ELECTRICAL RESISTIVITY AND STRENGTH ANALYSIS OF SOIL WITH VARIATION OF MOISTURE CONTENT

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Electrical Resistivity and Strength Analysis of Soil with Variation of Moisture Content

By

Arida Intan Nisha bt Ishak

Dissertation submitted in partial fulfillment of
the requirements for the Bachelor of Engineering (Hons)
(Civil Engineering)

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CERTIFICATION OF APPROVAL

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Approved by,

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(Dr Syed Baharom Azahar Syed Osman / AP Dr Zuhar Zahir Tuan Harith)

UNIVERSITI TEKNOLOGI PETRONAS

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.

ARIDA INTAN NISHA BT ISHAK

ABSTRACT

In general practice, soil investigation (SI) incorporating bore hole sampling will perhaps produce the most reliable value of the relevant soil parameters for the purpose of actual calculation on factor of safety (FOS) in slopes. However, bore hole sampling is in general time consuming and very expensive. This project is a part of the whole research which is to implement a quick method of establishing the factor of safety in slopes by replacing the conventional soil parameters such as cohesion and angle of internal friction with electrical parameters such as resistivity. Hence, eliminating the need of the more elaborate bore hole sampling which is very high in maintenance cost. This research is focusing on finding the correlation between resistivity and some soil parameters.

In this paper, a sandbox resistivity testing has been conducted for soil samples at two different locations and for each sample, the moisture content varies from 20%, 30% and 40%. It is an appropriate method mainly to collect the resistivity data in the laboratory, and for analysis purposes. The experiments involved resistivity sandbox, moisture content, particle size distribution and direct shear test. Direct shear tests were performed for each sample in order to investigate the strength behavior of soil due to the various amount of water content. Initial correlation is found and subjected to further testing for better findings.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

This project focuses on investigating the correlation between resistivity and some soil parameters which eventually serves as a simple and quick assessment method to predict the approximate factor of safety (FOS) in slopes. The general approach behind this quick assessment is to eliminate the usage of physical soil parameters such as cohesion (c), angle of internal friction (ø), as is currently being practice for the calculation of FOS and replaced these physical parameters with the correlated electrical parameters such as resistivity. This quick method of using the correlated electrical parameters replacing the actual physical parameters through simple instruments and equipments would mean that a rapid, regular and extensive check up on slopes could be possible and practical. Hence, this research in investigating the correlations between the various soil properties and electrical parameters hopefully will contribute to the improvement of establishment of FOS in slopes.

In this study, a set of laboratory sandbox and direct shear experiments was performed to establish the relationships between resistivity and shear strength parameters. These tests extend the understanding of electrical resistivity and strength of soils with changes of moisture content.

1.2 Problem Statement

Slope failures always cause great losses of life and property. Improper slope management such as inconsistent maintenance can arouse miserable tragedy to the public. One of the essential aspects to identify risk in slopes is to determine the factor of safety which will indicate the stability of slope. In the process of obtaining FOS, soil investigation (SI) incorporating bore hole sampling perhaps will produce the most reliable value of the relevant soil parameters for the purpose of actual calculation. However, bore hole sampling is time consuming and very expensive. Regular checking would not be practical due to the above mentioned reasons. This is because many boreholes are required to check the factor of safety at different locations on a certain stretch of slopes in order to determine hazard/risk. Therefore, a quick and less expensive method which is based on electrical resistivity method is needed to preliminary check the FOS of any slopes on initial and regular basis.

1.3 Objectives and Scope of Study

The objectives of this research are to identify the effect of moisture content on electrical resistivity and strength of soil and to find the correlation between resistivity and strength of soils with different moisture content as a preliminary study to predict FOS. This research will be focusing on the relationship between the electrical resistivity and the parameter of soil strength. In addition to that, the soil samples have been tested in the laboratory for further clarification.

There are many factors lead to different variation of resistivity result such as mineralogy, soil type, pH, porosity, particle size distribution, moisture content and temperature etc. As the moisture content is very much influences the resistivity, the research is specified into investigating the behavior of soils in terms of resistivity and strength with variation of moisture content.

CHAPTER 2

LITERATURE REVIEW

2.1 Electrical Resistivity

The investigating archaeological sites using geophysical prospection technique called soil resistivity was first used for archaeology by Richard Atkinson in the mid-1940s. Resistivity is a form of geophysical survey where the electric current is passed through the ground at regular point on a survey grid. The resistivity in soil varies and depends on the presence of archaeological features, moisture content of the soil and temperature of the soil itself. Soil passes electric current in different levels. Lesser electric current passes through as the resistivity of a given soil is getting higher.

In order to successfully conduct and interpret a resistivity survey, a grasp of basic electrical theory is necessary, beginning with the nomenclature. Electric current is defined as the rate of flow of charge passing through a cross section of a conducting medium for a specific length of time. To cause charge to flow, a voltage (also known as potential difference, a measure of energy used to move the charges) must be applied. When a voltage is applied and a current flows, a resistance is encountered to the movement of the charge, which is dependent on the characteristics of the medium in which the charges are moving. This can be described by Ohm's Law

$$V = IR$$

where voltage is in volts (V), current in amperes (A) and resistance is measured in Ohms (Ω). In a conductor of length (l) and cross section area of (S), the voltage difference per unit length can be thought of as the moving force, the current as the quantity that is moved, and the resistance as the opposition encountered by moving the current. Resistivity is defined as

$$\rho = \frac{RS}{l}$$

The basic unit of resistivity is the ohm-meter or ohm-centimeter (1 Ω-m = 100 Ω-cm). If a specified current is flowing in a known geometrical shape, the resistivity of the material can be deduced, providing the voltage difference is known. The conduction of current in soils is largely an electrolytic phenomenon that is moisture in soils containing free charged particles is responsible for the current flow. The resistance to currents flowing in all soil types depends directly upon soil moisture content, permeability, ion content, temperature etc. (Weymouth, Huggins, 1991)

Robert Hack (2000) mentioned that more and more studies scholars proved that electrical resistivity survey is a reliable geophysical method in slope stability analyses. The resistivity characterizes materials by their electrical resistance mainly when dealing with groundwater and sometimes can be used to trace the wet zone including both water table and aquifers. Since the phase of rupture often coincide with the wet zone, electrical resistivity method is possible. By grounding two electrodes to the ground and induced the electrical current, the potential difference between two electrodes can be measured (Forrester, 2001).

2.2 Shear Strength

Soil will eventually reach failure and deform excessively when it is subjected to gradually increasing load. This failure is related to the shear strength which is one of the most important engineering properties of a soil. The shear strength of a soil is the maximum load that can be supported by the soil mass before it yields. In geotechnical engineering, the shear strength of soil is an important property to evaluate for many cases, such as foundations, retaining walls, earth slopes, and road bases.

Some failure criteria are needed to define the shear strength of the soil. The failure criteria are developed based on stress-strain relationship of the soil. The concepts of elasticity theory apply to soil in a very approximate way. It assumed that the material is homogeneous, isotropic, and have a linear stress strain relationship. On the other hand, the soils in general are non-homogeneous, exhibit anisotropy, and have non-linear stress-strain relationships. The amount of strain developed in soil depends not only on the applied load, but also on the composition, void ratio, past stress history, and the manner in which the stress is applied.

Coulomb (1776) conducted numerous tests to measure the shear strength of a soil and concluded that the shear strength of a soil composed of two components: (1) that depends on the normal stress internal friction angle, ø and (2) the cohesion,c which is independent on the normal stress. This theory is combined with the Mohr failure envelope and resulted in the Mohr-Coulomb failure criterion which relates the shear strength of soil to the applied normal stress:

$$\tau_f = c + \sigma_n \tan ø$$

where c = apparent cohesion (assumed to be constant),

σ_n = normal stress on slip surface, and

ø = angle of friction (or angle of shearing resistance).

The relationship for the limiting shear strength is plotted as a straight line to obtain the shear strength parameters ø and c.

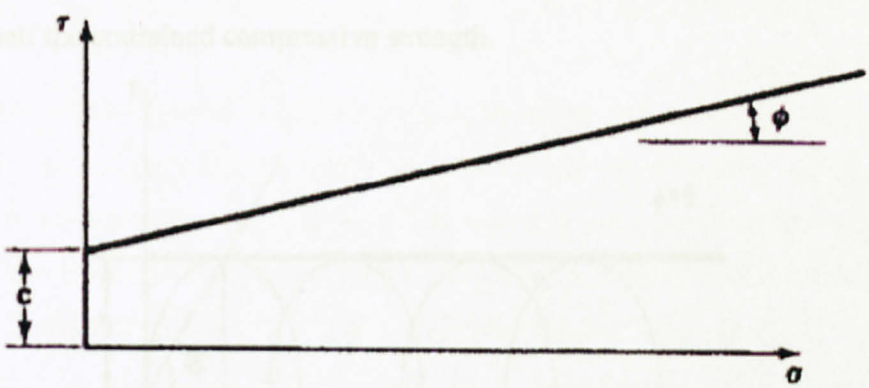

Figure 1: The Coulomb strength equation presented graphically (Holtz and Kovacs, 1981).

This simple criterion is used to predict the stresses on the failure plane at failure. The combination of the Coulomb equation and the Mohr Coulomb criterion can be written as:

$$\tau_{ff} = c + \sigma_{ff} \tan \phi$$

where: τ_{ff} = shear stress on the failure plane at failure,
c = apparent cohesion (assumed to be constant),
σ_{ff} = normal stress on slip surface, and
ϕ = angle of friction (or angle of shearing resistance).

The shear strength of soil is usually evaluated for total and effective stress conditions. The total stress condition happened in undrained condition with short time critical period, while the effective stress condition usually occurred in drained condition with long term critical period and zero pore water pressure. For total stress condition whereby the soil is in saturated condition and water flow is slower than the rate of stress increase, the shear strength is independent of the normal stress. Thus the Mohr failure envelope is horizontal and $\phi = \phi_u = 0$. This situation is shown in Figure 2, for which failure is theoretically occurs on the 45° plane. The shear strength is τ_f and the normal stress at failure is $(\sigma_{1f}+\sigma_{3f}) / 2$. For unconfined condition, the apparent cohesion c_u is equal to half the undrained compressive strength.

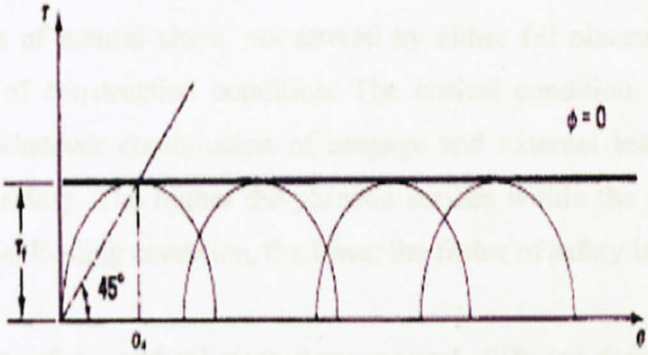

Figure 2: Mohr failure envelope for a purely cohesive material (Holtz and Kovacs,1981)

2.3 Slope Stability

Variations of loads acting on slopes, and variations of shear strength with time, result in changes in the factor of safety of slopes. As a consequence, it is often necessary to perform stability analyses corresponding to several different conditions, reflecting different stages in the life of a slope.

When an embankment is constructed on a clay foundation, the embankment load causes the pore pressures in the foundation clay to increase. Over a period of time the excess pore pressures will return to values governed by the groundwater conditions. As the excess pore pressure dissipate, the effective stresses in the foundation clay increase, the strength of the clay will increase, and the factor of safety of the embankment will also increase.

When a slope in clay is created by excavation, the pore pressures in the clay decrease in response to removal of the excavation material. Over time, the negative excess pore pressures dissipate and the pore pressures eventually return to values governed by the groundwater conditions. As the pore pressures increase, the effective stresses in the clay around the excavation decrease, and the factor of safety of the slope decreases with time. If the depth of excavation is constant and there are no external loads, the factor of safety continually decreases, and its minimum value is reached when the pore pressures reach equilibrium with the groundwater seepage condition.

In the case of natural slope, not altered by either fill placement or excavation, there is no end of construction condition. The critical condition for a natural slope corresponds to whatever combination of seepage and external loading results in the lowest factor of safety. The higher the phreatic surface within the slope and the more severe the external loading condition, the lower the factor of safety is.

In the case of an embankment dam, several different factors affect stability. Positive pore pressures may develop during construction of clay embankments, particularly if the material is compacted on the wet side of optimum. The same is true of clay cores in zoned embankments. Over time, when water is impounded and seepage develops through the embankment, the pore pressures may increase or decrease as the come to equilibrium with steady seepage conditions. Reservoir levels may vary with time during operation of the dam. A rapid drop in reservoir level may create a critical loading condition on the upstream slope. A rise from normal pool level to maximum pool level may result in a new state of seepage through the embankment and a more severe loading condition on the downstream slope.

Earthquakes subject slopes to cyclic variations in load over a period of seconds or minutes that can cause instability or permanent deformations of the slope, depending on the severity of the shaking and its effect on the strength of the soil. Loose sands may liquefy and lose almost all shearing resistance as a result of cyclic loading. Other, more resistant soils may deform during shaking but remain stable.

2.4 Factor of Safety

Once appropriate shear strength properties, pore water pressures, slope geometry and other soil and slope properties are established, slope stability calculations need to be performed to ensure that the resisting forces are sufficiently greater than the forces tending to cause a slope to fail. Calculations usually consist of computing a factor of safety using one of several limit equilibrium procedures of analysis. All of these procedures of analysis employ the same definition of the factor of safety and compute the factor of safety using the equation of static equilibrium.

The factor of safety, F is defined with respect to the shear strength of the soil as

$$F = s/\tau$$

$$FS = \frac{c'}{\gamma H cos^2\beta \tan\beta} + \frac{\tan \text{Ø}'}{\tan\beta}$$

where s is the available shear strength, τ is the equilibrium shear stress, γ is saturated unit weight, H is slope's height and β is the slope. The equilibrium shear stress is the shear stress required to maintain a just-stable slope and it may be expressed as

$$\tau = s/F$$

The equilibrium shear stress is equal to the available shear strength divided (factored) by the factor of safety. The factor of safety represents the factor by which the shear strength must be reduced so that the reduced strength is just in equilibrium with the shear stress, τ. The procedures used to perform such computations are known as limit equilibrium procedures.

The shear strength can be expressed by the Mohr-Coulomb equation. If the shear strength is expressed in terms of total stresses, it is written as

$$\tau = (c + \sigma \tan \phi) / F$$

where c and ϕ are the cohesion and friction angle for the soil, respectively, and σ is the total normal stress on the shear plane.

2.5 Factors Affecting Electrical Resistivity

Mitchell in his research explains that the behavior of soil depends on the composite effects of several interacting factors, namely compositional and environmental factors. Compositional factors include the amount and type of soil minerals, the shape and size distribution of soil particles, adsorbed cations and pore water composition. Environment factors include water content, density, confining pressure, fabric and temperature. Additionally, compositional factors determine the potential range of values for any soil properties whereas environmental factors dictate the actual value (Mitchell, 1993).

Moisture in soils is usually generated by rainfall with occasional contributions from areas having high water tables or from nearby streams. Generally, soils receiving little rainfall have a high average resistivity and conduct electricity poorly. The amount of water the soil can contain is determined by the soil porosity which exhibits wide spatial variation according to soil type, shape of the consistent grains and amount of compaction.

The ions responsible for conduction in the soil come from dissolved salts, such as calcium and sodium carbonates. They may be derived from a variety of cultural and non-cultural sources: from the soil itself, underlying geologic strata, rainwater, modern agricultural fertilizers, or compounds generated by cultural processes.

Temperature affects resistivity, particularly when freezing of the groundwater takes place. Fortunately, most field surveys can be performed when the temperature is above 0°C, where daily variations in temperature are not sufficient to affect the resistivity in an archaeological context.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

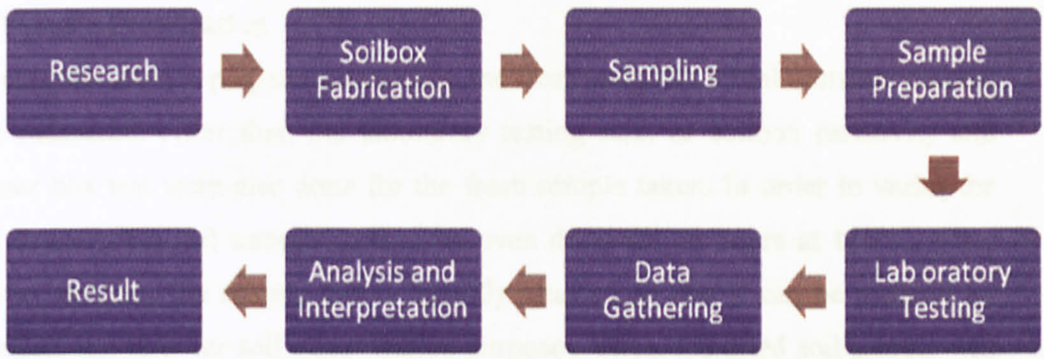

Figure 3: Research Methodology

3.1.1 Research

Research based project has been done during FYP1 where the data gathering takes place. Since the research is focused on identifying the soil behavior in terms of resistivity and strength with respect to moisture content, the test has been done in the laboratory to easily control moisture content of soils. Lots of research papers were collected and gathered for better understanding regarding the project research. Since by doing resistivity test in the laboratory is required, the methodology to conduct the test is according to ASTM G 57-58 standard.

3.1.2 Soilbox Fabrication

Electrical resistivity measurement in laboratory can be determined by using Soilbox Resistivity equipment. The second part of the research is to fabricate the soilbox itself. The box is fabricated by using Plexiglas with 4 plates which acts as the medium to connect the soilbox to the power supply.

3.1.3 Sampling

Sampling process starts by taking the sample at site for about 10kg. The sample was taken for about half meter from the ground surface in order to avoid impurities. The apparatus used are the large in size container and hoe. Since the sample was taken by using hoe, the sample is described as disturb sample.

3.1.4 Sample Preparation

During the sample preparation process, the fresh sample's initial moisture content has been measured. After that, the laboratory testing such as soilbox resistivity and direct shear box test were also done for the fresh sample taken. In order to varies the moisture content, the soil sample need to be oven dried for 24 hours at 110°C. After oven drying process, the sample has to be fully crushed so that it can be proceed by sieve analysis test later for soil classification purposes. Then, the dried soil sample will be added with some amount of water ranging from 20% to 40% water content with increment of 10%. Normal calculation for moisture content is considered in controlling the amount of moisture in each soil sample.

3.1.5 Laboratory Testing

An extensive laboratory investigation program was conducted on the clay-sand mixtures of two different samples. This laboratory is mainly to determine the moisture content, Particle Size Distribution (PSD), resistivity and shear strength of soil samples. The variation of moisture content was controlled by adding water to certain amount into the oven dried sample. The sieve analysis and sandbox resistivity test were also conducted.

The stress strain relationship and shear strength parameters (angle of internal friction and cohesion) were determined using Direct Shear Test with different amount of water content ranging from 20% up to 40% at 10% increments. The actual moisture content of various mixtures was experimentally determined.

3.1.5.1 Moisture Content Tests

The objective of moisture content test is to find the moisture loss of the soil sample. The test is done by oven dried the sample in the oven at 110°C for 16 to 24 hours.

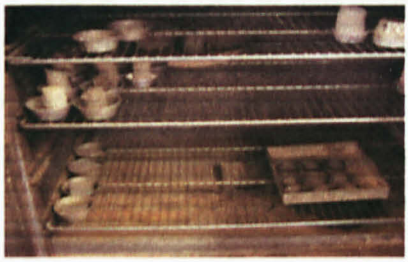

Figure 4: Oven dried sample (110°C)

3.1.5.2 Particle Size Distribution Tests

Dry sieving is suitable for soils containing insignificant quantities of silt and clay. Combined sieving and sedimentation procedures enable a continuous particle size distribution curve of a soil to be plotted from the size of the coarsest particle down to the clay size. The result is classified according to ASTM D 2487 standard.

3.1.5.3 Soilbox Resistivity Test

Soilbox are designed to measure the resistivity of soil in laboratory. The box is made of clear Plexiglas. The sandbox which is consist of 2 netting plates and 2 aluminum plates act as the medium to connect the sandbox to the power supply, ammeter and voltmeter. The reading for voltage and current are both taken at the same time as the power supply is set to 2V, 4V and up to 20V. The tests have been done by controlling the amount of water for the purpose of varying the water content. Resistivity value is calculated using formula:

$$\rho = \frac{RS}{l}$$

3.1.5.4 Direct Shear Test

In direct shear test, a square prism of soil is laterally restrained and sheared along a mechanically induced horizontal plane while subjected to pressure applied normal to that plane. The shearing resistance offered by the soil as one portion is made to slide on the other is measured at regular intervals of displacement. Failure occurs when the shearing resistance the maximum value which the soil can sustain. By carrying out the tests on a set (three) similar specimen of the same soil sample under different normal pressures, the relationship between measured shear stress at failure and normal applied is obtained.

Direct shear test is conducted in accordance with BS 1377(7) and ASTM D3080-04. Direct shear test is popular for determining the shear strength of soil with friction. In a direct shear test, the soil is placed in a split shear box and stressed to failure by moving one part of the container relative to the other. Figure 5 shows the direct shear apparatus.

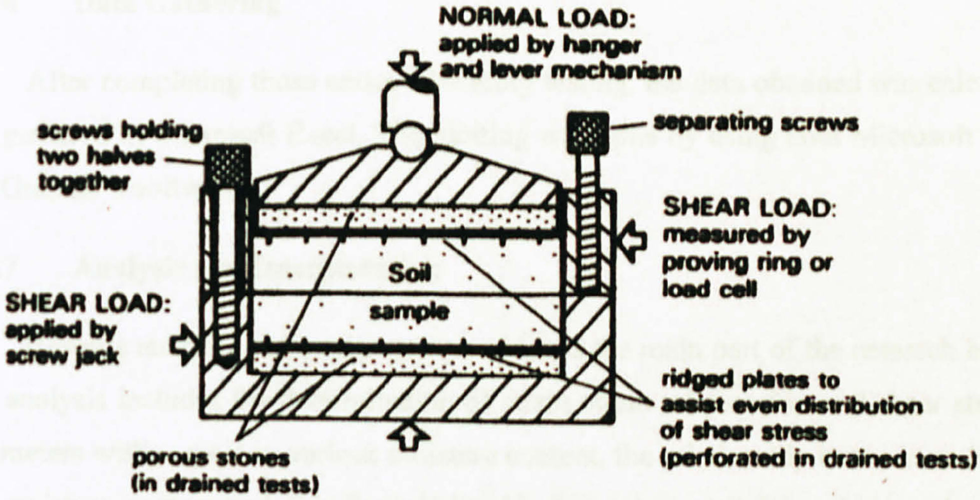

Figure 5: Direct shear apparatus (Whitlow, 2001)

A vertical force (N) is applied to the specimen through a loading plate and shear stress is gradually applied on horizontal plane by causing the two halve of the box to move relative to each other. The shear force (τ) being measured together with the corresponding shear displacement (Δl). Normally the change in thickness (Δh) of the specimen is also measured. A number of specimens of the soil are tested under different normal forces, and the value of shear stress at failure is plotted against the normal stress for each test. The shear strength parameters are often obtained from the best line fitting the plotted points.

If it is assumed that the horizontal plane is equivalent to the failure plane for the soil, then the friction angle can be calculated from the results of a series of tests performed at various normal stresses. The direct shear test offers the easiest way to measure the friction angle of sand or other dry soil. It is not useful for testing soils containing water unless they are free draining and have a very high permeability, because it is difficult to control the drainage and thus volume changes during testing. For this reason, the direct shear tests should be used with caution in determining the undrained shear strength of cohesive soils.

3.1.6 Data Gathering

After completing those entire laboratory testing, the data obtained was calculated and gathered in Microsoft Excel. The plotting was done by using both Microsoft Excel and Grapher 5 software.

3.1.7 Analysis and Interpretation

Result's analysis and interpretation which is the main part of the research begins. The analysis includes the determination of stress strain relationship and shear strength parameters with respect to various moisture content, the relationship between resistivity and moisture content and also the relationship between resistivity and strength of soil samples.

3.1.8 Result

The results would be a catalyst and starter for further research and clarification later.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Geotechnical Properties

The Gamma Ray-Resistivity result below shows the subsoil condition obtained from resistivity data.

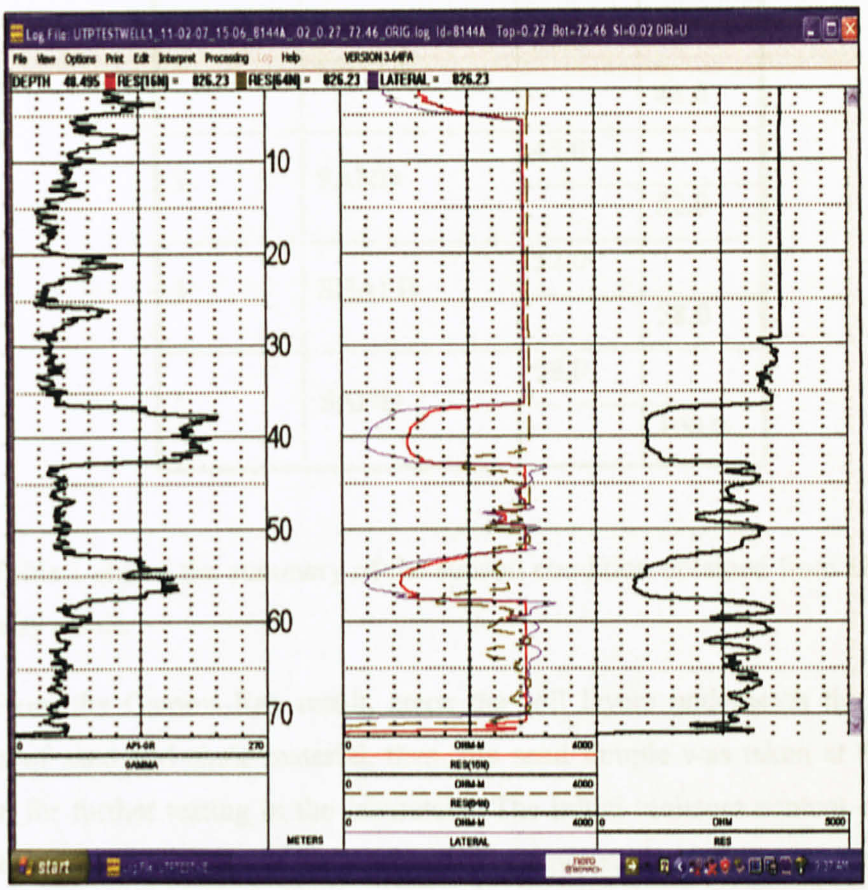

Figure 6: 8144A – Gamma Ray-Resistivity (RES 16N, RES 32N, LATERAL) Tool

The line at the most left in Figure 6 shows the graph of gamma ray of the borehole sample obtained from site investigation (SI). The graph plotted at the center and the most right of the column shows the variation of resistivity result. Sand layer normally lies at lower gamma ray resistivity as compared to shale layer. By assuming 50% cut-off shale, sand layer exist at the depth of 0m to 37m deep. At 37m to 43m and 52m to 58m, shale layer presents.

Table 1: Tabulation of Subsoil Condition

Stratum	Soil Description	Penetration (m)	
		From	To
1	SAND	0.0	37.0
2	SHALE	37.0	43.0
3	SAND	43.0	52.0
4	SHALE	52.0	58.0
5	SAND	58.0	100.0

Table 1 shows the summary of the subsoil condition obtained from Gamma Ray-Resistivity result.

From the Gamma-Ray result, since the soil layers underneath the ground are consists of sand and shale material, then, the sand sample was taken at the borehole location for further testing in the laboratory. The initial moisture content of the actual disturbed sample, P1 is 22%. For comparison purposes, the soil sample from different site location, P2 has been obtained to further assist the research. The initial moisture content for actual disturbed sample P2 is 38%.

Results of Particle Size Distribution (PSD) are mostly indicated that the samples are generally consists of fine sand with some traceable amount of clays as shown on Appendix Plate A1 and A2. Based on particle size distribution result, it can be concluded that the soil sample at the site can be categorized as fine sandy soil with the percentage of 97% and clay and silt is about 3%. Thus, 97% of the soil sample is categorized as fine sand. The same goes to the second sample P2 where the sand amount is 99.6% whereas the remaining part is the clay and silt content.

4.2 Electrical Resistivity

Figure 7 and 8 shows the resistivity relationship towards different amount of moisture content for both P1 and P2 samples. Resistivity of P1 in Figure 7 increased up to an optimum amount of moisture content to a certain value, beyond which is start to decrease. The same goes to P2 sample in Figure 8, the increase in moisture content results in the reduction of resistivity values. Ohm's law can best described the decreasing of resistivity behavior towards variation of moisture content. An increased in soil moisture content means that the soil is high in conductivity. Since resistivity is inversely proportional to conductivity, the resistivity decreases with an increment of water content in soil.

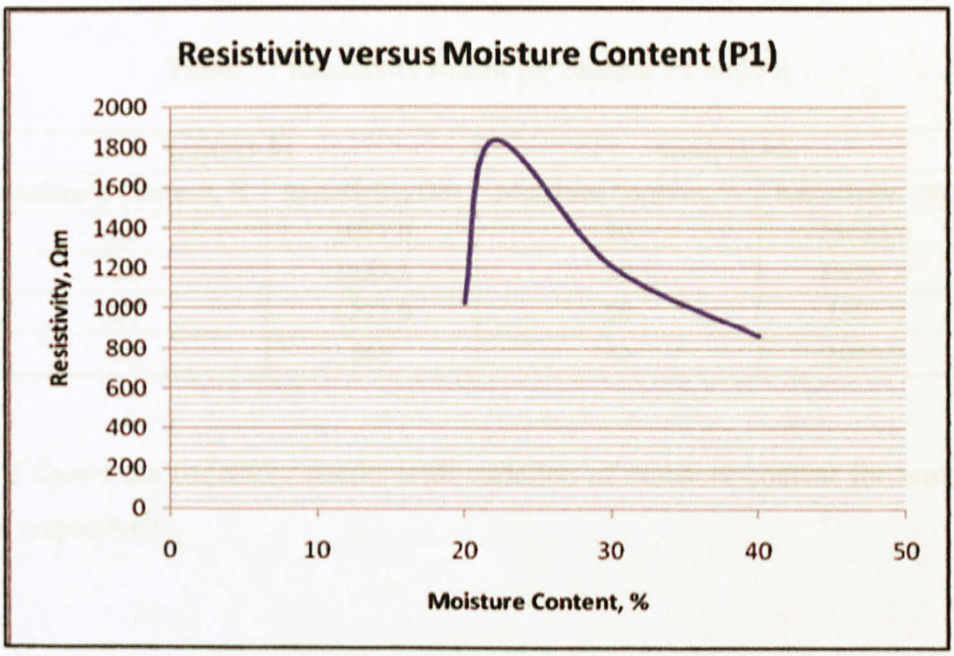

Figure 7 : Resistivity versus Moisture Content Graph for P1

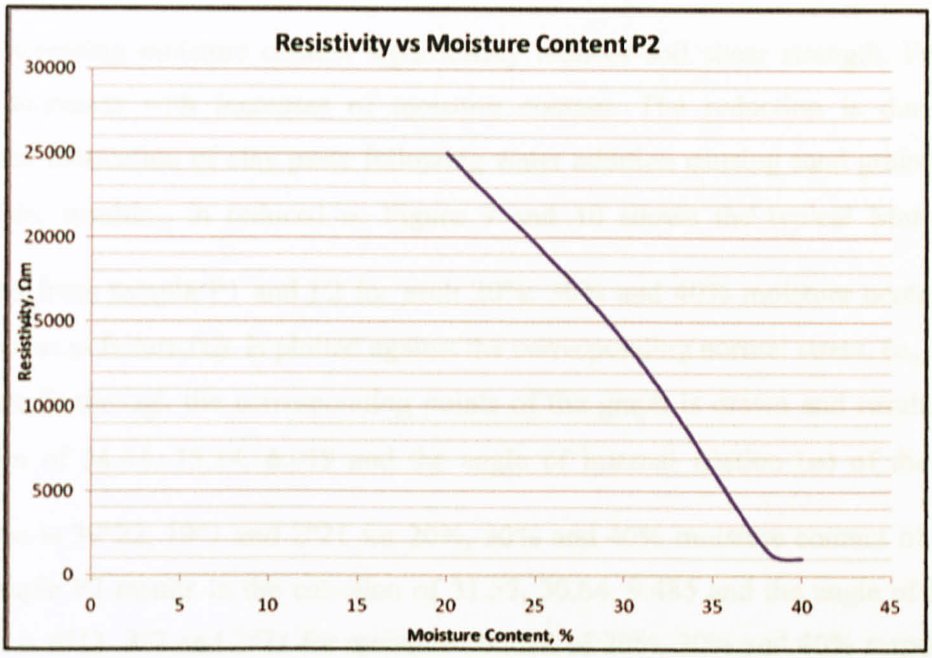

Figure 8 : Resistivity versus Moisture Content Graph for P2

Table 2 : Resistivity Result for Sample P1 and P2

SAMPLE P1		SAMPLE P2	
Moisture Content, %	**Resistivity, Ωm**	**Moisture Content, %**	**Resistivity, Ωm**
20	1027.0	20	25039.0
22	1837.3	30	13897.6
30	1211.9	38	1555.0
40	865	40	1025.9

Table 2 shows the resistivity results with variation of moisture content for sample P1 and P2 respectively.

4.3 Stress Strain Relationship

Increasing moisture content significantly reduces soil shear strength. Frictional angle decreases with increases of moisture content. The reduction is due to the increased lubrication of clay paste following water addition causing sand grains to slip and slide, resulting in reduced ø. Figure 9 and 10 shows the typical Mohr circle obtained from sample P1 and P2 for each 20%, 30% and 40% moisture content. The shear stress at failure,(τ_f) is plotted against the corresponding normal stress, (σ_n). A line that best fit through the corresponding points of the graph is drawn and results in the cohesion of 34.84, 15.14, 6.019 and the angle of internal friction (ø) of the failure envelope is 39°22, 19°1 and 2°21 for 20%, 30% and 40% moisture content of sample P1. Sample P2 results in the cohesion of 31.55, 30.64, 9.485 and the angle of internal friction is 4°13, 3°7 and 2°21 for moisture content of 20%, 30% and 40% respectively. From the graph, the trend can be seen clearly that the higher the moisture content is, the lower the angle of internal friction. It shows that the soil become weakened as it contains higher amount of water.

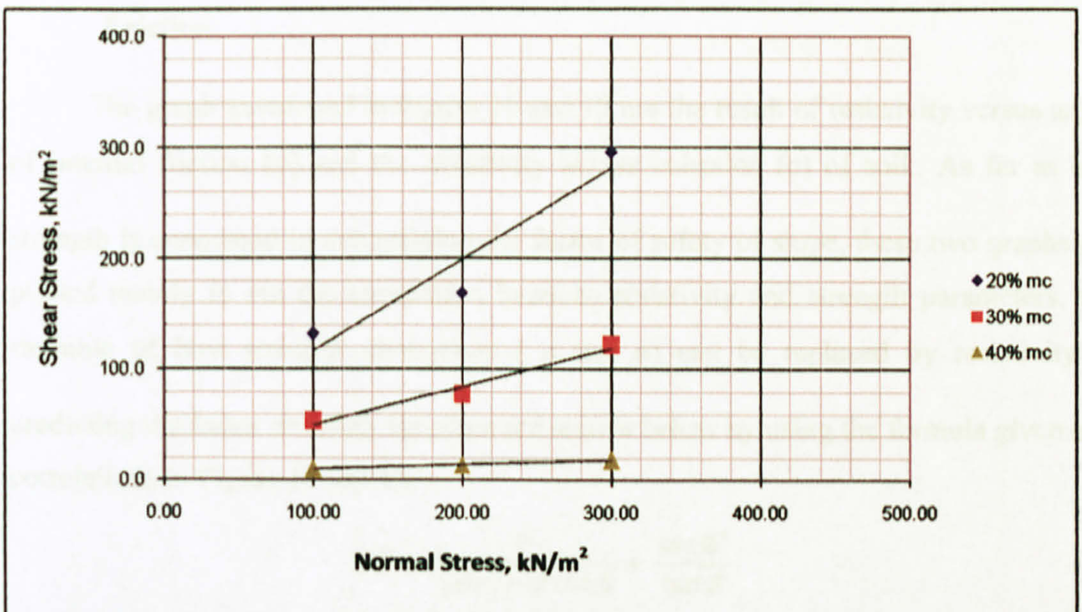

Figure 9 : Shear Stress versus Principal Stress of Sample **P1**, for **20%, 30% and 40%** Moisture Content

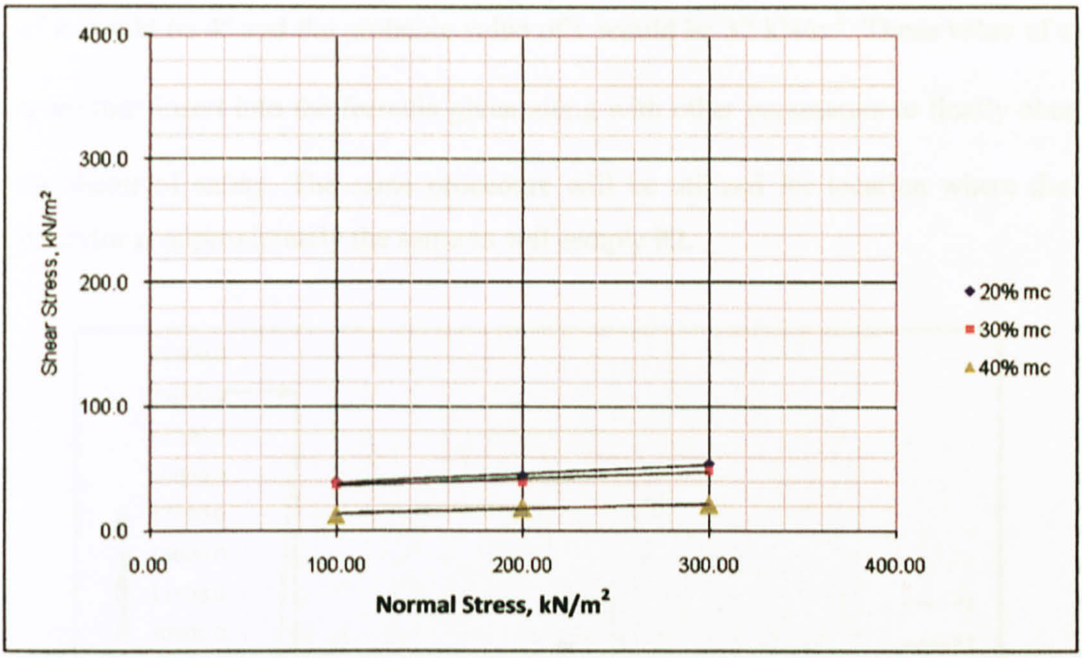

Figure 10 : Shear Stress versus Principal Stress of Sample **P2**, for **20%, 30% and 40%** Moisture Content

4.4 Relationship between Resistivity and Cohesion and Angle of Internal Friction

The graph developed in Figure 11 and 12 are the result of resistivity versus angle of internal friction (ø) and the resistivity versus cohesion (c) of soil.. As far as soil strength is concerned in determining the factor of safety of slope, these two graphs are plotted mainly to see the correlation between resistivity and strength parameters. An example of how strength parameters (c and ø) can be replaced by resistivity in predicting the factor of safety for slope are shown below by using the formula given and correlations in Figure 11 and 12.

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

For example, at location where the nature of soil is approximately the same as soil sample P2, if resistivity at a certain depth obtained is 25000 Ωm, the probable value of ø would be 4° and the probable value of c would be 32 kN/m^2. These value of c and ø are then insert into the formula given along with other parameters to finally obtained the factor of safety. The same procedure will be utilized for location where the soil behavior is approximately the same as soil sample P2.

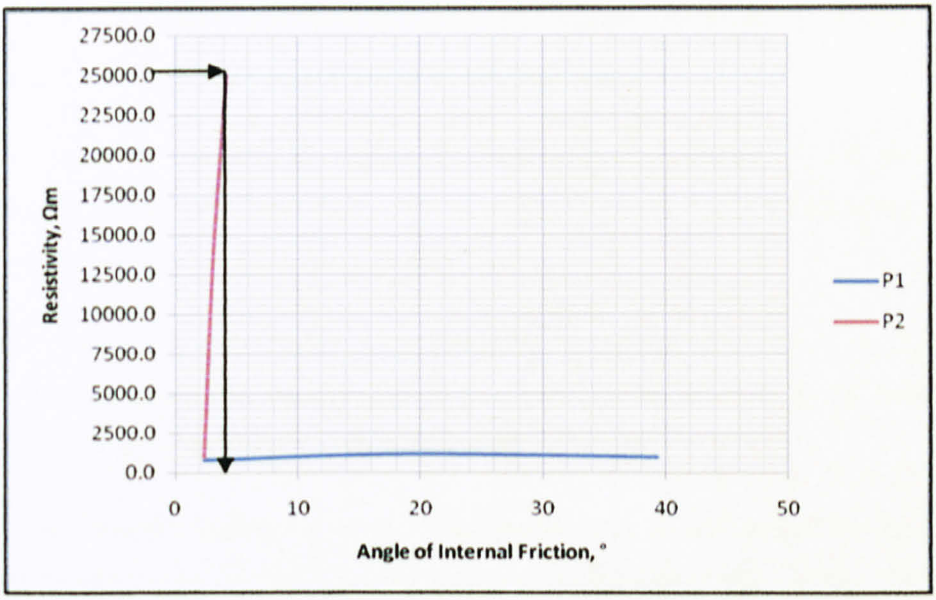

Figure 11 : Resistivity versus Angle of Internal Friction

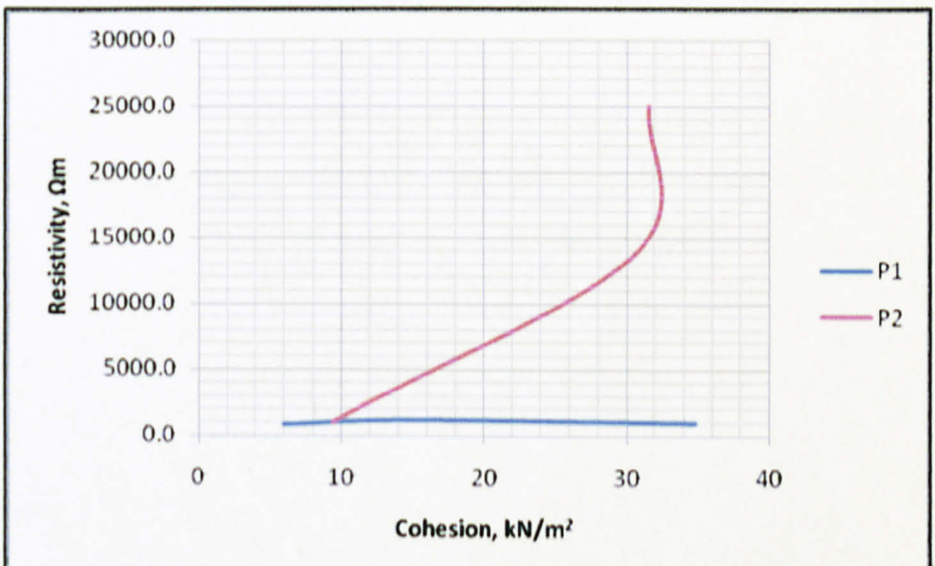

Figure 12 : Resistivity versus Cohesion

In this case, by referring to the equation given, β is the slope, H is the height of the slope and γ is the saturated unit weight of the soil. Since γ value is not available, the test should be conducted in the future in establishing the correlation between soil resistivity and saturated unit weight.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

Soil can have a resistivity of less than 1 to over 1000 Ohm.m depending on the porosity, nature of solid matrix (sand or clay), water saturation and concentration of dissolved solid. Sandy soil normally has a higher resistivity value than clayey soil. Since in this proposed site location is mostly consisting of sand and shale, sand is chosen as the sample for further testing in the laboratory.

In order to correlate the resistivity test with the strength of soil sample with variation in moisture content, resistivity sandbox, moisture content and direct shear test has been done on a set of similar soil specimen.

Frictional angle decreases with increases of moisture content. The reduction is due to the increased lubrication of clay paste following water addition causing sand grains to slip and slide, resulting in reduced Ø.

The electrical resistivity of soil was observed to be influenced by the moisture. The relationship between electrical resistivity and moisture content in two different soil sample P1 and P2 shown that the resistivity decreased with an increase in moisture content.

Results from all the tests conducted enhance the understanding of the preliminary correlations of soil properties with the electrical parameters. Further detail experiments are required to determine better and more precise correlations.

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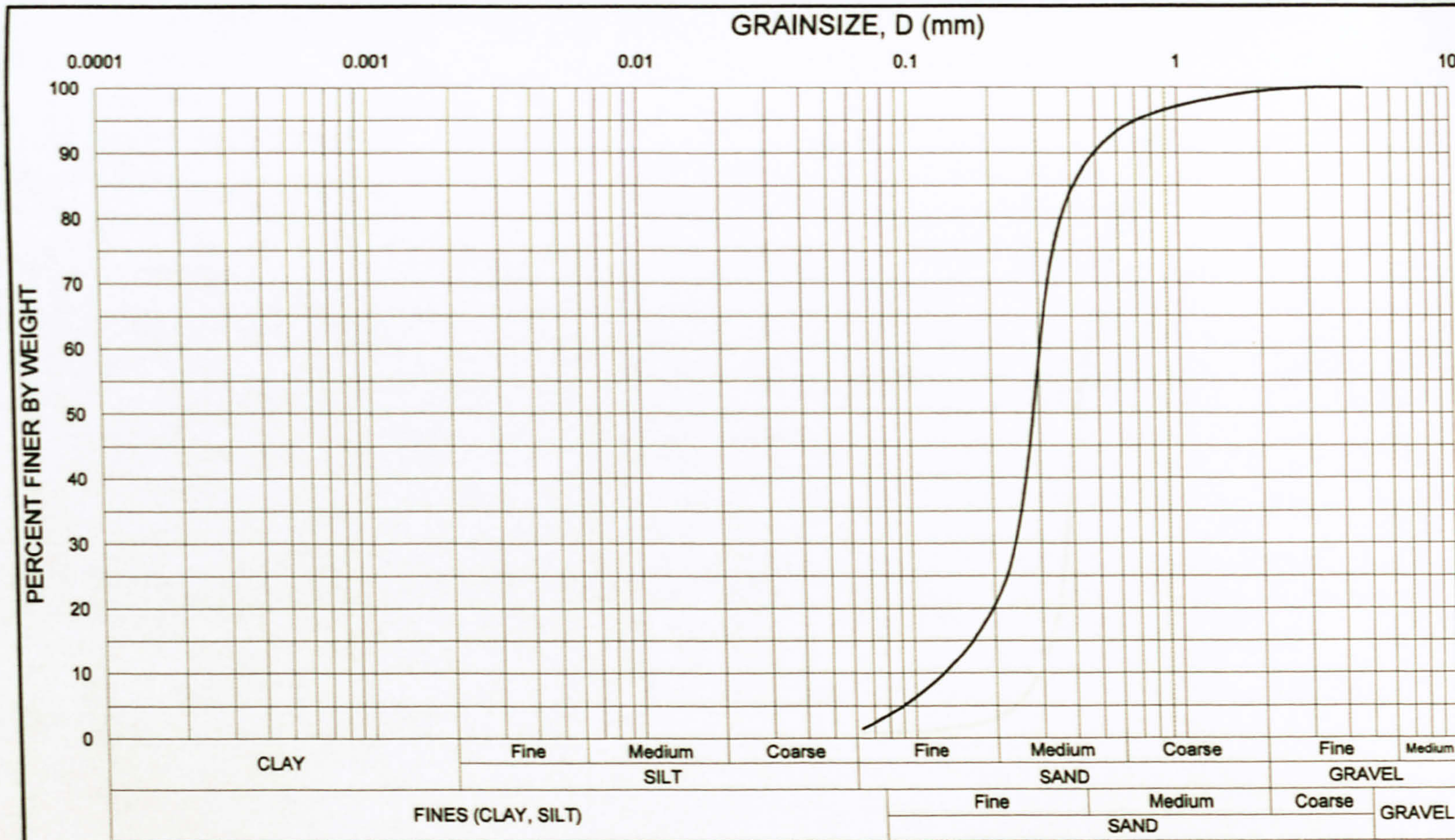
APPENDIX A

UTP/PROGRESS/SI/7569/FYP(2)

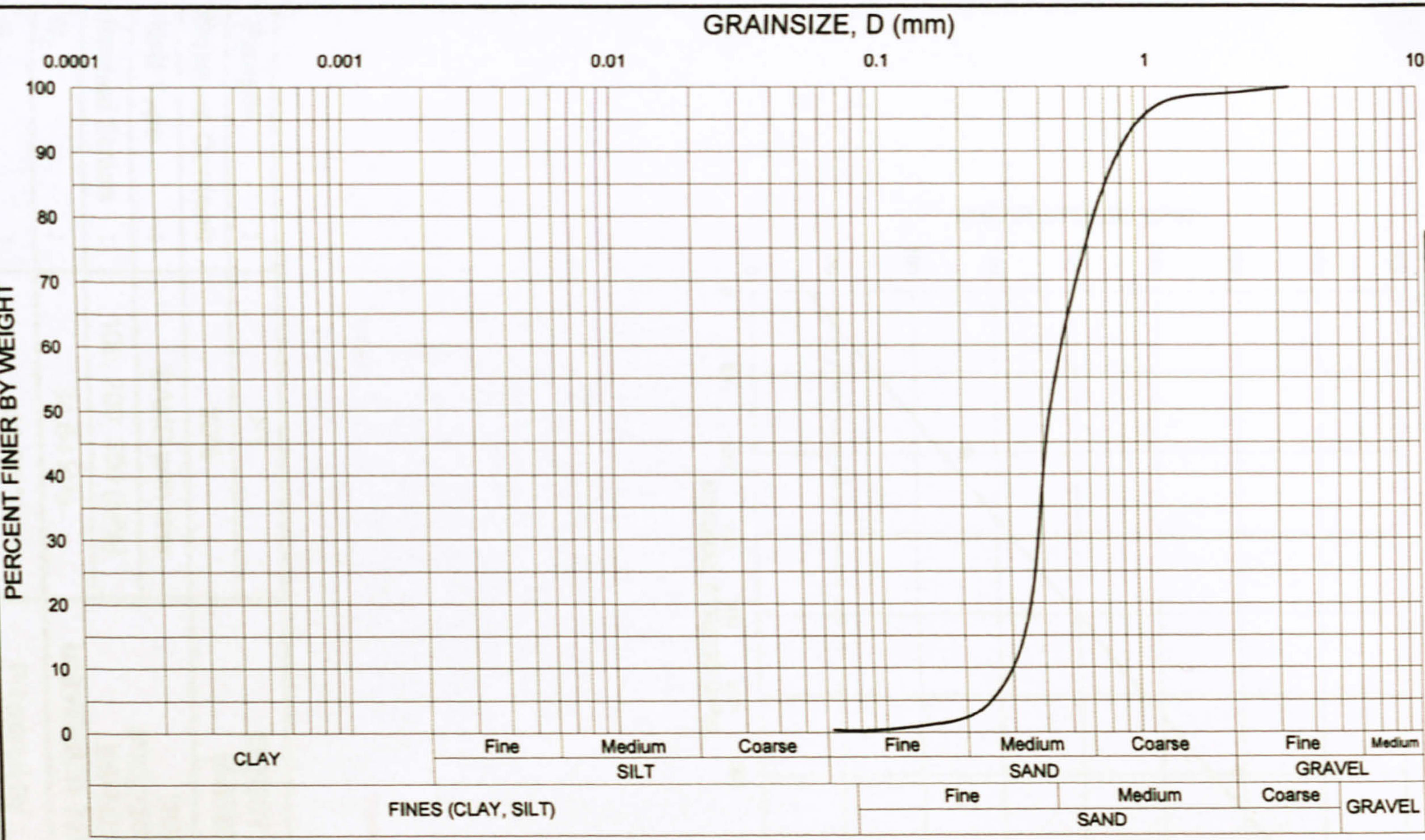


Soil Type	PERCENTAGE (%)			
	P1	-	-	-
Clay & Silt	3	-	-	-
Sand	97	-	-	-
Gravel	-	-	-	-

SAMPLE	DEPTH	CURVE	SOIL DESCRIPTION (ASTM D 2487)	GRAIN SIZE DISTRIBUTION CURVE
P 1	0.3m	————	SAND with clay	BOREHOLE 1 4°22.724'N, 100°57.786'E BEHIND BUILDING 13 UNIVERSITI TEKNOLOGI PETRONAS
-	-		-	
-	-		-	
-	-		-	Prepared by :

Plate A1

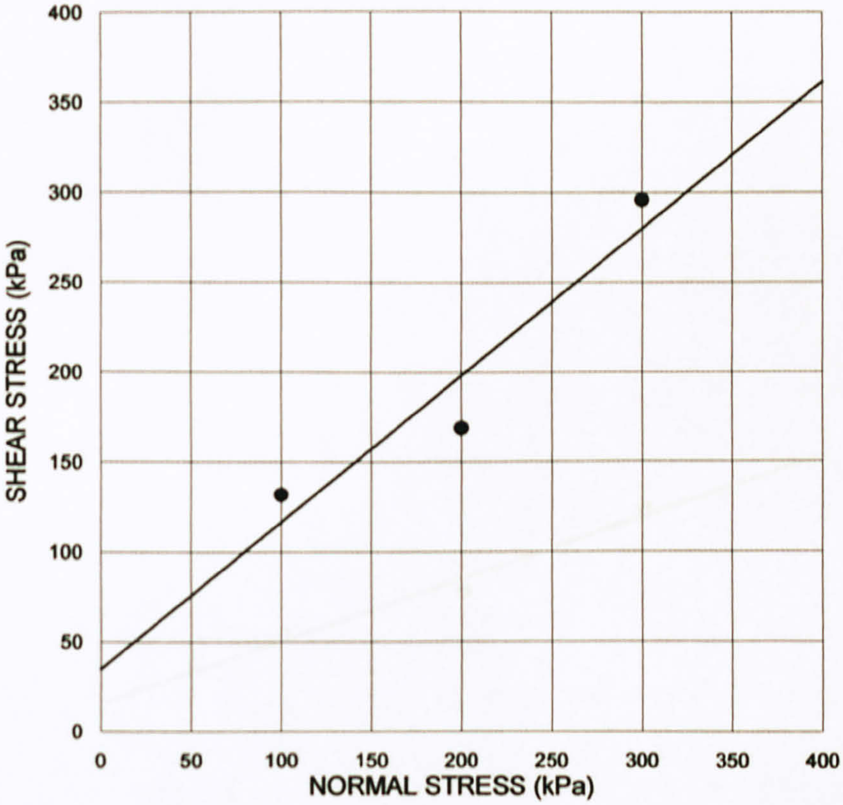
UTP/PROGRESS/SI/7569/FYP(2)



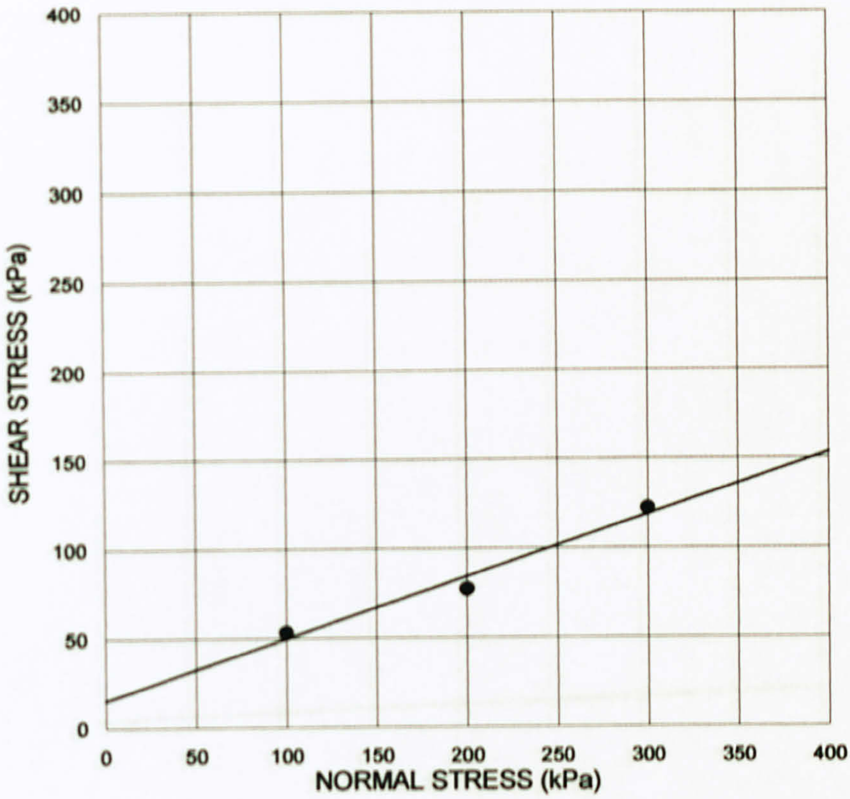
Soil Type	PERCENTAGE (%)			
	P2	-	-	-
	0.4			
Clay & Silt	99.6	-	-	-
Sand	-	-	-	-
Gravel		-	-	-

SAMPLE	DEPTH	CURVE	SOIL DESCRIPTION (ASTM D 2487)	GRAIN SIZE DISTRIBUTION CURVE
P 2	0.3m	————	SAND with clay	BOREHOLE 2 SLOPE FAILURE SAMPLE BEHIND BUILDING 13 UNIVERSITI TEKNOLOGI PETRONAS
-	-		-	
-	-		-	
-	-		-	Prepared by :

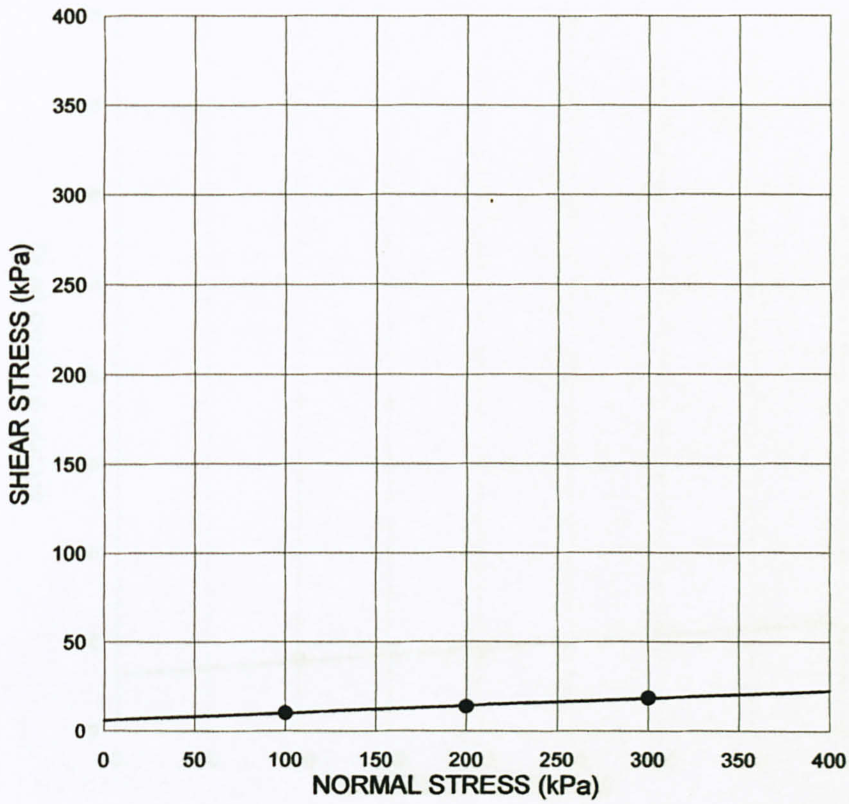
Plate A2



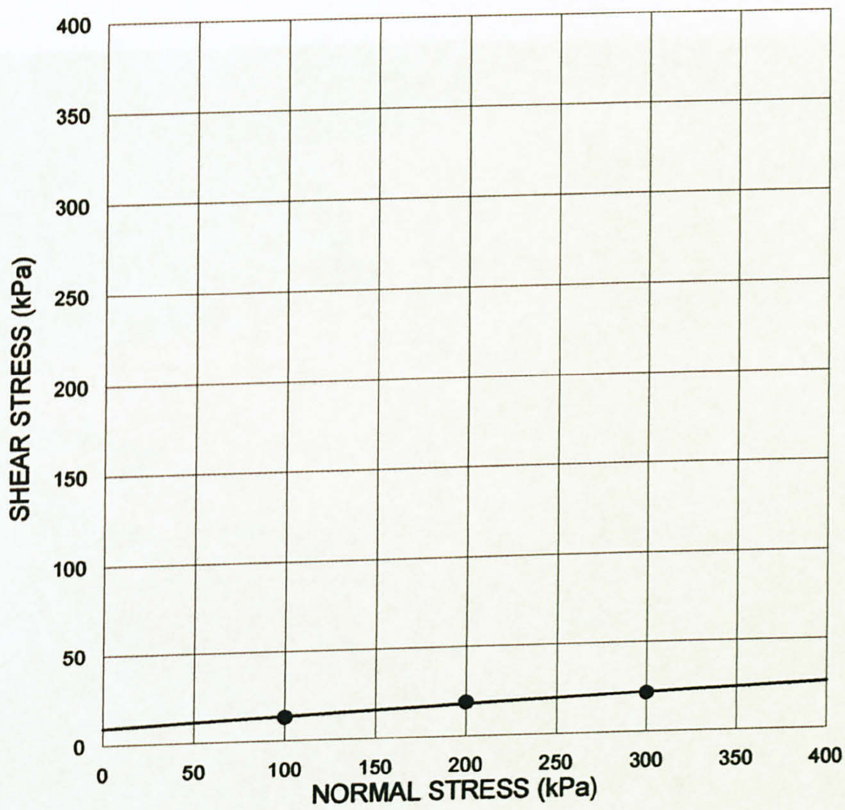
Sample :	P1	**DIRECT SHEAR TEST (ASTM : D 3080-04)**	
Moisture Content:	20%		
Soil Type :	SAND with clay	**BOREHOLE 1 4°22.724'N, 100°57.786'E BEHIND BUILDING 13 UNIVERSITI TEKNOLOGI PETRONAS**	
Normal Stress :	100, 200, 300 (kPa)		
C_d :	34.84 kPa		
ϕ_d :	39.38 °	Prepared by :	



Sample	:	P1	**DIRECT SHEAR TEST (ASTM : D 3080-04)**	
Moisture Content:		30%		
Soil Type	:	SAND with clay	**BOREHOLE 1 4°22.724'N, 100°57.786'E BEHIND BUILDING 13 UNIVERSITI TEKNOLOGI PETRONAS**	
Normal Stress	:	100, 200, 300 (kPa)		
C_d	:	15.14 kPa		
ϕ_d	:	19.02 °	Prepared by :	

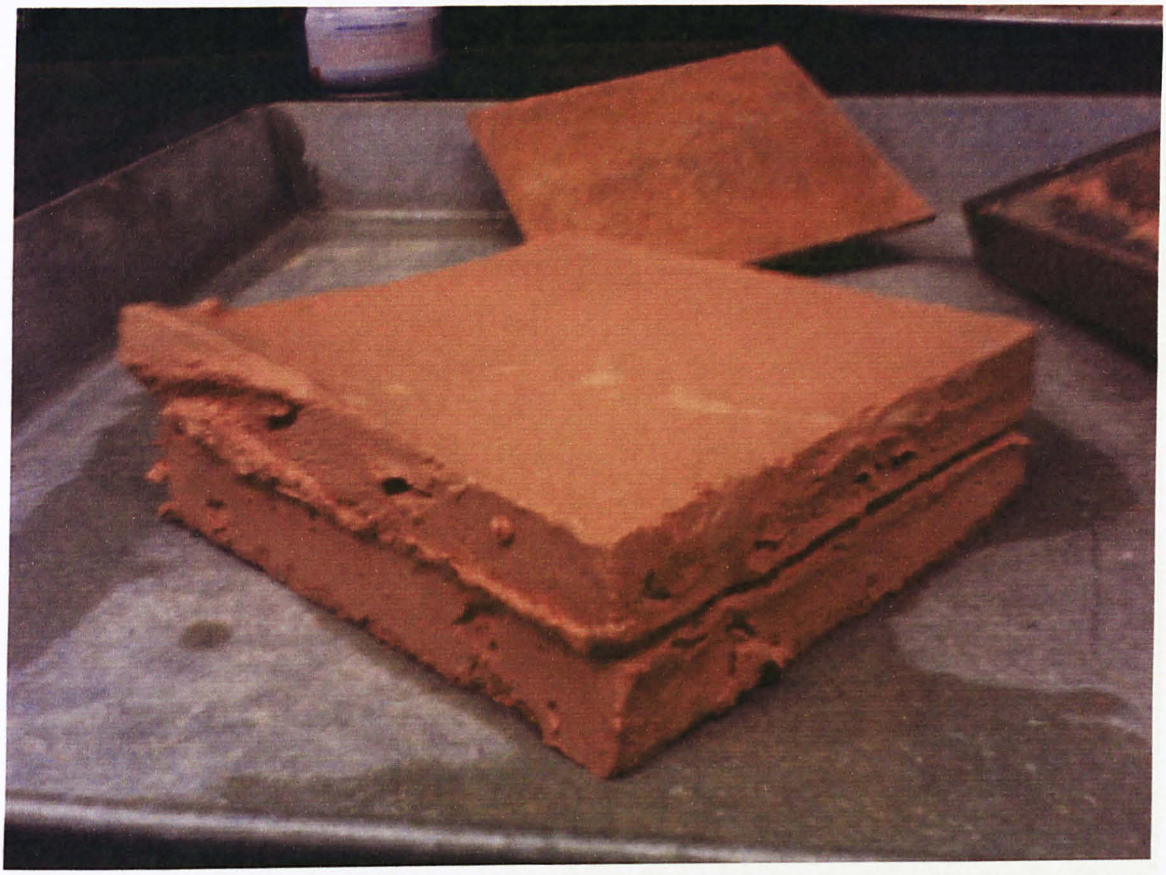


Sample :	P1	DIRECT SHEAR TEST (ASTM : D 3080-04)	
Moisture Content:	40%		
Soil Type :	SAND with clay	BOREHOLE 1 4°22.724'N, 100°57.786'E BEHIND BUILDING 13 UNIVERSITI TEKNOLOGI PETRONAS	
Normal Stress :	100, 200, 300 (kPa)		
C_d :	6.02 kPa		
ϕ_d :	2.35 °	Prepared by :	



Sample :	P2	**DIRECT SHEAR TEST (ASTM : D 3080-04)**	
Moisture Content:	40%		
Soil Type :	SAND with clay	**BOREHOLE 2 SLOPE FAILURE SAMPLE BEHIND BUILDING 13 UNIVERSITI TEKNOLOGI PETRONAS**	
Normal Stress :	100, 200, 300 (kPa)		
C_d :	9.49 kPa		
ϕ_d :	2.35 °	Prepared by :	

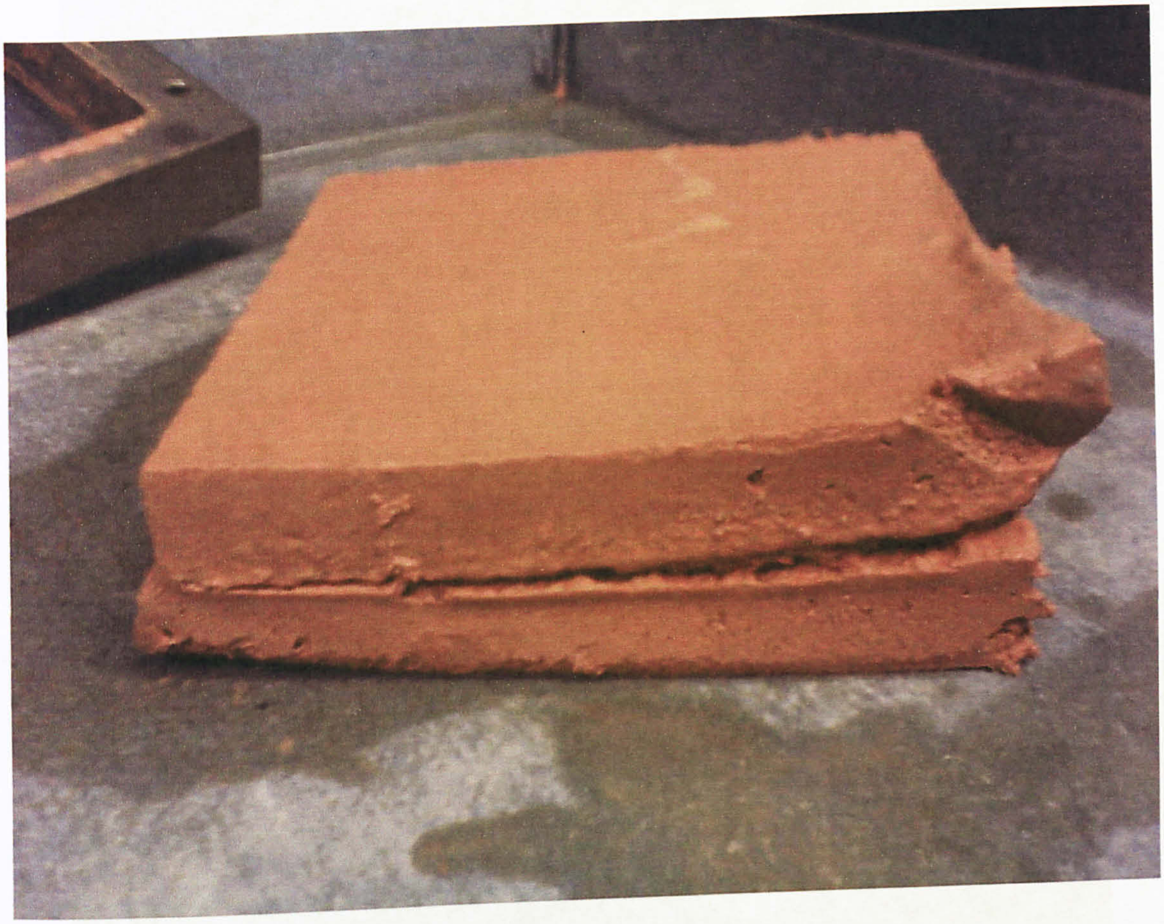
Plate A8



Sample P1 after Direct Shear Test

PHOTOGRAPH OF SELECTED SOIL SAMPLE

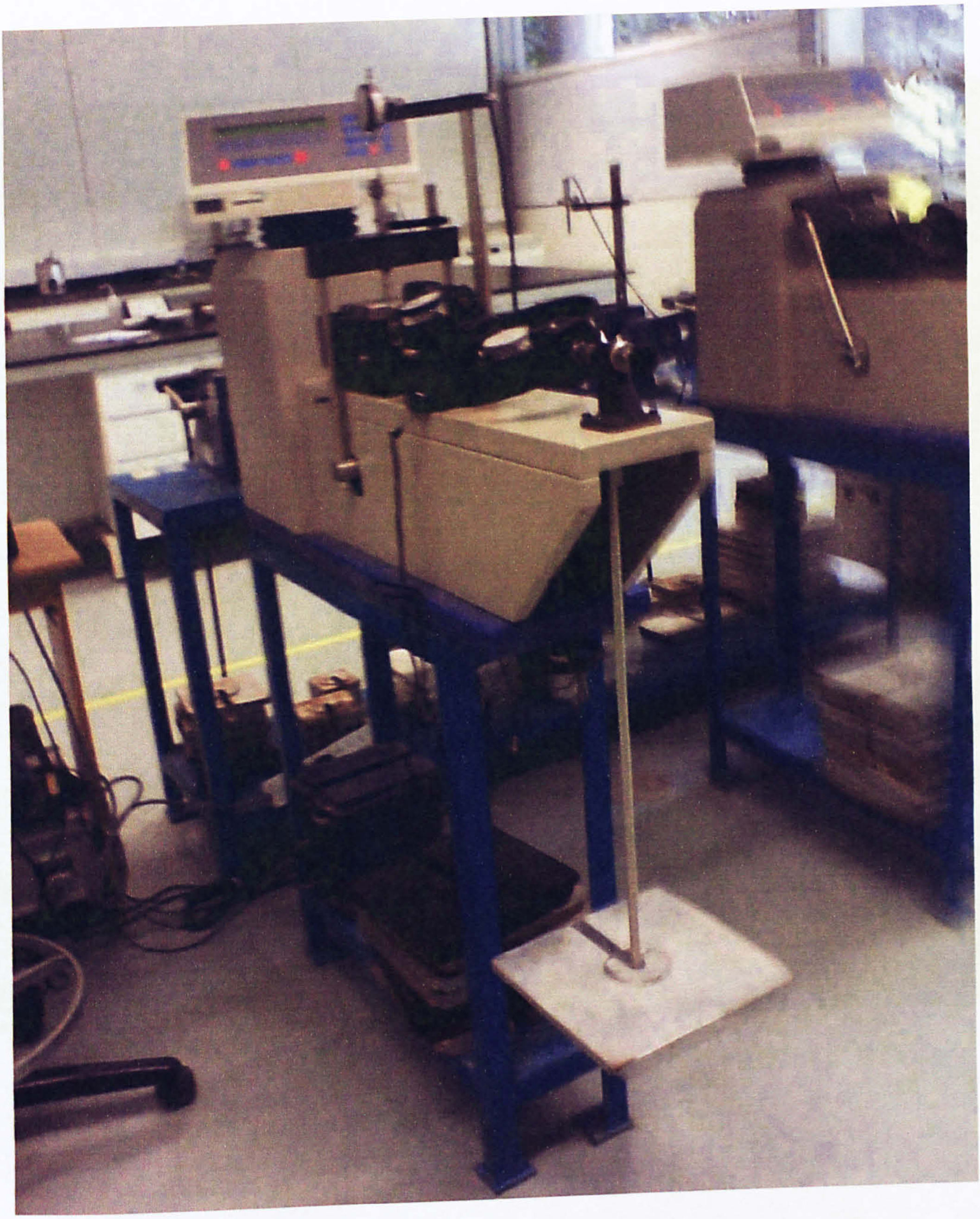
BOREHOLE 1
4°22.724'N, 100°57.786'E
BEHIND BUILDING 13
UNIVERSITI TEKNOLOGI PETRONAS



Sample P2 after Direct Shear Test

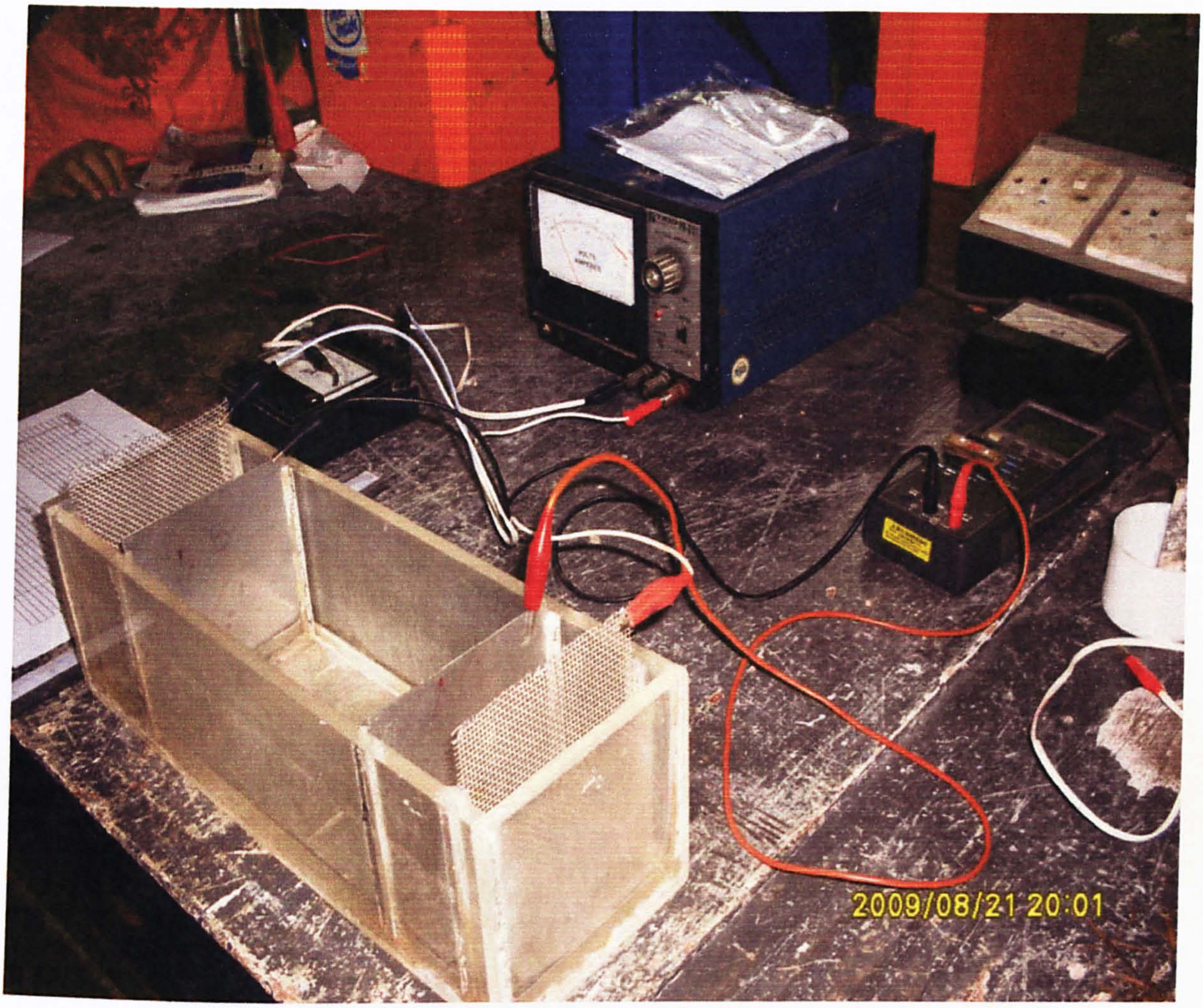
PHOTOGRAPH OF SELECTED SOIL SAMPLE

BOREHOLE 2
SLOPE FAILURE SAMPLE
BEHIND BUILDING 13
UNIVERSITI TEKNOLOGI PETRONAS



LABORATORY EQUIPMENT

DIRECT SHEAR TEST EQUIPMENT



LABORATORY EQUIPMENT

SOILBOX RESISTIVITY EQUIPMENT