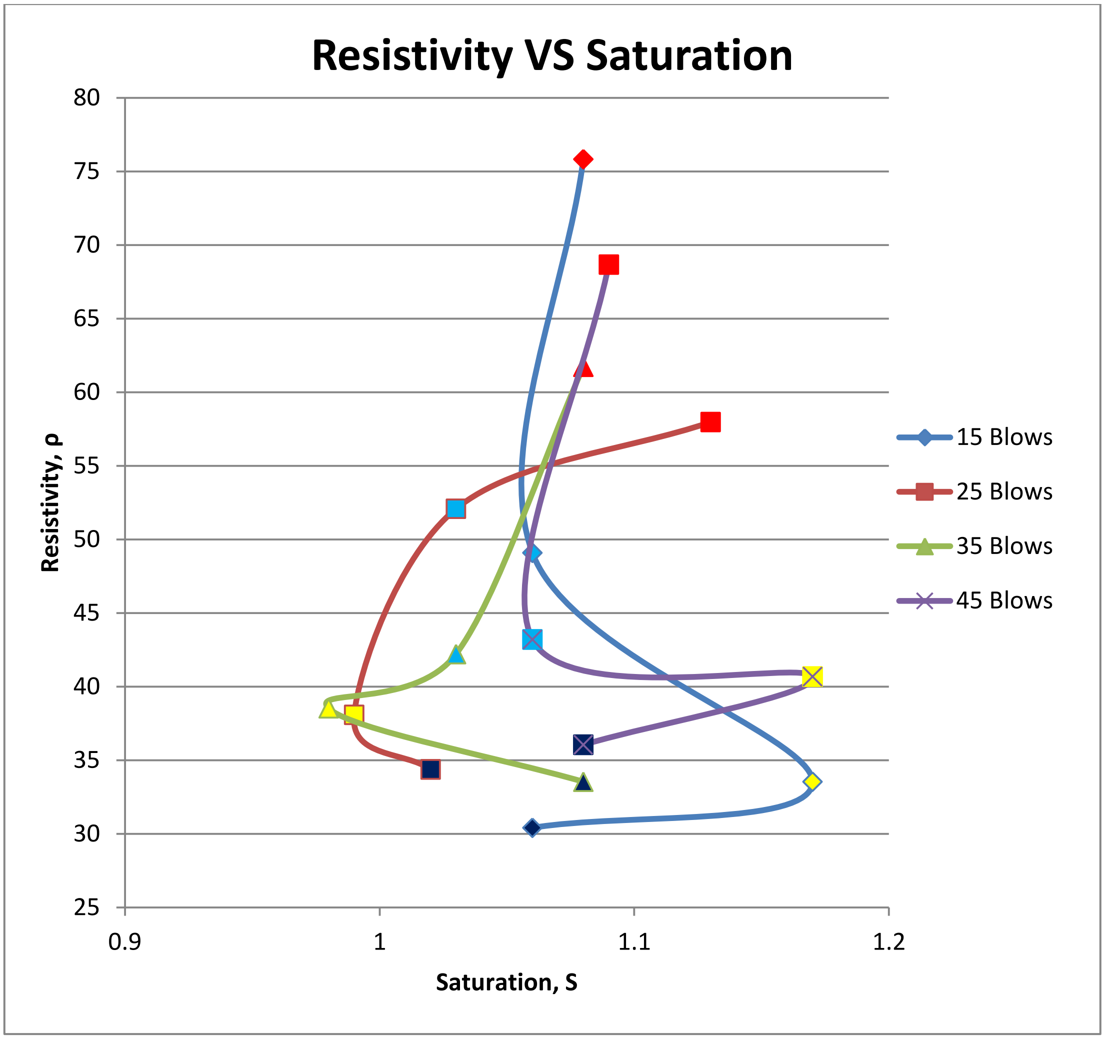


Figure 18: Resistivity vs. saturation for combination of multiple blows of compaction.

Figure 18 shows the graph of resistivity versus saturation for combination of multiple blows of compaction. This figure shows a different trend with the same sample but different number of blows. This happened because for saturation, it does not have any specific trend due to fluctuated data. For 25 blows of compaction has different trend. It is because of the phenomena for sandy soil and to make it more accurate and relevant, more test need to be done in the future but from previous studies by Kibria and Hossain (2012), they found out that when the saturation is lower, the resistivity will get higher.

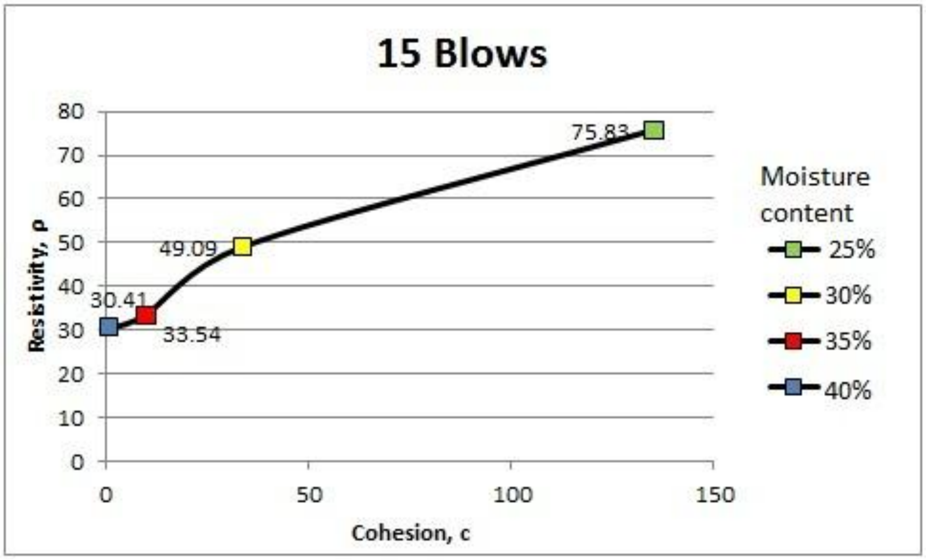


Figure 19: Resistivity vs. cohesion for 15 blows of compaction.

Figure 19 shows the graph of resistivity versus cohesion for 15 blows of compaction. 25% of moisture content has the highest resistivity which is 75.83Ωm and highest cohesion which is 135.35kPa while 40% of moisture content has the lowest resistivity which is 30.41Ωm as well as the cohesion which is 0.98kPa. This shows that the higher the moisture content, the lower the cohesion and the resistivity.

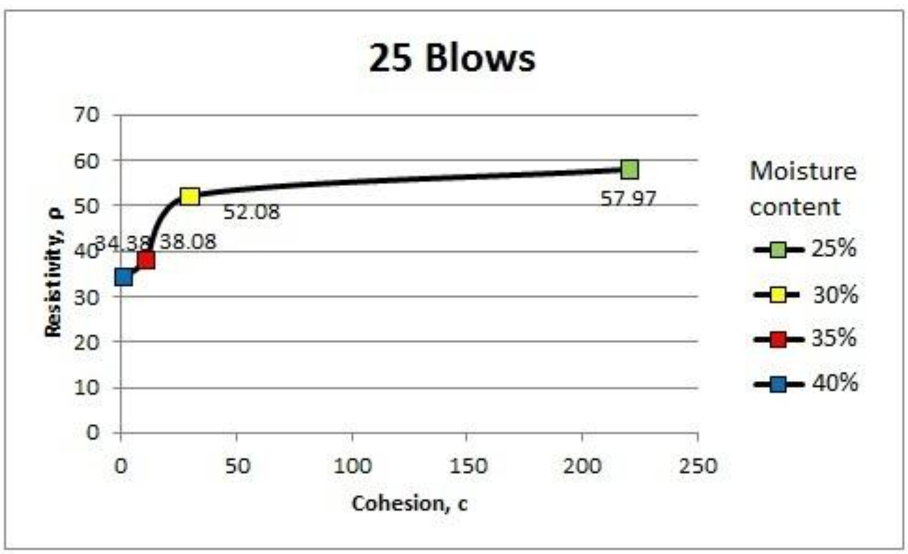


Figure 20: Resistivity vs. cohesion for 25 blows of compaction.

Figure 20 shows the graph of resistivity versus cohesion for 25 blows of compaction. 25% of moisture content has the highest resistivity which is 57.97Ωm and highest cohesion which is 220.68kPa while 40% of moisture content has the lowest resistivity which is 34.38Ωm as well as the cohesion which is 1.14kPa. This trend is quite similar with 15 blows of compaction but have a bigger gap between the cohesion values.

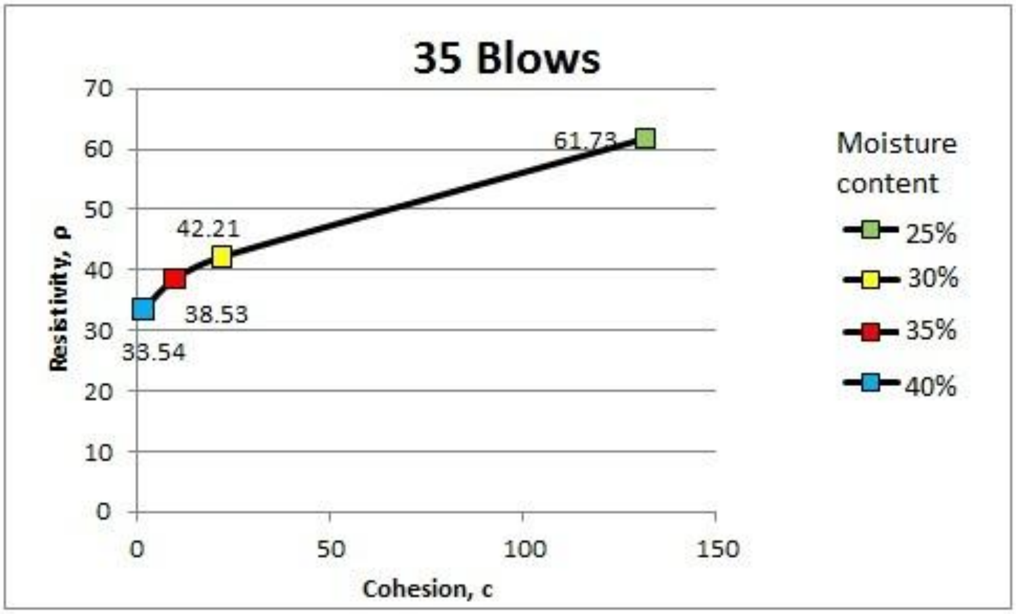


Figure 21: Resistivity vs. cohesion for 35 blows of compaction.

Figure 21 shows the graph of resistivity versus cohesion for 35 blows of compaction. 25% of moisture content has the highest resistivity which is 61.73Ωm and highest cohesion which is 131.43kPa while 40% of moisture content has the lowest resistivity which is 33.54Ωm as well as the cohesion which is 1.77kPa. This trend is smoother than 15 and 25 blows of compaction.

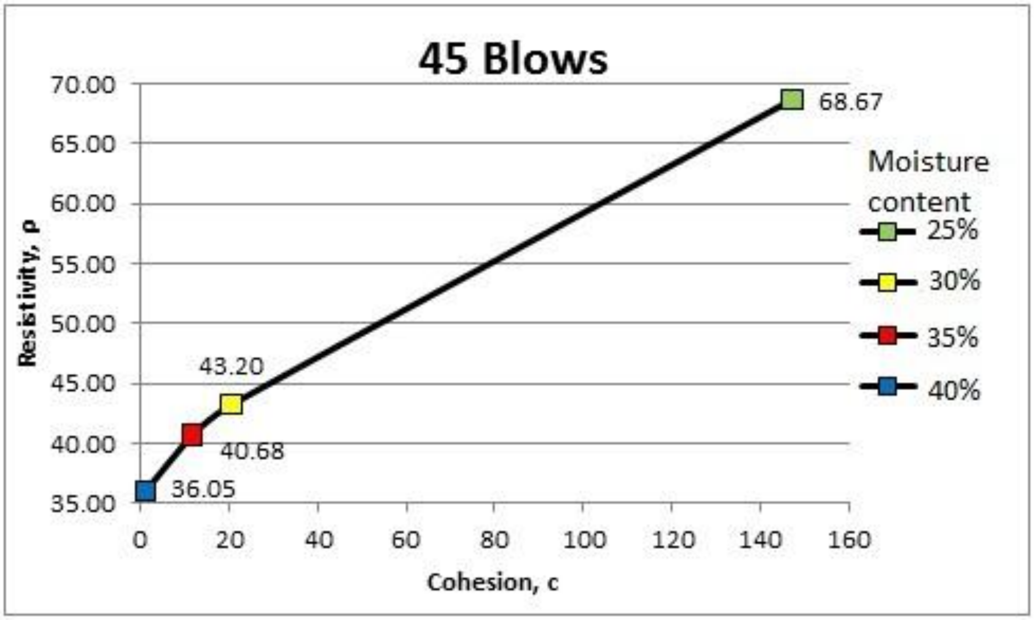


Figure 22: Resistivity vs. cohesion for 45 blows of compaction.

Figure 22 shows the graph of resistivity versus cohesion for 45 blows of compaction. 25% of moisture content has the highest resistivity which is 68.67Ωm and highest cohesion which is 147.12kPa while 40% of moisture content has the lowest resistivity which is 36.05Ωm as well as the cohesion which is 1.18kPa. The trend is quite similar with Figure 16 and Figure 17 but there is still a big gap of cohesion value from 25% to 30% of moisture content.

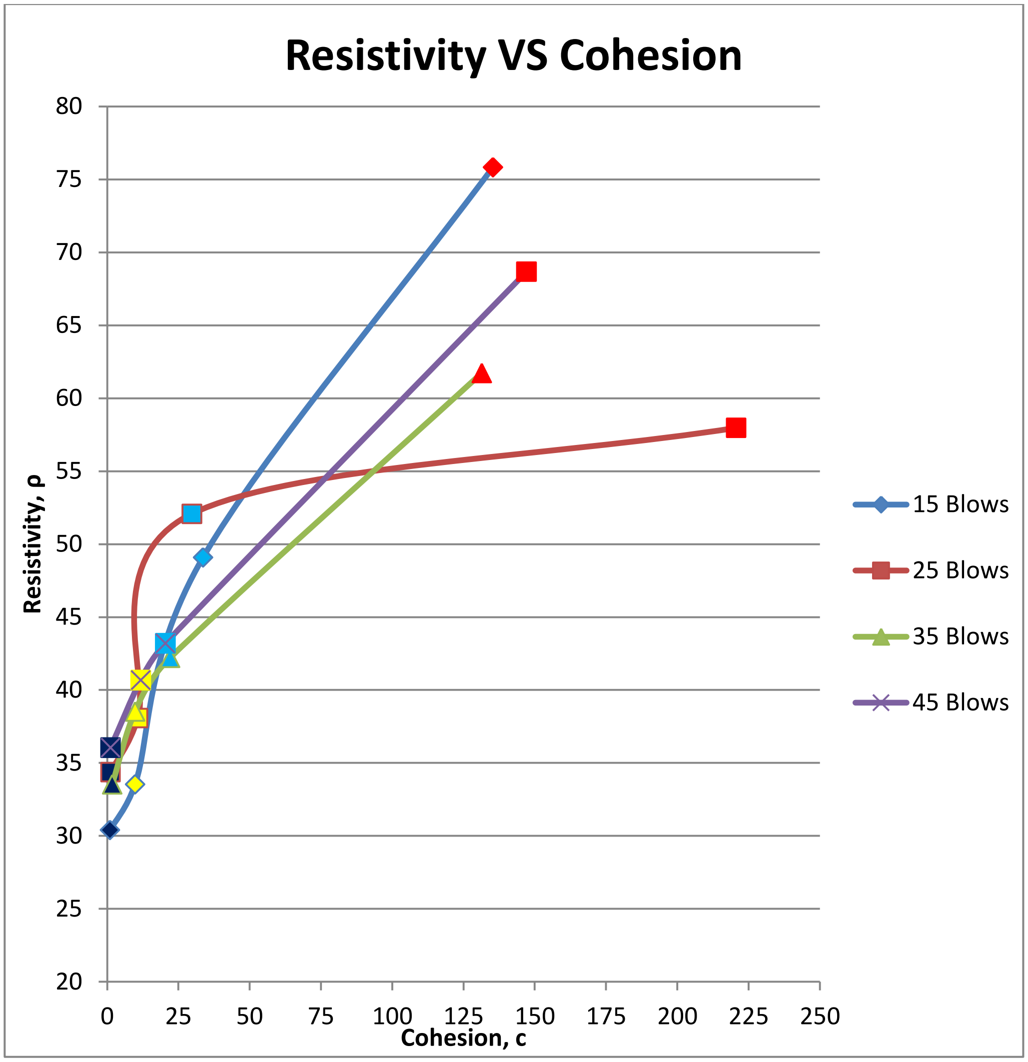


Figure 23: Resistivity vs. cohesion for combination of multiple blows of compaction.

Figure 23 shows the graph of resistivity versus cohesion for combination of multiple blows of compaction. All trend shows that the lower the moisture content, the higher the cohesion and the higher the resistivity. For 25 blows of compaction has different trend. It is because of the phenomena for sandy soil and to understand more about this phenomena, more test need to be done in the future.

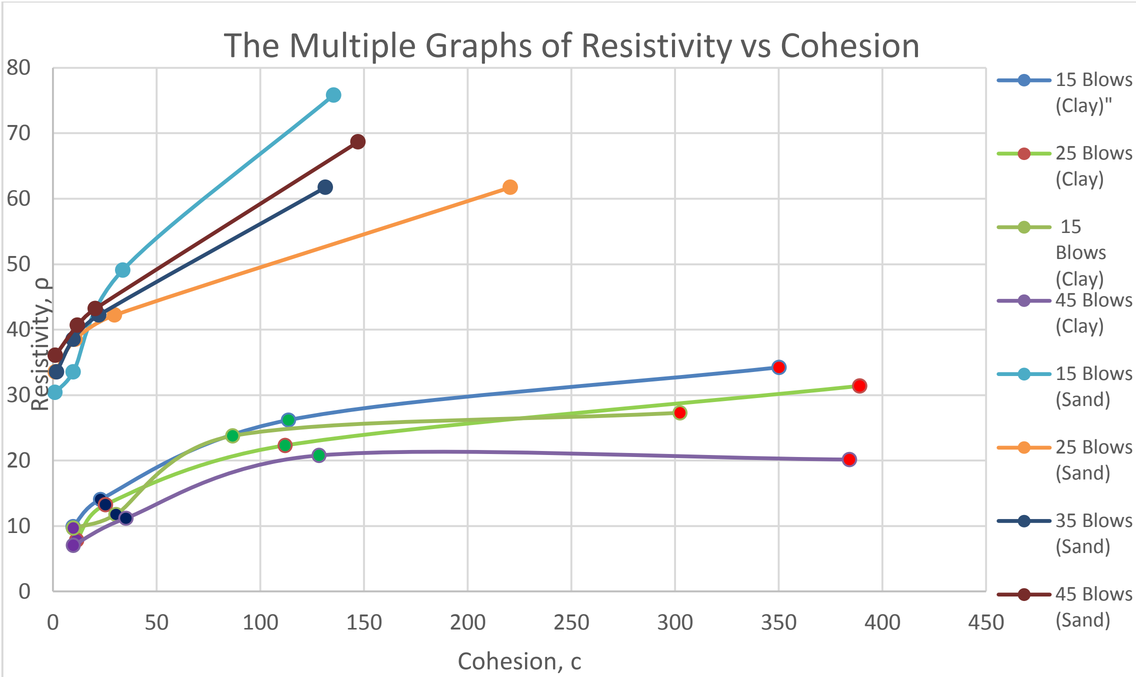


Figure 24: Resistivity vs. cohesion for combination of multiple blows of compaction for sand and clay size particles.

Figure 24 shows the graph of resistivity versus cohesion for combination of multiple blows of compaction for sand and clay size particles. All trends shows that the lower the moisture content, the higher the cohesion and the higher the resistivity but sand size particles have lower cohesion value compared to clay size particles. This is due to types of soil which clay is cohesive soil while sand is loose soil. When the soil is cohesive, the cohesion will increase.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.0CONCLUSION AND RECOMMENDATION

The trend and reliability of relationships between moisture content, porosity, saturation and cohesion with electrical resistivity were established from this research. As conclusion, the relationship between moisture content, porosity and electrical resistivity showed that the higher the moisture content, the higher the resistivity but lower resistivity as proven by Turesson (2005) and Abu Hassanaein, et al. (1996). From test, it shows that there is no specific trend for resistivity against saturation but past studies shows that the lower the saturation, the higher the resistivity. This happen because of bridging effect which means that there was water connection in the void between the particles due compactive effort. For the cohesion, the lower the moisture content, the higher the resistivity, the higher the cohesion. This showed that the higher the compaction, the stronger the soil will be. The results of this research can be used for geotechnical site investigation by using electrical resistivity.

As for recommendation, further tests need to be done to increase more understandings and findings. It is better to have more research in resistivity because it is now increasing practiced in engineering site characterization as being quicker, more economical, and allow more data to be taken than the present method.

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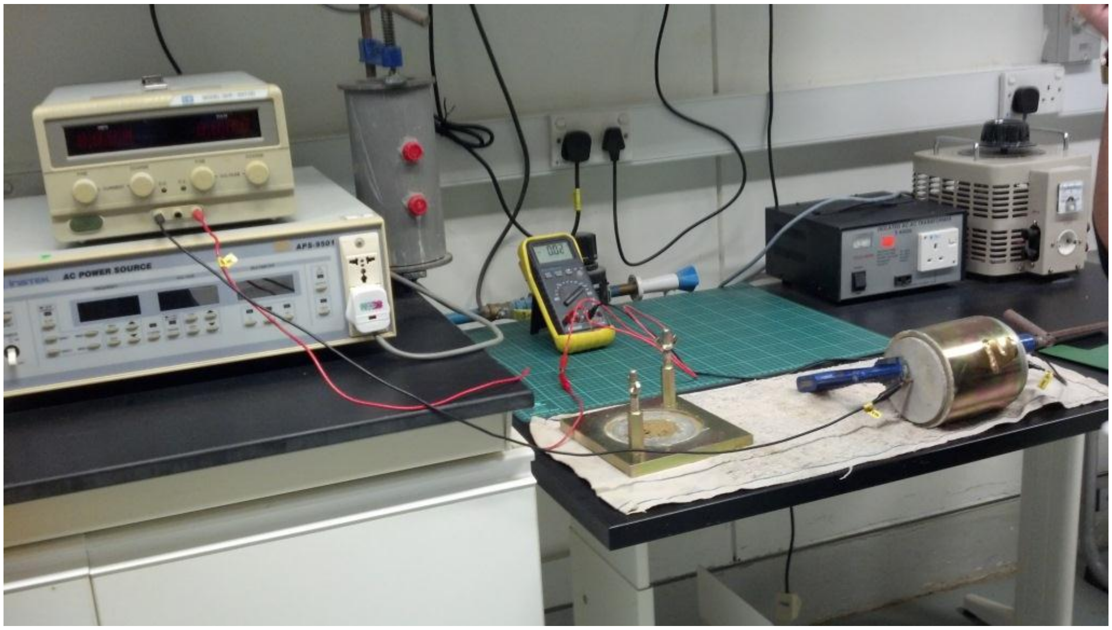
APPENDICES



Electrical resistivity test in laboratory.

ELE International Pocket Penetrometer

Hand held multimeter

CALCULATION FOR ELECTRICAL RESISTIVITY AND COHESION

Type of soil: Sand (Kaolin: L2B20)
Mold size:
Diameter: 10.4cm = 0.104m
Length: 11.5cm = 0.115m
Area, $A = \pi r^2 = \pi(0.052)^2 = 0.0085m^2$
Weight of Mold: 5.08kg

Moisture content: 25%
Blows: 15
Compaction: Layer 1: 5.64kg
Layer 2: 6.37kg
Layer 3: 7.02kg

Volt(Watt),V	Amp (A), I	R= V/I	ρ=(RA)/L
30	0.0255	1176.47	86.96
60	0.0627	956.94	70.73
90	0.0953	944.39	69.80
			75.83

Cohesion,c

Top (kg/cm²)	Bottom(kg/cm²)
C1 = 1.30	C4= 1.50
C2 = 1.25	C5 = 1.60
C3 = 1.25	C6 = 1.40

Moisture content: 25%
Blows: 25
Compaction: Layer 1: 5.64kg
Layer 2: 6.27kg
Layer 3: 7.04kg

Volt(Watt),V	Amp (A), I	R= V/I	ρ=(RA)/L
30	0.037	810.81	59.93
60	0.079	759.49	56.14
90	0.115	782.61	57.85
			57.97

Cohesion,c

Top (kg/cm²)	Bottom(kg/cm²)
C1 = 2.40	C4 = 2.25
C2 = 2.30	C5 = 2.25
C3 = 1.90	C6 = 2.40

Moisture content: 25%

Blows: 35

Compaction: Layer 1: 5.61kg
Layer 2: 6.48kg
Layer 3: 7.02kg

Volt(Watt),V	Amp (A), I	R= V/I	ρ=(RA)/L
30	0.035	857.14	63.35
60	0.071	845.07	62.46
90	0.112	803.57	59.39
			61.73

Cohesion,c

Top (kg/cm²)	Bottom(kg/cm²)
C1 = 1.30	C4 = 1.35
C2 = 1.35	C5 = 1.35
C3 = 1.45	C6 = 1.30

Moisture content: 25%

Blows: 45

Compaction: Layer 1: 5.72kg
Layer 2: 6.46kg
Layer 3: 7.01kg

Volt(Watt),V	Amp (A), I	R= V/I	ρ=(RA)/L
30	0.035	857.14	63.35
60	0.067	895.52	66.19
90	0.087	1034.48	76.46
			68.67

Cohesion,c

Top (kg/cm²)	Bottom(kg/cm²)
C1 = 1.30	C4 = 1.60
C2 = 1.50	C5 = 1.55
C3 = 1.55	C6 = 1.50

Moisture content: 30%

Blows: 15

Compaction: Layer 1: 5.69kg
Layer 2: 6.35kg
Layer 3: 6.94kg

Volt(Watt),V	Amp (A), I	R= V/I	ρ=(RA)/L
30	0.052	576.92	42.64
60	0.087	689.66	50.97
90	0.124	725.81	53.65
			49.09

Cohesion,c

Top (kg/cm²)	Bottom(kg/cm²)
C1 = 0.30	C4 = 0.26
C2 = 0.35	C5 = 0.45
C3 = 0.35	C6 = 0.35

Average : 0.343kg/cm²
: 0.343 x 98.08 = 33.64 kPa

Moisture content: 30%

Blows: 25

Compaction: Layer 1: 5.71kg
Layer 2: 6.45kg
Layer 3: 6.93kg

Volt(Watt),V	Amp (A), I	R= V/I	ρ=(RA)/L
30	0.0377	795.76	58.82
60	0.0862	696.06	51.45
90	0.1447	621.98	45.97
			52.08

Cohesion,c

Top (kg/cm²)	Bottom(kg/cm²)
C1 = 0.25	C4 = 0.30
C2 = 0.27	C5 = 0.40
C3 = 0.25	C6 = 0.35

Average : 0.303kg/cm²
: 0.303 x 98.08 = 29.72 kPa

Moisture content: 30%

Blows: 35

Compaction: Layer 1: 5.76kg

Layer 2: 6.56kg

Layer 3: 6.93kg

Volt(Watt),V	Amp (A), I	R= V/I	ρ=(RA)/L
30	0.0550	545.45	40.32
60	0.1021	587.66	43.44
90	0.1552	579.90	42.86
			42.21

Cohesion,c

Top (kg/cm²)	Bottom(kg/cm²)
C1 = 0.25	C4 = 0.15
C2 = 0.25	C5 = 0.26
C3 = 0.25	C6 = 0.25

Average : 0.225kg/cm²

: 0.225 x 98.08 = 22.07 kPa

Moisture content: 30%

Blows: 45

Compaction: Layer 1: 5.91kg

Layer 2: 6.77kg

Layer 3: 6.94kg

Volt(Watt),V	Amp (A), I	R= V/I	ρ=(RA)/L
30	0.0545	550.46	40.69
60	0.0995	603.02	44.57
90	0.1500	600.00	44.35
			43.20

Cohesion,c

Top (kg/cm²)	Bottom(kg/cm²)
C1 = 0.25	C4 = 0.15
C2 = 0.25	C5 = 0.15
C3 = 0.20	C6 = 0.25

Average : 0.208kg/cm²

: 0.208 x 98.08 = 20.43 kPa

Moisture content: 35%

Blows: 15

Compaction: Layer 1: 5.78kg
Layer 2: 6.59kg
Layer 3: 6.87kg

Volt(Watt),V	Amp (A), I	R= V/I	ρ=(RA)/L
30	0.0640	468.75	34.65
60	0.1352	443.79	32.80
90	0.2006	448.65	33.16
			33.54

Cohesion,c

Top (kg/cm^2)	Bottom(kg/cm^2)
C1 = 0.10	C4 = 0.10
C2 = 0.10	C5 = 0.10
C3 = 0.10	C6 = 0.10

Moisture content: 35%

Blows: 25

Compaction: Layer 1: 5.71kg
Layer 2: 6.37kg
Layer 3: 6.88kg

Volt(Watt),V	Amp (A), I	R= V/I	ρ=(RA)/L
30	0.0544	551.47	40.76
60	0.1207	497.10	36.74
90	0.1811	496.96	36.73
			38.08

Cohesion,c

Top (kg/cm^2)	Bottom(kg/cm^2)
C1 = 0.10	C4 = 0.10
C2 = 0.15	C5 = 0.10
C3 = 0.13	C6 = 0.10

Moisture content: 35%
Blows: 35
Compaction: Layer 1: 5.75kg
Layer 2: 6.35kg
Layer 3: 6.86kg

Volt(Watt),V	Amp (A), I	R= V/I	ρ=(RA)/L
30	0.054	555.56	41.06
60	0.115	521.74	38.56
90	0.185	486.49	35.96
			38.53

Cohesion,c

Top (kg/cm²)	Bottom(kg/cm²)
C1 = 0.13	C4 = 0.10
C2 = 0.10	C5 = 0.05
C3 = 0.10	C6 = 0.10

Moisture content: 35%
Blows: 45
Compaction: Layer 1: 5.90kg
Layer 2: 6.65kg
Layer 3: 6.87kg

Volt(Watt),V	Amp (A), I	R= V/I	ρ=(RA)/L
30	0.053	566.04	41.84
60	0.108	555.56	41.06
90	0.170	529.41	39.13
			40.68

Cohesion,c

Top (kg/cm²)	Bottom(kg/cm²)
C1 = 0.10	C4 = 0.05
C2 = 0.20	C5 = 0.10
C3 = 0.20	C6 = 0.05

Moisture content: 40%
Blows: 15
Compaction: Layer 1: 6.06kg
Layer 2: 6.67kg
Layer 3: 6.82kg

Volt(Watt),V	Amp (A), I	R= V/I	ρ=(RA)/L
30	0.084	357.14	26.40
60	0.135	444.44	32.85
90	0.208	432.69	31.98
			30.41

Cohesion,c

Top (kg/cm^2)	Bottom(kg/cm^2)
C1 = 0.01	C4 = 0.01
C2 = 0.01	C5 = 0.01
C3 = 0.01	C6 = 0.01

Average : 0.01 kg/cm^2
: 0.01 x 98.08 = 0.98 kPa

Moisture content: 40%
Blows: 25
Compaction: Layer 1: 5.82kg
Layer 2: 6.61kg
Layer 3: 6.79kg

Volt(Watt),V	Amp (A), I	R= V/I	ρ=(RA)/L
30	0.062	483.87	35.76
60	0.130	461.54	34.11
90	0.200	450.00	33.26
			34.38

Cohesion,c

Top (kg/cm^2)	Bottom(kg/cm^2)
C1 = 0.01	C4 = 0.01
C2 = 0.01	C5 = 0.01
C3 = 0.02	C6 = 0.01

Average : 0.0117 kg/cm^2
: 0.0117 x 98.08 = 1.14 kPa

Moisture content: 40%

Blows: 35

Compaction: Layer 1: 5.81kg

Layer 2: 6.41kg

Layer 3: 6.79kg

Volt(Watt),V	Amp (A), I	R= V/I	ρ=(RA)/L
30	0.0641	468.02	34.59
60	0.1336	449.10	33.19
90	0.2025	444.44	32.85
			33.54

Cohesion,c

Top (kg/cm²)	Bottom(kg/cm²)
C1 = 0.01	C4 = 0.05
C2 = 0.01	C5 = 0.02
C3 = 0.01	C6 = 0.01

Average : 0.018kg/cm²

: 0.018 x 98.08 = 1.77 kPa

Moisture content: 40%

Blows: 45

Compaction: Layer 1: 5.94kg

Layer 2: 6.80kg

Layer 3: 6.85kg

Volt(Watt),V	Amp (A), I	R= V/I	ρ=(RA)/L
30	0.0609	492.61	36.41
60	0.1251	479.62	35.45
90	0.1833	491.00	36.29
			36.05

Cohesion,c

Top (kg/cm²)	Bottom(kg/cm²)
C1 = 0.02	C4 = 0.01
C2 = 0.01	C5 = 0.01
C3 = 0.01	C6 = 0.01

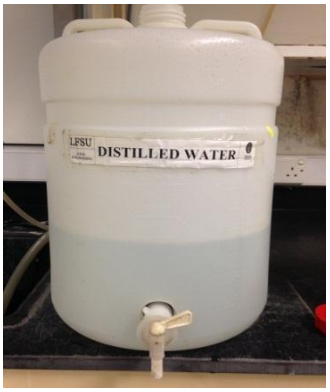
Average : 0.012kg/cm²

: 0.012 x 98.08 =1.18 kPa

MIXING PROCESS

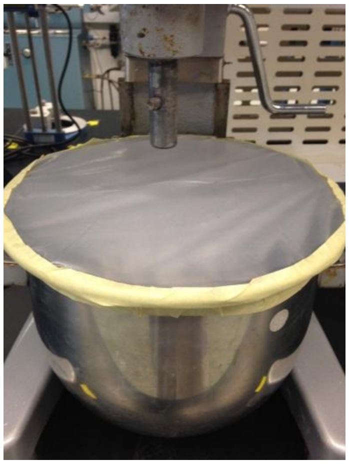
1) The L2B20 soil samples mixing

2) Weight the soil sample before



3) Mixed the soil sample with distilled water

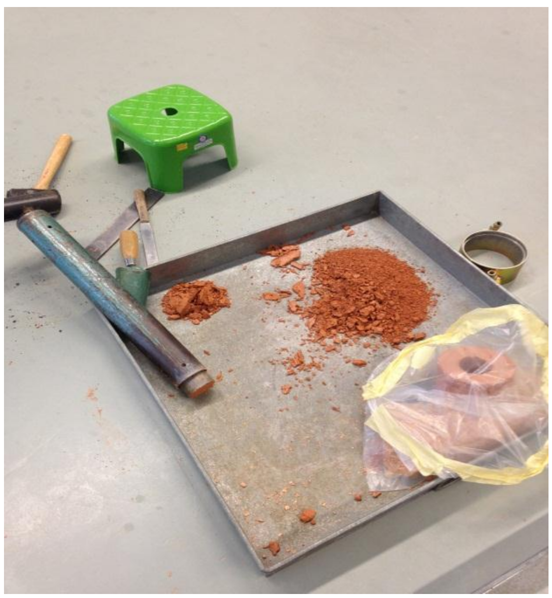
4)Mixed the sample by using mixer



5) Leave the sample for 24 hours

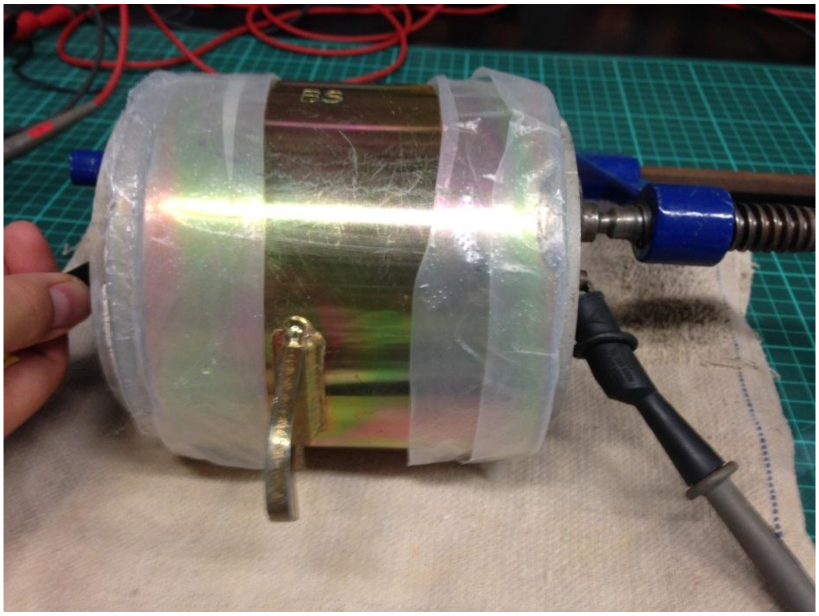
COMPACTION TEST

1) Sample was compacted layer by layer by using a Standard Proctor Hammer

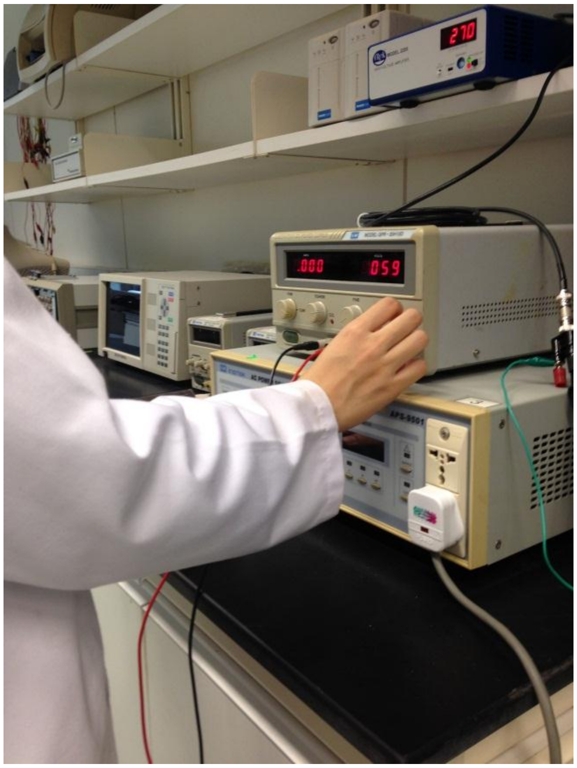


2) The apparatus that been used for compaction test

ELECTRICAL RESISTIVITY TEST

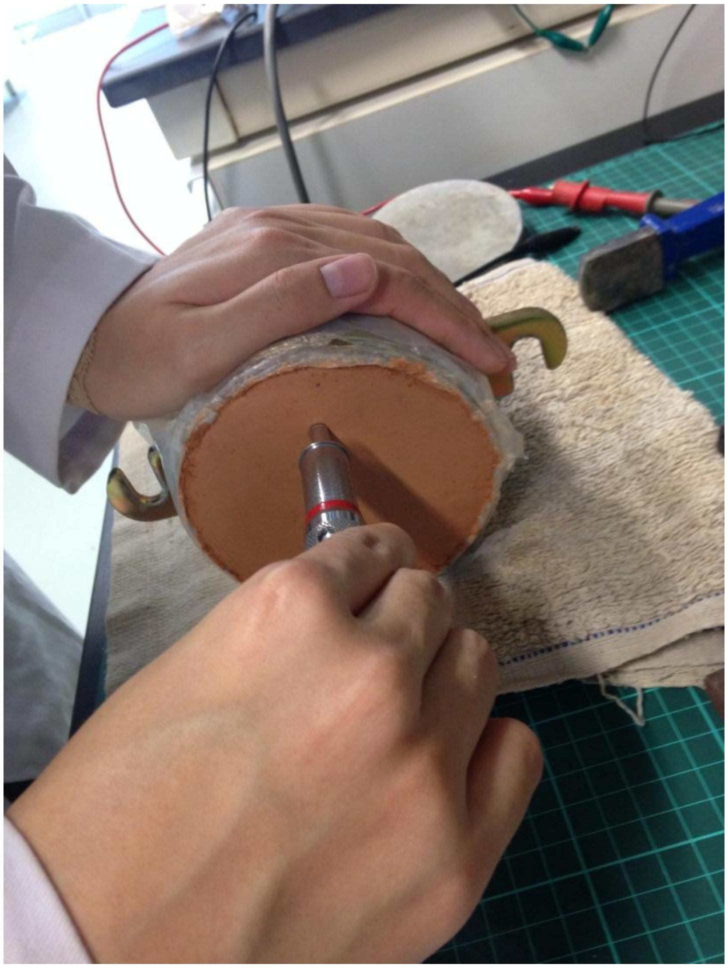


1) Sample was connected to the current and voltage



2) Different voltage were applied

POCKET PENETROMETER TEST



1) Push the pocket penetrometer into the soil.

2) Penetrate for both top and bottom of the samples.