CORRELATION OF ELECTRICAL RESISTIVITY WITH SELECTED SOIL PARAMETERS WITH VARIATION IN MINEROLOGY, ORGANIC CONTENTS AND TEMPERATURE

By

MOHD HILMAN BIN AHMAD

FINAL YEAR RESEARCH PROJECT REPORT

Submitted to the Civil Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Civil Engineering)

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CERTIFICATION OF APPROVAL

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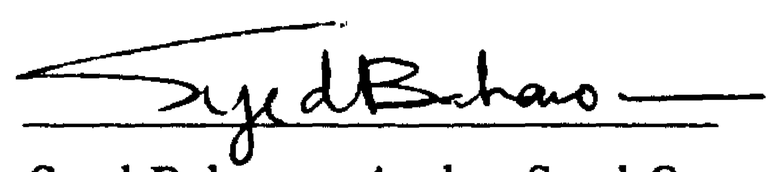
Approved:



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JUNE 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Mohd Hilman Bin Ahmad

ABSTRACT

In general, soil investigation (SI) incorporating bore hole sampling perhaps produces the most reliable value of relevant soil parameters for the purpose of actual calculation on factor of safety in slopes. However, bore hole sampling is in general time consuming and very expensive. The long term objective of this whole research is to implement a quick method of assessing the factor of safety (FOS) in slopes by replacing the conventional soil parameters such as cohesion and internal angle of friction with electrical parameters such as resistivity. This paper however is limited to the investigation of correlation between electrical resistivity with some soil properties. Field electrical resistivity surveys using basic multimeter were conducted on a slope in UTP and the result obtained were compared and correlated with some soil properties obtained from sand box test done in the geotechnical laboratory. Result from the experiment of electrical resistivity with different parameters indicated that soil resistivity reduced as the temperature increase, soil resistivity increased as the percentage of organic carbon increased and soil resistivity increased as the mineralogy density increased.

ACKNOWLEDGEMENTS

The author wishes to take the opportunity to express his utmost gratitude to the individual that have taken the time and effort to assist the author in completing the project. Without the cooperation of these individuals, no doubt the author would have faced some minor complications throughout the course.

First and foremost the author's utmost gratitude goes to the author's supervisor, Dr.Syed Baharom Azahar Syed Osman. Without his guidance and patience, the author would not be succeeded to complete the project. To the Final Year Research Project Coordinator, Assoc. Prof. Dr Mohamed Hasnain Isa and Ms Husna Takaijuddin for provide him with all the initial information required to begin the project.

To all the technician in Civil Engineering, Electrical Engineering and Mechanical Engineering Department, thank you for assisting the author in completing her project.

To all individuals that has helped the author in any way, but whose name is not mentioned here, the author thank you all.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Malaysia has many slopes/landslides failure and has cause extensive loss in properties and even to the extent of causing casualties. One of the essential aspect is to determine the factor of safety (FOS) which will indicate the stability of a certain slope. In the process of obtaining the FOS, among the crucial soil parameters to be obtained before calculating FOS are cohesion (c), internal frictional angle (Θ), unit weight of soil (γ) etc. since most of slope failure in Malaysia are mainly due to infiltration, the moisture content/pore water pressure also contributes to the FOS value. All these parameters are obtained for example through bore hole sampling.

1.2 Problem Statement

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

1.3 Objectives.

This study focused on continuing use of an earlier proven method, the four-electrode probe concept which was utilized throughout this research because all electrical resistivity methods applied in geophysics and soil science are based on this standard four-electrode principle. The primary objective of this study was to find the correlation between electrical resistivity with variation of organic content, temperature and mineralogy. Using all the data from the experiment, theoretical relationships between electrical resistivity and several types of soil with different condition will be testing to finally get an empirical formula to correlate slope stability with electrical resistivity

1.4 Scope of Study

Electrical resistivity depends on many factors such as porosity, electrical resistivity of the pore fluid, composition of the solids, degree of saturation, particle shape and orientation, and pore structure. The primary objective of this study was to focus on the first of these problems that is to correlate the relationships between electrical resistivity with the different conditions of soils.

The study of correlation between electrical resistivity and soil investigation is divided by many portions. Because the research areas are really wide, this research has been divide to several group. Authors have been more focused on doing the experiment by determine on the three important variable that are:

a) Correlation against different types of soil with percentage of organic content.
b) Correlation against different types of soil with temperature.
c) Correlation against different types of soil with mineralogy.

CHAPTER 2
LITERATURE REVIEW

The Relationship between electrical resistivity and soil resistivity has been extensively doing. It has been demonstrated that electrical resistivity can be correlated with other soil properties including molding water content and saturation, density, and void ratio. The net relationships between these soil properties and electrical resistivity are also influenced by percentage of organic content, temperature and mineralogy (Garcia-Bengochea et al. 1979).

The electrical characteristics of soils have received little investigative attention, with the exception of McCarter (1984). One model for the electrical conductivity of soil *ua* in mS/cm is

$$\sigma 0 = \sigma_w(a\theta^2 + b\theta) + \sigma s \qquad (1)$$

where θ = volumetric water content; σ_w = electrical conductivity of the pore water (mS/cm); σs = apparent conductivity of the soil grains (mS/cm); and a and b = dimensionless material constants (Rhoades et al. 1976).

The material constants in (1) quantitatively describe the tortuosity of the electrical current path through the soil. The term apparent conductivity is used for 65 because the added conductivity is attributable to both the soil grains and the ionically concentrated double layer on the surface of the soil grains (Frohlich and Parke 1989).

The apparent conductivity of the soil grains σs has been demonstrated to be related linearly to volumetric clay fraction for some soils (Rhoades et al. 1989; Kalinski 1992). Eq. (1) can also be expressed as a function of the air-filled porosity *na* and total porosity *n* as

$$\sigma a = \sigma[a\ (n - n_a)^2 + b\ (n - n)] + \sigma s \qquad (2)$$

Net relationships between electrical resistivity and hydraulic conductivity for compacted soils on the material level have not been examined. Samples compacted with less than optimum water content can have large air-filled porosities resulting in high hydraulic conductivity (Benson and Daniel 1990; Benson and Boutwell 1992). Eq. (1) and (2) suggest that high resistivity can be expected for soils compacted with low water content or high air-filled porosity.

Thus, field measurement of resistivity is potentially a useful indicator of high hydraulic conductivity from less than desired compaction due to inadequate water content or compactive effort. Electrical conductivity can also be expected to decrease with clay content on the material level. In this case, high resistivity can be indicative of liner areas with higher than desired sand or gravel content. In all cases, any relationships between resistivity and hydraulic conductivity can be expected to be material specific and warrant further investigation.

On the liner scale, failure can occur from desiccation cracking (Daniel 1984) and high interlift hydraulic conductivity due to poor bonding of lifts (Anderson et al. 1991). Resistivity measurements on field liners could prove useful for identifying these problems which would be indicated as areas with anomalously high resistivities.

2.1 Electrical Resistivity and Hydraulics Conductivity

The relationship between electrical resistivity and hydraulic conductivity has been studied (Worthington 1977; Huntley 1986; Heigold et al. 1979; Kelly 1977; Mazac et al. 1985), but contradictory results have been reported. Direct correlations between electrical resistivity and hydraulic conductivity (i.e., hydraulic conductivity increases as electrical resistivity increases) have been reported for some soils, whereas inverse relationships (i.e., hydraulic conductivity decreases as electrical resistivity in-creases) have been reported for others.

Mazac et W. (1990) conclude that the relationship between hydraulic conductivity and electrical resistivity is inverse for soils of a particular type. For example, saturated dense clean sands have lower porosity, lower hydraulic conductivity, and greater electrical resistivity than loose clean sands [e.g., see Arulanandan and Muraleetharan (1988)].

Conversely, when a comparison is made between the electrical resistivity and hydraulic conductivity of different types of soils (e.g., clay,

sand, and silt), the relationship between electrical resistivity and hydraulic conductivity is direct, with coarse-grained soils generally having the highest electrical resistivity and highest hydraulic conductivity. The direct relationship between electrical resistivity and hydraulic conductivity for soils of different type is primarily due to changes in surface conductance; that is, surface conductance decreases as soils become increasingly coarse grained.

For compacted clays, Sadek (1993) reports that the relation-ship between electrical resistivity and hydraulic conductivity is not unique since the same electrical resistivity can be attained for specimens having different structure and hydraulic conductivity. Kalinski and Kelly (1994) found that a distinct relation-ship between electrical resistivity and volumetric water content exists and suggest that this relationship may prove useful in assessing the hydraulic conductivity of compacted soil liners.

2.2 Field Measurement of Electrical Resistivity

The resistivity of soil can be measured in situ using the four-probe Wenner electrode configuration (Halvorson et al. 1977; Chaker 1981). The four-probed Wenner electrode configuration consists of four aligned evenly spaced electrodes and is described in ASTM G 57 ("Standard" 1978). This configuration is shown in Fig. 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 ρa in dZ • m is determined by

$$\rho a = 2\pi RL \tag{3}$$

Where L = electrode spacing (m); and R = measured resistance (Ω). For an infinite homogeneous medium, the apparent resistivity of the soil is equivalent to the true resistivity ρa.

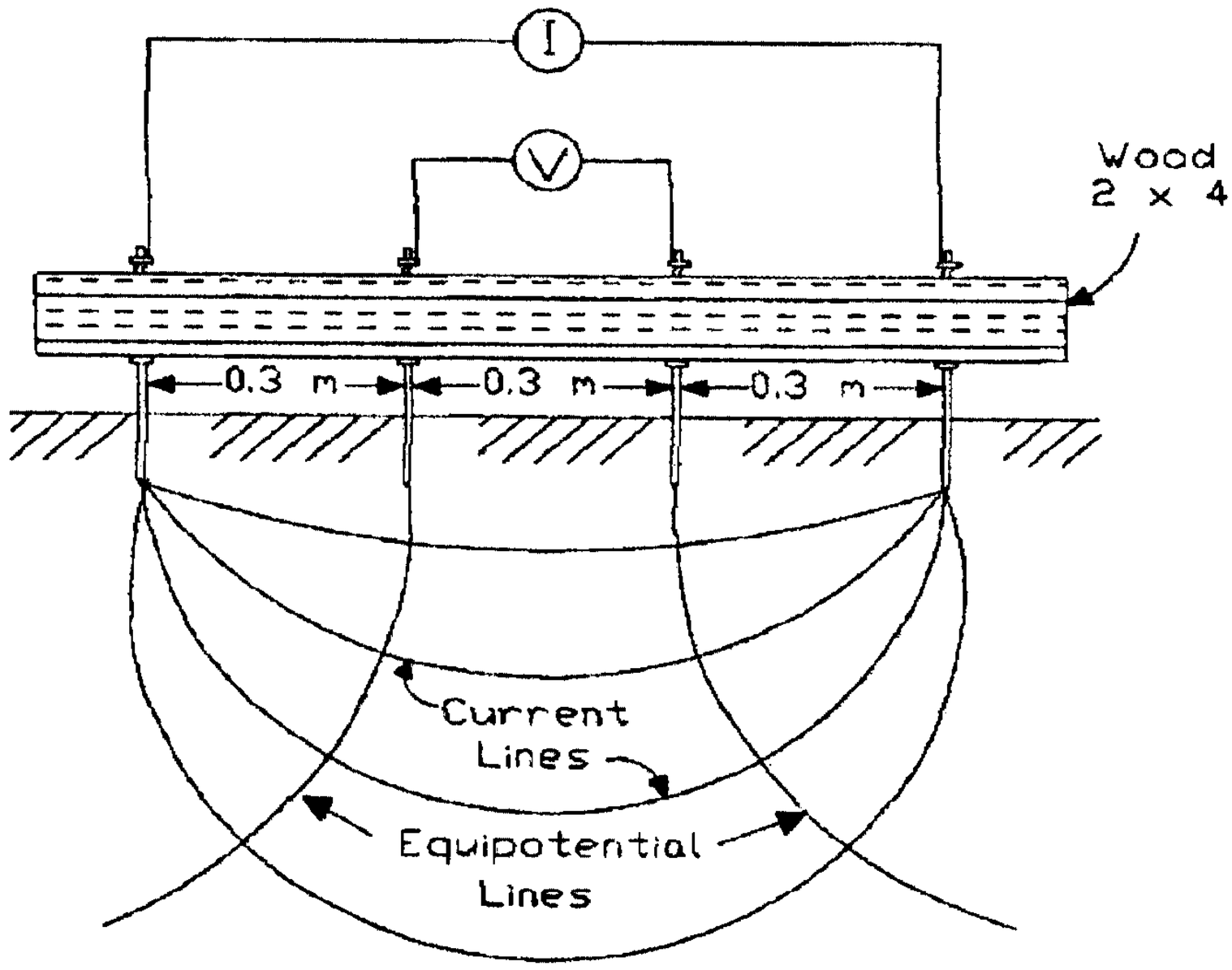


Figure 1. Liner Resistivity Measurement Using Fixed-Spacing Four-Probed Wenner Electrode Configuration

Portable devices with fixed electrodes have been used in field investigations for rapid measurements of soil resistivity where depths of penetration of less than one meter are desired (Halvorson et al. 1977). An advantage of resistivity measurements over noncontacting electromagnetic (EM) measurements is that the depth of observation can be more easily controlled.

With the Wenner configuration in homogeneous materials, it has been demonstrated that approximately 90% of the injected current flows through depths less than the spacing L and that distance can be practically assumed to be the depth of observation (Keller and Frischknecht 1966). For a field liner, the distance L can be the thickness of a single lift, a specified number of lifts, or the total liner, depending on the desired depth of observation.

2.3 Fixed-Spacing Four Probed Wenner Configuration

A device for performing apparent resistivity measurements in the field with a fixed-spacing four-probed Wenner configuration is shown as Fig. 1. A device similar to that shown was used to measure the average resistivity of two 0.15 m thick lifts for a 13,950 m2 soil at a municipal landfill (Kalinski 1992). With this device, 45 resistivity measurements could be performed on a 15 m grid by a two-person crew in 1 h or by one person in 90 min.

Electrodes should be inserted into the lift or liner at minimum depths of approximately 0.05 m to obtain representative measurements of lift or liner resistivity. This small depth of penetration allows for the destruction of holes created by the fixed-probe device by scarifying the lift surface prior to the construction of the overlying lift.

For materials with layers of significantly different electrical resistivities where the spacing L is greater than the upper layer thickness may be applicable for measuring apparent resistivity only. In this case, resistivity soundings at various spacings are necessary to determine resistivity variations with depth. Measured apparent resistivities can be reduced into values of thickness and resistivity of individual layers using computer interpretive methods such as those described by Koefoed (1979) and Zohdy and Bisdorf (1989).

For the scenario of an electrically conductive liner overlying a more resistive layer, such as sand or loam, current flow can be assumed to be essentially horizontal through the liner layer and the longitudinal resistivity, pi of the liner is measured by the sounding. Longitudinal resistivity pi in. f2 • m is defined as

$$\frac{H}{E} = 1 \; Pr \qquad (4)$$

Where H = liner thickness (m); and hi and p; = thicknesses and resistivities, respectively, of layers or lifts (Keller and Frischknecht 1966; Zohdy et al. 1974). When the resistivity of the liner is near that of the underlying material, the apparent resistivity approaches the true resistivity.

2.4 Electrode Arrays

There are many types of electrode arrays are possible in resistivity surveys. Table 1 gives the median depth of investigation for various types of electrode arrays for a homogenous sub-surface model. The median depth (Ze) indicates the depth to which a particular array can be used. The choice in the *types of array for a field survey is depending on the type of feature to be* surveyed (e.g., the sensitivity of the array to vertical and horizontal changes in the subsurface resistivity and the depth of investigation), the sensitivity of the resistivity meter, the background noise level, and the signal strength.

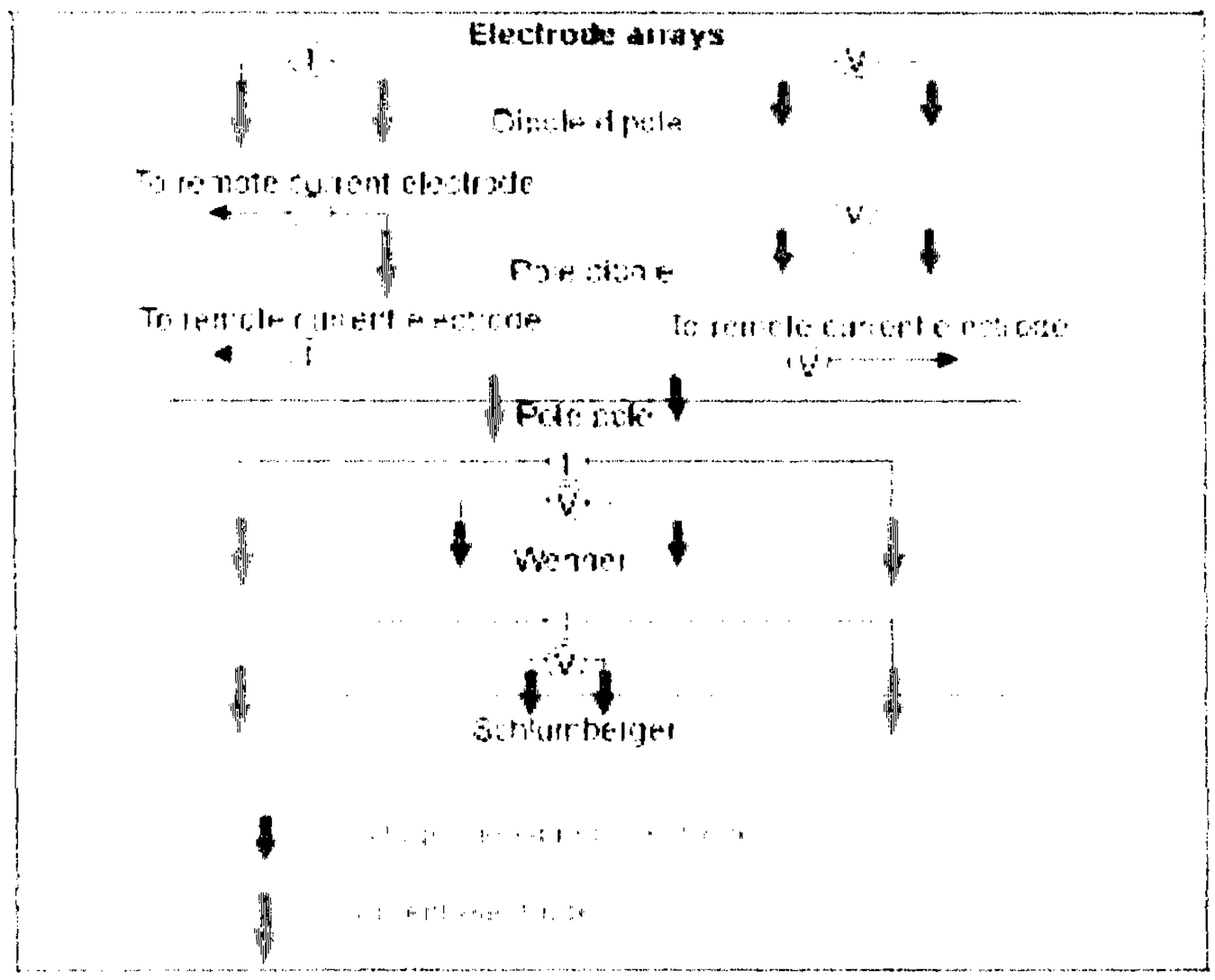


Figure 2. Electrode arrays used to measure resistivity

2.4.1 Wenner Array

The Wenner array is best used for horizontal structures, but in the other hand it is relatively poor in detecting narrow vertical structures. It is sensitive to vertical changes in the subsurface resistivity below the center of array and less sensitive to horizontal changes in the subsurface resistivity. This type of array has large signal strength.

2.4.2 Dipole-Dipole Array

This type is fit for vertical structures, vertical discontinuities and cavities, and less for identifying horizontal structures. Dipole-dipole array is sensitive to resistivity changes between the electrodes in each dipole pair the most. The depth of investigation is smaller as compared to the Wenner array. As the values of n become larger, the signal strength becomes smaller.

2.4.3 Wenner-Schlumberger Array

This type of array is moderately sensitive in horizontal and vertical structures. The median depth of this array is greater than the median depth of Wenner array for the same distance between electrodes. The signal strength is higher than the dipole-dipole array and smaller than the wenner array.

2.4.4 Pole-pole Array

This array can be simulated if one current and one potential electrode are placed at a distance more than 20 times the distance between the N and B electrodes. This array is sensitive for noise due to the large distance between potential electrodes.

2.4.5 Pole-dipole Array

This array is asymmetrical and results in asymmetrical apparent resistivity anomalies in the pseudo section for surveys over symmetrical structures. This kind of effect can be avoided by repeating the measurements with the electrodes reversed. The pole-dipole array has the higher signal rather than the dipole-dipole array. It is not as sensitive to noise as the pole-pole array because the distance between the potential electrodes is not large. The signal strength of the pole-dipole array is lower compared to the wenner and wenner-schlumberger arrays but higher than the dipole-dipole array.

2.4.6 High-Resolution Electrical Surveys with Overlapping Data Levels

This technique is done by using overlapping data levels with different combinations of a and n values for the wenner-schlumberger, dipole-dipole and pole-dipole arrays.

The electrical resistivity of soil varies between different soil parameter, soil types and depend on many factor that affecting the soil resistivity. The electrical resisitivity is determined by measuring the resistance between two point in the soil and this done by measuring the voltage across a pair of electrodes by transmitting a controlled DC or AC current (I) between two electrodes into the ground while measuring the potential (V) between two other electrodes. The field measurement of electrical resistivity is shown in figure 3.

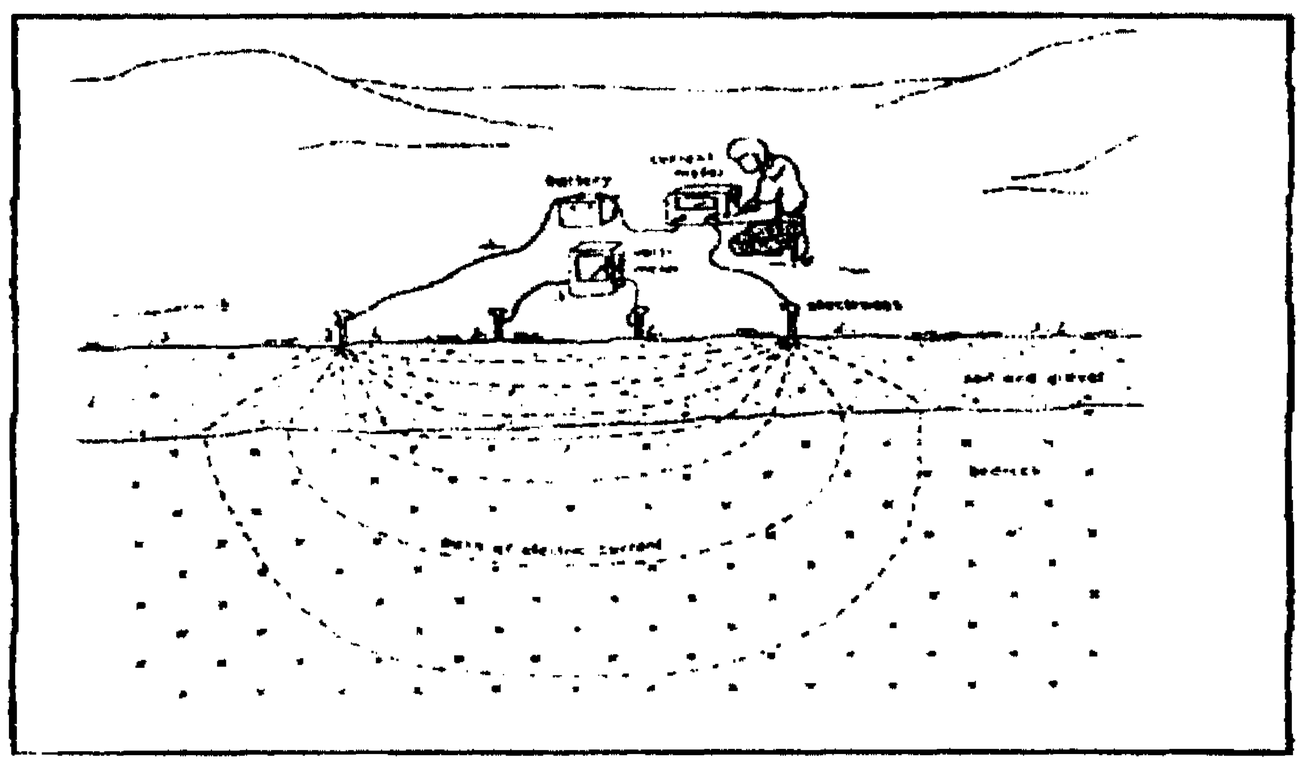


Figure 3. Principle set-up for direct current resistivity measurement

The resistance (R) is calculated using the Ohm's Law in (1)

$$R = V/I \tag{5}$$

Where V is the voltage and I is current.

The electrical resisitivity then can be measured as the following in (6).

$$P = 2\square R \tag{6}$$

Where □ is the distance between a pair of electrode and R is the resistance measured in (5).

The electrical resistivity method is one of the most useful techniques in Soil investigation because the resistivity of a rock and soil is very sensitive to its water content. In turn, the resistivity of water is very sensitive to its ionic content.

In general, it is able to determine the soil properties at the site and determine the mineralogy without need to wait for the sample to be sent to the lab for experiment and research.

Applications:

1. Water table depth.
2. Groundwater quality
3. Brine plumes.
4. Seawater intrusion
5. Well siting.
6. Aquifer exploration
7. General stratigraphic

mapping Advantages:

1. Less costly than drilling.
2. Non disturbing.

Disadvantages:

1. Cultural problems because interference, e.g., power lines, pipelines, buried casings, fences.
2. Resolution.

The geometrical factor for a cell is obtained from the calibration solutions of a known resistivity. The sample of soil is placed in a cell to measure electrical resistivity from the readings of voltage and current. The cell construction shown in figure 4 ensures the induction of static uniform electrical field in the cell. The field is imposed on homogenous soil sample to measure an accurate electrical resistivity of a sample.

The time variation and the different in electrical resistivity are less than 0.5% when measured in the same soil sample by the cells with different distances between electrodes. The measurements in four-electrode laboratory cell were utilized to develop the relationships between various soil properties and electrical resistivity as described by Pozdnyakov and Pozdnyakova (2002).

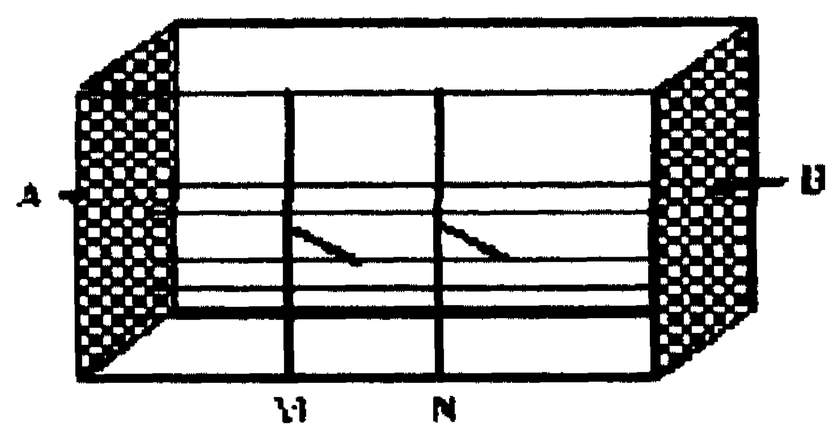


Figure 4. Scheme of the four-electrode laboratory conductivity cell. Electrical field lines are shown with thin straight lines (uniform electrical field).

2.5 Variation of Electrical Resistivity as a Function of Soil Properties

The electrical resistivity is a function of a number of soil properties, including the nature of the solid constituents (particle size distribution, mineralogy), arrangement of voids (porosity, pore size distribution, connectivity), degree of water saturation (water content), electrical resistivity of the fluid (solute concentration) and temperature.

The air medium is an insulator (i.e. infinitively resistive), the water solution resistivity is a function of the ionic concentration, and the resistivity of the solid grains is related to the electrical charges density at the surface of the

constituents. These parameters affect the electrical resistivity, but in different ways and to different extents. Electrical resistivity experiments have been performed to establish relationships between the electrical resistivity and each of these soil characteristics by Ary.buruan et al (2006).

2.5.1 Nature and arrangement of solid constituents

In the context of soil mapping, electrical resistivity exhibits a large range of values from 1 Ω m for saline soil to several 105 Ω m for dry soil overlaying crystalline rocks, Table 1 (Appendix). The electrical conductivity is related to the particle size by the electrical charge density at the surface of the solid constituents. In clay soil, the electrical charges located at the surface of the clay particles lead to greater electrical conductivity than in coarse-textured soils because of the magnitude of the specific surface (Fukue et al., 1999).

The electrical resistivity recorded by Giao et al. (2003) on 25 clay samples collected worldwide ranged from 1 to 12 Ω m. Lamotte et al. (1994) studied two cultivated sandy soils of very similar composition but significantly *different electrical resistivity: in the sandy soil showing the greatest resistivity,* few clay microaggregates were juxtaposed to the sand grains, while in the other soil the sand grains were coated and bridged by clay leading to a great continuity of the clay phase.

The geometry of the pores (void distribution and form) determines the proportion of air and water according to the water potential. Robain et al. (1996) linked resistivity variations with the structure of the pedological materials, identifying that high and low resistivity values were related to macro- and *mesoporosity, respectively. This enabled the detection of badger burrows and the* study of their network as demonstrated by Butler et al. (1994). This also enabled the study of the crack opening at the centimetric scale by Samouelian et al. (2003).

The porosity can be obtained for the electrical property via the Archie's law, which for a saturated soil without clay is written as :

$$F = \frac{r}{r_w} = a\phi^{-m} \tag{7}$$

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, r and rw are, respectively, the resistivity of the formation and the resistivity of the pore-water, f is the porosity. The factor F depends then on the pore geometry. Knowing the pore-water resistivity and the a and m constants the porosity can be calculated from the resistivity value. The calculated porosity should be considered as an "apparent" porosity values because Archie's law assumes that all the void space is filled with water excluding the possibility of the gas presence.

2.5.2 Water Content

Electrical current in soils is mainly electrolytic, i.e. based on the displacement of ions in porewater and is therefore greater with the presence of dissolved salts. Thus, electrical current in soils depends on the amount of water in the pores and on its quality. In most studies concerning the water content, the electrical conductivity of the solution is assumed to remain relatively constant to be neglected against its variation related to water content variation. Prior to field surveys, preliminary calibration of the volumetric water content related to the electrical resistivity is usually performed in the laboratory.

Fig. 2 shows examples of laboratory calibration between the electrical resistivity and the volumetric water content (McCarter, 1984; Michot et al., 2000; Fukue et al., 1999). The electrical resistivity decreases when the water content increases. It can also be seen that for water content <15%, the electrical resistivity rapidly decreases with increasing water content. The relationship between the electrical resistivity (or its reciprocal, the conductivity, expressed in Siemens/m noted mho/m) and the water content has firstly been studied by authors mainly in the field of petroleum research.

Archie (1942) proposed an empirical relationship based on laboratory measurements of clean sandstone samples. This relationship was a modified form of the previous equation (7) taking into account that the porosity can be filled by another medium as water, for example 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:

$$S^n = \frac{F\rho_w}{\rho} \tag{8}$$

by combining with the Eq. (6) we obtain :

$$S^n = \frac{a\rho_w}{\phi^m \rho} \tag{9}$$

where S is the saturation degree and n is a parameter related to the saturation degree. Eq. (9)was established to be valid for medium to coarse-grained soils. It assumes that the characteristic of the solid phase does not influence the electrical current conduction. Frohlich and Parke (1989) reported that the great practical success of Archie's law was related to the assumed validity of the determined constants on a large range of soils except for clayey soil.

Indeed, this relationship was successfully used for water content estimation in numerous studies (Binley et al., 2002; Zhou et al., 2001). An empirical linear relationship between the resistivity and the water content was proposed by Goyal et al. (1996) and Gupta and Hanks (1972) as follows:

$$\rho_{soil} = a - b\theta_{soil} \tag{10}$$

where a and b are empirical constants implicitly containing the soil and water characteristics (i.e. porosity, temperature, salinity) and assumed to be invariant with time. Temporal variations in the soil moisture profile are estimated by using

electrical resistivity sounding data acquired at different times (Aaltonen, 2001; Michot et al., 2003).

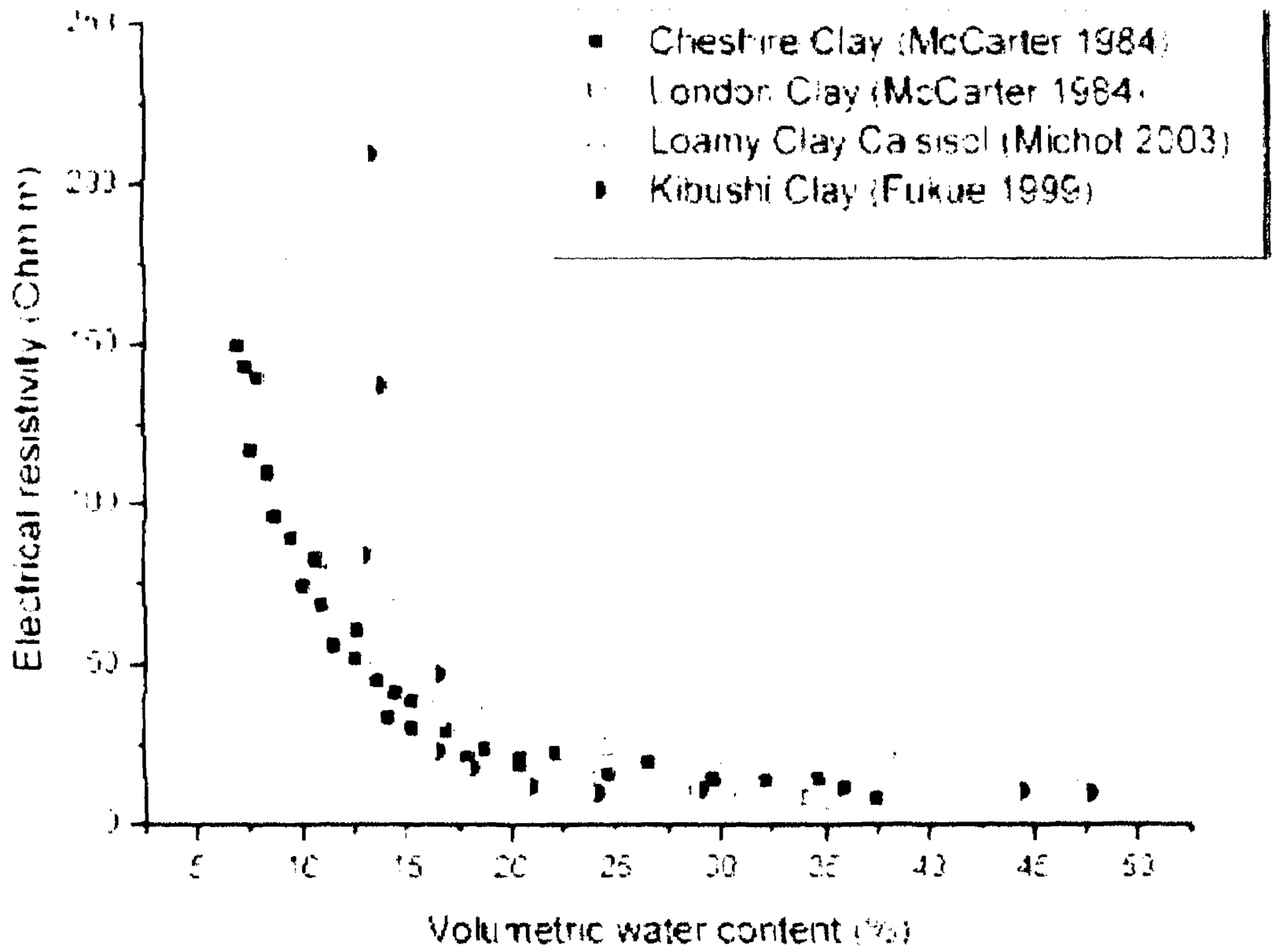


Figure 5. Relationship between the volumetric water content and the electrical resistivity for different soil types (values issues from Fukue et al., 1999; Michot et al., 2003; McCarter, 1984).

$$\frac{1}{\rho} = \frac{1}{\rho_w} a u^{b} + b u + \frac{1}{\rho_s} \tag{11}$$

where ρs and ρw represent the solid matrix and the pore-water resistivity, respectively, a and $b$are coefficients depending on the solid phase characteristics, related to the texture and mineralogy, and u is the volumetric water content (cm3 cm-3). By using Eq. (12), Kalinski and Kelly (1993) predicted the volumetric water content with a standard error of 0.009 for watercontents ranging from 0.20 to 0.50 in soil containing 20% clay.

2.5.3 Temperature

Electrical resistivity decreases when the temperature increases. Comparisons of electrical resistivity measurements require the expression of the electrical resistivity at a standardized temperature. By conducting laboratory experiments on 30 samples of saline and alkaline soils, Campbell et al. (1948) showed that conductivity increased by 2.02% per °C between 15 and 35°C.

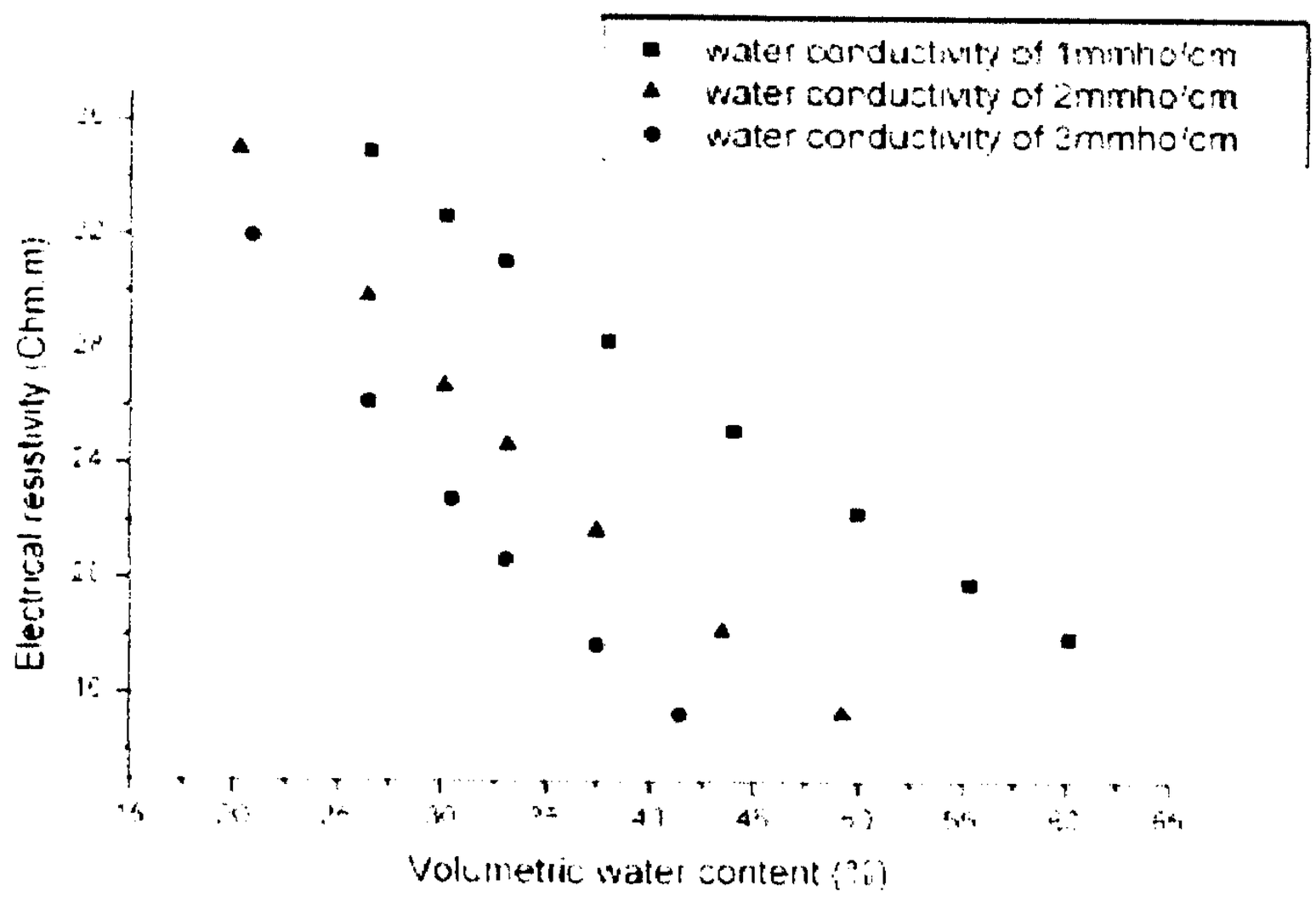


Figure 6. Relationship between the volumetric water content and resistivity for different values of pore-water conductivity. (values issues from Kalinski and Kelly, 1993).

Corrections can be then calculated to express the electrical conductivity at the standardized
temperature of 25 °C as follows :

$$\sigma_t = \sigma_{25°} [1 + \alpha (t - 25°C)] \quad (12)$$

where σt is the conductivity at the experiment temperature, σ25° the conductivity at 25 °C, and α is the correction factor equal to 2.02%. Colman and Hendrix (1949) discussed the validity of the Campbell's equation using 13 soils showing a wide range of texture. These results are in agreement with Campbell

and corresponded also to the references formula used to correct the temperature effect in the log interpretation chart of Schlumberg (1989). In soils, temperature variation during a year occurs at two temporal scales, day and season.

In studies where the temperature effect is not corrected, an assumption is made that temperature remains stable mostly because measurements are done every day at the same time over a short period (Bottraud et al., 1984b). At the annual scale, it is not possible to avoid the effect of temperature on electrical field resistivity measurements. Usually, the greatest resistivity values are recorded from September to November (in the Northern hemisphere), while the smallest resistivity values are recorded from June to July.

Aaltonen (2001) also reported that coarse grained materials presented a wider range in seasonal resistivity variation than clayey soil. Thus, knowledge of the seasonal variation of the temperature and its consequences on the electrical resistivity is essential to avoid misinterpretation of field measurements when comparing resistivity acquisition at the same place but on different dates.

2.6 Principal Factors Affecting Soil Resistivity

The factors chiefly affecting soil resistivity are:

2.6.1 Type of Soil

The soil composition can be: clay, gravel, loam, rock, sand, shale, silt, stones, etc. In many locations, soil can be quite homogenous, while other locations may be mixtures of these soil types in varying proportions. Very often, the soil composition is in layers or strata, and it is the resistance of the varying strata, especially at sub-soil level. Refer Table 2 (Appendix) for typical soil resistivity values.

2.6.2 Climate

Obviously, arid and good rainfall climates are at opposite extremes for conditions of soil resistivity.

2.6.3 Seasonal Conditions

The effects of heat, moisture, drought and frost can introduce wide variations in "normal" soil resistivity. Soil resistivity usually decreases with depth, and an increase of only a few percent of moisture content in a normally dry soil will markedly decrease soil resistivity. Conversely, soil temperatures below freezing greatly increase soil resistivity, requiring earth rods to be driven to even greater depths. See Table 3 (Appendix) for variations of soil resistivity with moisture content, and Table 4 (Appendix) for variations of soil resistivity with temperature.

2.6.4 Other Factors

Other soil properties conducive to low resistivity are chemical composition, soil ionisation, homogeneous grain size and even grain distribution - all of which have much to do with retention of soil moisture, as well as providing good conditions for a closely packed soil in good contact with the earth rod. In view of all the above factors, there is a large variation of soil resistivity between different soil types and moisture contents.

2.7 Recent Technological Improvements

Electrical resistivity prospecting has recently been improved with respect to measurement time. The improvement of computer-controlled multi-channel resistivity-meters using multi-electrode arrays has led to an important development of electrical imaging. Switching units allow any combination of four electrodes to be connected to the resistivity-meter at any time. The electrical data measurement is then fully automated and acquisition can be rapid (Binley et al., 1996).

These technological improvements in data acquisition allow efficient and complex arrays to be used, facilitating research that was inconceivable using manual methods in 2D and 3D electrical prospecting. Beside these 1D, 2D and 3D methods that allow the characterisation of electrical resistivity at different scales but on relatively few points, some specific experiments have been developed for surveys on large areas and with continuous measurements.

Hesse et al. (1986) introduced a new electrical device called the 'Résistivimètre Attelé à Enregistrement Automatique' ('RATEAU' the English equivalent terms is harrow), where the improvement in data capture time permits large scale soil prospecting (from 1 to 10 ha in a day).

The use of this device (Bourennane et al., 1998) allows the representation of the three-dimensional organization of the near surface materials, after interpreting the electrical resistivity data. Christensen and Sorensen (1998) introduced a "Pulled Array Continuous Electrical Profiling" (PACEP) for spatially dense measurements over large areas. In this case, the electrode array is towed across the field behind a small vehicle. Panissod et al. (1997a) used eight rolling electrodes corresponding to three depths of investigation (one pair of electrodes injects the current and three pairs record potential differences).

This system named Multidepth Continuous Electrical Profiling (MUCEP) is shown in Fig. 5. It can be towed by a tractor or a quad, the positioning of the data points being done by a differential GPS system and with an on-board Doppler radar system. If we consider geophysical techniques in soil mapping, the application of a mobile electrical quadripole allows a considerable increase in the size of potentially surveyed areas, whilst maintaining a high spatial resolution.

Figure 7. Multidepth Continuous Electrical Profiling (MUCEP)

2.8 Shear Box Test

The strength of a soil depends of its resistance to shearing stresses. It is made up of basically the components;

1. Frictional – due to friction between individual particles.
2. Cohesive - due to adhesion between the soil particles

The direct shear test is suited to the relatively rapid determination of the consolidated drained strength properties because the drainage path thought the test specimen are short, thereby allowing excess pore pressure to be dissipated more rapidly than with other drained stress test. The test results are applicable to assessing strength in a field situation where complete consolidation has occurred under the existing normal stress.

During the direct shear test, there is a rotation of the principal stress, which may or may not model field conditions. Moreover, failure may not occur on the weak plane since failure is forced to occur on or near a horizontal plane at the middle of the specimen. Shear stresses and displacements are non-uniformly distributed within the specimen and an appropriate height is not defined or calculating shear strains of any associated engineering quantity. The range in normal stress, rate of shearing, and general test conditions should be selected to approximate the specific soil conditions being investigate.

2.9 In-Situ Soil Sample

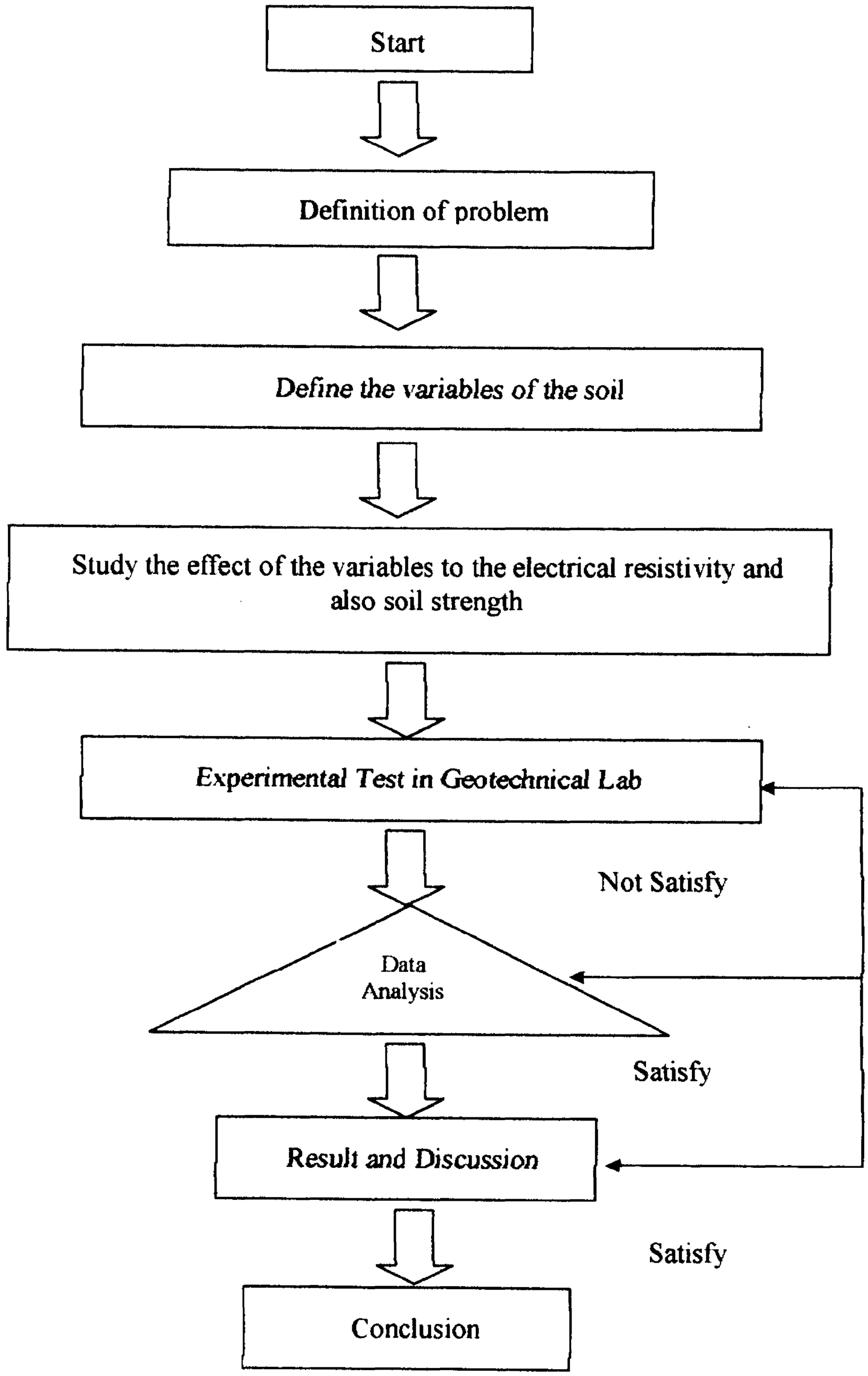
Samples obtained either for description or testing should be representative of the ground from which they are taken. They should be large enough to contain representative particle sizes, fabric, and fissuring and fracturing. They should be taken in such a way that they have not lost fractions of the *in situ* soil (for example, coarse or fine particles) and, where strength and compressibility tests are planned, they should be subject to as little disturbance as possible.

Generally, samples of two types are specified undisturbed and disturbed samples. Undisturbed samples are generally taken by cutting blocks of soil or rock, or by pushing or driving tubes into the ground. Disturbed samples are taken from cuttings produced by the drilling process. A large number of samplers and sampling methods are available, but before a suitable technique can be selected it is always necessary to consider whether the sample size will be adequate, and whether the most suitable method of sampling has been selected, to ensure that sample disturbance is sufficiently small.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology



3.2 Lab Method

Sand Box

For the lab method, the authors use sand box apparatus that has been designed to ease handling, save time, cost and give more accurate data. The sand box is designed by referring to the Wenner method. The Wenner method is suitable for horizontal structures such as sand box and also will give greater signal strength. Below is the specification of the sand box:

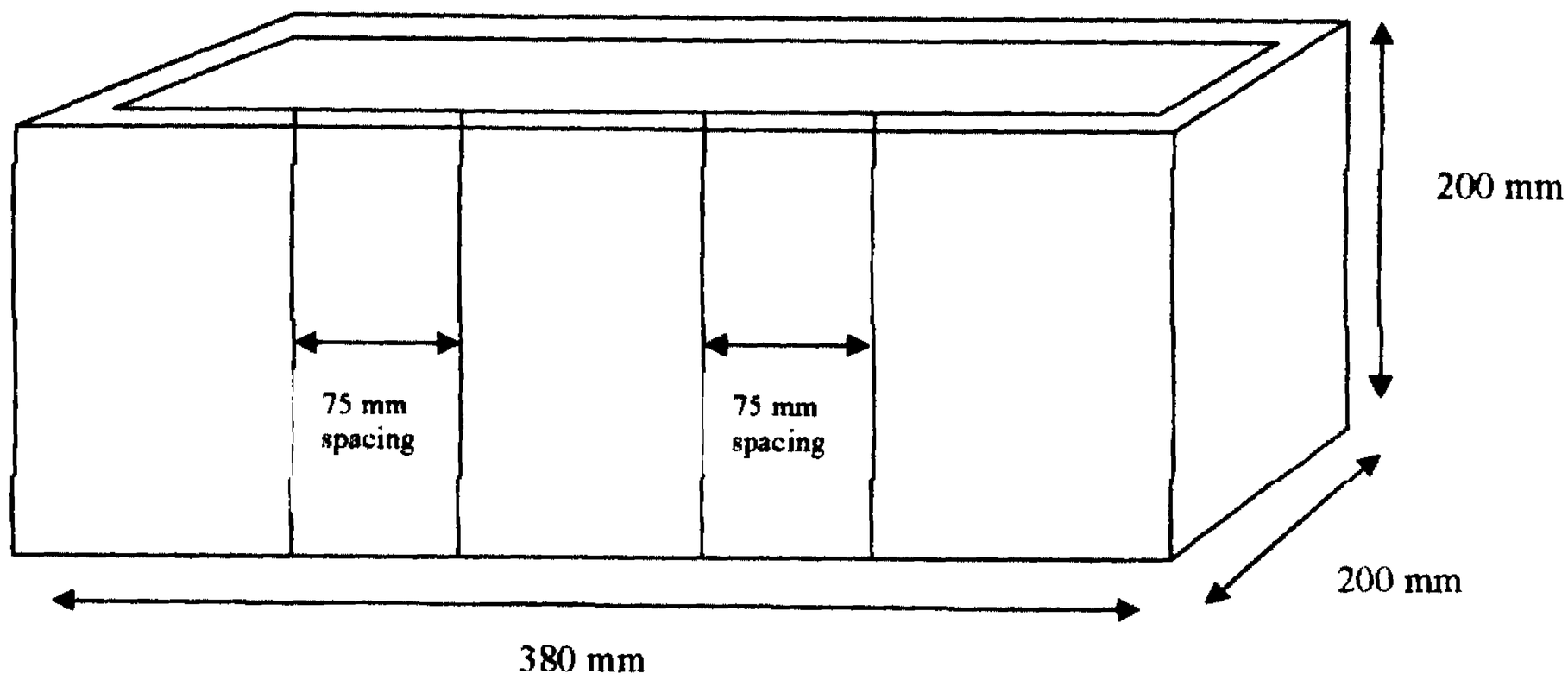


Figure 8. The designed sand box.

Using the Wenner's method, the sand box is set up and the sample is place inside the sand box. The voltage supply is set same for all trial and the I *(mA) is being measure using multimeter. There will be 2 multimeter used to* measure the I and V of the sample tested.

Test Conducted at The Lab

Test Category	Parameters	Description		
1	Organic Soil	Soil sample from various site		
		Swamp Soil	Palm oil Soil	Top Soil
2	Temperature	Different Soil Sample		
		80˚c	60˚c	40˚c
3	Mineralogy	Mineralogy sample with various mineral content		
		Kaolinite	Silicates	Brown Clay

Table 10. Test Category Conducted in Laboratory.

Authors have simplified the test that has been conducted in the geotechnical laboratory into 3 categories and can be referring to table 10 above.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Organic Soil

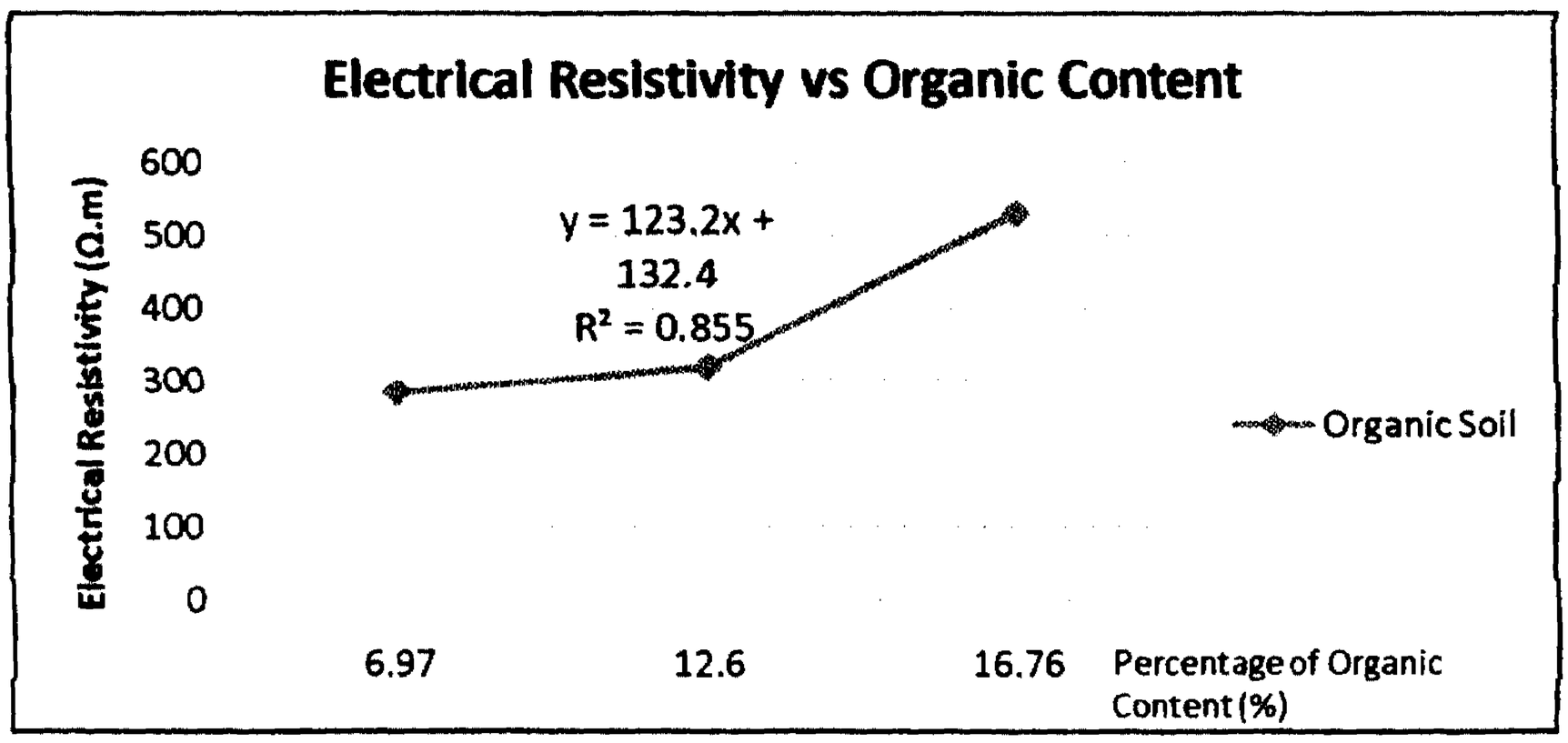


Figure 9. Electrical Resistivity versus Organic Content.

Figure 8 shows that soil that contain high percentage of organic content produce higher electrical resistivity. All three sample that being tested has been control its temperature, so that it will have the same temperature for all sample which is 27°c. The temperature will affect the electrical resistivity of the soil if not maintain throughout the experiment. Increasing the temperature increases the mobility of the ions and as a result, decreases the electrical resistivity of soil.

The soil sample moisture content is being set to 20% for all samples to make sure that the moisture content would not affect the electrical resistivity result of the soil sample. Since the entire variable has been the same for the entire soil sample, the result of electrical resistivity is based on the percentage of organic content.

The percentage of organic carbon in the soil sample indicates the physical properties of soil. The organic content in the soil increase the cation capacity (CEC) and water holding capacity of Sandy soil. Organic Content also contributes to the structural stability of clay soils. Organic carbon tends to be

trapped between clay particles. Soil with high clay content would probably have higher soil organic carbon than soil with low clay content under similar conditions.

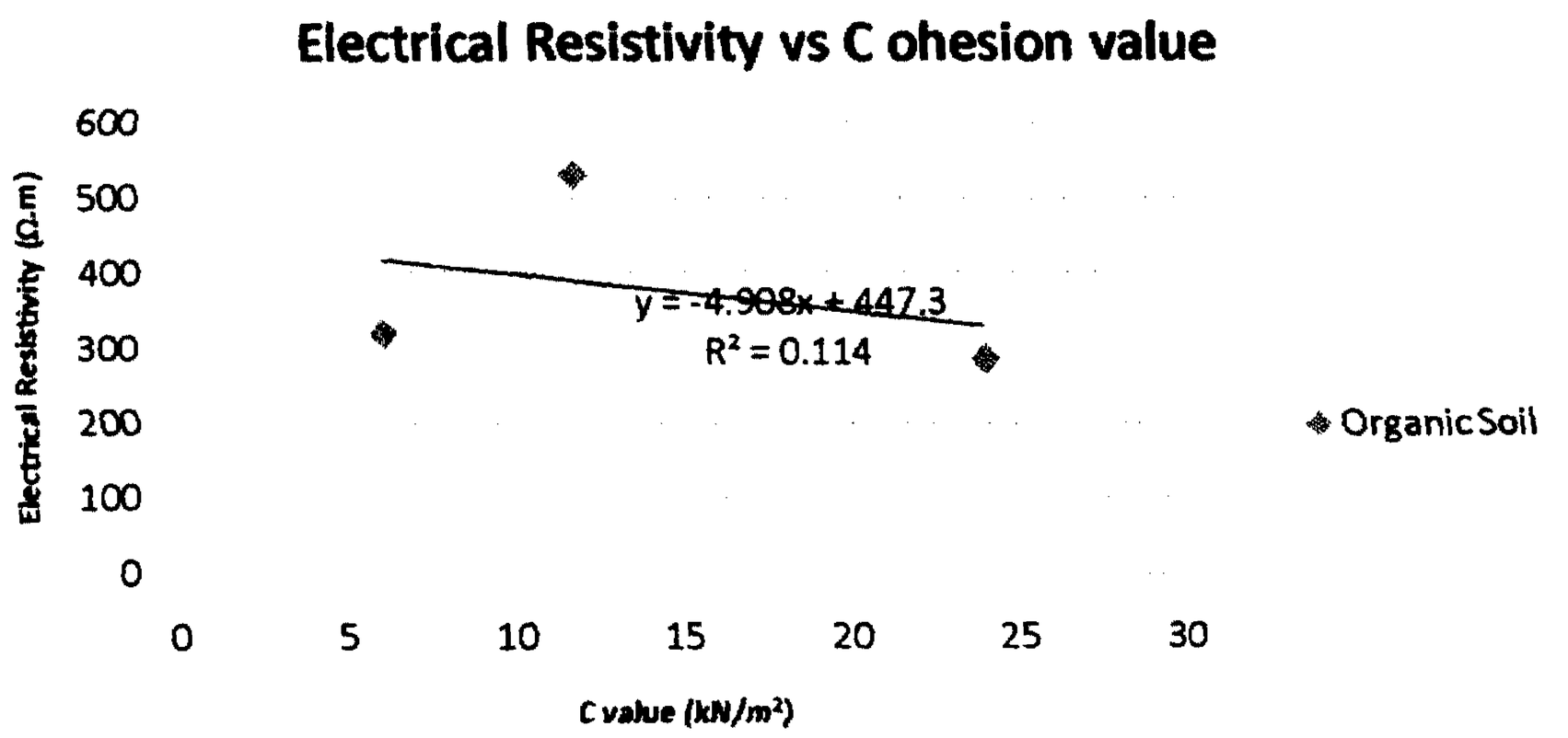


Figure 10. Electrical Resistivity versus Cohesion value.

Figure 10 shows that as cohesion increases, the electrical resistivity decreasing. It is indicates that higher organic soil strength is reduce the soil resistivity.

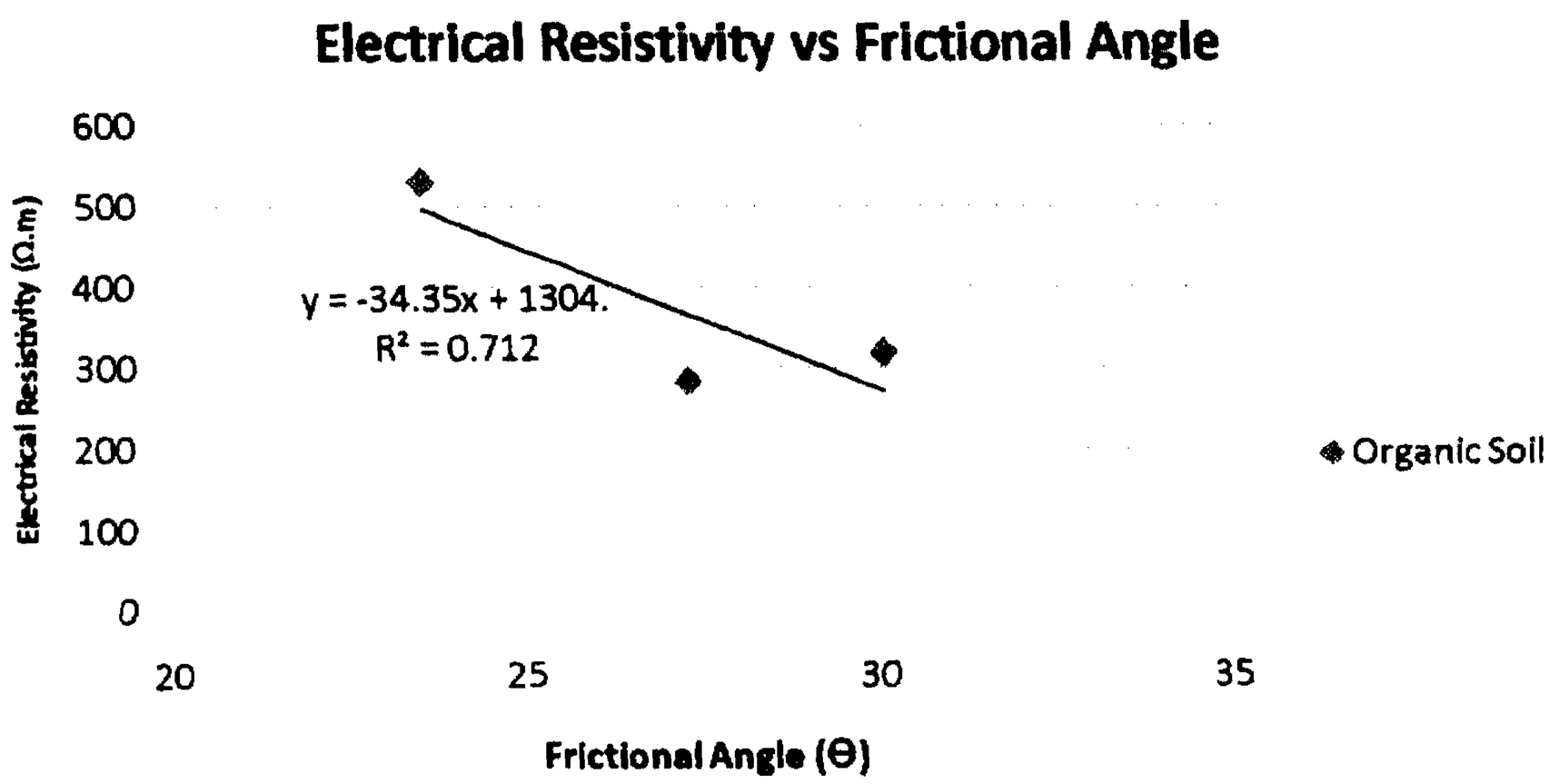


Figure 11. Electrical Resistivity versus Frictional Angle.

Figure 11 shows that the electrical resistivities reduce as frictional angle increase. It indicates that organic soil that has high frictional angle, has the higher ability to withstand the shear stress is reduce the electrical resistivity.

4.2 Different Temperature

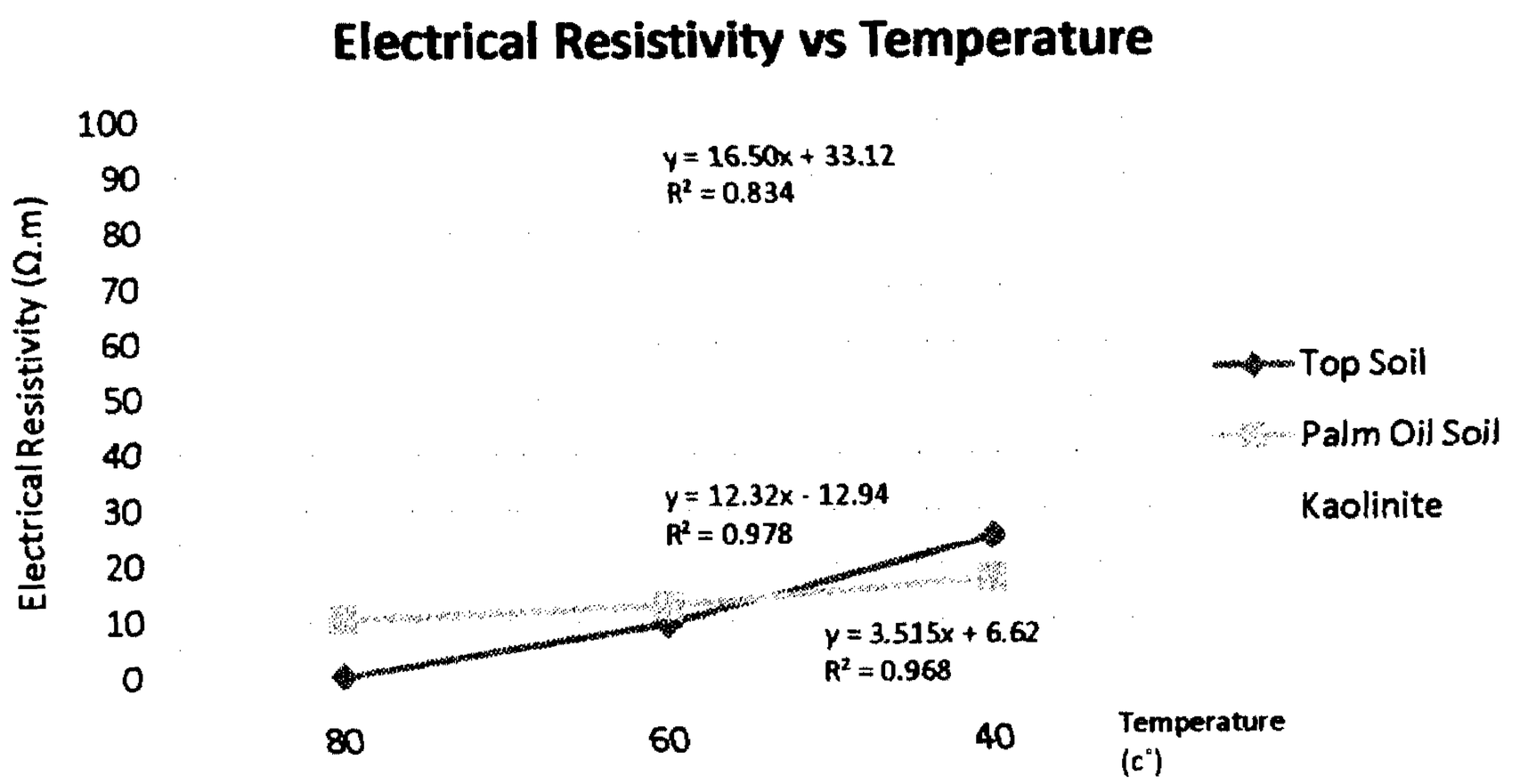


Figure 12. Electrical Resistivity versus Temperature.

Figure 12 shows that the electrical resistivity increases as the temperature reduces. Increasing the temperature, increasing the mobility of the ions and as a result decreases the electrical resistivity of soil. Increasing the temperature has caused in increasing electrolytic activity and reduces the conductivity of ions to be transferred.

4.3 Mineralogy Sample

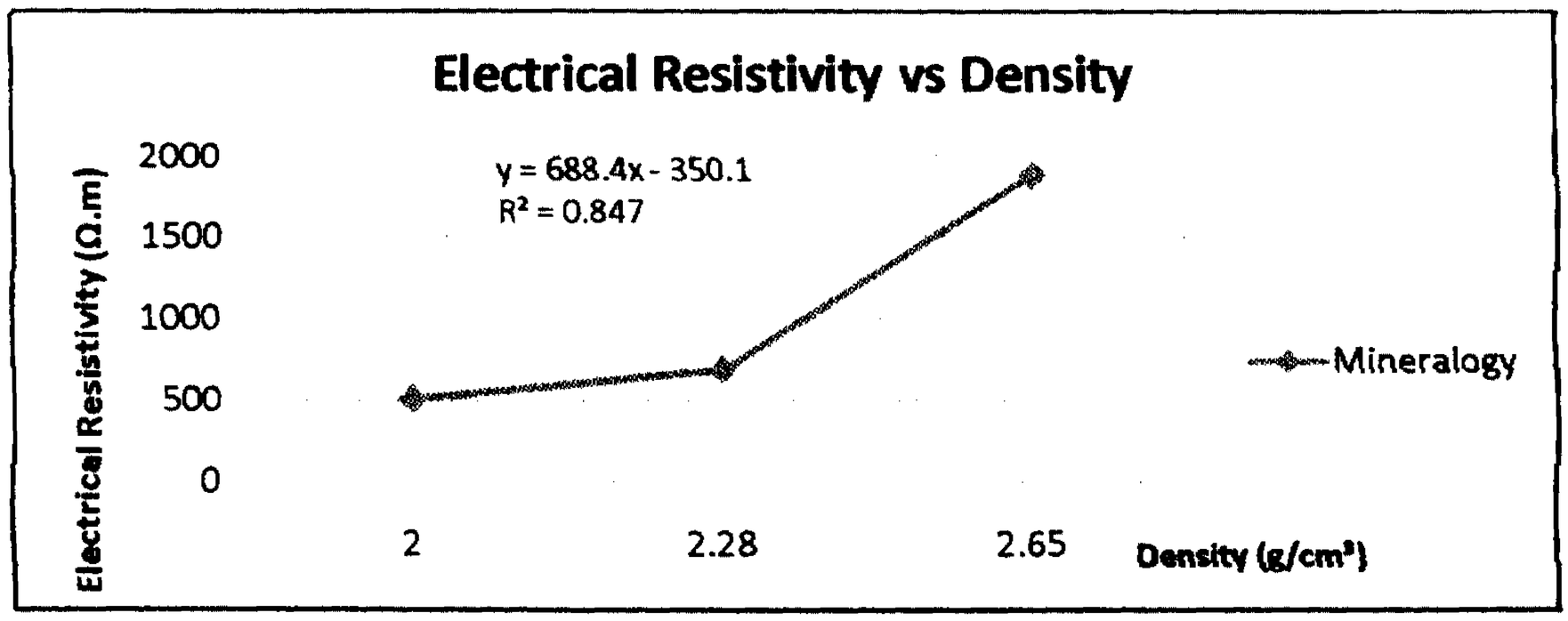


Figure 13. Electrical Resistivity versus Density.

Figure 13 show that as density of different type of mineral increases, the electrical resistivity also increase. The density of the sample shows in table 9 (appendix) indicates that kaolinite has highest density and produce highest electrical resistivity. Soil with high clay content has higher porosity than sandier soil. High density sample has low porosity, thus enhance the solid particle passes more electrical resistivity. The low porosity relatively improved the contact point between larger and small particle sample together. The percentage of mineral contain in the sample also affect the electrical resistivity because sample contain higher amount of mineralogy in the sample will have higher electrical resistivity as the kaolinites sample has highest kaolinite percentage in the sample that is 85% is produce high electrical resistivity compare to brown clay that contain 65% kaolinite mineral in the sample.

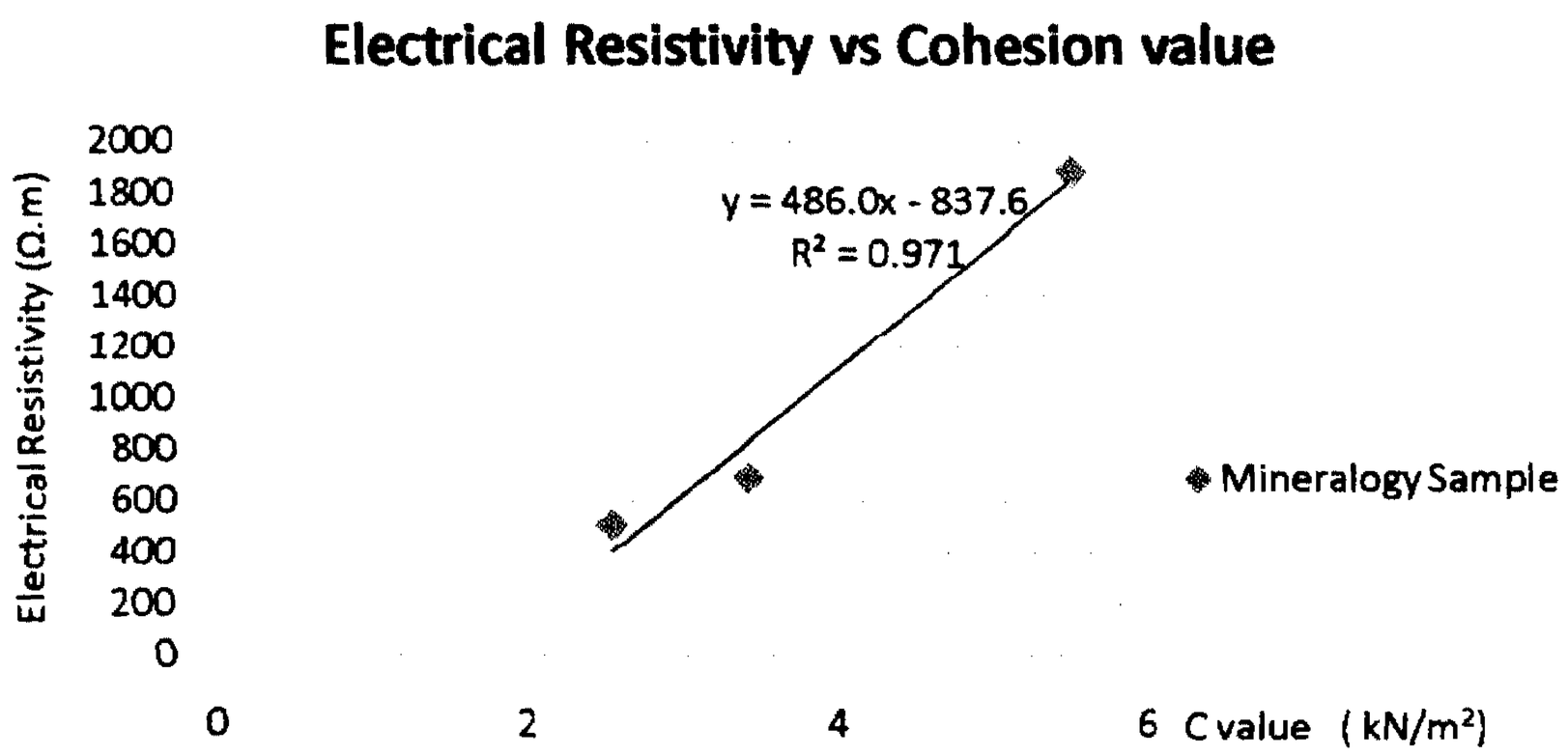


Figure 14. Electrical Resistivity versus Cohesion value.

Figure 14 show that as the increase in soil strength (c) , electrical resistivity also increase. It is indicates that mineral that has higher soil strength produce higher electrical resistivity than mineral that has low soil strength.

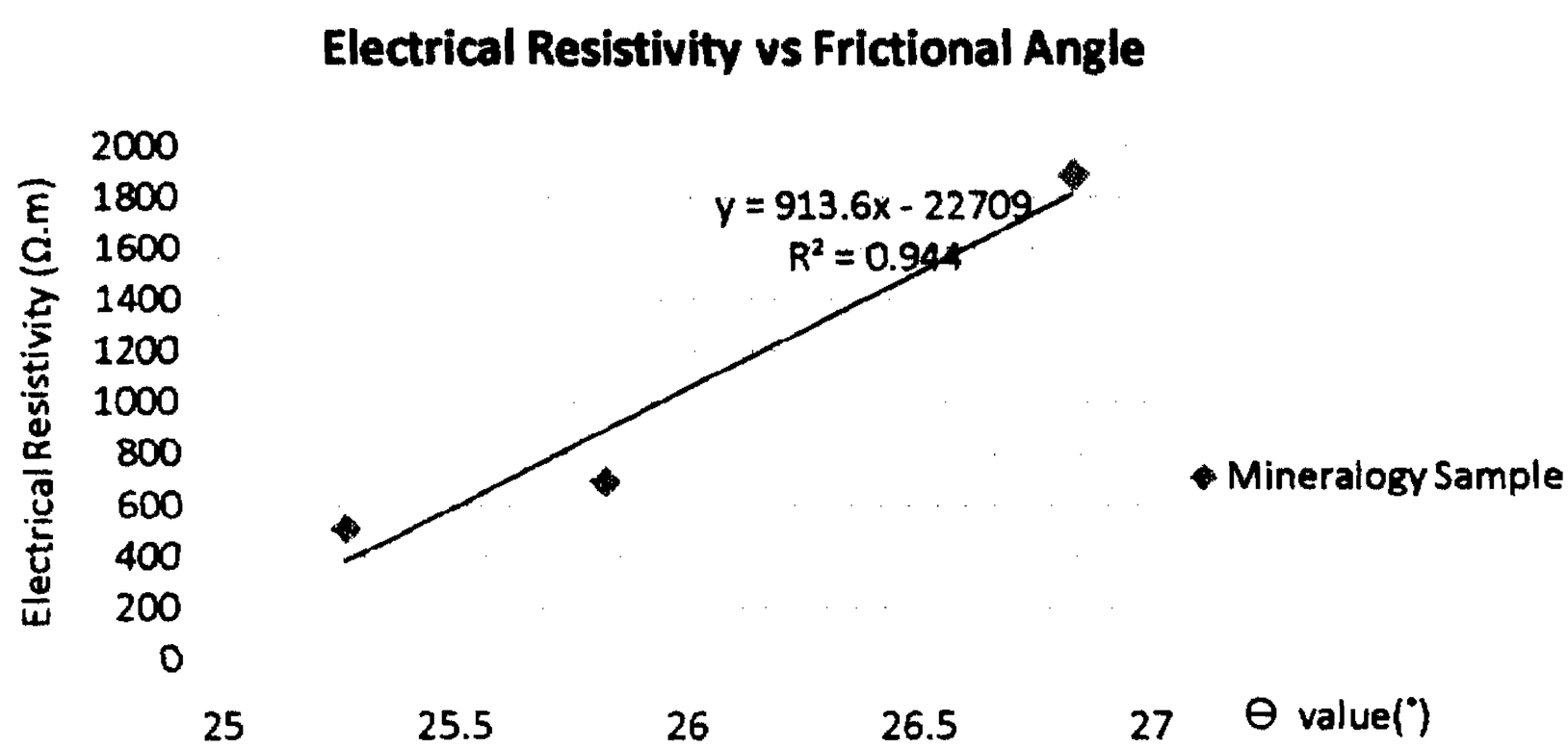


Figure 15. Electrical Resistivity versus Frictional Angle.

Figure 15 show that high mineral frictional angle produce high electrical resistivity. It indicates that mineral sample that has higher ability to withstand shear stress is producing higher electrical resistivity.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Conclusion

Parameters	Electrical Resistivity	Cohesion Value	Frictional Angle
Organic Content, ↑	ρ, ↑	c,↓	Θ ,↓
Temperature, ↑	ρ, ↓	-	-
Mineralogy, ↑	ρ, ↑	c,↑	Θ ,↑

Table 11. Correlation of Electrical Resistivity with Soil Parameters

The objective of the project has been achieved. The above results are the possible preliminary crude correlation between resistivity and some soil parameters with various soil conditions. As organic content increses, electrical resistivity also increses. Electrical resistivity decreses as temperature increses. Higher mineralogy content increses the electrical resistivity.

Recommendation

More detailed research need to be done to enhance result and to have more detailed correlation. The research need to be done with many different type of soil to get more accurate data.

CHAPTER 6
ECONOMIC BENEFITS

6.1 Equipment cost for project

Electrical Resistivity requirement the experimenter to use a lot of equipment in order to run the experiment. Most of the equipment that is needed for the experiment is founded or prepared by the University Technology of PETRONAS Geotechnical Lab. All the equipment for the experiment used by the final year project student is free and did not require the student to pay in order to use the equipment. Below is the list of equipment used for the project:

Equipment	Function
1. Mixer	Mixing the sample
2. Thermometer	Measure the temperature of the sample
3. Shear Box	Determine the sample shear force
4. Multimeter	Determine the Volt (V) and Amp (A)
5. DC power Supply	Supply the required Volt
6. Oven	Maintain the expected soil temperature

Table 12. List of Equipment

All the equipment is been using under supervision of the lab technician. The experiment for electrical resistivity is more to lab experiment and not require and software in order to get the result. The result from the experiment is been used to calculate the electrical resistivity.

6.2 Material for the project

Material of the project for the electrical resistivity is collected from many resources. Material like Organic Soil are collected fresh from the site, the sample is not purchased in order to avoid the sample from being mix with other soil sample and thus has disturb the soil sample. Mineralogy sample is complicated

because its require some of the sample to be purchased and other sample is getting from collaboration with Ipoh Mineralogy Research Department (IMRD) in order to get the mineralogy sample.

The Kaolinites and Silicates sample is get from IMRD and it is not require the author to buy it. Brown Clay sample which contain kaolinites mineralogy has been buy from Kaolin Sdn Bhd. The cost for the Brown Clay as below:

Brown Clay = RM 1/ kg
Used sample = 15kg
Total cost = RM 15.00

Electrical Resistivity experiment require sand box which has been fabricated by the author and the cost for the fabricated sand box and 4 rod is RM 50.00. Total cost for the project is RM 15.00 + RM 50.00 = RM 65.00.

6.3 Project Benefits

The project that has been done will bring benefit in term of creating a new formula to determine the factor of safety (FOS) for slope stability. Malaysia is well known having a land slide every year. With this project, the electrical resistivity can be found straight at the site and can proceed with the designing faster after all the soil parameters at the site have been found.

REFERENCES

1. Zeyad S.Abu-Hassanein, Craig H.Benson and Lisa R. Blotz, (1996) "Electrical Resistivity of Compacted Clays"
2. R.J.Kalinski, Member ASCE and W.E.Kelly (1994) " Electrical-Resistivity Measurements for Evaluating Compacted Soil Liners"
3. William E. Kelly, M.ASCE (1985) " Electrical Resistivity for Estimating Ground Water Recharge"
4. Rosemary Knight (1991) "Hysteresis in The Electrical Resistivity of Partially Saturated Sandstones"
5. Andrew Binley, Siobhan Henry-Poulter and Ben Shaw (1996) " Examination of solute transport in an undisturbed soil column using electrical resistance tomography"
6. G.Keller and Friskhknecht (1996) "Elctrical Method in Geophysical Prospecting"
7. D.Huntley (1986) " Relationship Between Permeability and Electrical Resistivity in Granular Aquifers"
8. P.Jackson (1975) "An Electrical Resistivity Method for Evaluating the in-situ Porosity of Clean Marine Sands"
9. A. Samouelian a,b,*, I. Cousin a, A. Tabbagh c, A. Bruand d, G. Richard e (2006) "Electrical resistivity survey in soil science: a review"
10. Syed Baharom Syed Osman, Zuhar Zahir Tuan Harith (2007) "Correlation of Electrical Resistivity with Some Soil Properties in Predicting Factor of Safety in Slopes using Simple Multimeter"
11. Pozdnyakov Anatoly and Pozdnyakova Larisa (2002) "Electrical Field and Soil Properties"
12. Kalinskl, R.J &Kelly, W.E (1993) "Estimating Water Content of Soils from Electrical Resistivity"
13. Ronald, A.E & Ronald C.G (1982) "Electrical Resistivity used to measure Liquefaction of Sand"
14. Frochlich, R.k and Parke C.D (1989) "The Electrical Resistivity of the vadose zone-field study"

15. Rhodes, J. Raats P andPrather R (1976) "Effect of Liquid Phase Electrical Conductivity, Water Content and Surface Conductivity on Bulk Soil Electrical Conductivity"
16. Sadek M (1993) "A Comperative Study of the Electrical and Hydraulics conductivities of compacted clays"
17. W.A. Ramirez, D.LaBrecque and J Nitao (1992) "Electrical Resistance Tomography of Vadose Water Movement"

APPENDIX

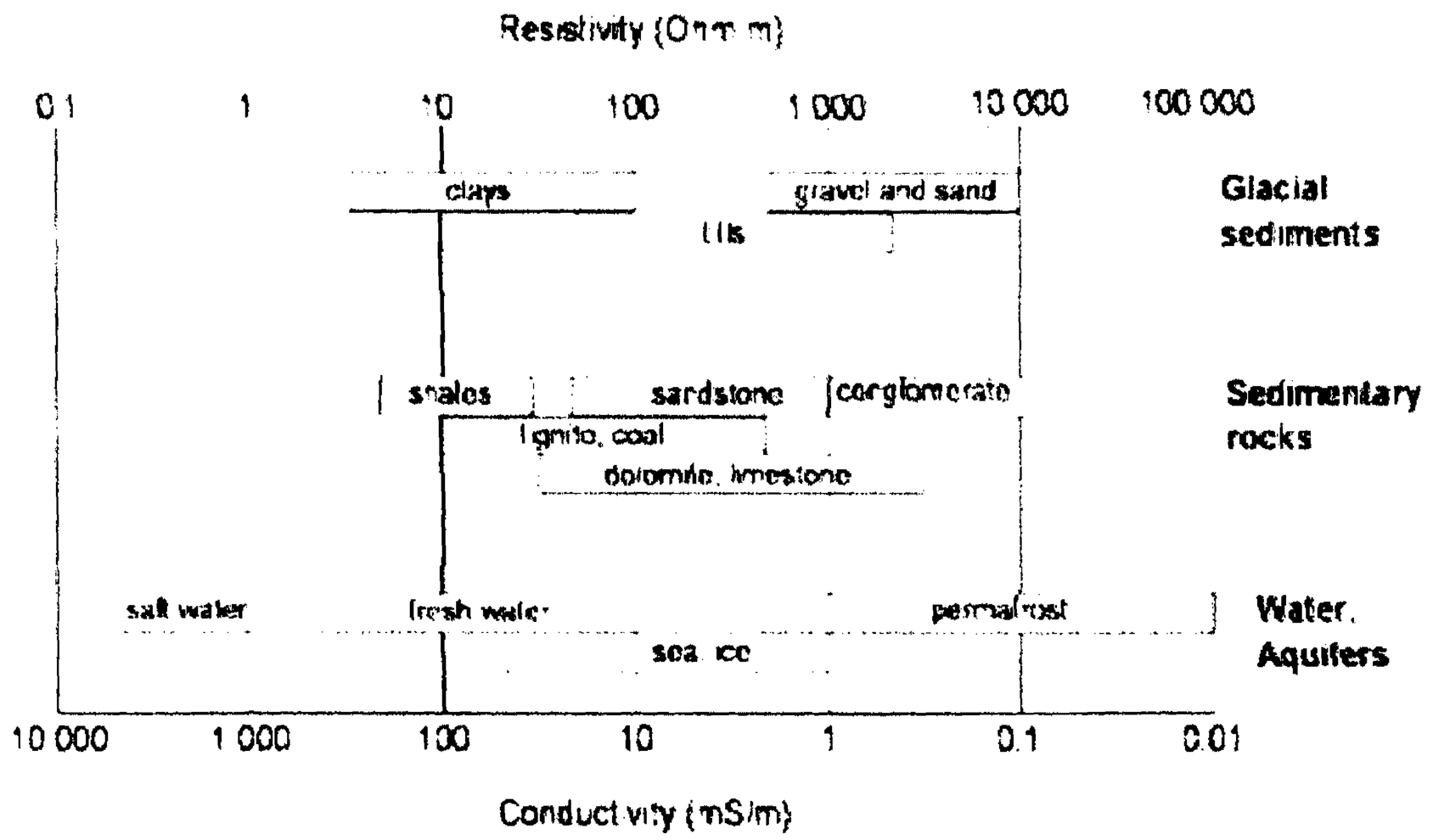


Table 1.Typical ranges of electrical resistivities of earth materials (after modified Palacky,1987)

Type of Soil or Water	Typical Resistivity Ω^T	Usual Limit Ω^T
Sea Water	2	0.1 to 10
Clay	40	8 to 70
Ground well and spring water	50	10 to 150
Clay and sand mixtures	100	4 to 300
Shale, slates, sandstone, etc.	120	10 to 1000
Peat, loam and mud	150	5 to 250
Lake and brook water	250	100 to 400
Sand	2000	200 to 3000
Morane gravel	3000	40 to 10000
Ridge gravel	15000	3000 to 30000
Solid granite	25000	10000 to 50000
Ice	100000	10000 to 100000

Table 2. Resistivity Values for Several Types of Soils and Waters

Moisture Content	Typical Value of Resistivity Ω^m	
% of Weight	Clay mixed with sand	Sand
0	10,000,000	-
2.5	1,500	3,000,000
5	430	50,000
10	185	2,100
15	105	630
20	63	290
30	42	-

Table 3. Variations of Soil Resistivity with Moisture Content

Temp. C	Typical Value of Resistivity Ω^m
20	72
10	99
0 (water)	138
0 (ice)	300
-5	790
-15	3,300

Table 4. Variation of Resistivity with Temperature in a Mix of Sand and Clay with a Moisture Content of about 15% by Weight.

Organic Soil

	V	ΔV	I(A)	Percentage of Moisture Content (%)	Resistance (Ω)	C value (kN/m²)	Θ value(°)	Electrical Resistivity (Ω.m)
Swamp Soil	30	6.076	0.0032	20	1899	24.03	27.29	284.85
Palm Oil Soil	30	5.767	0.0027	20	2136	6.106	30.03	320.4
Top Soil	30	6.375	0.0018	20	3542	11.75	23.51	531.3

Table 5. Electrical Resistivity for different type of organic soil.

Soil Sample	Percentage of Organic Carbon (%)
Swamp Soil	6.97
Palm Oil Soil	12.60
Top Soil	16.76

Table 6. Percentage of Organic Carbon for different type of organic soil.

Temperature

	Temperature °c	V	ΔV	I(A)	Percentage of moiture content(%)	Resistance (Ω)	Electrical Resistivity (Ω.m)
Top Soil	80	30	0.004	0.0014	0	2.857	0.43
	60	30	0.096	0.0015	0	64.00	9.60
	40	30	0.234	0.0014	0	167.143	25.07
Palm Oil Soil	80	30	0.084	0.0012	0	70.00	10.50
	60	30	0.112	0.0013	0	86.154	12.92
	40	30	0.187	0.0016	0	116.875	17.53
Kaolinite	80	30	0.395	0.0011	0	359.10	53.87
	60	30	0.538	0.0014	0	384.286	57.64
	40	30	0.695	0.0012	0	579.167	86.88

Table 7. Electrical Resistivity for different temperature

Mineralogy

	ΔV	I(A)	Percentage of Moisture Content (%)	Resistance (Ω)	C value (kN/m²)	Θ value(°)	Electrical Resistivity (Ω.m)
Kaolinite	40.193	0.0032	20	12560.31	5.513	26.84	1884.05
Silicates	58.839	0.0128	20	4596.797	3.433	25.83	689.52
Brown Clay	48.003	0.0142	20	3380.493	2.561	25.27	507.07

Table 8. Electrical Resistivity for different type of Mineralogy.

Type of Mineralogy	Density (g/cm³)
Kaolinite	2.65
Silicates	2.28
Brown Clay	2.00

Table 9. Density of different Mineralogy.