CORRELATION BETWEEN SPT, MACKINTOSH PROBE AND 2-D RESISTIVITY VALUES FOR SOILS STIFFNESS

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CORRELATION BETWEEN SPT, MACKINTOSH PROBE AND 2-D RESISTIVITY VALUES FOR SOILS STIFFNESS

by

TARMIZI

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LIST OF SYMBOLS

A	Area
I	Current
k	Geometric factor
km	Kilometer
ℓ	Length
m	Meter
R	Resistance
V	Voltage
x	Distance
Ωm	Ohm-meter
ρ	Resistivity
ρ_a	Apparent resistivity
ΔV	Potential difference
>	More than
<	Less than

LIST OF ABBREVIATIONS

BH	Borehole
C	Current electrode
CPT	Cone Penetration Test
ERT	Electrical Resistivity Tomography
ES	Electrode Selector
LB	Lembah Bujang
M	M-value
MP	Mackintosh Probe
N	N-value
P	Potential electrode
RMS	Root Mean Square
SAS	Signal Averaging System
SB	Sungai Batu
SPT	Standard penetration test
USM	University Sains Malaysia
Z	Depth
2-D	Two Dimension
3-D	Three Dimension

KORELASI ANTARA NILAI SPT, MACKINTOSH PROBE DAN KEBERINTANGAN 2-D UNTUK KETEKALAN TANIH

ABSTRAK

Kajian menggunakan kaedah geofizik dan geoteknik telah dijalankan untuk mengkaji ketekalan tanih di USM, Pulau Pinang dengan kawasan granit terluluhawa dan Sungai Batu, Kedah (Malaysia) dengan kawasan sedimen. Kaedah geofizik yang digunakan adalah kaedah pengimejal keberintangan 2-D, sementara kaedah geoteknik digunakan adalah kaedah mackintosh probe dan lubang bor. Terdapat 8 garisan tinjauan keberintangan 2-D, 5 titik mackintosh probe dan 5 lubang bor telah dijalankan pada dua kawasan tersebut. Data keberintangan 2-D diproses menggunakan perisian RES2DINV dan Surfer8. Objektif kajian ini adalah untuk mengetahui ciri-ciri tanih, untuk perbandingan nilai-M dengan nilai keberintangan 2-D dan untuk mengembangkan jadual nilai-N, nilai-M dan nilai keberintangan 2-D yang mempunyai hubungan untuk parameter tanih pada kawasan granit terluluhawa dan sedimen. Model penyongsangan keberintangan 2-D menunjukkan USM, Pulau Pinang memiliki nilai keberintangan 0-1600 Ωm dengan kedalaman 10 m dan Sungai Batu, Kedah memiliki nilai keberintangan 0-2000 Ωm dengan kedalaman 40 m. Hubungkait antara data kerintangan 2-D dengan data mackintosh probe dan lubang bor menyediakan jenis dan kekuatan tanih untuk kawasan USM, Pulau Pinang dengan kawasan granit terluluhawa menunjukkan dua jenis tanah lembut; pertama tanih berpasir longgar dengan nilai-N adalah 8 dan nilai-M adalah 170 yang mempunyai nilai keberintangan adalah 790 Ωm dan yang kedua kelodak berpasir keras dengan nilai-N adalah 9-11 dan nilai-M adalah 135-270 yang mempunyai nilai keberintangan adalah 415-785 Ωm. Sementara untuk Sungai Batu dengan kawasan pemendapan menunjukkan jenis tanih lempung berpasir/lempung yang bersifat setengah keras, keras dan sangat keras. Sifat setengah keras

dengan nilai-N adalah 6-7 dan nilai-M adalah 7-117 dengan nilai keberintangan adalah 4.5-12.9 Ωm, sementara sifat keras dengan nilai-N adalah 8-13 dan nilai-M adalah 73-130 dengan nilai keberintangan adalah 4.7-51 Ωm dan sifat sangat keras dengan nilai-N adalah 14-20 dan nilai-M adalah 224-360 dengan nilai keberintangan 20-205 Ωm.

CORRELATION BETWEEN SPT, MACKINTOSH PROBE AND 2-D RESISTIVITY VALUES FOR SOILS STIFFNESS

ABSTRACT

Study using geophysical and geotechnical methods were conducted to study soils stiffness at USM, Pulau Pinang with weathered granite and Sungai Batu, Kedah (Malaysia) with sedimentary areas. Geophysical method applied was 2-D resistivity imaging while geotechnical methods applied were mackintosh probe and borehole. A total of 8 2-D resistivity survey lines, 5 points of mackintosh probe and 5 boreholes were established. The 2-D resistivity data were processed using RES2DINV and Surfer 8 softwares. The objectives of this study are to characterize soils, to compare M-value and resistivity values and to develop N-value, M-value and resistivity values related to soil parameter for weathered granite and sedimentary area. The 2-D resistivity inversion model shows that the resistivity value of the USM, Pulau Pinang area is 0-1600 Ωm with penetration depth of 10 m. Sungai Batu area shows resistivity value of 0-2000 Ωm with penetration depth of 40 m. The integration of 2-D resistivity data with mackintosh probe and borehole data provide two soil types and stiffness of weathered granite at USM, Pulau Pinang area; first soil type is loose sand with N-value of 8 and M-value of 170 with resistivity value of 790 Ωm and the second type is stiff sandy silt with N-value of 9-11 and M-value of 135-270 and resistivity value of 415-785 Ωm. While at Sungai Batu with sedimentary area shows that soil of this survey area is classified as sandy clay/clay with medium stiff, stiff and very stiff condition. The medium stiff soil shows N-value of 6-7, M-value of 7-117 and resistivity value of 4.5-12.9 Ωm, while stiff soil gives the N-value of 8-13,

M-value of 73-130 and resistivity value of 4.7-51 Ωm. Lastly, the very stiff soil has the N-value of 14-20, M-value of 224-360 and resistivity value of 20-205 Ωm.

CHAPTER 1

INRODUCTION

1.0 Background

Malaysia is a developing country with rapid developments in infrastructures such as houses, buildings, roads, bridges, highways, rail tracks, waste water system and many other types of public facilities. Infrastructures become a part of our lives and the investigation of the surrounding environment and economic value are crucial. Development techniques for infrastructures must be kept at sustainable and affordable rates. Engineering design plays an important role since most building structures lie on ground and the load has to be supported by the ground safely upon construction. Subsurface information is very important for engineering design to provide knowledge about soil profile such as slopes stability, material inhomogeneities, subsurface boundaries and other properties of materials (Robert, 2000).

Soil is made up of many compositions such as weathered rock particles, decayed plant and animal matters. Soil was formed slowly from rocks (the parent material) which eroded into tiny pieces near the Earth's surface. Soil formation takes thousands of years to make a thin layer of soil. Every type of soil has different characteristics like colour, texture, structure, mineral content and the depth variation (Grim, 1953). Sand is a naturally occurring granular material composed of finely divided rock and mineral particles. It is defined by size, being finer than gravel and coarser than silt (Ottawa, 1976). Clay is a fine-grained natural rock or soil material that is a combination of one or more clay minerals with traces of metal oxides and organic matter. Clays are plastic due to their water content and harden, but brittle and non–plastic upon drying or firing (Guggenheim and Martin, 1995).

In engineering construction, soil problems often occur during or after construction. These problems happen as the soil cannot reach a required specification such as bearing capacity to support super structure above it. The existing soils at a construction site are not always totally suitable to support structures such as buildings, bridges, highways, and dams. Hence, if the building is constructed on poor soil, many problems will occur during and after the construction. The building will crack because of the settlement of the soil. Therefore, before such contraction are developed there is the need to understand the subsurface. Various technique can be used for detailed study of the subsurface such as drilling, pit test, geophysical methods and more. Nowadays, geophysical methods are well known and applied worldwide to provide useful and cost-effective information about subsurface features of interest at required level of spatial resolution and target definition. The methods are designed to measure specific parameters, with spatial variation within the study area of interest.

Geophysical methods have been used since nearly 70 years ago and they were predominantly applied in exploration for natural resources (Sirles, 2006). The application in near surface studies for engineering purposes such as groundwater exploration, environmental, geotechnical, and archaeological studies is progressively increasing. The information obtained from geophysical investigation is used to determine the important information such as hydrostatigraphic framework, depth to bedrock, extent of concentrated groundwater contaminant plumes, location of voids, faults or fractures, and the presence of buried materials, such as steels, drums or tanks (Julian et al., 2012). The common methods employed for engineering and environmental studies include seismic refraction, seismic reflection, multichannel analysis of surface waves (MASW), Refraction Micro-Tremor (ReMi), cross-hole seismic tomography, Ground Penetrating Radar (GPR), Electromagnetic (EM), electrical resistivity, Induced Polarization (IP), Self Potential (SP), gravity and magnetic surveys (Anderson, 2006; Wightman et al., 2004).

This study is focusing on 2-D resistivity method for investigating subsurface geological structure of soft soil. The 2-D resistivity is yet another powerful geophysical method which uses electrical current that is sent through the ground by a pair of current electrodes (C_1 and C_2) and measures the potential difference (ΔV) between potential electrodes (P_1 and P_2) which is used to calculate apparent resistivity (ρ_a) (Loke, 1999). This method is frequently used in evaluation of aquifers, wells and plumes, environmental aspects of landfills, detection of voids and boulders, locating fractures/weak zones and determination of depth to bedrock (Azwin, 2011).

1.1 Problem statements

The use of geophysical method by geotechnical engineers have been increasing all over the world suitability to study soils properties. 2-D resistivity method offers a non-destructive and a cost effective way of performing measurements of geotechnical properties. The principle of 2-D resistivity method was based on current flow in the subsurface profile by representing the resistivity of soil material. Howevwe, it is impossible to extract the soil parameters by judging from soil resistivity alone. The resistivity of soil differs depending on the soil type, mineralogy of the soil, particle size distribution, index properties, unit weight, porosity, degree of saturation and other parameters. Proper understanding on how resistivity causes variation of these parameters can be helpful for development of the correlations.

However, 2-D resistivity provides information of subsurface and the resulting model of 2-D resistivity can provide accurate estimation of depth, thickness and electrical resistivity of subsurface layers. Limited studies have been conducted to obtain geotechnical parameters using 2-D resistivity method. Quantification of geotechnical properties has become an important issue for rigorous use of resistivity values in engineering applications.

The correlation of different geotechnical properties (SPT and Mackintosh probe) with 2-D resistivity method will close the gap that currently exists between geophysical and geotechnical engineering methods. The geotechnical engineers will be able to interpret the 2-D resistivity data and utilize the information for their design. Therefore, the development of geotechnical parameters from 2-D resistivity method make the method more effective for subsurface investigation.

1.2 Research objective

The objectives of this study are:

i. To characterize soil of weathered granite at USM and sedimentary areas at Sungai Batu.
ii. To compare M-value and resistivity value of the soil types.
iii. To develop N-value, M-value and resistivity values related to soil parameters.

1.3 Scope of study

2-D resistivity imaging survey was carried out at Universiti Saints Malaysia (USM), Pulau Pinang, which is a weathered granite area and Sungai Batu, Kedah (Malaysia), which is a sedimentary area. The method used for this study were 2-D resistivity imaging measurement, mackintosh probe and borehole. All the data were integrated using RES2DINV, Excel and Surfer 8 software to identify the relationship between resistivity value, SPT (N-value) and number of blow (M-value) for soils at the study areas.

1.4 Thesis layout

The thesis chapters are organized as followed; Chapter Two discusses previous studies of geophysical methods using 2-D resistivity and geotechnical methods to understand soils.

Chapter Three contains a detailed description of the study area, research materials and methodology developed in this study. This chapter also describes briefly on data acquisition process in all the study areas involved in this research.

Chapter Four discusses all results obtained from borehole data, 2-D resistivity imaging and mackintosh probe. The chapter also discusses the correlation between geotechnical and geophysical methods.

Finally, Chapter Five includes the summary regarding the accomplishement of the work and the conclusion. Recommendations for future research are also presented in this chapter. Lastly, the list of references, appendices and publications are attached.

CHAPTER 2

LITERATURE REVIEW

2.0 Introduction

Basic soil engineering study is defined as the uncemented aggregate of mineral grains and decayed organic matter (solid particles) with liquid and gas in the empty spaces between the solid particles. Soil is used as construction material in various civil engineering projects and it supports structural foundations. Thus, the study of soil properties, such as its origin, grain-size distribution, water draining ablility, compressibility, shear strength and load-bearing capacity is vital (Das, 2005).

Soil mechanics is a branch of engineering mechanics that describes the behaviour of soils. Soil mechanics provide the theoretical basis for analysis in geotechnical engineering (Osano, 2012). In-situ behaviour of soils is complex because it is highly dependent upon numerous factors. To acquire appropriate understanding, it is necessary to analyze them not only through geophysics and geotechnical engineering skills, but also through other associated disciplines such as geology, geomorphology, climatology and other earth and atmosphere related to sciences (Bery and Saad, 2012).

2.1. Borehole method

Borehole is used to identify detailed changes of soil/rock types. The local variations indicated that borehole data alone could not define the problem sufficiently. The characteristic of the area between holes could only be determined by ground geophysical profiles. This combination proves to be an important and effective approach for detecting and verifying new impact structures, and it is essential for detecting and exploring buried ones (Jeffrey, 1999). Figure 2.1 shows two types of boring method that were used for this study which is wash boring and rotary drilling. Well bores are generally drilled by circulating a fresh-water suspension down through the drill pipe and back to the surface through the annular region between the drill pipe and the rock (Telford, 1990).

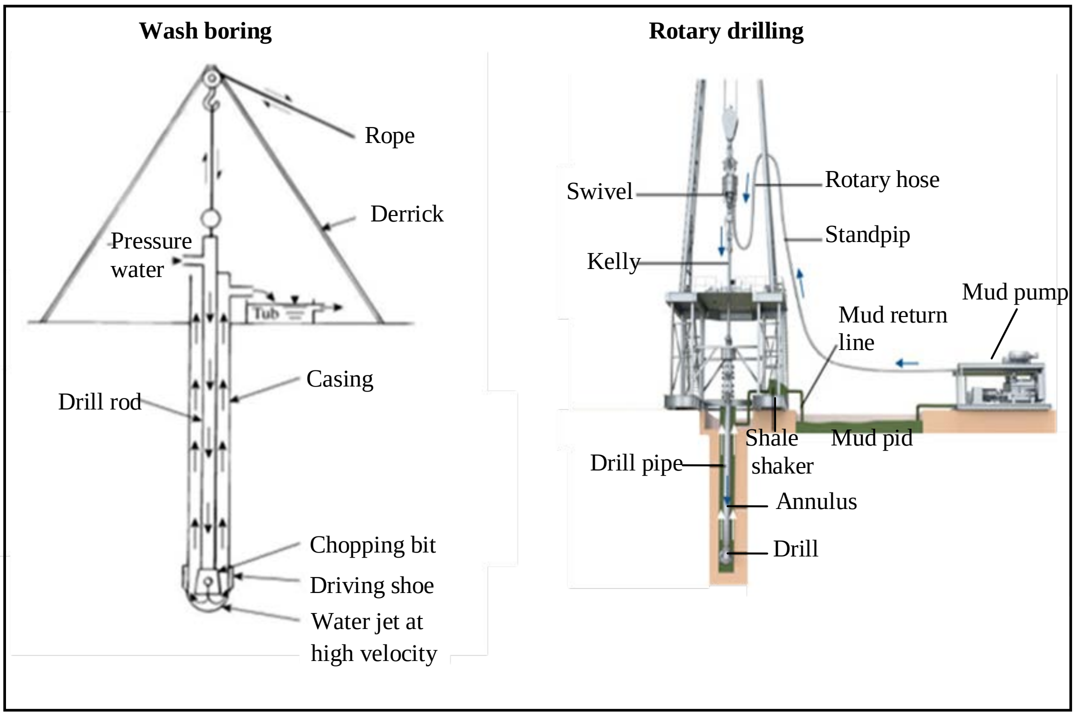

Figure 2.1: Types of the boreholes (Hvorsles, 1948).

Standard penetration test (SPT) is carried out in the boreholes and widely used throughout the world which serves as an indicator for the compressibility and density of granular soils. It is also commonly used to check the consistency of stiff or stony cohesive soil and weak rocks. The SPT is carried out at every 0.75 m vertical intervals in a borehole and it can be increased to 1.5 m. Furthermore, N-value is a number of blows required to achieve a penetration for each 0.75 m that measure the firmness or density of foundation material.

2.2 2-D resistivity method

2-D resistivity surveys have been used for many decades in hydrogeological, mining and geotechnical investigations. More recently, it has been used for environmental surveys. The purpose of 2-D resistivity survey is to determine the subsurface resistivity distribution by making measurements on the ground surface. From these measurements, true resistivity (ρ) of subsurface can be estimated. True resistivity (ρ) is related to various geological parameters such as mineral and fluid content, porosity and degree of water saturation in the soil/rock (Loke, 1999).

The basic principle of electrical resistivity method is the measurement of a materials behaviour to retard the flow of electrical current (I) or resistance (R) to the movement of charge (Awang et al., 2008). The resistivity measurements are normally made by injecting current (I) into the ground and meansuring the value of potential difference (V) (Loke, 1999). Electrical resistance measurement according to Ohm's Law is given by (Equation 2.1);

$$R = \frac{V}{I} \tag{2.1}$$

Where;

R: Resistance of the conductor.

The SI unit for resistance is volts per ampere or Ohm (**Ω**). The resistivity can be calculated as (Equation 2.2);

$$R = \rho \frac{L}{A} \tag{2.2}$$

Where;

ρ: Resistivity of the conductor material (Ωm)

L: Length of the conductor (m)

A: Cross-sectional area (m^2)

For a homogeneous medium (Figure 2.2), the resistivity measurements are normally made by injecting current into the ground through two current electrodes (C_1 and C_2), and measuring the resulting voltage difference at two potential electrodes (P_1 and P_2). From the current (I) and voltage (V) values, an apparent resistivity (ρ_a) value is calculated (Equation 2.3).

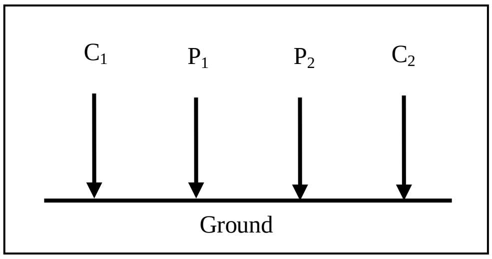

Figure 2.2: Four electrodes array for subsurface resistivity measurement.

$$\rho_a = k \frac{V}{I} \tag{2.3}$$

Where;

k : geometric factor which depends on the arrangement of the four electrodes.

Resistivity meter normally provides a resistance value (R), so in practice the apparent resistivity value is calculated by (Equation 2.4);

$$\rho_a = kR \tag{2.4}$$

The calculated resistivity value is not the true resistivity of the subsurface, but an apparent value which is the resistivity of a homogeneous ground which will give the same resistance value for the same electrode arrangement. The relationship between apparent resistivity and true resistivity is a complex relationship. To determine the true subsurface resistivity, an inversion of the measured apparent resistivity values using a computer program must be carried out (Loke, 1999; 2004).

2.2.1 2-D resistivity imaging

2-D resistivity imaging is a model of resistivity changes in vertical and horizontal direction. The technique assumed that resistivity does not change in the direction that is perpendicular to the survey line. It provides useful result besides being the most practical and economic compromise between providing an accurate result in many geological situations (Loke, 1999). However, typical 1-D resistivity sounding surveys is usually involve about 10-20 readings, while 2-D resistivity imaging surveys involve about 100-1000 measurements. For wider study area, the survey usually carried out in larger number of electrodes, 25 or more and connected to multi-core cable. The multi-core cable is then connected to an automated computer operated switch box known as electronic switching (Figure 2.3) to select the four electrodes to be used (C_1, C_2, P_1, P_2).

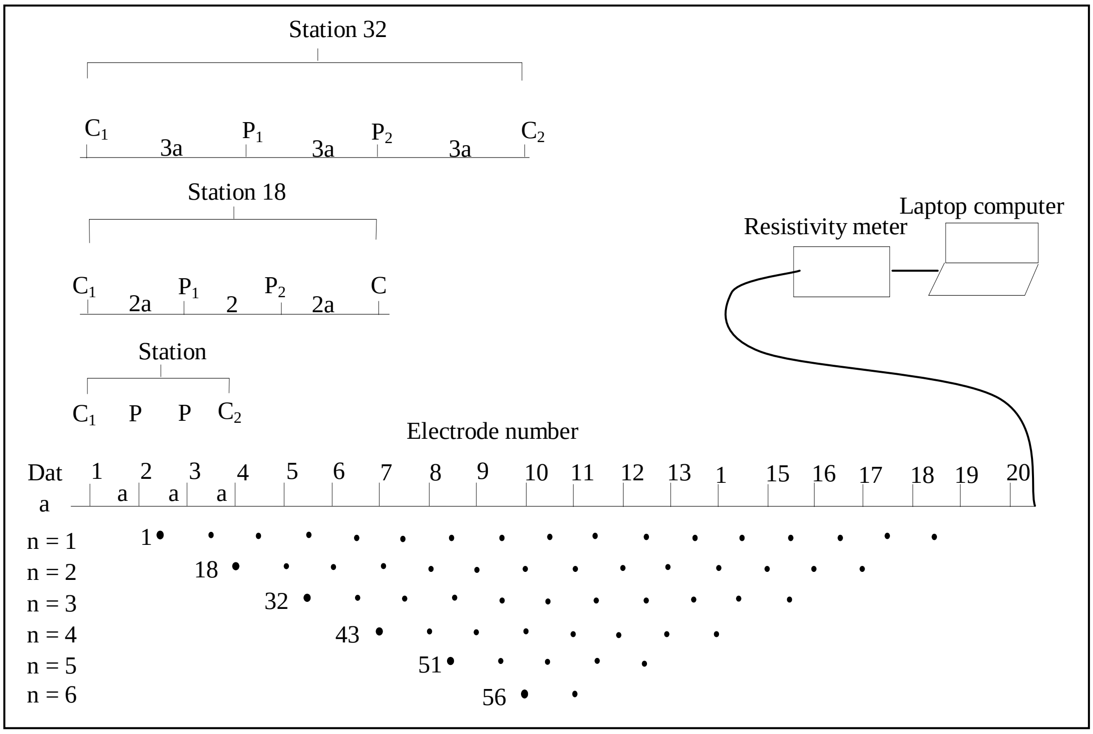

Figure 2.3: The arrangement of electrode for 2-D resistivity imaging survey and the sequence of measurements used to build up the resistivity section (Loke, 1999).

2.2.2 Arrays

Choosing the best array for a field survey depends on the type of structure to be mapped, sensitivity of the resistivity meter and background noise level. In practice, the arrays that are most commonly used for 2-D resistivity imaging surveys are Wenner, Dipole-dipole, Wenner-Schlumberger, Pole-pole and Pole-dipole. Among the characteristics of an array that should be considered are sensitivity of the array to vertical and horizontal changes towards subsurface resistivity, depth of investigation, horizontal data coverage and signal strength (ABEM, 2006). Figure 2.4 shows the common arrays used for 2-D resistivity survey with their geometric factor, k.

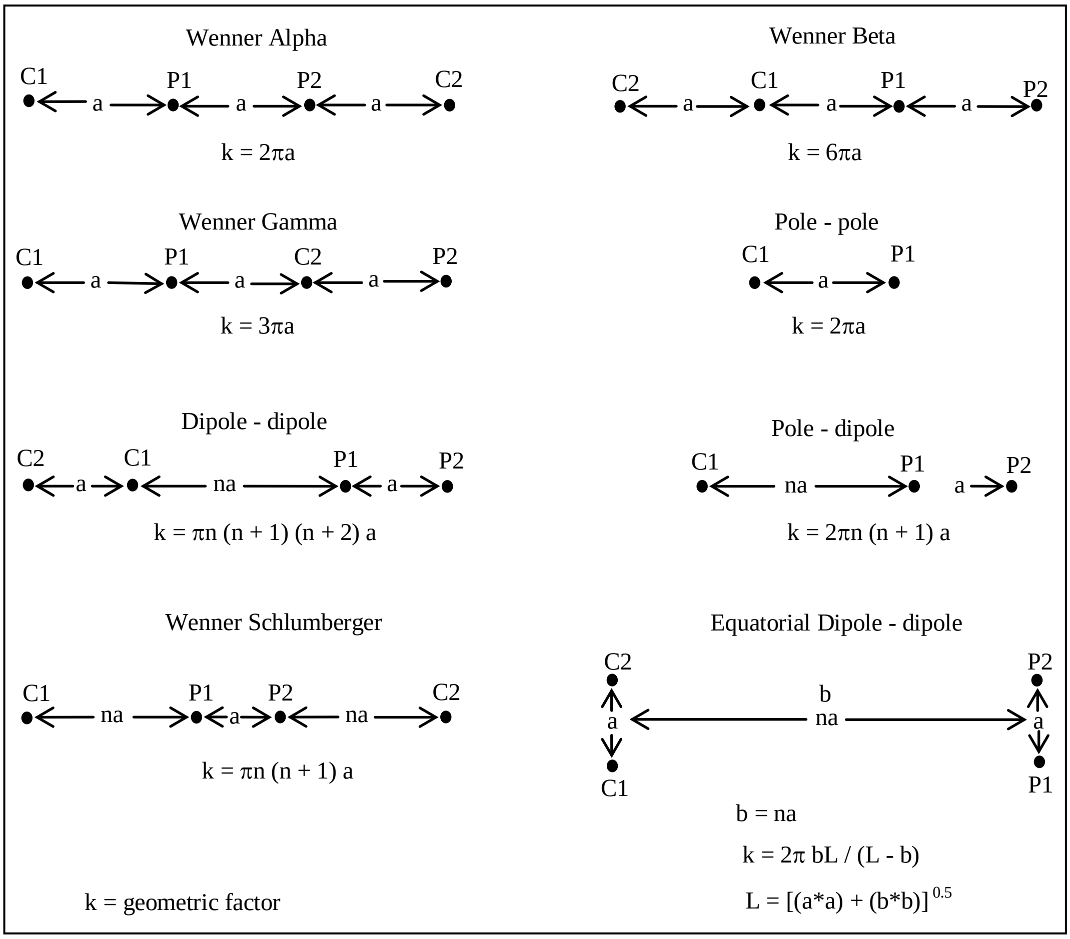

Figure 2.4: Common resistivity array and their geometric factors (Loke and Barker, 1996).

Pole-dipole array uses four electrodes, two potential electrodes (P_1 & P_2) and two current electrodes (C_1 & C_2), “a” is the spacing between P_1 and P_2 which move along the survey line for “n” spacing from current electrode C_1. The C_2 electrode acts as a remote electrode which must be placed sufficiently far from the survey line. The sufficient electrode effect can be stated as approximately proportional to square of ratio distance between C_1-P_1 and C_2-P_1. Pole-dipole array is not as sensitive to telluric noise as the Pole-pole array. This array also has relatively good horizontal coverage, but it has a significantly higher signal strength compared to Dipole-dipole array. Pole-dipole array is an asymmetrical array which produces asymmetrical apparent resistivity anomaly in resistivity section. To eliminate the effect of asymmetry resistivity section, measurements were repeated with the electrodes arranged in reverse manner and combining the forward and reverse measurements to produce a final section (Figure 2.5).

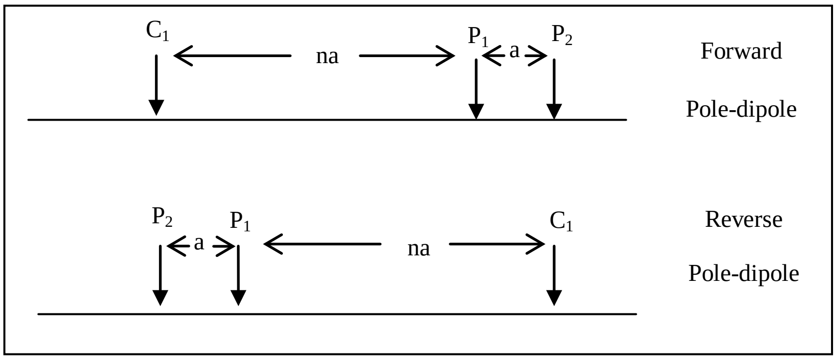

Figure 2.5: Forward and reverse Pole-dipole array (Loke, 1999).

2.2.3 Resistivity of rock and minerals

Rock and minerals have their own electrical conductivity and resistivity values. The same rock and minerals do not necessarily have the same resistivity values because different rocks may have the same resistivity value. This occurs because the value of the resistivity of rock and minerals has a range of values that can overlap. The electrical properties of the rocks are characteristics of rocks when electric current flows into it. This electric current can be derived from nature itself or due to an imbalance of electrical current that deliberately put into it.

Generally resistivity values of soil/rock depend on various numbers of physical parameters such as porosity, salinity, temperature, rock conductivity and thermal changes. In other words, porosity and saturation of the fluid tend to be dominant in resistivity measurements (Reynolds, 1997). Table 2.1 shows the resistivity values of some common minerals and rocks.

Table 2.1: Resistivity value of some common materials and rocks (Reynolds, 1997)

Rock /soils type	Resistivity (Ωm)
Granite	$3 \times 10^2 - 10^6$
Granite (weathered)	$3 \times 10 – 5 \times 10^2$
Schist (calcareous and mica)	$20 - 10^4$
Schist (graphite)	10×10^2
Sandstones	$1 – 7.4 \times 10^8$
Limestone	$50 - 10^7$
Clays	1×10^2
Alluvium and sand	$10 – 8 \times 10^2$
Consolidated shale	$20 – 2 \times 10^3$
Sand and gravel	30 – 225

2.3 Mackintosh probe

Dynamic probing test using mackintosh probe (MP) is a continuous soil investigation technique, which is one of the simplest soil penetration tests. It basically consists of a metal tipped probe which is repeatedly driven into the ground using a drop weight of fixed mass. Testing is carried out continuously from ground level to the final penetration depth. The continuous sounding profiles enable easy recognition of dissimilar layers and thin strata by the observed variation in the penetration resistance. Figure 2.6 illustrate the mackintosh probe equipment. The mackintosh probe (MP) is a light weight dynamic penetrometer and a considerably faster and cheaper tool than boring, particularly when the depth of exploration is moderate and the soils being investigated are soft or loose (Sabtan and Shehata, 1994). The method can be used in difficult terrain such as swampy ground (Kong, 1983). Mackintosh probe test is most widely used in in-situ tests to measure the soil bearing capacity of different layers in terms of M-value. This test is very useful to find out the bearing capacity of soil up to 15 m depth.

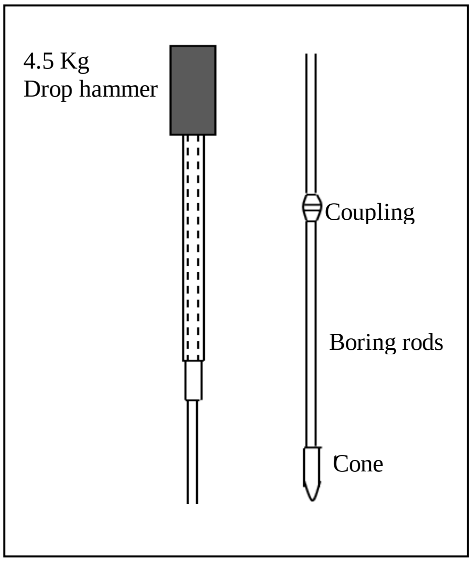

Figure 2.6: The illustration of mackintosh equipment (Fakhrer et al., 2006).

2.4 Previous study

Previously, there are many researchers discussing soils in engineering perspective. Ayob et al. (2015) studied the effects of penetration rate on the penetration resistance using Cone Penetration Test (CPT). The research was conducted at RECESS UTHM and CPT was used in three selected ranges; 0.5 cm/s, 1 cm/s and 5 cm/s. In addition, Mackintosh probe (MP) test has been considered as a comparison with CPT test for the unconfined compressive strength. The results show that the different penetration rate was influenced by the soil shear strength. It was found that the cone resistance increased when higher speed of soundings performed for the CPT. For the slowest rate (0.5 cm/s), the shear strength is approximately 0.15% less compared to the standard rate (2 cm/s). However, the highest rate (5 cm/s), the shear strength was 0.22% more than the reference rate (0.5 cm/s). In comparison, the soil strength from Mackintosh probe was lower than the CPT data. The mackintosh probe record show M-value increases with increasing depth (Figure 2.7).

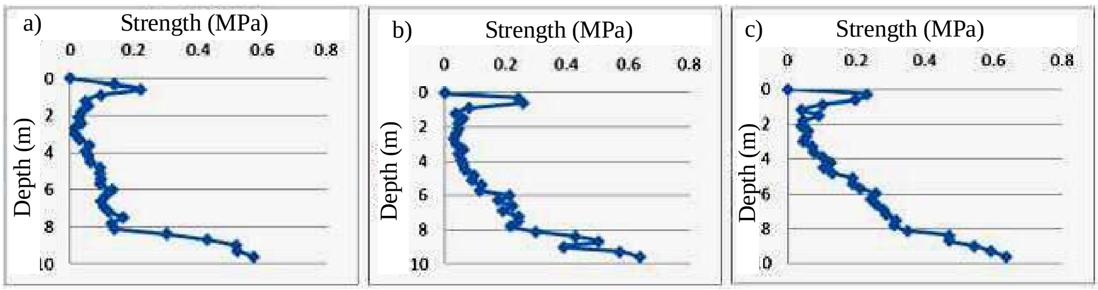

Figure 2.7: Soil strength based on mackintosh probe test (Ayob et al.,2005).

Tarawneh (2014) studied about the correlation between Standard Penetration Test (SPT) and Cone Penetration Test (CPT) for sand, silty sand and sandy silt soil. The study was conducted in Dubai, UAE. In this study, multiple linear regression (MLR) and symbolic regression (SR) were used to develop formulae that can predict N-value using CPT data for sand, sandy silt and silty sand soils samples. Data used in this study consist of 66 CPT-SPT pairs of sand, sandy silt and silty sand soils. Distance between each CPT-SPT pairs ranged from 3-40 m. The depth of the SPT-CPT pairs ranged from 3-9 m. It was concluded that SR showed some improvement to the developed MLR model and those developed models can be used to predict N-value from CPT data with acceptable accuracy.

Electrical Resistivity Tomography (ERT), Standard Penetration Test (SPT) and Dynamic Cone Penetration Test (DCPT) investigations have been carried out for thermal power plants at Aligarh and Jhansi sites (India). Two ERT profiles with 355 m long, 72 electrodes planted with 5 m interval. ERT of the two sites are presented in Figure 2.8.

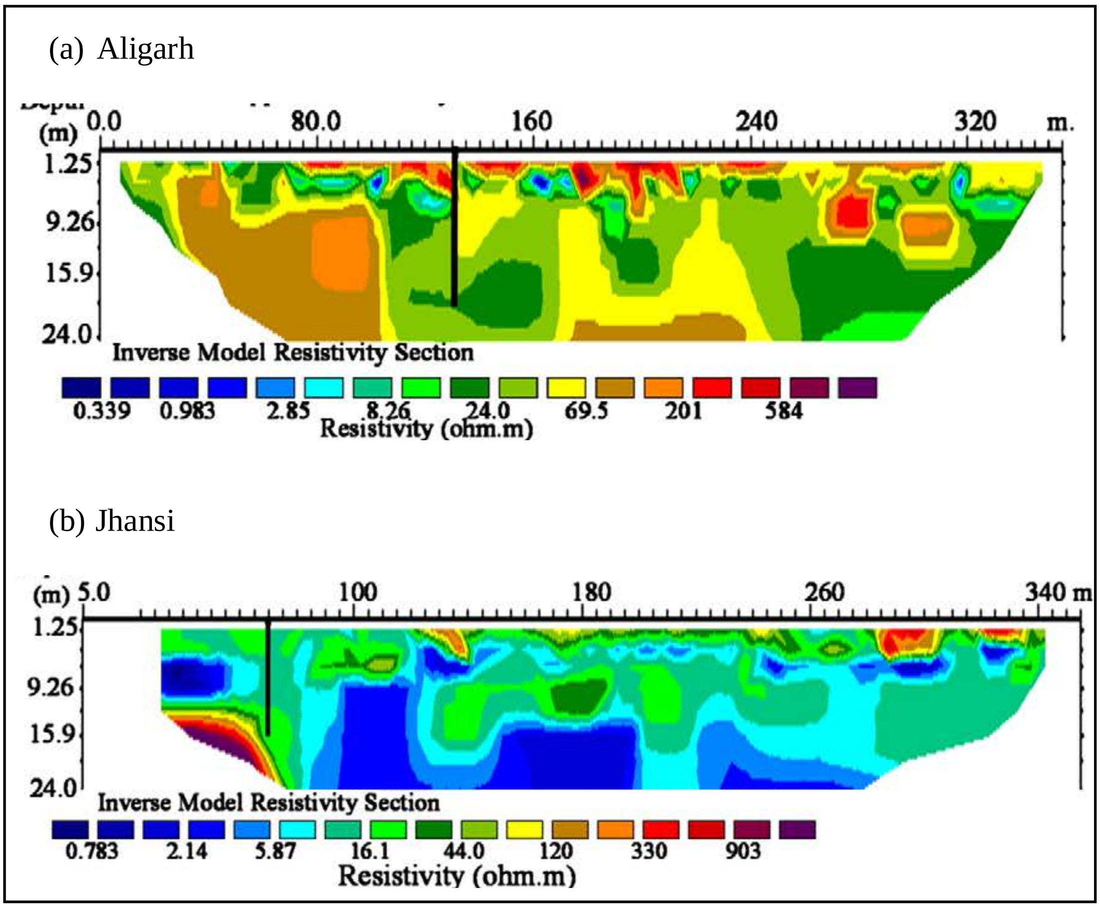

Figure 2.8: Resistivity imaging of (a) Aligarh and (b) Jhansi (Sudha et al., 2008).

Resistivity image of Aligarh and Jhansi showed high resistivity near the surface. High resistivity was characterized by the presence of boulder close to the surface. The low resistivity zone was reported due to the existence of fine soils in Jhansi. Obtained SPT values were plotted with resistivity at the borehole location as shown in Figure 2.9.

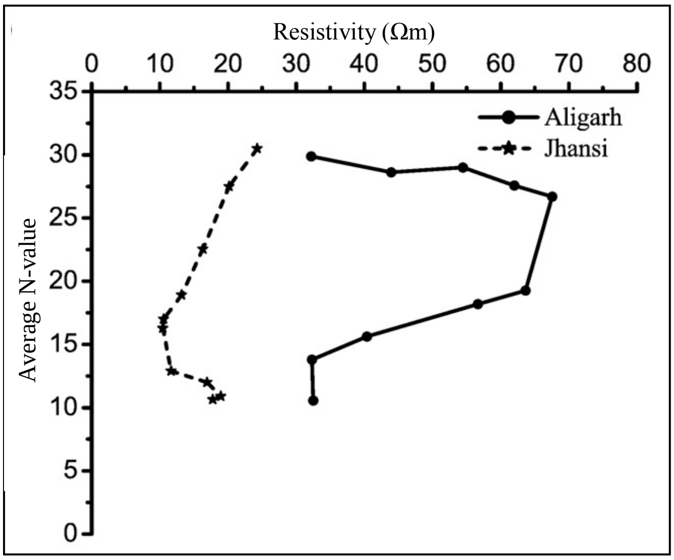

Figure 2.9: SPT value vs resistivity plot (Sudha et al., 2008).

Figure 2.9 showed no specific correlations between SPT and resistivity. However, linear correlation was observed when SPT values were plotted with transverse resistance as presented in Figure 2.10.

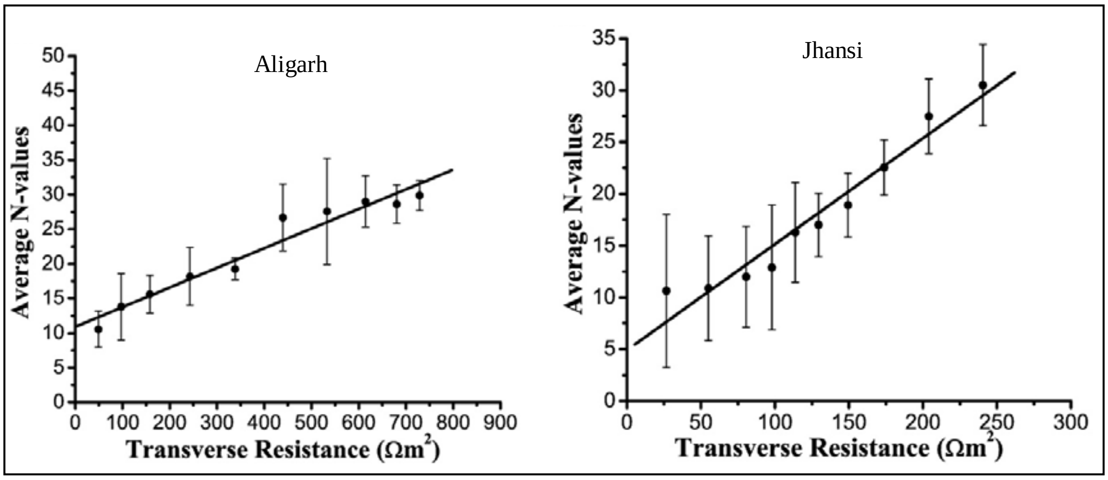

Figure 2.10: SPT vs transverse resistivity of two locations Aligarh and Jhansi (Sudha et al., 2008).

The authors concluded that the correlation of SPT with transverse resistivity was site specific and solely dependent on the geologic environment of the study period. The study illustrate the effectiveness of correlating geophysical method in geotechnical perspective which will lead to time and cost effective compared to only geotechnical method conducted at the area (Sudha et al., 2008).

A research was conducted at Magodo Phase II Lagos in Nigeria to study subsoil investigations using 2-D resistivity for geophysical method and Cone Penetration Test (CPT) for geotechnical method. The results show that this research consists of four soils types; Top soil with the resistivity value of 86-386 Ωm and depth 0.53-1.07 m, sandy clay and sand with resistivity value of 227-602 Ωm and 95-262 Ωm with a depth of 5.49 m and 14.33-37.3 m for sand respectively. While the clay was identified with thickness of 27.6-55.9 m and resistivity value of 110-342 Ωm. CPT shows competent values for penetrative resistance at 14-18 m. The study shows that shallow foundation was feasible in some part of the study area and the two methods correlate well with each other (Oyedele and Okoh, 2011).

Abidin et al. (2012) conducted a study at Kuala Lipis (Pahang) and Tanjung Malim (Perak) Malaysia to evaluate some relation between near surface ground stiffness status with integrated of geophysical and geotechnical method. This study also investigates the stability of slope with effect of heterogeneous subsurface in tropical region with 2-D resistivity and geotechnical SPT (N-value). Figure 2.11 (a) and (b) showed result of Kuala Lipis and Tanjung Malim respectively.

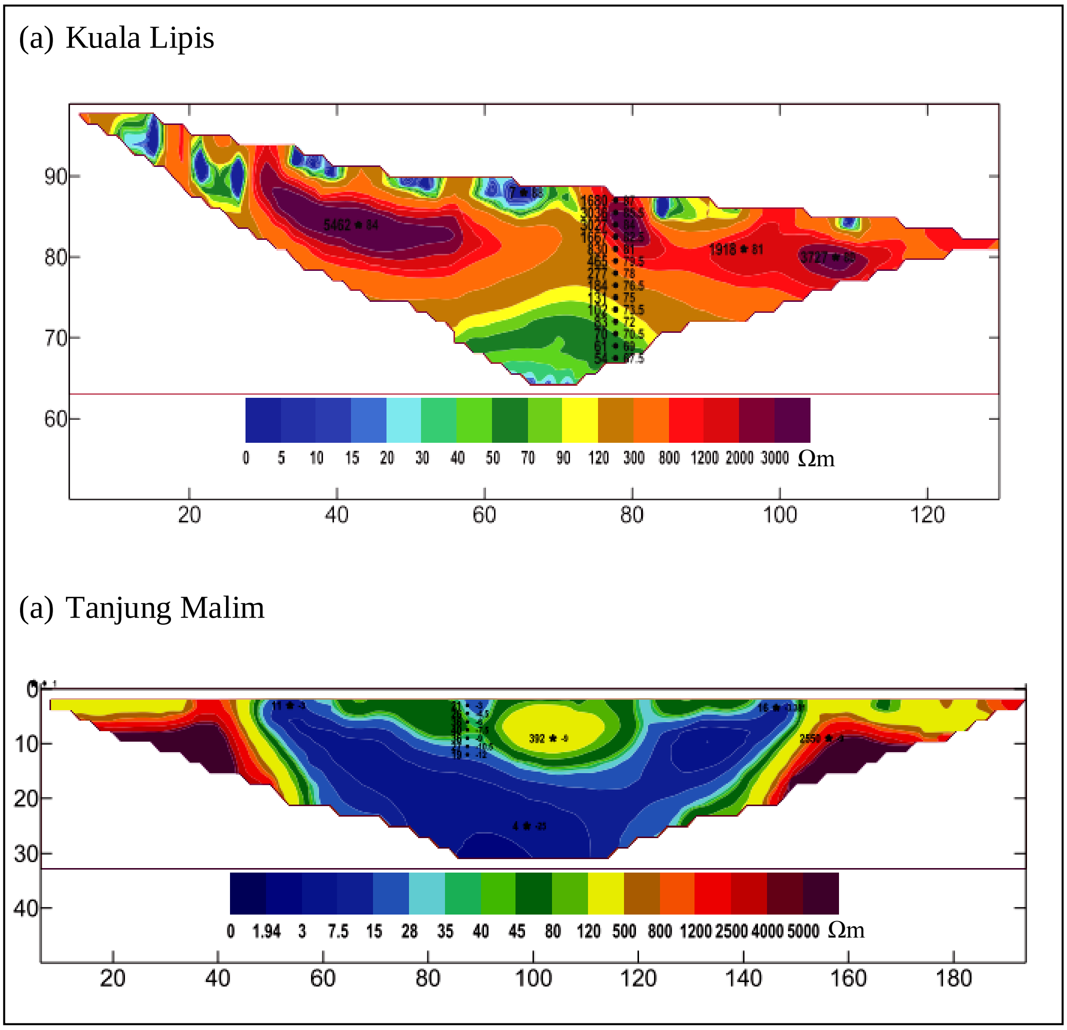

Figure 2.11: 2-D resistivity subsurface profile image obtained from geoeletrical survey (Abidin et al., 2012).

The results induced that a linear relationship between the parameters of high resistivity values will generate high stiffness for higher N-value. In contrast, the decrease in observed low resistivity did not decrease the N-value (Figure 2.12 and Figure 2.13).