SHEAR STRENGTH CHARACTERISTICS OF TROPICAL SOIL AT UNIVERSITI TEKNOLOGI PETRONAS CAMPUS

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CIVIL ENGINEERING
UNIVERSITI TEKNOLOGI PETRONAS
JUNE 2010

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by

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Dissertation submitted in partial fulfillment of

the requirement for the

Bachelor of Engineering (Hons)

(Civil Engineering)

JUNE 2010

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Civil Engineering Programme

Universiti Teknologi PETRONAS

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BACHELOR OF ENGINEERING (Hons)

(CIVIL ENGINEERING)

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JUNE 2010

CERTIFICATION OF ORIGINALITY

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

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MOHD YUSAIRI BIN MD YUSOF

ABSTRACT

Studies on spatial variability of soil engineering properties are limited in the south east Asia. This study examines the spatial variability of soil shear strength properties in a flat region under subtropical climate using geostatistical and statistical methods. This proposed study will allow understanding and characterization of small scale spatial variability nature of soil shear strength characteristics of tropical soil in University Technology of PETRONAS (UTP) campus area. The campus is built on a 400 hectare (1,000 acres) site. This campus is used as the experimental subject of the spatial variability of soil shear strength characteristic. Global Positioning System (GPS) was used for locating the samples position. This project was been towards the laboratory soil shear strength test from the samples that was taken at 50 different locations inside UTP campus. The data has been analysed statistically and geostatistically using special computer software. The study indicated geostatistical analysis in conjunction with conventional statistical analysis could reveal spatial variability nature of soil shear strength properties and causes behind the variability. Of significant importance to land management practices is the finding that the variability of the soil shear strength are largely due to topographic features and land disturbances. This will also allow identifying the effects of land disturbances and catchments characteristics inside the campus area of significant importance to land management practices.

ACKNOWLEDGEMENT

All praises be to Allah S.W.T, The Most Gracious, The Most Merciful for His Guidance and Blessing. The Author would like to take this opportunity to acknowledge the following parties for their help and support in completing this project :

- University of Technology PETRONAS..
- Civil Engineering Department, University of Technology PETRONAS.

A special acknowledgement and highly gratitude to the project's supervisor, Assoc. Prof. Dr. Rezaur R.B. Thank you also to the following staffs at Civil Engineering Department, University of Technology PETRONAS for their personal involvement and assistance which was direct or indirectly in completing this project :

- Ms. Izhatul Imma, UTP Geotechnical Laboratory Technician.
- Assoc. Prof. Dr. Saied Saiedi, Lecturer
- Ms. Husna Takaijuddin, FYP Coordinator
- Assoc. Prof. Dr. Hasnain Isa, FYP Coordinator

The Author would also like to thank you and wish grateful acknowledgement to everyone involved which their name is not mention here in ensuring the successfulness of this project. Their help and support is highly appreciated. Thank you very much.

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Shear strength in reference to soil is a term used to describe the maximum strength of soil at which point significant plastic deformation or yielding occurs due to an applied shear stress. There is no definitive shear strength of a soil as it depends on a number of factors affecting the soil at any given time and on the frame of reference, in particular the rate at which the shearing occurs.

The shear strength of the soil may be attributed to three basic components (Cernica,John N. , 1995) :

1. Frictional resistance to sliding between solid particles
2. Cohesion and adhesion between soil particles
3. Interlocking and bridging of solid particles to resist deformation

In other term, shearing strength in soils is the result of the resistance to movement at inter-particle contacts, due to particle interlocking, physical bonds formed across the contact areas (resulting from surface atoms sharing electrons at inter-particle contacts), and chemical bonds (i.e. cementation -particles connected through a solid substance such as re-crystallized calcium carbonate).(Terzaghi, K., Peck, R.B., and Mesri, G. 1996)

This is due to the stress-strain relationship of soils and therefore the shearing strength, is affected by soil composition, soil initial state, soil structure and loading condition (Poulus,1989). Spatial variability causes difficulty in representing a soil with a deterministic or precisely defined set of characteristics and precludes characterization of soil shear strength response.

From another perspective, it is neither easy nor practical to clearly delineate the effects of these components on the shear strength of the soil. This becomes more apparent when one relates these components to the many variables that directly or indirectly influence them, not to mention the lack of homogeneity and uniformity of the characteristics that typify most soil masses. The components may be influenced by changes in moisture content, pore pressures, structural disturbance, fluctuation in the groundwater table, underground water movement, stress history, time, chemical action or environmental actions. (Cernica,John N. , 1995)

This proposed project will allow understanding and characterization of small scale spatial variability nature of soil shear strength inside University Technology PETRONAS campus area. This will also allow identifying the effects of land disturbances and catchments characteristics inside the campus area of significant importance to land management practices.

1.2 Problem Statement

Universiti Teknologi PETRONAS (UTP) is built on a 400 hectare (1,000 acres) site. This campus is used as the experimental subject of the spatial variability of soil shear strength characteristic.

In many soil mechanics problems, the shear strength of the soil emerges as one of its important characteristics. Indeed, this problem group may include (Cernica,John N. , 1995) :

1. Stability of slopes (e.g: hillsides, cuts, embankments, earth dam)
2. Ultimate bearing capacity of a soil
3. Lateral pressure against retaining walls, sheeting or bracing
4. Friction developed by piles

In a specific big area such as this campus territory, classical statistics assumes that observation in the field is random regardless of their location. But some show that variation to be correlated across space. Therefore classical statistical method may be inadequate for interpolation of spatially dependant variables, because they assume random variation and do not consider spatial correlation and relative location of samples. Thus geo-statistical procedure recognizes these difficult and provides tool to facilitate the examination of spatial and temporal correlation in data. (Cromer, 1996)

Recently, there has been increasing concern about how to estimate attributes of spatially varying soil properties.(Sun et. Al, 2003) Therefore, spatial variability of soil shear strength properties should be monitored and quantified.

More advanced understanding of the behavior of soil undergoing shearing lead to the development of the critical state theory of soil mechanics (Roscoe, Schofield & Wroth 1958).

This proposed study will allow understanding and characterization of small scale spatial variability nature of soil shear strength characteristics of tropical soil in University Technology of PETRONAS (UTP) campus area. Besides, it is also allow mapping the variation in soil shear strength characteristics in the study area. Other than that, it can evaluate the effect of change in land use that affect on the variability of soil shear strength characteristics in the study area. Of significant importance to land management practices is the finding that the variability of soil shear strength are largely due to topographic features and land disturbances.

1.3 Objective of Study

The objective of this project :

- To characterize spatial variability of shear strength characteristics of soil in UTP area under tropical climate in term of semi-variogram parameter.
- To map the variation in soil shear strength characteristics in study area.
- To evaluate the effect of change in land use that affect on the variability of shear strength characteristics in the study area.

1.4 Scope of Study

The scope of study that will involve would be towards the laboratory soil shear strength test from the samples that has been taken at 50 different locations inside UTP campus and to do data analysis and geo-statistical analysis based on the laboratory results using special computer software. The statistic and geostatistic characterization of the data was formed and the Kriging method is used for mapping the contour mapping of the campus area as the result of the spatial variability of the soil shear strength.

CHAPTER 2

LITERATURE REVIEW

2.1 Soil Shear Strength

Soil shear strength is the maximum resistance of a soil to shearing stresses. Shear strength is one of the important characteristic in soil. There are several theories that have been obtained from this research used to estimate the shear strength of a soil depending on the rate of shearing.

1. Tresca Theory – For short term soil loading. Undrained strength or total stress condition.
2. Mohr-Coulumb Theory – For long term soil loading. Drained strength or effective stress condition.
3. Critical State Theory
4. Steady State Theory

Soil shear strength is the maximum strength of soil at which point significant plastic deformation or yielding occurs due to an applied shear stress.

In other perspective, shear strength is defined as the maximum value of shear stress that the soil can withstand. The shear strength of soils is controlled by effective stress, whether failure occurs under drained or undrained conditions. The two most important factors governing the strength of soils are the magnitude of the interparticle contact forces and the density of the soil. Larger interparticle contact forces and larger density of the soil results in larger shear strength of the soils. (J. Michael Duncan, Stephen G. Wright, 2005).

Drained conditions are those where changes in load are slow enough so that all of the soils reach a state of equilibrium and no excess pore pressures are caused by the loads and the pore pressures are controlled by hydraulic boundary conditions. (J. Michael Duncan, Stephen G. Wright, 2005)

Undrained conditions are those where changes in load occur more rapidly than water can flow in or out of the soil and the pore pressures are controlled by the behavior of the soil in response to changes in external loads. (J. Michael Duncan, Stephen G. Wright, 2005)

The drained strength is the strength of the soil when pore water pressures, generated during the course of shearing the soil, are able to dissipate rapidly. It also applies where no pore water exists in the soil. It is commonly defined using Mohr-Coulomb theory (Terzaghi, 1942) combined with the principle of effective stress.

Drained strength is the strength of the soil when it is loaded slowly enough so that no excess pore pressures are induced by applied load. In the field, drained conditions result when loads are applied slowly to a mass of soil. In the laboratory, drained conditions are achieved by loading test specimens slowly that excess pore pressures do not develop as the soil is loaded. (J. Michael Duncan, Stephen G. Wright, 2005)

Undrained strength is the strength of the soil when loaded to failure under undrained conditions. In the field, conditions closely approximating undrained conditions result when loads are applied to a mass of soil faster than the soil can drain. In the laboratory, undrained conditions are achieved by loading test specimens so rapidly that they cannot drain, or by sealing them in impermeable membranes. (J. Michael Duncan, Stephen G. Wright, 2005)

In critical state soil mechanics, distinct shear strength is identified where the soil undergoing shear at a constant volume. A more advanced understanding of the behavior of soil undergoing shearing lead to the development of the critical state theory of soil mechanics (Roscoe, Schofield & Wroth, 1958).

The steady state strength is defined as the shear strength of the soil when it is at the steady state condition. The steady state condition is defined as "that state in which the mass is continuously deforming at constant volume, constant normal effective stress, constant shear stress, and constant velocity." (Poulos 1981).

A normally consolidated soil is one that has not been subjected to an effective stress higher than the present effective stress, and its density is the lowest possible for any given effective stress. As a result, normally consolidated clays tend to compress when sheared. (J. Michael Duncan, Stephen G. Wright, 2005)

An over-consolidated clay is one that was subjected previously to higher effective stress and thus has a higher density than that of a normally consolidated soil at the same effective stress. As a result, over-consolidated soils compress less when sheared that do normally consolidated or if the previous maximum effective stress was much higher that the effective stress during shearing, the clay will dilate. (J. Michael Duncan, Stephen G. Wright, 2005)

The tendency of normally consolidated and lightly over-consolidated clays to compress when sheared result in increased pore pressures when shear stresses increased under undrained conditions. The tendency of heavily over-consolidated soils to dilate when sheared results in negative changes in pore pressures when shear stresses increase under undrained conditions. Thus, when clays are sheared under undrained conditions, the effective stress on the potential failure plane changes, becoming lower in normally consolidated soils and higher in heavily over-consolidated soils. (J. Michael Duncan, Stephen G. Wright, 2005)

A number of noteworthy differences exist between cohesive and non-cohesive soils (Cernica,John N. , 1995) :

1. The frictional resistance of soils is less that that of granular soils
2. The cohesion of clay is appreciably larger than that of granular soils
3. Clay is much less permeable than a sandy soil
4. The time related changes of volume in clays is slower than that for granular material.

2.2 Spatial Variability

Spatial variability of soil physical properties are important analysis which to determine the optimum size of spatial for distributed parameter hydrological models, estimating point or spatially averaged values of soil shear strength that using Kriging technique, in designing sampling networks and improving their efficiency. The semi-variogram and statistical parameters has been characterized the spatial variability of soil physical properties. (Rezaur R.B., Balamohan B., Ismail A.,2004)

Agricultural consultants have imported spatial and temporal field data into geographic information system to produce spatial distribution maps for improved on farm management. (Mulla, Schepers, 1997)

2.3 Semi-variogram

Semi-variogram is a function describing the degree of spatial dependence of a spatial random field or stochastic process. It can be defined as the expected squared increment of the values between locations x and y (Wackernagel 2003).

From another term, semi-variogram are statistical measures that assume the input sample data are normally distributed and that local neighborhood means and standard deviation show no trends. (Eastman, 2001)

Although shear strength theories for saturated soils have been formulated and seem to be consistent with observed experimental behavior, the laboratory measurement are time consuming and require large effort, leading to the desire to develop a simple approach for estimating shear strength of soil.(A. Burak Goktepe, Selim Altun, 2005)

2.4 Kriging Method

Kriging method is a technique to interpolate the value at an unobserved location from observations of some values at nearby area. The kriging interpolation may also be seen as a spline in a reproducing kernel Hilbert space, with reproducing kernel given by the covariance function. (Grace Wahba, 1990)

Kriging minimizes the error produced by differences in the fit of the spatial continuity to each local neighborhood. (Eastman, 2001)

Kriging provides statistically optimal and unbiased prediction and estimates of the errors of the interpolation. (Mac Bratney and Webster, 1983 ; Tao, 1995 ; Wang et al, 2003)

Wikipedia define Kriging as below;

"…a group of geostatistical techniques to interpolate the value of a random field (e.g., the elevation, z, of the landscape as a function of the geographic location) at an unobserved location from observations of its value at nearby locations.

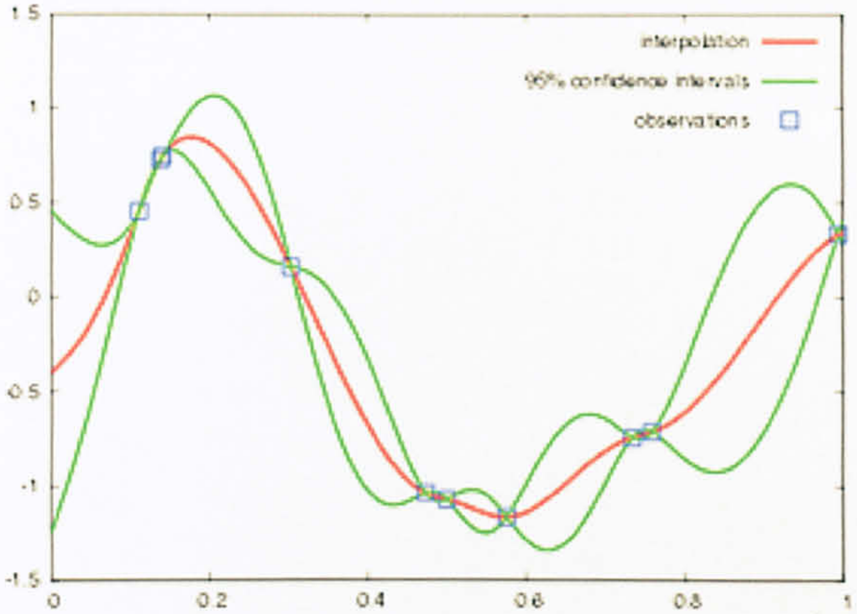


Figure 2.1 : Example of one-dimensional data interpolation by kriging, with confidence intervals. Squares indicate the location of the data. The kriging interpolation is in red. The confidence intervals are in green.

Kriging belongs to the family of linear least squares estimation algorithms. As illustrated in Figure 1, the aim of Kriging is to estimate the value of an unknown real-valued function, f, at a point, x *, given the values of the function at some other points, .

A Kriging estimator is said to be linear because the predicted value $\hat{f}(x^*)$is a linear combination that may be written as

$$\hat{f}(x^*) = \sum_{i=1}^{n} \lambda_i(x^*) f(x_i) \tag{2.1}$$

$$\varepsilon(x) = F(x) - \sum_{i=1}^{n} \lambda_i(x) F(x_i) \tag{2.2}$$

The weights λ_i are solutions of a system of linear equations which is obtained by assuming that f is a sample-path of a random process F(x), and that the error of prediction is to be minimized in some sense. For instance, the so-called simple Kriging assumption is that the mean and the covariance of F(x) is known and then, the Kriging predictor is the one that minimizes the variance of the prediction error.

From the geological point of view, the practice of Kriging is based on assuming continued mineralization between measured values. Assuming prior knowledge encapsulates how minerals co-occur as a function of space. Then, given an ordered set of measured grades, interpolation by Kriging predicts mineral concentrations at unobserved points.

Kriging is based on the assumption that the parameter being interpolated can be treated as a regionalized variable. A regionalized variable is intermediate between a truly random variable and a completely deterministic variable in that it varies in a continuous manner from one location to the next and therefore points that are near each other have a certain degree of spatial correlation, but points that are widely separated are statistically independent (Davis, 1986). Kriging is a set of linear regression routines which minimize estimation variance from a predefined covariance model.

Kriging is a procedure for constructing a minimum error variance linear estimate at a location where the true value is unknown.

The main controls on Kriging weight are :

- Closeness of data to the location being estimated
- Redundancy between data
- The variogram

Several software will be used to get the result of soil shear strength in UTP campus are based on this geo-statistical interpolation method.

2.5 Global Positioning System (GPS)

From what has been understood, Global Positioning System or GPS is a system for determining a position on the earth surface by comparing radio signals from several satellites by using GPS device.

The Global Positioning System allows the accurate positioning of an object using satellites signals. There are a lot of applications of this technology in many scientific fields in all over the world. The geographic and geometric information obtained by the use of Global Positioning System can be introduced to Geographic Information System (GIS) database thus thematic maps can be produced. (Elsevier B.V. , 2003)

In this project, Global Positioning System has been used to determine the location of researches samples in field with minimum error. The GPS device will help to determine the exact location in field by giving the latitude and longitude of the location.

2.6 Statistics

Statistics is the science of making effective use of numerical data relating to groups of individuals or experiments. It deals with all aspects of this, including not only the collection, analysis and interpretation of such data, but also the planning of the collection of data, in terms of the design of surveys and experiments.

In simple phrase, statistics is define as the mathematics of the collection, organization, and interpretation of numerical data, especially the analysis of population characteristics by inference from sampling.

Wikipedia define statistics as ;

'.... branch of mathematics concerned with collecting and interpreting data....'

According to other definitions, it is a mathematical science pertaining to the collection, analysis, interpretation or explanation, and presentation of data (Moses Lincoln E., 1986). Statisticians improve the quality of data with the design of experiments and survey sampling. Statistics also provides tools for prediction and forecasting using data and statistical models. Statistics is applicable to a wide variety of academic disciplines, including natural and social sciences, government, and business.

Statistical methods used to summarize or describe a collection of data; this is called descriptive statistics. This is useful in research, when communicating the results of experiments. In addition, patterns in the data may be modeled in a way that accounts for randomness and uncertainty in the observations, and then used to draw inferences about the process being studied; this is called inferential statistics.

In statistical analysis, the general statistical parameter in calculated includes the maximum, minimum, mean, median, standard deviation and also coefficient of variation. The parameter above is define as :

Mean: The average of a numerical set. It is found by dividing the sum of a set of numbers by the number of members in the group

Median: The value of a numerical set that equally divides the number of values that is larger and smaller. For example, in a set containing nine numbers, the median would be the fifth number.

Standard deviation : A number representing the degree of variation within a numerical set (ToolingU, 2009).

Coefficient of Variation: Normalized measure of dispersion of a probability of distribution.

2.7 Geostatistics

Geostatistics is a methodology for interpolating data on an irregular pattern but this is too simplistic. A number of interpolation methods were already well known when geostatistics began to be known. Geostatistics is concerned with spatial data. That is, each data value is associated with a location in space and there is at least an implied connection between the location and the data value. (Donald E. Myers, 2002)

Location has at least two meanings. One is simply a point in space (which only exists in an abstract mathematical sense) and secondly with an area or volume in space. For example, a data value associated with an area might be the average value of an observed variable, averaged over that volume. In the latter case the area or volume is often called the support of the data.

This is closely related to the idea of the support of a measure. Let x, y, ...,w be points (not just coordinates) in 1, 2, or 3 dimensional space and $Z(x)$, $Z(y)$,.... denote observed values at these locations. For example, this might be the hydraulic conductivity, of an area. Now suppose that t is a location that is not sampled. The objective then is to estimate/predict the value $Z(t)$ (and the data locations as well as the location t). If only this information is given then the problem is ill-posed, i.e., it does not have a unique solution. One way to obtain a unique solution is to introduce a model into the problem. There are two ways to do this; one is deterministic and the second is stochastic or statistical. Both approaches must somehow incorporate the idea that there is uncertainty associated with the estimation/prediction step.(Donald E. Myers, 2002)

The value at the unsampled location is not itself random but our knowledge of it is uncertain. One approach then is to treat $Z(x)$, $Z(y)$, and $Z(t)$ as being the values of random variables. If the joint distribution of these random variables were known then the best estimator (best meaning unbiased and having minimal variance of the error of estimation) would be the conditional expectation of $Z(t)$ given the values of the other random variables. However the data consists of only one observation of the random variables $Z(x)$, $Z(y)$, and none of the random variable $Z(t)$, hence it is not possible to estimate or model this distribution using standard ways of modeling or fitting probability distributions. (Donald E. Myers, 2002)

According to Wikipedia(2010) ;

"Geostatistics is a branch of statistics focusing on spatiotemporal datasets. Developed originally to predict probable distributions for mining operations, it is currently applied in diverse disciplines including petroleum geology, hydrogeology, hydrology, meteorology, oceanography, geochemistry, geometallurgy, geography, forestry, environmental control, landscape ecology, and agriculture (esp. in precision farming). Geostatistics is applied in varied branches of geography, particularly those involving the spread of disease (epidemiology), the practice of commerce and military planning (logistics), and the development of efficient spatial networks. Geostatistics are incorporated in tools such as geographic information systems (GIS) and digital elevation models.

CHAPTER 3

METHODOLOGY

In studying the spatial variability of the soil shear strength in University Technology PETRONAS (UTP) campus, the soil samples will be examined. Six steps involved which includes:

1. University Technology PETRONAS map is obtained from satellite image using Google Earth application.
2. Using the GPS device to get the reference points before generating the map into another software which is CorelDraw.
3. Preparation of the geo-grid for sampling of at least 50 different points using CorelDraw. Determine the coordinates of the location the soil sample will taken both by the software and GPS device for field work.
4. Conducting the Shear Strength Test to determine the soil shear strength data for different soil samples taken from different locations inside UTP campus area based on the generated map.
5. Digitizing Software use to digitize the boundary map of the study area.
6. Computer analysis of the soil shear strength data to examine the spatial variability of soil shear strength characteristic, to quantity the spatial correlation in the data in terms of the semi-variogram parameters, and to prepare spatial distribution maps of the soil shear strength by using the statistical and geo-statistical method from the GS+ and Surfer software. Use Kriging method for interpolation of areas that was not being experiment (also using software).

3.1 Obtaining Reference Points

In the first field activity of this project, a Global Positioning System (GPS) device is used to determine the longitude and latitude of two references points. The operating method of the device are :

1.The GPS device (Garmin GPSMap 76csx) is switched on by pressing "ON" button.

2. The device is allowed to load for a while and connecting to the satellites.
3. Latitude/Longitude location format is chosen to be find.
4. The device is placed at specific location without being disturbed for 3 minutes to get exact location.
5. The longitude and latitude of the specific location is obtained from the device.
6. The location is recorded.
7. The device is turned off by pressing "OFF" button.

Based on the findings in first activity, a map consisting of UTP area with location coordinates has been developed using Google Earth application and CorelDraw. This map shows the gridlines and coordinates of where the soil samples will be taken in next activity. It is very crucial to get the exact coordinates of two reference points before this map being generated. Digitizer software can be used to generate the boundary of UTP area.

All the samples has been taken from about 15cm – 30cm below the ground surface and avoiding the surface vegetation. This is due to hydrological response only to top surface as the surface controls the runoff because this is not the study of soil foundation.

3.2 Laboratory Vane Shear Test.

1. Sample container securely attached to the base of the vane apparatus, with the sample axis vertical and located centrally under the axis of the vane.
2. The upper surface of the sample trimmed flat and perpendicular to the axis.
3. A torsion spring that is most appropriate for the estimated strength of the soil was selected and being assembles into the vane apparatus.
4. The pointer and the graduated scale on the torsion head was set to their zero reading, and ensuring that there is no backlash in the mechanism for applying torque.
5. The vane assembly being lowered until the end of the vane just touches the surface of the sample. This provides the datum from which the depth of penetration of the vane can be measured.
6. The vane assembly lowered further to push the vane steadily into the sample to the required depth. The top of the vane should be at distance not less than four times the blade width below the surface. Depth of penetration recorded.
7. Torque applied to the vane by rotating the torsion head at the rate of 6°/min to 12°/min, until the soil has sheared.
8. The maximum angular deflection of the torsion spring and the angel of rotation of the vane at instant of failure recorded.
9. The vane is raised steadily. As it emerges from the sample, excessive disturbance due to tearing of the surface is prevented. The blade wiped clean.
10. Procedure 1-9 is repeated with another sample.
11. Soil shear strength of each sample is calculated.

3.3 Sample Calculation Theory :

1. K is calculated, where K is constant which depends on the dimensions of the vane. (The value of K for the vane 12.7mm wide and 12.7mm long is 4290mm³.

$$\mathbf{K = \prod D^2 [(H/2) + (D/6)]} \tag{3.1}$$

Where : D = overall width of the vane measured to 0.1mm.

H = length of the vane measured to 0.1mm.

2. The torque applied to shear. M (N.mm) for each determination calculated by multiplying the maximum angular rotation of the torsion spring (in degree) by the calibration factor (N.mm per degree).

3. Vane shear strength of the soil , τv (kPa) will be calculated from equation ;

$$\mathbf{Tv = (M/4.29)\ kN/m^2} \tag{3.2}$$

Table 3.1 : Typical Torsion Spring for Laboratory Vane

General Descriptive Term for Strength	**Suggested Spring Reference**	**Probable Maximum Shear Stress (kN/m²)**
Very Soft Soil	A (weakest)	20
Soft Soil	B	40
Soft to Firm Soil	C	60

Firm Soil	D (stiffest)	90

Table 3.2 : Typical Values for Laboratory Vane

Term	**Undrained Shear Strength (kPa)**	**Visual Identification**
Very Soft Soil	< 12.5	Exudes between fingers
Soft Soil	12.5 – 25	Easily moulded with fingers and intended considerably with the thumb
Firm Soil	25 – 50	Can be moulded with moderate pressure of fingers and indented with moderate pressure
Stiff Soil	50 – 100	Moulded with difficulty by fingers, can be indented by strong pressure of the thumb only a small amount
Very Stiff Soil	100 - 200	Can be indented to little more than a fingerprint with strong pressure of the thumb

Table 3.3 : Calibration Chart for Laboratory vane

Torque		Spring Number			
Kg.Cm	N.m	1	2	3	4
0.25	0.025	8	10	14	21
0.50	0.049	16	19	27	39
0.75	0.074	23	29	41	58
1.00	0.098	31	39	55	18
1.25	0.123	40	49	69	98
1.50	0.147	48	60	82	118
1.75	0.172	56	69	95	139
2.00	0.196	65	79	108	160
2.25	0.221	72	90	122	179
2.50	0.245	81	100	135	199
2.75	0.270	89	110	150	
3.00	0.295	98	120	161	
3.25	0.319	105	129	175	

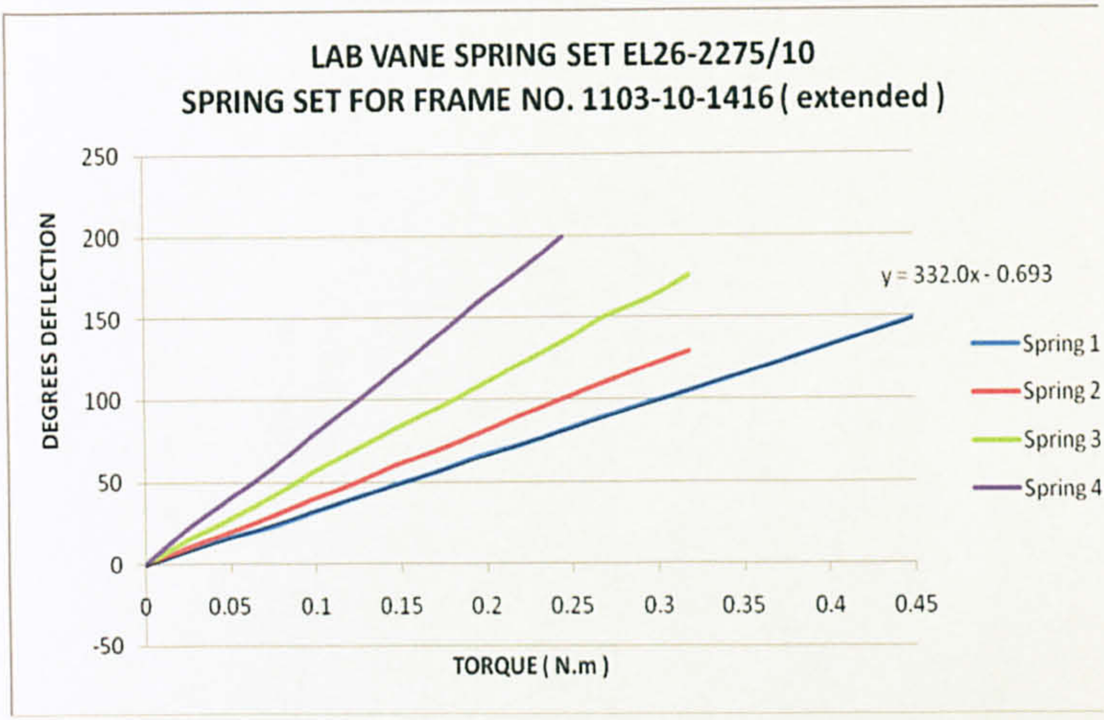


Figure 3.1 : Graph Degrees Deflection vs. Torque (extended)

3.4 Statistical Analysis

The general statistical parameters for all the 50 samples location will be calculated which includes the maximum, minimum, mean, standard deviation and coefficient of variation (CV) for each soil shear strength parameters.

The statistical analysis will be used in analyzing the results of shear strength test measurements on soil shear strength characteristics. The analysis involves the process of collecting and analyzing data and then summarizing the data into a numerical form. All the measurement for all 50 soil samples location will shows variation in each different point as the soil shear strength characteristics of each point are different with another making it difficult to identify the parameters.

3.5 Geostatistical Analysis

Geostatistical analysis included examining spatial variability nature of the soil shear strength by determining the semivariogram parameter. Semivariogram parameters namely the sill, nugget and range establishing best fitted semivariogram models for the soil shear strength.

All semivariogram parameters in this study are computed using the GS+ software (Gamma Design Software, Plainwell, MI, USA) and Surfer software. Semivariance is a measure of the degree of spatial dependence between samples. The Semivariance was estimated for the shear strength data. The Semivariance is defined as (Goovaerts, 1997):

$$\hat{\gamma}(h) = \frac{1}{2} \cdot \frac{1}{n(h)} \sum_{i=1}^{n(h)} (z(x_i + h) - z(x_i))^2 \tag{3.3}$$

Where z is a datum at a particular location, h is the distance between ordered data or known as the lag, and $n(h)$ is the number of paired data at a distance of h. The Semivariance is half the variance of the increments $z(x_i + h) - z(x_i)$, but the whole variance of z-values at given separation distance h (Bachmaier and Backes, 2008).

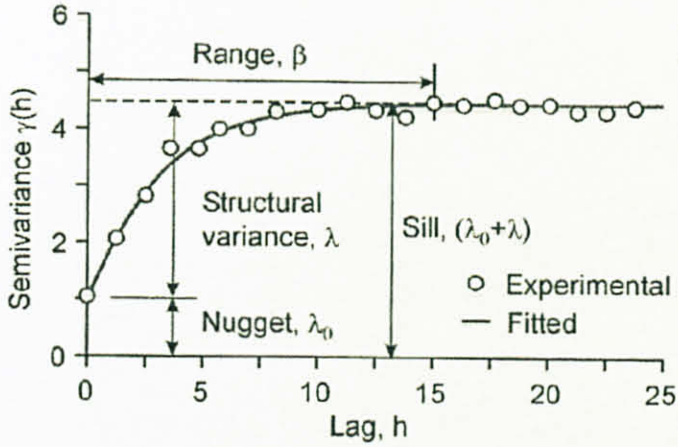


Figure 3.2 : Schematic diagram of a semivariogram and its parameters

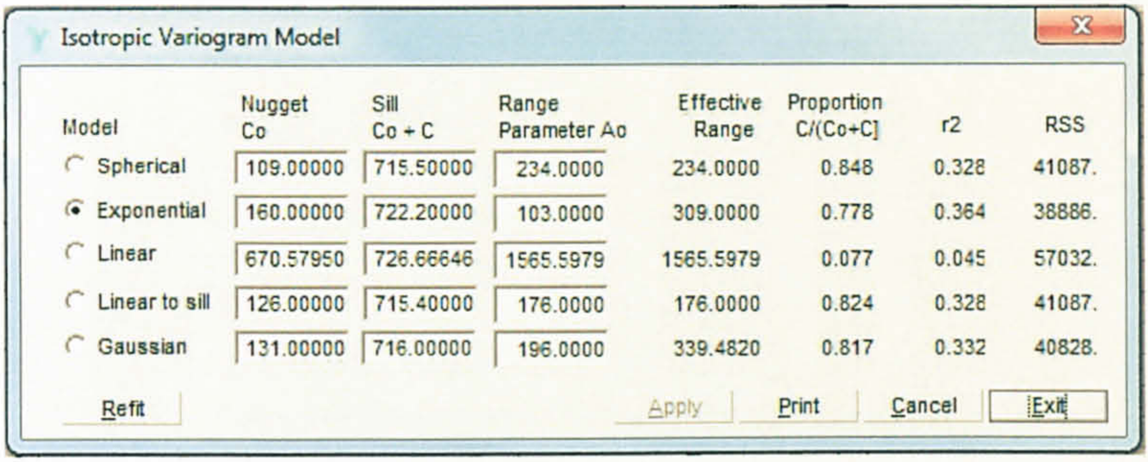
The magnitude of the semi variance between points depends on the distance between the points. A smaller distance gives a smaller semi variances and a larger distance gives a larger semi variances.

A property is called spatially dependent or autocorrelated if the probability of similar data values is higher for neighboring sample points than for points far from each other (Warrick et al., 1986). Thus $z(x_i)$ correlates to $z(x_i + h)$ by h being the lag between these two data. The correlation between $z(x_i)$ and $z(x_i + h)$ expresses the spatial structure of a variable of interest (Isaaks and Srivastava, 1989). Figure 3.2 illustrates an experimental and fitted semivariogram with parameters. The Semivariance rises with the increasing lag then levels off.

The lag at which the plateau is achieved is called the 'range' β, and the Semivariance value of the plateau is called the 'sill' Figure 3.2. Points within the range are considered to be spatially dependent while outside the range is considered independent.

The discontinuity is the 'nugget'. It represents all unaccounted spatial variability at distance smaller than the smallest lag while the semivariogram models the structural spatial dependence (Goovaert, 1997).

Therefore the 'nugget-to-sill' ratio gives a measure of the spatial dependence of shear strength data. The smaller the ratio, the stronger is the spatial dependence. Five different models Figure 3.3 were examined to fit the semivariance data. These include the spherical, exponential, linear, linear-to-sill and Gaussian model. The optimal models were determined by examining the fit of the model to the semivariogram as judged by the coefficient of determination (r^2) and RSS (residual sums of squares) (Wikipedia, 2010).



Model	Nugget Co	Sill Co + C	Range Parameter Ao	Effective Range	Proportion C/(Co+C)	r2	RSS
Spherical	109.00000	715.50000	234.0000	234.0000	0.848	0.328	41087.
Exponential	160.00000	722.20000	103.0000	309.0000	0.778	0.364	38886.
Linear	670.57950	726.66646	1565.5979	1565.5979	0.077	0.045	57032.
Linear to sill	126.00000	715.40000	176.0000	176.0000	0.824	0.328	41087.
Gaussian	131.00000	716.00000	196.0000	339.4820	0.817	0.332	40828.

Figure 3.3 : Example of best fitted variogram model

From the Figure 3.3 above, it shows the nugget, sill, range parameter, effective range, proportion, r2 and also RSS for every model. Range or A_0 is the distance over which spatial dependence is apparent. For some models there is a difference between the Range Parameter A_0 and the Effective Range. The Range Parameter is the value A_0 that is used in the formula that defines the best-fit line. The Effective Range is the separation distance at which spatial dependence is apparent. For Spherical and Linear-to-sill Models the Effective Range is defined as A_0.

For Exponential Models the Effective Range is defined as 3* A_0, or the distance at which the sill is within 5% of the asymptote (which the exponential model never meets).

For Gaussian models the Effective Range is $(3^{0.5})* A_0$. For the Linear Model A_0 is an arbitrary value, in the linear model there is no asymptote, i.e. spatial autocorrelation occurs across the entire range sampled, and for convenience A_0 is set to the Active Lag Distance.

Proportion of Spatial Structure or C/(Co+C) provides a measure of the proportion of sample variance (Co+C) that is explained by spatially structured variance C.

Regression Coefficient or r2 provides an indication of how well the model fits the variogram data but this value is not as sensitive or robust as the RSS value below for best-fit calculations.

RSS or Residual Sums of Squares provides an exact measure of how well the model fits the variogram data; the lower the reduced sums of squares, the better the model fits. GS+ uses RSS to choose parameters for each of the variogram models by determining the combination of parameter values that minimizes RSS for any given model.

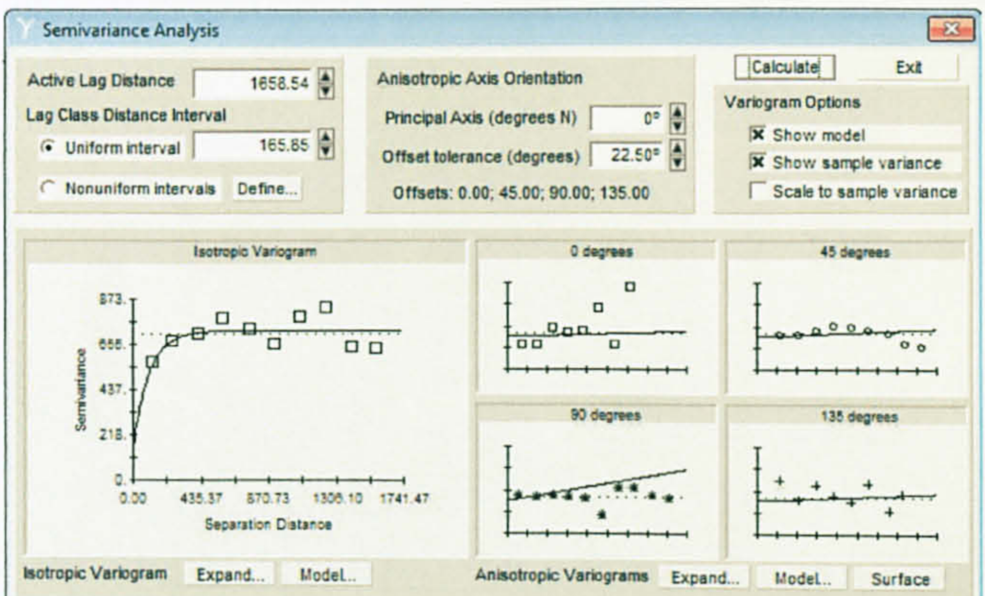


Figure 3.4 : Example of best fitted semivariance analysis

In statistics, the residual sum of squares (RSS) is the sum of squares of residuals. It is a measure of the discrepancy between the data and an estimation model. A small RSS indicates a tight fit of the model to the data.

3.6 Kriging Method Analysis

Kriging interpolation is used for mapping soil shear strength in the analysis and interpolation of spatial variation of soil. The soil contour maps will show the variability at the boundaries between different soil types which can provide valuable categorical information for interpreting variation in soil shear strength.

Kriging is most appropriate when it know there is a spatially correlated distance or directional bias in the data. It is often used in soil science and geology (Google, analyst using kriging, 2005).

The spatial distribution of soil shear strength for unsampled location obtained from interpolation between sampled locations by Kriging. The maps of spatial distribution of soil shear strength in conjunction with the site map allow examining the closeness of association between variation in soil shear strength and topographic condition.

CHAPTER 4

RESULT & DISCUSSION

4.1 Geo-grid Location

The study area was conducted in the University Technology of Petronas (UTP) campus area as shown in the Figure 4.1 below, located in Bandar Seri Iskandar, Perak Darul Ridzuan, Malaysia. The exact location is on coordinate 4^{o} 23.01' 30'' N and 100^{o} 58' 41'' E.

Figure 4.1 : Raw Satellite Image of University Technology PETRONAS campus.

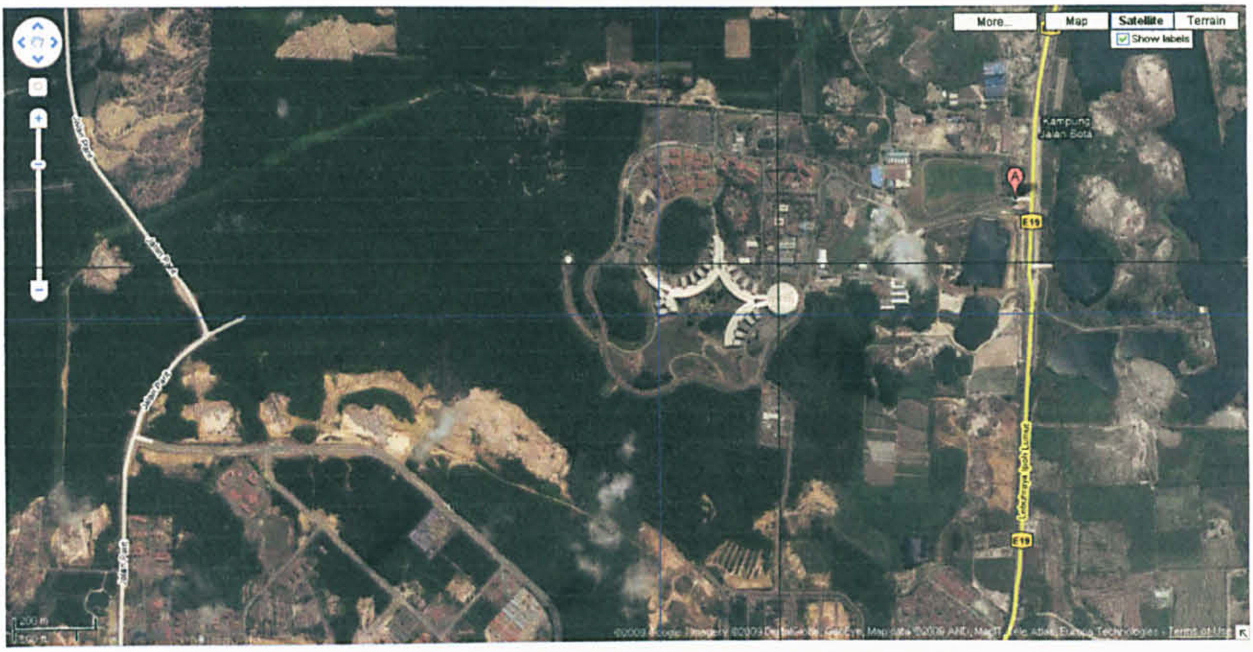


Figure 4.2 : The intersection of each lines (blue-blue) and (black-black) is taken as reference points.

First, use the UTP map which can be obtained from Google Earth. The map is the image from the satellite. Then the campus area from the map is divided by a number of regular geo-grids by using the CorelDraw software. There are two reference points that taken by Global Positioning System (GPS) device as reference to make the geo-grid as shown as in the map. One of the reference point lies on coordinate 4° 23' 00'' N and 100° 57' 51'' which is Block I (black line) while another point at block 13 lies on coordinate 4° 23'00'' N and 100° 58' 20'' E (blue line).

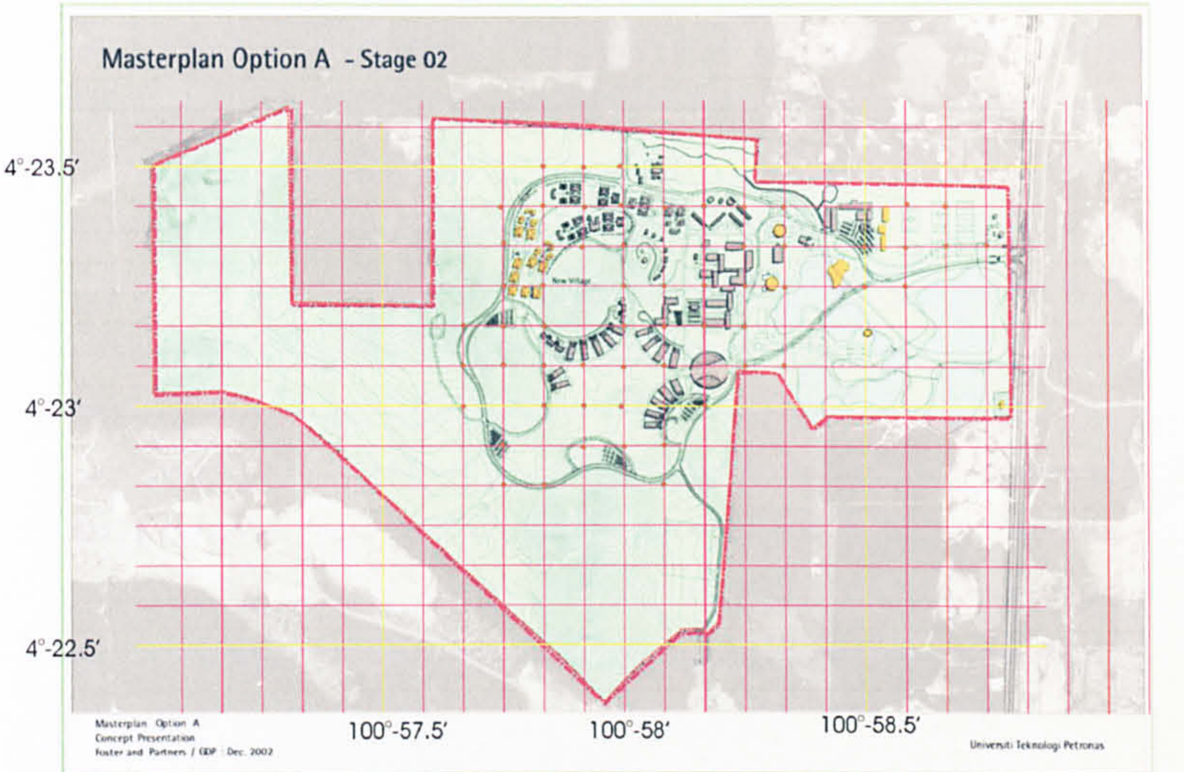


Figure 4.3 : Map which generated gridline using Coral Draw

The location for each soil samples collection points is marked based on the intersection of grid lines. The grid is subdivided by 5" for both vertical line and horizontal line so that it will be easier to determine the distance between the grid intersections which is 30 meter per 1 second. The geo-grid sampling method was used for this study on the premise that grid-sampling reduces the possibility of uneven samples.

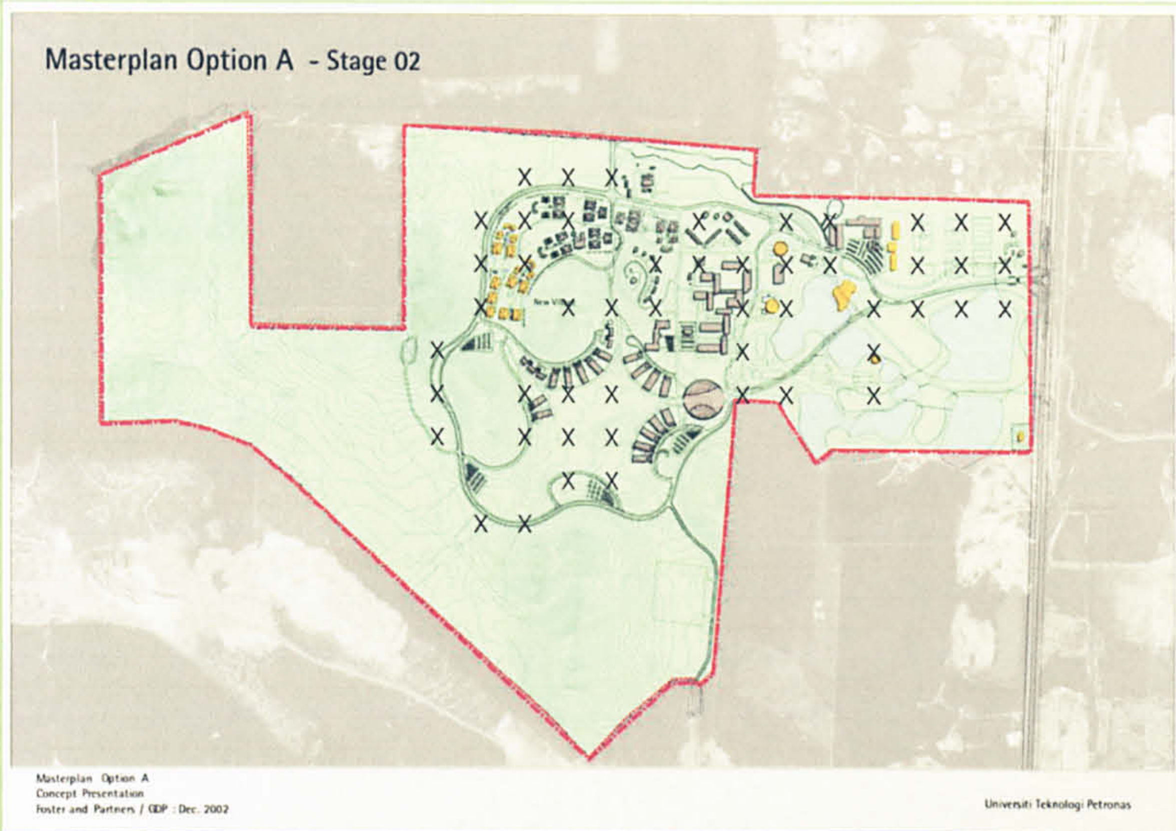


Figure 4.4 : Sampling locations.

50 points has been chosen from the generated campus map for soil samples testing. Each sample has been taken into laboratory for vane shear test. Global Positioning Device (GPS) has been used during field sampling work in obtaining the exact coordinates with error +-1 meter.

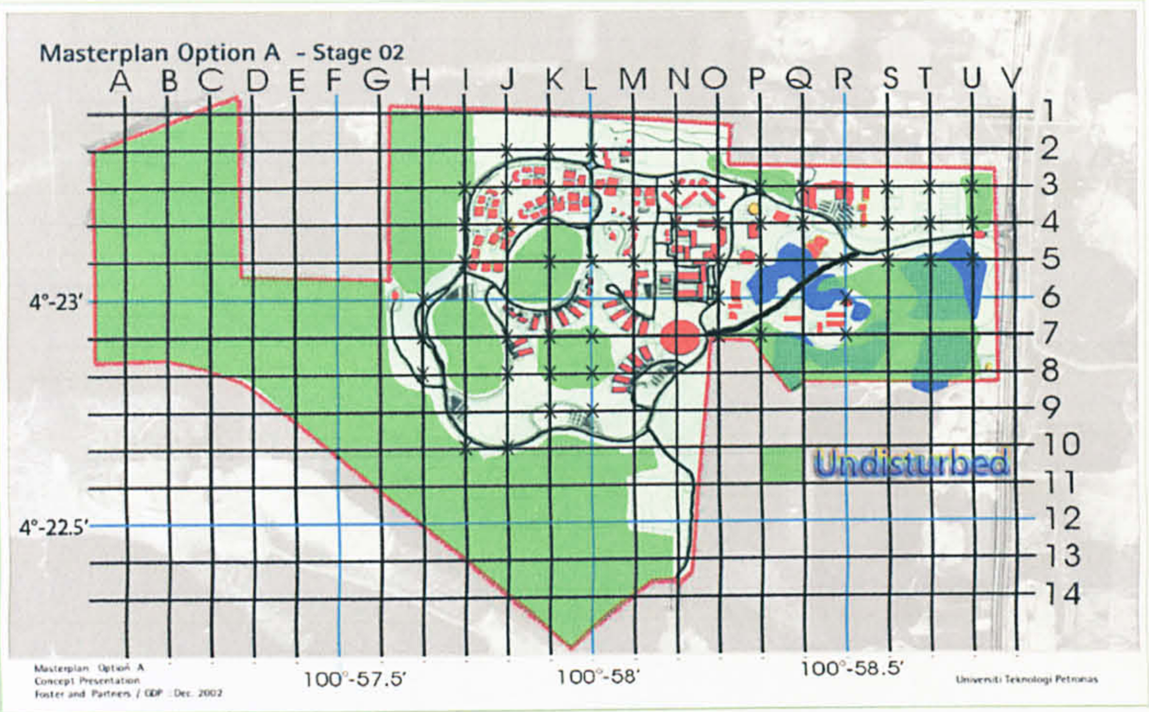


Figure 4.5 : Campus map with theoretical grid and undisturbed zones

Sampling points is based on randomly chosen points from the intersection of geo-grid which some criteria that has been taken which including the access to the point, the soil condition at the point, the disturbed area and the undisturbed area. Access to the point is the main criteria because the consideration of hazard. Soil condition is including the area that too wet or the presenting of huge rocks which are hard to be taken.

Disturbed area included areas where forest clearance and ground alteration have took place for building, pavement and road construction. Undisturbed area comprised of forest area, lake area and low lying areas where no significant land alteration have occurred. Areas which only have landscaping activities also being assume as undisturbed.

4.2 Sample Calculation & Laboratory Test Result

Based on soil sample at point 10 (H6).

Spring used for testing : Spring 1

Average reading : 103.5 °

By Interpolation of the chart provided : 0.295 + [(103.5-98)/(105-98)](0.319-0.295)

= 0.31386 N.m

Shear Strength = 0.31386 N.m / 4.29e-6 m^{-3}

= 73 160 N/m^{-2}

= 73.160 kPa

Based on soil sample at point 12 (H8).

Spring used for testing : Spring 1

Average reading : 122.5°

Using extended line graph : y = 332.0x – 0.693

122.5 = 332.0x – 0.693

X = 0.37106 N.m

Shear Strength = 0.37106 N.m / 4.29e-6 m^{-3}

= 86 495 N/m^{-2}

= 86.495 kPa

The result for all sampling points is attached in the appendices.

4.3 Statistical Analysis

Based on the laboratory results from 50 samples, important statistical data is calculated in the Table 4.1 below :

Table 4.1 : Sample size, Maximum, Minimum, Mean, Standard Deviation (SD) and Coefficient of Variance (CV) of tested soil shear strength.

N	50
Mean	59.5726
Median	66.822
Minimum	11.422
Maximum	134.941
Standard Deviation (SD)	26.265
Coefficient of Variation (CV)	44.1%

Statistical methods used to summarize or describe a collection of data; this is called descriptive statistics. This is useful in research, when communicating the results of experiments. In addition, patterns in the data may be modeled in a way that accounts for randomness and uncertainty in the observations, and then used to draw inferences about the process being studied; this is called inferential statistics.[Wikipedia, 2010]

Mean: The average of a numerical set. It is found by dividing the sum of a set of numbers by the number of members in the group.

Median: The value of a numerical set that equally divides the number of values that is larger and smaller. For example, in a set containing nine numbers, the median would be the fifth number.

Standard deviation: A number representing the degree of variation within a numerical set.

Coefficient of Variation (CV) : Normalized measure of dispersion of a probability of distribution.

From this project, the soil shear strength CV in UTP campus area was about 44.1%. The coefficient of variation (CV) is an indicator of variability (Rezaur R.B., Balamohan B., Ismail A.,2004). The significant variation occurs due to the samples are from a different geographical location but under similar climatic conditions. (Mapa and Kumaragamage, 1996)

The range of CV obtained suggests different degrees of heterogeneity between soil shear strength properties examined in the study area. The large variance in soil shear strength properties in a large area could be linked to heterogeneity of land formation, land use pattern or erosion processes (Sun. et al., 2003).

4.4 Geostatistical Analysis

Based on analysis using GS+ Software, the best fitted semi variogram model parameter is exponential model which is represent by Figure 4.6 below :

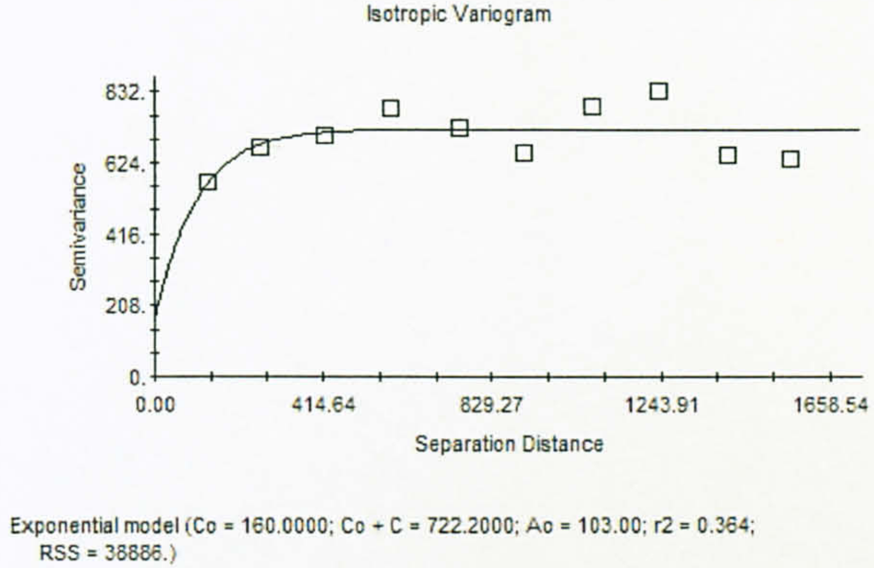


Figure 4.6 : Empirical semivariogram and best-fitted semivariogram of soil shear strength

Semi variogram model and parameters for soil shear strength was established to make it possible to examine the spatial structures dependencies of soil shear strength in terms of semi variogram parameters, the range, sill, nugget and nugget-to-sill ratio (Rezaur R.B., Balamohan B., Ismail A.,2004).

Proportion of Spatial Structure or C/(Co+C) or also known as nugget-to-sill ratio provides a measure of the proportion of sample variance (Co+C) that is explained by spatially structured variance C. It also indicate that the spatial dependency of the data. The higher the value, the stronger the dependency of data. (Rezaur R.B., Balamohan B., Ismail A.,2004).

Regression Coefficient or r2 provides an indication of how well the model fits the variogram data. The r2 is indicates by the higher the data of r2, the better the model fits the data. But this value is not as sensitive or robust as the RSS value below for best-fit calculations. (Rezaur R.B., Balamohan B., Ismail A.,2004).

RSS or Residual Sums of Squares provides an exact measure of how well the model fits the variogram data; the lower the reduced sums of squares, the better the model fits. GS+ uses RSS to choose parameters for each of the variogram models by determining the combination of parameter values that minimizes RSS for any given model. It is a measure of the discrepancy between the data and an estimation model. A small RSS indicates a tight fit of the model to the data. From the result, it shows that the RSS for exponential model is large. (Rezaur R.B., Balamohan B., Ismail A.,2004).

After combining the parameter values that minimize the RSS value, it is shows that the exponential model is the best model that fitted the shear strength data and that is why GS+ use it as the plotted model.

The sill is a measure of the variability in the data. The sill for soil shear strength is 722.2. This shows that the soil shear strength variability can be assumed as high due to the different sampling zones which are disturbed zones and undisturbed zones. This result obtained from the semi variogram analysis are consistent with the CV's of soil shear strength obtained from statistical analysis which is also quite high in percentages.

The nugget-to-sill ratio gives and indication of the spatial dependency of the data. A variable is considered to have a strong dependency if the ratio is less than 25%, and a moderate spatial dependency if ratio is 25% - 75% and weak dependency if greater than 75% [Goderya et al., 1996]. The nugget-to-sill ratio for the shear strength examined in the study is less than 25%. So the data is considered having a strong spatial dependence. The strong spatial dependency of the soil shear strength provides indication of the influence of intrinsic or extrinsic factors (Rezaur R.B., Balamohan B., Ismail A.,2004).

$$\boxed{\text{Nugget/Sill} * 100\% = \text{Spatial Dependency of Data}} \tag{4.1}$$

$$\boxed{160 / 722.2 \times 100\% = 22.15\%}$$

The nugget is measure of all unaccounted spatial variability at distance smaller than the smallest lag (160m in this study) while the structural variance accounts for variation due to spatial autocorrelation (Rezaur R.B., Balamohan B., Ismail A.,2004).

The relatively large value for range and sill for soil shear strength implies that soil shear strength is spatially dependent over long distances (indicated by large range) and the variability is high (indicated by large sill).

These various degrees of heterogeneity observed between soil shear strength examined clearly indicate the highly complex and variable nature of tropical soils within an area.

4.5 Kriging Method Analysis

The spatial distribution of soil shear strength for unsampled locations in the study area were obtained from interpolation between sampled locations by the method of Kriging,

The spatial distribution of soil shear strength for the study area is illustrated in Figure 4.7 below :

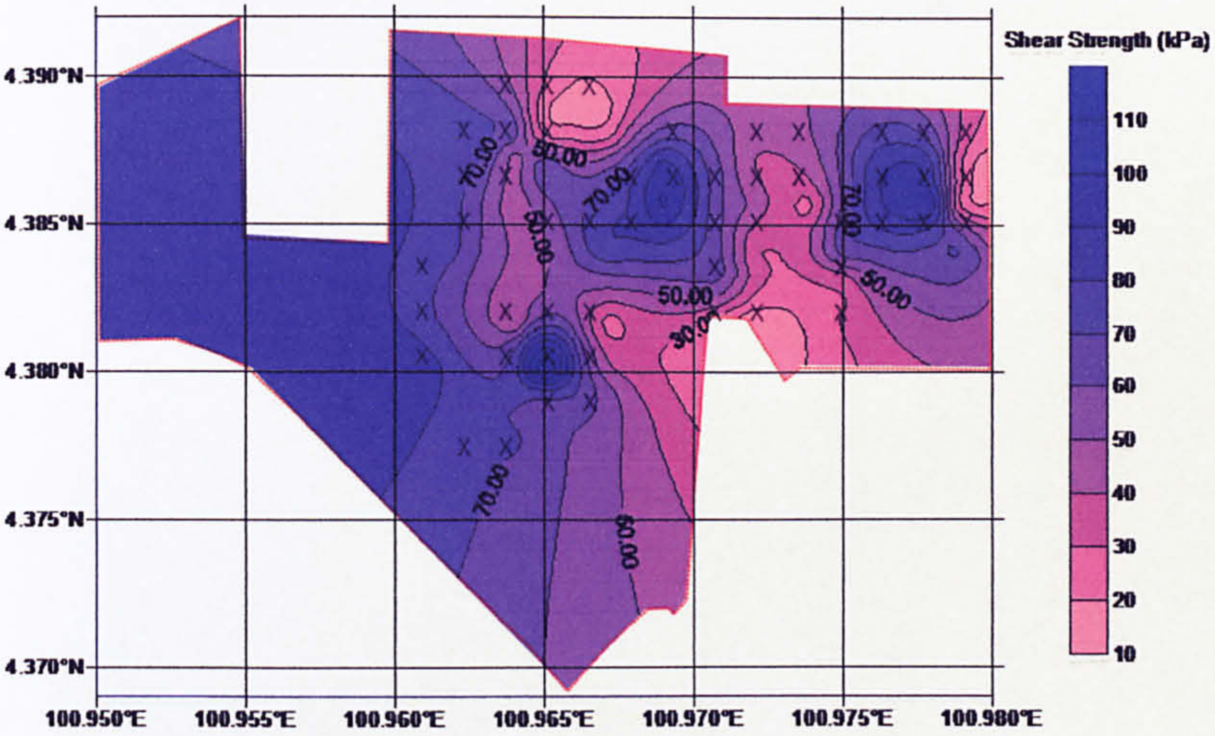


Figure 4.7 : Spatial distribution of soil shear strength in UTP campus area.

This map of spatial distribution of soil shear strength in conjunction with the site map Figure 4.5 now allows examining the closeness of association between variation in soil shear strength and topographic condition.

Based on Figure 4.7, soil shear strength is likely to associated with the zones. Higher soil shear strength is indicated in the disturbed zones such as near the buildings and near the roads. Lower soil shear strength is indicated in the undisturbed area such as in the forest areas and near the lakes areas. Thus, it is reasonable to infer that the spatial variability is induced partly by these topographic features present in the study area (Rezaur R.B., Balamohan B., Ismail A.,2004).

4.6 Variation of Soil Shear Strength Properties on Land Use Condition

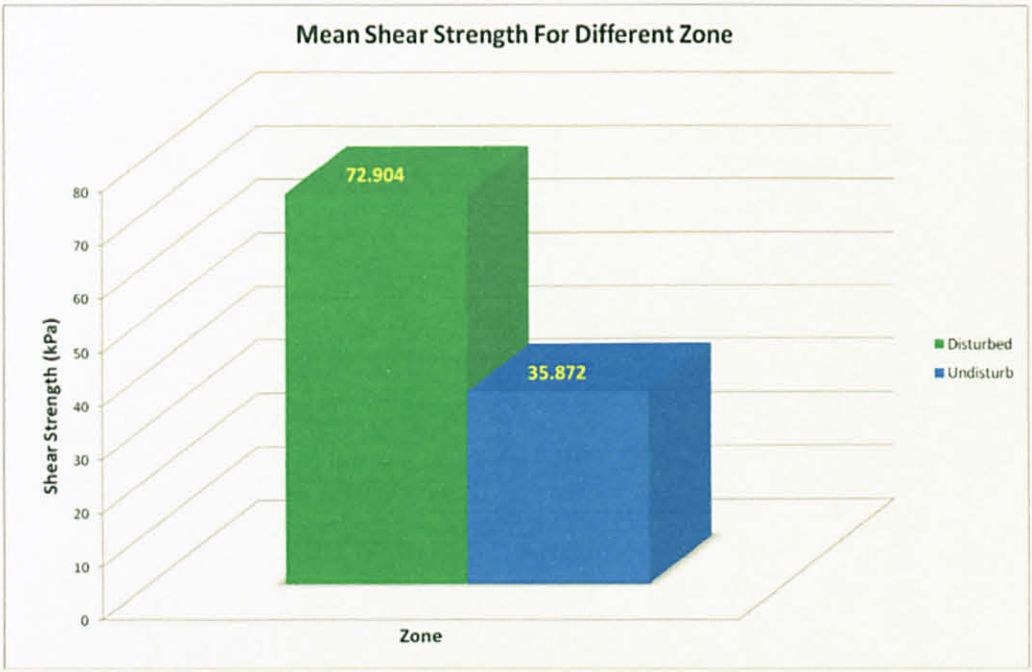


Figure 4.8 : Effects of land use patterns on soil shear strength

The effect of land used changes was examined because statistical and geostatistical characterization of the soil shear strength provided evidence to the existence of influence from intrinsic and extrinsic factor on the spatial variability of soil shear strength. The study area was categorized into two zones which are disturbed zones and undisturbed zones.

Disturbed zones included areas where forest clearance and ground alteration have took place for building, pavement and road construction. (Rezaur R.B., Balamohan B., Ismail A.,2004).

Undisturbed zones are comprised of low lying areas where no significant land alterations have occurred (Rezaur R.B., Balamohan B., Ismail A.,2004). Areas which only expose to landscaping activity only is also being assumed as undisturbed zones.

Figure 4.8 indicates that the mean soil shear strength were higher in disturbed zones compared to undisturbed zones. The higher shear strength in disturbed zones could be attributed to significant alteration of soil by compaction induced by construction activities. The two most important factors governing the strength of soils are the magnitude of the interparticle contact forces and the density of the soil. Larger interparticle contact forces and larger density of the soil results in larger shear strength of the soils. (J. Michael Duncan, Stephen G. Wright, 2005).

Even though the point which has the highest shear strength in this campus lies on point K8 which is inside undisturbed zones, but the sampling point was assumed as disturbed location because there is small area in the zone which has been compacted due to the construction of helipad.

The location which has lowest soil shear strength properties is at point P7 which lies in undisturbed zones. This is reasonable because the area is near the lake and there was no significant land alteration and construction activity near the area.

The soil in disturbed zones might also has come to drained condition due to the construction has taken part more than 10 years ago. Drained conditions are those where changes in load are slow enough so that all of the soils reach a state of equilibrium and no excess pore pressures are caused by the loads and the pore pressures are controlled by hydraulic boundary conditions. (J. Michael Duncan, Stephen G. Wright, 2005).

CHAPTER 5

CONCLUSION

As conclusion, the spatial variability of soil engineering properties has been characterized in terms of semivariogram and statistical parameters. Significant variation of soil shear strength characteristic existed in the area studied. Large coefficient of variation indicates irregular distribution of shear strength properties. Land disturbances and topographic conditions both contributed to the variability of soil shear strength.

The geostatistic application in conjunction with the normal statistic analysis in evaluate the spatial variability of soil shear strength revealed that certain aspects that not captured by normal statistic. By using geostatistic, it can indicate distance of where the correlated data occurred, the variability of the data and also the degree of the spatial dependency. Besides, it also can allows mapping of the spatial distribution and the normal statistics will helped in identifying causes of the variability in the soil shear strength. Others, even the semivariogram shows the consistent result, however the relatively low r^2 (0.364) show poor fit to data. This is because in the fact that the number of the samples is not enough for that extend of area studied (Rezaur R.B., Balamohan B., Ismail A.,2004).

This study could give useful information for future references regarding spatial variability nature of soil shear strength inside University Technology PETRONAS campus area. This study was already find out and characterized spatial structure of shear strength characteristics of soil under tropical climate in terms of semivariogram parameters. The characterization of the spatial variability and scale dependence of shear strength characteristics was performed by using geostatistical approaches. For the author, this project could contribute to the better understanding and appreciation to the important of land management practices.

RECOMMENDATIONS

For recommendations, the author would like to recommend to Civil Department to get the field vane shear test apparatus which is much more convenience and easy to use in field and also reduce time consumption. The author also recommends to have more sampling points to get more accurate results regarding soil shear strength properties in the study area. The author also would like to recommend that further study of soil shear strength properties being included with the study of other soil properties such as the soil particles size distribution or moisture contents in order to relate the soil shear strength properties with other soil properties.

CHAPTER 6

ECONOMIC VALUES

6.1 Project Cost

Universiti Teknologi PETRONAS was used as the experimental subject of this project which is the spatial variability of soil shear strength characteristic. Civil Department laboratory has provided the apparatus and tools needed in conducting the experimental test. Project Supervisor, AP Dr. Rezaur R.B also provided all the software required in analysis work. Thus, there was no direct cost to the Author in this project.

6.2 Business Element

Based on the result of this project, significant variation of soil shear strength characteristics existed in the area studied. Large coefficient of variation indicates irregular distribution of shear strength properties. Land disturbances and topographic conditions, both contributed to the variability of soil shear strength.

This study was already find out and characterized spatial structure of shear strength characteristics of soil under tropical climate in terms of semivariogram parameters. Therefore, spatial variability of soil shear strength properties has been monitored and quantified. For the author, this project could contribute to the better understanding and appreciation to the important of land management practices.

From this study, many soil mechanics problems such as stability of slopes (e.g: hillsides, cuts), ultimate bearing capacity of soil, lateral pressure against retaining wall, sheeting or bracing, and friction developed by piles could be reduced.

Based on Wikipedia ;

" a typical geotechnical engineering project begins with a review of project needs to define the required material properties. Then follows a site investigation of soil, rock, fault distribution and bedrock properties on and below an area of interest to determine their engineering properties including how they will interact with, on or in a proposed construction. Site investigations are needed to gain an understanding of the area in or on which the engineering will take place. Investigations can include the assessment of the risk to humans, property and the environment from natural hazards such as earthquakes, landslides, sinkholes, soil liquefaction, debris flows and rock falls."

Thus, from business element, soil investigation such as the shear strength characteristic is an important element for a certain project. Based on the investigation, then only, safe and economical design of foundation or structure can be design.

As conclusion, this study could give useful information for future references regarding spatial variability nature of soil shear strength inside University Technology PETRONAS campus area.

CHAPTER 7

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CHAPTER 8

APPENDICES

1. GPS DEVICE

2. DATA READING (GPS)

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3. FINDING REFERENCE POINT COORDINATES

4. HAND AUGER (1 METER)

5. MOULD

6. SPRING 1

7. SPRING 2

8. SPRING 3

9. SPRING 4

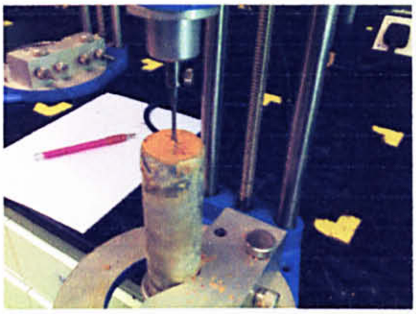
10. SET OF SPRINGS

11. VANE SHEAR APPARATUS

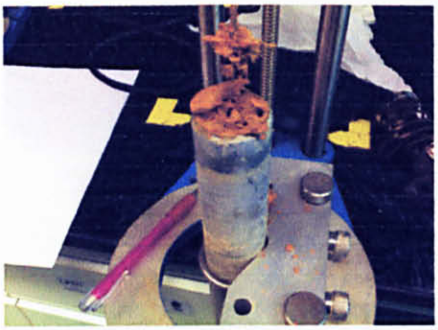
12. VANE

13. LABORATORY WORK

14. SAMPLE TESTING



15. FINISHED TEST

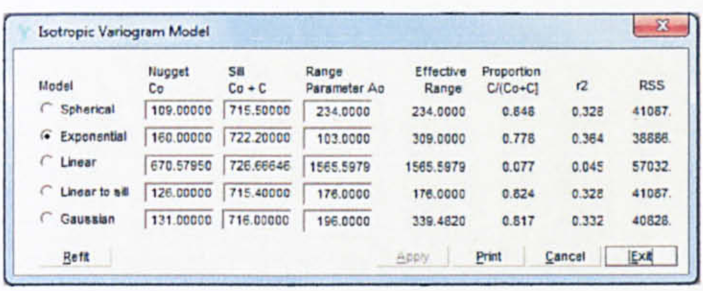


16. SITE CLEARING

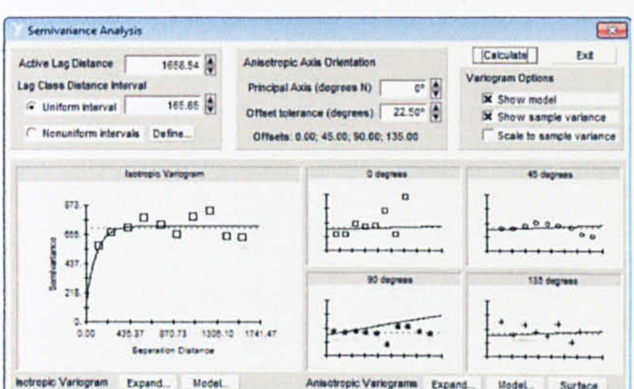
17. DISTURBED ZONE

18. UNDISTURBED ZONE

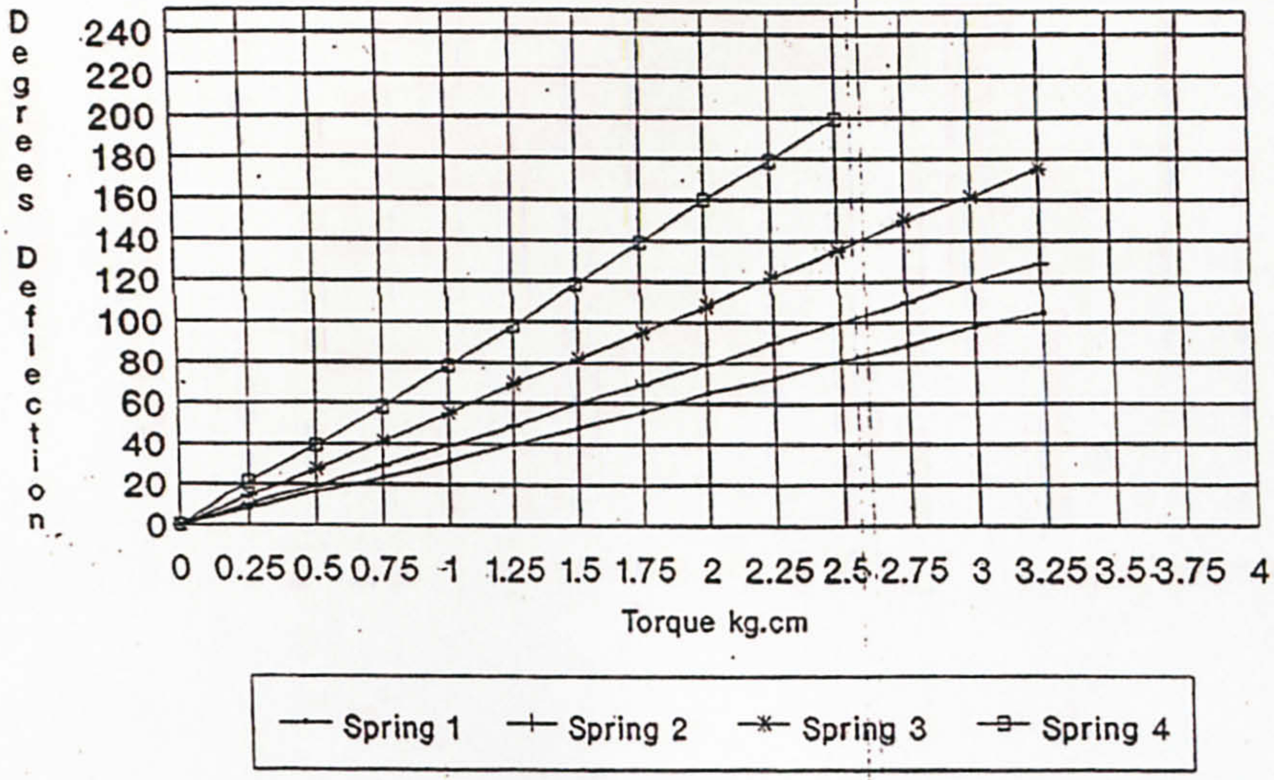
19. ISOTROPIC VARIOGRAM MODEL



20. SEMIVARIANCE ANALYSIS (BEST FITTED MODEL)

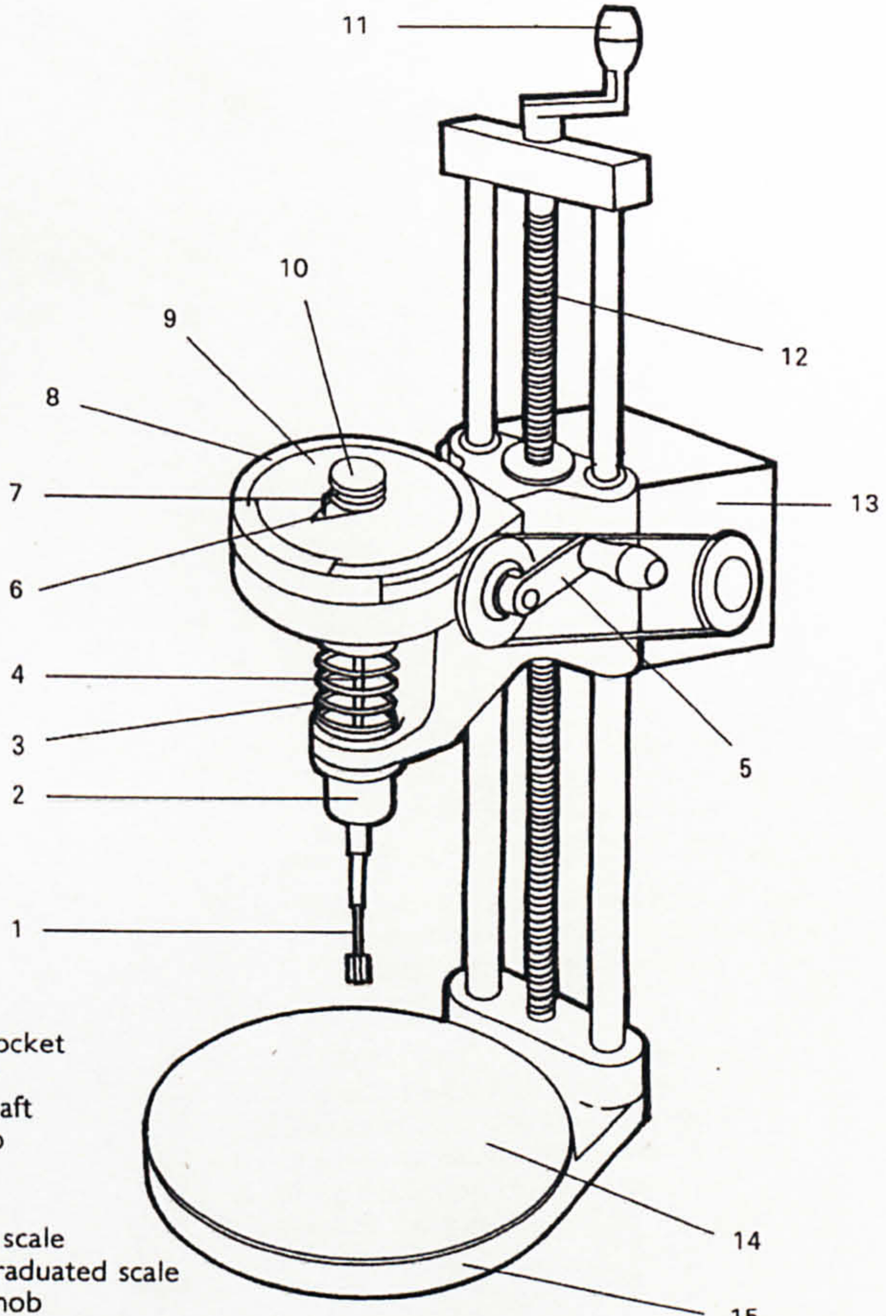


LAB-VANE SPRING SET EL26-2275/10
SPRING SET FOR FRAME No.1103-10-1416



Signed..............................

Calibration Valid From Date of Sale



1. Vane
2. Rotating socket
3. Spring
4. Vertical shaft
5. Hand knob
6. Pointer
7. Carrier
8. Secondary scale
9. Circular graduated scale
10. Knurled knob
11. Crank (raise/lower)
12. Lead screw
13. Motorising unit (if fitted)
14. Base plate
15. Base

Figure 1

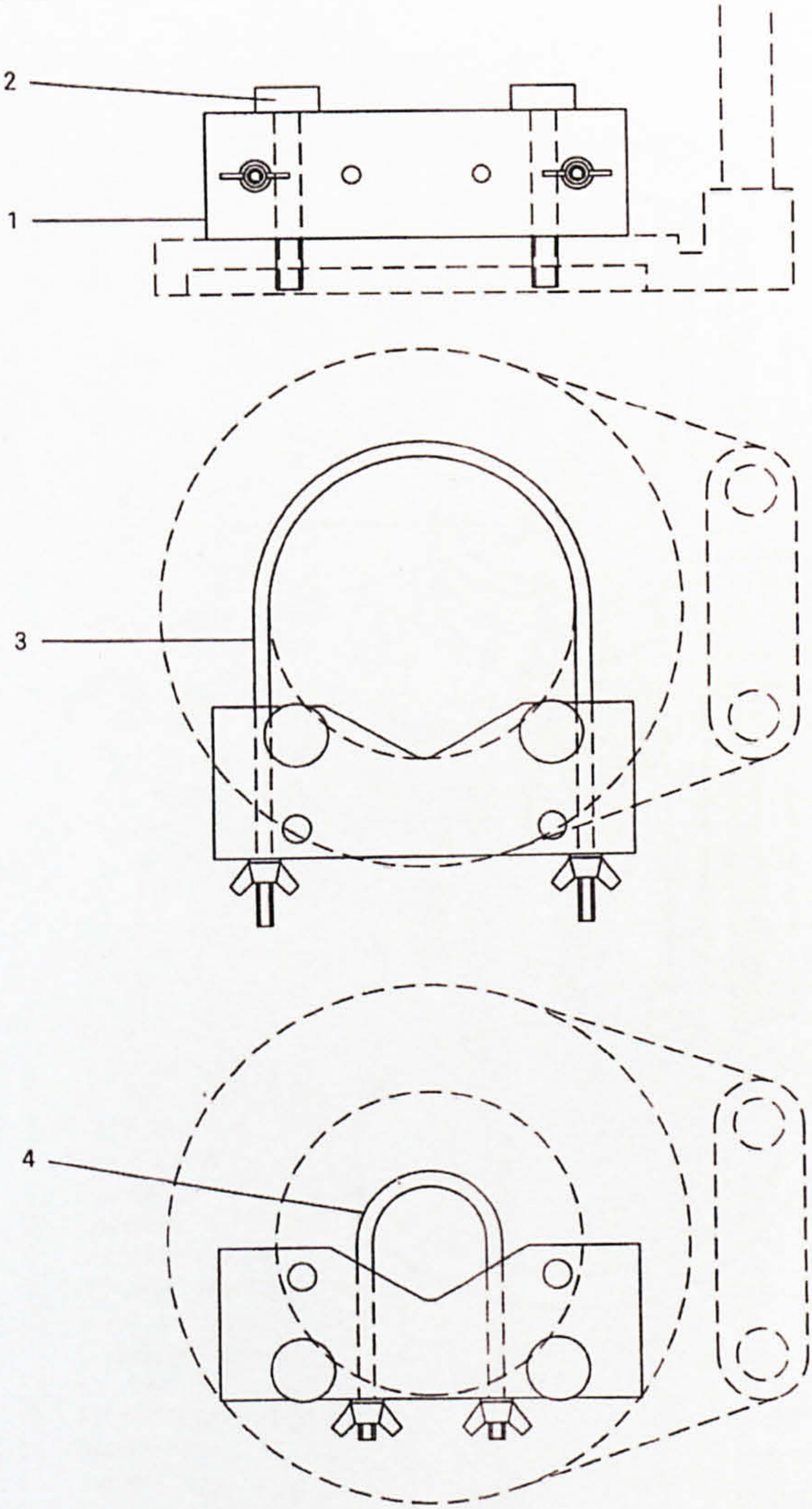


Figure 2

Point	Coordinate	Spring	Reading			Average Reading (˚)	Shear Strength (kPa)	Soil Type
			Inner	Outer	Inner - Outer			
1	4˚22'55"	2	70	10	60	69	40.093	Sand + Clay
	100˚57'50"		93	15	78			
2	4˚22'50"	2	106	9	97	101	71.162	Red Soil + Clay
	100˚57'50"		120	15	105			
3	4˚23'10"	1	115	15	100	103.5	73.160	Red Soil + Clay
	100˚57'45"	1	117	10	107			
4	4˚23'15"	1	117	16	101	99	69.564	Red Soil + Clay
	100˚57'45"		112	15	97			
5	4˚23'20"	1	126	23	103	101	71.162	Compacted Red Soil
	100˚57'50"	1	119	20	99			
6	4˚23'20"	1	41	20	21	20	14.752	Sand + normal soil
	100˚57'55"	1	47	28	19			
7	4˚23'20"	1	27	9	18	19.5	14.336	Normal Soil
	100˚58'0"	1	34	13	21			
8	4˚23'15"	1	86	35	51	55.5	39.729	Red Soil + Sand
	100˚57'50"	1	85	25	60			
9	4˚23'5"	1	131	26	105	104.5	73.959	Compacted red soil
	100˚57'45"	1	131	27	104			
10	4˚23'0"	1	131	29	102	103.5	73.160	Compacted red soil
	100˚57'45"	1	137	32	105			

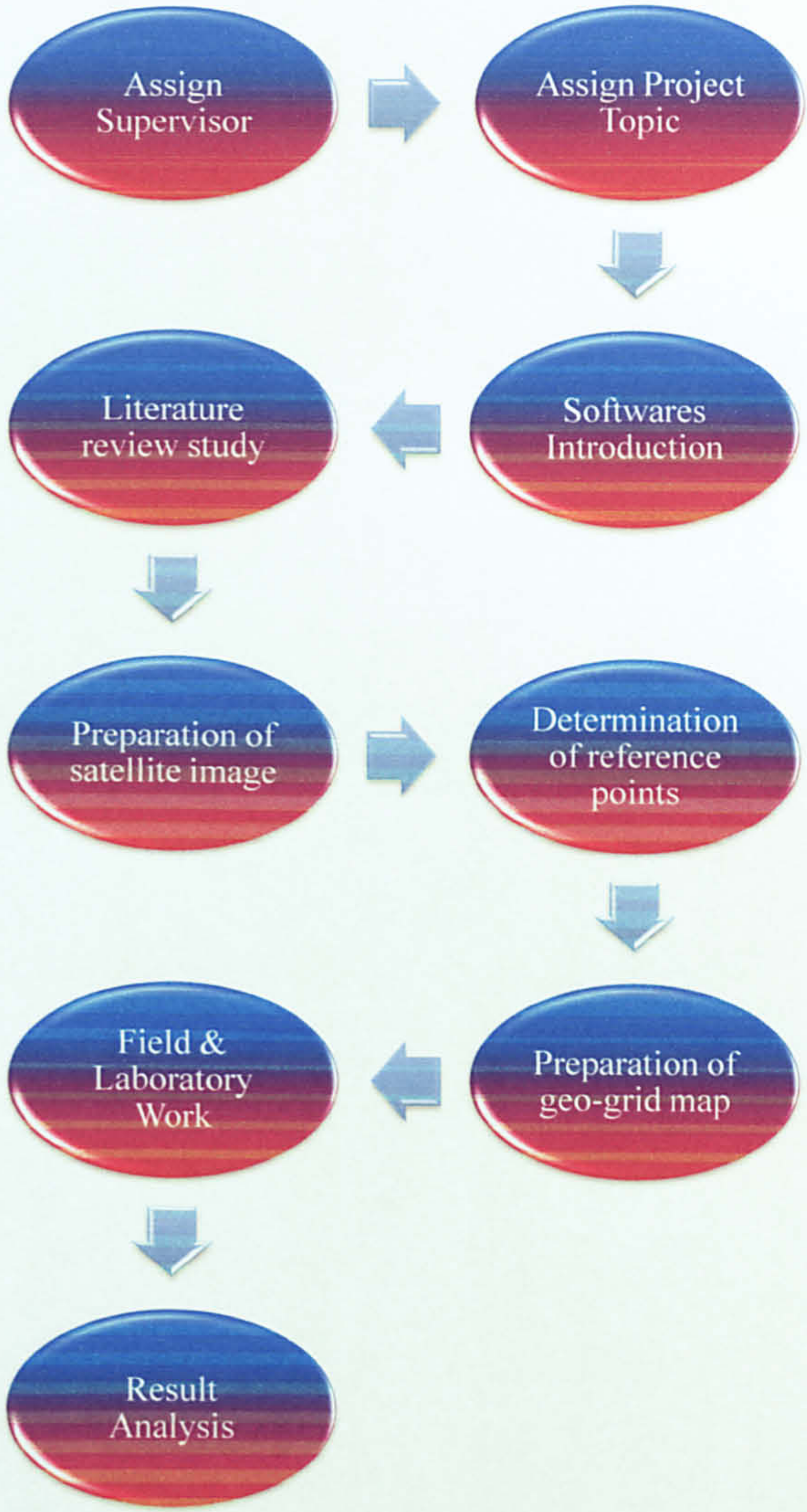
Point	Coordinate	Spring	Reading			Average Reading (˚)	Shear Strength (kPa)	Soil Type
			Inner	Outer	Inner - Outer			
11	4˚22'55"	1	132	26	106	104	73.560	Compacted red soil
	100˚57'45"	1	131	29	102			
12	4˚22'50"	1	151	33	118	122.5	86.495	Compacted red soil
	100˚57'45"	1	168	41	127			
13	4˚22'40"	1	118	17	101	100	70.363	Compacted red soil
	100˚57'45"	1	113	14	99			
14	4˚22'40"	1	108	9	99	102	71.961	Compacted red soil
	100˚57'50"	1	115	10	105			
15	4˚22'45"	1	98	13	85	85	60.023	Red Soil + Clay
	100˚57'55"	1	102	17	85			
16	4˚22'45"	1	97	12	85	83.5	58.931	Red Soil + Clay
	100˚58'0"	1	99	17	82			
17	4˚22'50"	1	205	10	195	191.5	134.941	Compacted Soil
	100˚57'55"	1	211	23	188			(Helipad)
18	4˚22'50"	1	70	15	55	57.5	41.026	Soil
	100˚58'0"	1	77	17	60			
19	4˚22'55"	1	128	30	98	95	66.822	Soil + Sand
	100˚57'55"	1	118	26	92			
20	4˚22'55"	1	50	10	40	35	25.434	Clay + Soil
	100˚58'0"	1	30	0	30			

Point	Coordinate	Spring	Reading			Average Reading (˚)	Shear Strength (kPa)	Soil Type
			Inner	Outer	Inner - Outer			
21	4˚23'15"	1	135	10	125	120	84.740	Compacted soil
	100˚58'35"	1	124	9	115			
22	4˚23'15"	1	133	7	126	124	87.548	Compacted soil
	100˚58'40"	1	131	9	122			
23	4˚23'10"	1	170	27	143	140.5	99.133	Compacted soil
	100˚58'40"	1	161	23	138			
24	4"23'10"	1	142	17	125	121.5	85.793	Compacted soil
	100˚58'35"	1	131	13	118			
25	4˚23'10"	2	32	10	22	27	20.047	Natural sand
	100˚58'45"	2	43	11	32			
26	4˚23'5"	1	46	14	32	31.5	23.168	Natural sand
	100˚58'35"	1	50	19	31			
27	4˚23'5"	1	110	14	96	95	66.822	Sand + Soil
	100˚58'40"	1	102	8	94			
28	4˚23'5"	1	122	17	105	104.5	73.959	Compacted red soil
	100˚58'45"	1	119	15	104			
29	4˚23'5"	1	117	18	99	102	71.961	Compacted red soil
	100˚58'30"	1	121	16	105			
30	4˚23'5"	1	113	14	97	98	68.765	Sand + Soil
	100˚58'35"	1	108	9	99			

Point	Coordinate	Spring	Reading			Average Reading (˚)	Shear Strength (kPa)	Soil Type
			Inner	Outer	Inner - Outer			
31	4˚23'15"	2	75	5	70	66.5	38.485	Natural Soil
	100˚58'20"	2	67	4	63			
32	4˚23'15"	1	71	13	58	63.5	44.755	Red Soil + Sand
	100˚58'25"	1	86	17	69			
33	4˚23'10"	2	110	25	85	84.5	48.601	Natural + red + sand
	100˚58'20"	2	113	29	84			
34	4"23'10"	1	98	11	87	83.5	58.931	Compacted Red+
	100˚58'15"	1	88	8	80			Brown soil
35	4˚23'5"	1	45	5	40	41	29.471	Sand + red soil
	100˚58'20"	1	56	14	42			
36	4˚23'5"	2	55	13	42	47	27.506	Sand + red soil
	100˚58'25"	2	68	16	52			
37	4˚23'5"	1	95	12	83	84.5	59.659	Red soil
	100˚58'15"	1	101	15	86			
38	4˚23'0"	1	106	21	85	88.5	62.573	Compacted Red+
	100˚58'15"	1	117	25	92			Brown soil
39	4˚23'15"	1	155	17	138	138.5	97.729	Compacted red soil
	100˚58'10"	1	161	22	139			
40	4"23'10"	1	169	14	155	143.5	101.239	Compacted red soil
	100˚58'10"	1	138	6	132			

Point	Coordinate	Spring	Reading			Average Reading (˚)	Shear Strength (kPa)	Soil Type
			Inner	Outer	Inner - Outer			
41	4˚23'10"	1	131	13	118	114.5	80.878	Compacted Red+
	100˚58'5"	1	127	16	111			Brown soil
42	4˚23'5"	1	132	21	111	110	77.719	Compacted red soil
	100˚58'5"	1	127	18	109			
43	4˚23'15"	1	112	7	105	106	74.910	Red+Brown soil,
	100˚57'55"	1	118	11	107			White clay
44	4˚23'10"	1	74	19	55	62	43.823	Red Soil + Clay
	100˚57'50"	1	83	14	69			
45	4˚23'5"	1	83	14	69	67.5	47.769	Brown soil
	100˚57'55"	1	77	11	66			(natural)
46	4˚23'5"	1	131	10	121	115	81.229	Compacted red soil
	100˚58'0"	1	122	13	109			
47	4˚22'55"	2	23	5	18	19	11.422	Sand
	100˚58'20"	2	27	7	20			(natural)
48	4˚22'55"	2	38	9	29	33.5	19.767	Sand
	100˚58'15"	2	54	16	38			(natural)
49	4˚23'0"	2	65	5	60	48.5	28.380	Sand+brown soil
	100˚58'30"	2	48	11	37			(natural)
50	4˚22'55"	2	65	26	39	54	31.214	Sand+Clay
	100˚58'30"	2	76	7	69			(natural)

Project Flow Chart



FINAL YEAR PROJECT GANNT CHART

No.	Detail/ Month	1	2	3	4	5	6	7	8	9	10	11	12
1	Selection of Project Topic												
	- Propose Topic												
	- Confirmation of Topic Selection												
2	Research Work												
	- Softwares												
	- Literature review												
3	Submission of Reports												
	-Progress reports												
	-Interim report												
4	Oral presentation												
	-Poster presentation												
5	Project Work												
	- Woking on Softwares												
	- Mapping												
	- Sample Collection												
6	Laboratory Work												
	-Vane shear test												
7	Result Analysis												
	-Result												
	-Discussion												

Milestone