Behaviour of Electrical Resistivity and

Seismic Correlated with Heterogeneous Soil Strength Parameters

by

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14955

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ABSTRACT

The soil strength parameters which can be obtained from site investigation are increasingly essential in geotechnical engineering in order to understand the soil stability to sustain the load of building or structure. The conventional soil investigation incorporates borehole sampling which is reliable but is time consuming and costly. Besides, this method is invasive and requires high density sampling for accurate assessment for high spatial variation of soil properties. As an alternative, in this study, geophysical methods, namely seismic surface wave and electrical resistivity survey are utilized to estimate the soil strength parameters. The objective of this study is to establish a correlation between the seismic and electrical resistivity values with the soil strength properties obtained from standard penetration test (SPT) and laboratory tests for soil samples obtained in tropical environment with heterogeneous soil. Both seismic behaviour and electrical resistivity values are studied in laboratory test and field surveys. Throughout the study, Surface Wave method and Wenner configuration method will be applied for field assessment. Then, the field parameters will be analyzed and correlated with soil strength properties. The correlation study shows the empirical correlation between SPT-N with SPT-N value inverted by surface wave velocity (using OYO SeisImager and pickwin software) is SPT-N = 0.8316 $\text{SPT-N}_{seismic}$ + 1.2404 with the regression of 0.6349 (63.49%). The empirical correlation between SPT-N and resistivity value is SPT-N = 0.0528ρ + 2.0105 with the regression of 0.1414 (14.14%). Also, the correlation between moisture content and plasticity index (PI) with soil resistivity are performed. The relationship of moisture content and field resistivity is formulated to be MC (%) = $27.426e^{-9E-04\rho}$ with correlation coefficient of 0.4333. On the other hand, the relationship for plasticity index and field resistivity is PI (%) = -0.0145ρ + 19.065 with correlation coefficient of 0.3156. However, the relationship between these parameters is subject to change with increasing data availability. In conclusion, this study will improve the estimation of SPT-N values and other soil strength parameters using non-invasive, in-situ and rapid methods instead of relying on soil boring method.

CHAPTER 1
INTRODUCTION

1.1 Background

For the past two decades, Malaysia has been a rapid developing country. In other words, rapid construction of high-density infrastructure and buildings in Malaysia is inevitable at the same time. However, the country has suffered numerous failures in slopes as consequence of mass movements of soil (landslide and creep). As a result, the country has to bear with severe loss in properties and significant number of casualties. Since 1973 to 2007, it is estimated that landslides have cost an economic loss of more than RM 2.5 billion to the nation with number of casualties exceeding 500 lives (Karim & Abdullah, 2009). Therefore, identification of soil strength parameters by soil investigation (SI) has been increasingly essential to estimate the ability of soil to tolerate load impact for slope recovery or site construction. In short, soil investigation allows geo-hazards at the construction site to be controlled or minimized, maximizing the safety of people and environment.

One of the main purposes of SI is to acquire geotechnical model of soil for construction purpose. SI involves the determination of ground water level, depth of bedrock, drainage situation as well as the soil stratification. Thus by identifying these parameters will allow efficient foundation design with respect to the soil bearing capacity and factor of safety (FOS) of the soil.

Some of the conventional SI techniques are soil boring, vane shear test and cone penetration test. However, these methods are destructive to soil and at the same time are expensive and tedious. Moreover, it requires high density of sample to have reliable information for high variation of soil properties. As a result, alternate non-destructive and rapid in-situ investigation technique such as electrical geophysical and seismic survey are more appropriate to acquire soil strength parameter because these methods are non-destructive, rapid and economical compared to the conventional methods.

1.2 Problem Statement

Accurate identification of geotechnical properties is crucial in successful construction of buildings or structure. Therefore, soil investigation or exploration is required to acquire soil strength parameters to estimate the ability of the soil to sustain the structure's weight. The conventional soil investigation method incorporating borehole sampling contributes to reliable determination of the soil strength parameters. Nevertheless, this method is costly and time consuming especially during mobilization of sampling equipment and borehole sample. In addition, the process of acquiring borehole sample will disturb the soil mechanics. Other than that, high density of sampling is necessary to accurately delineate the high spatial and temporal variation of soil properties. Alternately, geophysical assessment such as geo-electrical and seismic refraction are widely applied. These techniques are done in-situ, non-destructive, time and cost-saving assessment compared to the conventional technique which is tedious and time-consuming borehole sampling procedure.

1.3 Objectives and Scope of Study

The objectives of this research are:

1. To study the correlation between the behavior of electrical resistivity and seismic with heterogeneous soil strength parameters through comparison of soil parameters obtained from borehole sample with parameters obtained from electrical resistivity and seismic survey.

2. To establish a solid correlation between the behavior of electrical resistivity and seismic with heterogeneous soil strength parameters to come out with rapid and reliable assessment of heterogeneous soil strength parameters.

The scope of study are:

1. The correlation of soil resistivity and seismic behaviour with soil engineering properties is performed by using the parameters obtained from field work and laboratory work based on 120 samples from 6 fields in Malaysia (tropical environment).

2. For field work, resistivity survey and seismic survey are performed at area where boreholes are drilled and SPT tests are performed. Then, the soil properties of borehole samples will be analyzed at the laboratory.

3. Through the analysis of seismic surface wave raw data, the inverted value of resistivity and Standard Penetration Test (SPT-N) values as well as the soil layer images can be obtained using SeisImager and pickwin software.

4. The engineering properties such as moisture content and plasticity index can be obtained through laboratory tests.

5. The correlation between soil resistivity and SPT-N value inverted from seismic survey with soil engineering properties is established by using simple regression in Microsoft Excel.

CHAPTER 2
LITERATURE REVIEW

The slope failures in our country are mostly results of infiltration (Neoh, 2009) as the soil moisture affect the FOS. Among the common SI methods, soil boring is doubtlessly contributing to the highest accuracy in determining the soil strength properties of soil. Unfortunately, this method involves disturbance to the soil, time and economically costly procedure. In addition, the properties of soil at the site can be spatial during the analysis at the laboratory. Consequently, representative data requires high density of sampling which can significantly affect the dynamics of the soil. Conversely, geophysical methods provide quick and non-destructive in-situ assessment of soil properties (Pozdnyakov & Pozdnyakova, 2002). Furthermore, resistivity survey is inexpensive and an environmentally friendly (quiet) assessment tool (Rucker, Noonan & Greenwood, 2011).

Generally, electrical resistivity survey ultimately provides estimation to bearing capacity based on parameters like cohesion, internal angle of friction and unit weight with electrical resistivity values (Siddiqui & Syed, 2012). The primary reason that soils have various resistivity is due to weathering and mechanical process. Therefore, different type of soil will possess different range of resistivity values as portrayed in Figure 2.1. The moisture content is the controlling parameter of the resistivity because the conducting minerals are insufficient to possess electrical conducting properties (Siddiqui & Syed, 2012).

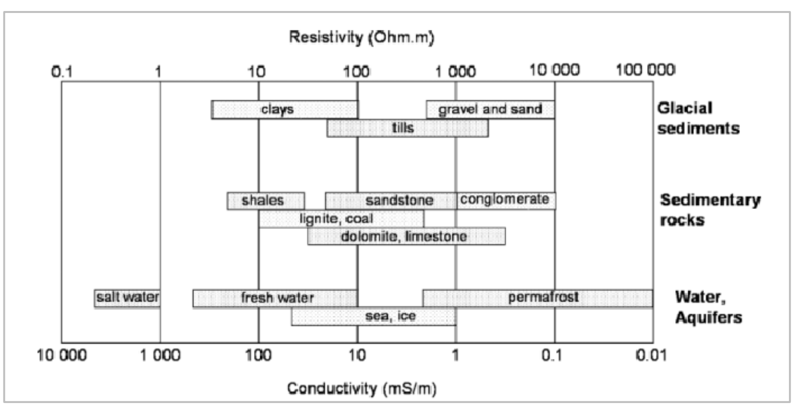

Figure 2.1: Typical Resistivity and Conductivity Values in Various Earth Materials

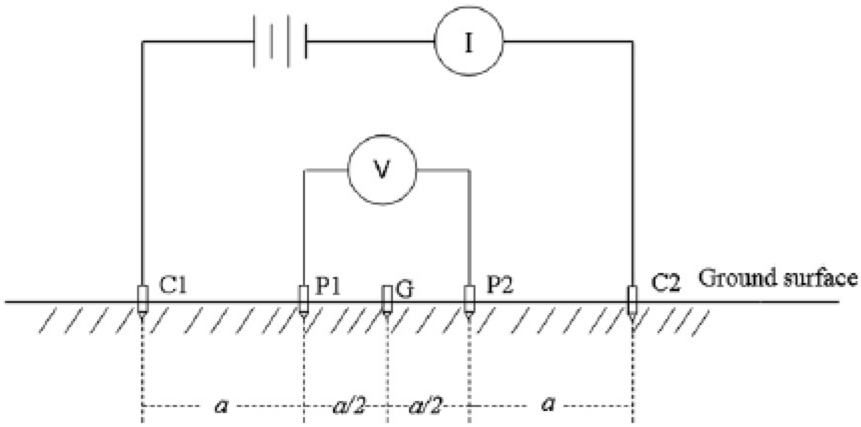

Figure 2.2: Wenner's Configuration

Wenner configuration method is utilized to measure the resistivity of soil and compare it with soil strength parameters. This method involves a 4 electrodes configuration where an electrical current (I) is to be injected into the soil to measure the soil resistivity (Rhoades, 1976). Subsequently, the potential difference (V) can be measured, followed by the determination of resistance (R).

The measurement of resistivity can be calculated by using the formula:

$\rho = 2\pi Ra$ Equation 2.1

Where R: resistance, Ω

a: distance between each electrode

This method can be applied to both 1D and 2D resistivity survey method. Both methods will produce similar results except that 2D resistivity survey will produce the soil stratigraphy with respect to the soil resistivity.

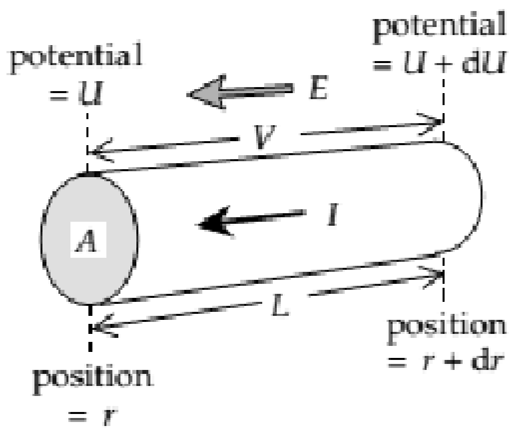

Figure 2.3: Determination of resistivity in cylinder soil sample

Whereas for laboratory soil resistivity test, the resistivity is distributed in soil cylinder body. Similar to field resistivity survey, the resistance (R) can be determined from the laboratory test but the laboratory resistivity test involve injection of potential volume (V) instead of the current to the soil. The resistivity for cylinder soil sample can be determined by using the equation:

$$\rho_a\ (\Omega.m) = \left(\frac{A}{L}\right) R \qquad \text{Equation 2.2}$$

Where A: cross sectional area, m^2

L: sample length, *m*

Seismic survey portrays the soil profile by determining the shear wave velocity as the function of depth. When the seismic rays are produced and intruded into the soil, it will be split into two media with distinctive acoustic impedance where it will either be reflected or partially refracted into the lower medium (Roe, 1953). In this study, the surface wave, specifically Rayleigh waves will be utilized. Rayleigh wave exhibit lower frequency, velocity but high amplitude (Sheriff, 1991). At a specific mode, surface waves with greater wavelength can reach deeper into the earth than surface waves with shorter wavelength. The surface wave passing through each of the earth materials is mainly controlled by its elastic properties (Babuska & Cara, 1991). Hence, the different materials will possess different properties and distinctive range of seismic velocity at distinctive wavelength. For this reason, the seismic velocity and wavelength are dependent on nature of surface waves.

Table 2.1: Typical values of v_p for various materials

Material	Vp (m/s)
Air	330
Damp loam	300-750
Dry sand	450-900
Clay	900-1800
Fresh, shallow water	1430-1490
Saturated, loose sand	1500
Basal/lodgement till	1700-2300
Weathered igneous sand	450,3700
Weathered sedimentary rock	600-3000
Shale	800-3700
Sandstone	2200-4000
Metamorphic rock	2400-6000
Unweathered basalt	2600-4300
Dolostone and limestone	4300-6700
Unweathered granite	4800-6700
Steel	6000

On the other hand, seismic survey is effective in mapping of bed rock and fracture zone. In-situ seismic measurements provide the most precise shear wave velocities of soil profile. Also, SPT-N values can be integrated by having the surface velocity processed through OYO Geospace Seismic Recorder (GSR). At the same time, with the velocity obtained from the seismic survey, the maximum shear modulus (G_{max}) can be estimated as suggest by Kramer (1996) using the formula:

$$G_{max} = \rho V_s^2 \quad \text{Equation 2.3}$$

Where ρ: mass density

V_s: shear wave velocity

Spectral analysis is able to convert time-domain function into constituent frequencies. The phase cross-spectral phase difference will be converted to time with function of frequency by using:

$$\Delta t(f) = \frac{\Phi(f)}{2\pi f} \qquad \text{Equation 2.4}$$

Where Δt (f): frequency-dependent time difference

Φ (f): cross-spectral phase at frequency f

f: frequency to which the time difference applies

Meanwhile, the velocity with function of frequency with respect to the distance apart from two geophones can be analyzed by:

$$V(f) = \frac{d}{t(f)} \qquad \text{Equation 2.5}$$

Where *d*: distance between geophones

t (f): term determined from the cross-spectral phase

The velocity can also be determined with the function of wavelength and frequency by:

$$V(f) = f * \lambda(f) \qquad \text{Equation 2.6}$$

Where λ: wavelength

f: frequency

Table 2.2: Correlation values between SPT-N and resistivity value

Author	Year	Method	Soil Sample	Coefficient value, R
Seokhoon, O. & Chang-Guk, S.	2007	Dipole-dipole	Sand & Gravel	0.4756
Siddiqui, F.I. and Syed, B.S.O.	2012	Wenner Configuration	Homogeneous soil	0.675

Table 2.2 shows the correlation values between SPT-N and resistivity value obtained by previous researches. The study of correlation between SPT-N with resistivity behaviour is uncommon as compared to with seismic behaviour and have only been studied for the past decade. Siddiqui and Syed (2012) has achieved moderate coefficient value between SPT-N values and resistivity values by implementing the similar method applied in this research. Therefore, this study shows vast potential in achieving strong correlation value to estimate SPT-N value through resistivity survey.

Table 2.3: Correlation values between moisture content and resistivity value

Author	Year	Method	Soil Sample	Coefficient value, R
Cosenza, P., Marmet, E., Rejiba, F., Jun C. Y., Tabbagh, A., & Charlery, Y.	2006	Electrical resistivity tomography	Silty Clay	0.821
Zhu, J.J, Kang, H. Z. and Gonda, Y.	2007	Wenner configuration	Sandy	0.883
Ozcep, F., Yildirim, E., Tezel, O., Asci, M., & Karabulut, S.	2010	Vertical electrical sounding	Sandy Soil	0.76
Celano, G., Palese, A. M., Ciucci, A., Martorella, E., Vignozzi, N., & Xiloyannis, C.	2011	Pole-dipole	Calcic Soil	0.886
Calamita, G., Brocca, L., Perrone, A., Piscitelli, S. Lapenna, V., Melone, F., et al.	2012	Wenner Alpha configuration	Sandy Loam	0.65

Brillante, L., Bois, B., Mathieu, O., Bichet, V., Michot, D., & Lévêque, J.	2014	Electrical resistivity tomography	Homogeneous Soil	0.65

Table 2.3 portrays the correlation values between moisture content and resistivity value obtained by previous researchers. Several studies have been conducted to have the correlation between electrical resistivity and soil parameters. Previously, Cosenza et al. (2006) performed a 2D electrical resistivity survey using Wenner electrode configuration to correlate resistivity with cone penetration test (CPT) values. However, there is no strong correlation between resistivity and CPT values and further investigation is recommended to be carried out for better correlation. On the other hand, by applying electrical resistivity tomography method, Cosenza et al. (2006) has acquired a strong correlation of resistivity and moisture content for silty clay sample, with an empirical relationship of $\rho=1.187w^{-2.444}$. Meanwhile, Celano et al. (2011) has obtained the strongest correlation using pole-dipole on calcic soil.

Furthermore, Abu-Hassanein et al. (1996) proved a curvilinear correlation of plasticity index (PI) and electrical resistivity of clay. In addition, Abu-Hassanein et al. (1996) also came out with the conclusion that high plasticity soil possess lower electrical resistivity values. Table 2.3 is the summary of the values done by different researchers.

The previous studies have achieved good correlation especially for Cosenza et al., Zhu, Kang and Gonda, and Celano et al. Unfortunately, previous studies are performed based on the authors' respective countries. For this reason, there is no correlation studies performed on the correlation between soil strength parameters and soil resistivity for tropical environment area. Therefore, this study will focus on the soil resistivity behaviour with soil strength parameters for tropical environment with heterogeneous soil sample. Meanwhile, this study will utilize Wenner's configuration, which is a convenient, simple and reliable method to measure soil resistivity. As a result, this study will correlate the soil resistivity with soil strength parameters to establish a soil strength assessment method which is suitable in a tropical area on heterogeneous soil.

TABLE 2.4: Correlation values between SPT-N value and seismic velocity

Author	Year	Method	Correlation Parameters		Coefficient Value, R^2
Maheswari, R.U., Boominathan, A. & Dodagoudar, G.	2010	Seismic Surface Wave	Shear wave velocity (Vs) VS SPT-N	All Soil	0.83
				Sand	0.84
				Clay	0.93
Nassaji, F. & Kalantari, B.	2011	Seismic Surface Wave	Shear wave velocity (Vs) VS SPT-N	All Soil	0.83
				Sand	0.83
				Clay	0.92
Andy, B. & Rosli, S.	2012	Seismic Refraction	P-wave velocity (Vp) VS SPT-N	All Soil	0.93
Imai, T. & Tonouchi, K.	1982	Seismic Refraction	S-wave velocity (Vs) VS SPT-N	All Soil	0.87

Previous studies by the above authors in correlating seismic behaviours with SPT-N values have achieved strong correlations with high coefficient values. However, the authors except for Andy & Rosli (2012) have performed their studies in a non-tropical environment in Chennai, India and Tehran, Iran. Andy & Rosli (2012) have study in a tropical environment using seismic refraction method. Meanwhile, in this study, the method used is seismic surface wave with OYO SeisImager and pickwin to convert the seismic data into SPT-N value based on Imai and Tonouchi's correlation. These software are developed in Japan, which does not incorporate of tropical environment, specifically Malaysia. Hence, the correlation of seismic behaviour and SPT-N value using seismic surface wave method will establish a more accurate measurement of SPT-N value in a tropical environment with heterogeneous soil.

CHAPTER 3

METHODOLOGY

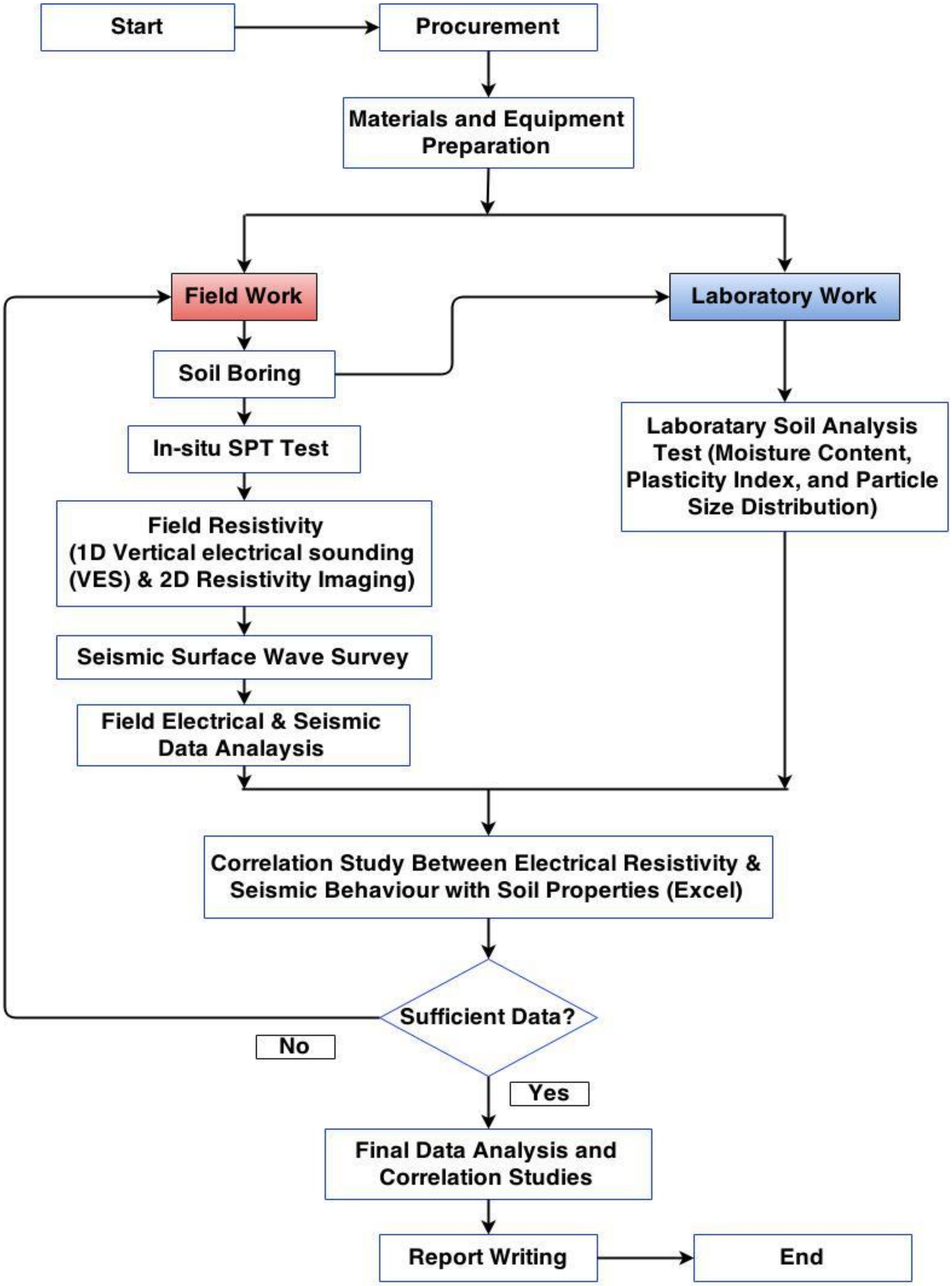

Figure 3.1 Methodology Flow Chart

This project is divided into 2 major parts, which are field work (soil boring, 1D and 2D, SPT Test, electrical resistivity and seismic surface wave survey) and laboratory work (soil test analysis).

A. Field work

a. Soil boring

The borehole samples are acquired by drilling boreholes at designated locations are using petrol operated percussion drilling set (CobraTT, Atlas Copco) with 1 meter core sampler. Boreholes are drilled at similar area where field resistivity and seismic survey were conducted. The maximum depth of borehole can reach up to 3 meter.

Then, the undisturbed samples are preserved in a capped plastic cylinder to avoid disturbance from the environment. After that, the samples will be brought back to UTP laboratory to acquire physical, chemical and engineering properties by conducting laboratory experiments, namely moisture content, direct shear test, particle size distribution test, and bulk and dry density test. The samples are labeled with respect to its location and depth.

b. Standard Penetration Test (SPT)

The test will be performed at where the field resistivity and seismic survey were conducted for comparison purpose. The test procedure is performed in accordance of British Standard BS EN ISO 22476-3. From this, information such as the relative density of granular deposits like sands can be determined. The borehole report from the contractor will indicate the SPT values at different depth, which will be further compared with the SPT values acquired from the seismic surface wave survey.

c. 1D survey or Vertical Electrical Sounding Survey (VES)

This method requires components such as electrodes, power source (DC power supply), voltmeter, insulated wires and measuring tape.

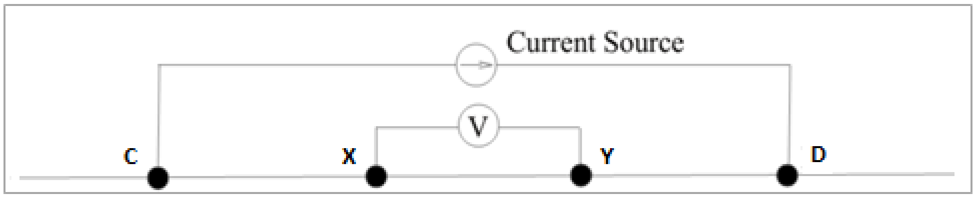

Figure 3.2: Wenner's Configuration for VES Survey

From the configuration above, electrodes C & D produce current whereas electrodes X & Y will act as the receivers for the produced current from C & D. The test should be conducted at the same location as the borehole samples are drilled. The distance between each electrodes (C & X, X & Y, Y & D) must be spaced out at the same distance. The current received from C & D will be displayed at the voltmeter attached to X & Y. With that, the apparent resistivity of soil can be calculated using the formula:

$$\rho_a\ (\Omega.m) = 2\ \pi\ R\ L \qquad \text{Equation 3.1}$$

Where R: resistance, Ω

L: length, m

Next, the calculated apparent resistivity will be input into IX1D software. Then, the software will interpret and deliver the soil resistivity with thickness and different soil layers.

d. 2D Electrical Resistivity Survey

This survey will be performed at the same location where VES and soil boring are done. This survey delivers a more precise result compared to VES. The equipment used are namely the terrameter system (ABEM SAS 4000), multi-conductor cables, jumper cables, steel electrodes, switching unit, 12 volts battery, layout cables, rubber mallet and measuring tape. Similarly, the electrodes are nailed into the ground with the same arrangement as the VES survey.

The results are collected and filtered by electrode selector system for the measurement of resistivity data. Later, the data will be saved in ABEM terrameter in .s4k format and subsequently transferred to the computer with SAS4000 utilities software. Afterwards, it will be converted into .dat file and the data will be inverted into 2D image of survey, delineating the resistivity value of soil, soil layering and survey length.

e. 2D Seismic (Surface Wave) Survey

Surface wave technique is used to produce the seismic imaging. Also, this survey is conducted at the location where VES, 2D electric resistivity survey and soil boring are performed. The equipment required are; seismograph set; 2 set of 12 channels seismic cable; 24 units of geophone; fully charge car battery; remote cable and trigger switch; hammer and steel plate; measuring tape.

The geophones are clipped on the seismic takeout cable at a fixed distance away from each geophones. The geophones will be triggered by hammer (trigger switch attached) hitting on a steel plate. The seismograph unit will record the trigger level and saved at the computer in .sg2 file.

The data will undergo three phases until seismic image with soil structure is generated. By using the pickwin (surface wave) software, the details such as source interval and source receiver will be analyzed and verified by the wave equation program before the model of seismic image is presented in geo plot program. Finally, the seismic image with surface velocity and SPT-N value is generated.

B. Laboratory Work

a. Laboratory Soil Analysis Test

Once the samples are transported to the laboratory, the soil samples are to undergo the soil characterization and electrical resistivity test.

Table 3.1: Methods for Soil Analysis

Parameters	Methods
Moisture Content	BS 1377: Part 2: 1990: 3.2
Particle Size Distribution	BS 1377: Part 2: 1990: 9.6
Liquid and Plastic Limit	BS 1377: Part 7: 1990: 4.3

b. Laboratory Soil Electrical Resistivity

By applying disk electrode technique (BS 1377: Part 3: 1990: 10.2), electrical disk are clamped at both ends of a 100 mm cylinder of sample soil and tested with 3 different voltage (30V, 60V and 90V) to obtain the resistivity of the soil. The purpose of this laboratory test is to verify the quality of preservation of soil boring sample, particularly by having strong correlation between both values by comparing the laboratory soil electrical resistivity with field soil electrical resistivity value. The resistivity of the soil can be calculated using the formulas:

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

$$\rho_a\,(\Omega.m) = \left(\frac{A}{L}\right) R \qquad \text{Equation 3.2}$$

Where A: cross sectional area, m^2

L: sample length, m

C. Correlation Study

The correlation studies were performed by using Microsoft Excel. The data gathered from the field work and laboratory work will be plotted in a graph by using Microsoft Excel. As far as the project is concerned, the primary graphs plotted will be SPT (actual) vs SPT (seismic), SPT (actual) vs Field Resistivity. Also, other parameters such as moisture content and plasticity index will be correlated with seismic and resistivity. From this, the behaviour of seismic and resistivity can delineate the soil strength properties in a more accurate manner since the soil strength can be affected by various factors. From the graphs, the trend line and coefficient of correlation (or R-squared value) can be obtained. Also, the equations can be obtained at the same time to estimate the soil strength parameters from the seismic and resistivity values.

CHAPTER 4
RESULTS AND DISCUSSION

4.1 Soil properties, seismic, resistivity and SPT-N value

The study was performed based on 56 samples from Ulu Pudu, Selayang, Shah Ala. In total, boring test were carried out involving 12 boreholes with the maximum depth of 3m and the other 2 were 10m depth. The gap at each borehole is 0.5m. Also, the particle size distribution (PSD) had been done by using hydrometer test, wet and dry sieving for all fields. The locations chosen were based on previous boreholes results performed at the fields, with 3 fields dominated by clay and 3 fields dominantly sand. However, the samples after PSD test indicated that the samples collected were mostly dominantly sand except for the samples from Shah Alam. Hence, the study would be more appropriate to be conducted based on all types of soil with the data available.

The vertical electrical sounding (VES) was performed for 4 sites and the results are compared with the actual SPT-N value. The values acquired from the 1D electrical resistivity survey were inverted to the field resistivity values as displayed in Figure 4.1. The field resistivity ranges from 0 Ω.m to 520 Ω.m. The field resistivity values varies in minor difference from respective layers of depth from 0.5m to 2.5m implies the similar type of soils type in each boreholes. Other than Selayang (BH1) and Shah Alam (BH2), the value of resistivity increases with the SPT-N value. Although the relationship of both parameters is not significantly strong, but thorough investigation in the future is strongly suggested for other factors of resistivity (such as the salinity) should be studied so that the study can be narrowed down with proper classification to have a more robust trend between resistivity and SPT-N value.

The surface wave seismic survey was also performed for 4 sites and the results again were compared with the actual SPT-N value, shown in Figure 4.1. There is an obvious trend of SPT-N obtained from seismic velocity inversion and actual value. The SPT-N from seismic velocity inversion increases with the increasing of actual SPT-N value for the 6 fields except for BH 2 at Ulu Pudu. This may be due to the huge amount noise and vibration during the execution of seismic survey not totally removed by the pickwin software. In overall, the seismic behaviour proved a good trend with the actual SPT-N value.

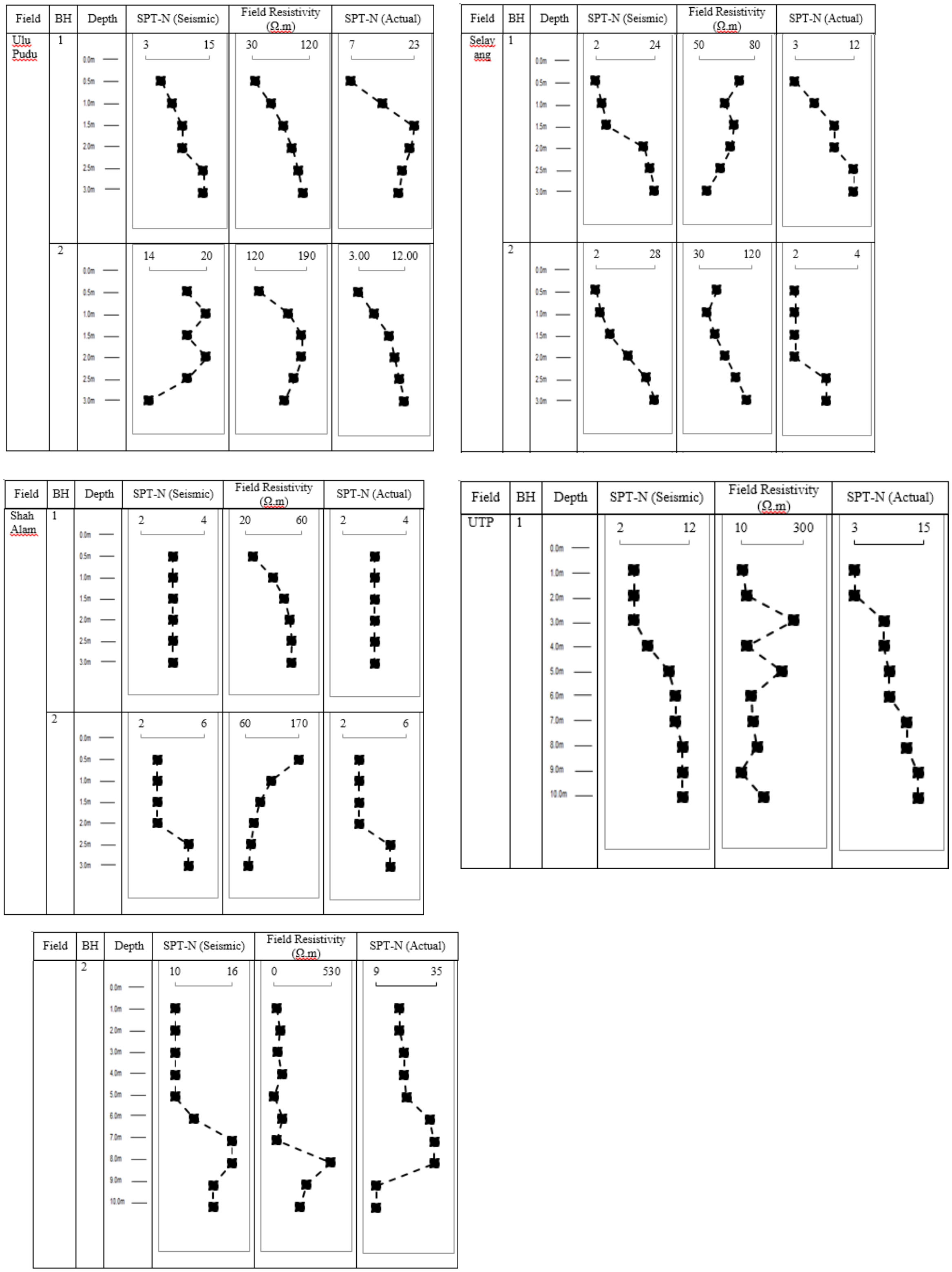

Figure 4.1: Comparison of SPT-N (Seismic), Field Resistivity and SPT-N (Actual) value with respect to different fields and respective depths

4.2 Correlation studies between the behaviour of resistivity and seismic with soil strength parameters

The correlation studies consisted of 4 plotted graphs, involving SPT-N from SPT test, SPT-N converted from surface wave velocity, field resistivity, moisture content and plasticity index. This correlation study is done based on field and laboratory results on the soil at Ulu Pudu, Selayang, Shah Alam, Parit and in Universiti Teknologi PETRONAS (UTP).

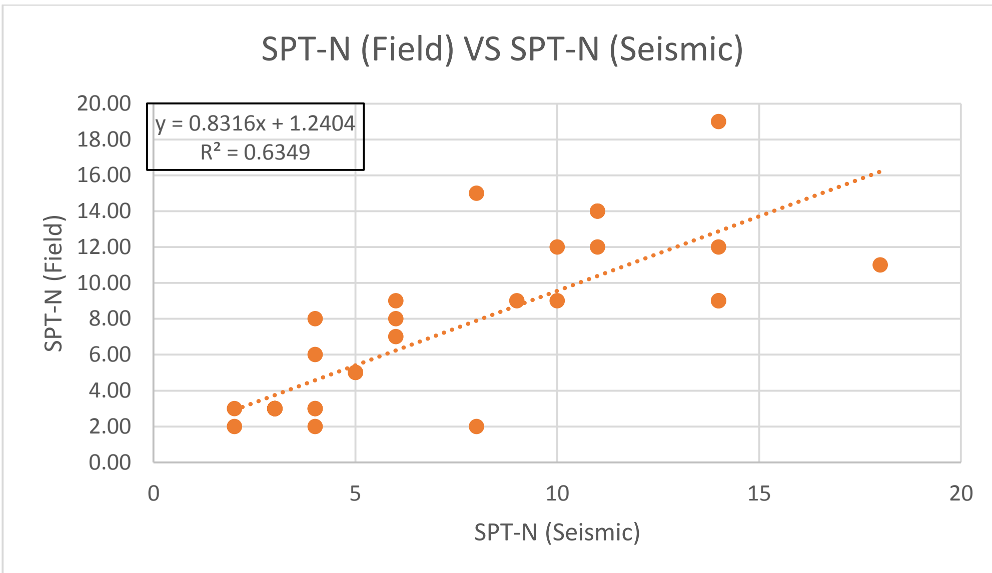

Figure 4.2: Relationship of SPT-N (Field) and SPT-N (Seismic) converted from surface wave velocity

The correlation coefficient obtained from the research is 0.6349. Therefore, the correlation of both SPT-N obtained from SPT test and seismic survey velocity inverted SPT (using pickwin software) is strong. This correlation is done between SPT-N from field and seismic instead of conventional seismic velocity versus SPT-N because this research is to determine the suitability of Oyo McSEIS seismograph and SeisImager in determining SPT-N value in heterogeneous soil in tropical environment like Malaysia. However, the surface wave velocity can be said to be approximately equals to SPT-N which the software are developed based on robust correlation performed by Imai and Tonouchi (R^2=0.87). Similar to homogeneous soil, surface wave reflection wave of heterogeneous soil is strongly correlated with the soil's penetrability. Though, the correlation coefficient is slightly lower as compared to Maheswari et al (2010), Nassaji and Kalantari (2011), and Andy & Rosli (2012). This can be due to the uncertainty from the software because the SPT values are inverted from seismic surface velocity. Furthermore, during the inversion, the noise resulted from the surrounding will be removed, but not totally. Furthermore, the manual hammering process to trigger seismic wave can also affect the quality of the wave received by the geophones. Nevertheless, the correlation shows vast potential in the application of using seismic survey in estimating the SPT-N value for heterogeneous soil.

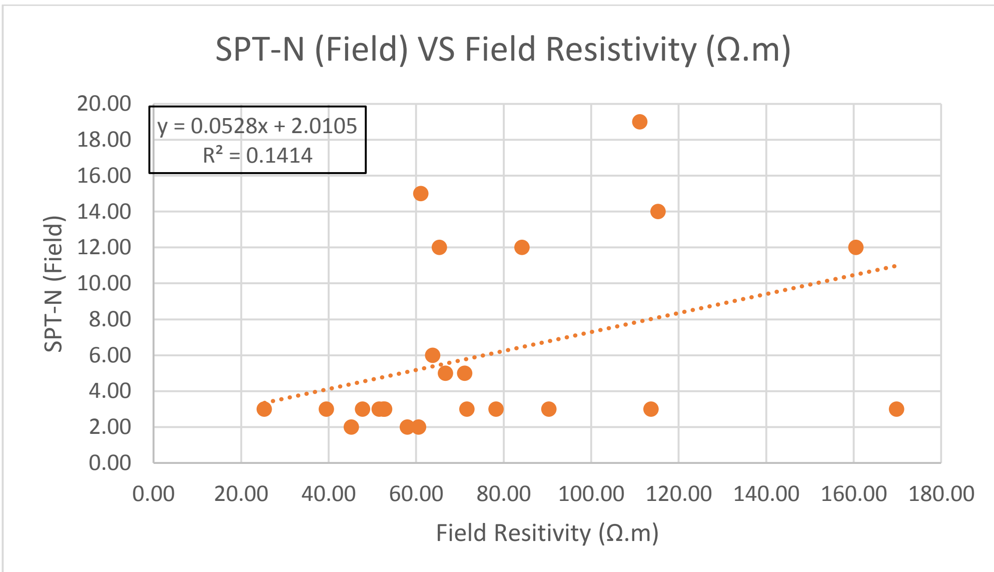

Figure 4.3: Relationship of SPT-N (Field) and field resistivity

The graph of SPT-N versus Field Resistivity shown in Figure 4.3 a moderate relationship. From the figure, the relationship of both parameters was SPT = $0.0528\rho + 2.0105$ with the correlation, $R^2 = 0.1414$. This also indirectly suggested that field resistivity and SPT-N was not strongly dependent on each other for heterogeneous soil samples. Although with a weak correlation factor, the correlation study revealed a trend of increasing SPT-N value with the increasing of field resistivity, which has a similar trend as compared to correlation study by Syed and Siddiqui (2012).

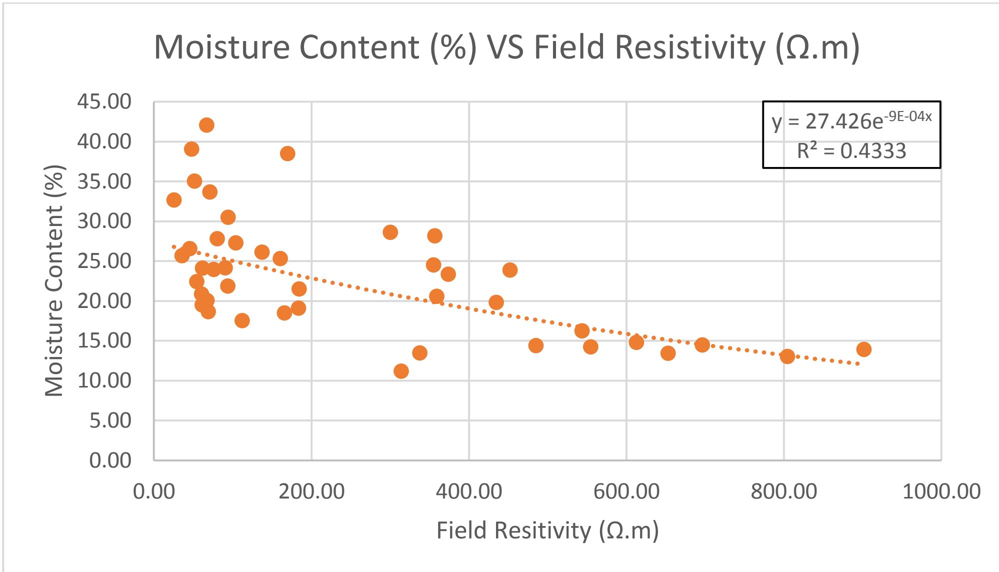

Figure 4.4: Relationship of moisture content and field resistivity

The relationship of moisture content and field resistivity is formulated to be MC (%) = $27.426e^{-9E\text{-}04\rho}$ with correlation coefficient of 0.4333. This research showed exponential relationship between moisture content with field resistivity. Nevertheless, the study showed that the moisture content decreases as the resistivity increases. The trend implied that the moisture content in the soil act as a medium for the current flow. Hence, the decrement in moisture content would amplify the resistance for the current flow. This research obtained a relatively lower coefficient of correlation than previous authors. The main reason would be the characteristic of heterogeneous soil samples. The analysis of heterogeneous soil in the ability to hold moisture is considerably more complex than homogeneous soil. Other than that, field resistivity does not only depend solely on the moisture content. There are other factors which can contribute to the electrical resistivity value, namely the salinity and total organic content (TOC). Thus, experiments such as TOC and pH tests should be performed for further studies to delineate the relationship between soil parameters and resistivity in a more detailed manner.

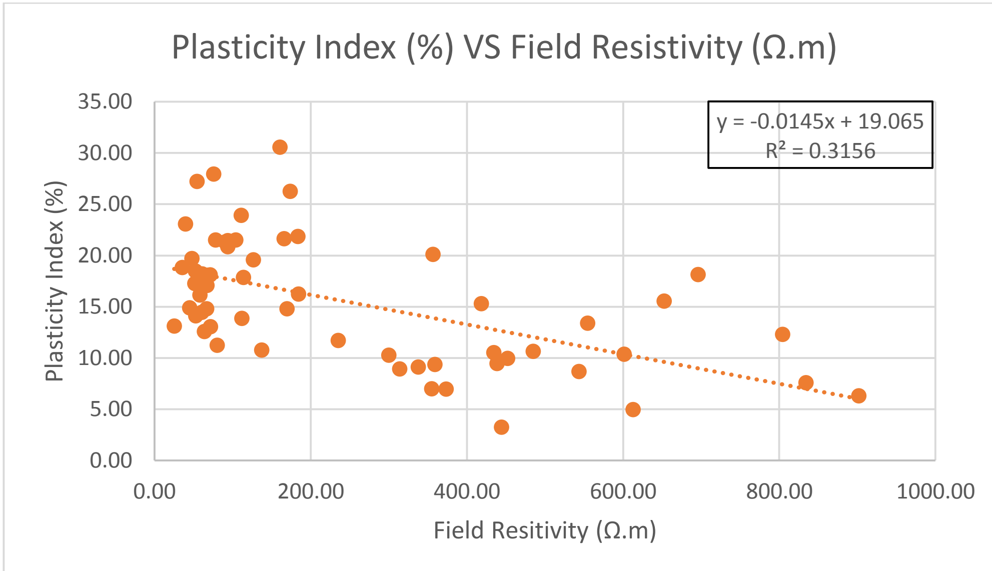

Figure 4.5: Relationship of plasticity index and field resistivity

From Figure 4.5, the relationship of plasticity index and field resistivity is PI (%) = -0.0145 ρ + 19.065 with correlation coefficient of 0.3156. The plasticity index decreases with the increasing of field resistivity. The downward trend has also been studied by Abu-Hassanein et al. (1996) stating that soil with higher plasticity index will have less resistivity values. Soil that possesses high plasticity index has higher tendency to have more clay composition whereas the lower range tends to be silt and zero plasticity index indicates non-plastic soil, commonly sand. The trend is also verified by the range of resistivity as shown in Figure 2.1 as the resistivity of clay is relatively higher compared to silt and clay.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

The objective of this study is to estimate the relationship between soil electrical resistivity and seismic behaviour with soil engineering properties to support the applications of geophysical methods in determining the heterogeneous soil strength parameters. The overall regression obtained for SPT-N inversed from seismic survey with actual SPT-N value is 0.6349 and for electrical resistivity with actual SPT-N is 0.1414. A reliable correlation was established between the seismic behaviour with the SPT-N value whereas the relationship between electrical resistivity with SPT-N value is still uncertain. For the implementation of seismic survey to estimate SPT-N values, it is encouraged to increase the depth of study since the correlation factor shows vast potential. Although electrical resistivity behaviour is yet to have a reliable relationship with SPT-N, but the relationship between resistivity with moisture content (R^2=0.4333) and with plasticity index (R^2=0.3156) are noticeably good. The study of electrical resistivity behaviour and soil strength parameters should also include other soil strength parameters such as angle of friction, cohesion and pH which potentially affect the resistivity of soil sample. By doing so, the study can be performed in a more focused and detailed manner. In conclusion, the study has proved an established estimation of SPT-N values using seismic survey whereas the application of electrical resistivity survey requires further study of its mechanism in affecting various soil strength parameters.

CHAPTER 6

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CHAPTER 7

APPENDICES

		Depth	SPT-N (Seismic)	Field Resistivity (Ω.m)	SPT-N (Actual)	MC (%)	Liquid Limit (%)	Plasticity Index (%)	Clay	Silt	Sand	Gravel
Ulu Pudu	BH1	0.5	6	35.64	7.00	25.69	49.00	18.82	26.63	23.47	49.80	0.00
		1	8	61.08	15.00	19.53	51.00	18.20	12.91	5.99	81.00	0.00
		1.5	10	80.18	23.00	27.83	55.00	11.25	13.72	4.28	81.90	0.00
		2	10	93.99	22.00	30.52	62.20	20.85	12.11	10.49	76.20	1.20
		2.5	14	103.90	20.00	27.32	51.00	21.53	5.65	1.75	92.50	0.00
		3	14	111.10	19.00	16.09	58.00	23.92	7.26	4.04	88.60	0.00
	BH2	0.5	18	126.70	3.00	14.30	44.00	19.59	3.23	1.37	90.80	4.60
		1	20	165.80	6.00	18.51	51.00	21.64	4.04	3.66	92.20	0.10
		1.5	18	184.30	9.00	21.53	58.00	16.24	5.65	3.15	91.10	0.10
		2	20	183.70	10.00	19.12	57.00	21.86	7.26	2.64	90.00	0.10
		2.5	18	173.80	11.00	13.34	57.00	26.26	5.65	3.45	90.90	0.00
		3	14	160.50	12.00	25.32	80.00	30.58	18.00	32.00	50.00	0.00
Selayang	BH1	0.5	2	71.64	3	18.03	35.5	13.04	24	23.05	52.95	0
		1	4	63.8	6	20.28	34	12.58	20	17.31	62.69	0
		1.5	6	68.88	9	18.68	37	18.09	18.5	22.06	59.44	0
		2	20	67.17	9	20.09	41	17.07	18.5	22.06	59.44	0
		2.5	22	61.53	12	24.11	46	17.03	23	20.8	56.2	0
		3	24	54.46	12	22.43	60	27.24	25	18.8	56.2	0
	BH2	0.5	2	60.54	2	20.86	35	14.46	18	7.96	74.04	0
		1	4	45.18	2	26.59	42	14.91	22	20.18	57.82	0
		1.5	8	57.99	2	16.02	38	16.14	20	22.4	57.6	0

		2	16	75.66	2	23.96	63	27.96	20	28	52	0
		2.5	24	93.88	3	21.87	46	21.44	30	20.29	49.71	0
		3	28	112	3	17.55	40.5	13.86	28	15.8	56.2	0
Shah Alam	BH1	0.5	3	25.32	3	32.68	46	13.12	28	33.65	38.35	0
		1	3	39.52	3	64.45	60	23.07	52	33.2	14.8	0
		1.5	3	47.74	3	39.05	56	19.71	52	26	22	0
		2	3	51.58	3	35.06	48	17.28	43	29.8	27.2	0
		2.5	3	52.78	3	53.47	56	14.11	53	34.4	12.6	0
		3	3	52.5	3	66.32	60	18.49	54	29	17	0
	BH2	0.5	3	169.8	3	38.52	44	14.79	37	32	31	0
		1	3	113.7	3	52.7	43.6	17.87	38	21.8	40.2	0
		1.5	3	90.37	3	24.16	55	21.32	44	26	30	0
		2	3	78.28	3	71.91	53	21.51	36	28	36	0
		2.5	5	71.11	5	33.67	50	18.12	40	32	28	0
		3	5	66.69	5	42.08	45	14.79	38	41	21	0
Parit	BH1	0.5	6	137.1		26.14	31	10.77	12	28	60	0
		1	5	235.4		10.51	38	11.71	1.6	7.1	91.3	0
		1.5	5	314.1		11.2	33.8	8.94	8.88	11.12	80	0
		2	4	373.6		23.37	38	6.95	2.42	3.23	94.35	0
		2.5	4	418.5		27.09	38.4	15.31	18	32	50	0
		3	4	452.3		23.87	32	9.95	17	23	60	0
	BH2	0.5	5	438.8		29.97	33	9.45	15	27.77	57.23	0
		1	5	300.1		28.63	33.8	10.28	14	18.28	67.72	0
		1.5	4	337.7		13.5	30	9.13	8.07	13.72	78.21	0
		2	4	355		24.55	34.4	7.01	8.88	11.12	80	0
		2.5	4	358.9		20.58	31	9.38	10	30	60	0
		3	4	356.7		28.18	46	20.11	23	24.62	52.38	0

Tronoh	BH1	0.5	2	434.60		19.84	30.00	10.51	12.91	7.09	80	0
		1	4	444.50		27.82	28.00	3.25	7.26	4.74	88	0
		1.5	6	484.90		14.40	29.00	10.66	11.3	3.23	85.47	0
		2	20	543.50		16.25	25	8.69	23.4	18.57	58.03	0
		2.5	22	601.40		23.84	24.5	10.38	16.95	8.07	74.98	0
		3	24	652.80		13.44	31.5	15.56	23.4	11.6	65	0
	BH2	0.5	2	834.5		27.35	30	7.59	14.53	5.47	80	0
		1	4	901.8		13.92	23	6.3	4.04	4.84	91.12	0
		1.5	8	804.5		13.04	31	12.31	20	10	70	0
		2	16	696.2		14.51	37	18.15	26.63	16.14	57.23	0
		2.5	24	612.7		14.81	19.5	4.96	2.42	2.48	95.1	0
		3	28	554.5		14.25	31	13.39	25.83	7.26	66.91	0
UTP	BH1	1	4	17.40668	3							
		2	4	35.8188	3							
		3	4	255.4446	8							
		4	6	37.45264	8							
		5	9	197.6318	9							
		6	10	56.556	9							
		7	10	65.32218	12							
		8	11	84.2056	12							
		9	11	11.3112	14							
		10	11	115.3114	14							
	BH2	1	10	21.6798	19							
		2	10	54.23092	19							
		3	10	33.4623	21							
		4	10	69.87808	21							
		5	10	0.1571	22							

		6	12	75.21948	32	
		7	16	21.994	34	
		8	16	520.3152	34	
		9	14	299.7468	9	
		10	14	237.5352	9	

Seismic Survey Equipment

2D Resistivity Survey Equipment

Soil Boring

1D Electrical Resistivity Test

2D Electrical Resistivity Test

Seismic Surface Wave Survey