CORRELATION OF ELECTRICAL RESISTIVITY WITH VARIOUS SOIL PROPERTIES: A PRELIMINARY STUDY

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by

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the requirements for the
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CERTIFICATION OF APPROVAL

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Approved by,

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TRONOH, PERAK

July 2009

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.

ALIA SHAZWANI BINTI ABD HAKIM

ABSTRACT

This report basically discusses the preliminary research done and basic understanding of the chosen topic, which is **Correlation of Electrical Resistivity with Various Soil Properties: A Preliminary Study.** The use of electrical resistivity on soil reduces the tedious work in the laboratory and cost and can also ease the future generation in utilizing the method mentioned. The objective of the project is to find correlation between soil resistivity and soil parameters to find the factor of safety (FOS) by applying the Wenner method through simple resistivity method. Conducting a number of experiments on locations such as on a failed slope and on a flat ground to compare the soil types, cohesion, angle of friction (ϕ), standard penetration test, moisture content, and pH undertook the analysis. The experimental tests included the Wenner simple resistivity method on site, direct shear box test, moisture content, and particle size distribution to obtain graphs for the correlation work. Achieving a much more in depth understanding of the soil resistivity behaviors such as the resistivity and shear strength are directly proportional to each other, resistivity and bulk density are directly proportional to each other, resistivity and cohesion are directly proportional to each other, resistivity and standard penetration test are also directly proportional to each other, while the behavior for resistivity and moisture content are inversely proportional to each other. This finding is a part of a much more extensive study which is to eventually develop an empirical formula and is subjected to more studies in the future.

ACKNOWLEDGEMENTS

There are a great number of people that I need to express my gratitude to during my two semesters worth of Final Year Project. These people have guided me to right path and have been advising me throughout my ups and downs in order to stay strong and keep and open mind to whatever that was coming to me in my last memorable year in University Technology of PETRONAS.

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Last but not least, I would like to thank my mother and father for their sacrifices, guidance, and endless support and encouragement in order for me to pursue my higher education. Throughout the past 5 years, countless ups and downs that I have been through, they have been supporting and encouraging to be where I am now.

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CHAPTER 1

1. INTRODUCTION

1.1 Background of Project

Landslide, mudslide, erosion, earthquake, creep, and earth flow are the effects of slope failure. These types of soil failures can be very dangerous for the civilians nearby where it can lead to death. To avoid these kinds of disasters, slope failures must be prevented before it happens. This study research is to correlate electrical resistivity with some soil properties to find factor of safety of slope in hope to eliminate the death toll, natural disasters such as mentioned earlier, financial loss, and time loss if possible.

1.2 Problem Statement

Due to the wet and humid tropical weather in this part of the region, weathering and erosion of soil plays a big factor in slope failure in Malaysia. Erosion of soil can change the geometry of the slope and eventually will result to slope failure or can be known as landslide. Other than that, rainfalls in Malaysia are usually heavy and long that can actually soften and erode the soils. Water may enter into cracks and can weaken the underlying soil layers leading to failure. These types of failures have actually happened and are actually very tragic where it involves in taking away a lot of innocent lives. Tragedy of slope failures such as the Bukit Antarabangsa, Highland Condominium, North – South Highway nearby Gua Tempurung, and many more.

The normal conventional method for finding the factor of safety such as the soil boring where procedures involving in finding the standard penetration test on site and several laboratory works can be very tedious. The main idea of this project is to make the process of finding the factor of safety simpler by using electrical resistivity and soil parameters to save time and cost also in order to achieve preliminary checking to ease the process of finding the factor of safety where it can save money and time.

1.3 Objective and Scope of Study

The objective of this research study is to find the correlation between soil resistivity and soil parameters by utilizing the electrical resistivity method in order to find factor of safety of slope. It is a part of a much more extensive study which is to eventually develop and empirical formula. While the scope of work of this research study focuses on two locations where a failed slope nearby Building 13 in UTP and flat ground nearby Building 14 are involved. Also, two types of work were conducted throughout this project and there were the field investigation work and laboratory work. Field investigation work involved in finding the soil resistivity and the laboratory work involved in finding the particle size distribution, the shear strength by conducting the direct shear box test, and moisture content of the soil. After all these factors are found and gathered, correlation work is done in order to achieve the objective.

CHAPTER 2

2. LITERATURE REVIEW

2.1 Electrical Resistivity; Wenner Method

Electrical resistivity method is one of the most useful techniques in groundwater hydrology exploration. The resistivity method measures the apparent resistivity including the effects of soil type, bedrock fractures, contaminant, and ground water as a function of depth or position. Variations in electrical resistivity may indicate changes in composition, layer thickness or contaminant levels. The resistivity of soils is a complicated function of porosity, permeability, ionic content of the pore fluids, and clay mineralization. Most commonly used method in environmental investigations is vertical resistivity profiling.

Dependencies of earth resistivities:

- Water ↑, ρ ↓
- Temperature ↑, ρ ↓
- Porosity ↑, ρ ↓ (water filled)
- Clays ↑, ρ ↓

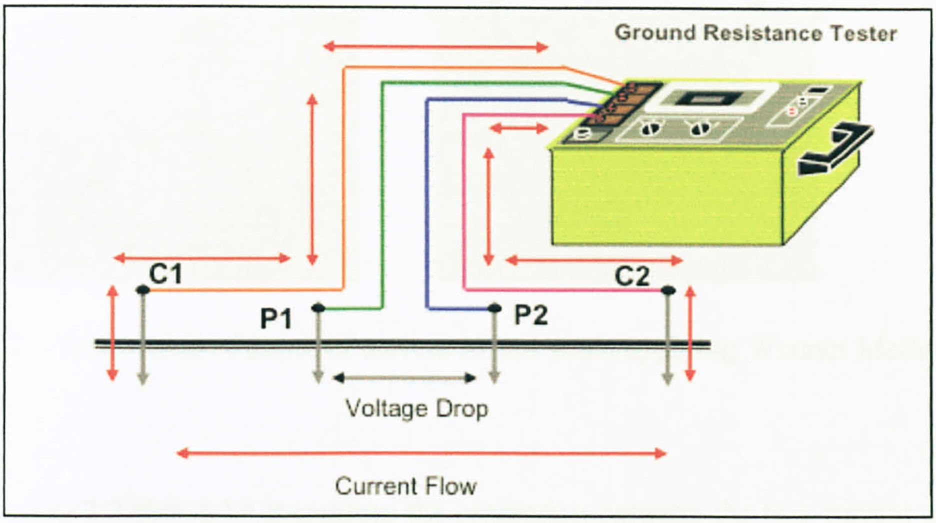


Figure 2.1 – Setup of the equipment using Wenner method.

Soil resistivity data is important when it comes to designing a grounding system for a specific performance where designers have a better understanding towards the underlying soil. All soil conducts electrical current, with some soils having good electrical conductivity while the majority has poor electrical conductivity. Resistivity of soil varies widely where its resistivity mainly influenced by the type of soil, such as clay, shale, etc., moisture content, the amount of electrolytes (minerals and dissolved salts) and finally, temperature.

The best method for testing soil resistivity is the Wenner Four Point method. It uses a four ground resistance meters or electrodes to measure the resistivity of the soil along with other necessary equipments such as the laboratory DC power supply, multimeter, and electrodes. The electrodes are required to be installed in the ground to establish electrical contacts with the earth in the test area. The electrodes installed must be in a straight line and equally spaced. Once the current value is set to a constant, the electrodes will inject the current through the two outer electrodes and the current flowing through the earth will eventually develop voltage values.

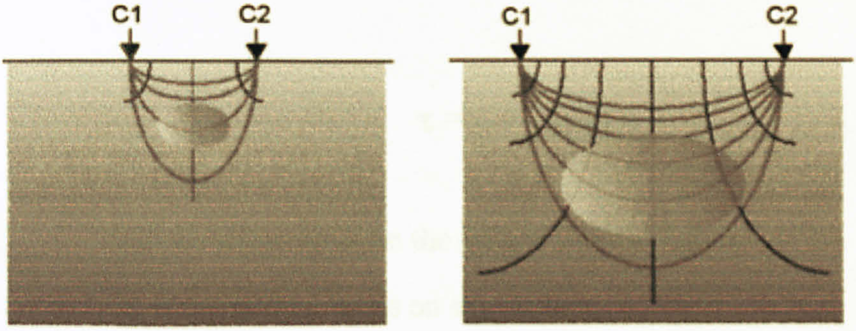


Figure 2.2 – Penetration of depth of current in soil when applying Wenner Method.

Figure 2.2 shows by increasing the separation between the two current electrodes electrical current is able to penetrate deeper into the ground and the measured earth resistance is affected by features at greater depth (Schmidt, 2007).

2.2 Shear Strength: Mohr-Coulomb's Failure Criterion

Due to many studies and development of the related subject, many analyses are expressed in terms of the Mohr-Coulomb cohesion (c) and friction angle (ϕ), defined in Equation 2.1, which is used to calculate factor of safety against sliding.

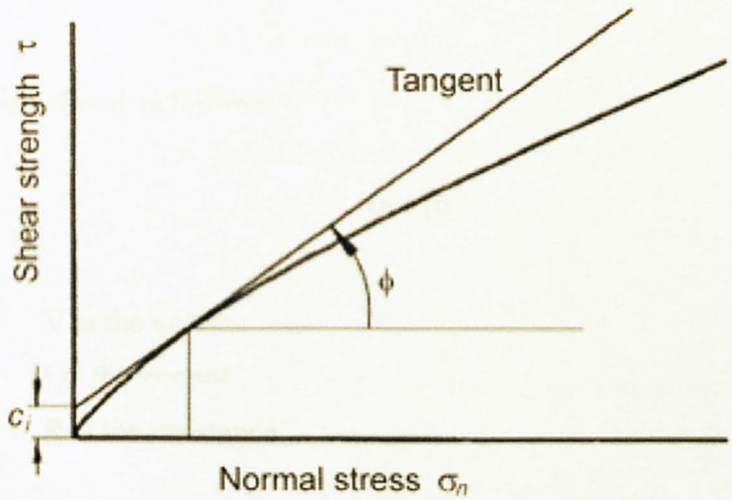


Figure 2.3 – Definition of instantaneous cohesion c_i and instantaneous friction angle ϕ_i for a non-linear failure criterion.

$$\tau = c + \sigma_n \tan \phi \tag{2.1}$$

where; τ is the shear stress on the failure plane at failure

σ_n is the normal stress on slip surface

c is the apparent cohesion and

ϕ is the angle of friction

Figure 2.3 above gives a better picture on the definition of the instantaneous cohesion c_i and the instantaneous friction angle ϕ_i for a normal stress of σ_n. The interception and inclination of the tangent to the non-linear relationship between shear strength (τ) and normal stress (σ_n), respectively. The obtained quantities may be used for stability analyses, which the Mohr-Coulomb failure criterion equation is developed (Equation 2.1) provided that the normal stress σ_n is reasonably close to the value used to define the tangent point (Barton, 1976).

2.3 Ohm's Law

Ohm's law is defined as follows:

$$V = IR \tag{2.2}$$

where: V is the voltage

I is the current

R is the resistance

Ohm's Law can be used to solve simple circuits. The law stating that the direct current flowing in a conductor is directly proportional to the potential difference between its ends. Basically, it describes the relationship between voltage, current, and resistance. A complete circuit, which is a closed loop, contains at least one source of voltage and at least one potential drop, a place where potential energy decreases. The sum of the voltages around a complete circuit is zero.

2.4 Factor of Safety (FOS)

Failure of slopes are mainly due to its material shear strength on the sliding surface is insufficient to resist the actual stresses. Factor of safety (FOS) is a value that is used to measure the stability of the slopes.

$$FOS = \frac{c'}{\gamma H \cos^2\beta \tan\beta} + \frac{\tan\phi'}{\tan\beta} \qquad (2.3)$$

where; c is the effective cohesion

ϕ is the effective angle of friction

σ_f is the effective stress at failure, and

τ_f is the shear stress at failure

For FOS values greater than 1 means the slope is stable, while values lower that 1 means slope is unstable. In accordance to the shear failure, the factor of safety against slope failure is simply calculated as Equation 2.3 (Arai and Tagyo, 1985).

2.5 Factors Affecting Resistivity in Soil

2.5.1 Particle Size Distribution (PSD)

Particle size distribution of a material can be important in understanding its physical and chemical properties. It affects the strength and load-bearing properties of rocks and soils and reactivity of solids participating in chemical reactions. PSD is usually determined by the method of sieve analysis, where powder like soil is separated on sieves of different sizes. The sieve analysis method is simply shaking of the sample in sieves until the amount retained becomes more or less constant. This is mainly due to the sample been blown through with an air current. In the end, it is to determine the size distribution of soil with the sieve analysis particle size distribution test.

2.5.2 Moisture Content

Moisture content is the quantity of water contained in a material, such as soil, rock, ceramics, or wood. This property is used in a wide range of scientific and technical areas that can be measured by the method of drying the soil sample in a drying oven. In geotechnical perspective, it is required that the moisture content to be expressed as a percentage.

$$U = \frac{M_{wet} - M_{dry}}{M_{dry}} \times (100) \qquad (2.4)$$

2.6 Slope Stability

Analysis of slope stability is usually performed to assess the potential for failure of the slope by rupture. There are a number of slope stability problems such as illustrated in Figure 2.4. The slope failures depend on the soil stratification, soil type, groundwater, seepage, and the slope geometry. The main objective of a stability analysis is to determine the factor of safety (FOS) of a particular slope, to predict when failure is about to happen, and to assess which type of treatment to the slope is necessary. This study is focused on a quick method of determination of slope stability (Hack, 2002).

Landslide basically describes a wide variety of processes that result in the downward and outward movement of slope-forming materials including rock, soil, artificial fill, or a combination of these. The materials may move by falling, toppling, sliding, spreading, or flowing. These are the five (5) categories of landslide that is most common in the world. If two or more types of movements are involved, the slides are termed as complex. For further understanding of the landslide categories, it is illustrated in Figure 2.5.

Although landslides are primarily associated with mountainous regions, they can also occur in areas of generally low relief. In these areas, landslides occur as cut-and-fill failures, such that in roadway and building excavations, river bluff failures, lateral spreading landslides, and a wide variety of slope failures associated with quarries and open-pit mines (Van Impe and Verastegui Flores, 2007).

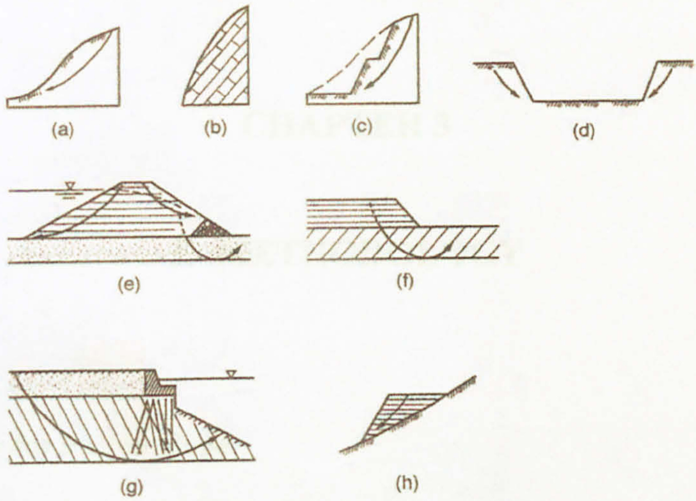
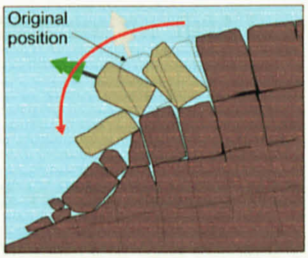
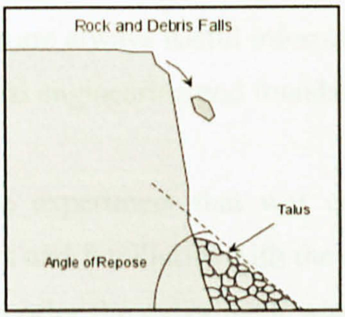


Figure 2.4 – Categories of slope stability problems: (a) natural soil slope; (b) natural rock slope; (c) cut slope; (d) open excavation; (e) earth dam embankment; (f) embankment over soft soils; (g) waterfront structure; (h) side hill fill.

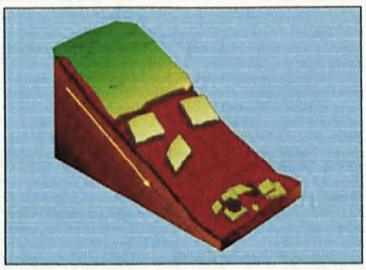
(a) Lateral Spread



(b) Topple



(c) Fall



(d) Flow

Figure 2.5 – Categories of Landslides.

CHAPTER 3

3. METHODOLOGY

3.1 Process Flow for Failed Slope

In order to meet with the objective of this project, the work required includes planning and doing research on related topics, such as the electrical resistivity device and study of geotechnical engineering and foundation earth and structures, conducting experiment on the factors discussed, analyzing the result of experiment, and finally coming up with the best alternative based on the results of experiment. Figure 3.1 and 3.2 show the process flow diagrams of the project, which are the field investigation and laboratory work.

The best technique for conducting research is via the Internet, where there are a lot of online resources available that are related to engineering and related to the topic of study. Other than that, online journals are also useful and a good source for the research. Also, there are always useful information about the related topic in books that are used in geotechnical engineering and foundation earth and structures.

The experiment that was conducted needed a preparation such as tools and equipments and familiarity with the site due to its condition. Installation of rods needed to be done prior the experiment where the span of the lining of the rods was more than forty meters (40m). In addition, setting up of equipments such as the generator, DC Power Supply, and the multimeter need to be placed at a precise location for convenience purposes where the slope can be a challenging place to conduct experiments. Once the tools and equipments are installed and ready, Wenner simple resistivity method in 1D can be performed at a point near borehole up to fourteen meters (14m) deep. After the first line was done, points at eight meters (8m) down away from the borehole and eight meters (8m) up away from the borehole were also performed. With the obtained data, a comparison of the properties of the various soil could be assessed and conclusions relating to the finding of the factor of safety.

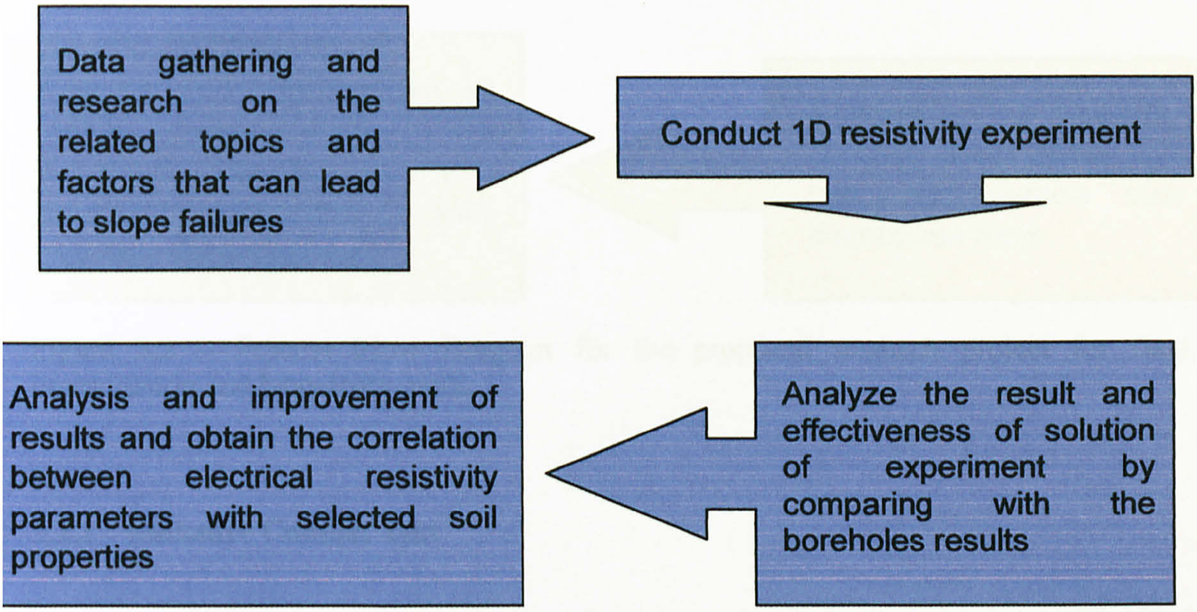


Figure 3.1 – Process Flow Diagram for the proposed research project for field investigation.

3.2 Process Flow for Flat Ground

As for the laboratory work, other soil samples from a site nearby Building 14 in UTP were excavated in order to conduct the moisture content test, shear box test, and particle size distribution test. This was followed by Wenner simple resistivity method test in 1D on the sample locations. The testing includes determining the size of the soil particles, shear characteristics, and assessing the moisture content of the soil samples.

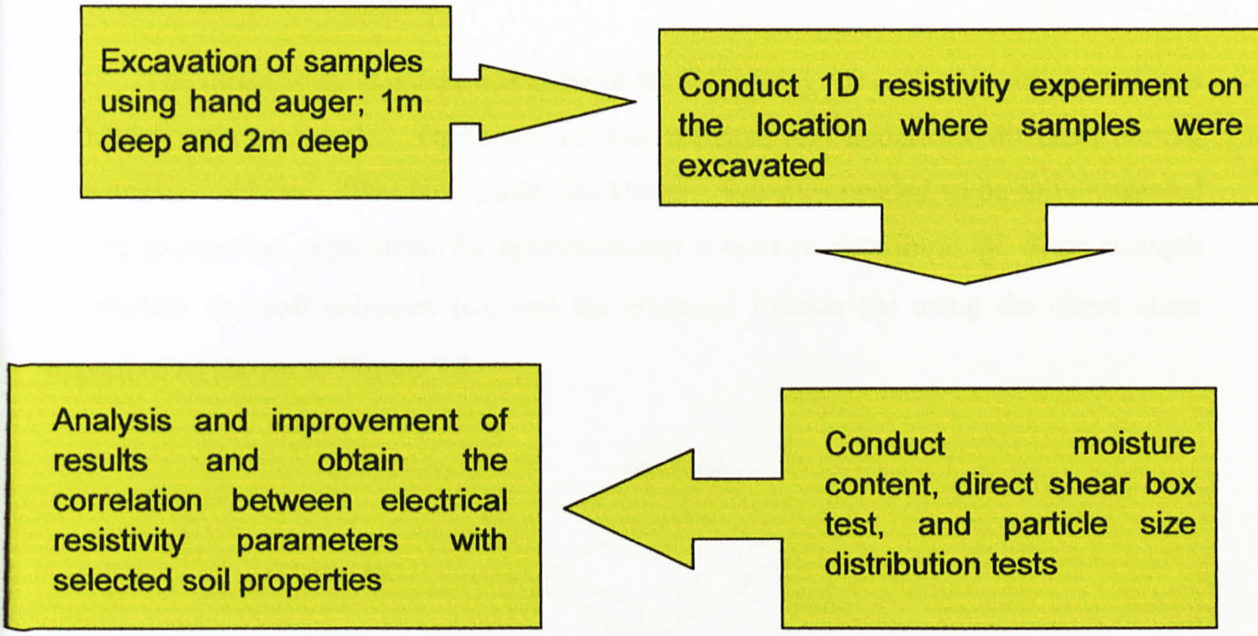


Figure 3.2 – Process Flow Diagram for the proposed research project for field investigation and laboratory work.

3.2.1 Moisture Content Test

Moisture content tests would take about 16 to 24 hours with oven temperature at 110°C to dry the soil sample in order to find the moisture loss. It is also can be calculated by utilizing Equation 2.4.

Figure 3.3 – Oven dried samples at 110°C.

3.2.2 Direct Shear Box Test

The direct shear box test was done in the laboratory for each soil sample that was extracted from each hole. Three sets of specimens of soil undertook different normal pressures, 100kN/m^2, 200 kN/m^2, and 300 kN/m^2. Samples needed to be fully saturated before conducting experiment for approximately 1 hour to determine the shear strength parameters, the soil cohesion (c), and the angle of friction (ϕ) using the direct shear apparatus as shown in Figure 3.4.

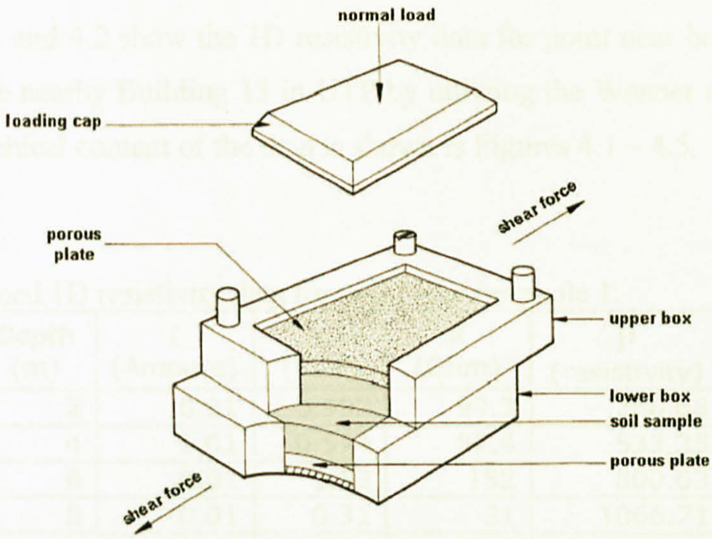


Figure 3.4 – Schematic diagram of direct shear apparatus.

3.2.3 Particle Size Distribution (PSD)

As a measurement technique for particle size distribution, sieve analysis seems to be the most reliable type of measurement where this method involved shaking of the sample in sieves until the amount retained becomes more or less constant. Sieve sizes ranged between 2mm - 63µm will be adequate enough to determine the soil particle size distribution. Sample preparations include drying of samples and have it in a powder form before proceeding to the sieve analysis where the final result will be classified according to the ASTM D 2487 standard.

CHAPTER 4

4. RESULT AND DISCUSSION

4.1 Results and Analysis of Field Investigation on Failed Slope

Tables 4.1 and 4.2 show the 1D resistivity data for point near borehole 1 located on the failed slope nearby Building 13 in UTP by utilizing the Wenner simple resistivity method. The graphical content of the data is shown is Figures 4.1 – 4.5.

Table 4.1 – Obtained 1D resistivity data for point near borehole 1.

Depth (m)	I (Ampere)	V (Volt)	R (Ohm)	ρ (resistivity)
2	0.01	0.993	99.3	266.68
4	0.01	0.574	57.4	533.35
6	0.01	1.52	152	800.03
8	0.01	0.31	31	1066.71
10	0.01	0.357	35.7	1333.39
12	0.01	0.91	91.0	1600.06
14	0.01	0.21	21	1866.74
		R_{ave} =	69.63	

Table 4.2 – Data for point near borehole 1, correlation with other factors of the soil conducted by contractors.

ρ (resistivity)	Standard Penetration Test	Moisture Content	Bulk Density	ϕ, Shear Angle
266.7	10	32	1.823	
533.4	9	24	1.98	32
800.0	9	22	1.98	
1066.7	9	24		
1333.4	25	17	2.122	35
1600.1	50	16		
1866.7	50	13		

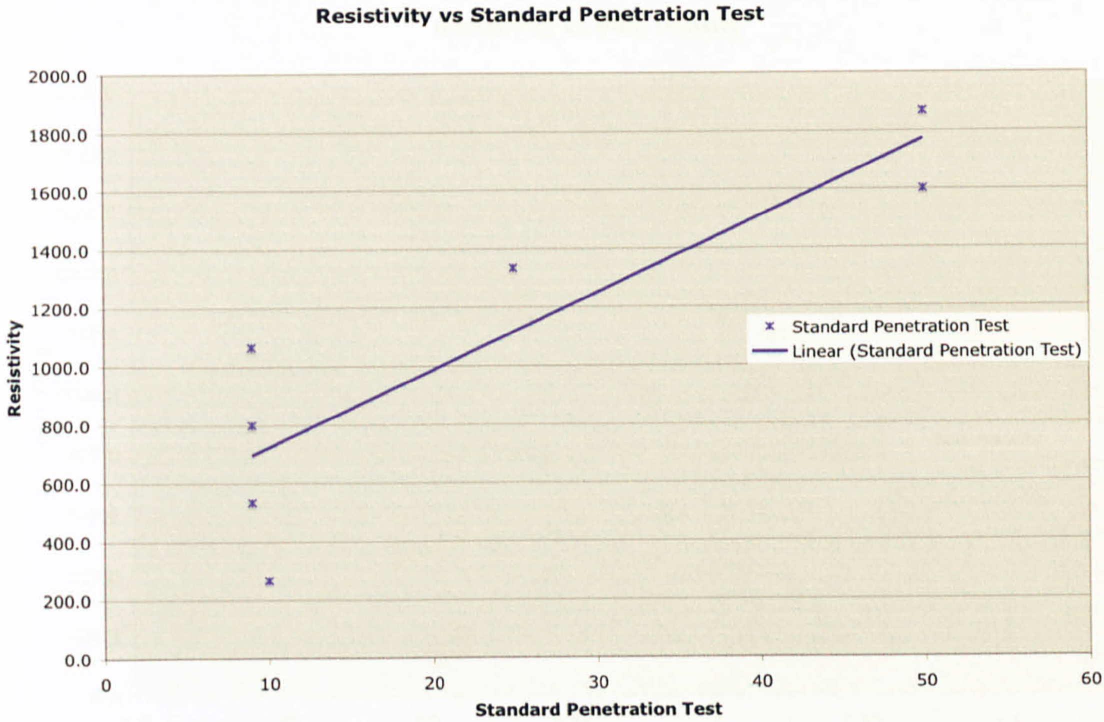


Figure 4.1 – Resistivity vs Standard Penetration Test for borehole 1.

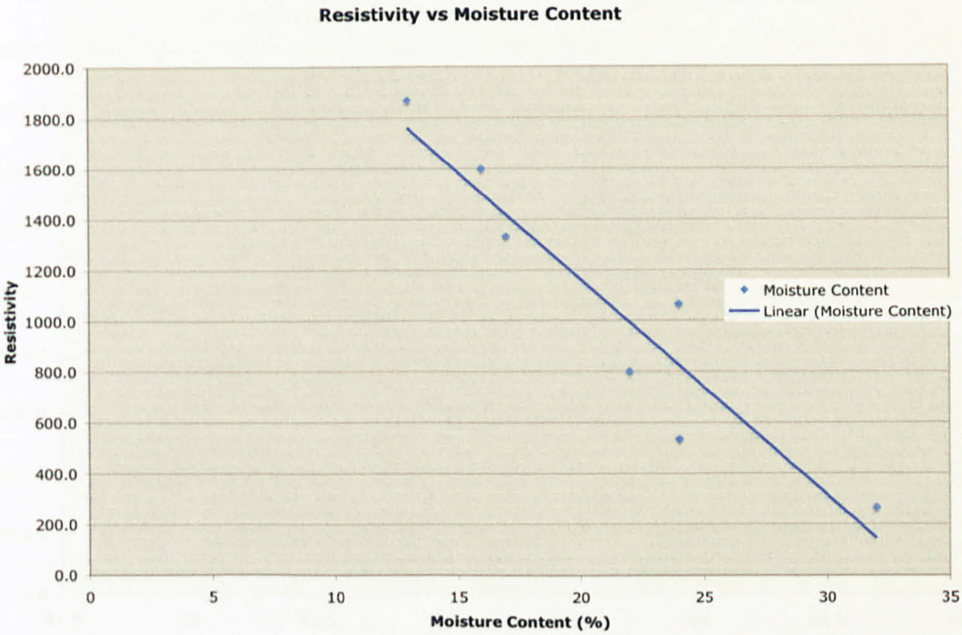


Figure 4.2 – Resistivity vs Moisture Content fo borehole 1.

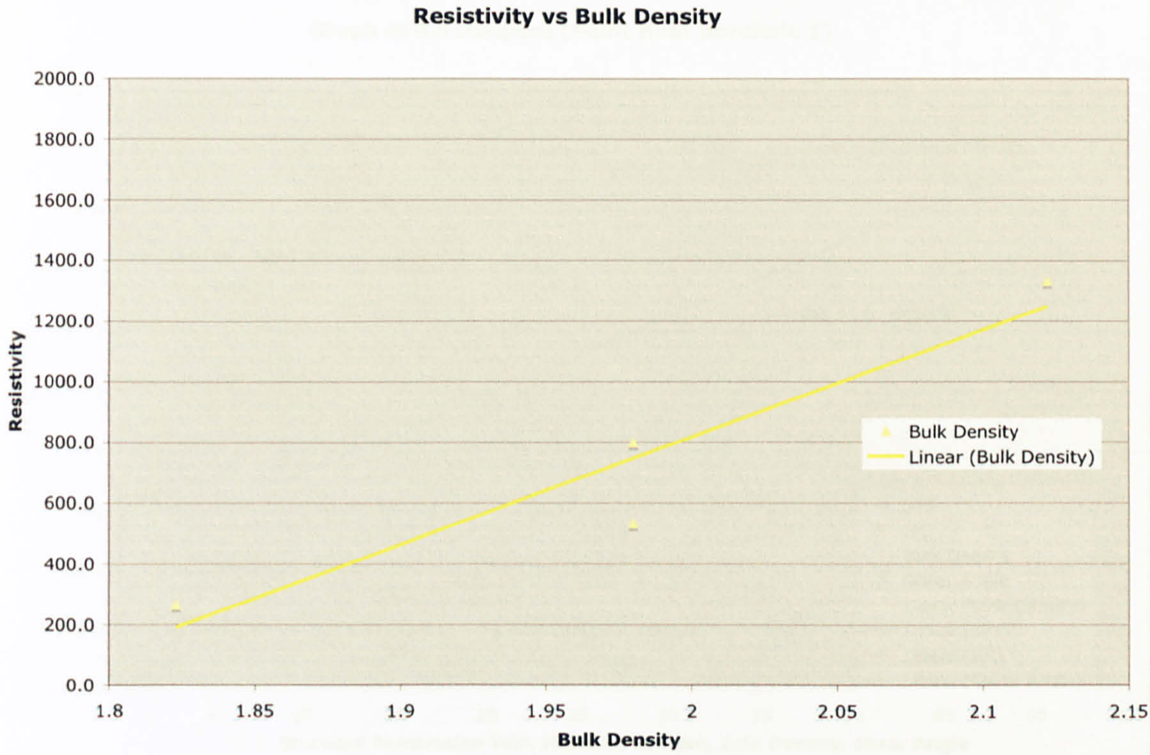


Figure 4.3 – Resistivity vs Bulk Density for borehole 1.

Figure 4.4 – Resistivity vs Shear Angle for borehole 1.

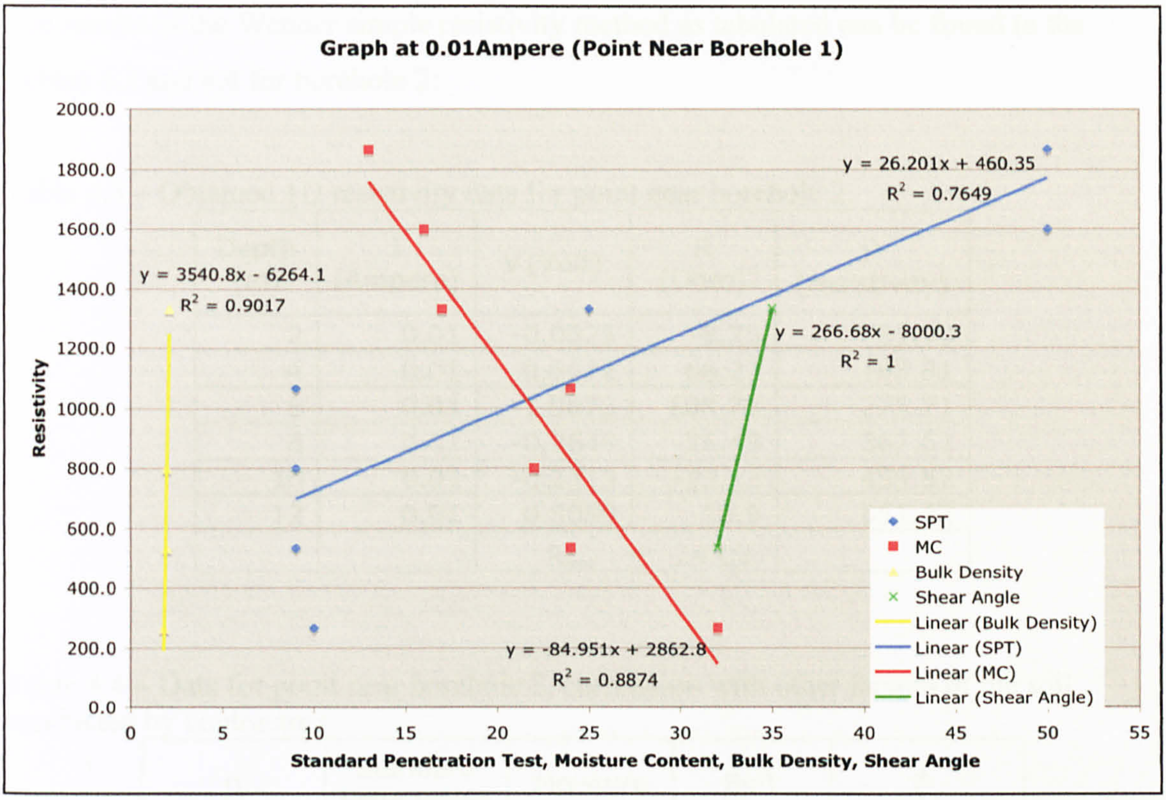


Figure 4.5 – Graph at 0.01A, point near borehole 1.

A field investigation was done at the chosen slope and the experiment conducted was based on Wenner method using simple resistivity method where data obtained were in forms of one-dimensional (1D). The result of the Wenner simple resistivity method shows that the deeper the soil is, the higher resistivity value is obtained. Together with the laboratory data that was previously done on the borehole, the graph above was able to put together in order to see the correlations between the laboratory data with the resistivity data.

The resistivity values were calculated through the equation below:

$$\rho = 1.915 * R_{ave} * D \qquad (4.1)$$

where; R_{ave} is the average resistance, and

D is the depth

The results of the Wenner simple resistivity method as tabulated can be found in the Tables 4.3 and 4.4 for borehole 2:

Table 4.3 – Obtained 1D resistivity data for point near borehole 2.

Depth (m)	I (Ampere)	V (Volt)	R (Ohm)	ρ (resistivity)
2	0.01	-0.0825	-8.25	91.90
4	0.01	0.6622	66.22	183.81
6	0.01	1.0873	108.73	275.71
8	0.01	-0.2649	-26.49	367.61
10	0.01	-0.2313	-23.13	459.52
12	0.01	0.5089	50.9	551.42
		R_{ave} =	24.00	

Table 4.4 – Data for point near borehole 2, correlation with other factors of the soil conducted by contractors.

ρ (resistivity)	Standard Penetration Test	Moisture Content	Bulk Density	ϕ, Shear Angle
91.90	2	30	1.828	27
183.81	9	25	1.864	
275.71	0	22	1.951	
367.61	16	22		30
459.52	36	17		
551.42	50	15		

As for the result for point near borehole 2, the outcome of the graphs are very much similar to the graph result from point near borehole 1. The results of these tests implied that the correlations between the laboratory data such as the standard penetration test, moisture content, bulk density, and shear angle and the resistivity data are possible.

Refer to Figures 4.6 – 4.10 for graphical data of the obtained results from the field investigation and Appendix A for details of laboratory data done by the contractors.

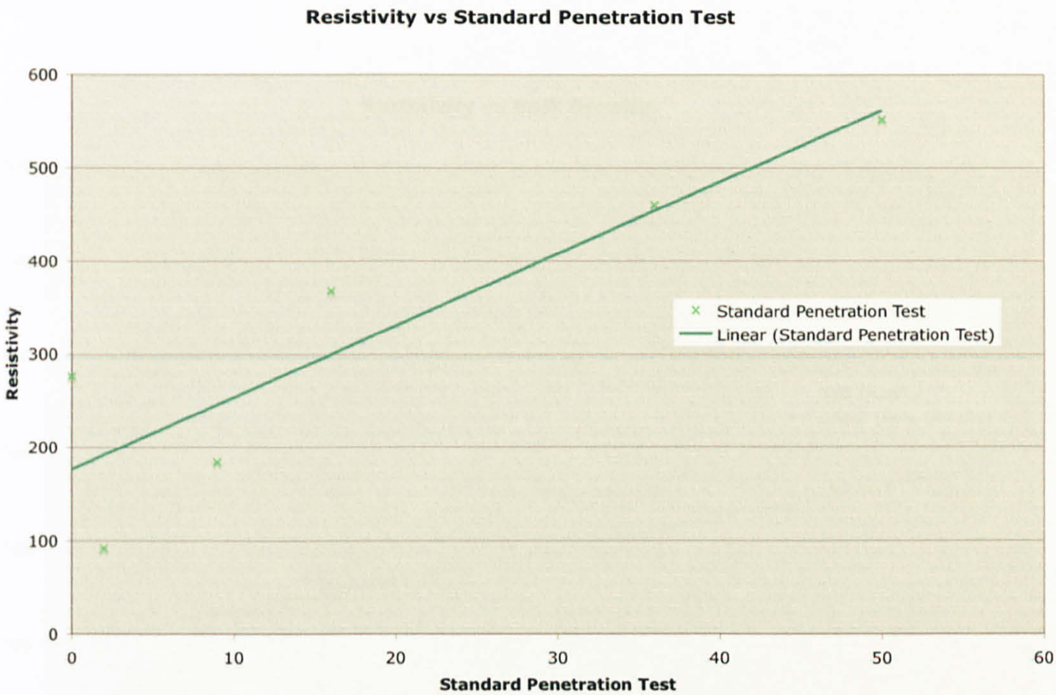


Figure 4.6 – Resistivity vs Standart Penetration Test for borehole 2.

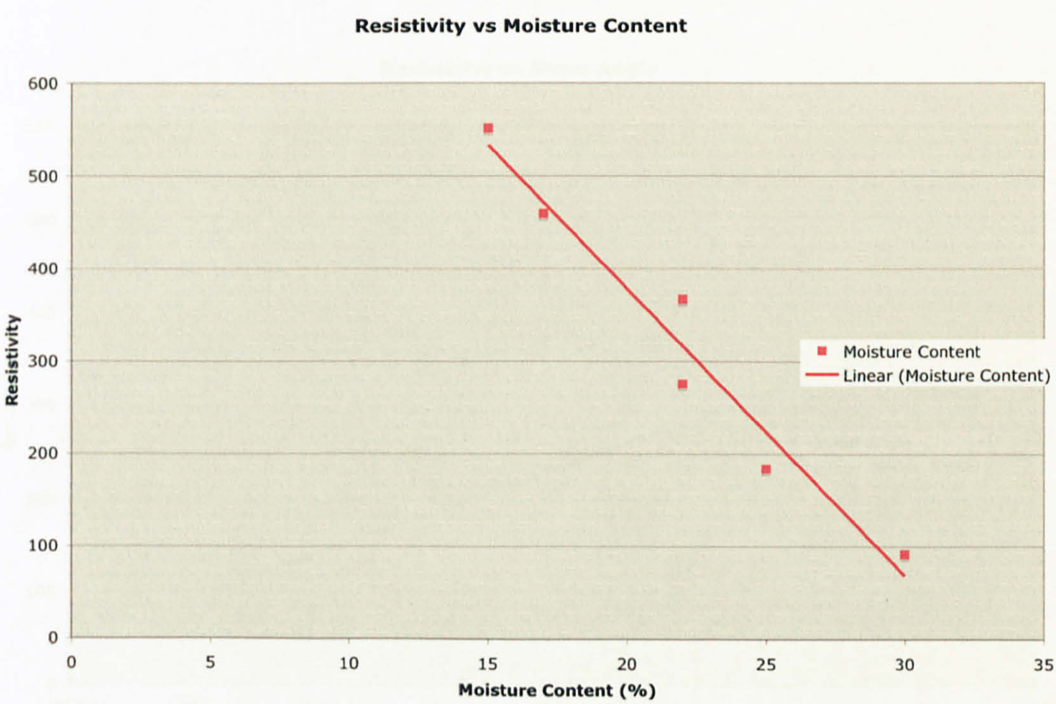


Figure 4.7 – Resistivity vs Moisture Content for borehole 2.

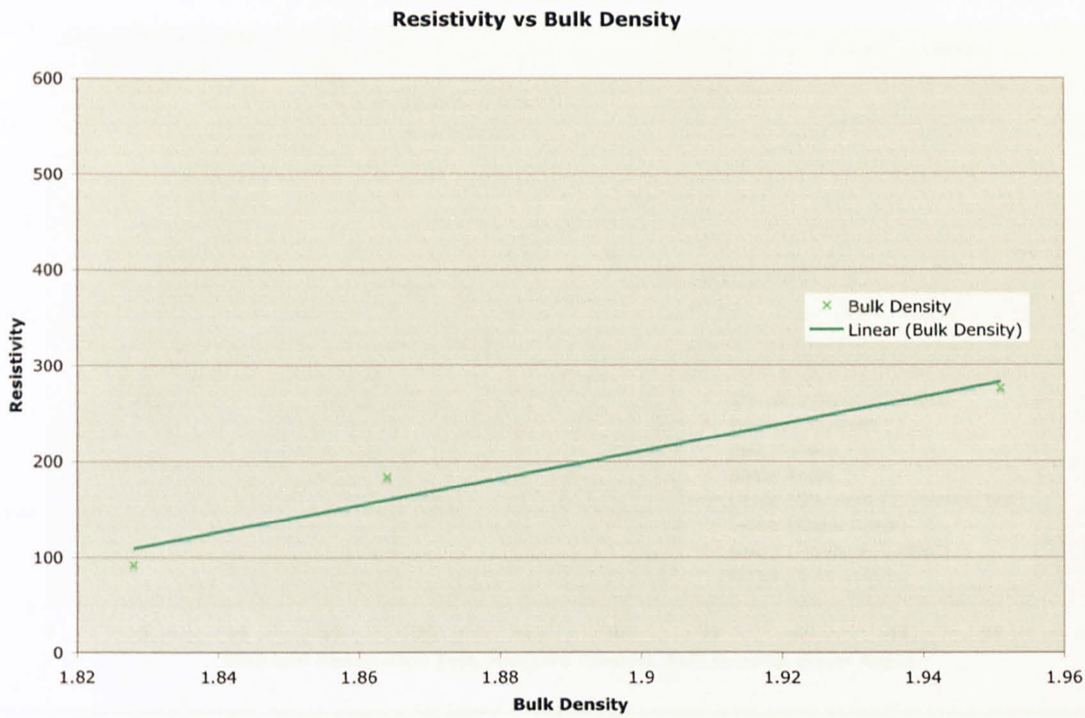


Figure 4.8 – Resistivity vs Bulk Density for borehole 2.

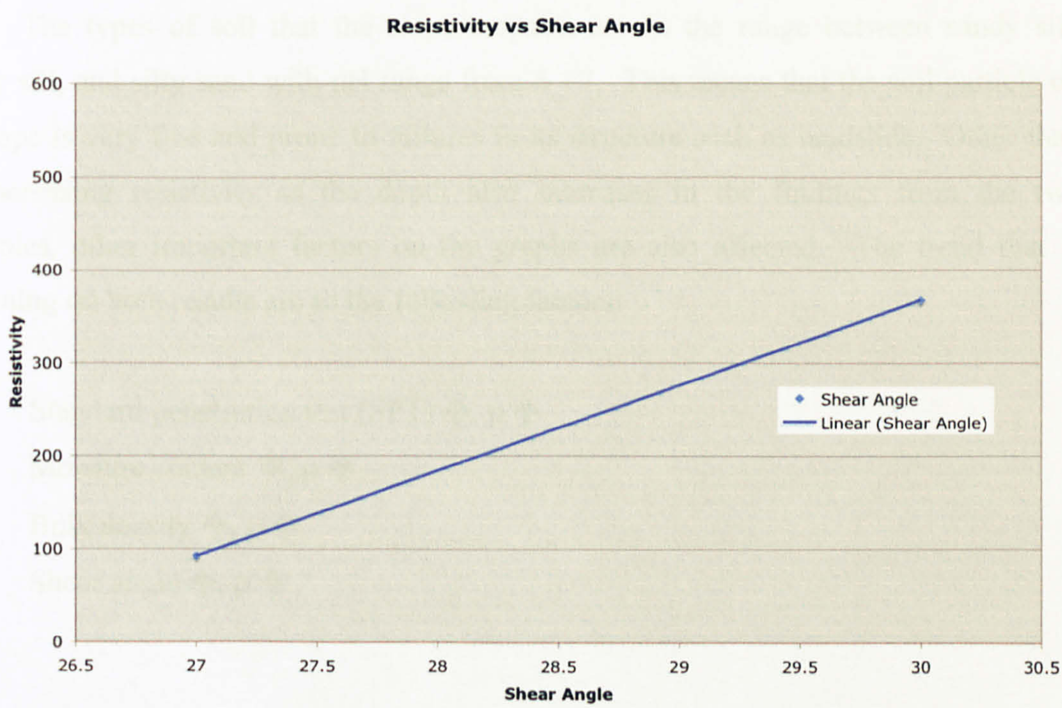


Figure 4.9 – Resistivity vs Shear Angle for borehole 2.

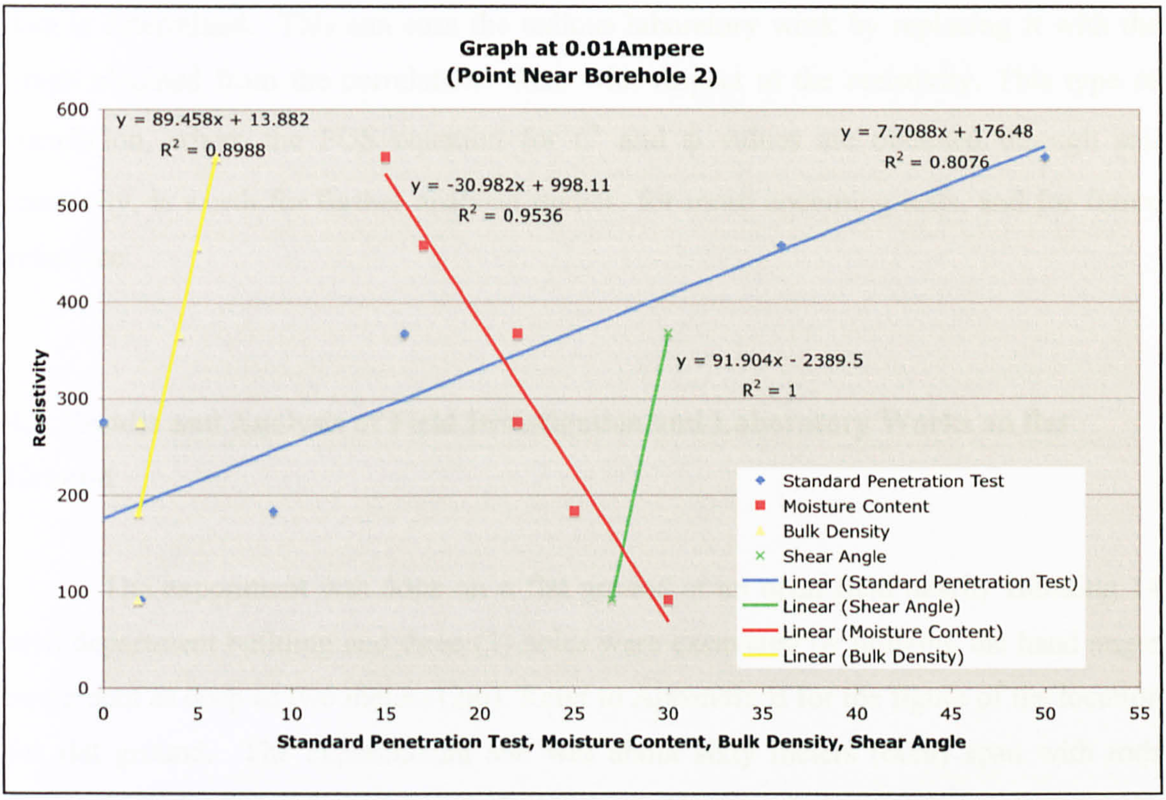


Figure 4.10 – Graph at 0.01A, point near borehole 2.

The types of soil that the slope contains are in the range between sandy silt, clayey silt, and silty sand with pH range from 6 - 7. This means that the soil particle on the slope is very fine and prone to failures in its structure such as landslide. Other than the increasing resistivity as the depth also increases in the findings from the two boreholes, other important factors on the graphs are also affected. The trend that is happening on both results are as the following factors:

- Standard penetration test (SPT) ↑, ρ ↑
- Moisture content ↓, ρ ↑
- Bulk density ↑, ρ ↑
- Shear angle ↑, ρ ↑

In addition to this type of result outcome, a new way of finding laboratory work data is determined. This can ease the tedious laboratory work by replacing it with the graph obtained from the correlations done with respect to the resistivity. This type of correlation, where the FOS equation for c' and ϕ values are obtained through soil resistivity, is worth for further analysis studies, for more upcoming tests, and for future reference.

4.2 Results and Analysis of Field Investigation and Laboratory Works on flat Ground

The experiment was done on a flat ground at an open field nearby Building 14 civil department building and three (3) holes were excavated by utilizing the hand auger equipment as deep as two meters (2m). Refer to Appendix B for the figure of the location for flat ground. The experimental site was about sixty meters (60m) span with rods installed at the gap of one meter (1m). In order to get the voltage values of the underlying soil, current value was set to a constant of 0.2A. For 1D data, the center of the line is at point seventeen meters (17m) and values are obtained up to three meters in depth, while for the other two holes, 1D data was obtained up to three meters as well. Tables 4.5 and 4.6 show the result for 1D resitivity and the laboratory results done for direct shear test, moisture content, and particle size distribution.

Table 4.5 – Obtained data for 1D Wenner method at seventeen meters (17m) center point of hole 1.

Depth (m)	I (Ampere)	V (Volt)	R (Ω)	ρ (resistivity)
1	0.2	0.921	4.61	9.87
2	0.2	1.471	7.36	19.74
3	0.2	0.7008	3.50	29.61
		R_{ave} =	5.15	

Table 4.6 – Laboratory data for hole 1.

Depth (m)	Resistivity (ρ)	Moisture Content (%)	Cohesion (c)	Phi (φ)
1	9.87	42.97	16.597	0.64°
2	19.74	24.9	29.734	2.86°

Figures 4.11 – 4.14 are graphical data where values for cohesion (c) and shear angle (φ) and particle size distribution were found for hole one at 1m and 2m depth soil samples.

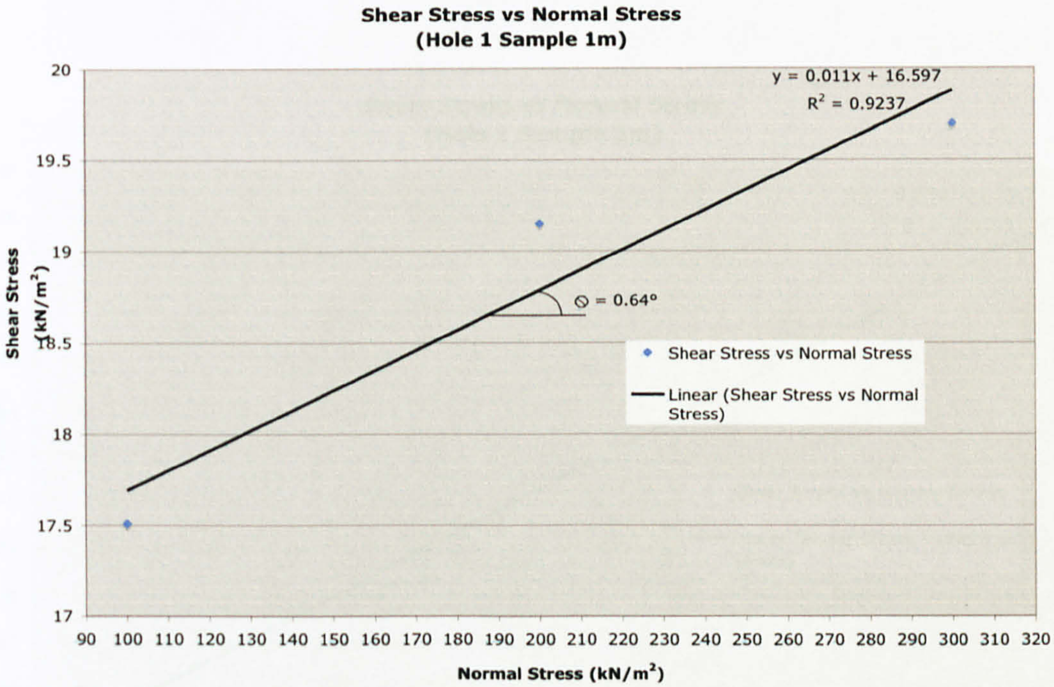


Figure 4.11 – Shear Stress vs Normal Stress for hole 1 sample 1m.

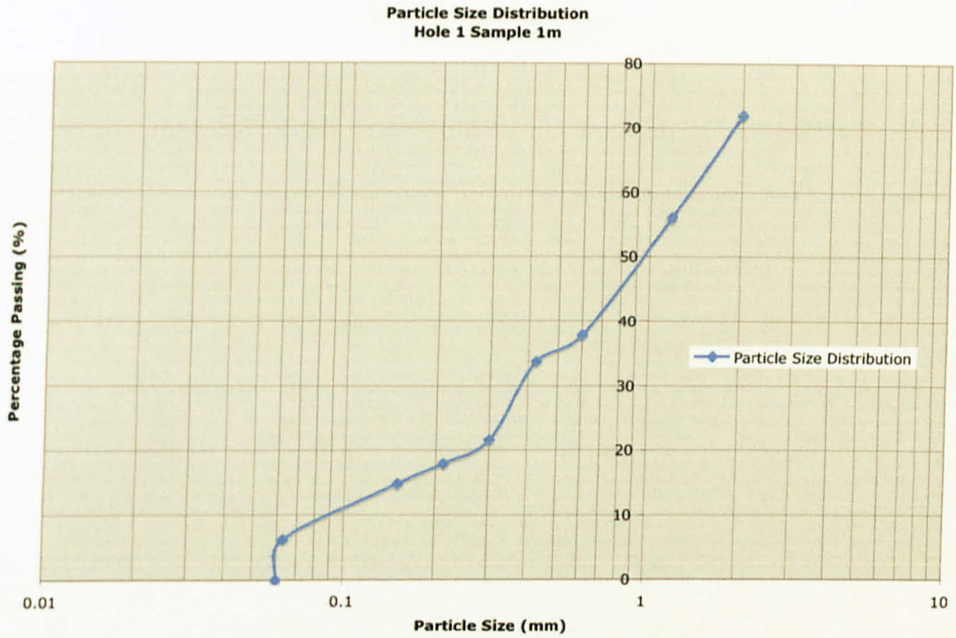


Figure 4.12 – Particle Size Distribution for hole 1 sample 1m.

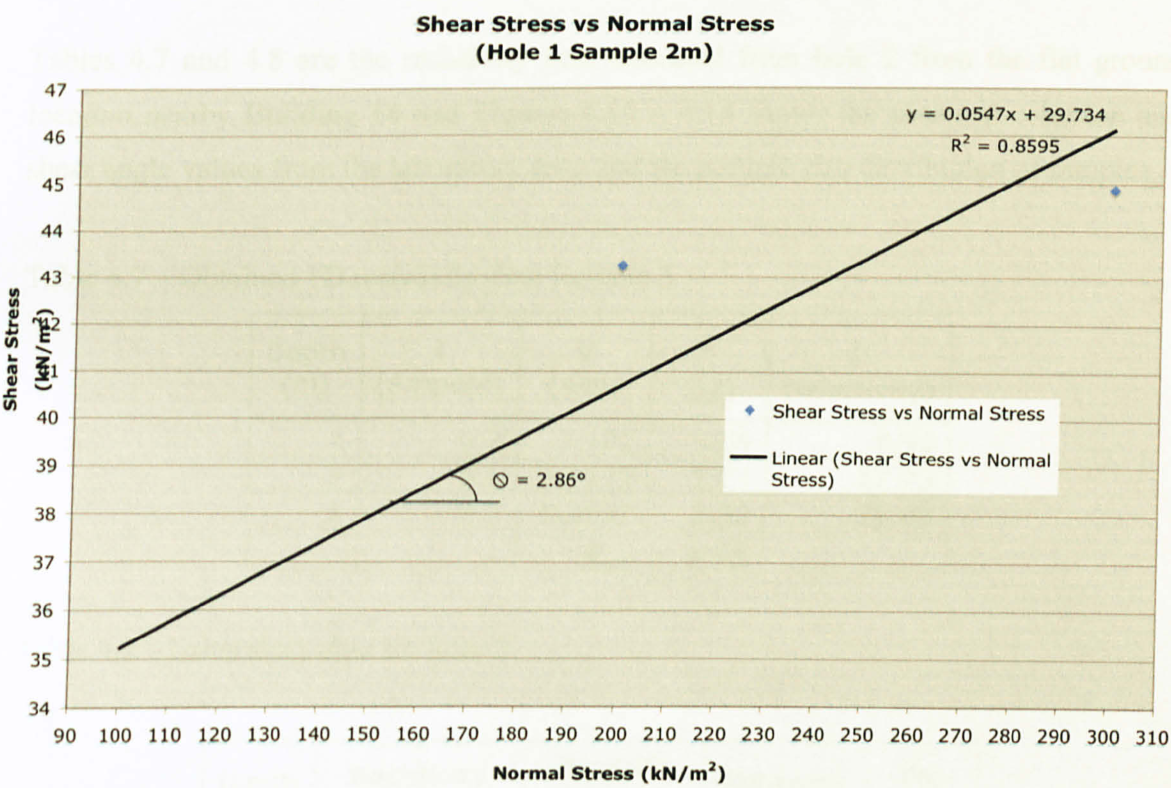


Figure 4.13 – Shear Stress vs Normal Stress for hole1 sample 2m.

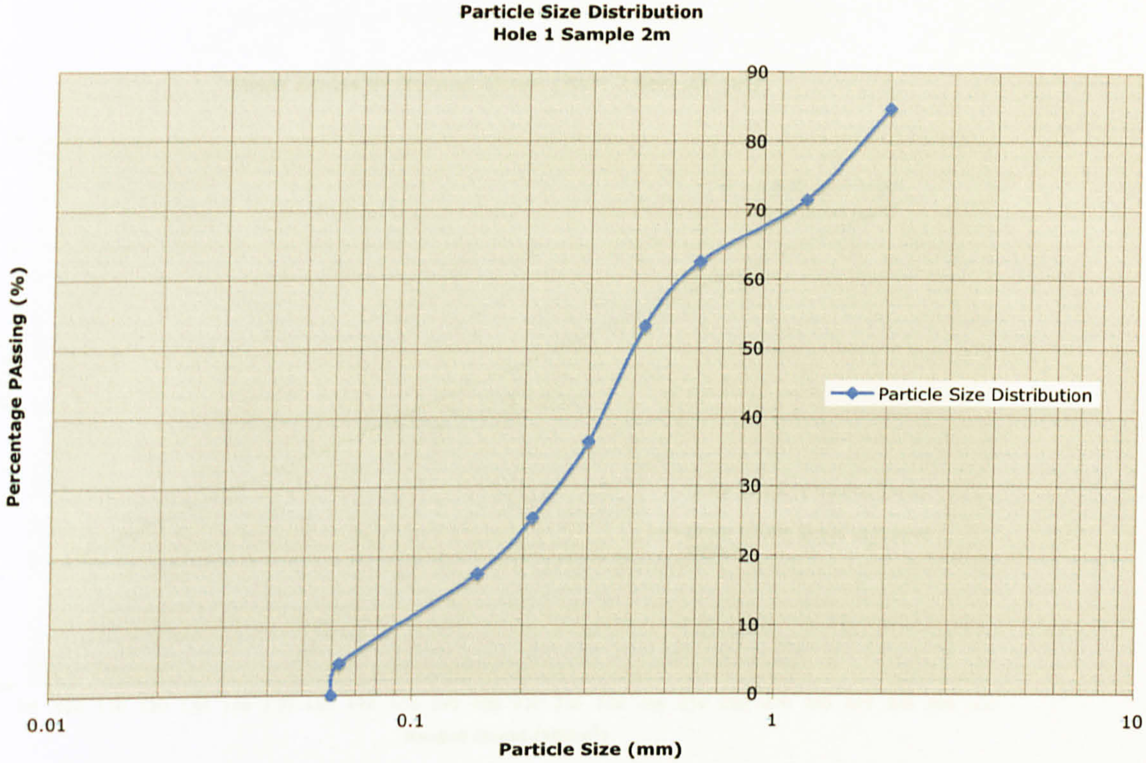


Figure 4.14 – Particle Size Distribution for hole 1 sample 2m.

Tables 4.7 and 4.8 are the resistivity data collected from hole 2 from the flat ground location nearby Building 14 and Figures 4.15 – 4.18 shows the obtained cohesion and shear angle values from the laboratory tests and the particle size distribution of samples.

Table 4.7 – Obtained 1D resistivity data for hole 2.

Depth (m)	I (Ampere)	V (Volt)	R (Ω)	ρ (resistivity)
1	0.2	1.107	5.54	8.96
2	0.2	1.1377	5.69	17.93
3	0.2	0.5637	2.82	26.89
		R_{ave} =	4.68	

Table 4.8 – Laboratory data for hole 2.

Depth (m)	Resistivity (ρ)	Moisture Content (%)	Cohesion (c)	Phi (ϕ)
1	8.96	48.33	13.503	0.95°
2	17.93	38.29	12.033	1.74°

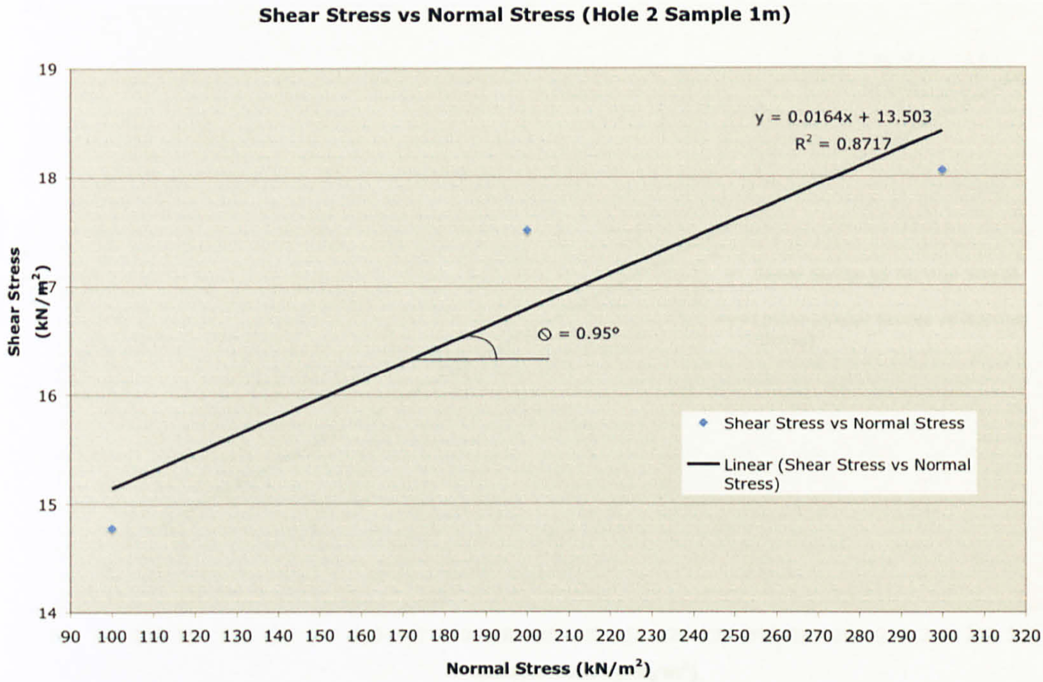


Figure 4.15 – Shear Stress vs Normal Stress for hole 2 sample 1m.

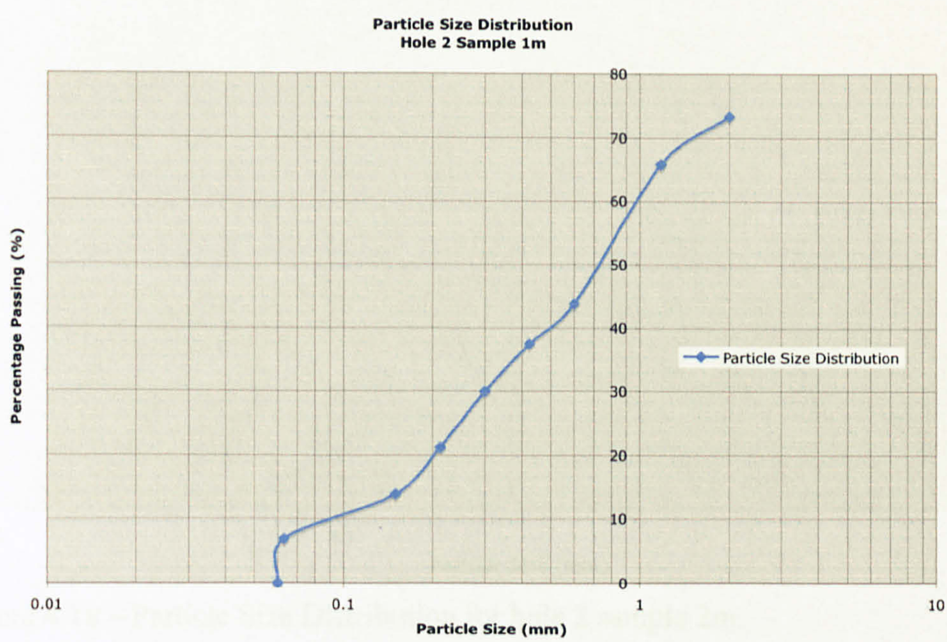


Figure 4.16 – Particle Size Distribution for hole 2 sample 1m.

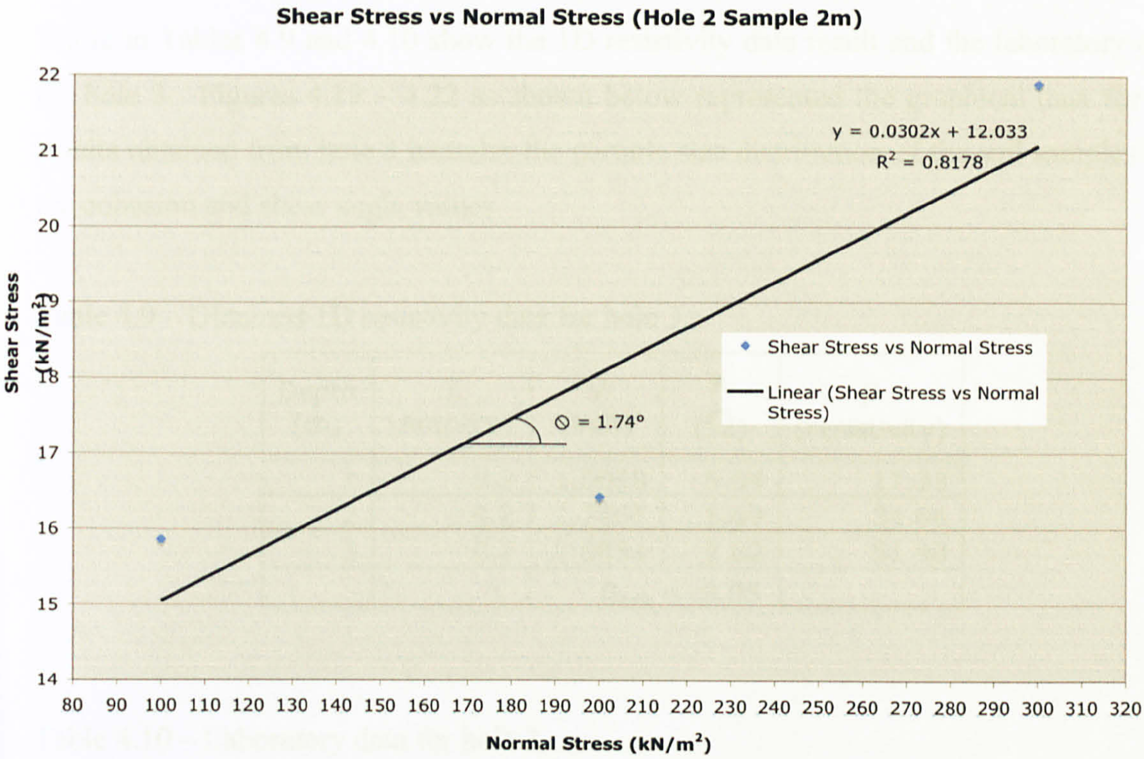


Figure 4.17 – Shear Stress vs Normal Stress for hole 2 sample 2m.

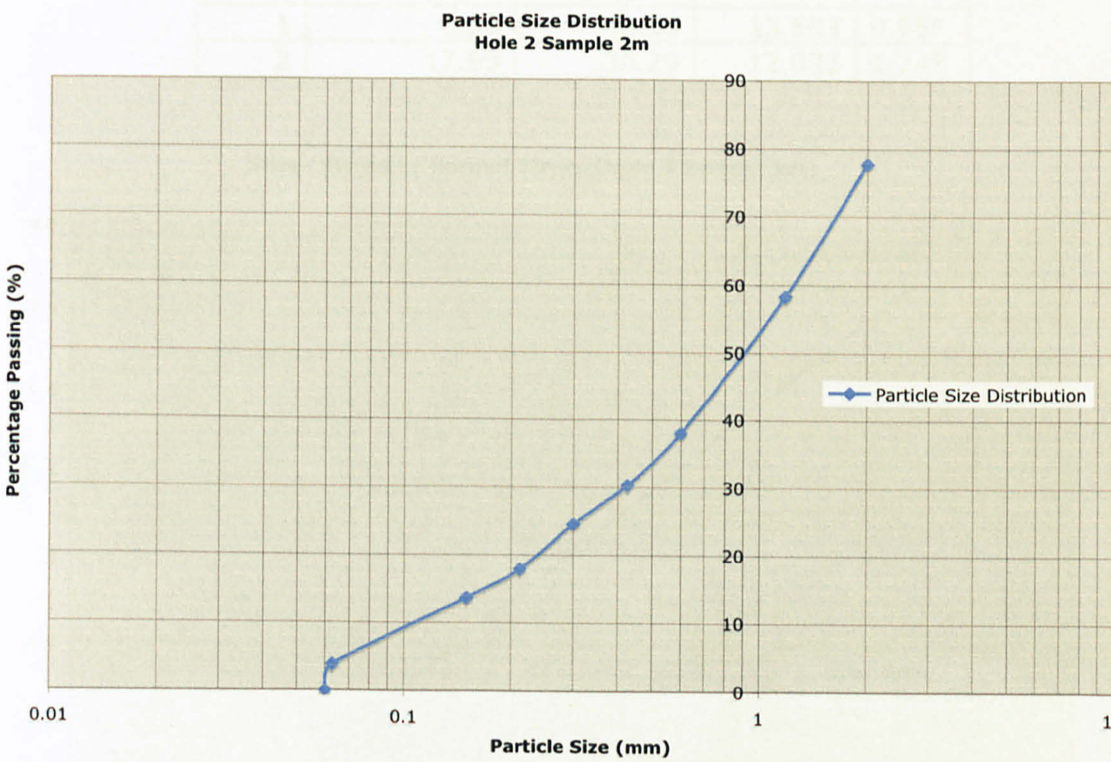


Figure 4.18 – Particle Size Distribution for hole 2 sample 2m.

While in Tables 4.9 and 4.10 show the 1D resistivity data result and the laboratory data for hole 3. Figures 4.19 – 4.22 as shown below represented the graphical data for the results obtained from hole 3 includes the particle size distribution of the soil samples and the cohesion and shear angle values.

Table 4.9 – Obtained 1D resistivity data for hole 3.

Depth (m)	I (Ampere)	V (Volt)	R (Ω)	ρ (resistivity)
1	0.2	1.6058	5.54	17.33
2	0.2	1.7401	5.69	34.66
3	0.2	2.0831	2.82	51.98
		R_{ave} =	9.05	

Table 4.10 – Laboratory data for hole 3.

Depth (m)	Resistivity (ρ)	Moisture Content (%)	Cohesion (c)	Phi (ϕ)
1	8.96	48.33	13.503	0.95°
2	17.93	38.29	12.033	1.74°

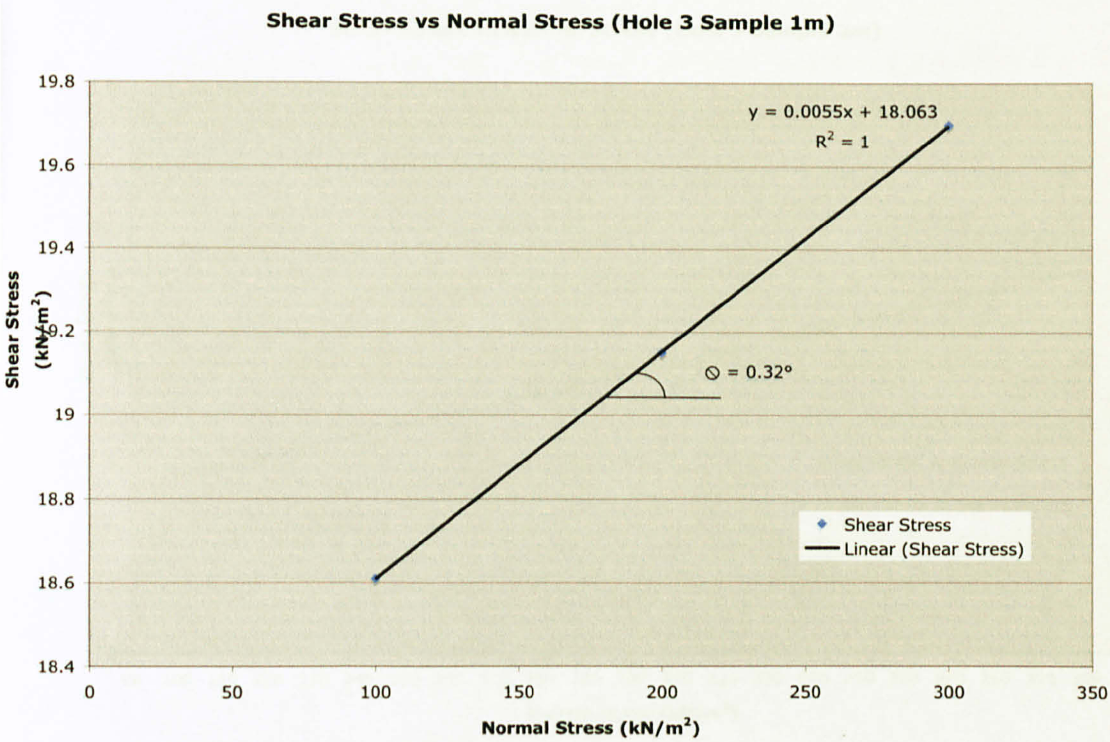


Figure 4.19 – Shear Stress vs Normal Stress for hole 3 sample 1m.

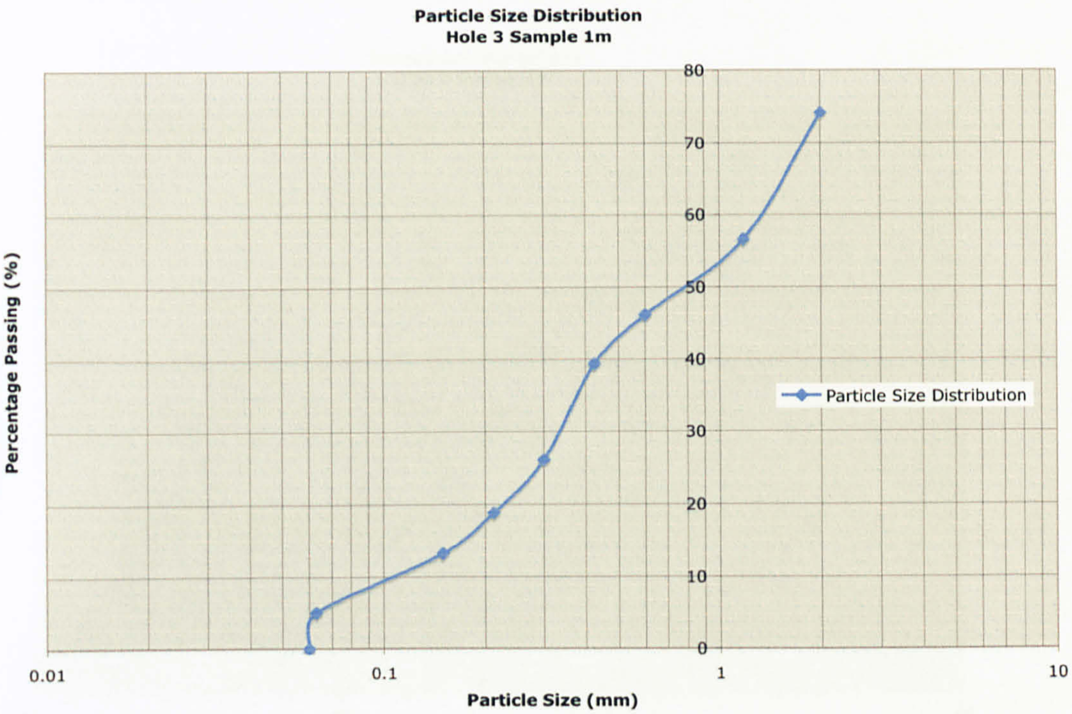


Figure 4.20 – Particle Size Distribution for hole 3 sample 1m.

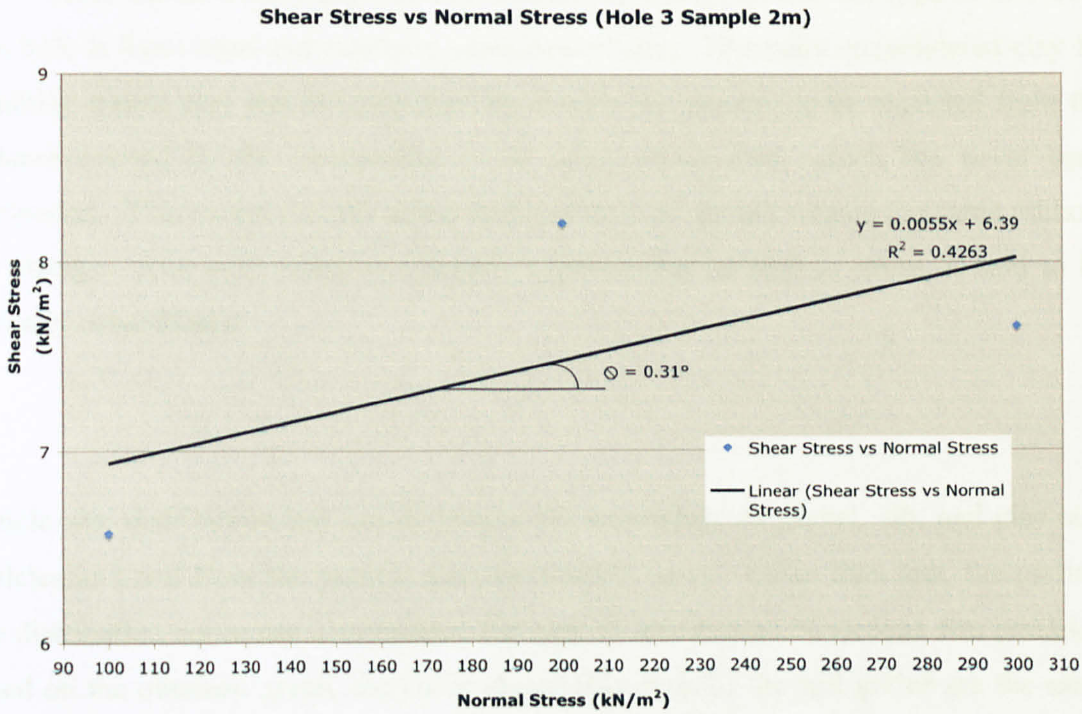


Figure 4.21 – Shear Stress vs Normal Stress for hole 3 sample 2m.

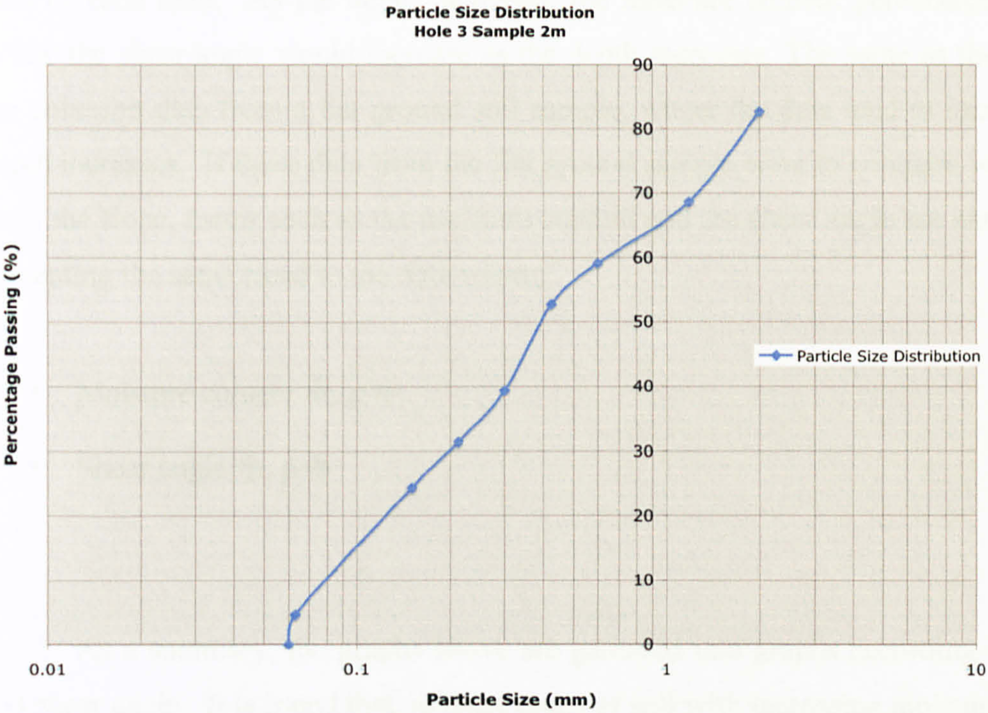


Figure 4.22 – Particle Size Distribution for hole 3 sample 2m.

From the laboratory experiments conducted, it is found that the type of soil from each hole is loose sand and normally consolidated clay. Normally consolidated clay by definition means clay that is compacted by exactly the amount to be expected from the pressure exerted by the overburden; or in other words clay, which has never been overloaded. This means that the stress factor of the soil should remain the same without any change. Also soil, which is currently experiencing its highest stress, is said to be normally consolidated.

Particle size distribution test can determine the percentage of gravel, silt, and clay size particles in a soil from the particle size distribution curve. Other than that, the particle size distribution curve can also present the type of distribution of various size particles. Based on the obtained graph, the curve shows that most of the soil grains are the same sizes. This means that the soil specimen can be classified as poorly graded.

Whereas as for the moisture content test, it is found that there is a trend for the data of each hole. As the depth increases, the moisture content percentage decreases. While the shear angle would increase as the depth increases. The same as the values for the cohesion data from a flat ground soil sample, where the data tend to increase as the depth increases. If these data from the flat ground sample were to compare with the data from the slope, factor such as the moisture content and the shear angle are analogous and presenting the same trend to the data where;

- Moisture content ↓, ρ ↑
- Shear angle ↑, ρ ↑

As a summary, the graphs above are gathered into graphs according to cohesion and shear angle. It is found that, at these types of soil with increasing moisture content at 1m depth, the cohesion is found to be increasing as the resistivity increases. While the shear angle is found to act in a decreasing manner as the resistivity increases. At 2m depth, the trend is found that, cohesion values decreases as the resistivity increases which is the opposite of the trend that is found at 1m depth soil. As for the shear angle at 2m depth soil, the shear angle is showing the same trend as the shear angle at 1m depth where as resistivity increases, the shear angle decreases. This conclusion can be summarized as follows:

At 1m depth (Figures 2.23 – 2.24):

- Cohesion ↑, ρ ↑
- Shear angle (ϕ) ↓, ρ ↑

At 2m depth (Figures 2.25 – 2.26):

- Cohesion ↓, ρ ↑
- Shear angle (ϕ) ↓, ρ ↑

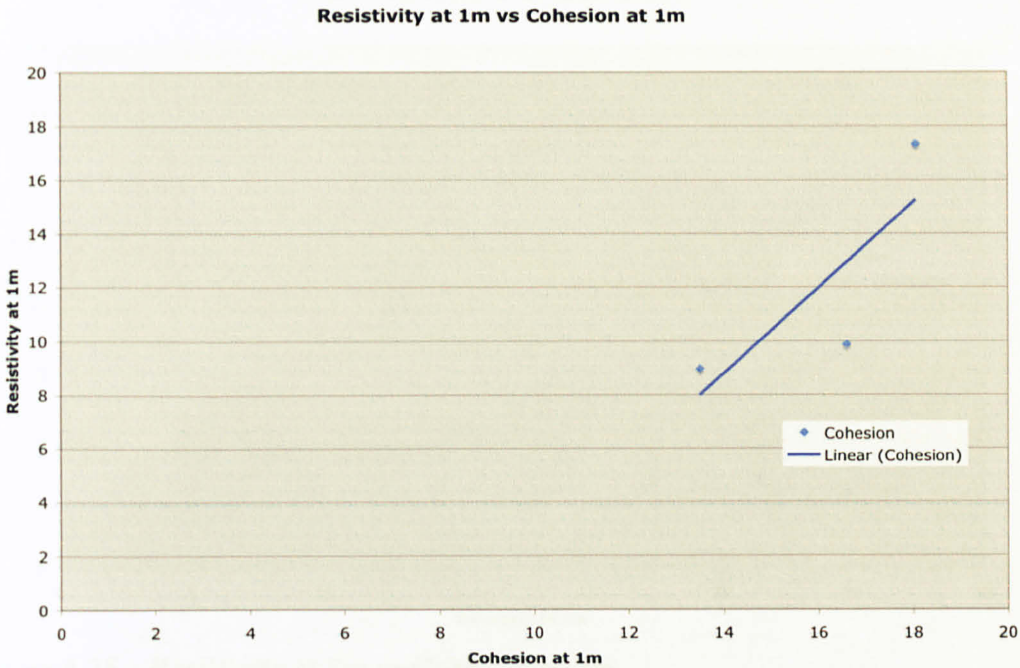


Figure 4.23 – Resistivity at 1m vs Cohesion at 1m.

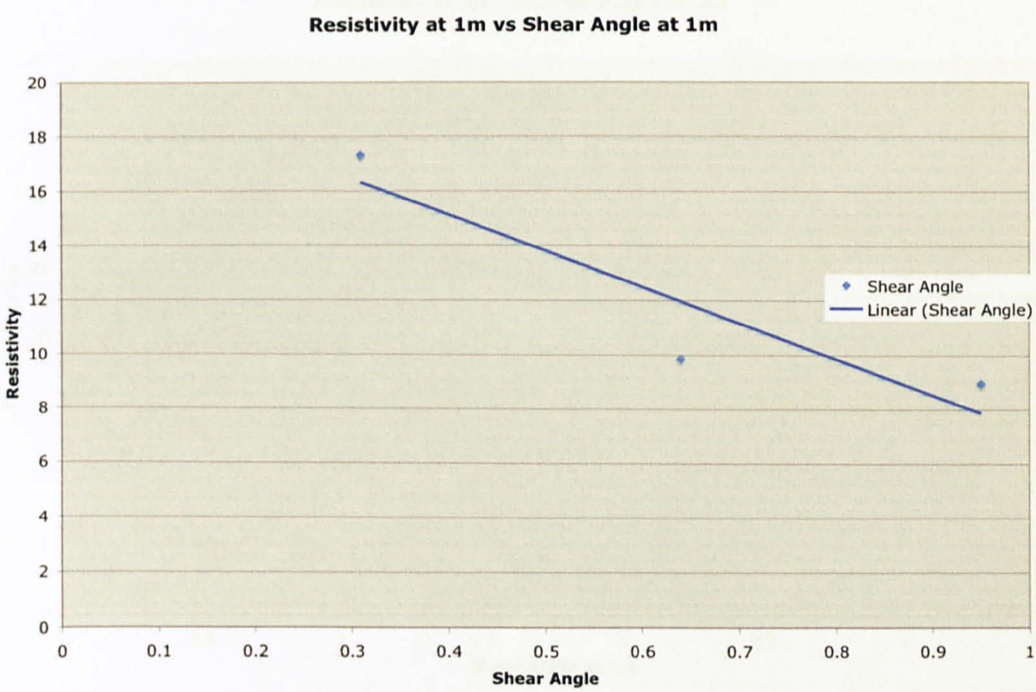


Figure 4.24 – Resistivity at 1m vs Shear Angle at 1m.

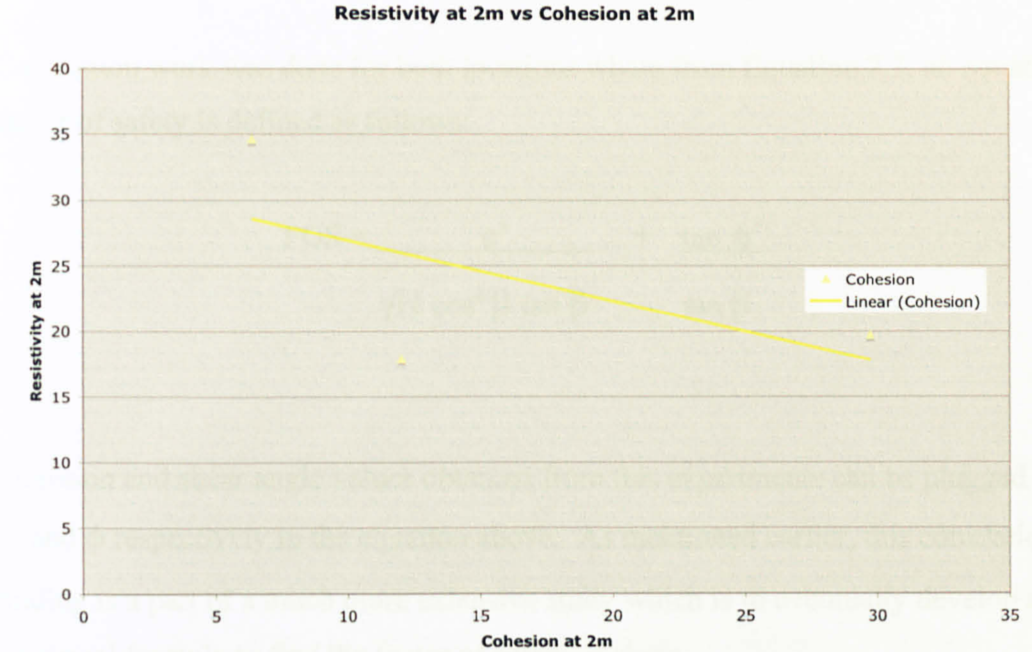


Figure 4.25 – Resistivity at 2m vs Cohesion at 2m.

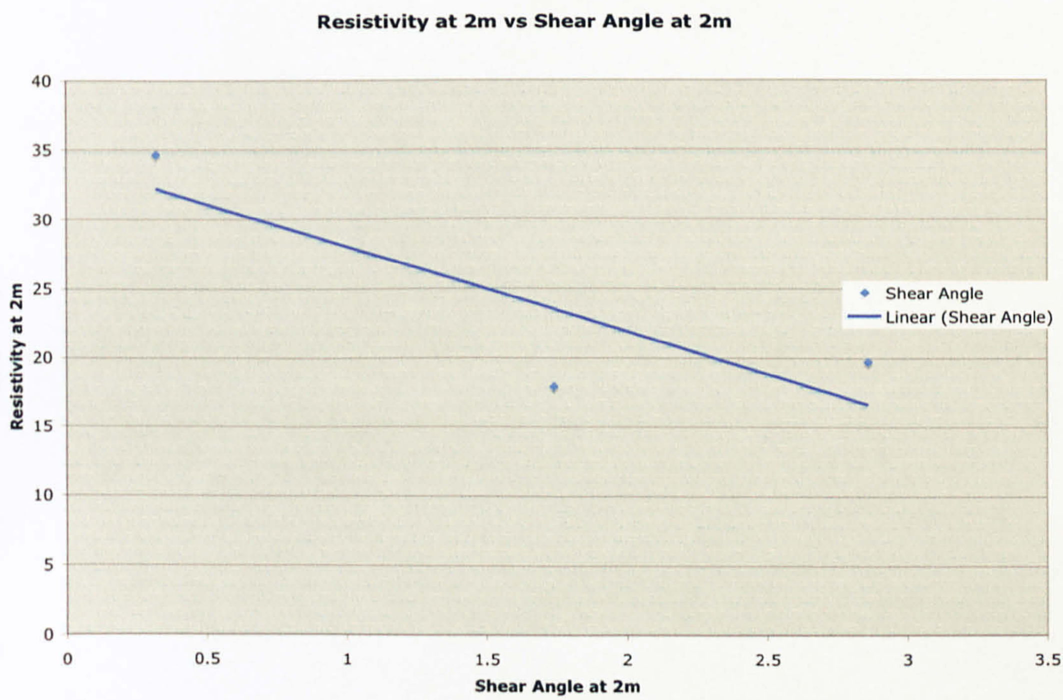


Figure 4.26 – Resistivity at 2m vs Shear Angle at 2m.

Correlation work was done for both locations where from Equation 2.3, an equation for factor of safety is defined as follows:

$$FOS = \frac{c'}{\gamma H \cos^2\beta \tan\beta} + \frac{\tan\phi'}{\tan\beta}$$

Cohesion and shear angle values obtained from this experiments can be plugged into the c' and ϕ respectively in the equation above. As mentioned earlier, this correlation finding is a part of a much more extensive study which is to eventually develop an empirical formula to find the factor of safety of slope.

CHAPTER 5

5. CONCLUSION AND RECOMMENDATION

5.1 Conclusion

There was a similarity in the outcome of the result from both field investigations done on the failed slope and on the flat ground. Both locations provided data that showed a similar trend in the graphs (refer to Figures 4.5, 4.10, and 4.23 – 4.26) and that the soil acts in a manner similar to what was found in both locations. The following table for comparison purposes can sum this up:

Table 5.1 – Comparison of data between failed slope and flat ground field investigations.

Failed Slope	Flat Ground
• Moisture content ↓, ρ ↑	• Moisture content ↓, ρ ↑
• Shear angle ↑, ρ ↑	• Shear angle ↑, ρ ↑
• Bulk density ↑, ρ ↑	• Cohesion ↑, ρ ↑
• Standard penetration test ↑, ρ ↑	

Other than that, it is also to be concluded that the soil on the slope comprises of the following factors:

- Types of soil ranged between sandy silt, clayey silt, and silty sand
- pH ranged between 6 – 7, where it is said to be fairly neutral
- Contains no organic content

- Liquid limit (LL) ranged between 33 – 47%
- Plastic limit (PL) ranged between 21 – 28%, and
- Plasticity index (PI) ranged between 7 – 19%

While the soil on the flat ground comprises of the following factors:

- Type of soil is loose sand and normally consolidated clay
- Moisture content ranged between 20.64 – 48.33%, and
- Particle size distribution classified as a poorly graded soil

In conclusion, with the research that has been done thus far in developing a "Preliminary Analysis to Correlate Electrical Resistivity with Various Soil Properties", a very convincing result from the conducted experiments up to this point can give a promising hope that with this study, it can contribute to the advancement of engineering technology development. Or the least that this study of quick method of slope stability assessment will contribute some kind of aid in helping to reduce the death toll and financial loss due to the slope failure tragedy that has been happening.

5.2 Recommendation

In order to further this particular research study in the findings of factor of safety empirical formula, it is recommended to do additional experiments on various soil samples in order to correlate with other factors such as the pH, bulk density, standard penetration test, correctional factor, temperature, and among others that is related. Besides that, with the current data, it is still inadequate because this is only the crude assessment and analysis. In order to make sure that the data are concrete enough, a lot of testing and experiments are needed such as adding more parameters, like above mentioned, in finding the correlation.

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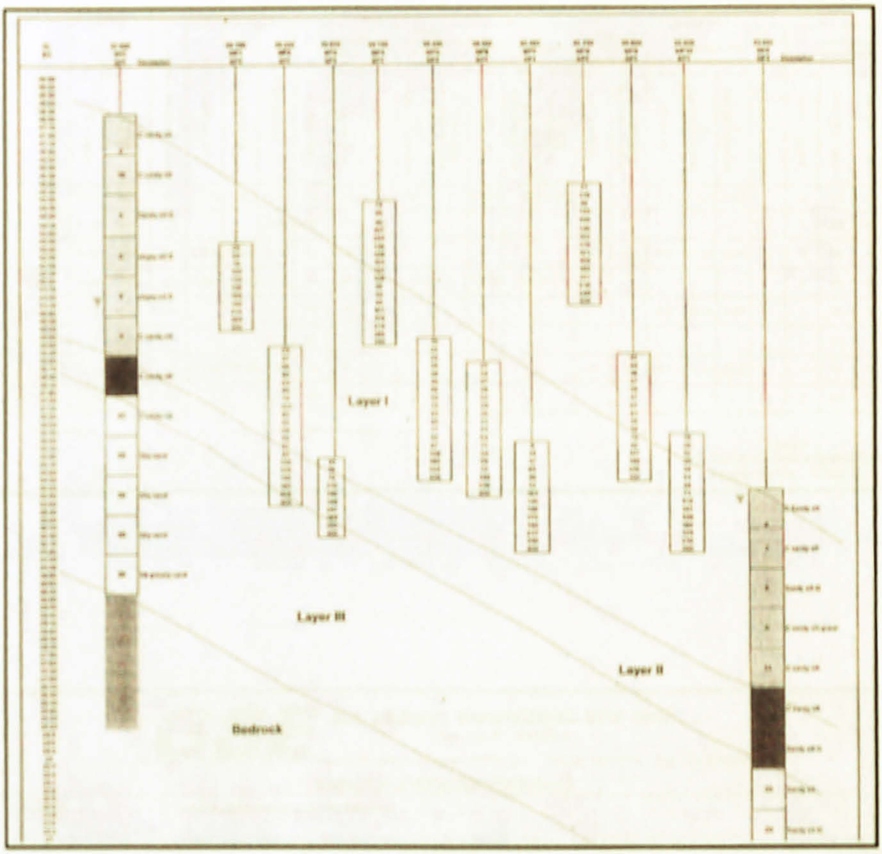
APPENDIX A



Boreholes 1 and 2 layout

Details of Laboratory Data For Borehole 1

GSE B.K. GEOSOIL ENGINEERING SDN. BHD.
(Company No. : 583349-X)
No. 30, Jalan PS 5, Taman Prima Selayang, Off Jalan Rawang, 68100 Selangor Tel: 03-61373861 Fax: 03-61376139

SUMMARY OF LABORATORY TEST RESULTS

PROJECT: UNIVERSITI TEKNOLOGI PETRONAS

Borehole No.	Sample No.	Depth (m) From	Depth (m) To	Natural Moisture Content, %	Bulk Density, Mg/m³	Dry Density, Mg/m³	Specific Gravity	Atterberg Limits: Liquid Limit, %	Plastic Limit, %	Plasticity Index, %	Triaxial Compression Test (UU): Apparent Cohesion, kPa	Angle of Shearing Resistance, °	Consolidation Test: Void Ratio, e	Pre-Compression Load, kPa	Compression Index, Cc	Shear Box Test: Cohesion, kPa	Angle of Shearing Resistance, °	Chemical Test: pH Value	Sulphate Content, %	Organic Content, %	Chloride Content, %	Particle Size Distribution, %: Gravel, >2 mm	Sand, 0.06-2 mm	Silt, <0.06 mm	Clay
BH 1	UD 1	1.50	2.00	32	1.823	1.381	2.54	45	28	17	62	3	0.624	106	0.228			6.4	<0.01	0.05		0	14	51	35
	P 1 / D 1	3.00	3.45	26			2.68	40	27	13												3	58	25	14
	P 2 / D 2	4.50	4.95	24	1.980	1.597	2.64	41	29	12						0	32	6.6	<0.01	0.02		6	42	36	16
	UD 2	6.00	6.50	22	1.980	1.623	2.65	41	29	12	69	7	0.639	138	0.168							0	49	38	13
	P 3 / D 3	7.50	7.95	24			2.61	48	29	19								6.5	<0.01	0.02		1	35	38	26
	P 4 / D 4	9.00	9.45	20			2.61	40	27	13												0	36	42	22
	P 5 / D 5	10.50	10.95	17	2.122	1.814	2.66	44	27	17						0	35	6.7	<0.01	0.02		0	54	25	21
	P 6 / D 6	12.00	12.375	10			2.66	30	25	5												0	54	33	13

N.P = Non Plasticity I.S = Insufficient Of Sample

B.K. GEOSOIL ENGINEERING SDN. BHD.
(Company No. : 583349-X)

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(Company No. : 583349-X)
No. 30, Jalan PS 5, Taman Prima Selayang, Off Jalan Rawang, 68100 Selangor Tel: 03-61373861 Fax: 03-61376139

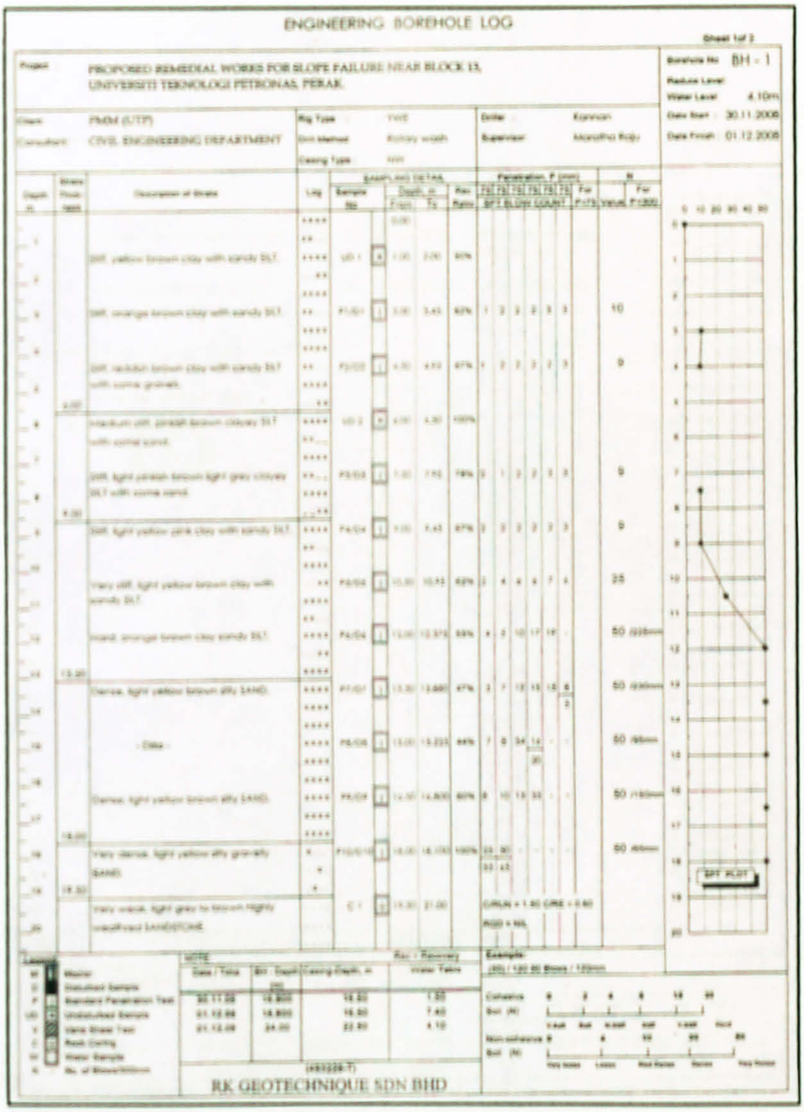
SUMMARY OF LABORATORY TEST RESULTS

PROJECT: UNIVERSITI TEKNOLOGI PETRONAS

Borehole No.	Sample No.	Depth (m) From	Depth (m) To	Natural Moisture Content, %	Bulk Density, Mg/m³	Dry Density, Mg/m³	Specific Gravity	Atterberg Limits: Liquid Limit, %	Plastic Limit, %	Plasticity Index, %	Triaxial Compression Test (UU): Apparent Cohesion, kPa	Angle of Shearing Resistance, °	Consolidation Test: Void Ratio, e	Pre-Compression Load, kPa	Compression Index, Cc	Shear Box Test: Cohesion, kPa	Angle of Shearing Resistance, °	Chemical Test: pH Value	Sulphate Content, %	Organic Content, %	Chloride Content, %	Particle Size Distribution, %: Gravel, >2 mm	Sand, 0.06-2 mm	Silt, <0.06 mm	Clay
BH 1	P 7 / D 7	13.50	13.880	13			2.72	NP	NP	NP								6.6	<0.01	0.02		0	72	28	
	P 8 / D 8	15.00	15.225	12			2.69	29	25	4												0	62	27	11
	P 9 / D 9	16.50	16.800	15	2.166	1.883	2.70	43	28	15						0	37	6.7	<0.01	0.02		0	67	20	13
	P 10 / D 10	18.00	18.100	11			2.69	35	27	8												1	61	27	11

N.P = Non Plasticity I.S = Insufficient Of Sample

B.K. GEOSOIL ENGINEERING SDN. BHD.
(Company No. : 583349-X)


ENGINEERING BOREHOLE LOG
Sheet 1of 2
Project PROPOSED REMEDIAL WORKS FOR SLOPE FAILURE NEAR BLOCK 13, UNIVERSITI TEKNOLOGI PETRONAS, PERAK
Borehole No BH - 1
Water Level 4.10m
Date Start 30.11.2008
Date Finish 01.12.2008
Client PMM (UTP)
Consultant CIVIL ENGINEERING DEPARTMENT
Rig Type YWE
Drill Method Rotary wash
SPT PLOT
RK GEOTECHNIQUE SDN BHD

ENGINEERING BOREHOLE LOG

Sheet 2 of 2

Project	PROPOSED REMEDIAL WORKS FOR SLOPE FAILURE NEAR BLOCK 13, UNIVERSITI TEKNOLOGI PETRONAS, PERAK
Borehole No	BH - 1
Reduce Level	
Water Level	4.10m
Date Start	30.11.2008
Date Finish	01.12.2008
Client	PMM (UTP)
Main Contractor	CIVIL ENGINEERING DEPARTMENT
Drill Method	Rotary wash

Depth m	Strata Thick. (m)	Description of Strata	Log	Sample No	Depth From	Depth To	SPT BLOW COUNT
21	21.00	Very weak light brown highly weathered SAND STONE		C2	21.00	22.50	CR/LR = 1.50 CRE = 0.80 RQD = NIL
22–24		Very weak light pinkish brown highly weathered SAND STONE		C3	22.50	24.00	CR/LR = 1.50 CRE = 0.80 RQD = NIL

END OF BH - 1 AT DEPTH 24.00m

Installed Standpipe at depth 19.50m

RK GEOTECHNIQUE SDN BHD

SPT PLOT

NOTE

Date / Time	BH - Depth (m)	Casing Depth m	Water Table
30.11.08	18.800	18.50	1.50
01.12.08	18.800	18.50	7.40
01.12.08	24.00	22.50	4.10

RK GEOTECHNIQUE SDN BHD

Details of Laboratory Data For Borehole 2

GSE B.K. GEOSOIL ENGINEERING SDN. BHD.
(Company No. : 583349-X)
No. 30C, Jalan PS 5, Taman Prima Selayang, Off Jalan Rawang, 68100 Selangor Tel: 03-61373901 Fax: 03-61376139

SUMMARY OF LABORATORY TEST RESULTS

PROJECT: UNIVERSITI TEKNOLOGI PETRONAS

BOREHOLE NO.	SAMPLE NO.	DEPTH (m) FROM	DEPTH (m) TO	NATURAL MOISTURE CONTENT, %	BULK DENSITY, Mg/m³	DRY DENSITY, Mg/m³	SPECIFIC GRAVITY	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %	TRIAXIAL COMPRESSION TEST (UU) - 38 mm: APPARENT COHESION, kPa	ANGLE OF SHEARING RESISTANCE, °	CONSOLIDATION TEST: VOID RATIO, e	PRE-COMPRESSION LOAD, kPa	COMPRESSION INDEX, Cc	SHEAR BOX TEST (60 x 60 mm): COHESION, kPa	ANGLE OF SHEARING RESISTANCE, °	CHEMICAL TEST: pH VALUE	SULPHATE CONTENT, %	ORGANIC CONTENT, %	CHLORIDE CONTENT, %	PARTICLE SIZE DISTRIBUTION, %: GRAVEL, >2 mm	SAND, 0.06-2 mm	SILT, <0.06 mm	CLAY
BH 2	UD 1	1.50	2.00	23	1.911	1.554	2.57	40	26	14	74	4	0.646	120	0.175			6.5	<0.01	0.08		0	22	44	34
	P 1 / D 1	2.00	2.45	30	1.838	1.406	2.56	43	27	16						2	27					0	21	45	34
	P 2 / D 2	3.00	3.45	23			2.56	41	26	15								6.4	<0.01	0.04		0	14	44	36
	UD 2	4.50	4.70	26	1.864	1.431	2.54	46	28	18	70	3	0.706	122	0.180							0	13	50	37
	P 3 / D 3	6.00	6.45	22			2.57	39	21	18								6.4	<0.01	0.06		0	23	44	33
	P 4 / D 4	7.50	7.95	22	1.901	1.590	2.56	47	28	19						1	30					0	21	44	35
	P 5 / D 5	9.00	9.45	21			2.60	45	29	16								6.6	<0.01	0.02		20	15	42	23
	P 6 / D 6	10.50	10.95	17			2.55	33	26	7												2	14	59	25

N.P = Non Plasticity I.S = Insufficient Of Sample

B.K. GEOSOIL ENGINEERING SDN. BHD.
(Company No. : 583345-X)

GSE B.K. GEOSOIL ENGINEERING SDN. BHD.
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SUMMARY OF LABORATORY TEST RESULTS

PROJECT: UNIVERSITI TEKNOLOGI PETRONAS

BOREHOLE NO.	SAMPLE NO.	DEPTH (m) FROM	DEPTH (m) TO	NATURAL MOISTURE CONTENT, %	BULK DENSITY, Mg/m³	DRY DENSITY, Mg/m³	SPECIFIC GRAVITY	ATTERBERG LIMITS: LIQUID LIMIT, %	PLASTIC LIMIT, %	PLASTICITY INDEX, %	TRIAXIAL COMPRESSION TEST (UU) - 38 mm: APPARENT COHESION, kPa	ANGLE OF SHEARING RESISTANCE, °	CONSOLIDATION TEST: VOID RATIO, e	PRE-COMPRESSION LOAD, kPa	COMPRESSION INDEX, Cc	SHEAR BOX TEST (60 x 60 mm): COHESION, kPa	ANGLE OF SHEARING RESISTANCE, °	CHEMICAL TEST: pH VALUE	SULPHATE CONTENT, %	ORGANIC CONTENT, %	CHLORIDE CONTENT, %	PARTICLE SIZE DISTRIBUTION, %: GRAVEL, >2 mm	SAND, 0.06-2 mm	SILT, <0.06 mm	CLAY
BH 2	P 7 / D 7	12.00	12.370	15			2.64	35	26	9								6.7	<0.01	0.02		34	14	34	18
	P 8 / D 8	13.50	13.880	14	2.163	1.897	2.75	NP	NP	NP						0	42					60	23	17	
	P 9 / D 9	15.00	15.375	15			2.61	36	26	10								6.7	<0.01	0.02		5	33	45	17

N.P = Non Plasticity I.S = Insufficient Of Sample

B.K. GEOSOIL ENGINEERING SDN. BHD.
(Company No. : 583345-X)

ENGINEERING BOREHOLE LOG

Sheet 1 of 1

Project : PROPOSED REMEDIAL WORKS FOR SLOPE FAILURE NEAR BLOCK 13, UNIVERSITI TEKNOLOGI PETRONAS, PERAK.

Borehole No : BH - 2
Reduce Level :
Water Level : 0.40m
Date Start : 28.11.2008
Date Finish : 29.11.2008

Client : PMM (UTP)
Consultant : CIVIL ENGINEERING DEPARTMENT

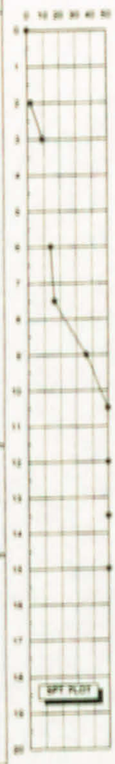
Rig Type : YWE
Drill Method : Rotary wash
Casing Type : NW

Driller : Kamran
Supervisor : Marzuki Baju

Description of Strata	Sample No	Depth From (m)	Depth To (m)	Rec Ratio	SPT Blow Count (75 mm ×6)	N Value
Very soft, yellow clay with sandy SILT.	UD 1	1.00	2.00	100%		
Soft, yellow brown clay with sandy SILT.	P1/D1	2.00	2.45	22%	0 0 0 0 1 1	2
Stiff, yellow brown sandy SILT with some gravels.	P2/D2	3.00	3.45	44%	1 2 2 2 2 3	9
Stiff, yellow brown clay with sandy SILT with some little gravels.	UD 2	4.30	4.70	100%		
Stiff, yellow to traces of brown clay with sandy SILT.	P3/D3	6.00	6.45	67%	2 3 3 3 4 4	14
Very stiff, yellow brown clay with sandy SILT.	P4/D4	7.50	7.95	80%	2 3 4 4 4 4	16
Hard, yellow brown sandy SILT with some gravels.	P5/D5	9.00	9.45	89%	3 3 4 7 12 13	36
Hard, yellow brown sandy SILT.	P6/D6	10.50	10.95	78%	2 2 4 7 13 24	50
Hard, yellow brown traces sandy SILT with some gravels.	P7/D7	12.00	12.375	81%	1 10 12 14 24/70	50 /225mm
(13.20) Very dense, dark brown to pale silty gravelly SAND.	P8/D8	13.50	13.495	100%	3 13 30/45	50 /45mm
(15.00) Hard, dark brown gravelly SILT.	P9/D9	15.00	15.375	73%	3 10 12 13 25	50 /225mm

END OF BH : 2 AT DEPTH 15.375m

Installed Standpipe at depth 6.00m



Legend: W Washer; D Disturbed Sample; P Standard Penetration Test; UD Undisturbed Sample; V Vane Shear Test; C Rock Coring; W Water Sample; N No. of Blows/300mm

NOTE: Rec : Recovery

Date / Time	BH : Depth (m)	Casing Depth, m	Water Table
28.11.08	15.375	15.00	4.00
29.11.08	15.375	15.00	0.40

Example: (50) / 120 50 Blows / 120mm

Cohesive Soil (N): 0 2 4 8 15 30 — V.soft, Soft, M.stiff, Stiff, V.stiff, Hard

Non-cohesive Soil (N): 0 4 10 30 50 — Very loose, Loose, Med dense, Dense, Very dense

(489228-T)
RK GEOTECHNIQUE SDN BHD