Behaviour of Electrical Resistivity with Soil Strength Parameters by Varying the Particle Size Proportion for Mixed Sand and Silt Samples

by

Nur Atikah Binti Haron

16379

Dissertation submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Civil Engineering)

January 2016

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CERTIFICATION OF APPROVAL

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Approved by,

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Dr. Syed Baharom Azahar bin Syed Osman

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
January 2016

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 ATIKAH BINTI HARON

ABSTRACT

Geotechnical properties should be precisely identified as it is essential for a successful construction of a structure. Bore hole sampling is known as a conventional method of soil investigation and contributes to reliable determination of soil strength parameters but this method is costly, time consuming and causes soil disturbance. Geophysical methods such as electrical resistivity, is proven to be more efficient because of the non-invasive, non-destructive, rapid and cost-effective aspect. This paper presents the effects of porosity and saturation on electrical resistivity for different particle size proportion. In addition, the behaviour of electrical resistivity with soil strength parameters by varying the particle size proportion for mixed sand and silt samples is also presented. The research involves laboratory test on the mixture of sand and silt with different particle size proportion of; (1) 100% sand, (2) 80% sand, 20% silt, (3) 60% sand, 40% silt, (4) 40% sand, 60% silt, (5) 20% sand, 80% silt, and (6) 100% silt under different moisture content ranging from 15% to 35%. The correlation of electrical resistivity with porosity, saturation and soil strength parameters by varying the particle size proportion of sand and silt is performed by using the parameters obtained from laboratory work that includes electrical resistivity test and direct shear test based on 20 samples. The relationship obtained between electrical resistivity and porosity for all points is electrical resistivity decreases with increasing porosity with regression coefficient R^2=0.3292. Electrical resistivity decreases with the increasing of saturation for all points with regression coefficient R^2=0.822. On the other hand, the relationship between electrical resistivity and angle of friction for all points indicates that the electrical resistivity increases as angle of friction increases with regression coefficient R^2=0.3921. Meanwhile, regression coefficient of R^2=0.632 is established between electrical resistivity and cohesion for all points. Electrical resistivity increases with the increasing cohesion. The correlation and relationship between porosity, saturation and soil strength parameters (angle of friction and cohesion) by varying the particle size proportion for mixed sand and silt samples has been established in this research.

ACKNOWLEDGEMENT

First and foremost, I wish to express my sincere gratitude particularly to my Final Year Project (FYP) supervisor, Dr. Syed Baharom Azahar bin Syed Osman for his support and kind guidance throughout the period of my final year project. His passionate supervision has helped me in overcoming various difficulties faced during the FYP. Without the attention and dedicated guidance from my supervisor, my final year project would not be successfully completed.

Besides, I am also very thankful to graduate assistant, Mr. Hisyam Jusoh who has provided endless guidance throughout my FYP. It is lucky to have him as part of the team, whom never hesitate to give me necessary advice and help.

Finally, I am also grateful to the geotechnical laboratory technicians; Mr. Redzuan, and Mr. Ruzaimi for their kindness and in lending helping hand in the time of needs. Without them, this research can hardly be completed in time. Heartfelt appreciation is given sincerely to all of them from me.

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CHAPTER 1

INTRODUCTION

1.1 Background

The soil is the most important aspect in a construction project as it is the natural foundation that supports all structures and investment. Proper soil investigation and analysis is crucial to acquire the complete information or data of the environment and ground condition to enable a safe practical and economical design of the building. According to Timari and Kumawat (2013), the purpose of soil investigation is to assess the general suitability of the soil for the proposed project and to allow an adequate and economical design to be made. In addition, soil investigation is done to acquire physical and mechanical properties of soils for design and construction and also to calculate total and differential settlements of foundation soil.

Soil boring is done on site or field to acquire the soil samples. Laboratory test is then performed on the samples to determine the engineering properties and the shear strength parameters such as cohesion (c) and angle of internal friction (φ) of the soil which then enable us to compute the bearing capacity of soil and factor of safety (FOS). However, the determination of these properties involves extensive soil boring, sample acquisitions and laboratory testing which consume a lot of time and money.

As oppose to the conventional method, geophysical methods such as geo-electrical, ground penetration radar and seismic refraction is proven to be more efficient in terms of time and cost. Because of the non-invasive, non-destructive, rapid and cost-effective aspect of geo-electrical survey, there have been many researches done to explore the phenomenon of electrical resistivity in soils.

1.2 Problem Statement

Malaysia is a developing country which results in massive construction and development of buildings and infrastructure. Geotechnical properties should be identified accurately as it is essential for a successful construction of a structure. Bore hole sampling is known as a conventional method of soil investigation and contributes to reliable determination of soil strength parameters. However, some of the drawbacks of this method are time consuming, costly and the process of acquiring bore hole sample causes disturbance to the soil mechanics. Bore hole sampling also involves the mobilization of heavy equipment to the site. Not only that, soil properties are subjected to high spatial and temporal variations, resulting in high density of sampling for precise assessment of soil properties. In addition, a hillside development for example, requires checking of the slope stability by calculating factor of safety (FOS). For a regular checking of slope stability and calculation of FOS, many bore holes at different locations are required on a particular stretch of slope to enable the determination of possible hazards or risks which is not practical (Syed et al., 2014).

Geophysical method such as electrical resistivity is an alternative which is rapid, cost effective, and non-destructive. Correlation between electrical resistivity and soil strength parameters (e.g. cohesion, angle of friction) will help in quicker assessment of geotechnical problems such as bearing capacity and factor of safety in soil slopes. The correlation will also enable designing and checking of any geotechnical structure.

1.3 Objectives

The objectives of this project are:

1. To determine the effects of porosity and saturation on electrical resistivity for different particle size proportion.
2. To determine the behaviour of electrical resistivity with soil strength parameters by varying the particle size proportion for mixed sand and silt samples.

1.4 Scope of Study

The research involves only laboratory test. This study uses two types of soil; sand (grade S10100) and silt (grade S300). The soil samples were purchased from soil processing company. The two types of soil will be mixed into respective proportion; (1) 100% sand, (2) 80% sand, 20% silt, (3) 60% sand, 40% silt, (4) 40% sand, 60% silt, (5) 20% sand, 80% silt, (6) 100% silt.

The moisture content will be fixed to (1) 15%, (2) 20%, (3) 25%, (4) 30% and (5) 35%. All the different percentage of particle size proportion will be tested with every moisture content value. The correlation of electrical resistivity and soil strength parameters by varying the particle size proportion of sand and silt is performed by using the parameters obtained from laboratory work based on 20 samples. The engineering properties such as moisture content, pH, porosity, saturation, plasticity index, angle of friction and cohesion can be obtained through laboratory tests.

CHAPTER 2

LITERATURE REVIEW

2.1 Electrical Resistivity of Soil

An electrical resistivity of soil is the measure of its resistance to the passage of current through it (Syed & Siddiqui, 2012). Ozcep et al. (2009) believes that soil electrical properties are the parameters of natural and artificially created electrical fields in soils and influenced by distribution of mobile electrical charges, mostly inorganic ions, in soils.

For a simple body, the resistivity ρ (Ω m) is defined as follows:

$$\rho = R\ \frac{A}{L} \qquad \text{Equation 2.1}$$

Where R = electrical resistance (Ω), L = length of the cylinder (m) and A = cross-sectional area (m^2).

The electrical resistance of the cylindrical body R (Ω), is defined by the Ohm's law as follows:

$$R = \frac{V}{I} \qquad \text{Equation 2.2}$$

where V = potential (V) and I = current (A).

As stated by Samouelian et al. (2004), four electrodes are usually required to measure electrical resistivity. To inject current, two electrodes called A and B are used (current electrodes). To record the resulting potential difference, two other electrodes called M and N are used (potential electrode).

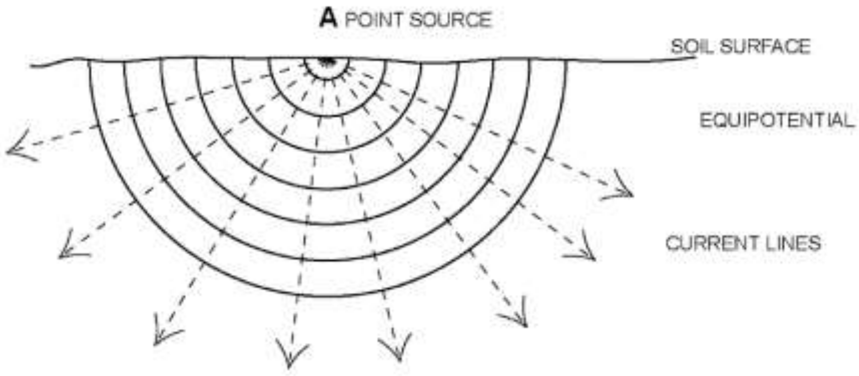


FIGURE 1: Distribution of the current flow in a homogeneous soil (Samouelian et al., 2005).

For field measurement of electrical resistivity, Hersir and Flovenz (2013) mentioned that the measured apparent resistivity will be transformed into mod of the true resistivity structure since the apparent resistivity does not show the true resistivity structure of the Earth. There are three types of modelling done which is 1D, 2D and 3D. The resistivity distribution changes only with depth and is assumed to resemble a horizontally layered Earth in the 1D modelling. For the 2D modelling, the resistivity distribution changes with depth and in one lateral direction, but is constant in the other orthogonal horizontal direction. Resistivity varies in all three directions in the 3D modelling (Hersir & Flovenz, 2013).

Vertical Electric Sounding is used when resistivity variation with depth is of concern (Mariita, nd). This method can be applied to both 1D and 2D resistivity survey method. Giao et al. (2002) explains for VES method, the electrode spacing is gradually extended on both sides apart from the central point. Depending on the respective position of the potential electrodes and on the current electrodes, several array configurations can be defined: Wenner, Wenner–Schlumberger, dipole–dipole pole–pole or pole–dipole arrays are the most commonly used as shown in Table 1 (Samouelian et al., 2005).

TABLE 1: 2D in-line electrodes array configuration, and 3D electrode device (Samouelian et al., 2005)

		Electrodes array	K
2D	Wenner	A ↔ M ↔ N ↔ B (a, a, a)	$2\pi a$
	Wenner-Schlumberger	A ↔ M ↔ N ↔ B (na, a, na)	$\pi n(n+1)a$
	Dipole-Dipole	A ↔ B ↔ M ↔ N (a, na, a)	$\pi n(n+1)(n+2)a$
	Pole-Pole	B ↔ A ↔ M ↔ N (x, a, x)	$2\pi a$
	Pole-Dipole *Forward*	A ↔ M ↔ N (na, a)	$2\pi n(n+1)a$
	Reversed	M ↔ N ↔ A (na, a)	
3D	Square	A ↔ B, A ↕ M, B ↕ N, M ↔ N (a)	$\frac{2\pi a}{2-\sqrt{2}}$

A and B current electrodes, M and N potential electrodes
A: spacing between electrodes used in a particular measurement
n: spacing factor (integer values 1-6)
x: distance to "infinite electrodes" in pole-pole array

One of the most common arrays used for VES is Wenner array. Kalinski and Kelly (1994) states that for the four probed Wenner electrode configuration, it consists of four aligned and evenly spaced electrodes as described in ASTM G 57 ("Standard" 1978). This configuration is shown in FIGURE 1. Current is passed between the two outer electrodes and the potential or voltage drop is measured between the two inner electrodes. The apparent resistivity of the soil ρ_a in Ω m is determined by

$$\rho_a = 2\pi RL \qquad \text{Equation 2.3}$$

Where L = electrode spacing (m) and R = measured resistance (Ω).

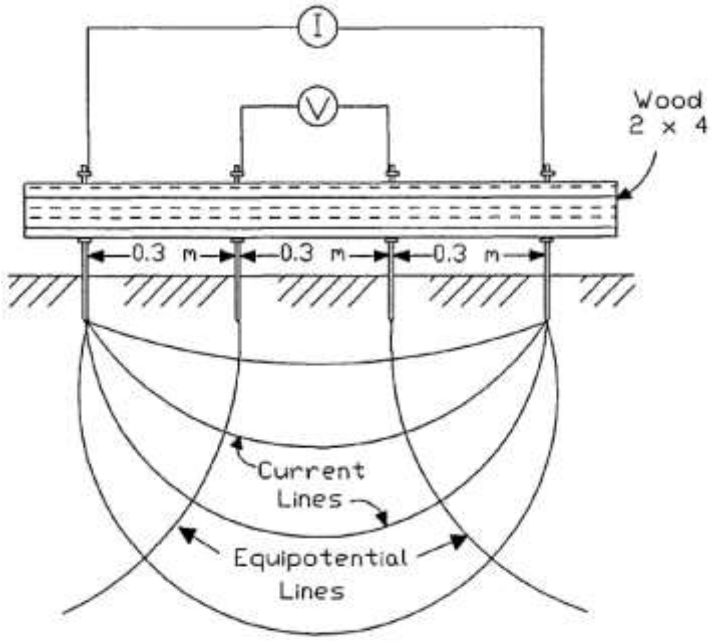


FIGURE 2: Liner Resistivity Measurement Using Fixed-Spacing Four-Probed Wenner Electrode Configuration (Kalinski & Kelly, 1994)

For this research however, measurement of electrical resistivity will be done in laboratory, similar to the research method done by Syed et al. (2014). Disc electrode method was employed to enable disturbed or undisturbed samples of soil to be measured in the laboratory in compliance with BS 1377 (Syed et al., 2014). By using this disc electrode method of measurement, the resistivity of the soil ρ in Ωm is determined by the formula given in Equation 2.1 (see above).

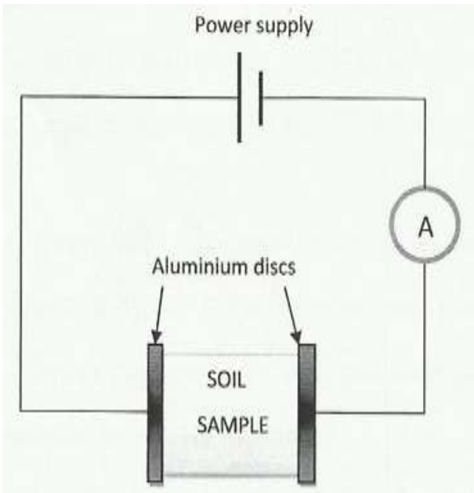


FIGURE 3: Laboratory electrical resistivity setup.

2.2 Factors Affecting Resistivity of Soil

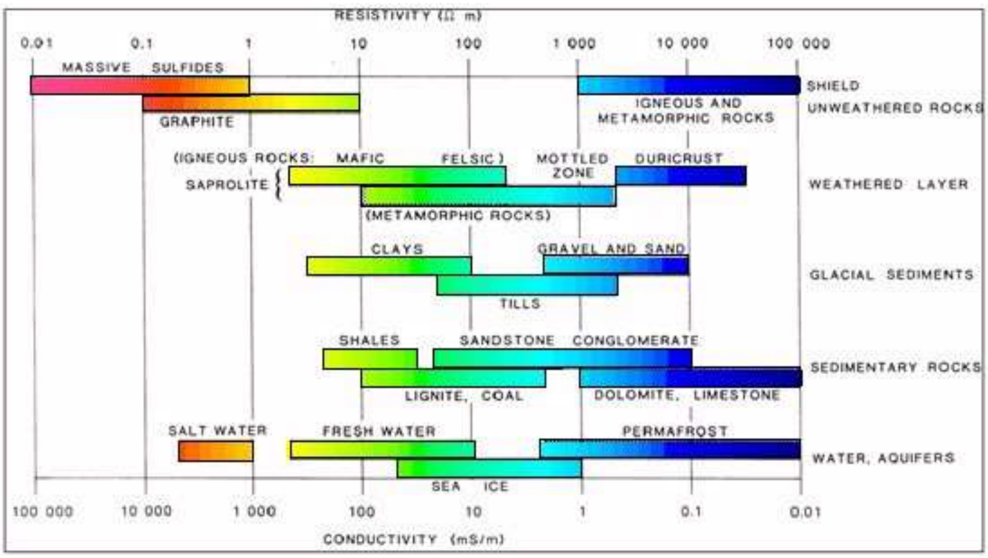
As mentioned by Samouelian et al. (2005), the electrical resistivity is affected by some soil properties:

a) Nature of the solid constituents (particle size distribution and mineralogy).
b) Arrangement of voids (porosity, pore size distribution and connectivity.
c) Degree of water saturation (water content).
d) Electrical resistivity of the fluid (solute concentration).
e) Temperature.

2.2.1 Nature and Arrangement of Solid Constituents

Referring to TABLE 2, electrical resistivity showcased a large range of values from 1 Ω m for saline soil to several 10^5 Ω m for dry soil overlaying crystalline rocks. The electrical conductivity is related to the particle size by the electrical charge density at the surface of the solid constituents (Samouelian et al., 2005). As mentioned by Fukue et al. (1999), particularly for clay soil, due to the electrical charges located at the surface of the clay particles, it causes greater electrical conductivity than in coarse-textured soils because of the magnitude of the specific surface.

TABLE 2: Typical ranges of electrical resistivities of earth materials (Palacky, 1987).



A research was done by Archie (1942) to determine the resistivities of a large number of brine-saturated cores from various sand formations in the laboratory. The samples vary in porosity and salinity of the electrolyte filling the pores (Archie, 1942). From the samples investigated, he plotted *F* against permeabilities and porosity as shown in FIGURE 4 and FIGURE 5:

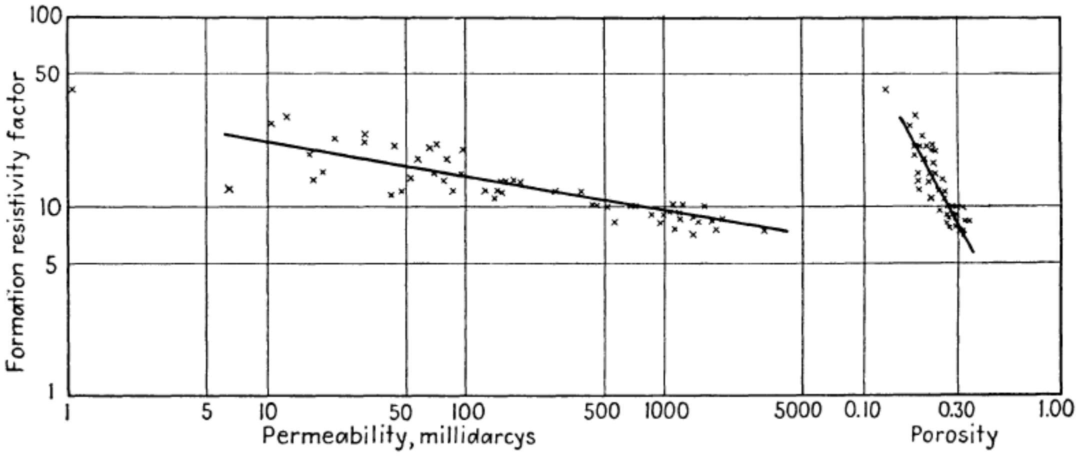


FIGURE 4: Relation of Porosity and Permeability to Formation Resistivity Factor For Consolidated Sandstone Cores of the Gulf Coast (Archie, 1942)

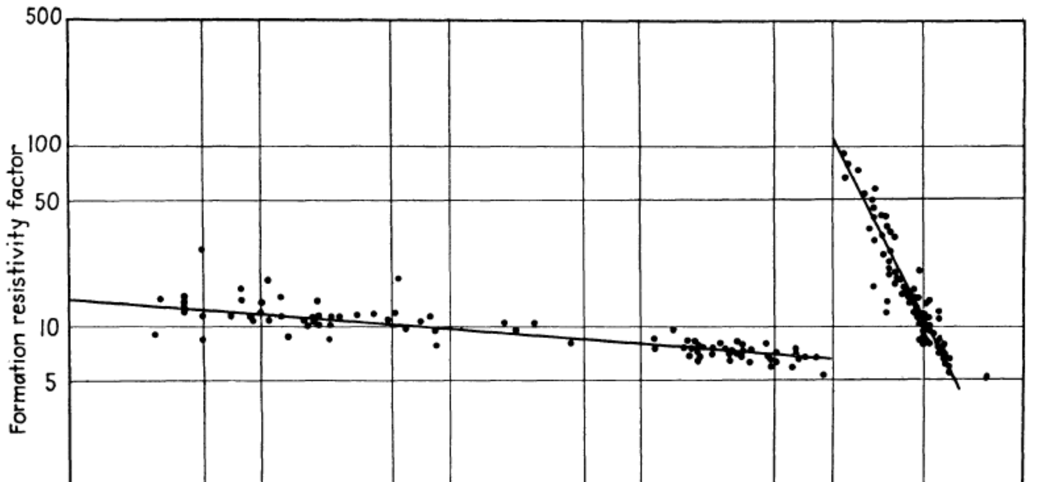


FIGURE 5: Relation of Porosity and Permeability to Formation Resistivity Factor, Nacatoch Sand, Bellevue, LA (Archie, 1942).

As mentioned by Samouelian et al. (2005), the porosity can be obtained for the electrical property using Archie's law, which for a saturated soil without clay is written as:

$$F = \frac{\rho}{\rho_w} = a\phi^{-m} \qquad \text{Equation 2.4}$$

where the proportionality factor F is called the formation factor, a and m are constants related, respectively, to the coefficient of saturation and the cementation factor, ρ and ρ_w are the resistivity of the formation and the resistivity of the pore-water, ϕ is the porosity. The factor F depends then on the pore geometry. By knowing the pore-water resistivity and the a and m constants the porosity can be calculated from the resistivity value (Samouelian et al., 2005).

2.2.2 Water Content

Zhou et al. (2015) explains that soil resistivity is highly influenced by water in soil. This is due to the electrical conduction in soil that is primarily electrolytic and occurs through water in pore spaces or along the continuous films of water adsorbed on grain boundaries. Water content influences the mobility of electrical charges in soils.

Pozdnyakova (1999) studies the relationship between electrical resistivity and soil bulk density or soil water content in laboratory conditions, and the mobility of electrical charges exponentially increases with the increase in those properties.

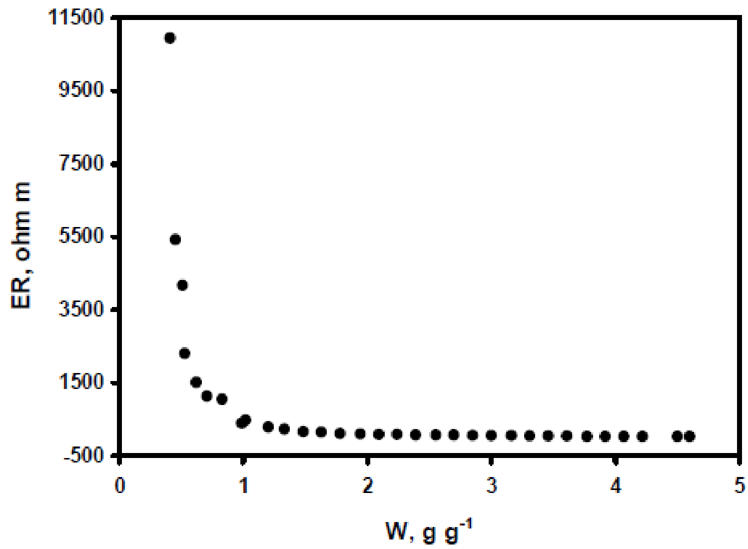


FIGURE 6: An example of experimental relationship between electrical resistivity and water content of a peat soil (Podznyakov & Podznyakova, 2002).

Archie (1942) suggested an empirical relationship based on laboratory measurements of clean sandstone samples. This relationship, as shown below as Equation 2.6, was modified from the Equation 2.4 mentioned previously, taking into account that the porosity can be filled by other medium as water, such as air or petroleum. The water saturation was expressed in function of the formation factor F, of the formation resistivity ρ and of the water resistivity ρ_w:

$$S^n = \frac{F\rho}{\rho_w} \qquad \text{Equation 2.5}$$

By combining with equation 2.4, we obtain:

$$S^n = \frac{a\rho}{\phi^m \rho_w} \qquad \text{Equation 2.6}$$

where S is the saturation degree and n is a parameter related to the saturation degree. Equation 2.6 was valid for medium to coarse-grained soils and rocks as it presumes that the characteristic of the solid phase which is grain matrix does not influence the electrical current conduction (Frohlich & Parke, 1989). However, the electrical resistivity of the grain matrix cannot be ignored for small grain sizes especially when clay minerals are present.

FIGURE 7 presents the results of Zhou et al. (2015) research on the electrical resistivity of five soils under different soil saturation levels. For all the five soils, when the soil saturation increases, the soil electrical resistivity decreases. They also added that there exists a critical soil saturation level below which the resistivity will increase rapidly. Under the same soil saturation level, the electrical resistivity of sandy soil > silty sand > silt > silty loam > clay loam. It can be concluded that the smaller the soil particle, or the higher the clay contents of the soil, the lower the electrical resistivity (Zhou et al., 2015).

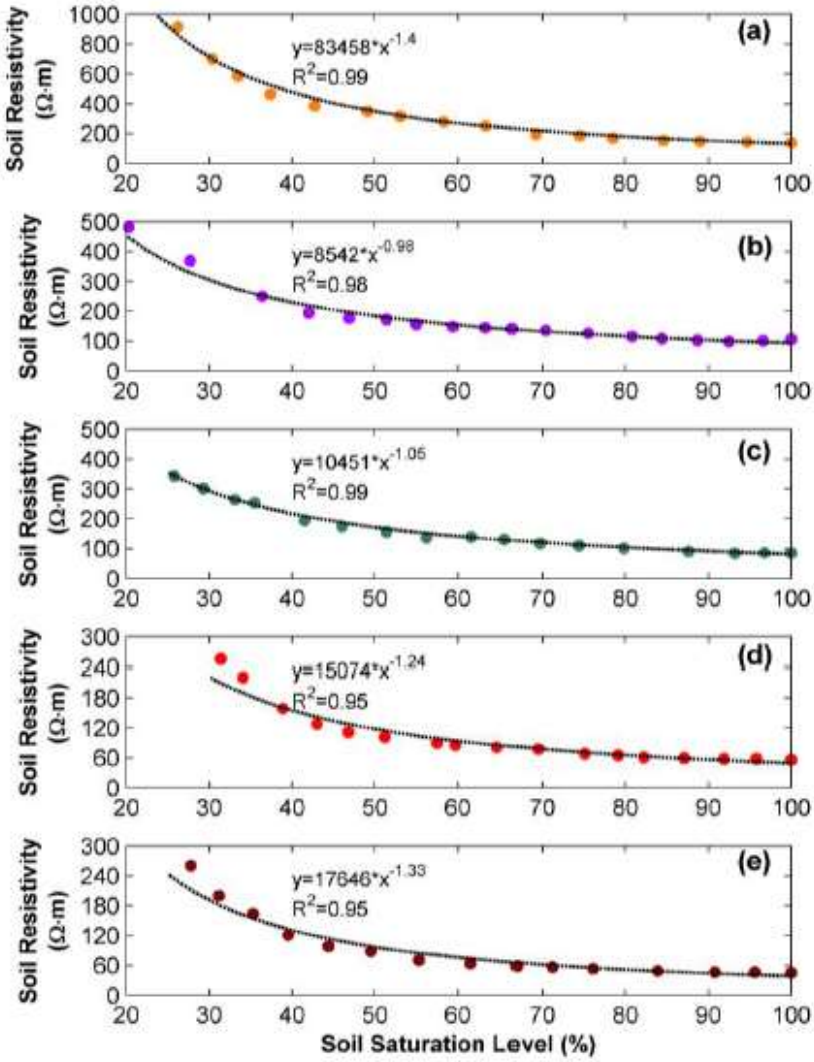


FIGURE 7: Effect of soil saturation levels on soil electrical resistivity of (a) sandy soil, (b) silty sand, (c) silt, (d) silty loam, and (e) clay loam (Zhou et al., 2015).

In addition, experiment done by Kibria and Hossain (2012) also achieved good correlation between degree of saturation and soil resistivity. Soil resistivity decreases with the increase in degree of saturation.

2.2.3 Pore Fluid Composition

According to Scollar et al. (1990), concentration and the viscosity of water affects electrical conductivity. Kalinski and Kelly (1993) discovered that soil solutions of the same concentration but with different ionic composition might have different electrical resistivity because of differences in ion mobility. According to them, the electrical resistivity decreases when the water conductivity increases at a given water content. They claimed that ions within the solution like H+, OH-, So_{2-}^{4}, Na+ and Cl can have different conductivity values although of the same concentration.

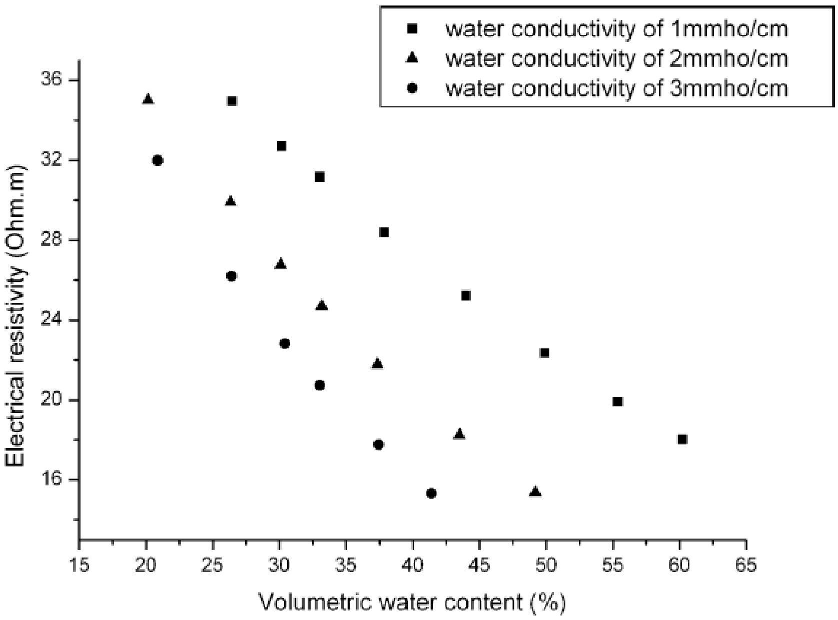


FIGURE 8: Relationship between the volumetric water content and resistivity for different values of pore-water conductivity (Kalinski and Kelly, 1993).

Sandy soil and silt were adopted by Zhou et al. (2015) to study the effect of pore fluid composition on soil electrical resistivity using electrolytes of three common ions presented in the pore fluid of soil, Na^+, K^+, Cl^- and SO_4^{2-}. There were significant drops in resistivity for all the soil samples. The soil with the electrolyte of NaCl has the largest electrical resistivity, while the soil with KCl has the lowest. Basically the relationship between electrical resistivity and the pore fluid composition is the same for the study done by Kalinski and Kelly (1993) and Zhou et al. (2015)

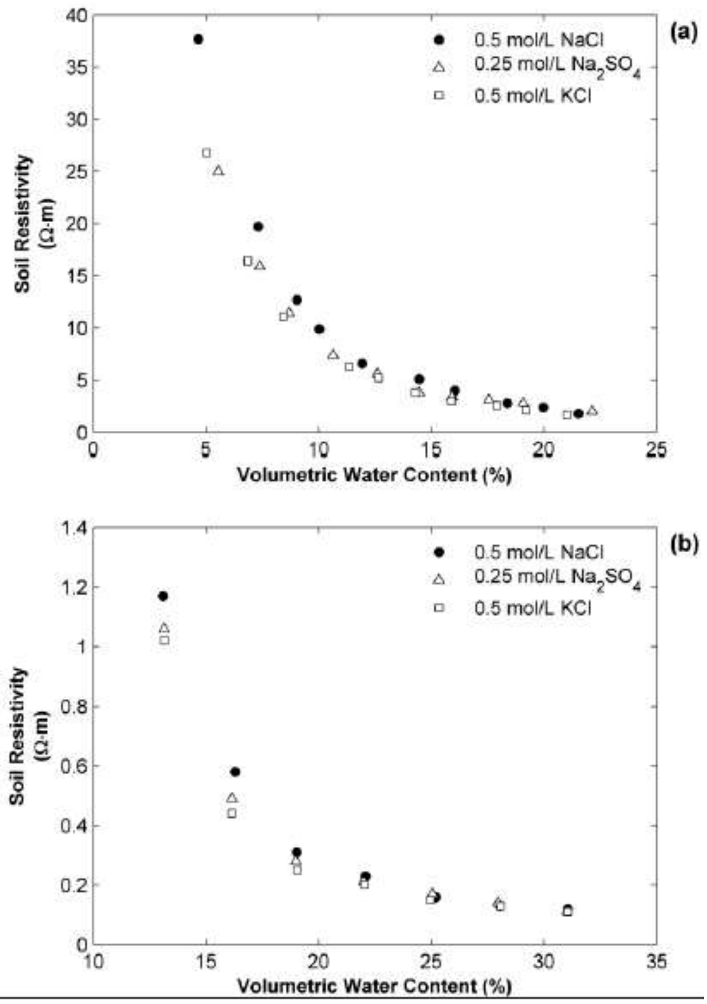


FIGURE 9: Effect of pore fluid composition on soil electrical resistivity of (a) sandy soil and (b) silt (Zhou et al., 2015).

2.2.4 Temperature

When the viscosity of a fluid decreases, ion agitation increases with temperature causing the electrical resistivity to decrease as the temperature increases. Campbell et al. (1948) conducted laboratory experiments on 30 samples of saline and alkaline soils and he demonstrated that conductivity increased by 2.02% per °C between 15 and 35°C. The electrical conductivity is expressed at the standardized temperature of 25°C as in Equation 2.7:

$$\sigma_t = \sigma_{25°\mathrm{C}} \left[1 + \alpha(T - 25°C)\right] \qquad \text{Equation 2.7}$$

where σ_t = the conductivity at the experiment temperature, $\sigma_{25°\mathrm{C}}$ = the conductivity at 25 °C, and α is the correction factor equal to 2.02%.

Abu-Hassanein et al. (1996) studied the effect of temperature on the electrical resistivity of compacted clays. The result shows electrical resistivity decreases with increasing temperature, as expected. In the same time, a large drop in electrical resistivity occurs as the temperature passes the freezing point (-O°C). Keller and Frischknecht (1966) explain, this abrupt change occurs due to change in dielectric constant when the pore fluid changes phase.

Similar result was also achieved by Zhao et al. (2005) in their experiment. At temperatures above 0°C, the electrical resistivity tends to decrease slightly with the increase of temperature. The temperature causes abrupt changes in resistivity at the transition near 0 °C while at temperature below 0 °C, as the temperature decreases, the resistivity increases dramatically (See FIGURE 10).

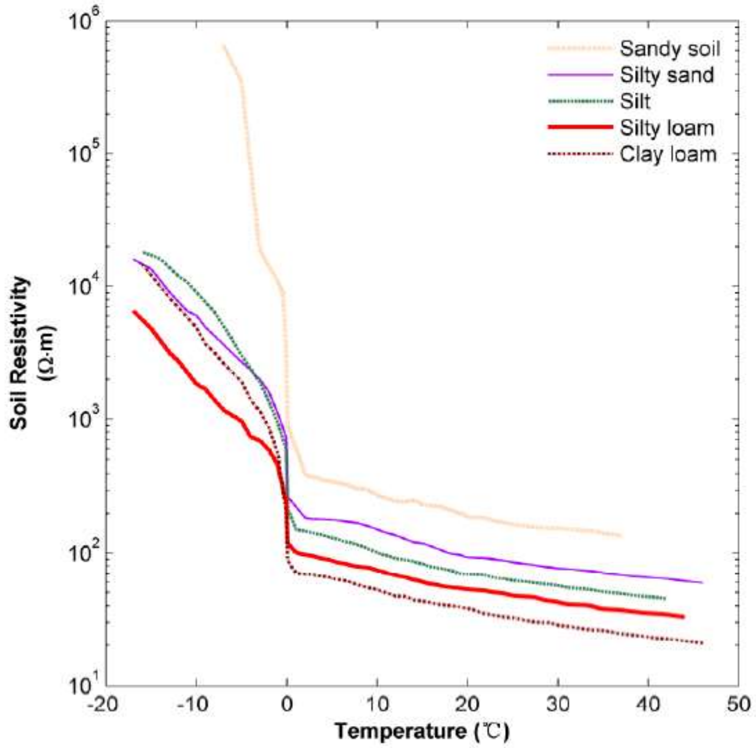


FIGURE 10: Effect of soil temperature on the electrical resistivity of the five soils (Zhao et al., 2015).

As stated by Samouelian et al. (2005), the effect of temperature on electrical field resistivity measurements at the annual scale is not avoidable as temperature variation in soil occurs at two different temporal scales, which is day and season during a year. Typically, in the Northern hemisphere, the highest resistivity values are obtained between September to November. The lowest resistivity values are recorded between June to July (Samouelian et al., 2005).

2.3 Relation of Current Research with Previous Research

There are many researchers that have studied the correlation of electrical resistivity with various soil properties, such as the various researchers mentioned in the previous section. There are no researches done regarding the aspects of correlation of electrical resistivity with strength properties such as cohesion and angle of internal friction, until Syed et al. (2014) started to do a research to look into this aspect. Three types of soil were used in his research; clay, silt and sand. From his research, he concluded that the values of angle of internal friction increases with the increase in the electrical resistivity. However, when the combined points of all the three soil types is plotted into one graph, a weak correlation between angle of internal friction and electrical resistivity is established as shown in FIGURE 11. He added that in order to get a stronger correlation, one of the factor to be looked into is the porosity. This is because porosity influences the transmission of ions which in turn can directly affect the value of electrical resistivity (Syed et al., 2014).

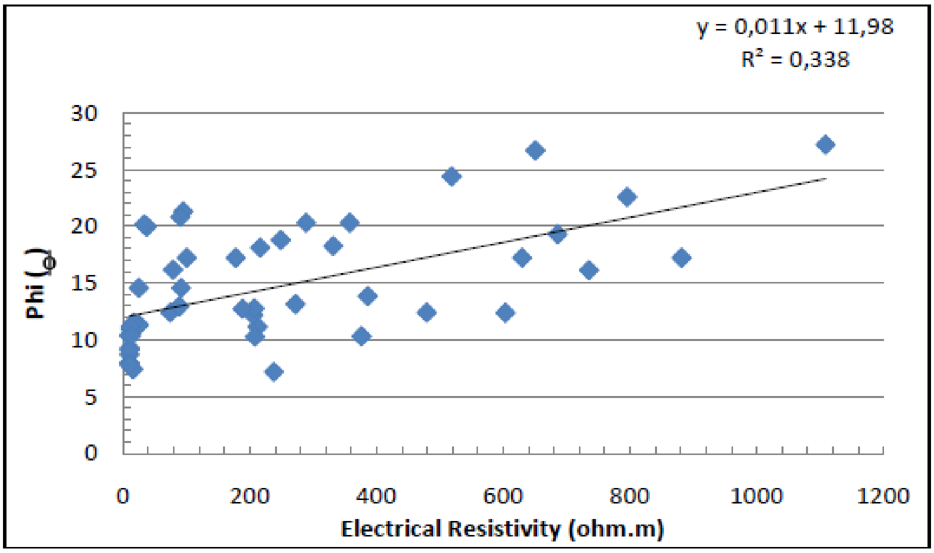


FIGURE 11: Angle of friction (Phi) vs. electrical resistivity for all soil samples; sand, silt and clay (Syed et al., 2014)

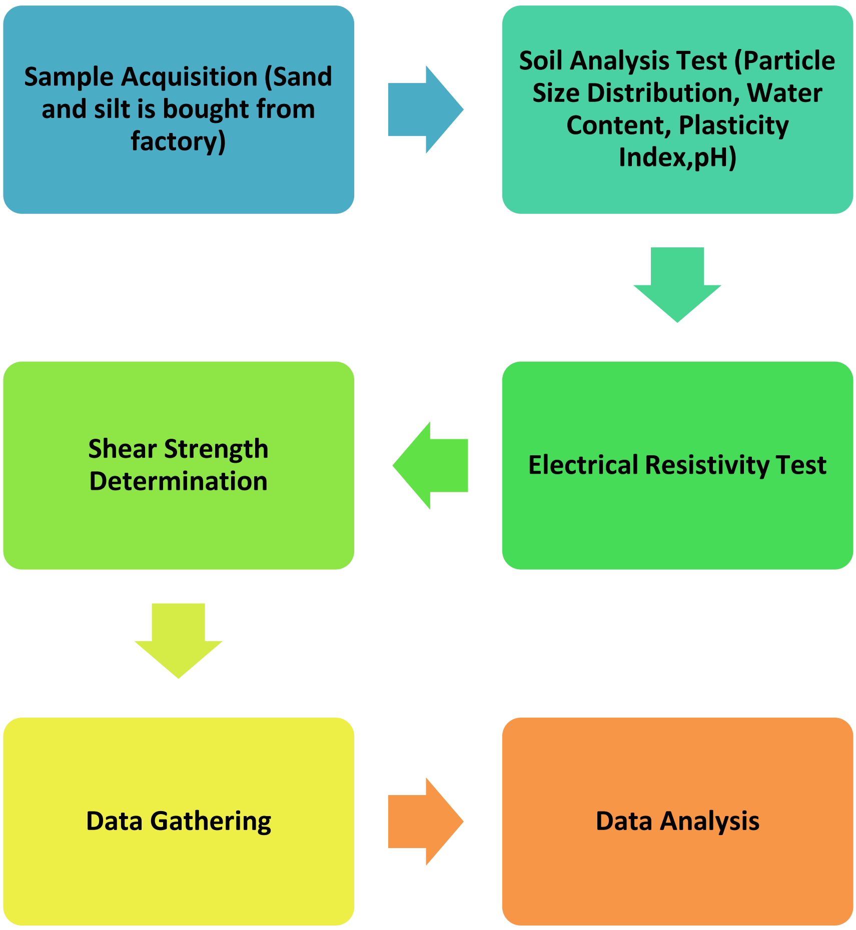
Therefore, the purpose of this research is to look into the factor of porosity by varying the particle size proportion for mixed sand and silt samples, in the hope of getting a stronger correlation between porosity and electrical resistivity. This will directly affect the strength of correlation between soil strength parameters (cohesion and angle of internal friction) with electrical resistivity.

CHAPTER 3

METHODOLOGY

The objective of this study is to determine the effects of porosity and saturation on electrical resistivity for different particle size proportion and also to determine the effects of varying the particle size proportion for mixed sand and silt samples on the behaviour of electrical resistivity with soil strength parameters.

The four purposes of this chapter are to (1) describe the research methodology of this study, (2) explain the sample selection, and (3) describe the procedure used in designing the instrument and collecting the data.



3.1 Research Methodology

The type of research used in this study is quantitative research. This study applies experimental research where scientific method is used to establish the cause-effect relationship among a group of variables that make up this study. In this study, the proportion of mixed sand and silt samples is varied to determine the effects on the behaviour of electrical resistivity along with soil strength parameters.

3.2 Sample Acquisition and Preparation

For this study, 20 samples of mixed sand and silt soil is needed. Two different types of soil specimen with different particle size are bought from a specific supplier. The first type is sand grade S10100 with particle size from 0.029mm to 2.00mm. The second type is silt grade S300 with particle size from 0.0045mm to 0.250mm. Different particle size proportion is prepared using the two types of soil specimen bought, with the proportion of (1) 100% sand, (2) 80% sand, 20% silt, (3) 60% sand, 40% silt, (4) 40% sand, 60% silt, (5) 20% sand, 80% silt, (6) 100% silt.

3.3 Soil Analysis Test

3.3.1 Particle Size Distribution

This test is performed to check the particle sizes of the samples bought. Since the soil samples obtained are very fine and the sieve test was impractical to measure its size distribution, another method was adopted. Hydrometer test was used according to BS 1377 part 2 1990, 9.6 standard.

50 g of the sample was placed in a conical flask and 100ml of sodium hexametaphosphate was added and mixed in the shaker for 24 hours. The next day the sample was sieved through 63µm sieve. Two procedures were followed with the

retained and passing mass, to be able to generate a size distribution graph that represents the size variation throughout the soil sample.

The mass passing 63µm was placed in a 1000ml cylinder and placed in the water bath and readings were taken at 30s, 1min, 4min, 8min, 15min, 30min, 1 hours, 2 hours, 4 hours, and 24 hours using a hydrometer. On the other hand, the mass retained on 63µm was washed off on a tray using distilled water and placed in the oven for 24 hours. The next day the dry sample was sieved through 1.18mm, 600µm, 425µm, 300µm, 212µm, 150µm, and 63µm respectively.

To calculate the mass percentage in the 1000ml cylinder, the following equations were used;

$R_H = R'_h + C_m \text{Rh}$ Equation 3.1

Where; C_m = the meniscus correction = 0.5mm

R_h= hydrometer reading

D = Particle diameter = $0.005531\sqrt{\frac{\eta H}{(\rho s-1)t}}$ Equation 3.2

Where; η = water viscosity = 0.857 mPa.s at 27ºC, and ρs = 2.65 Mg/m3

H_R= effective depth = $H + 0.5 [(h - (Vh\frac{L}{90})] = 189.67-3.8321 R_h$ Equation 3.3

T = time elapsed

The modified hydrometer reading, $R_d = R_h' - R_0$ Equation 3.4

Where; R_0 = 0.5mm

$D = [\frac{100\rho s}{m}(\rho s - 1)]\, Rd$ Equation 3.5

D= the percentage by mass passing, K smaller than the equivalent particle size

m = mass of dry soil = 50 g

To calculate the mass percentage in the dried sample, after sieving it, the percentage of mass retained, and the cumulative percentage passing each sieve was calculated and represented in the graph. The resultant graph of percentage passing vs particle size mm represents the size distribution for the entire 50 g sample. Starting from clay, then to silt, to sandy size. The percentage of sand, silt, and clay was taken from the distribution of the particle sizes in that graph.

3.3.2 Moisture Content

This test is performed to determine the water (moisture) content of soils by oven drying method. The water content is the ratio, expressed as a percentage, of the mass of "pore" or "free" water in a given mass of soil to the mass of the dry soil solids. For many soils, the water content may be an extremely important index used for establishing the relationship between the way a soil behaves and its properties. The consistency of a fine-grained soil largely depends on its water content. Apparatus required are:

- Thermostatically controlled oven maintained at a temperature of 105ºC to 110ºC.
- Scientific balance with a readability of 0.01g for specimens with mass of 200g and less, readability of 0.1g for specimens with mass over 200g.
- Air-tight container made of non-corrodible material with lid
- Tongs

The following calculation is used to calculate the water content:

$$W = \frac{W_2 - W_3}{W_3 - W_1} * 100\% \qquad \text{Equation 3.6}$$

Where W= Water content

W_1= Weight of empty container with lid, g

W_2= Weight of container + Wet soil, g

W_3= Weight of container + Dry soil, g

3.3.3 Plasticity Index (Liquid Limit and Plastic Limit)

Atterberg Limit Test was done on the soil samples to obtain the liquid limit and plastic limit. The Atterberg Limits are based on the moisture content of the soil. The Liquid Limit, also known as the upper plastic limit, is the water content at which soil changes from the liquid state to a plastic state. The Plastic Limit, also known as the lower plastic limit, is the water content at which a soil changes from the plastic state to a semisolid state.

To perform this test, a soil sample is placed into the cup of the liquid limit machine and separated into two halves using a grooving tool. The crank on the machine is then rotated so that the cup holding the sample strikes the base of the test machine. The number of blows is recorded until the two halves flow together and close the groove.

Apparatus needed are:

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

To analyse the data for Liquid Limit:

1. The water content of each of the liquid limit moisture cans is calculated after they have been in the oven for at least 16 hours.
2. The number of drops, N, is plotted (on the log scale) versus the water content (w). The best-fit straight line through the plotted points is drawn and the liquid limit (LL) is determined as the water content at 25 drops.

To analyse the data for Plastic Limit:

1. The water content of each of the plastic limit moisture cans is calculated after they have been in the oven for at least 16 hours.

2. The average of the water contents is computed to determine the plastic limit, PL.
3. The plasticity index is calculated

$$PI = LL - PL \quad \text{Equation 3.7}$$

Report the liquid limit, plastic limit, and plasticity index to the nearest whole number, omitting the percent designation.

3.4 Electrical Resistivity Test

To prepare the soil for electrical resistivity test, all samples were stored in airtight containers to reduce the absorption of moisture. The instruments needed for the test are:

- Two 100mm aluminium electrodes
- 200 volts DC power supply & handheld multimeter

For every specimen, 3 kg of soil were mixed with a certain amount of distilled water according to the percentage of moisture content required which are 15%, 20%, 25%, 30% and 35%. Mixing of soil and distilled water was done using soil mixer. The samples were then wrapped with plastic and left aside in the mixing bowl for 24 hours.

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 is dissembled. Also, during electrical resistivity test, the plastic material prevents the reading from being affected by the mould which is made by steel. The specimens were then compacted directly in the round mould in three equal layers using the standard compaction machine. The number of blow is 27. The procedure for compaction is the same as prescribed in BS 1377.

Upon completion of compaction, the mould was dissembled and the specimen was placed between two circular aluminium electrodes for the purpose of determination of electrical resistivity using disc electrode method in accordance with BS 1377. The specimens along with the aluminium disc were connected to both the negative and positive terminals of a DC power supply and in the same time connected to a multimeter where an initial potential with varying voltages from 30V, 60V and 90V were applied. The resulting values of current in ampere were then recorded and calculated using equations. The resistivity of the soil can be calculated using the formulas:

$$R = \frac{V}{I}$$ Equation 3.8

Where *V*= Voltage (v), *I*= Current, (A)

$$\rho = R\left(\frac{A}{L}\right)$$ Equation 3.9

Where A = cross-sectional area of the sample, i.e. the mould area, $A = \pi r^2$ (m^2), L= Length of the mould (m) and ρ = Resistivity

3.5 Shear Strength Determination

The Direct Shear Test is used for determination of the consolidated drained (or undrained) shear strength of soils. The test is performed on three or four specimens from a relatively undisturbed soil sample. A specimen is placed in a shear box which has two stacked rings to hold the sample; the contact between the two rings is at approximately the mid-height of the sample. A confining stress is applied vertically to the specimen, and the upper ring is pulled laterally until the sample fails, or through a specified strain. The load applied and the strain induced is recorded at frequent intervals to determine a stress–strain curve for each confining stress. Several specimens are tested at varying confining stresses to determine the shear strength parameters, the soil cohesion (c) and the angle of internal friction, commonly known as friction angle (ϕ). The results of the tests on each specimen are plotted on a graph with the peak (or residual) stress on the y-axis and the confining stress on the x-axis. From the plot, a straight-line approximation of the Mohr-Coulomb failure envelope curve can be drawn, f may be determined, and, for cohesionless soils (c = 0), the shear strength can be computed from the following equation:

$$s = s \tan f$$ Equation 3.10

The apparatus needed for the test are:

- Direct shear box apparatus
- Loading frame (motor attached)
- Dial gauge
- Proving ring
- Tamper
- Balance to weigh up to 200 mg
- Aluminium container
- Spatula

3.6 Project Timeline

3.6.1 Final Year Project 1 (FYP 1)

TABLE 2: Timeline for FYP 1

Activities \ Week Number		1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of Project Topic															
Briefing															
Research on Required Tools & Equipments															
Implement the Process of the Project															
Searching for Soil Samples															
Lab Safety Briefing															
Submission of Extended Proposal															
Proposal Defense															
Particle Size Distribution Test															
Plasticity Index (For all soil proportion)															
Moisture Content = 25%	80% sand, 20 % silt														
	60% sand, 40 % silt														
	40% sand, 60 % silt														
Submission of Interim Draft Report															
Submission of Interim Report															

Project Milestone and Process

Lab Work Milestone and Process

3.6.2 Final Year Project 2 (FYP 2)

TABLE 3: Timeline for FYP 2

Activities	Week Number	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Moisture Content = 25%	20% sand, 80 % silt															
	100% silt															
Moisture Content = 30%	40% sand, 60% silt															
	20% sand, 80 % silt															
	100% silt															
Moisture Content = 35%	20% sand, 80 % silt															
	100% silt															
Moisture Content = 20%	80% sand, 20 % silt															
	60% sand, 40 % silt															
	40% sand, 60 % silt															
	20% sand, 80 % silt															
	100% silt															
Submission of Progress Report																
Moisture Content = 15%	100% sand															
	80% sand, 20 % silt															
	60% sand, 40 % silt															
	40% sand, 60 % silt															
	20% sand, 80 % silt															
	100% silt															
Additional Lab Work (If any)																
Data Analysis & Interpretation																
Pre-SEDEX																
Coordinator will assign 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)																

Project Milestone and Process

Lab Work Milestone and Process

CHAPTER 4

RESULTS & DISCUSSION

A total of 20 soil samples with moisture content of 15%, 20%, 25%, 30% and 35% were tested using compaction test, electrical resistivity test and shear box test to obtain pH, plasticity index, porosity, saturation, electrical resistivity, angle of friction and cohesion. The results were tabulated in TABLE 4 and TABLE 5 below.

TABLE 4: Results for porosity, saturation, electrical resistivity, angle of friction and cohesion.

Moisture Content	Proportion		Number of Blows	Porosity, n	Saturation, S	Electrical Resistivity, ρ (Ωm)	Angle of Friction, ϕ (˚)	Cohesion, c (kPa)
	Sand (%)	Silt (%)						
15%	100	0	27	0.3924	0.6156	241.7042	48.81	57.28
	80	20		0.3336	0.7942	127.1908	45.07	64.24
	60	40		0.3270	0.8180	130.1498	41.55	57.08
	40	60		0.3434	0.7602	185.2993	41.75	82.26
	20	80		0.3858	0.6327	254.2604	39.80	99.19
	0	100		0.4250	0.5377	294.6964	37.73	102.14
20%	80	20	27	0.3739	0.8877	88.3448	43.12	60.04
	60	40		0.3739	0.8877	81.2289	41.12	60.40
	40	60		0.3864	0.8417	132.0072	40.19	67.53
	20	80		0.3895	0.8307	164.7321	38.66	69.88
	0	100		0.4146	0.7485	291.9804	37.73	85.03
25%	60	40	27	0.4049	0.9737	77.7419	40.58	52.65
	40	60		0.4109	0.9497	91.9926	37.32	62.03
	20	80		0.4350	0.8606	135.0422	36.77	62.46
	0	100		0.4440	0.8297	154.7263	33.62	78.01
30%	40	60	27	0.4625	0.9240	92.2096	37.26	61.59
	20	80		0.4654	0.9133	98.9860	35.88	62.03
	0	100		0.4915	0.9046	125.2394	32.46	77.82
35%	20	80	27	0.4852	0.9842	92.3644	34.33	47.43
	0	100		0.4991	0.9309	100.2232	31.58	54.93

TABLE 5: Results for pH and plasticity index.

Proportion		pH	Plasticity Index, PI
Sand (%)	Silt (%)		
100	0	6.15	0
80	20	5.72	0.3
60	40	5.37	6.6
40	60	4.92	5.34
20	80	4.29	4.3
0	100	4.15	12.04

From TABLE 4 above, only soil sample with moisture content of 15% can be tested for all 6 proportion of sand and silt. For other moisture contents, some proportion of sand and silt cannot be tested because the samples turn out to be too watery, therefore electrical resistivity test and shear box test cannot be performed.

4.1 Graph of Porosity, Saturation, Angle of Friction, Cohesion and Electrical Resistivity versus Proportion of Sand and Silt

Figure 12, 13, 14, 15 and 16 below shows the graph for porosity, saturation, angle of friction, cohesion and electrical resistivity versus proportion of sand and silt.

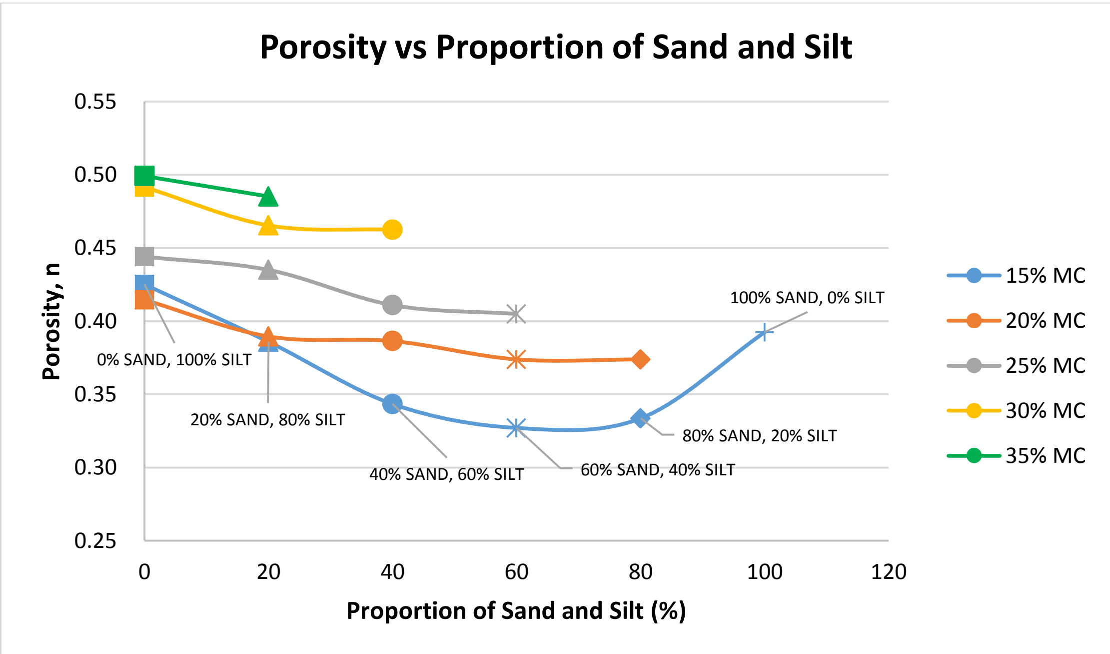


FIGURE 12: Porosity vs proportion of sand and silt for all moisture content.

FIGURE 12 shows the relationship between porosity and proportion of sand for all moisture content. It can be seen that the trend shows porosity decreases as proportion of sand decreases and silt increases. Fleming (n.d.) stated that porosity is inversely proportional to grain size. Silt and clay that is composed of finer grains have a considerably greater volume of open spaces than sand and gravel which composed of coarse grains. As the range in grain sizes getting wider, the resulting porosity is lower. This explains the relationship portrayed in FIGURE 12.

In addition, for the same proportion of sand and silt but with the increasing of moisture content, porosity increases. According to Nimmo (2004), porosity indicates the amount of space available to fluid within a specific body of soil. Therefore, when porosity is higher, more water can be filled within the pores. The result for moisture content of 15% shows inconsistency due to increment in porosity at 80% sand and 20% silt. This behaviour might occur due to the low water content causing it harder to facilitate the movement of soil particles during compaction.

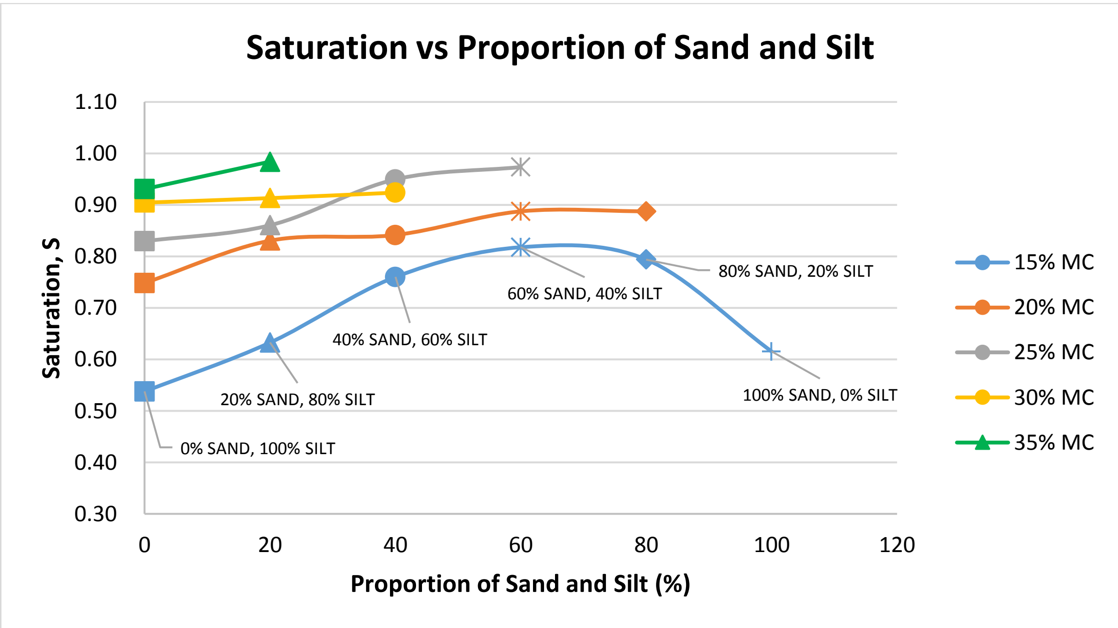


FIGURE 13: Saturation vs proportion of sand and silt for all moisture content.

FIGURE 13 shows the relationship between saturation and proportion of sand for all moisture content. The graph shows that saturation increases as proportion of sand increases and silt decreases. For the same proportion of sand and silt but with the increasing of moisture content, saturation increases. As mentioned above in FIGURE

12, the result for moisture content of 15% shows inconsistency due to the low water content.

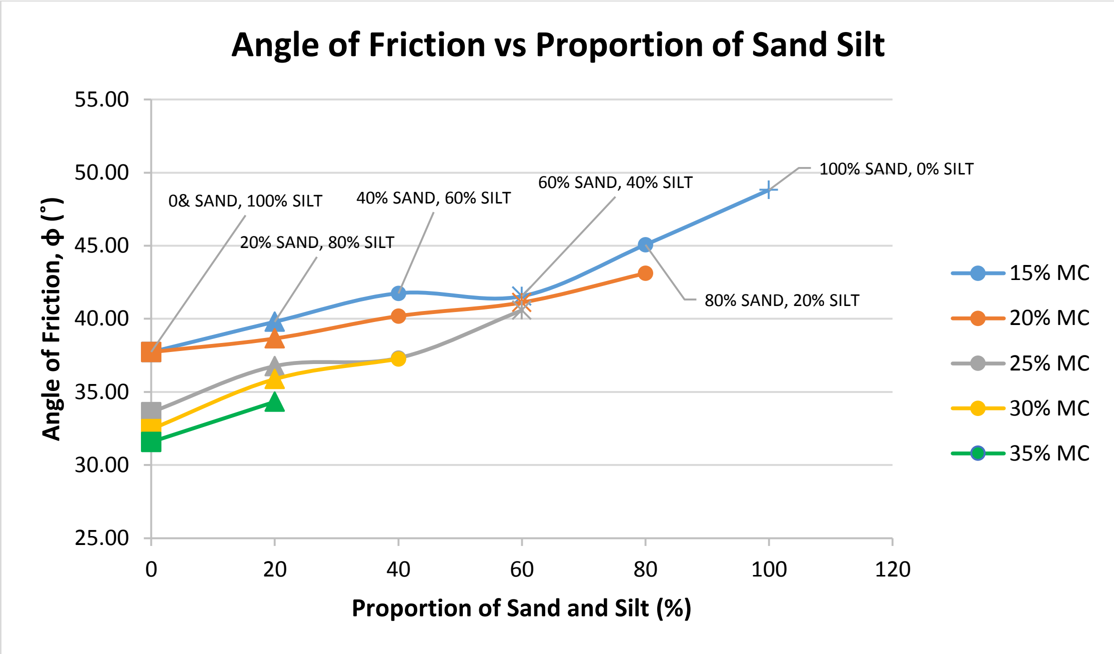


FIGURE 14: Angle of friction vs proportion of sand and silt for all moisture content.

FIGURE 14 shows the relationship between angle of friction with proportion of sand under different moisture content. Based on the graph, as the proportion of sand increases and silt decreases, angle of friction increases. Under the same proportion of sand and silt but with the increasing of moisture content, the value of angle of friction is decreasing. Angle of friction is a measure of the ability of a unit of rock or soil to withstand a shear stress. As the proportion of sand increases and silt decreases, the strength of soil becomes lesser, therefore it is easier for shear failure to occur in the soil, causing the angle of friction to be increased. The same principle is also applied when moisture content increases under the same proportion of sand and silt, because with the presence of higher moisture content, the soil strength becomes weaker and contributes to the decrease in angle of friction.

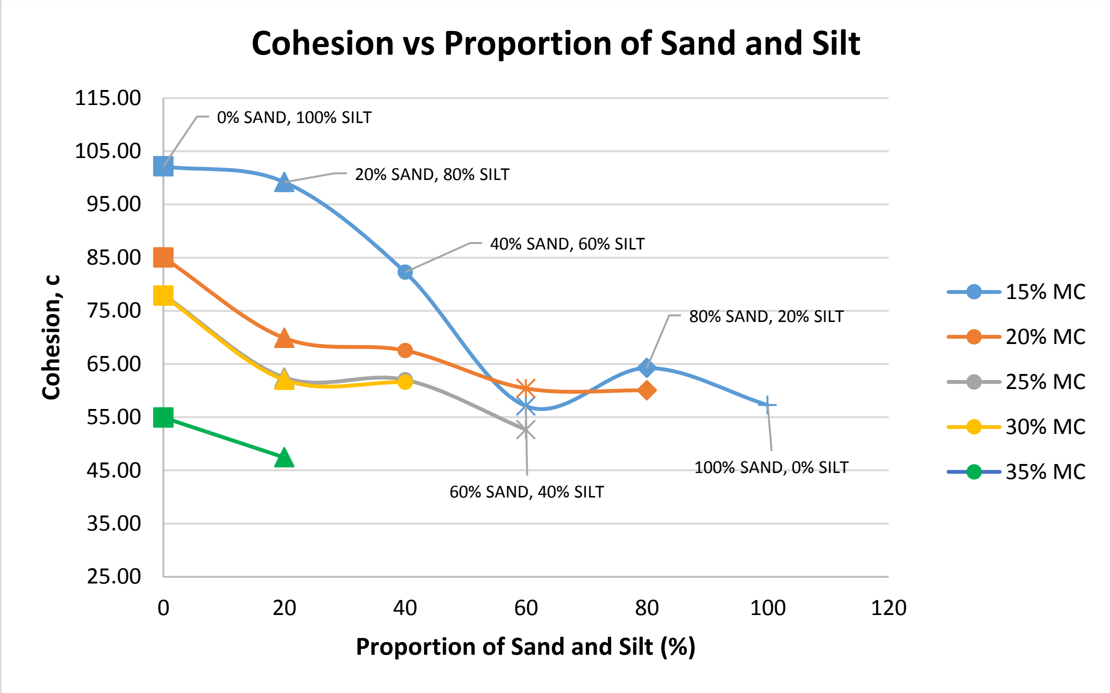


FIGURE 15: Cohesion vs proportion of sand and silt for all moisture content.

FIGURE 15 shows the relationship between cohesion with proportion of sand under different moisture content. The graph shows that as the proportion of sand increases and silt decreases, cohesion decreases. In addition, under the same proportion of sand and silt but with the increasing of moisture content, cohesion decreases. Saturation plays an important role for this relationship, as we know that when proportion of sand increases and silt decreases and also when moisture content becomes higher under the same proportion of sand and silt, saturation will increase. Yokoi (1968) mentioned that sieved soils under saturated condition have little soil cohesion. Soil which has strong soil cohesion has strong shear strength.

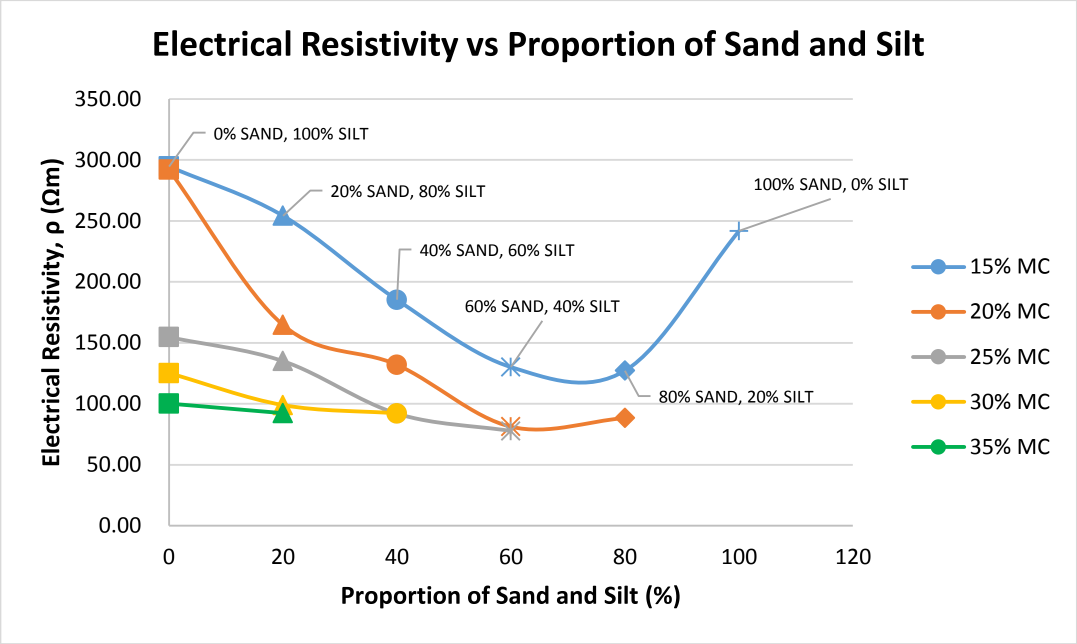


FIGURE 16: Electrical resistivity vs proportion of sand and silt for all moisture content.

The relationship between electrical resistivity and proportion of sand under different moisture content is shown in FIGURE 16. Electrical resistivity is decreasing when the proportion of sand is increasing and silt decreasing. As moisture content increases, electrical resistivity decreases under the same proportion of sand and silt. This is again due to the effect of saturation, where it is easier for electric charge to be conducted through the pores with the presence of higher moisture content.

4.2 Graph of Electrical Resistivity versus Porosity, Saturation, Angle of Friction and Cohesion

Figure 17, 18, 19, and 20 below shows the graph for electrical resistivity versus porosity, saturation, angle of friction and cohesion.

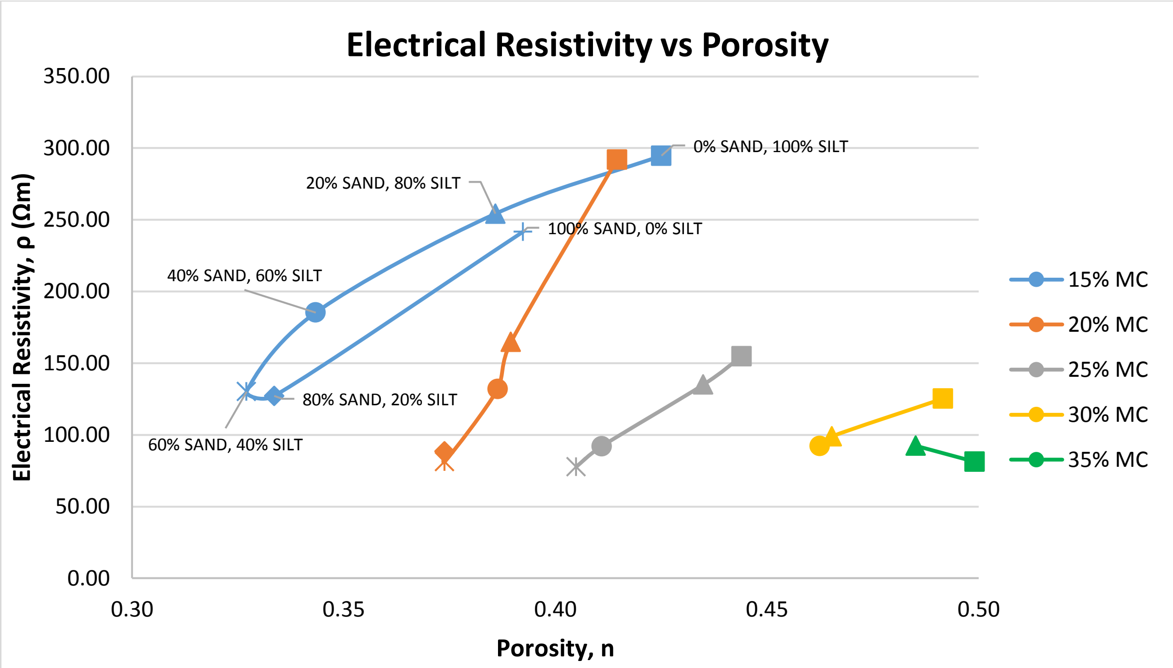


FIGURE 17: Electrical resistivity vs porosity for all moisture content.

FIGURE 17 shows the relationship between electrical resistivity and porosity under different moisture content. Under most of the moisture content (20%, 25%, 30% and 35%), electrical resistivity increases as porosity increases. However, for moisture content of 15%, the electrical resistivity decreases with the decreasing of porosity at first, and then the behaviour changes to electrical resistivity increases with the increasing of porosity. The behaviour might occur due to the low amount of water, thus making it hard to facilitate the movement of soil particles during compaction and causing the porosity to decrease.

The relationship that shows electrical resistivity increases as porosity increases is against Archie's (1942) finding, where electrical resistivity is supposed to be decreasing with the increasing of porosity. The cause of this trend will be explained below after analysing the result in FIGURE 18.

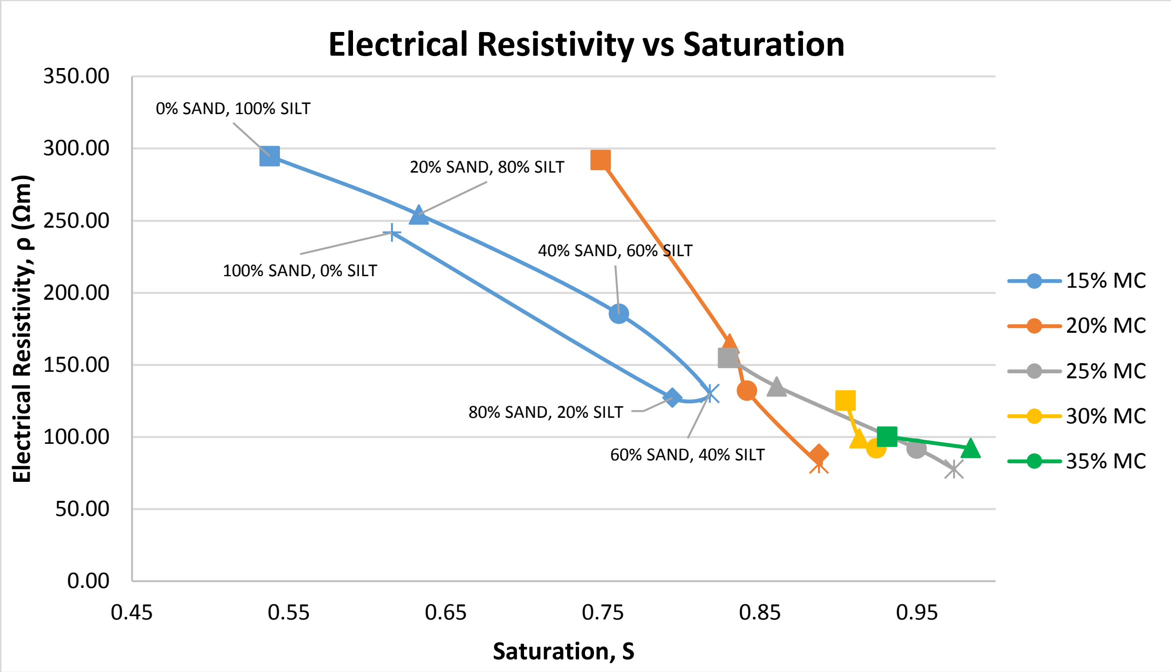


FIGURE 18: Electrical resistivity vs saturation for all moisture content.

The relationship between electrical resistivity and saturation under different moisture content is shown in FIGURE 18. Under most of the moisture content (20%, 25%, 30% and 35%), when the saturation is increasing, the value of electrical resistivity is decreasing. However, for moisture content of 15%, the electrical resistivity decreases with the increasing of saturation at first, and then the behaviour changes to electrical resistivity increases with the decreasing of saturation. The behaviour is again as mentioned in FIGURE 17; might occur due to the low amount of water, thus making it hard to facilitate the movement of soil particles during compaction and causing the porosity to decrease and therefore leads to the decrease in saturation.

From FIGURE 17 and FIGURE 18, the relationship established indicates that the higher the porosity, the higher the electrical resistivity but with the decreasing of saturation. Therefore, it can be said that in this research, the effect of saturation over rules the effect of porosity. This is because nearly saturated pores of soil have greater particle-to-particle contact and also form bridges among the particles (Sadek, 1993). With higher saturation, it is easier for the electricity to be conducted through the pores.

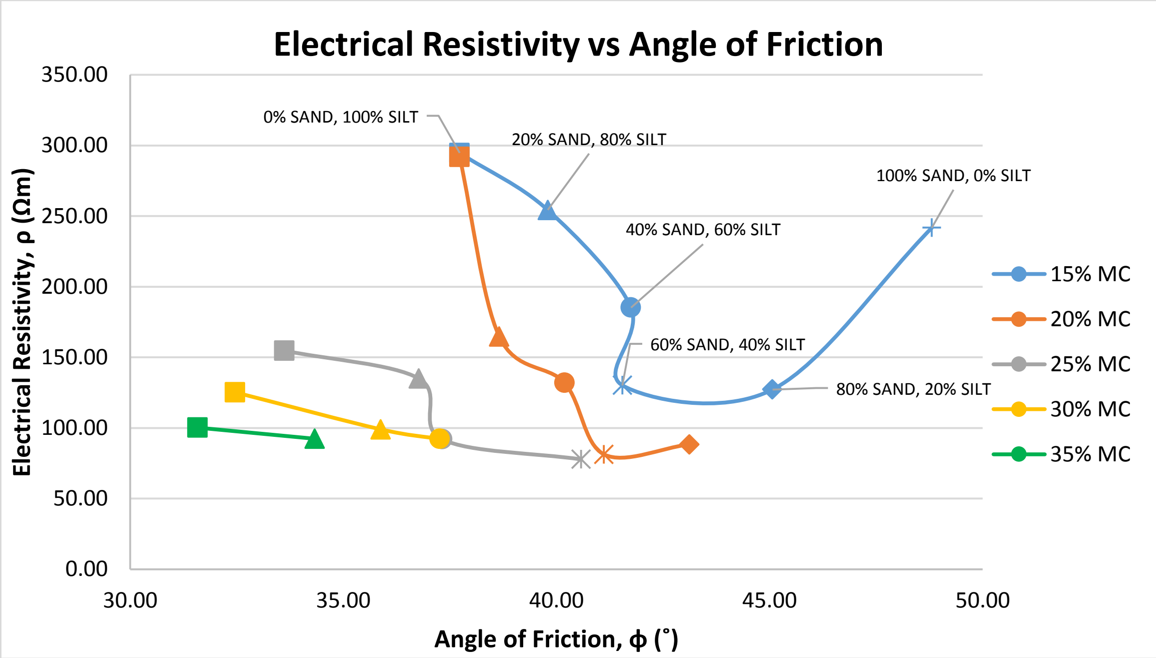


FIGURE 19: Electrical resistivity vs angle of friction for all moisture content.

FIGURE 19 presented the relationship between electrical resistivity and angle of friction under different moisture content. From the graph, the general trend indicates that with the increase in angle of friction, electrical resistivity decreases. This is due to the factor of saturation, which causes the electrical resistivity to decrease. Higher saturation has impact on reducing the strength of soil thus increasing the angle of friction.

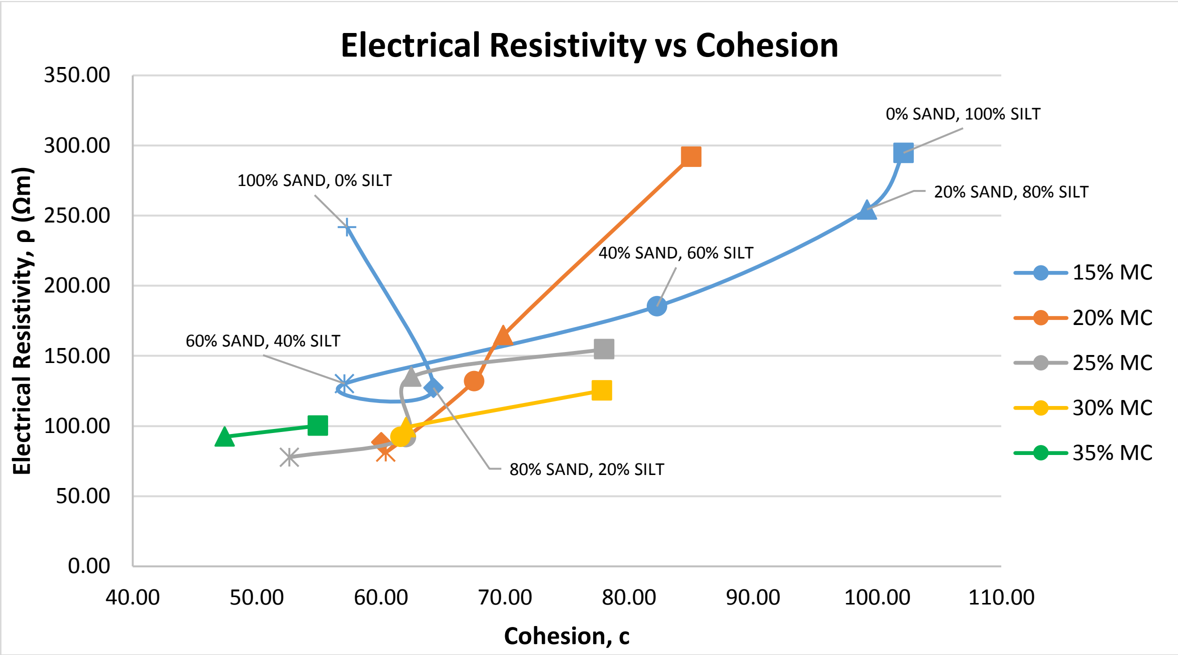


FIGURE 20: Electrical resistivity vs cohesion for all moisture content.

The relationship between electrical resistivity and cohesion under different moisture content is displayed in FIGURE 20. The graph demonstrates for moisture content of 20%, 25%, 30% and 35%, electrical resistivity will increase when cohesion increases. However, the trend for moisture content of 15% indicates that electrical resistivity decreases as cohesion increases at first, then changes to electrical resistivity increases as cohesion increases. This inconsistent trend could be caused by low amount of water as explained before.

4.3 Correlation of Electrical Resistivity versus Porosity, Saturation, Angle of Friction and Cohesion for All Soil Samples

Figure 21, 22, 23 and 24 below shows the correlation of electrical resistivity versus porosity, saturation, angle of friction and cohesion for all soil samples

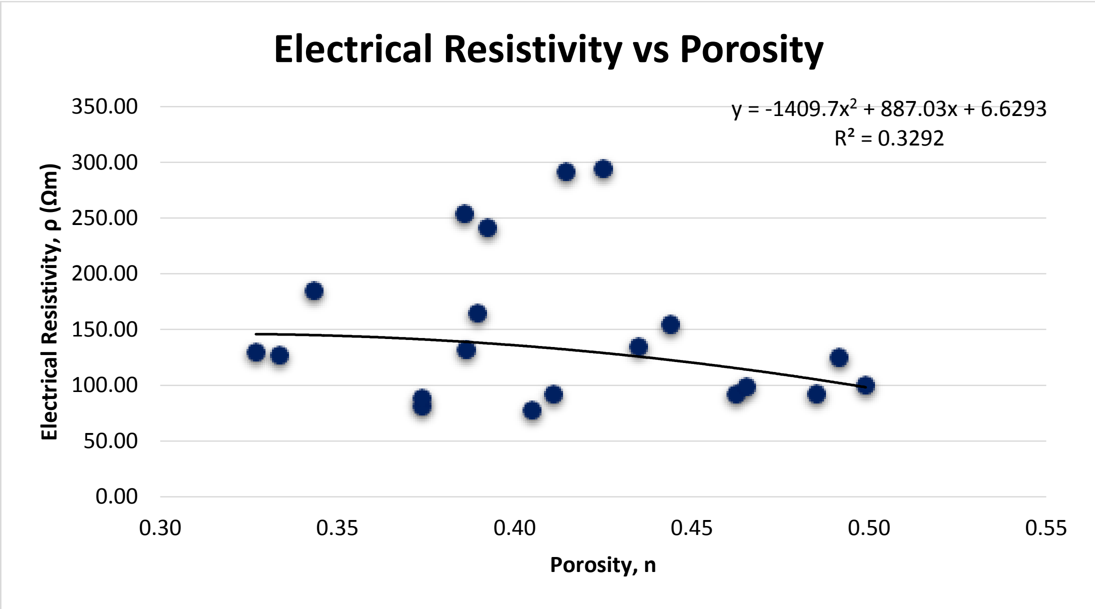


FIGURE 21: Correlation of electrical resistivity with porosity for all soil samples.

FIGURE 21 shows the correlation of electrical resistivity with porosity for all soil samples. Relationship between resistivity and porosity values demonstrates non-linear polynomial correlation with regression coefficient R^2=0.3292. Electrical resistivity decreases with increasing porosity. The result is in agreement with the finding of Archie (1942).

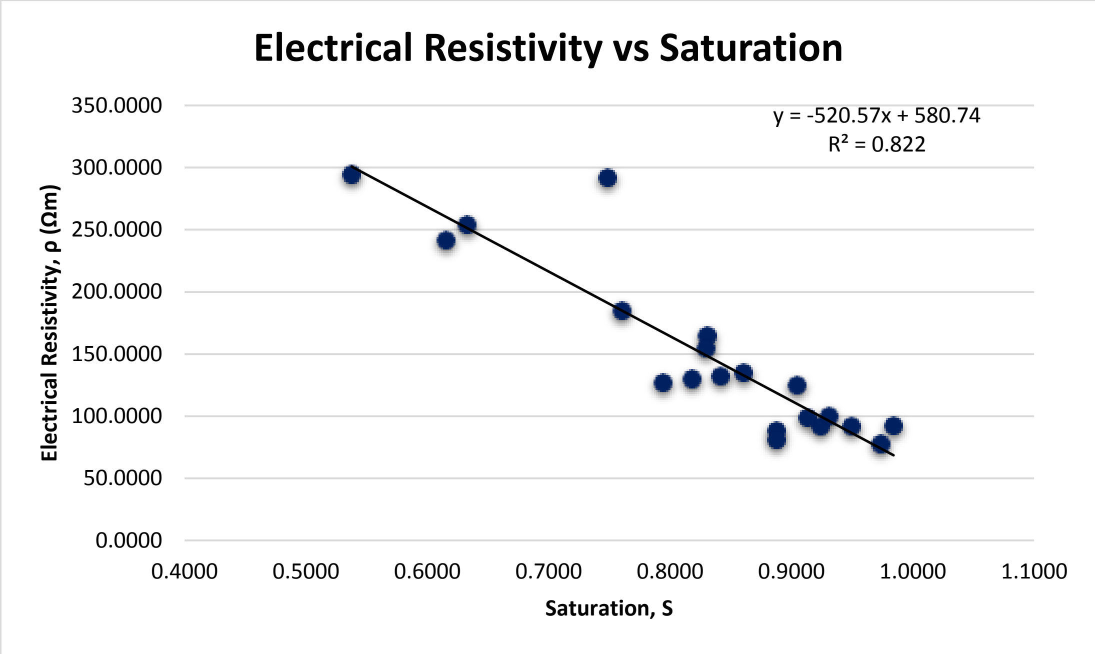


FIGURE 22: Correlation of electrical resistivity with saturation for all soil samples.

The correlation of electrical resistivity with saturation for all soil samples is portrayed in FIGURE 22. Relationship between resistivity and saturation values demonstrates linear correlation with strong regression coefficient R^2=0.822. Electrical resistivity decreases with the increasing saturation as reported in various previous studies including the research of Pozdnyakova (1999), Kibria and Hossain (2012) and also Zhou et al. (2015). According to Zhou et al. (2015), water in soil exerts dominant control over the soil resistivity due to the electrical conduction in soil that is mainly electrolytic and occurs through water in pore spaces or along the continuous films of water adsorbed on grain boundaries. The mobility of electrical charges in soils is influenced by water content.

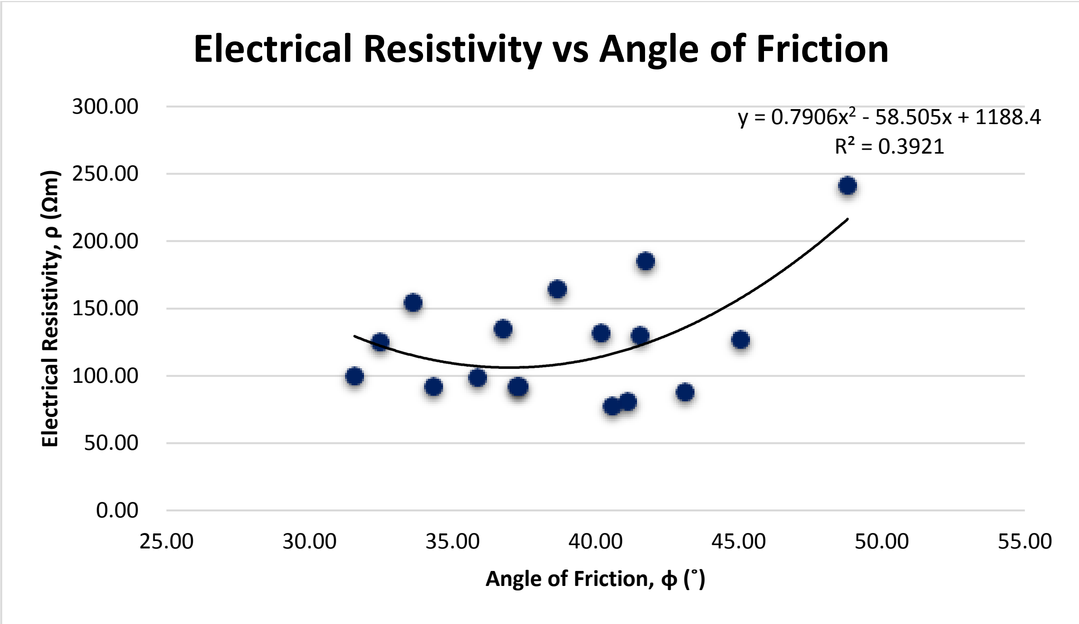


FIGURE 23: Correlation of electrical resistivity with angle of friction for all soil samples.

FIGURE 23 displayed the correlation of electrical resistivity with angle of friction for all soil samples. Non-linear logarithmic correlation with moderate regression coefficient R^2=0.3921 is demonstrated in the relationship between resistivity and angle of friction. Based on the figure, as the angle of friction increases, the value of electrical resistivity increases. The relationship obtained is similar with previous researches of Syed et al. (2012, 2014). This behaviour is related to the saturation of soil. Water content or saturation can reduce the soil's strength by losing its soil particles chain and thus enable the soil's conductivity to increase. As saturation increase, strength decreases. This is because increasing water content cause greater separation of soil particles and leads to softening of soil.

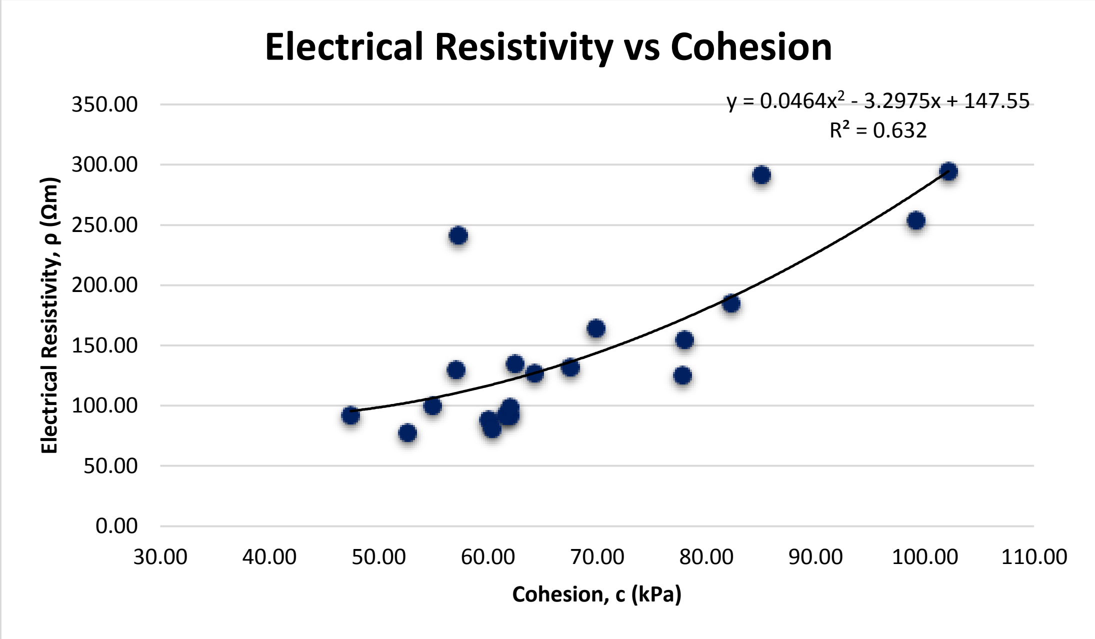


FIGURE 24: Correlation of electrical resistivity with cohesion for all soil samples.

The correlation of electrical resistivity with cohesion for all soil samples is shown FIGURE 24. Electrical resistivity increases with the increasing cohesion, and demonstrates non-linear polynomial correlation with strong regression coefficient R^2=0.632. Higher electrical resistivity values can be related to the lower saturation of soil. With lower water content, strength of soil becomes higher. Soil which has strong soil cohesion has strong shear strength (Yokoi, 1968).

CHAPTER 5

CONCLUSION AND RECOMMENDATION

The objective of this study is to estimate the relationship between electrical resistivity with porosity, saturation and soil strength parameters by varying the particle size proportion for mixed sand and silt samples. The relationship obtained between electrical resistivity and porosity for all points is electrical resistivity decreases with increasing porosity with moderate regression coefficient R^2=0.3292. The result is in agreement with the finding of Archie (1942). Looking at the relationship between electrical resistivity and saturation for all points, the relationship obtained is electrical resistivity decreases with the increasing of saturation with good regression coefficient R^2=0.822. The result obtained is similar with the previous reports and studies. Overall, when analysed according to different moisture content, the trend established in this study were the higher the porosity, the higher the electrical resistivity but with the decreasing of saturation. This is in contrast with general understanding that the higher the porosity, the lower the electrical resistivity. Therefore, it can be concluded that in this research, the effect of saturation over rules the effect of porosity. With higher amount of water, it is easier for the electricity to be conducted through the pores. This is because nearly saturated pores of soil have greater particle-to-particle contact and also form bridges among the particles (Sadek, 1993).

On the other hand, the relationship between electrical resistivity and angle of friction for all points indicates that the electrical resistivity increases as angle of friction increases with moderate regression coefficient R^2=0.3921. Meanwhile, moderate correlation between electrical resistivity and cohesion is obtained with good regression coefficient R^2=0.632. Electrical resistivity increases with the increasing cohesion as reported in various previous studies.

In conclusion, the correlation and relationship between porosity, saturation and soil strength parameters (angle of friction and cohesion) by varying the particle size proportion for mixed sand and silt samples has been established in this research. Further tests need to be done to increase more understandings and findings, as well as to establish more generalized and precise correlation between strength properties and electrical resistivity of soil. Hopefully in the future, a strong correlation between electrical resistivity and soil strength parameters can be established, enabling this method to be implemented and reducing full dependency of site investigation by soil boring.

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APPENDICES

Appendix 1: Example of Calculation Using Experiment Data

MOISTURE CONTENT : 15%

SOIL PROPORTION : 80% SAND, 20% SILT

DATE : 16 MARCH 2016 (MIXING 15 MARCH 2016)

COMPACTION MOULD DATA:

Length = 0.116 m

Diameter = 0.105 m

Radius = 0.0525 m

Area = 0.008659 m^2

Weight of mould + base = 4.15 kg

NO. OF BLOWS : 27

RESISTIVITY TEST:

VOLT (V)	AMPERE (A)	RESISTANCE	RESISTIVITY (Ωm)
30	0.0167	1796.4072	135.2619
60	0.0367	1634.8774	123.0994
90	0.0550	1636.3636	123.2113
Average			**127.1908**

SHEAR BOX TEST:

Angle of Friction = 43.12˚

Cohesion = 64.24 kPa

Weight of mould + base plate + moist compacted soil, w_2 = 6.19 kg

Weight of mould + base, w_1 = 4.15 kg

Weight of moist compacted soil, w_2 - w_1 = 6.19 – 4.15

= 2.04 kg

Obtained Moist Unit Weight:

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

= 2.04 kg / (1.004446x10^{-3}) m^3 = 19.9238kN/m^3

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

γ_B = $G_s \cdot \gamma_w (1-n)(1-w)$

19.9238 = $(2.65)(9.81)(1-n)(1+0.15)$

19.9238 = $(29.896)(1-n)$

0.6664 = $1-n$

n **=** **0.3336**

To find Saturation, *S*

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

19.9238 = $(2.65)(9.81)(1-0.3336) + (0.3336)S(9.81)$

2.5997 = $3.2726S$

S **=** **0.7944**

MOISTURE CONTENT : 30%

SOIL PROPORTION : 40% SAND, 60% SILT

DATE : 17 FEBRUARY 2016 (MIXING 16 FEBRUARY 2016)

COMPACTION MOULD DATA:

Length = 0.116 m

Diameter = 0.105 m

Radius = 0.0525 m

Area = 0.008659 m^2

Weight of mould + base = 4.15 kg

NO. OF BLOWS : 27

RESISTIVITY TEST:

VOLT (V)	AMPERE (A)	RESISTANCE	RESISTIVITY (Ωm)
30	0.0217	1382.4885	104.0955
60	0.0496	1209.6774	91.0836
90	0.0832	1081.7308	81.4498
Average			**92.2097**

SHEAR BOX TEST:

Angle of Friction = 43.12˚

Cohesion = 64.24 kPa

Weight of mould + base plate + moist compacted soil, w_2 = 6.01 kg

Weight of mould + base, w_1 = 4.15 kg

Weight of moist compacted soil, w_2 - w_1 = 6.01 – 4.15

= 1.86 kg

Obtained Moist Unit Weight:

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

= 1.86 kg / (1.004446x10^{-3}) m^3 = 18.1658 kN/m^3

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

γ_B = $G_s \cdot \gamma_w (1-n)(1-w)$

18.1658 = $(2.65)(9.81)(1-n)(1+0.30)$

18.1658 = $(33.7955)(1-n)$

0.5375 = $1-n$

n **= 0.4625**

To find Saturation, *S*

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

18.1658 = $(2.65)(9.81)(1-0.4625) + (0.4625)S(9.81)$

4.1927 = 4.5371S

S **= 0.924**

Appendix 2: Laboratory Test

PARTICLE SIZE DISTRIBUTION TEST (HYDROMETER & SIEVE ANALYSIS)

Mixture of sodium carbonate anhydrous, sodium hexametaphosphate and distilled water is being mixed

100g sand/ 50g silt is added into the mixture

The mixture is left to be shaken for 24 hours in the shaker

The mixture is massaged on 63μm sieve

The material passing the 63 μm sieve is added in the measuring cylinder and distilled water is added up to 1L mark

The measuring cylinder is put in the water bath

The hydrometer reading is taken at 30s, 1min, 2min, 4min, 8min, 15min, 30min, 1h, 2h, 4hr and 24hr

The remaining material that did not pass the 63 μm sieve will be dried in the oven. Sieve analysis is done on the dried material

COMPACTION TEST

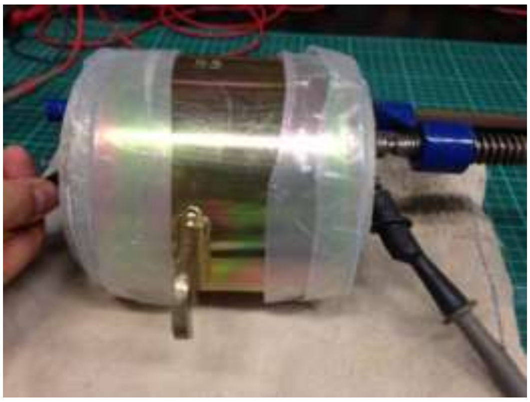
Sand and silt is weighed according to the respective proportion

The sand and silt is mixed together using the mixer

The inner of the mould is lined with plastic

The sample is compacted using standard compaction rammer with 27 blows

RESISTIVITY TEST



The sample is connected to the current and voltage

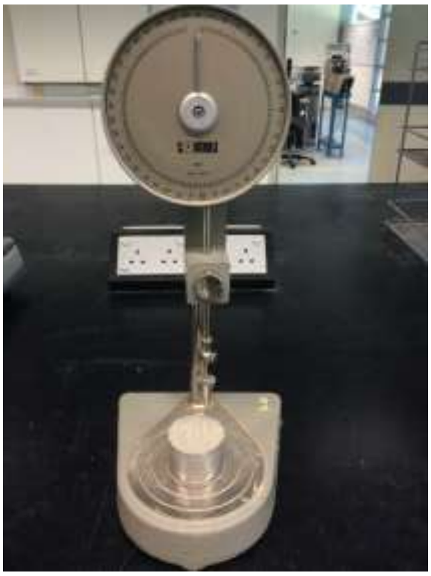
The setup for electrical resistivity test

Different voltage is applied

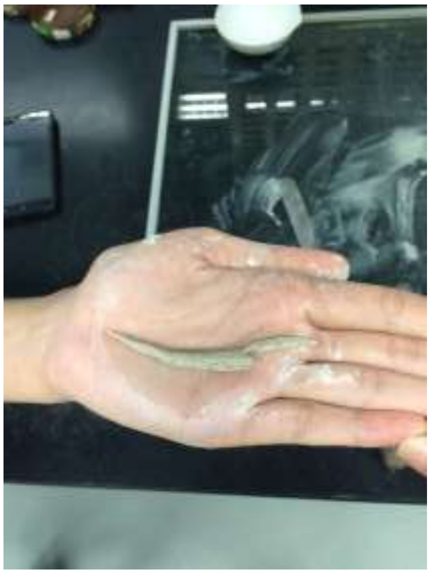
PLASTICITY INDEX TEST

The sand and silt is mixed together using spatula and distilled water is added

The sample is then filled in the small mould



The mould is put under the penetration machine. This process is done to find the liquid limit



The sample is rolled into thin pieces to find the plastic limit

All the wet samples are put into the
oven to find the dry mass