Study on the variation of pore water pressure with different depth due to rainfall

by

Nur Athirah Binti Mohd Shipah
14242

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

SEPTEMBER 2014

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATE OF APPROVAL

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Approved by,

____

Assoc. Prof. Dr. Khamaruzaman bin Wan Yusof

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
September 2014

CERTIFICATE OF ORIGINALITY

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

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NUR ATHIRAH BINTI MOHD SHIPAH

ABSTRACT

Slope failure is one of the most common problem happened in many regions including Malaysia. It may occur on natural, fill and cut slope as well as embankments. Most of the analyses show that the infiltration of rainfall into the slope triggered the slope failure. This paper will concentrate more on the variation of pore water pressure and how the presences of rainfall affect the pore water pressure at different depth. Thus, an experimental work on the pore water pressure is carried out using tensiometers and rainfall measuring devices on a cut slope in the Universiti Teknologi PETRONAS campus. The data collected is based on the two sets of information which are the amount of rainfall and the changes in pore water pressure subjected to different depth due to rainfall. From the data, the pore water pressure varies and increases with time according to the rainfall pattern. Though, there is no positive pore water pressure developed either at 0.6 m depth or 1.5 m depth. Studies shows that the changes in pore water pressure at the slope subjected to rainfall do not affect the slope stability.

ACKNOWLEDGEMENT

First and foremost, I would like to thank the Almighty God for the guidance and protection bestowed upon me throughout this final year project.

I would like to extend my utmost appreciation to my supervisor, Assoc. Prof. Dr. Khamaruzaman bin Wan Yusof and co-supervisor, Dr. Muhammad Raza Ul Mustafa from Civil Engineering Department, Universiti Teknologi PETRONAS for their assistance and help in completing my final year project. The advice and guidance might be the one of the reasons for this project ended successfully to be possible.

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Last but not least, I would like to thank everyone who directly or indirectly involved in assisting me to complete my project.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Slope failure issues had increased over the past decade and it has become a common phenomenon all over the world. This phenomenon can be defined as the movement of soil beneath the slope in response to gravitational stresses under various influences. Slope failure can be attributed to a number of factors such as erosion, rainfall, earthquakes, geological factors, construction activities such as excavated and fill slope, rapid drawdown and change in topography. In Malaysia, according to Public Works Department Malaysia (2010), 42% of landslide occurred in hilly terrain areas and more than 90% of landslide occurred in developed areas such as infrastructure, residential and commercial areas had been recorded from year 1966 to 2003.

Research shows that most of the landslides occurred due to the infiltration of rainfall into the slope. The infiltration of rainfall into the soil causes the changes in pore water pressure in the soil which can lead to slope instability. Steeper slope are most likely subjected to rapid slope failure compare to the relatively flat slope given that they are weakly bounded (Thanapackian et al., 2012).

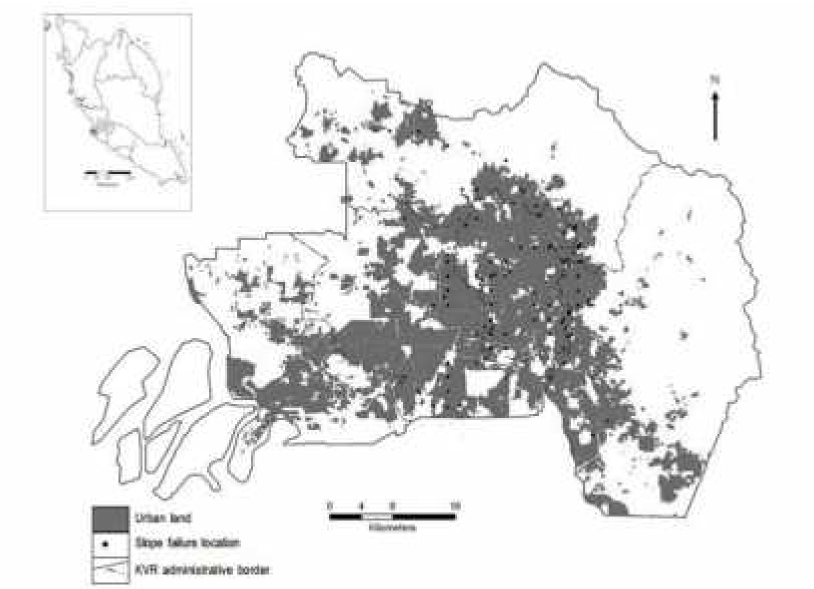

Figure 1.0: Distribution of slope failure in the Klang Valley Region. (Thanapackian et al., 2012)

Figure 1.1: Massive landslide occurred in 2011 in Hulu Langat due to heavy rainfall

Figure 1.0 and 1.1 show the distribution of slope failure in the Klang Valley Region and the landslide occurred in Hulu Langat which is mainly due to heavy rainfall. Numerous studies had been conducted to examine the effect of rainfall infiltration into the residual soil slope and how if affect the slope stability. In order to understand the rainfall infiltration behavior, many infiltration models had been produced such as Green-Amp infiltration model, Kostiakov model, Horton model, Philip model and Richards equations (Wang et al., 2014). From those models, a lot of discussion had been made regarding pore water pressure distribution in the soil under the influence of rainfall which is subjected to slope failure.

However, research also shows that the depth of slope has the greatest influence on the slope stability. The pore water pressure of the soil appeared to be different at the different depth due to rainfall infiltration. The shallower depth easily and frequently influenced by the rainfall infiltration compare to the deeper depth and is subjected to frequent changes in pore water pressure. The infiltration of water causes the pore water pressure and the saturation to be increase especially in depths relatively close to the soil surface where the matric suction becomes less negative. As the infiltration continues, positive pore water pressure will developed. During this time, the slope has high potential to be subjected to failure.

1.2 PROBLEM STATEMENT

Slope failure has become one of the most serious issues in Malaysia especially when it is related to the development at the hilly terrain areas such as Klang Valley and Kuala Lumpur area. These slope failures has become threat to human because it contribute too much damage to household properties and had claimed many lives among the urban residents. There are several factors that lead to the slope stability failure. One of them is the presence of rainfall which alters the pore water pressure as well as the water table below the ground. Usually, slope failure occurs after being subjected to heavy rainfall for a long period. The high infiltration of rainwater into the slope in a long period will reduce the soil matric suction as well as the strength of the soil. Apart from that, the depth of slope also has the greatest influence on the slope stability as during rainfall event, the pore water pressure will be changed subjected to the different depth.

Therefore, this study is mainly being looked on the variation of pore water pressure and how the presences of rainfall affect the pore water pressure at different depth. The relative increase in pore water pressure and its changes according to the depth appears to be related to the rainfall intensity. Thus, it is important to understand the rainfall infiltration effect on the pore water pressure which leads to slope failure.

1.3 OBJECTIVES AND SCOPE OF STUDY

The objectives of this study are :

i. To determine the effect of pore water pressure at different depth to the slope stability

ii. To examine the changes in pore water pressure at different depth of soil slope subjected to rainfall

The scope of study is mainly being looked on the variation of pore water pressure at different depth due to rainfall. Site work will be conducted in a small scale on a cut slope in the Universiti Teknologi PETRONAS campus. Several tests will be done to determine the relationship between the variations of pore water pressure and rainfall intensity which induced the slope failure.

1.3 RELEVANCY OF THE PROJECT

Slope failure is one of the issues that had been taken into serious consideration in this era where there are still rapid developments on or near to the slope area. Taken this project, “Study on the variation of pore water pressure with different depth due to rainfall” for Final Year Project, the author realized that it could be a very wide topic.

However, focusing on the relevancy of this project, as for the purpose of this Final Year Project, the author believes that this project is relevant to be studied and presented as it is still within the author’s field of study. The experimental works for this project will collect some data based on two sets of parameters which will help the author a lot in completing this project.

1.4 FEASIBILITY OF THE PROJECT WITHIN SCOPE AND TIME FRAME

Within 28 weeks duration which is from May 2014 until January 2014, this project is feasible as the data will be taken for short period which is around one to three month depending on the rainfall frequency. The major key milestones will be observed to ensure that all the key milestones will be in placed as being planned at the end of the time frame given. Thus, this project should be completed within the 28 week duration.

CHAPTER 2

LITERATURE REVIEW

2.1 LITERATURE REVIEW

A lot of sources had been taken to be part of reference in this study. A large portion of it came from research papers, books and reports made specifically regarding the effect of pore water pressure on the slope stability due to rainfall. Examples of related literatures which are associated with this study are "Effect of Pore Water Pressure Distribution on Slope Stability under Rainfall Infiltration" by Wang Ji Cheng, Gong Xiao Nan and Ma Shi Guo, "Components of Pore Water Pressure and Their Engineering Significance" by J. K. Mitchell, "Response of a Residual Soil Slope to Rainfall" by H. Rahardjo, T. T. Lee, E. C. Leong and R. B. Rezaur and "The Stability of Slopes with Negative Pore Water Pressures" by Delwyn G. Fredlund.

Most of the literatures were made from year 1995 until 2014 respectively. Even though the literature is backdated, the author would strongly agree that the literatures are still relevant for this scope of study. The study on the slope failures due to rainfall which had been discussed in the literatures are applicable to be implemented nowadays because the basic idea is the still the same. Therefore, the author concludes that the literatures are still relevant and can be used in this project.

2.1.1 Pore Water Pressure

Pore water pressure is a pressure developed by water to its surrounding within the pore space of soil. Pore water pressures are made up of combination four components which are elevation head pressure, hydrostatic pressure, osmotic pressure and adsorption pressure. All of the components will combine to give the total pressure (Mitchell, n.d.). The pore water pressure can be positive and negative. Negative pore water pressure developed in unsaturated soil where the pressure is less than atmospheric pressure. This will cause the soil to absorb more water (matric suction increase) as a result from the rainfall infiltration. As the rainfall infiltration continues, positive pore water pressure will be developed as the soil saturated. This is where the pressure is more than atmospheric pressure (Dunnicliff, 1993 and Gasmo et al., 1999). Virtually, pore water pressure is dynamic and usually changes in time subjected to rainfall infiltration as well as soil condition.

The presence of negative pore water pressure is due to several factors (Fredlund, 1995). They are:

a. The duration and intensity of the rainfall
b. Saturated and unsaturated coefficient of permeability function for the soil
c. The storage characteristic of the unsaturated soil

Normally, natural slopes are unsaturated slope covered by residual soils and have negative pore water pressure. Depending on the parent material and degree of weathering, residual soils has a wide range of properties (Cho & Lee, 2001). In general, slope failure on unsaturated residual soil usually takes place during wet periods. This is because during wet periods, matric suction of the soil tends to decrease which results in the development of positive pore water pressure and an increase in the water content of the soil (Wang et al., 2014). The added shear strength provided by the matric suction during wet period can be reduced enough to prompt the failure. Thus, when analyzing the slope stability, both negative and positive pore water pressure should be taken into account (Fredlund, 1995).

2.1.2 Rainfall Infiltration

Rainfall has been considered as one of the most frequent triggering factors to natural slopes and soil structures failure. Rainfall infiltration affects the pore water pressure distribution of slopes especially the changes of characteristics and water content of soils above wetting front. In an unsaturated soil, rainfall infiltration will cause negative pore water pressure to develop as a result from the increment of matric suction (Gasmo et al., 1999). The increment of matric suction will affect the movement of water through the soil as the soil water content will be increase. As the rainfall infiltration is higher, self weight of residual soils increases, matric suction of wetted zones will decrease (Cho & Lee, 2001 and Wang et. al, 2014). This will also result in an increase in moisture content of the soil and development of positive pore water pressure.

The flow or movement of water through the soil is explained using Darcy's law.

$$\frac{\partial}{\partial}\left(k_w \frac{\partial h_w}{\partial}\right) + \frac{\partial}{\partial}\left(k_w \frac{\partial h_w}{\partial}\right) = m_2^w \rho_w g \frac{\partial h_w}{\partial}$$

where h_w is the hydraulic head, z is the elevation head, u_w is the pore water pressure, x and y are the Cartesian coordinates in x and y directions, k_w is the hydraulic conductivity, ρ_w is the density of water, g is the gravitational acceleration, m_2^w is the coefficient of water volume change with the respect to the matric suction changes (Rahardjo et al., 2005). Based on the equation above, the changing in the pore water pressure due to rainfall infiltration will influence the hydraulic conductivity and the coefficient of water volume change.

The increase in pore water pressure due to rainfall infiltration can be analyzed by using two models which are nonlinear model of power form and nonlinear model of logarithmic form where a and b are the empirical equation (Rezaur et al., 2003). The models are shown in equation 1 and 2 below:

$$\Delta u_w = a_1 R^{b1} \quad (1)$$

$$\Delta u_w = a_2 b_2 \log (R) \quad (2)$$

Figure 2.0 shows the typical slope used for numerical study to see how the infiltration of rainfall into the slope. Study on the rainfall infiltration into the slope shows that the face slope received more infiltration because the infiltration at the crest flows vertically downwards (Gasmo et al., 1999). This infiltration results in the increment of water content of the soil throughout the rest of the slope as it interflow the slope and flow down towards the toe.

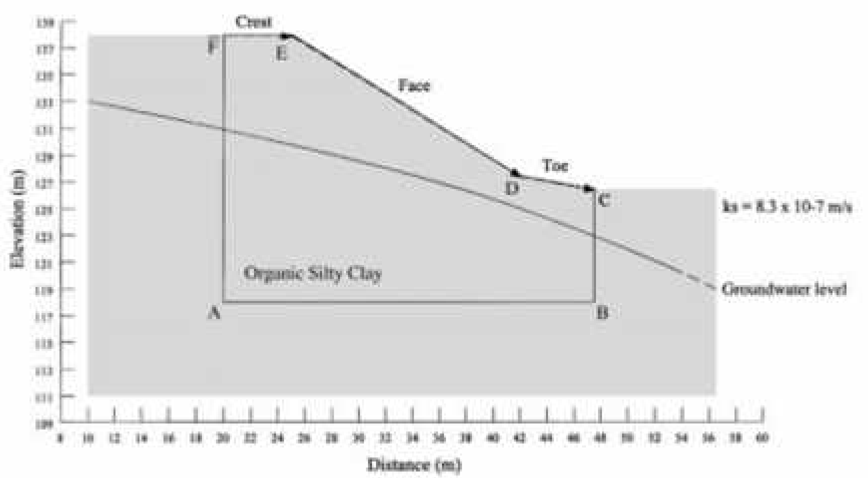

Figure 2.0: Numerical model representation of typical slope for numerical study Gasmo et al., 1999)

During slight rainfall, the rate of rainfall infiltration will be increase and the whole rainfall may end up as fully infiltration. However, when there are high intensities of rainfall, the rate of infiltration may decrease as it may produce high amount of runoff. However, the infiltration rate of heavy rainfall is still higher than slight rainfall (Rahardjo et al., 2002). Figure 2.1 shows the percentage of infiltration against the amount of rainfall. The data plotted are based on the slope study using artificial rainfall conducted at Nanyang Technological University in Singapore.

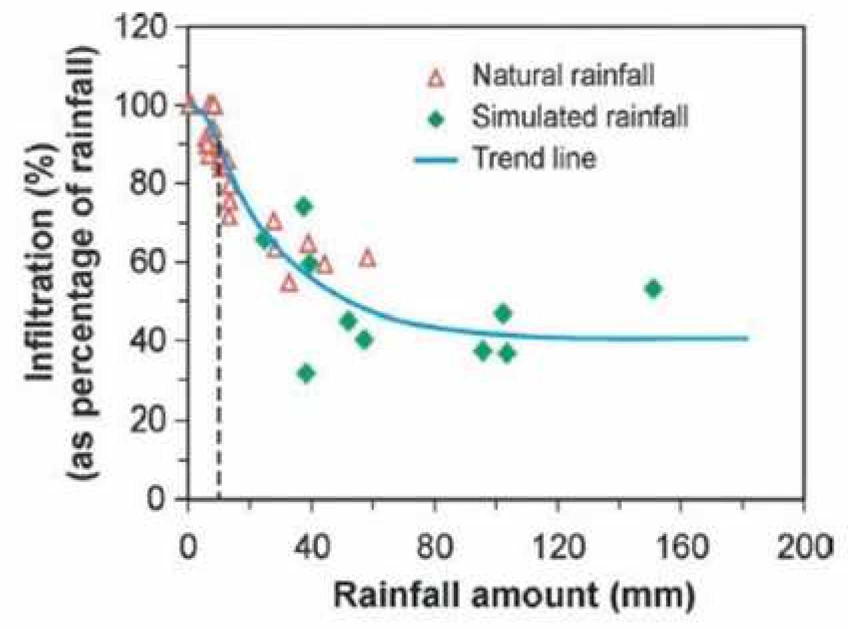

Figure 2.1: Percentage infiltration against rainfall amount (Rahardjo et al., 2005)

The threshold existed in the figure above shows that any rainfall below that amount will not produce any runoff and the whole rainfall might end up as infiltration. Rainfall intensities and percentage of rainfall infiltration will have dominant effect on the soil matric suction. Consequently, the matric suction will influence the shear strength of the soil as well as the development of pore water pressure profile which may affect the slope stability under certain conditions (Zhang et al., 2010).

An analysis which has done using Green –Ampt infiltration model method, showed that there are few conditions that influence the changes in pore water pressure distribution at the wetted zone under rainfall infiltration (Wang et al., 2014).

a. During slight rainfall, the matric suction of the soil will be higher. This will enable the soil to absorb more water as the rainfall infiltration does not give any effect to the soil water content of the slope soil. Thus, slope has no potential to be subjected to failure.

b. For the hard crust or fully vegetation covered surface, the slope surface as well as soil at shallow depth may be saturated in a short period under slight rainfall. Then, the rainfall will infiltrate slowly down the wetting front to the deeper depth. However, during this time, the slope still not subjected to failure.

c. When there is heavy rainfall, the wetted zone above the wetting front will get almost saturated. This will cause the wetting front to move downward and make the matric suction to decrease extensively. During this time, there is high possibility for positive pore water pressure to develop and thus, the slope has high potential to be subjected to failure.

2.1.3 Slope Depth

Depth of slope has the greatest influence on the slope stability. The pore water pressure will be different depending on the depth of the slope subjected to rainfall (Rahardjo et al., 2005). The pore water pressure at shallow depth will experienced rapid and high matric suction development compare to the pore water pressure at the deeper depth which showed delayed response toward the rainfall infiltration.

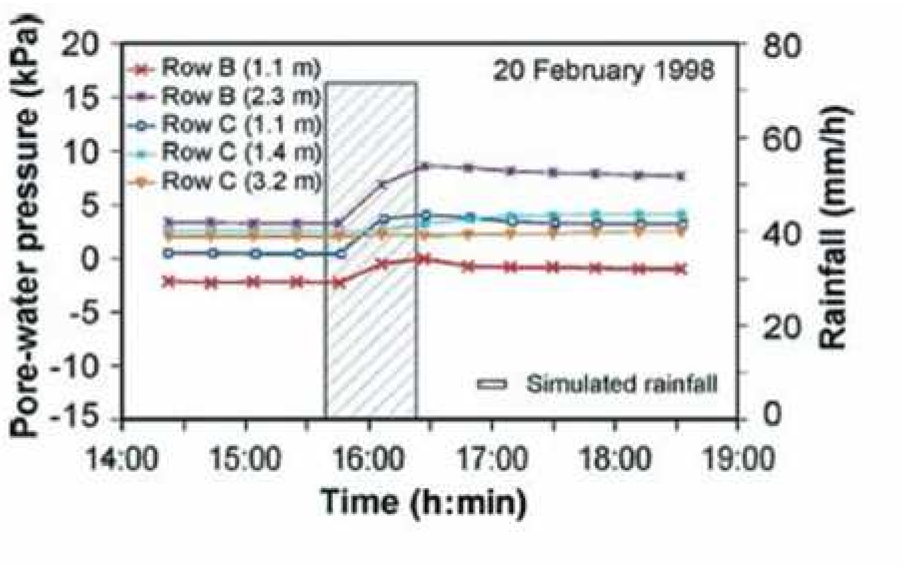

Figure 2.2: Pore water pressure changes due to simulated rainfall (Rahardjo et al. 2005)

Figure 2.2 shows the differences in the pore water pressure subjected to difference depth due to rainfall infiltration. The pore water pressure at shallow depth has high negative pore water pressure compare to the deeper depth (Rezaur et al., 2003). This is because the soil at the shallow depth is easily and frequently influenced by the rainfall infiltration.

As the rainfall infiltration reaches shallow depth near the slope crest the matric suction of the soil will decreases. The increment in the pore water pressure which is from more negative to less negative or to nearly zero (positive pore water pressure developed) at the shallow slope is larger than at the deeper depth. Figure 2.3 shows the pore water distribution across the soil depth and the infiltration of rainwater during rainy season based on a study conducted in 1999. From the figure below, it shows that the deeper the slope depth, the more positive the pore water pressure.

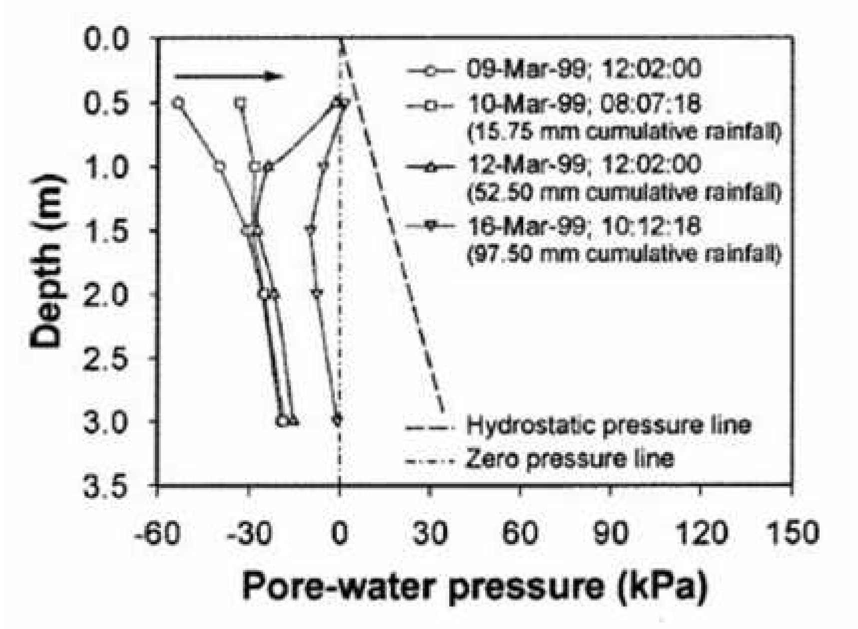

Figure 2.3: Pore water pressure profile at different depth during wet period (Rezaur et al., 2003).

The shallower depth experienced high pore water pressure and is subjected to quicker matric suction recovery compare to the deeper depth. As the rainfall continues, positive pore water pressure will be developed and the self weight of the soil will be increase. During this time, the slope has high potential to be subjected to failure.

The pore water pressure at deeper depth may response in the infiltration rate during heavy rainfall. Deeper depth may develop positive pore water pressure but it is quite different to the pore water pressure developed at the shallower depth (Rezaur et al., 2003). Even though the soil at the deeper slope depth is fully saturated and has positive pore water pressure, the slope has no potential to be subjected to failure.

2.2 FINDINGS

No	Author	Year	Findings
1	Delwyn G. Fredlund	1995	Analysed how the presence of negative pore water pressure affects the stability of flat and steep slope.
2	H. Rahardjo, E. C. Leong & R. B. Rezaur	2002	Study and analyse on the procedure of slope stability, soil properties, flux boundary condition, changes in pore water pressure as well as the instrumentation used.
3	H. Rahardjo, T. T. Lee, E. C. Leong & R. B. Rezaur	2005	Analysing the effect of rainfall infiltration to a residual soil slope with changes in pore water pressure and water content
4	John Dunnicliff	1993	Evaluates monitoring methods for observing and monitoring groundwater pressure, deformation and total stress in soil.
5	J. M. Gasmo, H. Rahardjo & E. C. Leong	1999	Study on the amount of rainfall infiltration infiltrates into the slope and how the infiltration can affect the slope stability.
6	J. K. Mitchell	n.d.	Analysis regarding pore water pressure components and how it is related to the stresses between particles

7	P. Thanapackiam, Khairulmaini Osman Salleh & Fauza Ab Ghaffar	2012	Conduct an observation on the parameters that cause slope failure which threats the urban residents in the Klang Valley Region
8	R. B. Rezaur, H. Rahardjo, E. C. Leong & T.T. Lee	2003	Analysing the hydrological data of rainfall and its effect on the changes of pore water pressure as well as matric suction which lead to slope instability
9	S. E. Cho & S. R. Lee	2001	Analysing the safety factor for unsaturated slope due to rainfall infiltration using numerical study as well as analysing the variation in strength of the soil due to the presence of matric suction using modified Mohr-Coloumb.
10	Wang Ji Cheng, Gong Xiao Nan & Ma Shi Guo	2014	Discussed the theory concerning the rainfall infiltration using Green-Ampt infiltration model method as well as analysing few types of pore water distribution and established stability analysis model
11	Zhang L. L., Zhang J., Zhang L. M., Tang W. H.	2010	Research on infiltration analysis and slope stability analysis under rainfall infiltration by studying the conceptual models, analytical analysis and numerical modelling.

CHAPTER 3

METHODOLOGY

3.1 RESEARCH METHODOLOGY

In order to complete this study, various sources of information had been sought by the author. This is to ensure adequate resourceful data and reliable information is obtained. The following methods had been implemented throughout the project:

a. **Data gathering from various resources**

   General information regarding the slope stability analysis, pore water pressure and the rainfall infiltration effect related to the project can be easily retrieved from the internet or books

b. **Reviewing experimental reports**

   Experimental reports prepared for slope analysis was reviewed by the author. Based on the report, the author is able to gain some information regarding the pore water pressure effect on the slope stability which can be used as reference.

c. Experimental and Laboratory Work

An experiment is conducted on a cut slope at Universiti Teknologi PETRONAS campus to study the pore water pressure effect on the slope stability due to rainfall infiltration. Two sets of information were being collected which are the amount of rainfall and the changes in pore water pressure subjected to different depth. The rainfall is measured using a tipping-bucket rain gauge while the pore water pressure is obtained using tensiometers. The instruments used were installed together with the data logger. This data logger will receive and stored the data from the pressure transducer.

Figure 3.0 shows the illustration for the experimental works layout. There are a total of four (4) numbers of tensiometers were installed at different depth of 0.6 m and 1.5 m at the crest and face slope.

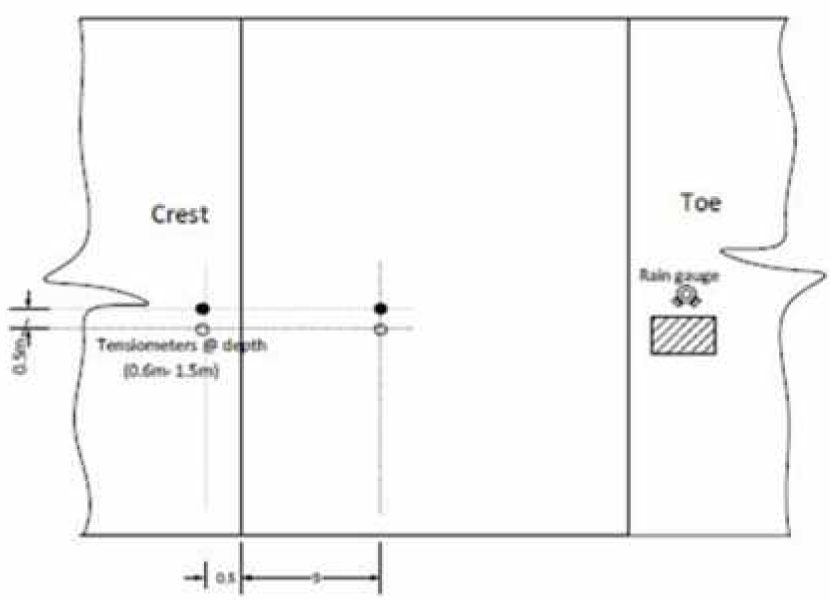

Figure 3.0: The illustration for the experimental works layout

Before all the instruments were installed, the instruments were being set up at the laboratory and pictures are taken as evidence. Figure 3.1 to 3.4 show the laboratory set up and the installation of tensiometers and rain gauge at the site.

Figure 3.1: Setting up the tensiometers at the laboratory

Figure 3.2: The tensiometers which had been set up

Figure 3.3: The tensiometers installed at the site

Figure 3.4: Rain gauge installed at the site

The experimental work started on 17th October 2014. However, due to some disturbance, there is instrumental error of the tensiometers and the tensiometers needed to be reinstalled. This disturbance caused by the animals at that area. Fences have been fitted in order to avoid further disturbance from the animals. Thus, for the data collection, it was taken from 30th October to 14th December 2014 which is about 46 days.

The experimental area was located using Global Positioning System (GPS) and soil samples of about 0.5 m depth were taken for laboratory test. The soil samples were dried in the oven for 24 hours before being crushed. The soil samples were tested and examined for physical properties such as moisture content, specific gravity, particle size distribution (PSD), plastic limit and liquid limit. For the PSD, the crushed soil sample was sieved using sieve size of 2 mm to 63 µm.

d. Analysis and Calculation

The data for the pore water pressure and rainfall in the data logger will be logged using HOBOware and SpecWare 9 Basic. The data is then being plotted and analysed using Microsoft Office Excel. Based on the plotted data, it can determine whether the rainfall infiltration will affect the pore water pressure at the different depth.

3.2 KEY MILESTONES

The project completion can be identified in stages. There are few key milestones that had been set which are:

a. **Selection and confirmation of the project title**

   The project title was selected based on the suggestion from the supervisor and approval from the Final Year Project coordinator. Evaluation on the project title has been done to foresee the requirements, objectives and expected outcomes from the topic.

b. **Data gathering**

   The author searched for any information related to the project title from various sources such as reports, articles and research papers from the internet.

c. **Submission of Extended Proposal**

   The extended proposal include the problem statements, objectives and general information regarding the slope stability analysis, pore water pressure and the rainfall infiltration which are retrieved from the internet or books

d. **Experimental Work**

   After all general information is obtained, the experimental work will be started. The experimental work will be conducted in a small scale on a cut slope to study on the variation of pore water pressure at different depth due to rainfall.

e. **Submission of Proposal Defence and Interim Report**

f. Submission of Progress Report

This progress reports will discuss all of the data collected and analysed based on the current progress of the experimental works conducted.

g. Submission of Draft Final Report, Technical Paper and Project Dissertation

3.2 GANTT CHART

Activities	**Duration (Weeks)**													
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
Project Confirmation														
Data Gathering														
Submission of Extended Proposal														
Extended Proposal Submitted							●							
Proposal Defence														
Experimental Work														
Submission of Interim Report														
Interim Draft Report Submitted														●
Interim Report Submitted														●

Table 1.0: Gantt Chart for FYP I

Activities	**Duration (Weeks)**														
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Experimental Work Continues															
Experimental Work Completed												●			
Submission of Progress Report															
Progress Report Submitted							●								
Pre-SEDEX															
Submission of Draft Final Report															
Draft Final Report Submitted											●				
Submission of Dissertation (Soft Bound)															
Dissertation Submitted													●		
Submission of Technical Paper															
Technical Paper Submitted													●		
Viva															
Submission of Project Dissertation															
Project Dissertation Submitted															●

Table 1.1: Gantt Chart for FYP II

CHAPTER 4

RESULTS AND DISCUSSION

At the current point of the project, the soil test and the data for the pore water pressure and rainfall has been completed.

4.1 CUT SLOPE DETAILS AND SOIL TESTS

Based on GPS and site measurement, the details for the cut slope were obtained. Soil sample were also taken for laboratory testing and from the testing, the physical properties of the soil were obtained. The results are shown as below:

Table 2.0: Cut slope details

Details of Cut Slope	
Area Covered (m^2)	200
Vegetation Cover (%)	100
Slope Height (m)	11.2
Slope Length (m)	20
Slope Angle (^{o})	34
Soil Type	CL

Table 2.1: Soil tests results

Soil Properties	
Moisture Content, W (%)	23.18
Particle Density (Mg/m^3)	2.72
Plastic Limit (%)	21.63
Liquid Limit (%)	35.80
Plasticity Index (PI)	14.17

For particle size distribution of the soil sample, it is presented both in the table and graph below:

Table 2.2: Particle size distribution test results

Sieve Size	Mass retained (g)	Percentage Retained (%)	Percentage Passing (%)
2 mm	0	0	100.12
1.18 mm	67.8	13.56	86.58
600 µm	96.7	19.34	67.22
425 µm	54.5	10.90	56.32
300 µm	53.0	10.60	45.72
212 µm	43.4	8.68	37.04
150 µm	44.7	8.94	28.10
63 µm	76.5	15.30	12.80
Pan	64.0	12.80	0

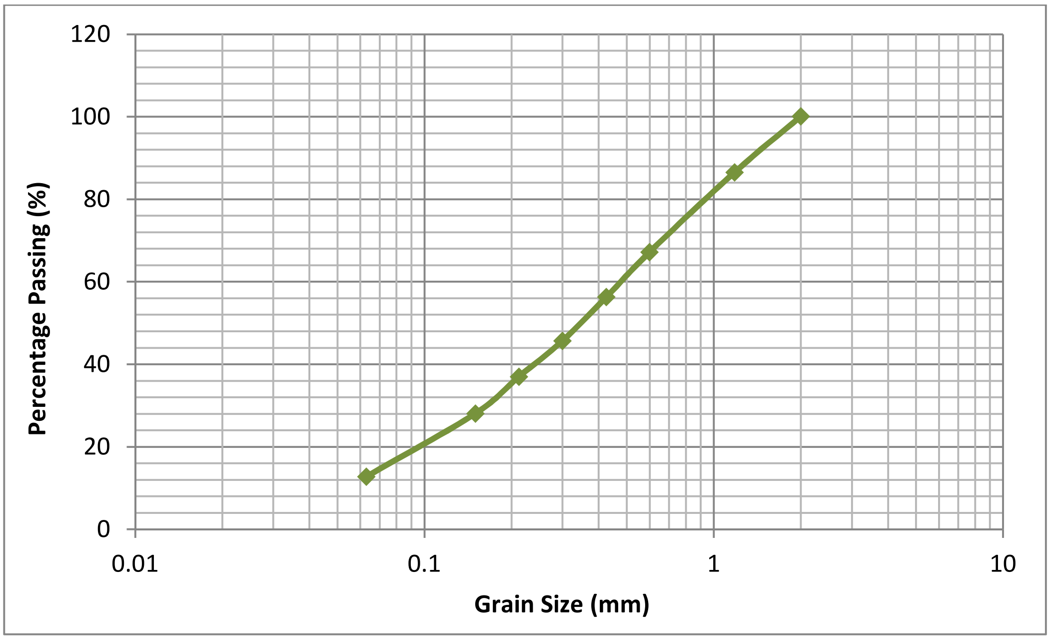

Figure 4.1: Particle size distribution graph

From the results obtained above, it is found that the soil sample is fine-graded soil. Based on Unified Soil Classification System (USCS) – ASTM Test Designation D-2487, the soil is classified as inorganic clay with low plasticity (CL). This means that the slope is predominated by clayey soil. The laboratory tests also show that the soil has low liquid limit and exhibited plasticity index of 14.17%. Low plasticity of soil has high shear strength and less expendability (Nigussie, 2013). Usually, clay has high influence to slope failure. However, based on the laboratory tests that had been conducted, this clayey soil may not contribute to slope failure. The presence of vegetation at that area also influenced the stability of the slope.

4.2 PORE WATER PRESSURE AND RAINFALL

Graph below shows two (2) sets of data obtained from the experimental work which is pore water pressure and rainfall for crest and face.

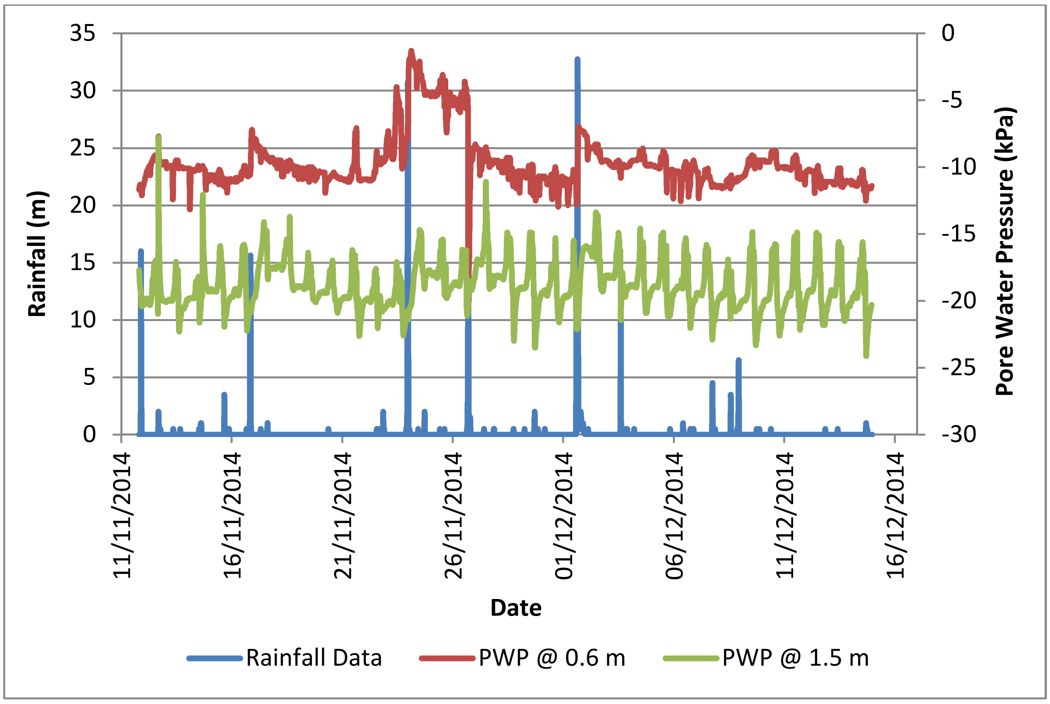

Figure 4.2: Rainfall amount and pore water pressure at crest slope

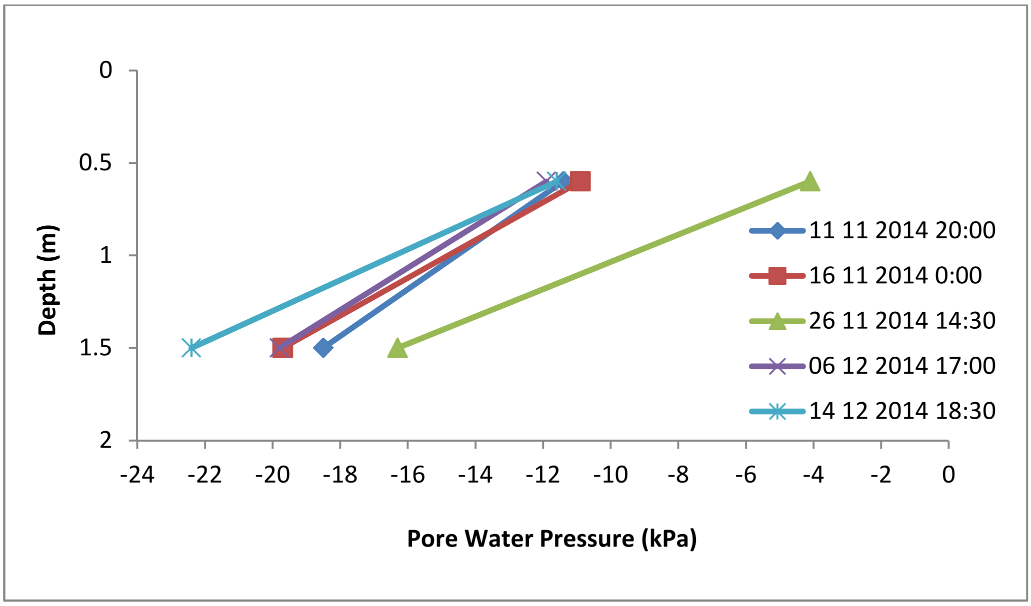

Figure 4.3: Changes of pore water pressure at different depth at crest slope

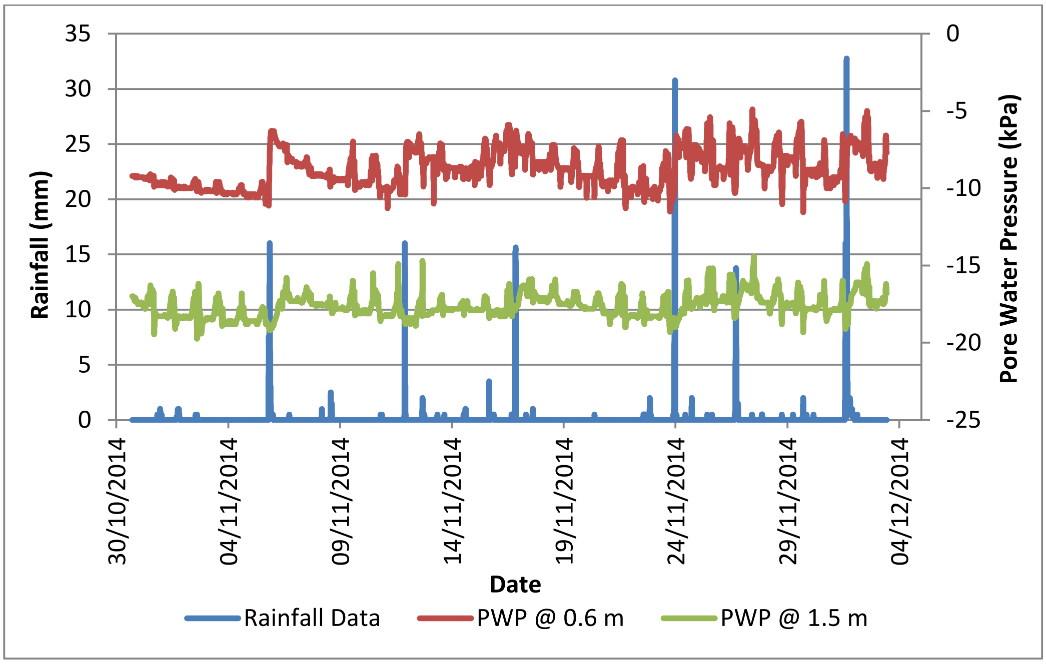

Figure 4.4: Rainfall amount and pore water pressure at face slope

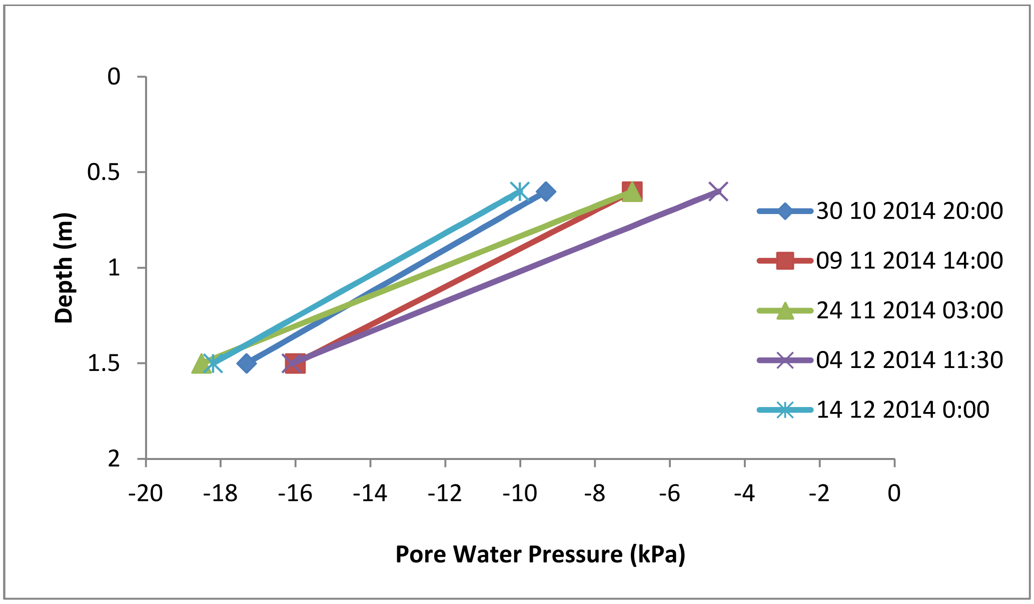

Figure 4.5: Changes of pore water pressure at different depth at face slope

The data presented above shows the reading of pore water pressure at two (2) different depths which are 0.6 m and 1.5 m at crest and face slope. The data obtained were used for variation of pore water pressure and slope stability analysis. Based on the rainfall amount and pore water pressure graph, it is found that the pore water pressure changes for crest and face slope have almost similar pattern for both depth.

In comparing the rainfall amount and the variation of pore water pressure based on the plotted graphs, it is shown that the pore water pressure changed according to the rainfall pattern and only negative pore water pressure was developed. The highest negative pore water pressure developed during rainy season was -24.1 kPa recorded at 1.5 m depth of crest slope while the lowest negative pore water pressure developed was -1.3 kPa recorded at 0.6 m depth of crest slope. In the case of dry season, the pore water pressure may increase (from less negative to more negative). It is expected that the pore water pressure at 0.6 m will be increase to approximately -30 kPa during dry season and -50 kPa at 1.5 m. This is because during dry season, the matric suction will be increased as the soil is not saturated with water.

For the period of heavy rainfall, the pore water pressure at 0.6 m has increased (from more negative to less negative) compare to 1.5 m depth. Shallower depth is closer to the slope surface and easily influenced by the rainfall infiltration compare to the deeper depth. For the period of slight rainfall, pore water pressure at 0.6 m depth did not show much increment. On the contrary, the pore water pressure at 1.5 m increased with time especially at slope part. During this time, the rainfall may end up as fully infiltration. Thus, the rainfall will infiltrates further down the wetting point of the crest and face slope. This caused the pore water pressure at the deeper depth to increase as result of high matric suction.

Thus, the soil at deeper will remain wet for a long period of time as the soil is saturated with water and does not subjected to the quick matric suction recovery.

Though, both 0.6 m and 1.5 m depth did not show any development in positive pore water pressure. Usually, as the soil depth goes deeper, positive pore water pressure will developed due to the presence of groundwater table. This can be concluded that, the groundwater table at that particular area is much lower as the soil at 1.5 m depth does not show any development of positive pore water pressure. Normally, the positive pore water pressure developed at the deeper depth did not have influence on the slope stability. Nevertheless, if there is development observed at the shallow depth, the slope may be subjected to failure. But, since no positive pore water pressure developed at the shallow depth, the slope has low potential to be subjected to failure. This can be further explained by the presence of vegetation on the slope. Fully covered grass has high influence to the slope stability and this made the slope difficult to fail.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The experimental work that has been conducted is able to provide data for the analysis on pore water pressure and rainfall events in understanding how the parameters can affect the slope stability. It is proven that the pore water pressure varies with time according to the rainfall events. The pore water pressure at 0.6 m influenced more on the rainfall events compare to 1.5 m depth. From the data analysis, it shows that only negative pore water pressure developed for both depths. Thus, it is said that the slope has no potential to be subjected to failure. Even though the soil slope is predominated by clayey soil, the presence of vegetation at the slope surface reduces the probability of slope failure. Thus, the changes in pore water pressure at different depth of the slope do not contributed to the slope failure.

5.2 RECOMMENDATION

Further improvement can be made in this project. The data for pore water pressure at different depth could be clearly observed if there are more tensiometers installed at different depth at the site. Currently, there are only two (2) nos. of tensiometers installed at 0.6 m and 1.5 m depth at both crest and face slope. Thus, it may give advantages to have more tensiometers for the study as this may help to improve the data accuracy as well as analyzing the data.

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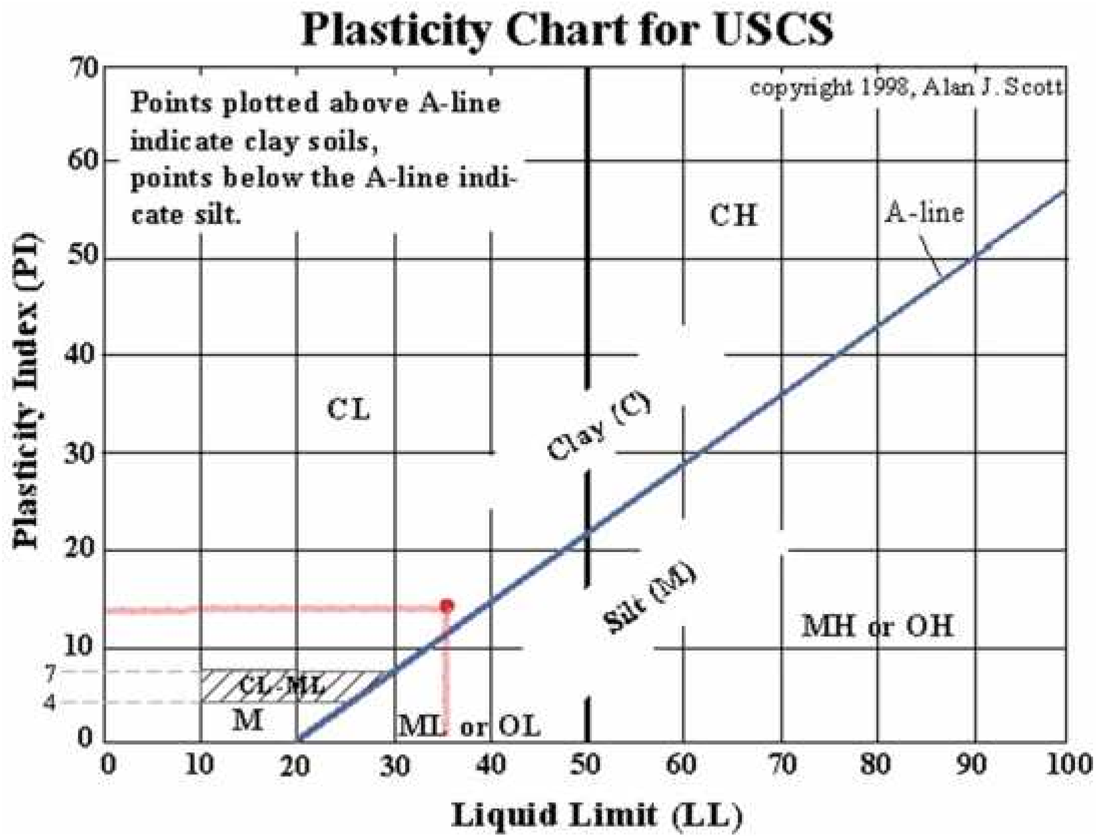
APPENDIX



Plasticity chart used to determine soil type

Sieve Size	Sieve Size (mm)	Weight (Sieve) (g)	Weight (Sieve +Soil) (g)	Mass Retained (g)	Percent Retained (%)	Cum. Percent Retained (%)	Percentage Passing (%)
2 mm	2	478.1	478.1	0	0	0	100.12
1.18 mm	1.18	430	497.8	67.8	13.56	13.56	86.56
600 µm	0.6	408.9	505.6	96.7	19.34	32.9	67.22
425 µm	0.425	383.6	438.1	54.5	10.9	43.8	56.32
300 µm	0.3	358.1	411.1	53	10.6	54.4	45.72
212 µm	0.212	348.1	391.5	43.4	8.68	63.08	37.04
150 µm	0.15	339.3	384	44.7	8.94	72.02	28.1
63 µm	0.063	412.7	489.2	76.5	15.3	87.32	12.8
Pan		351.1	415.1	64	12.8	100.12	0
Total Weight =				500.6			

Particle Size Distribution Table