RAINFALL INDUCED RESIDUAL SOIL SLOPE INSTABILITY: BUILDING CRACKED AND SLOPE FAILURE

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ABSTRAK

Hujan adalah salah satu faktor kegagalan cerun kerana intensiti hujan akan menjejaskan dengan meresap, kandungan lembapan tanah atau sedrik matriks. Salah satu peranan penting dalam kestabilan cerun ialah sedutan matriks. Analisis kestabilan cerun melibatkan bangunan yang boleh menyebabkan ketidakstabilan akibat variasi sedutan. Kajian ini membentangkan hubungan antara hujan dan sedutan tanah yang menyebabkan ketidakstabilan cerun. Cerun telah dipisahkan kepada tiga bahagian yang terletak di atas cerun, tengah cerun dan kaki cerun. Setiap bahagian akan memasukkan tiga tensiometer dengan kedalaman 0.3 m, 0.45 m dan 0.9 m. Sedutan tanah di cerun dilakukan menggunakan tensiometer. Bacaan untuk tanah sedetik tanah matriks diambil setiap hari pada pagi yang bermula dari 3 Ogos 2017 hingga 15 Ogos 2017. Intensiti hujan dikumpulkan dengan menggunakan tolok hujan yang diletakkan di kawasan terbuka. Keamatan hujan harian selama 13 hari dibandingkan dengan tanah sedetik matriks. Curah hujan telah menjejaskan sedutan tanah. Pada 7 Ogos 2017, intensiti hujan adalah tinggi iaitu 15.6 mm manakala nilai sedutan matrik pada ketiga-tiga bahagian ini adalah rendah. Beberapa tapak dan ujian makmal telah dijalankan untuk mengenal pasti sifat-sifat tanah. Kestabilan cerun dianalisis menggunakan Slope / w dan Excel dengan memasukkan parameter yang dikumpulkan dari ujian makmal dan ujian medan. Dalam kecemerlangan, kaedah Fellenius dengan formula digunakan untuk mentafsirkan faktor keselamatan untuk kajian cerun. Faktor keselamatan di tengah-tengah cerun dengan menggunakan kaedah cerun / w ialah 1.963 manakala dengan kecemerlangan ialah 2.65, peratusan yang berbeza adalah 25.92. Kaedah Fellenius digunakan untuk menganalisis faktor keselamatan kepingan yang dipilih dengan nilai sedutan matriknya. Faktor keselamatan untuk menengah dan kaki cerun berada di bawah 1.3, jadi cerun tidak stabil. Dari analisis, apabila hujan meningkat, sedutan tanah menurun dan terjejas penurunan faktor keselamatan. Ia mencadangkan bahawa cerun perlu direkonstruksikan dan diubahsuai semula.

ABSTRACT

Rainfall is one of the factors for slope failures because intensity of rainfall will affect by seeping, moisture content of soil or matric suction. One of the important role in slope stability is matric suction. The slope stability analysis involved a building which may cause by instability due to suction variation. This study presents the relationship between rainfall and suction of soil which induced the slope instability. The slope had separated into three parts which are top of slope, middle of slope and toe of slope. Every part will insert three tensiometer with 0.3 m, 0.45 m and 0.9 m depth. Suction of soil on slope was carried out by using tensiometer. Reading for matric suction of soil was taking daily in the morning which from 3rd August 2017 until 15th August 2017. Intensity of rainfall was collected by using rain gauge which placed at open area. The daily intensity of rainfall for 13 days was compared with matric suction of soil. The rainfall had affected suction of soil. On 7th August 2017, the intensity of rainfall was high which is 15.6 mm while the matric suction value at these three parts was low. Several site and laboratory tests were carried out to identify the soil properties. Stability of slope was analyzed using Slope/w and Excel by insert parameters collected from laboratory test and field test. In excel, Fellenius' method with formula was used to interpret the factor of safety for slope study. The factor of safety at middle of slope by using slope/w method was 1.963 while by excel was 2.65, the percentage different for it was 25.92. Fellenius' method was used for analyses the factor of safety of slices selected with its matric suction value. The factor of safety for middle and toe of slope was below than 1.3, so the slope is unstable. From the analysis, when the rainfall increased, suction of soil decreased and affected the decreased in factor of safety. It suggested the slope need to be reconstruct and redesign.

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LIST OF SYMBOLS

C’	Soil Cohesion
Φ’	Effective Friction Angle (phi)
Z	Mid-height
b	Size Width
W	Weight
α	Base Angle
Mg	Milligram
%	Percentage
SC	Clayey Sand
SM	Silty Sand
SP	Poorly Graded Sand
ML	Silt
MH	Silt of High Plasticity, Elastic Silt
CH	Clay of High Plasticity, Fat Clay
kPa	Kilo Pascal

LIST OF ABBREVIATIONS

FOS	Factor of Safety
IIUM	International Islamic University Malaysia
ASTM	American Society for Testing and Materials
FTEK	Faculty of Engineering Technology
SPT	Standard Penetration Test
UU	Unconsolidated Undrained Triaxial Test
CD	Consolidated Drained Triaxial Test
TP	Trial Pit
PL	Plastic Limit
LL	Liquid Limit
PI	Plasticity Index
USCS	Unified Soil Classification System
BH	Borehole

CHAPTER 1

INTRODUCTION

1.1 Introduction

Slope instability can cause by three different factor or categories. The three categories are Geological, Climate change and Human activities. The activities involved in geological that could cause the slope instability are layer of soil and soil profile. Intensity of rainfall, earthquake, flooding and more are including in climate change. While human activities are the activities such as cut and fill, deforestation and more which cause the lack of protection on the surface of slope and caused the slope instable. When the rain is occurred, it will separate into two which is one into ground and one on surface become a runoff. If the volume of penetration of rainwater is not much and there is runoff, a shallow slope instable is happened. It normally just effect on the depth of 3m. When there is river nearby and the increase of the ground water added with the rainfall, the deep slope or soil instable is happened. The deep failure normally is more than 4m.

Rainfall induced slope instability create a common geotechnical hazard in tropical region which is Malaysia (Gofar et al., 2008). The intensity of rainfall will affect the measurement of rain gauge and the suction of soil because of the measure amount of the rain that falls over time. In Peninsular Malaysia, the climate generally is hot and humid with a uniform temperature throughout the year. Peninsular Malaysia also had copious rainfall with the average annual rainfall exceeded 2000mm (Yunus & Fariza, 2011). In Malaysia, there are two type of monsoon seasons which is southwest monsoon seasons and northeast monsoon seasons. During northeast monsoon seasons, east cost of Peninsular Malaysia will experience heavy rainfall from November to February (Ghani et al., 2016). Rainfall was one of the cause of the majority slope failures or slope instability when the area or region experience heavy rainfall. Therefore, the characteristic of the rainfall should be considered in the analysis of the slope instability.

Suction plays an important role in the stability of the slope especially in tropical region. Hence, the evaluation on the measurement of suction in soil of slope stability is needed (Gofar et al., 2008). Rainfall which happening at the area will cause the moisture content increased, the matric suction is reduced which reduces the intergranular of the soil and the effective stress also reduced. Since the effective stress decreased so the shear strength also reduced (Varsei et al., 2013). Matric suction is a primary variable in the analysis of hydromechanical behaviour of soil. Matric suction is forms at soil-air interface because of the surface tension which result in reduced vapor pressure in the water. The vapor pressure decrease or become negative, the matric suction pressure increases (Tarantino & Mongiovi, 2003). The reduction matric suction when there is rainfall which cause wetting of soil affect the unsaturated shear strength of soil slope decrease. This is called rainfall infiltration (Mahmood et al., 2016).

In conclusion, rainfall is the one mechanics that study which is an issue for slope stability. The measurement or result of soil suction and pore pressure on water table is affect by the rainfall because it raises soil unit weight and reduce the strength of soil.

1.2 Problem Statement

International Islamic University Malaysia (IIUM) is located near the hilly area. There is a building near IIUM located at the hill slope area. In the building had found that there is some crack around it. In Malaysia, most of the hill slope area are variable to soil erosion and shallow slope landslide due to the rainfall happened at the area. Rainfall may be a cause factor for the slope instability.

Rainfall infiltration affects the shear strength of soil at the research area and pore water pressure which will also affect the soil suction. The parameter that had considered in the previous research included intensity and duration of antecedent rainfall. The laboratory test need to be done to study the mechanism of the rainfall infiltration and which may cause the building crack.

1.3 Objectives

The objective of this study is to form a statistic of rainfall and suction of soil for slope instability in the area and to analyse and investigate the relationship between these parameters.

- To determine suction of soil of slope at study area.
- To identify instability of slope related to rainfall events.

1.4 Scope of Study

Rainfall, geological formation of slope, soil suction and humidity are the important factors to slope instability. Rainfall-induced slope instability involves some of the mechanism that governed by some of the parameters and uncertainties. In this paper, parametric studies were performed to study the effect of the rainfall intensities and soil suction in affecting the stability of slope. The relationship is important in this study therefore the understanding on the rainfall event and the corresponding suction distribution is needed to successful in the evaluation of the effect of rainfall infiltration on the slope stability. The measurement of the rainfall and the soil suction are recorded and the analysis of these two parameters in the period of research project. The observation, field instrumentation work and laboratory work are monitored in the progress of the studies.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

There are many studies related to the slope stability with the rainfall, suction, and vegetation cover have been reported by the researchers. Slope instability had affected by some factor and there is some method to express the relationship between the factor and the slope instability. Peak (1969) stated that when geotechnical engineers contract with doubts by recognized the risk and uncertainty and apply the observation method can control the problems. However, the observation method just can apply during the construction design stage, for the critical cases cannot be observed. So, the designer must rely on calculate the risk and the slope stability also need to be calculate.

Slope stability is the potential of soil covered slopes to withstand and undergo movement. The balance of shear stress and shear strength are consisting in the stability of slope. The slope considered stable if the force available to resist movement are greater than the forces driving movement. Preparatory factors is initially affected to the stability of slope or make it unstable. It also leading to mass movements which caused by increase in shear stress. Weathering, rainfall, change in pore water pressure and organic material may decreased the shear strength. Slope stability needed to be investigated and analysis to ensure the safety of the area and it typically completed by geologist, engineering geologist or geotechnical engineers.

To produce a success design of the slope, the geological information and site characteristics should be provided. The information included properties of soil and rock, slope geometry or contour of the area, groundwater condition and others which related to geological, geometry and geomechanically. The presence of the water from rainfall or underground water also will give some effect on the slope stability. The methodology for analysis is needed to be carefully consider during define the strength, weakness and limitation.

2.2 Slope Stability

Slope stability or slides occur can be separate into two, which are deep-seated and shallow slides. Slides will occur when the driving forces is greater than the resisting forces. This may be happened due to the cut and fill activities, water level increases, loss of vegetation and more.

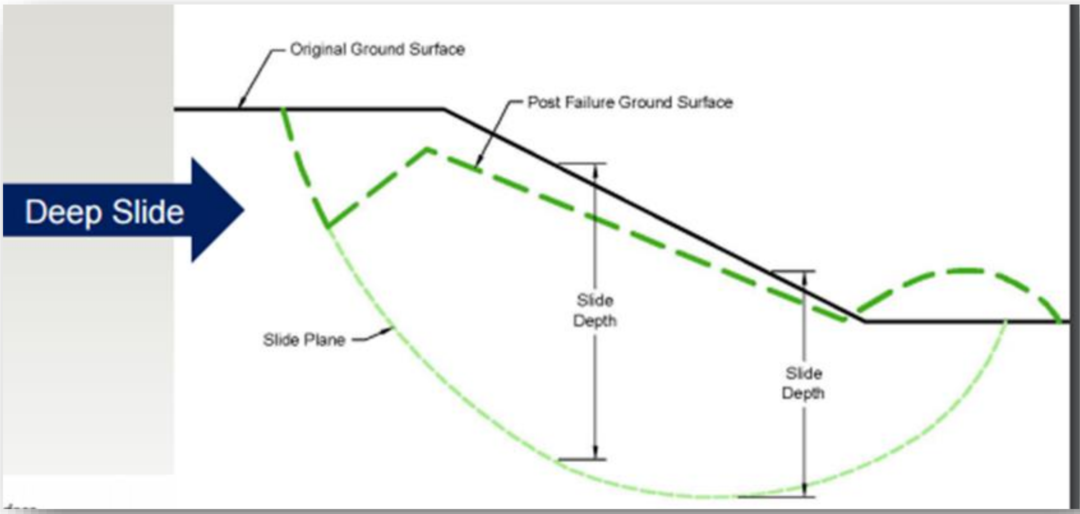


Figure 2.1 Deep Slide

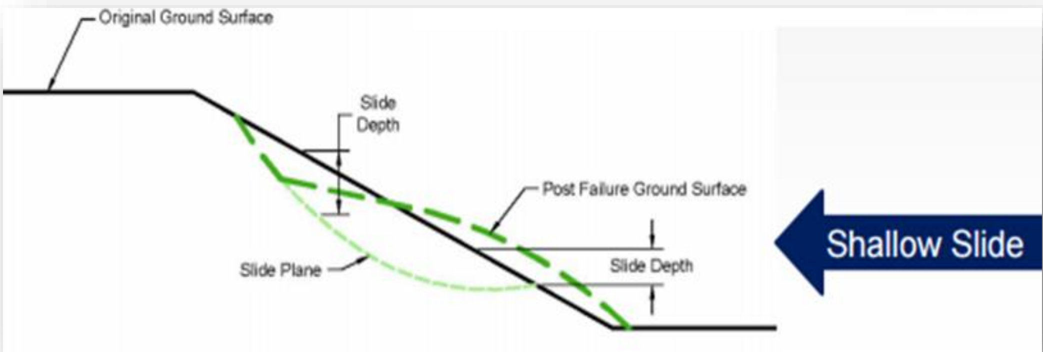


Figure 2.2 Shallow Slide

2.2.1 DEEP–SEATED, ROTATIONAL FAILURES AND DEEP SLIDES

Deep-seated landslide also can call as the rotational earth movements, this is because the mass of the slide rotates backward as gravity pull it downward. The reduction of the stability of deep-seated can raised ground water and following up the effective stresses also reduced. Besides that, the reduced in suction caused by the reduction in above ground water level and effective stresses due to increase in water content. For the deep-seated, the circular shear surfaces are small, and this shows that the slope stable effect of suction is small (Rahardjo & Leong, Suction Measurements, 2006). The constant rainfall over period of 30 to 90 days nearby the area is the cause of the activity of the more deeply-seat landslides of rotational. Furthermore, the instability of slope caused the deep slides. The deep slides are the failure of the area which is more than 10 feet below the ground surface.

2.2.2 Shallow Slides

The shallow slides in layer is near to the surface of slope so the mechanism for triggering of shallow is different with deep-seated. Shallow slides normally happened at the dividing line between stable and unstable soil and it is less than 10 feet below the ground surface. The 10 feet is measured vertically directly above the point at the area. The strength of the top layer is reduced by water saturation which is an unsaturated soil. The presence of the vegetation cover and the root system is strongly linked to the depth of a shallow slide.

In short, there are the different of the shallow and deep landslides by the physical explanation. These two types of landslides is related to the infiltration process or can say as the soil characteristic control the different pressure head responses to rainfall.

2.3 Soil Suction

Suction plays an important role in the stability of the slope in tropical region, therefore suction was one of the parameter in the evaluation of the slope stability. The responses of the suction distribution in coarse and fine soil to rainfall infiltration are different. The result shows that in the short and intense rainfall, the suction distribution of coarse-grained soil was more influenced, while suction distribution of fine-grained soil was affected in a long period of rainfall. So that, the slope which contain more fine-grained soils was more susceptible to rainfall-induced slope instability (Gofar et al., 2008). Gasmo et al (1999) stated that matric suction or negative pore-water pressure is important in stability of the slopes, shear strength and volume change. The addition shear strength that exists in soil due to matric suction however is lost as the result of rainwater infiltration into the soil (Gasmo.J et al., 1999). Besides that, soil properties affect the occurrence of the minimum factor of safety of slope. The minimum factor of safety may not occur at the end of rainfall but after several hours the factor of safety change (Rahardjo et al., 2010).

Suction measurement is a problem when dealing with unsaturated soils. The engineering properties of unsaturated soil is affected by the suction directly or indirectly. Normally the suction is affected by climate conditions. In theory, soil suction consists of osmotic suction and matric suction. The range of the suction can be from 0 kPa to 1 GPa and there is no single instrument can measure the range accurately. The jet fill tensiometer are suitable use for defined the suction of soil because the others suction measurement instrument only can measure the suction which up to 10 MPa (Rahardjo et al., 2006).

The amount of the water applied to the soil is changed when a development occurs at the area. The changes will cause the change in soil suction profile. Since there is a new development at the area, the suction decreased in few meter and it also have a consequence impact over the degree and extent of suction changes. The degree is the amount by which suction changes while extent is the depth over which a change occurs (Walsh et al., 2006).

2.3.1 Analytical Techniques: Soil Water Characteristic Curve (SWCC)

A model for prediction of the soil-water characteristic curve (SWCC) is based on the particle size distribution, dry density, void ration, and specific gravity of soil. Fredlund et al. (1993) stated that the shear strength of unsaturated soil can be compound using the soil-water characteristic curve and the saturated shear strength parameters of the soil. The proposed models make us of the soil-water characteristic curve and the unsaturated shear strength parameters to predict the variation of shear strength with respect to suction. The pore-size distribution is primarily determined in the coefficient of permeability and it also can be predicted from the soil-water characteristic curve. A general equation is used to describe the soil-water characteristic curve over the entire suction range (i.e., from 0 to 10^6 kPa).

There are many constitutive relations for unsaturated soils use matric soil suction as a state variable. Based on soil index properties such as the grain-size distribution (GSD) function SWCC, the relationship between soil suction and some measure of the water content can be measured and predicted. SWCC provided the accuracy of the estimate in the study. Besides that, based on GSD, the variability in the SWCC associated with direct suction measurements as well as the variability associated with the prediction of the SWCC was investigated. Surprisingly, Claudia et al. (2000) stated that the variability in the SWCC as predicted by soil index properties and/or GSD-based algorithms was found to be as small or smaller than that associated with the operator or person measuring the SWCC.

2.3.2 Use of Soil-Water Characteristic Curve

The soil-water characteristic curve may be defined as the variation of suction with the water storage capacity within the soil. The soil-water characteristic curve is generally plotted as the variation of gravimetric water content, w or degree of saturations, S with suction. At high suction, matric suction can generally be assumed to be similar in magnitude.

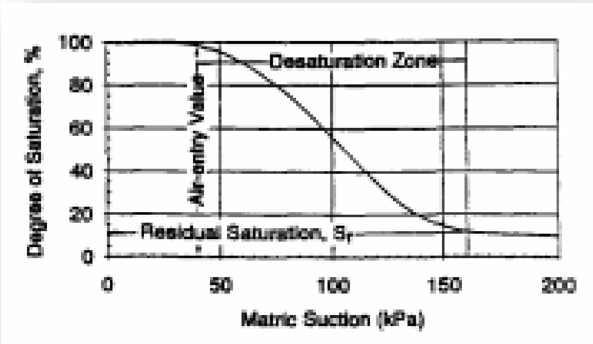


Figure 2.3 Matric Suction vs Degree of Saturation

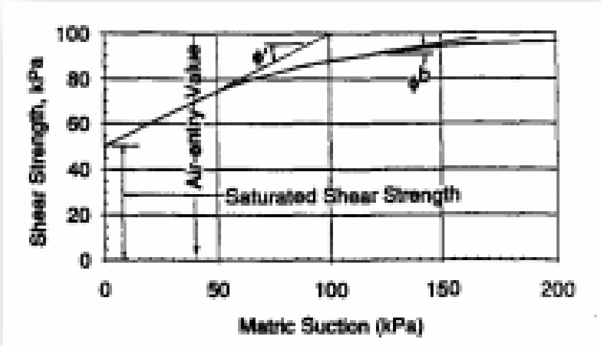


Figure 2.4 Matric Suction vs Shear Strength

2.4 Rainfall

Rainfall is one of the causes that should be considered in slope failures especially in a region with high seasonal rainfalls (Shaw-Shong, 2004). Rainfall-induced slope instability is widely known in many tropical areas that covered by residual soils. The growth of economies at the region had caused the tremendous demand for hillside development and construct on the slope of the area. The slope at the region is unstable due to tropical rainfall events. The slope failure had caused the damage to the infrastructure and building (Rahardjo et al., 2008). Slope responses to rainfall, infiltration and evaporation processes and it also influenced by the dynamic climate, soil properties and vegetation (Rahardjo et al., 2002). The study by Zhang. G. et al. (2014) shows that the upper soil mainly influenced by the rainfall. The shallow part of the soil-slope will be saturated immediately, and the temporary saturated zone is formed. This had lead the matric suction of the shallow slope body to reduce and slip. In short, the cause of the shallow slope and local slope is more likely by the rainfall.

2.4.1 Analytical Techniques: Intensity-Duration-Frequency (IDF) Curve

Both rainfall intensity and duration take part in determining the water condition which related to the shallow landslides. Rosso. R. et al. (2006) specified that other scientists had analysed the intensity and duration of rainfalls causing landslides by envelope curves for the geographic area. Gofar, N. et al. (2009) had used IDF curve for slope analysis the slope stability at Johor Bahru area. The 1-day, 2-day, 3-day, 5-day, 7-

day, 14-day and 30-day extreme rainfalls were obtained from statistical analysis. The analysis of IDF curve is shown in below.

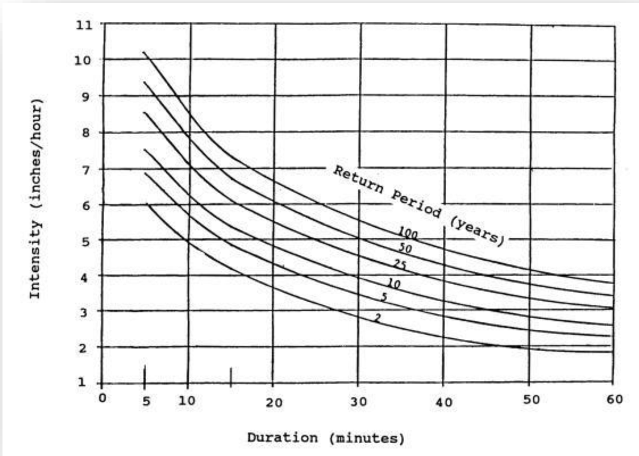


Figure 2.5 IDF Curve

2.4.2 Analytical Techniques: Preliminary Evaluation of Rainfall-Induced Slope Instability (PERISI)

Frequent rainfall commonly happened in Malaysia tropical region which always facing slope failure. The rainfall can be category and it has their characteristic throughout a period or duration. To analysis the rainfall-induced slope failure at the tropical region, Malaysia, the various rainfall patterns should be included under the situation or circumstance. Lee. M.L et al. (2009) having a study on the development of a simple model for preliminary evaluation of rainfall-induced slope instability which to analyse the statistic of rainfall and the soil. The result from the study by Lee M.L. et al. (2009) showed the important role in determine the critical rainfall pattern by using the ratio of the rainfall intensity and the soil permeability and there is two critical combination type of rainfall which are antecedent rainfall and major rainfall in different days. The critical combination of two types of rainfall were take part in affecting the soil suction. PERISI is a model develop based on the findings from numerical simulation and Rahardjo et al. (1995) was developed the model for derived the suction and factor of safety from the PERISI model to analysis the critical rainfall patterns for four types of soil at the selected region in Malaysia with using software Seep/W and Slope/W.

2.5 Vegetation Cover

About the vegetation cover effect on suction variation and slope stability, Lee, M. L. et al. (2006) had stated that there are two ways: through hydrological effects and mechanical effects. The result from their study stated that vegetation cover is not the dominant factor to increase the soil suction, climatic condition plays an important role as well and under natural vegetation cover, even though less water is infiltrating into the slope during intense rainfall, somehow it is still not capable to resist the reduction in soil suction at shallow depth. During dry period, the vegetated slope could produce higher suction than the bare slope (Lee, M. L. et al., 2006).

2.6 Analytical Techniques for Slope Stability: Seep/W Software And Slope/W Software

The basis of analysis of slope analysis is used to established suction profiles. A program or software had been run to determine whether the slope is possible to reproduce the design suction conditions. The program been chosen for doing the analysis on the slope and suction condition is GeoStudio 2004, Seep/W. It is a software to doing the analysis of excess pore-water pressure dissipation and groundwater seepage problem in under rock and soil (Khalili et al., 2014). This software able to analyse the infiltration of rainfall.

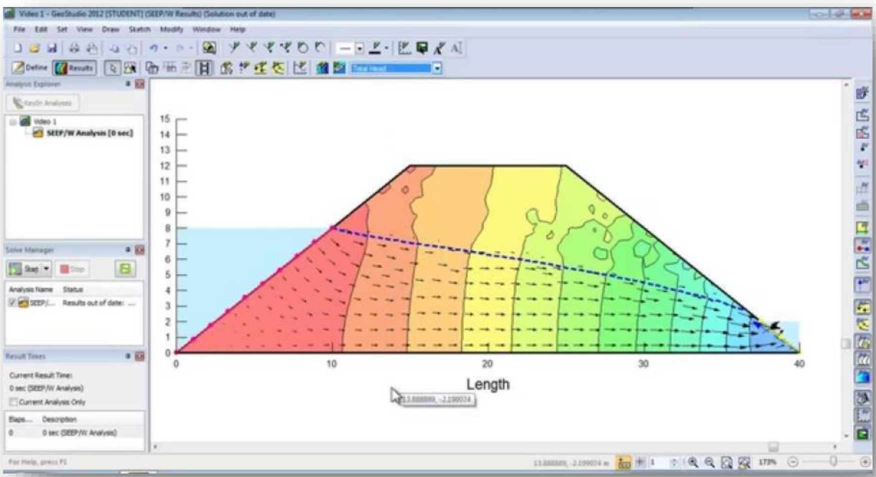


Figure 2.6 Soil Suctions Generated with SEEP/W

By using SLOPE/W software, the suction values for the wettest condition at the rear of revetment wall is shown. The values also been used for further analysis in the stability of slope. The shear strength equation for unsaturated soils is used or formulated in this software in terms of the independent stress state variables. The net normal stress and the contributions of effective cohesion are clearly show in equation. The increase in the shear strength because of the increase in the matric suction. This program recognises examination of the separate contributions of the effective cohesion (c’), the normal stress component ((b-u_a - tan Φ’) and the matric suction component ($u_a - u_w$) tan Φ^b on the stability of a slope. For the Adelaide soils the result obtained for c’ = 5kPa, Φ’ = 25° and Φ^b = 10°. If the result as shown like what had stated it means that failure did not occur even under the wet conditions in the Seep/W modelling. The SLOPE/W model can be a reference for monitoring, early warning and prevention of rainfall-induced shallow landslide (Zhang, Li et al., 2014).

In short, adopt the SEEP/W can simulated the transit seepage caused by rainfall infiltration. The moisture content of shallow soils from back to front of the landslide is analysed by SEEP/W. The landslide stability is calculated using SLOPE/W during a continuous precipitation process.

2.7 Analytical Techniques for Slope Stability: Fellenius’ Method

The simplest method is known as Ordinary Method of Slices or known as Fellenius’ method. The failure surface is assumed to be arc as shown in Figure below. The ratio of moment of the total available resisting forces on the trial failure to the net moment of the driving forces due to the embankment weight is shown as factor of safety. The parameter and information of each slices are insert into table shown below for further derivation. Fellenius’ method formula (Figure 2.8) as used the same with data from the table to define the factor of safety of the slope. This method underestimates the FOS by 5 – 20% compared to more rigorous methods.

Table 2.1 Table for Information of Slices from Slope

***Slice* No**	***z* (cm)**	***b* (m)**	***W* (kN)**	***a*** (^{0})	***sin*a**	***Wsin*a (kN) (4)**	***l* (m)**	***y* (kPa)**	***tan*f'**	***tan*fb**	***c'l* (kN) (1)**	***Wcos*a (m)**	***Wcos*atanf' (kN) (2)**	***y*ltanfb (kN) (3)**
1														

$$F = \frac{\sum c'l + (W\cos\alpha - ul)\tan\phi'}{\sum W\sin\alpha}$$

Figure 2.7 Fellenius' Method Formula

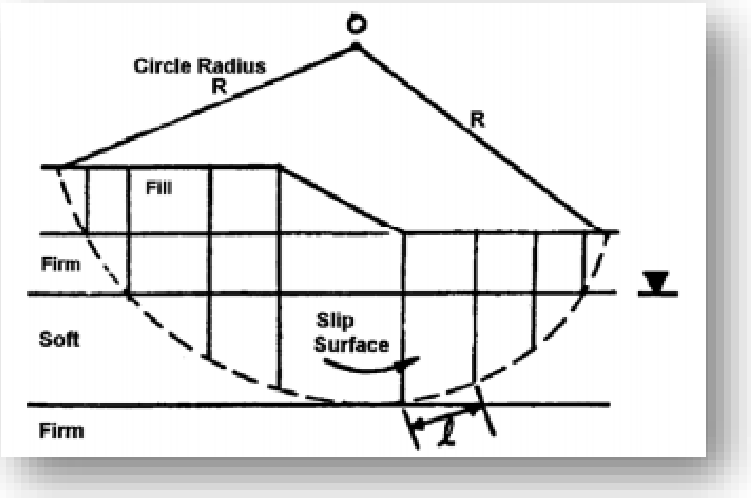


Figure 2.8 Geometry of Fellenius' Method of Slices

2.8 Suction and Factor of Safety

The effect of changing shear strength of soil due to suction is related to the stability of slope, so the soil suction profile of soil needed to be take noted which described by Estabragh, A.R., and Javadi, A.A. (2012) and Faroukm A., et al., (2004). The analysis on the stability of slope is mainly focus on the effect of the suction shearing angle Φb. Based on the parameters from Mohr-Coulomb's, the initial suction related to the suction shearing angle and the ration Φb /Φ on safety of slope is indicated. It had found that the suction shearing angle has a significant effect on the factor of safety of slope. The increased in suction shearing angle, Φb, the increased in the factor of safety. M. Mossaad, et al. (2013) stated that the increase in factor of safety by consider the changes of initial matric suction about 28% higher compared to the conventional slope stability analysis at Φb /Φ = 0.5. The suction effect in the analysis leads to change the stability and the failure of slope. The soil shear strength increases as suction shearing angle increases, therefore, the slope become more stable.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

The research methodology is a technique of collecting data, evaluate and analyse the data in the stage of study through the steps. Researchers are searching and obtaining the information for the study through reading, previous data and statistic and more. All the information can have found from journal, books and some articles from electronic media such as website.

3.2 Research Methodology

This chapter will carry out the method of study and the steps to achieve the objective of this research study. Problem statement related to the research and the title of research are identified. The objective of the research is defined to answer or respond the research problem. Next, the previous research and study are reviewed to gain more information which related to the research topic. Moreover, there are four approaches been used in this study to obtain and analysis the data so that the data collected are accurate and related to the topic study. The four approaches are shown below.

i. Site Investigation

ii. In Situ Test or Site Test

iii. Laboratory Test

iv. Data Analysis

The research process is illustrated in Figure 3.1. and the flowchart of the testing in Figure 3.2.

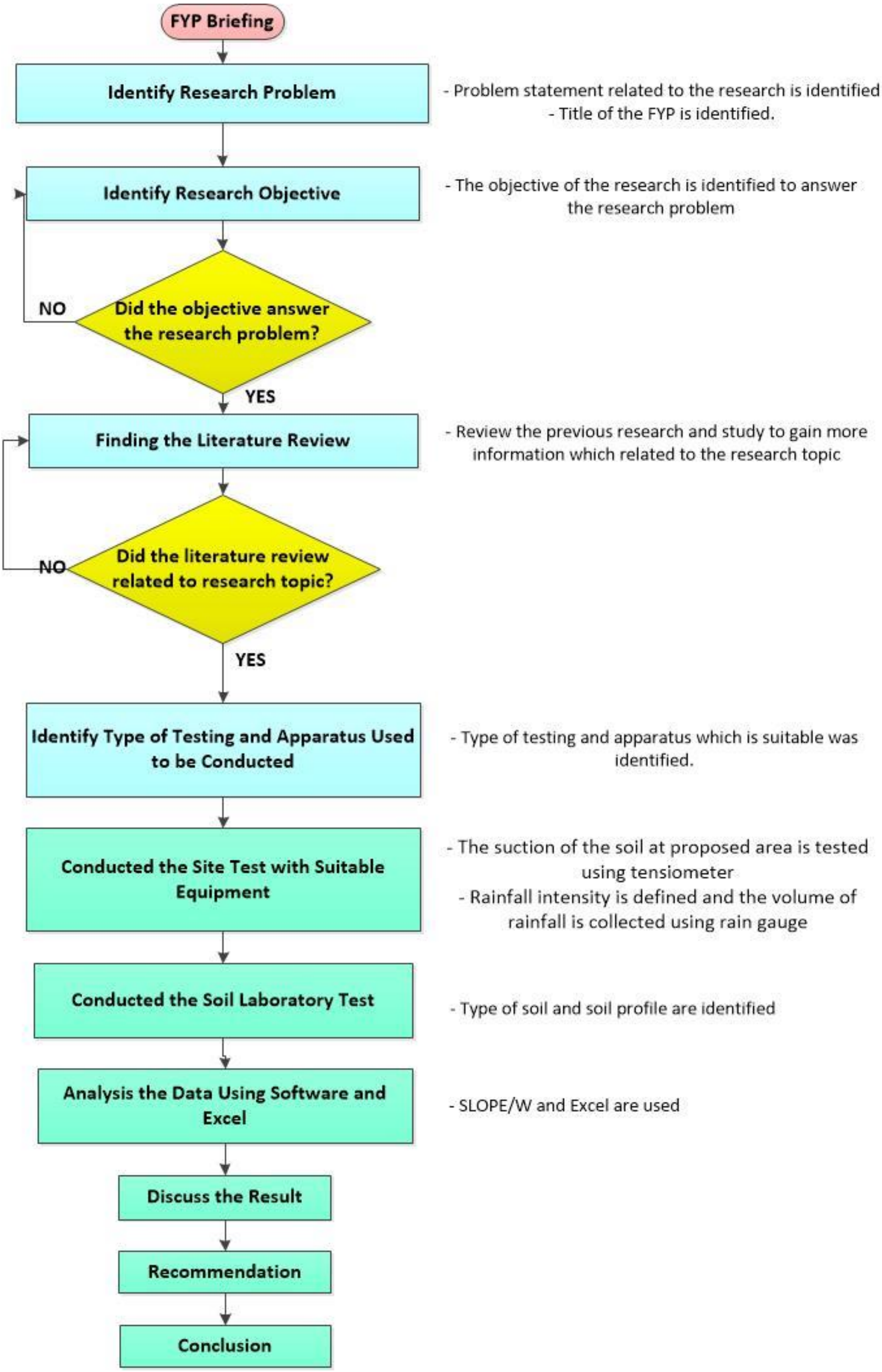


Figure 3.1 Research Process

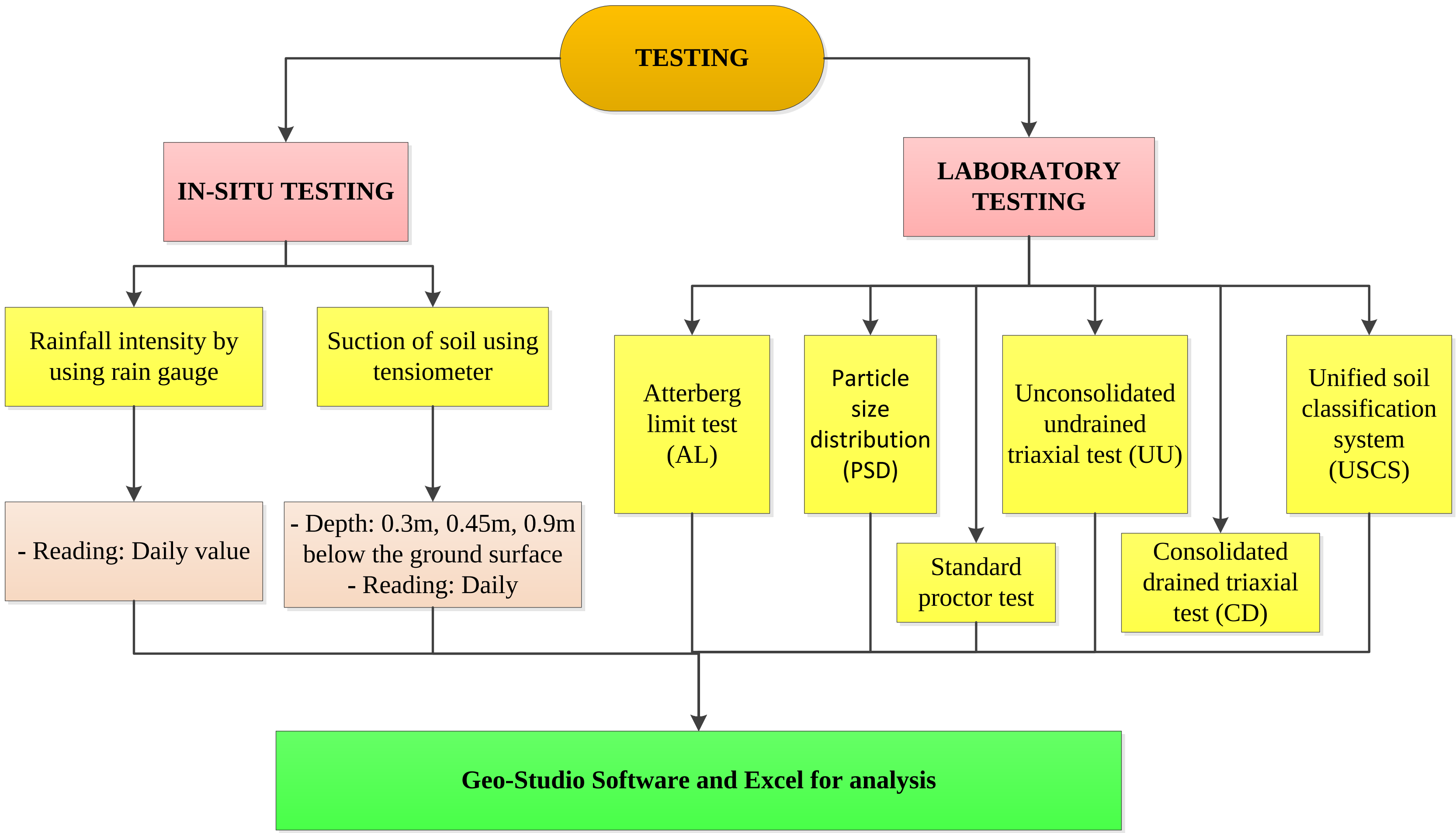


Figure 3.2 The Flowchart of the Testing

3.3 Data Collection

The data collection was primary data which is the original data from the people involved in the project to determine the problem statement. Besides that, the primary data also can be collected through the testing done on site or in the laboratory. These data are also the help in solve the problem and it must be related to the topic chosen.

The location for this data collection is a slope with building near IIUM Kuantan Campus. This building is located at slope which is suitable for this study topic which is to define the slope instability may affect by the rainfall. Building cracks and damage (Figure 3.5 and Figure 3.6) was the problem statement related to the research.

Figure 3.3 Location Map of Study Area

Figure 3.4 Location of The Study Area

Figure 3.5 Cracked Around the Building Structure

Figure 3.6 Cracked on the Wall of Building

3.3.1 Site Investigation

First for the research study, site investigation is carried out in order to enable geotechnical and environmental assessment around the site. Preliminary site investigation is the first stage to determining the situation of site and risk of site contamination. Visual inspect on the site and the surrounding area is done in this stage to contribute an initial view of the natural and structural at surrounding. Some aspects been considered in this stage are: surveying and observe the slope failure, crack on building and site topography.

3.3.1.1 Visual Inspection on Site

The slope for this research study is located near International Islamic University Malaysia (IIUM), Kuantan. A building was placed on the medium of slope and found that there are many cracks around the building. Besides that, the structural and road also failure due to the slope instable.

Figure 3.7 Side View (Right Elevation) of the Building (Middle of Slope)

Figure 3.8 Side View (Left Elevation) of the Building

Figure 3.9 Front View of the Building (Toe of Slope)

Figure 3.10 Cracked Around the Building Structure

Figure 3.11 Collapsed of Road along the Slope

3.3.1.2 Site Topography

Topography map is used in study of the relief and shape of the surface of the site. It is also a detailed map shows the surface features of land. Topography is measured with the contour lines which representing the different elevation of slope. The topography and terrain of the research site was shown in figure below. The topography is analyse using contour and different colour with different elevation. The elevation at research site is 318 ft. from chart datum.

Figure 3.12 Topography of research site near IIUM, Kuantan

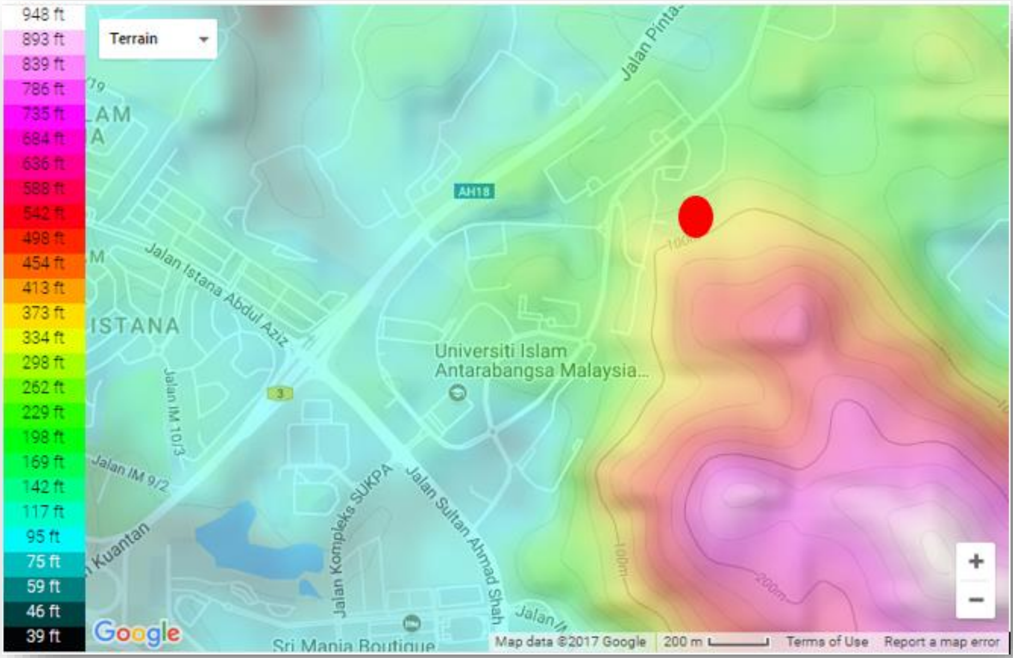


Figure 3.13 Terrain of research site near IIUM, Kuantan

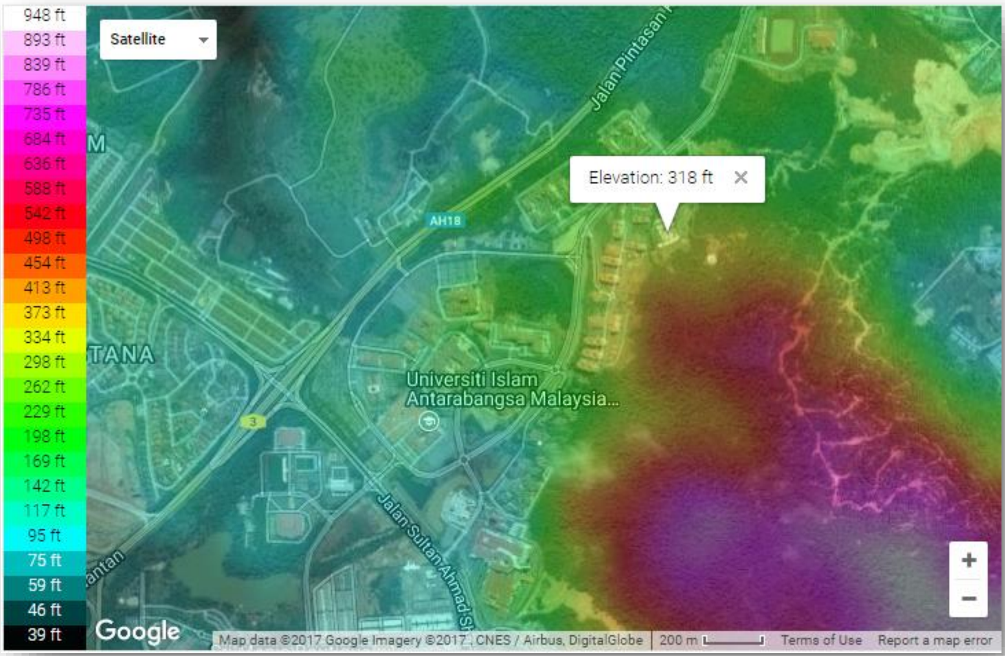


Figure 3.14 Elevation of research site near IIUM, Kuantan

3.3.2 In Situ Test or Site Testing

In situ testing will be carry out on the site we had selected or chosen. The correct instrument or apparatus had defined and install at the site. The sample of soil is collected by Standard Penetration Test (SPT) and Trial Pits to find out the type of soil at the area and bring it back to laboratory for further testing. Besides that, there are two sets of measurements will carry out at site: (i) rainfall intensity by using rain gauge, (ii) suction of soil using tensiometer.

3.3.2.1 Standard Penetration Test (SPT)

Standard Penetration Test (SPT) was carried to determine the penetration resistance using a split barrel sampler and a self-tripping hammer of approved design. All boreholes were carried out by rotary wash boring, continuous sampling, rotary drilling or a combination of these methods. The dimension of the three boreholes were 100mm in diameter and with depth of 11.7 m, 18.6 m and 23 m respectively. The value of the N was reported with the number of blow counts for each 75mm penetration of the sampling tube. Figure below is shown the location of the SPT boreholes.

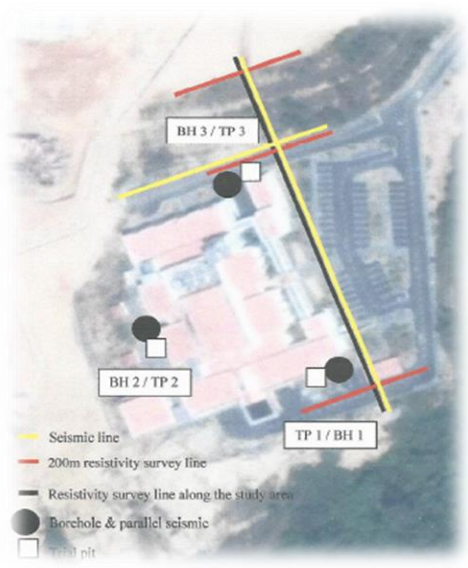


Figure 3.15 Location of SPT boreholes at research site near IIUM, Kuantan

SPT test is reflects soil density, stress and strain history effects and horizontal effective stress which would influence the liquefaction resistance but difficult to obtain with undisturbed samples. SPT N-values and others information recorded in borehole log can be performed the soil conditions in different depth.

3.3.2.2 Trial Pits

Trial pit is used to obtaining information on the subsurface soil conditions by digging during site investigation, soil survey or geological survey. A total of two trial pits were excavated at the location shown in the Trial Pits Location Plan (Figure below). Trial pits of 1.5m x 1.5m x up to 2.0m deep were excavated by backhoe and inspection were made on soil strata exposed at its side and bottom. The disturbed sample and undisturbed samples were taken from the site for further laboratory testing. The result of trial pits helps in check out the conditions of sub-surface on the instability slope.

Figure 3.16 Trial Pits Location Plan

3.3.2.3 Suction and Rainfall

The slope had separated into three parts which are top, middle and toe. Each part was designed to measure suction at the depth of about 0.3 m, 0.45 m and 0.9 m below the ground surface which show in Figure 3.17. The reading from the tensiometer were taken manually every morning. Rain gauge is placed at the open area of the site or installed it at the centre of research area.

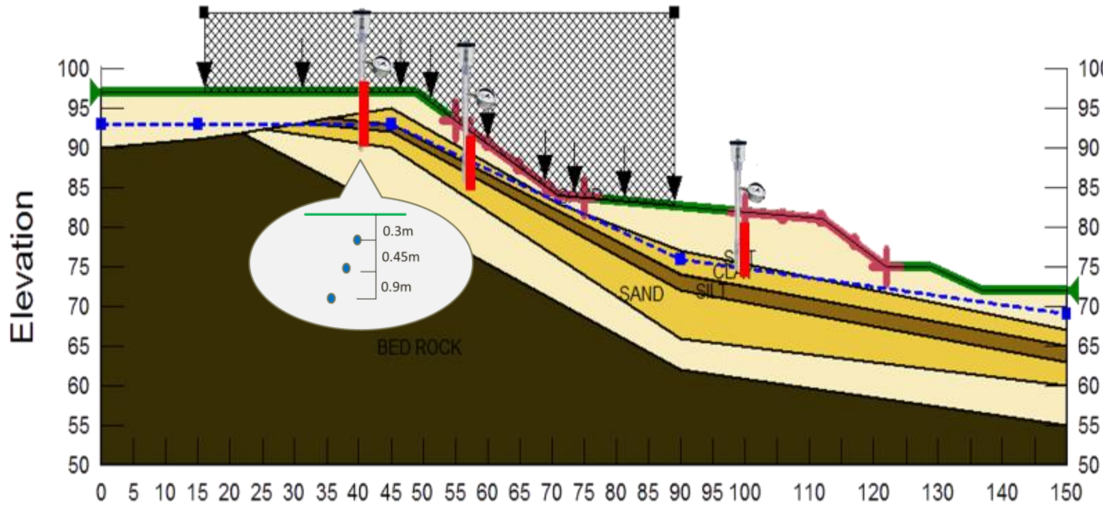


Figure 3.17 Location of tensiometer

Apparatus Used for In Situ Test

Jet fill tensiometer (2011) was used in this study to measure the soil suction. The tensiometers were installed at three part which are above the slope, on the slope and below the slope. The tensiometer were installed at depths of 0.3m, 0.45m and 0.9 m below the ground surface in each part. The measuring range of the tensiometer was from 0 kPa to 90 kPa. The sampling frequency of each tensiometer was 5 min. The tensiometer consists of a tube with a porous ceramic tip on the bottom, a vacuum gauge near the top and a sealing cap. When it is filled with water and placed into the soil, the water will move into and out of the tensiometer through the connecting pores in the tip. The water move out of the tensiometer because the soil is dried. It had created a vacuum inside the tensiometer and this vacuum created is equal to “soil suction”. The dial gauge reading is showing the measurement of the pressure required to remove water from the soil. If the soil is too dried, water is added and make sure the water added is enough for soil completely saturated. If the soil had completely saturated, the gauge reading on tensiometer will drop to zero.

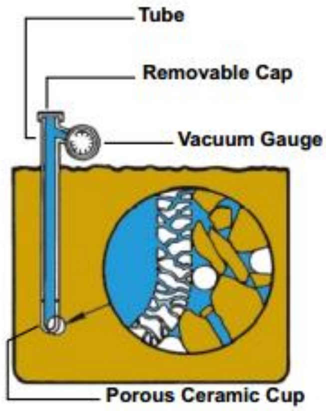


Figure 3.18 Example of Jet Fill Tensiometer

Figure 3.19 Tensiometer was Placed in Soil

Rain gauge is an instrument to collect rainfall. The rain gauge should place at an open area and away from the buildings or make sure there is nothing overhead such as trees, roof or more. This is because the overhead will cause the inaccuracy of the measurement. Besides that, the rain gauge is placed at a flat surface. The reading is recorded daily. The example of the rain gauge is show at figure 3.5.

Figure 3.20 Example of Rain Gauge

3.3.3 Laboratory Test

The laboratory testing is the constitutive part of the research study on the soil and slope to provide some informative parameters and soil properties and behaviour. The soil samples were collected from site during detailed site investigation. All the samples are labelled and sealed properly for further testing. The laboratory tests were conducted at FTeK ETIM's Geotechnical Engineering Laboratory in University Malaysia Pahang. All the testing undergoes according suitable manual method with specific ASTM Standard and other standard.

Table 3.1 Laboratory Tests conducted for Soil Samples

No.	List of Laboratory Test
1	Particle Size Distribution (PSD)
2	Atterberg Limit Test (AL)
3	Standard Proctor Test
4	Unconsolidated Undrained Triaxial Test (UU)
5	Consolidated Drained Triaxial Test (CD)

The laboratory test is carry out to measure the soil properties. Some soil tests measure direct properties of the soil, while others measure "index properties" which provide useful information about the soil without directly measuring the property desired. Variety of soil properties is carried out by conduct several laboratory tests. Every soil has their own properties and some of its properties are inherent to the formation of the soil matrix and it does not affected by the sample disturbance. For other properties of soil is depends on the its structure. There are five laboratory tests conducted to obtain data and information by using the samples been collected from site. Unified Soil Classification (USCS) with standard of ASTM is system used to classify the type of soil at slope.

Particle size distribution (PSD) is to determine the size range of the soil and the apparatus used for this test is sieve shaker with ASTM standard. Atterberg limit test is a simple classification tests to categorised soil into types and provide their engineering properties such as permeability, strength and compressibility. ASTM D41318, standard test methods for Plasticity Index, Plastic Limit, and Liquid Limit. Furthermore, standard proctor test is to determine the optimum moisture and maximum dry unit weight of the sample collected from site with standard ASTM 698. ASTM D2850 which is the standard test method for unconsolidated undrained triaxial test on the soil samples while for consolidated drained triaxial test, ASTM D7181 was the standard to obtain shear strength parameters for a variety of soil types under drained or undrained soil.

3.3.4 Data Analysis

Data analysis is arranged and organized the unorganised data which collected from primary and secondary data. All the information of the data is pointed out detail and systematic. The analysing and evaluation process help in recognise what is present in the data. The data is recorded when in the process of doing site testing, laboratory testing and software. These tools are used as a guideline in analysing the data. All the data will analyse to obtain the result and finding for this study. The result will present in terms of tables, figures or graphs to let the readers easy to understand.

3.3.4.1 Stability Analysis Method: Slope/w

The computer software or program used to analyse the stability of slope is Geo-Studio software or SLOPE/W (2004). The soil strength is characterized by the soil parameters which from Mohr Coulomb in SI report. The soil parameters are cohesion c' and effective friction angle Φ'. Bishop, Ordinary and Janbu are the analysis type use in SLOPE/W while for this study ordinary method been choosing to identify the stability of slope. The direction of movement is left to right and slip surface option is entry and exit. Stability calculations were performed for specific events by using the pore pressure resulting from flow analyses in SEEP/W (2004).

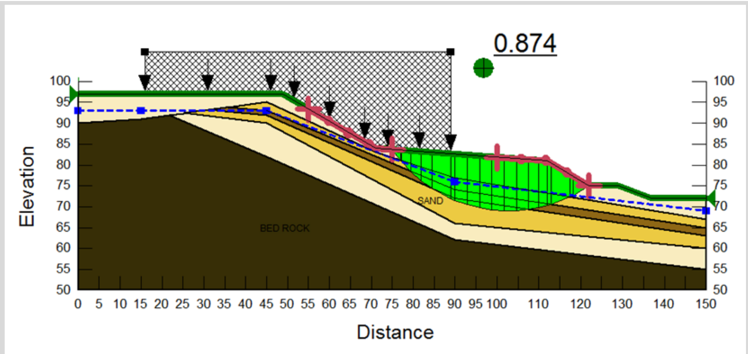


Figure 3.21 Example of Slope/w

3.3.4.2 Stability Analysis Method: Fellenius' Method

The parameters (cohesion c', effective friction angle Φ', suction and etc.) carried out from laboratory test was inserted in the formula with the slices selected in each part of slope. The Fellenius' method of Slices was derived or calculated in Excel with the formula in table to define the factor of safety (FOS) at each part of slope.

CHAPTER 4

RESULTS AND ANALYSIS

4.1 Introduction

This chapter present the analysis of data collected from field test, laboratory test, forensic report and consulting reports. The field monitoring is done with the tensiometer to get the suction of the landslide area. The data from the soil investigation were taken from the forensic report of the case study being studied. Soil investigation was conducted to get the information on the physical properties of rock and soil around the site area to understand earthworks and foundations. This is because the subsurface condition related to landslide happened at that area. For this case study, the important of correlating landslide occurrences at a building near IIUM Kuantan Campus with rainfalls, soil properties and suction were presented.

4.2 Site Test

After the site investigation, several onsite tests were carried out to collect disturbed and undisturbed soil samples from various depth. The onsite tests are standard penetration test and trial pits test.

4.2.1 Standard Penetration Test (SPT)

SPT test is reflects soil density, stress and strain history effects and horizontal effective stress which would influence the liquefaction resistance but difficult to obtain with undisturbed samples. SPT N-values and others information recorded in borehole log can be performed the soil conditions in different depth. The soil profile would affect the stability of slope and it be insert into geo-slope (slope/w) for further analyse. Figure below shown the soil profile from the three boreholes.

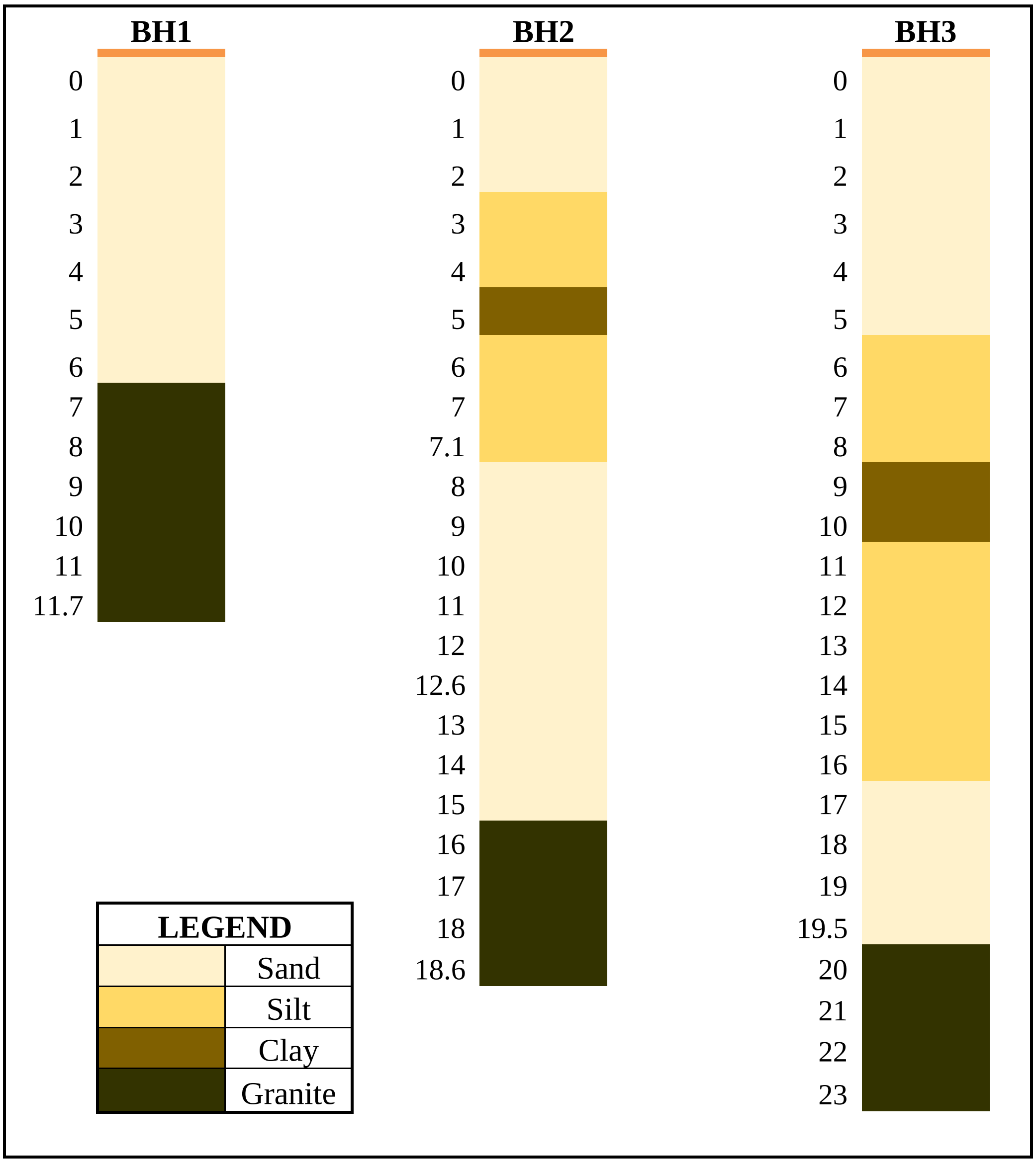


Figure 4.1 Soil Profile from Three Boreholes

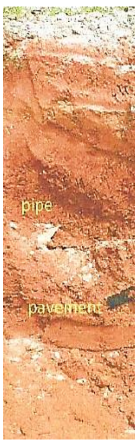
4.2.2 Trial Pits

There are two trial pits were excavated at site to collect the samples for further laboratory testing. The result of trial pits helps in check the condition of soil was shown in tables below.

Table 4.1 Condition of Soil at Trial Pit 1

TRIAL PIT LOG (TP-1)					
Depth (m)	**Face A**	**Face B**	**Face C**	**Face D**	
0.00 0.50					Dark reddish brown, orange, silty SAND with some gravels, rootlets & dumping material
1.00 1.50					Dark reddish brown, orange, greyish yellow silty SAND with some gravels (soil wet, smelly and organic material present)
Width (m)	1.50	1.50	1.50	1.50	

Table 4.2 Condition of soil at Trial Pit 2

TRIAL PIT LOG (TP-2)					
Depth (m)	**Face A**	**Face B**	**Face C**	**Face D**	
0.00					Crusher run, rootlets, netting
0.50 1.00					Dark reddish brown silty SAND with some gravels (some dumping material: pavement & pipe)
1.50					Encountered waterlogged area with boulders at corner of Face C
Width (m)	1.50	1.50	1.50	1.50	

4.3 Laboratory Testing

There are six laboratory tests conducted at ETIM's Geotechnical Engineering Laboratory by using the samples collected from research study site.

4.3.1 Particles Size Distribution (PSD)

The samples from BH-1, BH-2, BH-3 and two Trial Pits were used in particles size test. There are 6 samples from every 1-meter depth of BH-1 been collected for this test. Furthermore, 11 samples and 13 samples were collected from BH-2 and BH-3 respectively. 2 samples from each trial pit collected for sieve analysis test. A total of 9 sieves used in this test with a range from 0.063 mm until 3.350 mm. Sieve analysis used to classify the type of soil with different of particle sizes. Particles size of clays is diameter less than 0.002mm. Diameter of silt particles are from 0.002 to 0.05 mm while sand is from 0.05 to 2.0 mm. The particles which larger than 2.0mm were classified as gravel or stones. The tables of particle size distribution analysis for borehole 1, 2 and 3 are show in appendix. Figure 4.5 show particle size distribution analysis for borehole 1, 2 and 3 at 1 m depth.

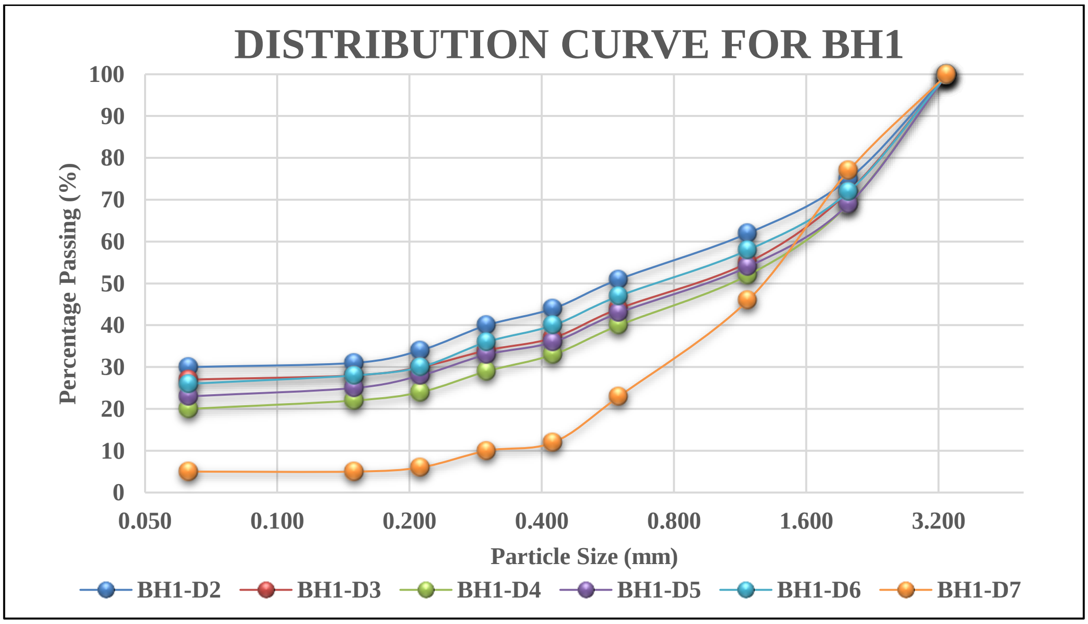


Figure 4.2 Distribution Curve for Borehole 1

The graph proof that the sieve analysis test result on the soil samples is well graded. BH-1 D2 to D6 are almost same type of soil because the curve line shown are in same grading characteristic of grain size. From the graph, the curve line of D7 is lower than others because the grain size is greater than others. At 0.60 mm sieve, D7 has the lesser particle passed through this sieve. The type of soil from D2 to D6 are very silty SAND but D7 is slightly silty SAND. The lower the percentage of the particle pass through the sieve shows the soil is become more gravel. The deeper the sample collected, the bigger the size of particles.

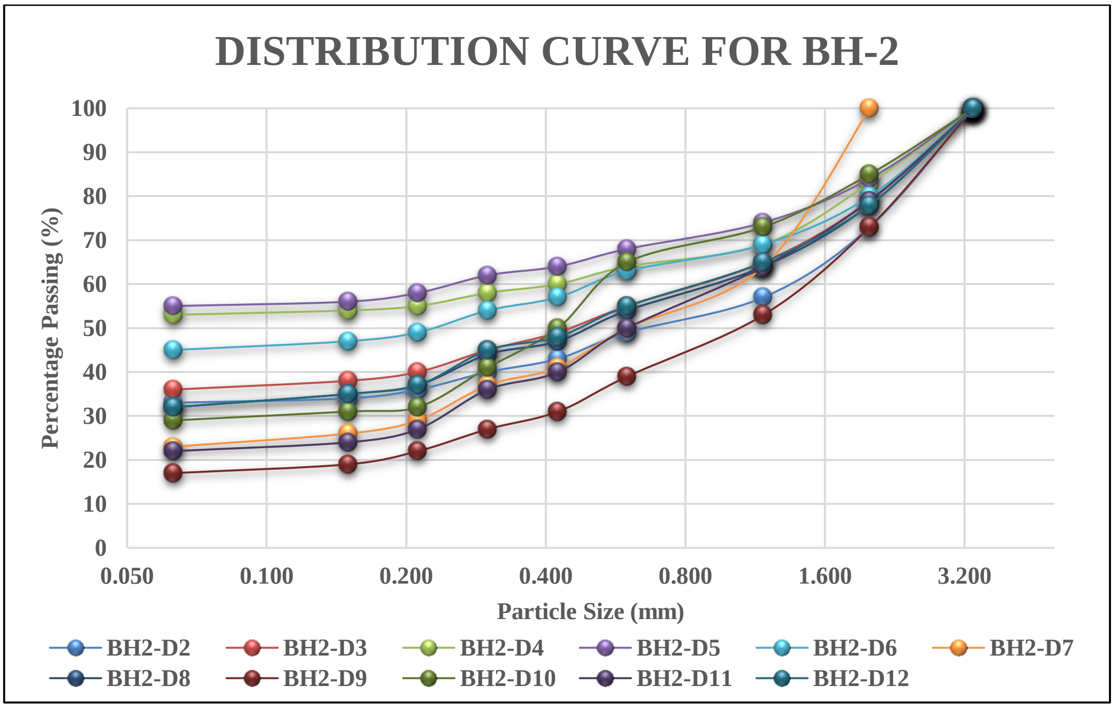


Figure 4.3 Distribution Curve for Borehole 2

Based on the graph shown in above, BH-2 D7 contain more finer soil compare to others. This is because soil sample from D7 can totally pass through 2.00mm sieve. Although D7 had finer soil but it had high amount of sand. BH-2 D5 having highest percentage in 0.063 mm and this shows this sample had very fine soil. The type of soil in D5 sample is slightly sandy CLAY. Next, 53% from D4's sample and 45% from D6's sample pass through 0.063 mm sieve. Mostly SLIT are contain in this two samples. For others, the samples pass through the sieve of 0.063 mm are in the range 36% -17% which mostly contain SAND.

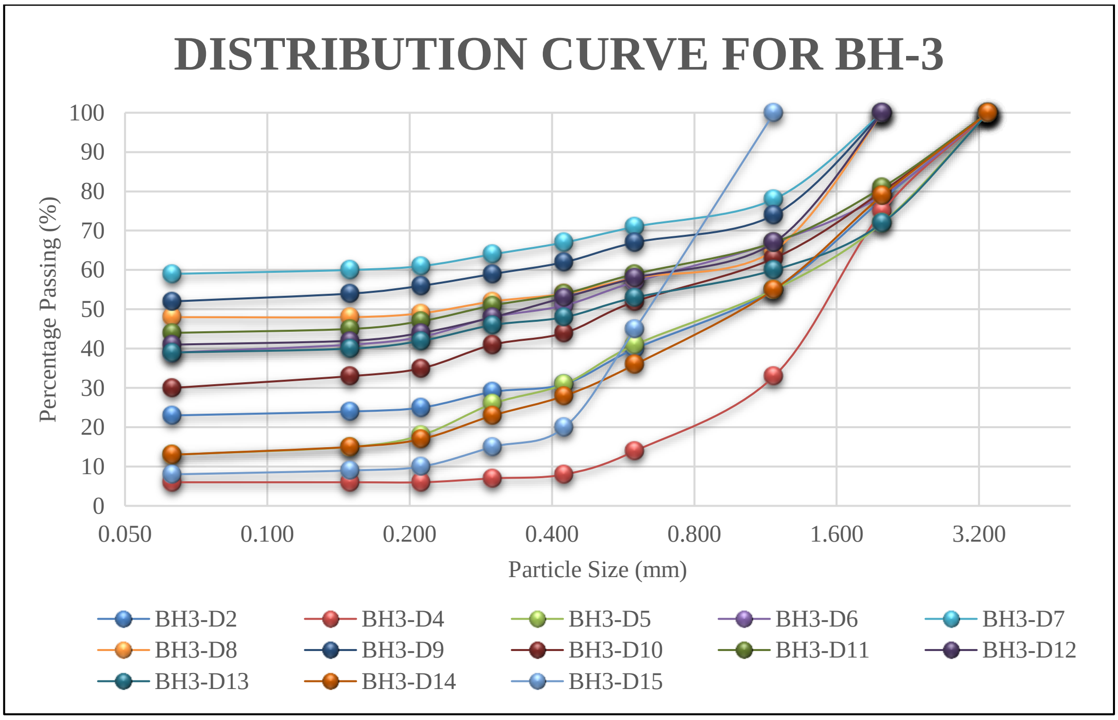


Figure 4.4 Distribution Curve for Borehole 3

Based on the graph, sample from BH-3 D15 is the one 100% passed through sieve size of 1.18 mm. Samples from BH-3 D7, D8, D9, D12 are totally passed through sieve size of 2.00 mm while others 100% passed through sieve size of 3.35 mm. So, D15 does not contain any gravel in the sample and it had high contain in SAND. The sample from D4 had lowest passing through percentage because it contain high silty SAND.

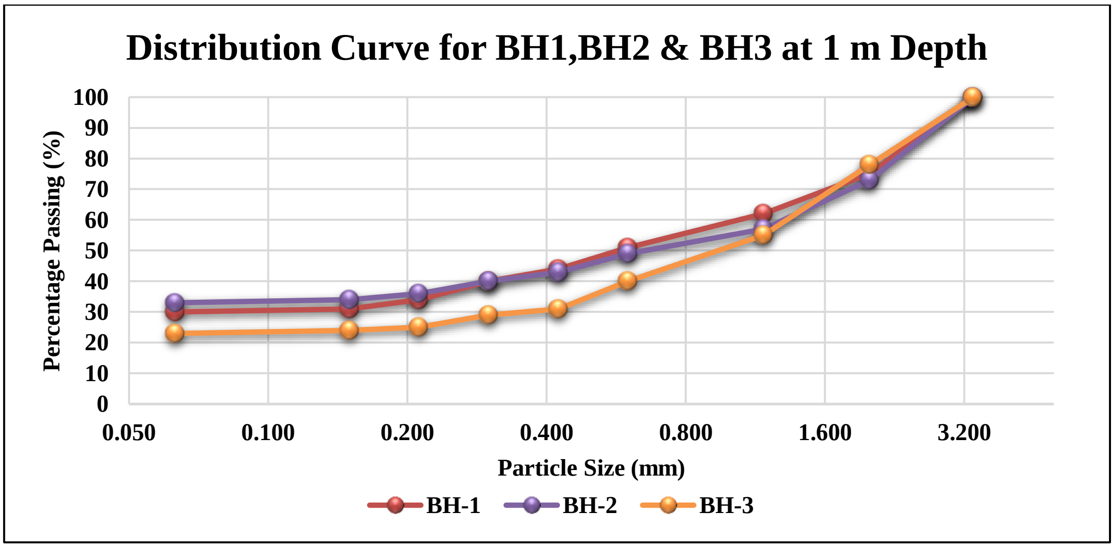


Figure 4.5 Particle Size Distribution Analysis for BH1,2&3 at 1m Depth

Depth of the tensiometer insert at the site was below 1m. Based on the graph above, BH 3 has the lowest percentage passing compare to BH 1 and BH 2. Three samples at 1 m depth are 100% passed through sieve size of 3.35 mm. Size of soil at BH 1 and BH 2 are almost same.

4.3.2 Atterberg Limit Test (AL)

There are several samples collected from BH-1, BH-2 and BH-3 for conducted this test. Based on table in appendix, BH 1 had low plasticity because from the sample had low plasticity index which in the range 5% to 8%. The samples had low plasticity due to low liquid limits which are lower than 40%. For BH 2, it contains low, medium and high plasticity soils since it had the plasticity index between 4% to 40%. The samples from BH 3 contains medium and high plasticity soils but it had more medium plasticity soil. Moreover, the liquid limits for BH 2 and BH 3 are high. In BH 1, soil collected after the depth in 6.0 m are non-plasticity soil. While BH 2, the soil sample collected at 10.50 m (D9) and after 15.60 m depth are non-plasticity soil. The soil samples from 3.00 m, 5.00 m and after 18.00 m depth in BH 3 are non- plasticity soil. All the plastic limits for BH 1, BH 2 and BH 3 are in the range 20% to 35%.

4.3.3 Standard Proctor Test

The optimum moisture and maximum dry unit weight were carry out from the 5 samples which taken from Trial pit 1 and Trial pit 2 respectively. In this test, compaction test was conducted, and the results are shown in graph below.

Table 4.3 Result for Compaction Test of Soil (TP-1 & TP-2)

Test Number for TP	**1**	**2**	**3**	**4**	**5**
Moisture Content (%) for TP-1	3.12	7.14	10.12	13.36	17.20
Dry Density (Mg/m^3) for TP-1	1.709	1.800	1.860	1.884	1.797
Moisture Content (%) for TP-2	4.14	8.04	11.16	14.80	18.30
Dry Density (Mg/m^3) for TP-2	1.671	1.723	1.796	1.843	1.745

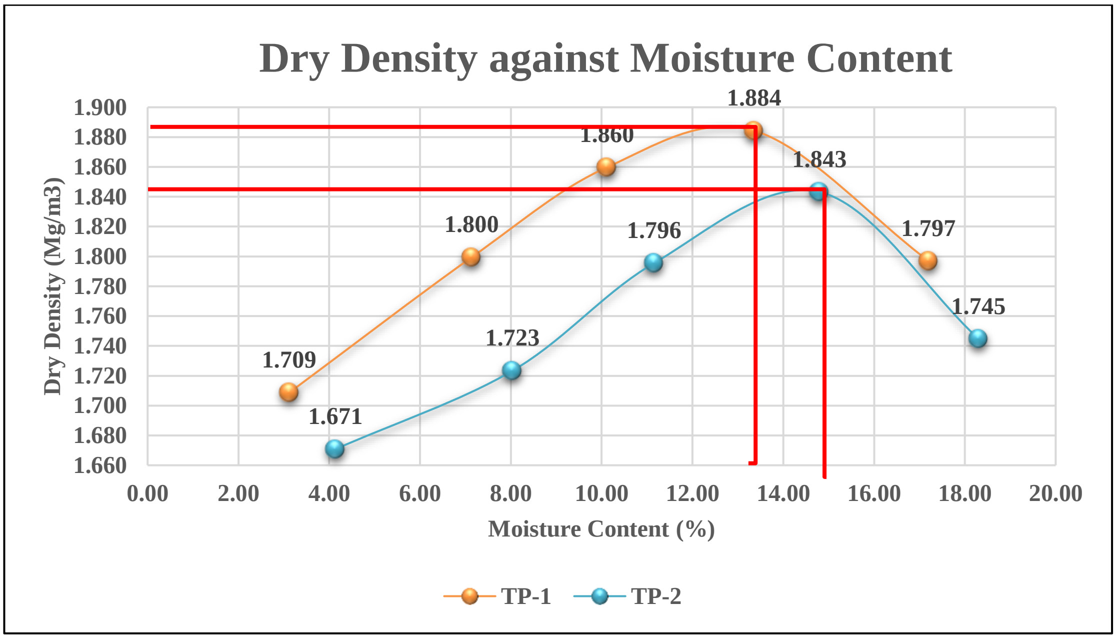


Figure 4.6 Graph of Soil Compaction test for TP-1 & TP-2

Based on the graph above, the optimum moisture contains in the soil collected from TP-1 is 13.3% while from TP-2 is 14.8%. Dry density of the sample from TP-1 and from TP-2 are 1.884 Mg/m3 and 1.843 Mg/M3 respectively. From the graph, the dry density increased gradually with the increased in moisture content. Dry density starts dropped declined after met the maximum dry density of the samples and optimum moisture been carried out.

4.3.4 Unconsolidated Undrained Triaxial Test (UU)

The bulk samples about 38 mm diameter x 76 mm in height was prepared. This test ability to control specimen drainage and without measurements of pore water pressures to give the shear strength properties of slope.

Table 4.4 Result of UU test

Failure Strain	%	**8.55**
Maximum Deviator Stesss	kN/m^2	**72**
Sample at Failure Sketch		
Mode of Failure	**INTERMEDIATE**	

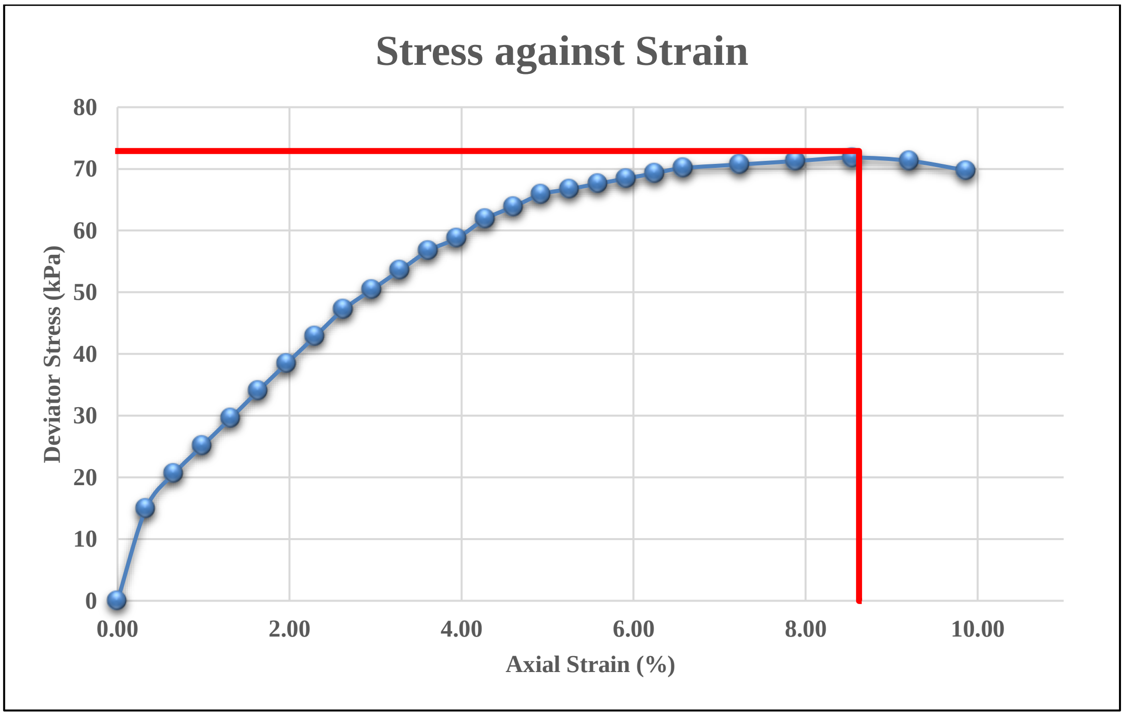


Figure 4.7 Graph Plotted using Data UU Test

Based on the graph, the axial strain (%) increased with increased in deviator stress (kPa). After the maximum deviator stress achieved, the stress start decreased, this is because the failure condition is occurred. The maximum deviator stress from the sample is 71.825% and the failure strain is 8.55%.

4.3.5 Consolidated Drained Triaxial Test (CD)

In this test, 3 specimens from trial pits sample was used to determine the shear parameters of the soil which these parameters had to insert into geo-slope (slope/w). These parameters used to analyse the stability of the slope by using geo-slope. Consolidation stage and shearing stage at failure for the testing of specimens was summarised and recorded in the table below.

Table 4.5 Summary of CD's Result for TP-1

SHEAR STRENGTH PARAMETERS	Cohesion, cu	Angle Resistance
	C' = 9 kPa	**ϕ' = 32°**

Table 4.6 Summary of CD's Result for TP-2

SHEAR STRENGTH PARAMETERS	Cohesion, cu	Angle Resistance
	C' = 8 kPa	**ϕ' = 35°**

From the table above, the shear strength parameters had defined. Parameters for TP-1 are cohesion, C' = 9 kPa and angle resistance, ϕ' = 32˚ while for TP-2, cohesion, C' = 8 kPa and angle resistance, ϕ' = 35˚. Cohesion for TP-1 is higher than TP-2 but angle resistance for TP-1 is lower than TP-2.

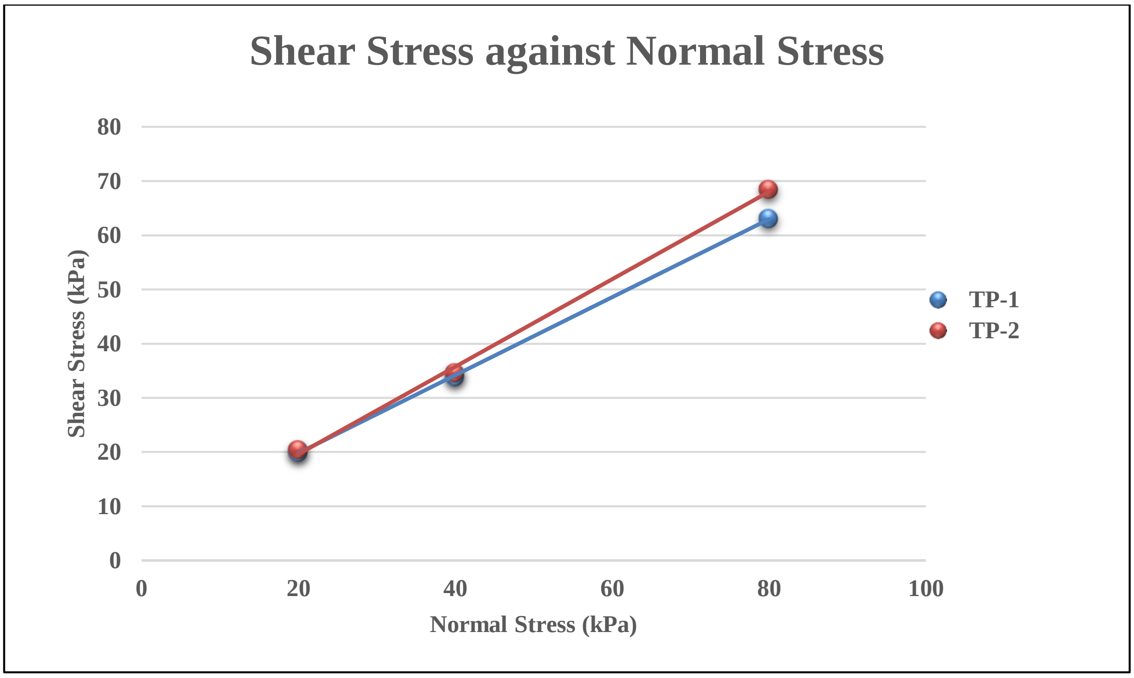


Figure 4.8 Graph of Shear Stress against Normal Stress for TP-1 & TP-2

From the graph above, shear stress of TP-2 is higher than TP-1 during the normal stress is 80 kPa.

4.4.2 Unified Soil Classification System (USCS)

The soil is classified by using unified soil classification system (USCS). USCS is used to describe the texture and grain size of soil from BH-1, BH-2 and BH-3. The classification of gravel, sand, silt and clay by using the percentage of sieve analysis of each data had illustrated the major element contain of soil in each sample for further soil description.

Table 4.7 Unified Soil Classification System (USCS) For BH-1

BH NO.	SAMPLE NO.	DEPTH (m)	SOIL DESCRIPTION
BH1	D2	1.00	Very Clayey/Silty SAND
	D3	2.00	Very silty SAND
	D4	3.00	Very Clayey/Silty SAND
	D5	4.00	Very Clayey/Silty SAND
	D6	5.00	Very silty SAND
	D7	6.00	Slightly silty SAND (weathered GRANITE)
	C2	8.70	Moderately weathered GRANITE
	C2	10.20	Ver strong fresh GRANITE

Table 4.8 Unified Soil Classification System (USCS) For BH-2

BH NO.	SAMPLE NO.	DEPTH (m)	SOIL DESCRIPTION
BH2	D2	1.00	Very Clayey/Silty SAND
	D3	2.00	Sandy SILT
	D4	3.00	Slightly sandy SILT
	D5	5.00	Slightly sandy CLAY (weathered GRANITE)
	D6	6.00	Slightly sandy SILT (weathered GRANITE)
	D7	7.50	Silty SAND (weathered GRANITE)
	D8	9.00	Very silty SAND (weathered GRANITE)
	D9	10.50	Silty SAND (weathered GRANITE)
	D10	12.00	Vey Silty SAND (weathered GANITE)
	D11	13.50	Very silty SAND (weathered GRANITE)
	D12	15.00	Very silty SAND (weathered GRANITE)
	C3	15.60	Slightly weathered GRANITE
	C4	17.10	Slightly weathered GRANITE

Table 4.9 Unified Soil Classification System (USCS) For BH-3

BH NO.	SAMPLE NO.	DEPTH (m)	SOIL DESCRIPTION
BH3	D2	1.00	Very Silty SAND
	D4	3.00	Very Silty SAND
	MZ1	4.00	Slightly sandy SILT
	D5	5.00	Clayey/Silty SAND
	D6	6.00	Sandy SILT (weathered GRANITE)
	D7	7.50	Sandy SILT (weathered GRANITE)
	D8	9.00	Sandy CLAY
	D9	10.50	Sandy SILT (weathered GRANITE)
	D10	12.00	Sandy SILT (weathered GRANITE)
	D11	13.50	Sandy SILT (weathered GRANITE)
	D12	15.00	Sandy SILT (weathered GRANITE)
	D13	16.50	Sandy SILT (weathered GRANITE)
	D14	18.00	Clayey/Silty SAND (weathered GRANITE)
	D15	19.50	Clayey/Silty SAND (weathered GRANITE)

4.4 Rainfall Pattern Analyses

The total rainfall received from 3rd August 2017 until 15th August 2017 at Kuantan area is given by Meteorological Department Kuantan. The changes volume of the rainfall depends on the type of climate, the higher the changes volume of rainfall in time. The average precipitation in Kuantan for August is 180 mm, so average precipitation for daily in August is 6 mm.

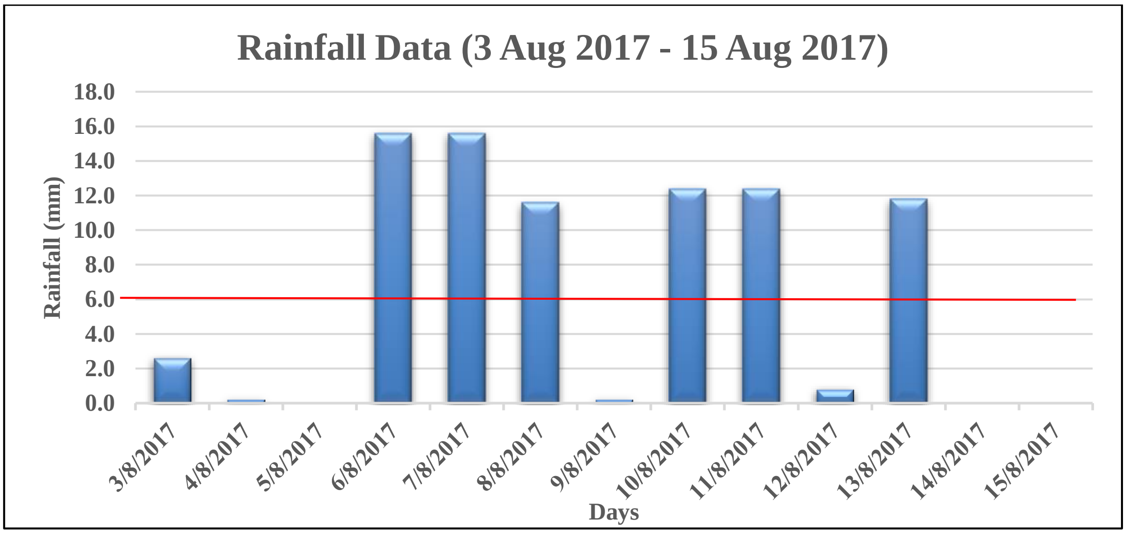


Figure 4.9 Graph for Rainfall from 3/8/2017 to 15/8/2017

4.5 Relationship Between Rainfall and Suction

Rainfall intensity display roles on the potential failure of slope because the water content and shear stress developed along the surface. Slope had divide into three parts, which are top, middle and toe of slope. Three tensiometers were inserted into three different depth (0.3 m, 0.45 m and 0.9m) at each part of slope. The tensiometer was the apparatus which record suction of soil. The reading of suction had taken daily and recorded in the tables below. Normally, when the rainfall or number of precipitation increased, the suction value decreased due to the water contain increased at soil.

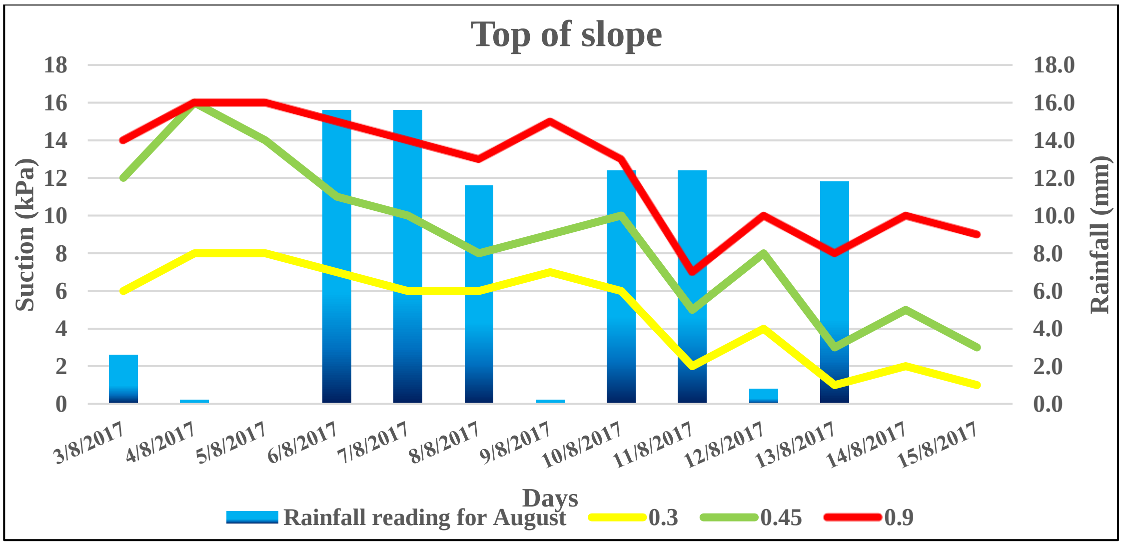


Figure 4.10 Graph of suction & Rainfall against Days on Top of Slope

The graph above shown the rainfall and suction of soil which located on top of slope. Based on the graph above, the value of suction at 0.9 m is higher than 0.45 m and 0.3 m. The high value of suction shows the soil is in dry condition. On 4th August, the suction reading at 0.45 m depth is same as suction reading at 0.9 m. This is because the on that day the precipitation of rainfall decreased, the soil at 0.45 m become dry. Normally the rainwater is flow from surface into the soil, the seepage and groundwater may give effect the water content of soil in different depth. On 6th August and 7th August having the same volume of rainfall. With two days of rainfall event, the suction for these three depths had reduced due to more rainwater had absorb by soil. The precipitations reduce on 8th August and sharply decreased to 0.2 mm on 9th August shows the suction slightly rose. There is a clear image which show the rainfall is inversely proportional to suction. From 10th August until 11th August, the rainfall remains at 12.4 mm and on 12th August the rainfall sharply decreased to 0.8 and the suction for three depths had happened dramatically fell and rose in these three days.

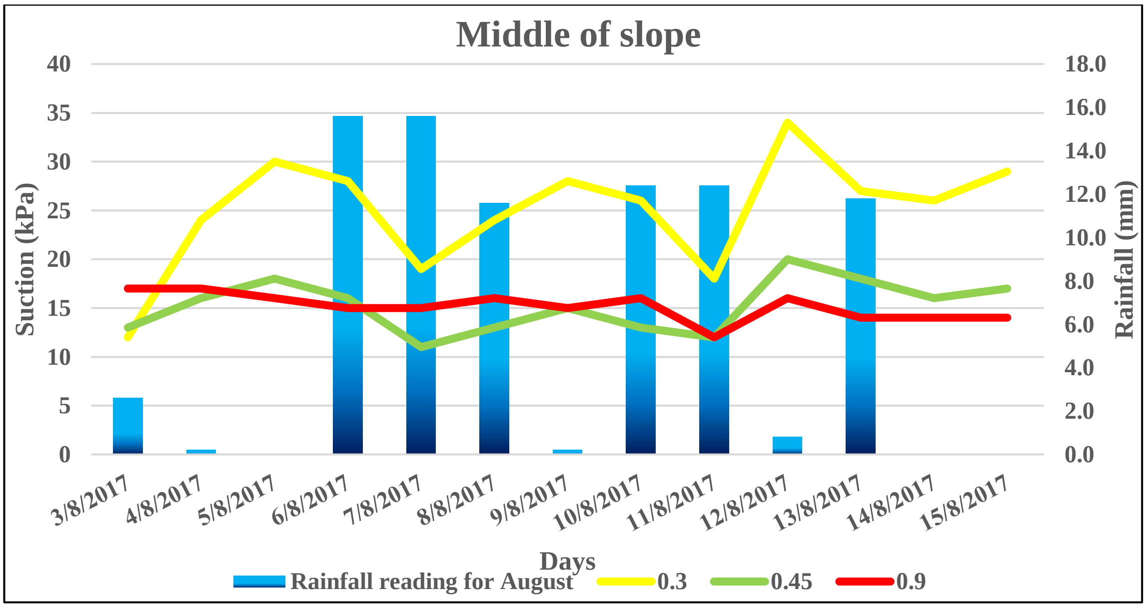


Figure 4.11 Graph of suction & Rainfall against Days on Middle of Slope

The tensiometers are placed at middle of slope where there is slope steepness. The slope angle influences the water infiltration with difference in soil profile and its permeability ratio. Based on the graph above, the suction at 0.3 m shows dramatical line graph because of the depth of rainwater seep is shorter than 0.45 m and 0.9 m. Suction of soil at 0.9 m from surface of ground does not have critical changes with different volume of rainwater. This shows the deepness of slope, more difficult the rainwater infiltration and effect the suction. Although the rainwater difficult to infiltrate and effect the suction but from the graph had shown the suction of soil is inversely proportional to rainfall day by day. From 3rd August to 5th August, the rainfall event had reduced and the suction of soil at 0.3 m and 0.45 m increased but the suction of soil at 0.9 m remain and slightly decreased. After few days with high rainfall event, there is some changes of suction at 0.9 m which shown from 10th August to 13th August. The suction at 0.9 m slightly decreased and increased because of the steeply grew and declined of rainfall.

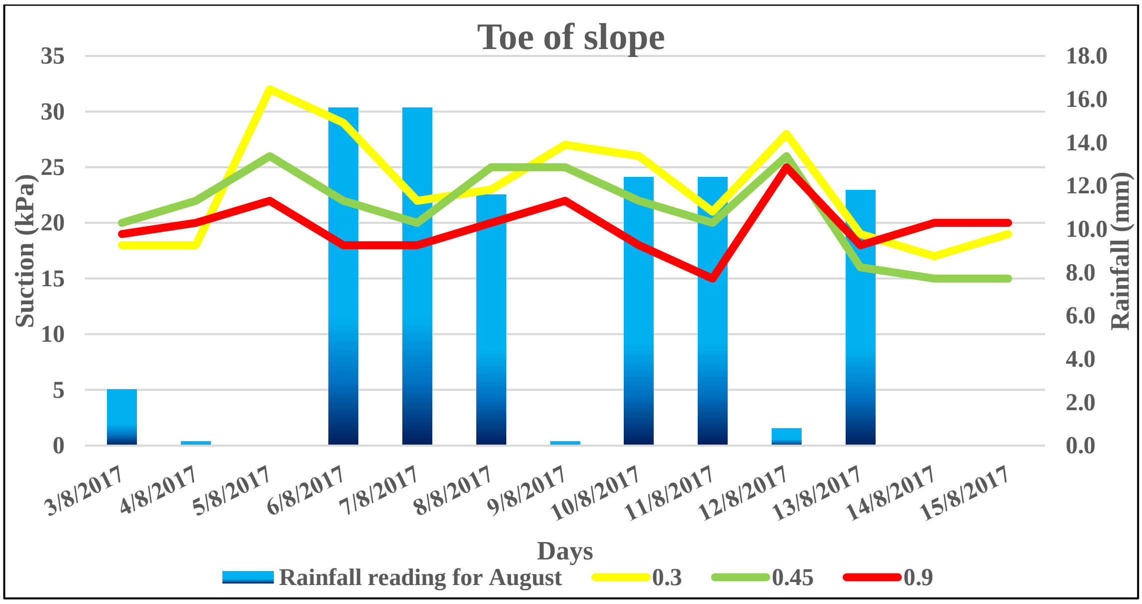


Figure 4.12 Graph of suction & Rainfall against Days on Toe of Slope

Usually the water flow from height to low and at toe of slope the stability was affected by seepage and soil liquefaction. Soil liquefaction in base layer removes the support to inclined slope layer had caused the toe of slope instability. So that, the suction at 0.9 m had critical changes compared to suction at 0.45 m and 0.3 m. Suction of soil at 0.3 m had increased 14 kPa due to the decreased of rainfall. The suddenly rose of the suction may cause by depth and the temperature on 5th August. On 8th August, suction of soil at 0.3 m, 0.45 m and 0.9 m had increased 1 kPa, 5 kPa and 2 kPa respectively with 4 mm declined of rainfall. When there is a sharply dropped of rainfall on 9th August, suction at 0.3 m and 0.9 m increased but suction of soil at 0.45 m remain. From the graph, the increased in the volume of rainfall, the decreased in the suction of soil.

4.6 Slope Stability Analysis

For slope stability analysis, two methods been used to analyse the factor of safety (FOS) of slope, one is using Geo-Slope software (Slope/w), and another is analysis of calculation using spreadsheet or excel. The targeted Factor of Safety (FOS) is 1.3 for slope. Geo-mechanical parameters which from laboratory test and field were substituted into Geo-Slope software and the calculation. The parameters are the effective cohesion, effective angle of shearing resistance, and unit weight. The effective cohesion and effective angle result were from Mohr Coulomb soil model. Besides that, soil profile also needed inserted into software and the soil layering is based on SPT test with the value of N in three boreholes.

Geo-Slope software is used to analyse stability of the three parts of slope which are top, middle, and toe of slope. Factor of Safety is using Ordinary theory coupled with Entry-Exit slip circle locating method. While for analyse factor of safety using calculation on spreadsheet, Ordinary or Fellenius' method is used. This method is calculated by using formula in slices. The effective cohesion and effective angle also substituted in the formula.

4.6.1 Geo-mechanical Parameters

Table 4.10 Soil Properties for Slope Design

PARAMETERS ADOPTED IN SLOPE STABILITY ANALYSIS					
REGION	**SLOPE DESCRIPTION**	**UNIT WEIGHT (kN/m3)**	**COHESION, C' (kPa)**	**FRICTION ANGLE, ϕ (°)**
1	Sandy CLAY	19.4	9	32
2	Sandy SILT	22.2	9	34
3	Silty SAND	19.9	8	35
4	GRANITE (Bedrock)	-		

4.6.2 Slope Stability with FOS By Using Geo-Slope Software (Slope/w)

Table 4.11 Slope Design Description for Toe of Slope

SLOPE DESIGN DESCRIPTION	UNIT	REMARKS
Geotechnical Analysis Method		Ordinary
Slip Surfaces Technique		Entry-Exit
Slip Surfaces Direction Movement		Left - Right
Structural Surcharged Load	kN/m3	373.36
Piezometric Level - BH1	M	93
Piezometric Level - BH2	M	93
Piezometric Level - BH3	M	76
Number of Slices		19
Minimum Slip Surface Depth	M	0.1

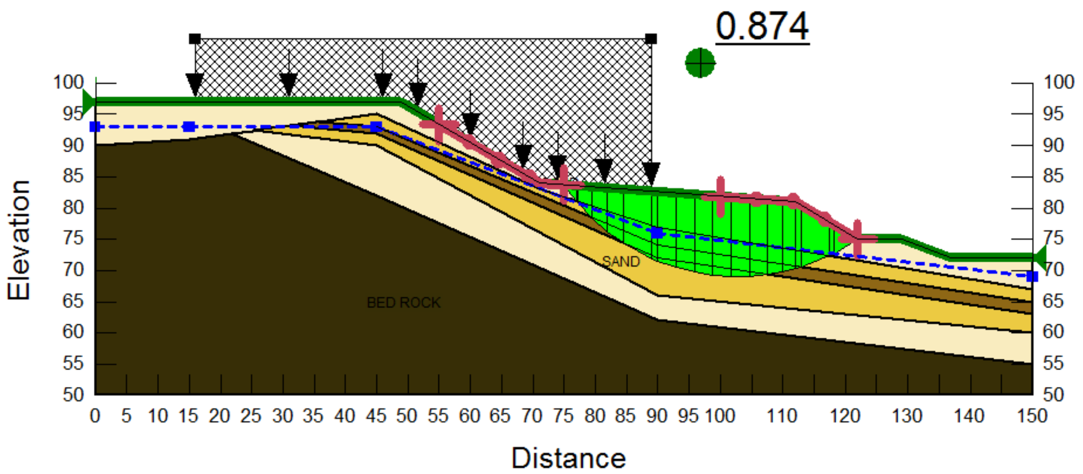


Figure 4.13 Analysis Result of Critical FOS with Building Surcharged Load on Toe of Slope

4.6.3 Slope Stability Analysis with FOS by Using Fellenius' Method in Spreadsheet

Table 4.12 Slope Stability Analysis for Toe of Slope

Slice No	***Wsin*α (kN) (4)**	***c'l* (kN) (1)**	***Wcos*αtanϕ' (kN) (2)**	ψltanfb ***(kN) (3)***
1	-38.190	25.971	20.225	0.000
2	-9.391	3.313	5.348	0.000
3	-127.524	29.344	80.944	0.000
4	-201.787	30.054	144.392	0.000
5	-231.505	27.861	201.628	0.000
6	-427.076	46.552	527.803	0.000
7	-87.950	9.799	137.753	0.000
8	-232.751	28.067	437.933	0.000
9	-183.359	27.289	478.501	0.000
10	-123.495	26.779	504.043	0.000
11	-58.019	26.497	514.378	0.000
12	8.551	26.422	509.532	0.000
13	71.860	26.550	489.674	0.000
14	100.370	21.824	347.772	0.000
15	109.237	18.554	273.019	0.000
16	55.385	8.626	116.062	0.000
17	264.061	44.956	448.280	0.000
18	26.974	5.492	37.881	0.000
19	89.945	35.655	105.333	0.000
Total	***2447.430***	***469.606***	***5380.502***	***0.000***

FOS = (1+2+3)/4 = (469.606 + 5380.502 + 0)/2447.43

= 2.3

4.6.4 Comparison Value of Factor of Safety from Slope/w and Excel

Table 4.13 Comparison value of factor of safety

Slope	Factor of Safety		Percentage Different (%)
	Slope/w	Excel	
Top	2.04	2.4	15
Middle	1.963	2.65	25.92
Toe	0.874	2.3	49.62

From the analysis by using Slope/w software, on top of slope, the factor of safety is higher than factor of safety at middle and toe of slope. Factor of safety at toe of slope is less than 1.3, so the slope is failure. This may happen because seepage forces in the sloping direction add with gravity forces and make the slope susceptible to instability. The factor of safety at middle of slope given by slope/w is 1.963. Since at the middle of slope had constructed a building the factor of safety may higher than targeted factor of safety because before construct the building, cut and fill work and compaction of soil had been done. Factor of safety had affect by the surcharge load from building or structure.

The value of factor of safety is 2.4 for simulation in spreadsheet or excel program by using Ordinary method which located at top of slope. In excel, factor of safety at middle of slope is higher than top and toe of slope due to the surcharge load. Since the building located at there, the stability should higher but the soil at middle of slope may affect by the instability of soil at toe of slope. Furthermore, the building had cracked and the road at toe of slope collapsed. The suction value had assumed as 0 to define the factor of safety where no suction of soil.

By using software and excel, the factor of safety for each part should having a different in the range of 0.2. But from the table above shows there is a big different between these two methods. The result may affect by layer of the soil. The different layer of soil had substituted into software to analyse the factor of safety. So, the analyse is contained different type of soil but for Fellenius' method, it is using slices method to analyse the factor of safety. Every slice may contain different type of soil but in table every slice just can be consider it just had one type of soil and every slice had different type of soil. With the different type of soil, the shear strength parameters were different. Therefore, it had affected the factor of safety and the different of it in slope/w and excel.

4.7 Relationship Between Factor of Safety, Suction and Rainfall

Factor of safety is directly proportional to suction of soil. For top of slope, the tensiometer had insert at the area near slices no. 4. So, the factor of safety of slices no. 4 in spreadsheet was derived with the suction of soil tested using the tensiometer. While for middle and toe of slope, the tensiometer was placed at area near slices no.2 and no.11 respectively which shown in Geo-Slope software. A graph of FOS calculated with suction of soil in specific slices against suction had plotted to show the relationship between it.

4.7.1 Relationship Between Factor of Safety, Suction and Rainfall at Top of Slope

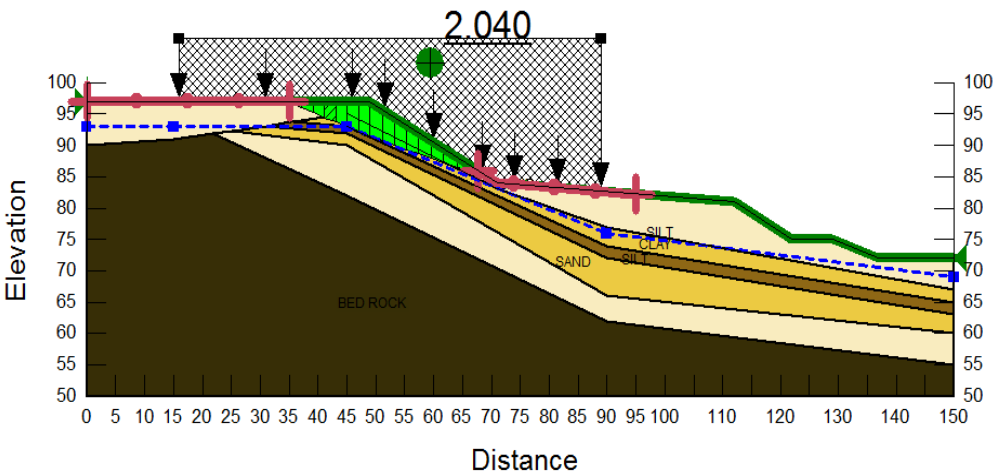


Figure 4.14 Location of Tensiometer placed on top of Slope (Slice no. 4)

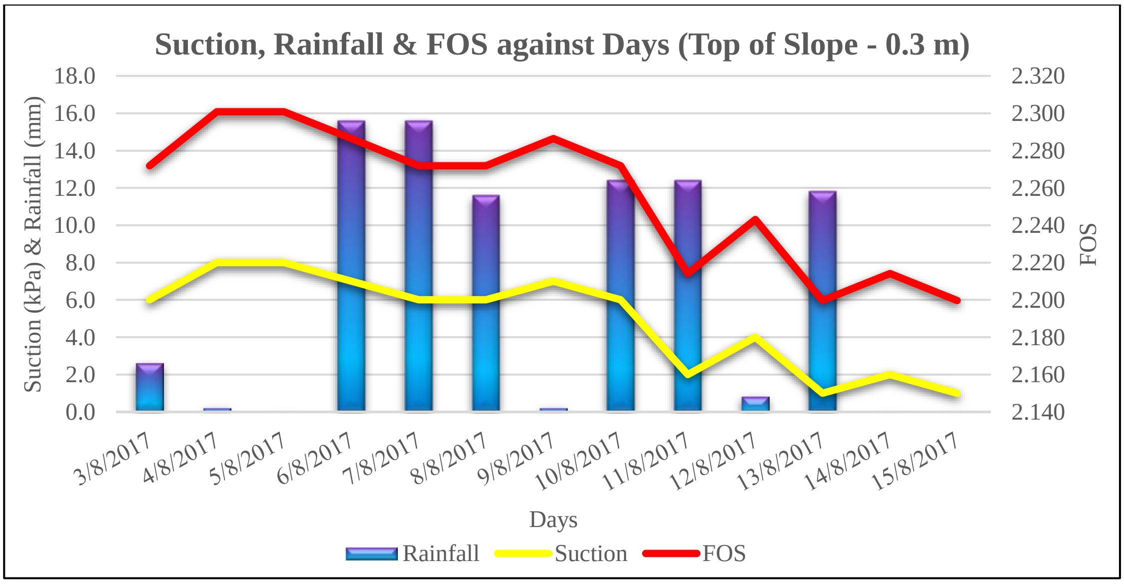


Figure 4.15 Suction, Rainfall and FOS against Days on Top of Slope for 0.3 m

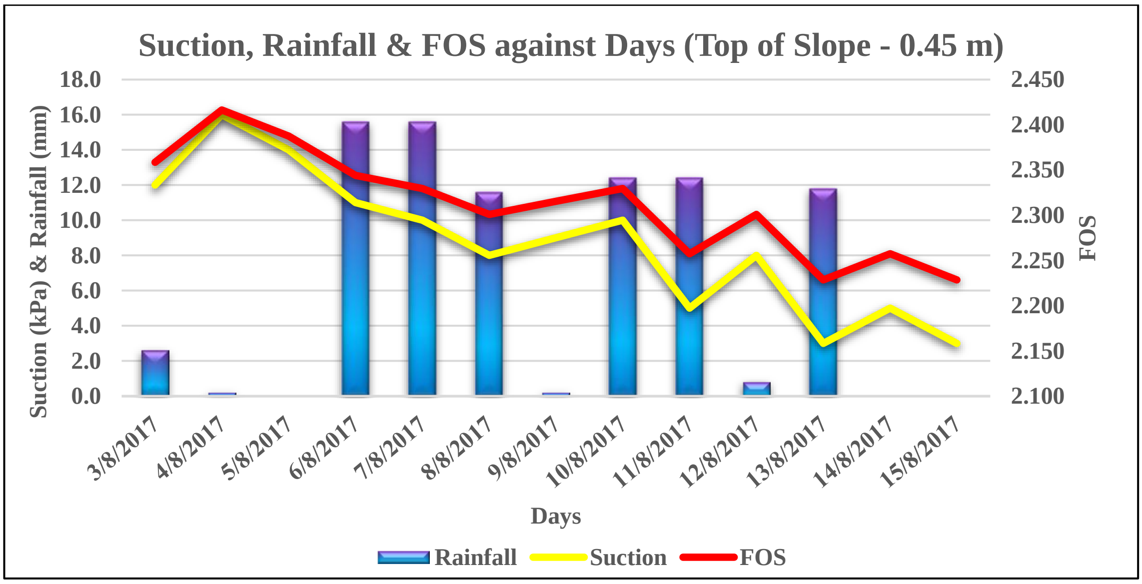


Figure 4.16 Suction, Rainfall and FOS against Days on Top of Slope for 0.45 m

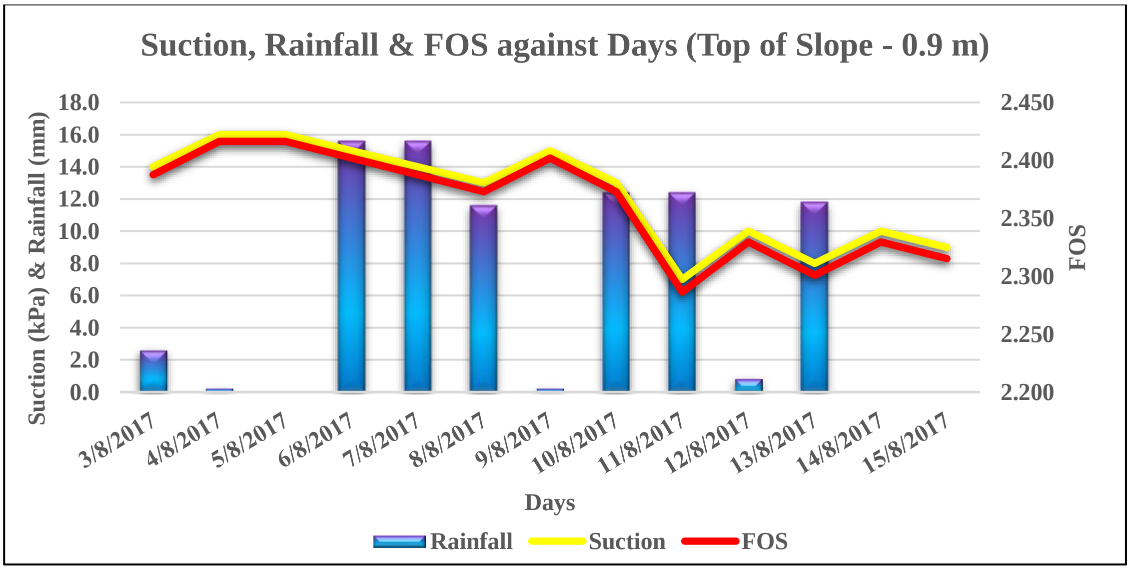


Figure 4.17 Suction, Rainfall and FOS against Days on Top of Slope for 0.9 m

Three graphs shown above were the relationship between suction, rainfall and factor of safety (FOS) on top of slope with different depth of tensiometer testing. Based on the graphs above, suction and rainfall were having same trend, and both are inversely proportional to the FOS. At 0.3 m and 0.9 m depth from ground, the trend line for suction is same with rainfall but in different values. While at 0.45 m, on 4th August, the trend of suction and rainfall are met at same point when there is 0.2 mm of rainfall. In short, volume of rainfall increased, FOS and suction of soil decreased.

4.7.2 Relationship Between Factor of Safety, Suction and Rainfall at Middle of Slope

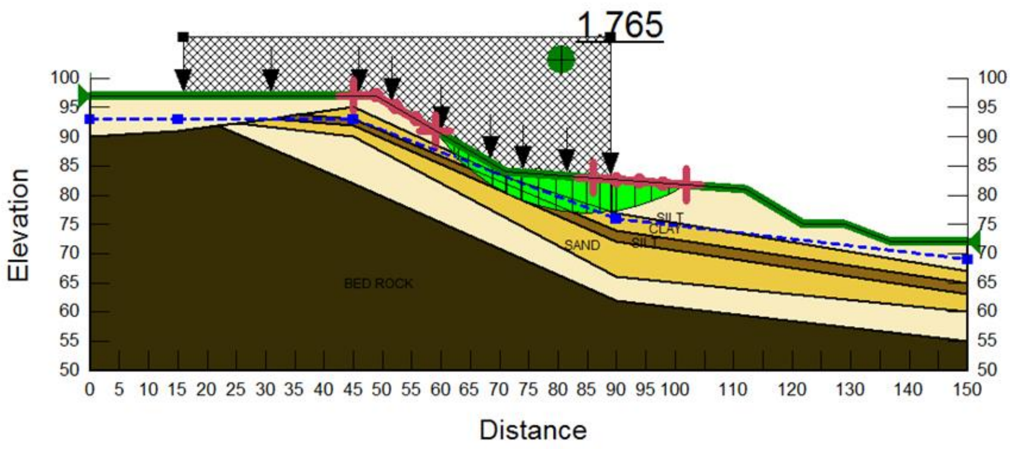


Figure 4.18 Location of Tensiometer Placed near Slice no. 2 at Middle of Slope

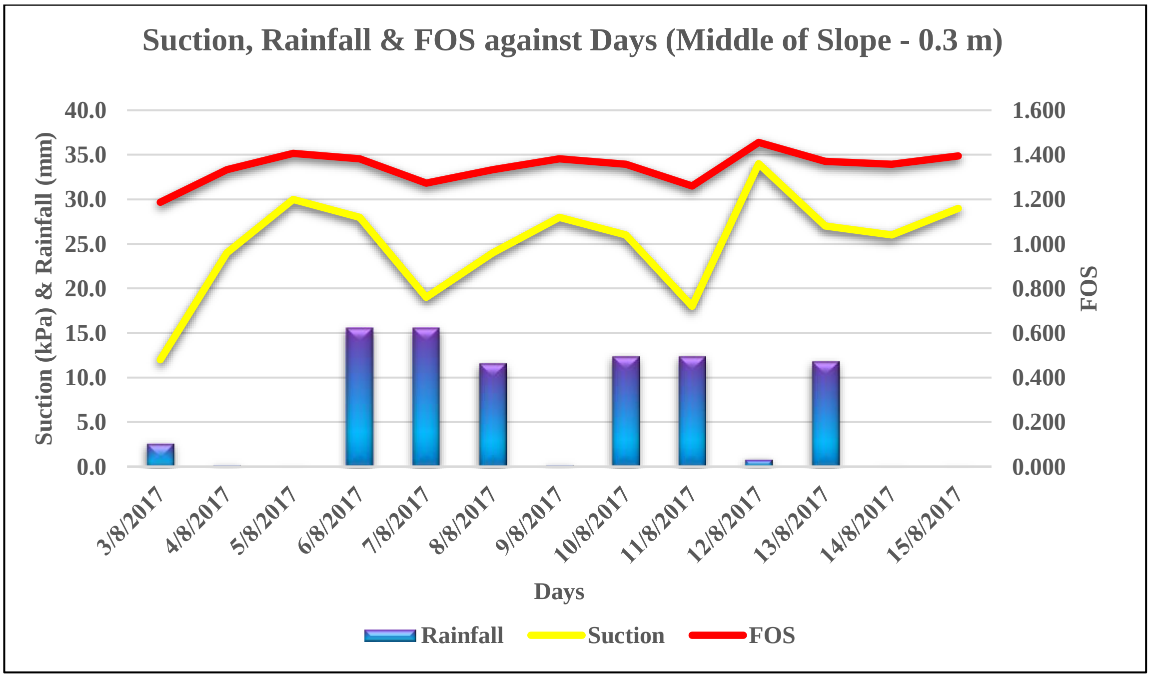


Figure 4.19 Suction, Rainfall and FOS against Days on Middle of Slope for 0.3 m

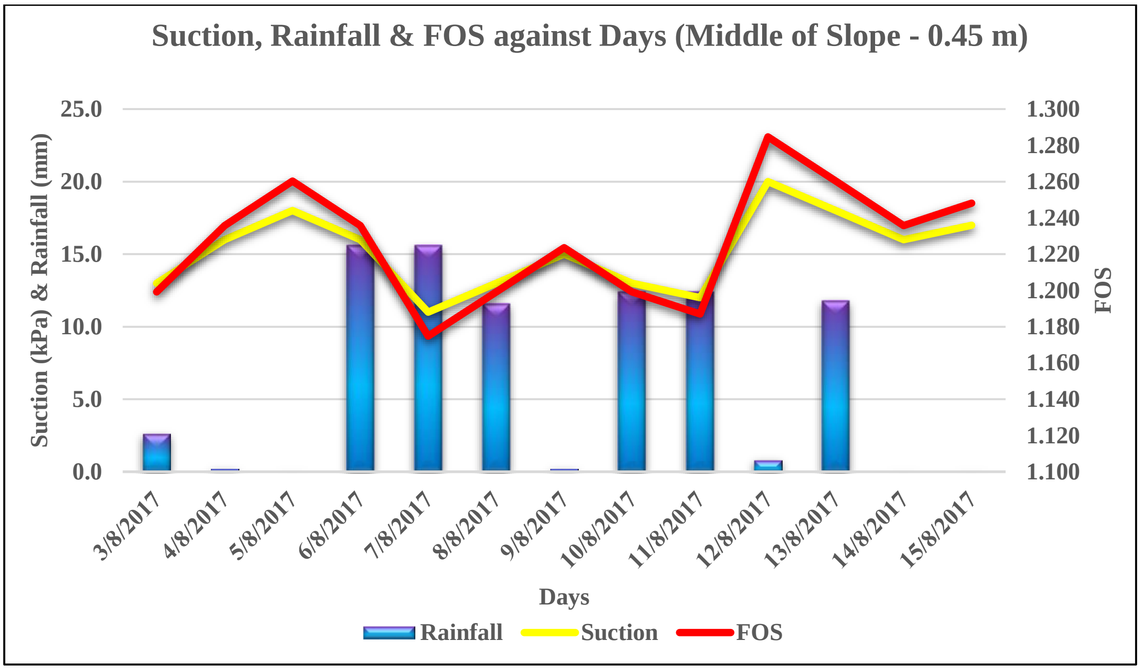


Figure 4.20 Suction, Rainfall and FOS against Days on Middle of Slope for 0.45 m

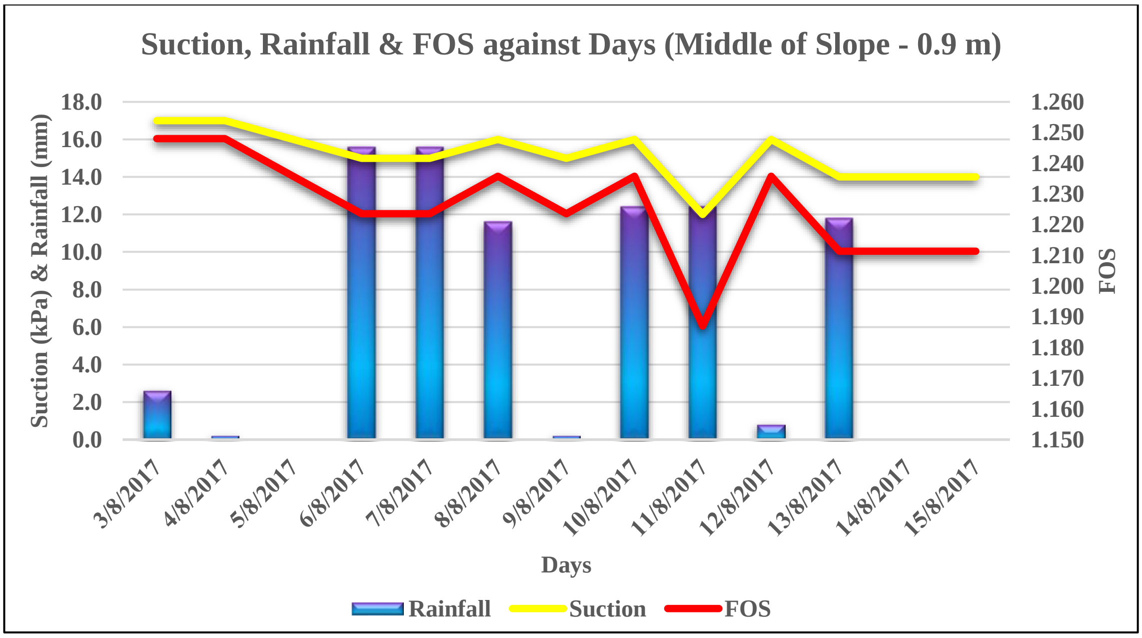


Figure 4.21 Suction, Rainfall and FOS against Days on Middle of Slope for 0.9 m

The relationship between suction, rainfall and factor of safety (FOS) were shown in graphs above with different depth at middle of slope. At 0.3 m from ground, the changes of suction were dramatically compare with FOS. Although the trends are different, but both were affected by rainfall. At 0.45 m of the middle of slope, the increase of 3 kPa of suction had increased the FOS from 1.199 to 1.236 on 4th August. For the trend line of suction is almost same with trend line of rainfall and both are affected by rainfall at 0.9 m. On 12th August, the reading of tensiometer which placed at 0.9 m from ground had increased and FOS also sharply rose when the volume of rainfall declined rapidly. The rainfall is directly affect the suction of soil and further affected on FOS at middle of slope.

4.7.3 Relationship Between Factor of Safety, Suction and Rainfall at Toe of Slope

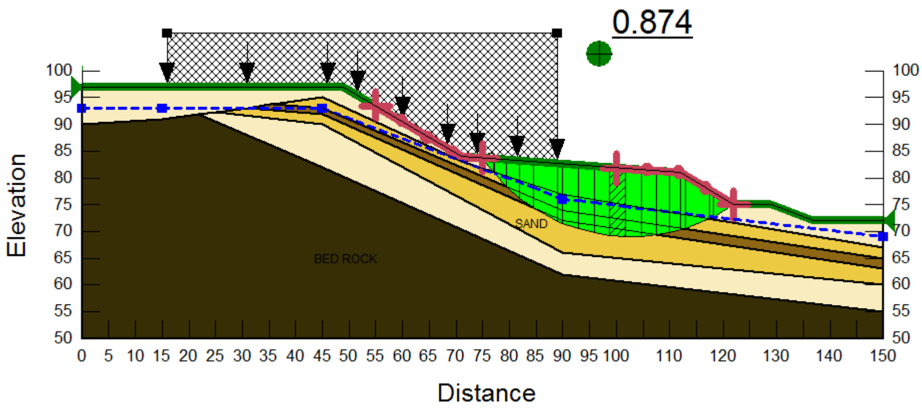


Figure 4.22 Location of Tensiometer Placed at Toe of Slope

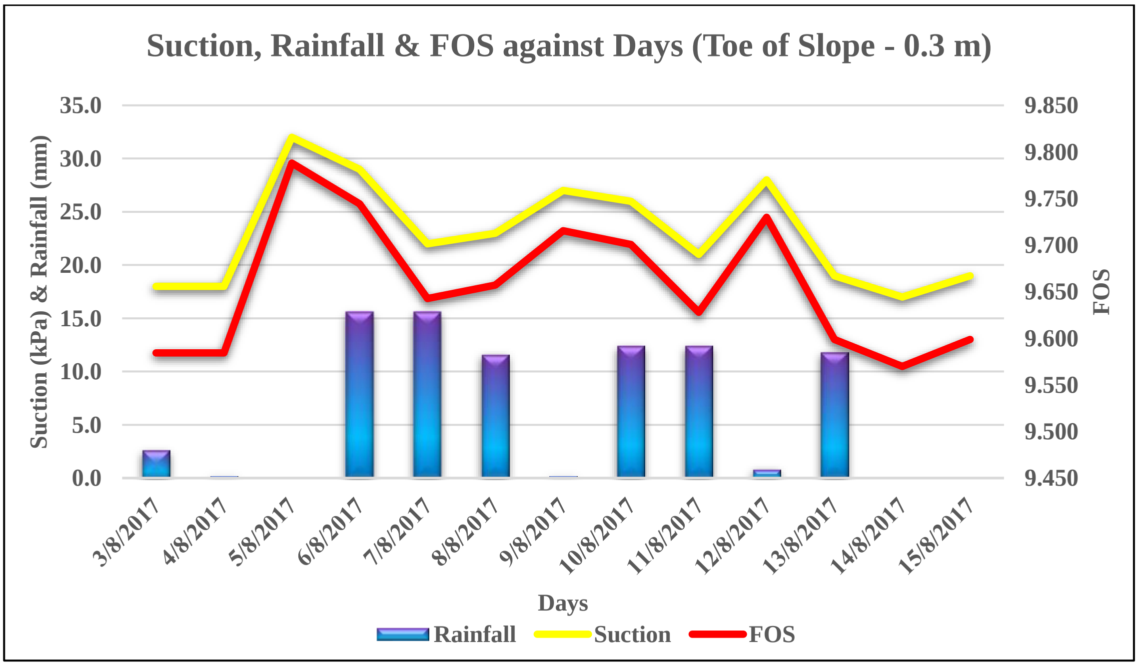


Figure 4.23 Suction, Rainfall and FOS against Days on Toe of Slope for 0.3 m

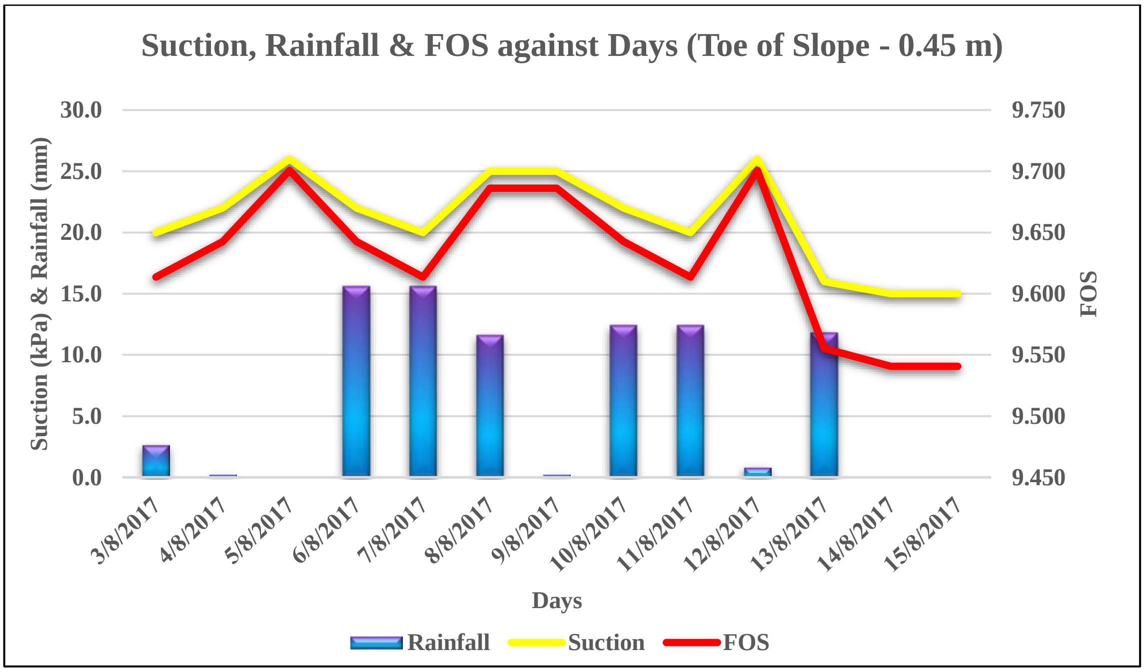


Figure 4.24 Suction, Rainfall and FOS against Days on Toe of Slope for 0.45

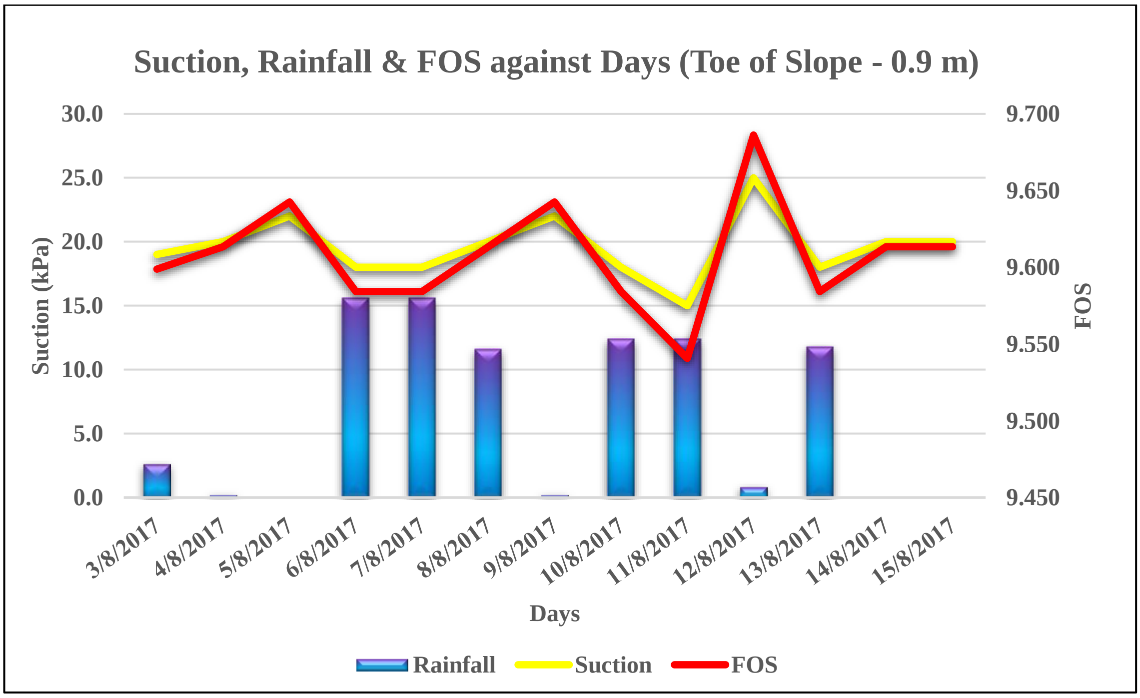


Figure 4.25 Suction, Rainfall and FOS against Days on Toe of Slope for 0.9 m

Based on graphs above, the trend line for suction and FOS at 0.3 m from ground of toe of slope is critical compared to 0.45 m and 0.9 m. On 4th August and 5th August, the volume of rainfall had dropped from 0.2 mm to 0.0 mm. On same day, the suction of soil and FOS at 0.3 m depth had rose rapidly but suction and FOS at 0.45 m and 0.9 m just inclined slightly. Furthermore, the rainfall event remains constant at 0.0 mm from 14th August to 15th August. The suction of soil with FOS at 0.45 m and 0.9 m also remains constant but at 0.3 m suction and FOS had increased gradually.

Different depth of soil had different suction and FOS due to infiltrate of rainwater with different type of soil and groundwater. In conclusion, the rainfall had influenced the changes of suction and FOS. The suction of soil and FOS are interrelated affect each other.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusions

In the previous chapter, the research has described about the relationship between suction, rainfall and factor of safety. The slope stability analysis be done using two different methods where using Geo-slope software (Slope/w) and Fellenius' method with formula in excel. The slope stability analysis for the slope was according two main objectives. From this study, it can be concluded that all the objectives which stated in first chapter had achieved. The conclusion was outline as below with the objectives:

The tensiometer was placed at three different location of the slope, which are top, middle and toe of slope. Tensiometers were insert in each location with different length of it to identify the suction of soil at 0.3 m, 0.45 m and 0.9 m depth from the ground. The site investigation and laboratory test, the engineering properties and soil profile had interpreted. Suction of soil was affected by rainfall. The result and analysis in fourth chapter, rainfall intensity increased, the suction decreased. In the analysis with different depth, the suction at middle of slope with 0.3 m depth had critical trend compared with others.

Factor of safety is interrelated with rainfall and suction of soil. Suction of soil increased and affect to increase in factor of safety. Slope stability analysis was study using software and method of slices (Fellenius' method). The factor of safety at specific slice is analysed using the suction which affected by rainfall. The changes of rainfall intensity caused the factor of safety to reduce, the lower factor of safety had caused the instability of slope. The analysis on the middle of slope, the factor of safety of the specific slice was below 1.4 for 0.3 m depth and below 1.3 for 0.45 m and 0.9 m. At 0.45 m of the middle of slope, the lowest factor of safety was 1.175 when there was two days higher rainfall event. The targeted factor of safety is 1.3 so the slope is unstable.

The relationship between the rainfall intensity and suction of soil is interpret and these two elements was interrelated to factor of safety or stability of slope. The stability of slope had defined using Geo-slope software (Slope/w) and Fellenius' method in excel.

5.2 Recommendations

Based on the study being conducted with the purpose of dissertation, the slope stability was very important to be carried out to understand the cause of the failure of slope and structure. This also help in plan and proposed some slope remedial work. From analysis, we can summarize safety of slope is low which is induced by rainfall. I proposed that the slope need to be reconstruct and redesign. Cut and fill and proper compaction was suggested to be used. Suitable slope protected method was proposed to increase the factor of safety for the slope especially during high rainfall intensity.

Following the study herein, the further research could be done on the slope stability analysis with rainfall and suction by using different method of analysis. Characteristic of each layer of soil had affected the result of factor of safety during substitute into formula. So, the study can become more challenging with different situation of underground or soil. Further researched is a must to discover the suitable method to analyse the factor of safety with different layer of soil, so that the slope failure problem can reduce.

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APPENDIX A
PARTICLE SIZE DISTRIBUTION ANALYSIS FOR BOREHOLE 1, 2 AND 3

PARTICLE SIZE - SIEVE ANALYSIS TEST (% PASSING)						
Borehole No.	BH-1					
Depth (m)	1.00	2.00	3.00	4.00	5.00	6.00
Sample No.	D2	D3	D4	D5	D6	D7
3.350	100	100	100	100	100	100
2.000	75	72	69	69	72	77
1.180	62	55	52	54	58	46
0.600	51	44	40	43	47	23
0.425	44	37	33	36	40	12
0.300	40	34	29	33	36	10
0.212	34	30	24	28	30	6
0.150	31	28	22	25	28	5
0.063	30	27	20	23	26	5

PARTICLE SIZE - SIEVE ANALYSIS TEST (% PASSING)											
Borehole No.	BH-2										
Depth (m)	1.00	2.00	3.00	5.00	6.00	7.50	9.00	10.50	12.00	13.50	15.00
Sample No.	D2	D3	D4	D5	D6	D7	D8	D9	D10	D11	D12
3.350	100	100	100	100	100		100	100	100	100	100
2.000	73	79	83	84	80	100	78	73	85	79	78
1.180	57	65	69	74	69	64	64	53	73	64	65
0.600	49	55	64	68	63	50	54	39	65	50	55
0.425	43	49	60	64	57	41	47	31	50	40	48
0.300	40	45	58	62	54	37	44	27	41	36	45
0.212	36	40	55	58	49	29	37	22	32	27	37
0.150	34	38	54	56	47	26	35	19	31	24	35
0.063	33	36	53	55	45	23	32	17	29	22	32

PARTICLE SIZE - SIEVE ANALYSIS TEST (% PASSING)													
Borehole No.	BH-3												
Depth (m)	1.00	3.00	5.00	6.00	7.50	9.00	10.50	12.00	13.50	15.00	16.50	18.00	19.50
Sample No.	D2	D4	D5	D6	D7	D8	D9	D10	D11	D12	D13	D14	D15
3.350	100	100	100	100				100	100		100	100	
2.000	78	75	72	79	100	100	100	80	81	100	72	79	
1.180	55	33	55	67	78	65	74	63	67	67	60	55	100
0.600	40	14	41	57	71	58	67	52	59	58	53	36	45
0.425	31	8	31	51	67	54	62	44	54	53	48	28	20
0.300	29	7	26	48	64	52	59	41	51	48	46	23	15
0.212	25	6	18	43	61	49	56	35	47	44	42	17	10
0.150	24	6	15	41	60	48	54	33	45	42	40	15	9
0.063	23	6	13	39	59	48	52	30	44	41	39	13	8

APPENDIX B
ATTERBERG LIMIT TEST

Classification of Plasticity Based on Plasticity Index

Soil	PI [%]
Non-plastic	0
Slightly plastic	1 – 5
Low plasticity	5 – 10
Medium plasticity	10 – 20
High plasticity	20 – 40
Very high plasticity	40 -

Result of Atterberg Limit Test for Borehole 1, 2 and 3.

BH NO.	SAMPLE NO.	DEPTH (m)	ATTERBERG LIMITS		
			LL (%)	PL (%)	PI (%)
BH1	D2	1.00	32	24	8
	D3	2.00	30	24	6
	D4	3.00	26	22	4
	D5	4.00	29	25	4
	D6	5.00	31	26	5
	D7	6.00	Non-Plasticity		
	C2	8.70			
	C2	10.20			
BH2	D2	1.00	36	25	11
	D3	2.00	38	26	12
	D4	3.00	55	32	23
	D5	5.00	58	28	30
	D6	6.00	47	25	22
	D7	7.50	28	23	5
	D8	9.00	34	24	10
	D9	10.50	Non-Plasticity		

	D10	12.00	29	24	5
	D11	13.50	26	22	4
	D12	15.00	35	25	10
	C3	15.60	Non-Plasticity		
	C4	17.10			
BH3	D2	1.00	27		27
	D4	3.00	Non-Plasticity		
	MZ1	4.00	-		
	D5	5.00	Non-Plasticity		
	D6	6.00	38	26	12
	D7	7.50	57	32	25
	D8	9.00	50	26	24
	D9	10.50	54	33	21
	D10	12.00	35	25	10
	D11	13.50	42	29	13
	D12	15.00	40	28	12
	D13	16.50	41	29	12
	D14	18.00	Non-Plasticity		
	D15	19.50			

APPENDIX C
COMPACTION TEST

Data Sheet for Compaction Test of Soil (TP-1)

DATA SHEET FOR COMPACTION TEST OF SOIL (TP-1)					
Test Number for TP-1	**1**	**2**	**3**	**4**	**5**
Mass of Mould+Base+Compacted Specimen (m_2)	7144	7310	7430	7518	7488
Mass of Mould+Base (m_1)	5382	5382	5382	5382	5382
Mass of Compacted Specimen (m_2-m_1)	1762	1928	2048	2136	2106
Container No.	**A1**	**B1**	**C1**	**D1**	**E1**
Bulk Density (Mg/m^3)	1.762	1.928	2.048	2.136	2.106
Moisture Content (%)	3.12	7.14	10.12	13.36	17.20
Dry Density (Mg/m^3)	1.709	1.800	1.860	1.884	1.797

Data Sheet for Compaction Test of Soil (TP-2)

DATA SHEET FOR COMPACTION TEST OF SOIL (TP-2)					
Test Number for TP-2	**1**	**2**	**3**	**4**	**5**
Mass of Mould+Base+Compacted Specimen (m_2)	7122	7244	7378	7498	7446
Mass of Mould+Base (m_1)	5382	5382	5382	5382	5382
Mass of Compacted Specimen (m_2-m_1)	1740	1862	1996	2116	2064
Container No.	**A2**	**B2**	**C2**	**D2**	**E2**
Bulk Density (Mg/m^3)	1.740	1.862	1.996	2.116	2.064
Moisture Content (%)	4.14	8.04	11.16	14.80	18.30
Dry Density (Mg/m^3)	1.671	1.723	1.796	1.843	1.745

APPENDIX D

UNCONLIDATED UNDRAINED TRIAXIAL TEST

Result of UU test

Sample Height	mm	76
Sample Diameter	mm	38
Strain Rate	mm/min	1.200
Ring Factor	kN/div	0.00131
Moisture Content	%	15.50
Bulk Density	Mg/m^3	1.993
Dry Density	Mg/m^3	1.726
Failure Strain	%	**8.55**
Maximum Deviator Stesss	kN/m^2	**72**
Sample at Failure Sketch		
Mode of Failure	**INTERMEDIATE**	

Data of UU Test

DEFLECT READING (mm)	AXIAL STRAIN (%)	CORRECT. AREA (SQ.CM)	PROVING RING READING	AXIAL LOAD (KN)	DEVIATOR STRESS (KPa)
0	0.00	11.35	0	0.000	0.000
25	0.33	11.38	13	0.017	14.966
50	0.66	11.42	18	0.024	20.654
75	0.99	11.46	22	0.029	25.160
100	1.32	11.50	26	0.034	29.636
125	1.64	11.54	30	0.039	34.081
150	1.97	11.57	34	0.045	38.496
175	2.30	11.61	38	0.050	42.881
200	2.63	11.65	42	0.055	47.235
225	2.96	11.69	45	0.059	50.438
250	3.29	11.73	48	0.063	53.618
275	3.62	11.77	51	0.067	56.775
300	3.95	11.81	53	0.069	58.800
325	4.28	11.85	56	0.073	61.916
350	4.61	11.89	58	0.076	63.907
375	4.93	11.93	60	0.079	65.882
400	5.26	11.98	61	0.080	66.749
425	5.59	12.02	62	0.081	67.607
450	5.92	12.06	63	0.083	68.458
475	6.25	12.10	64	0.084	69.302
500	6.58	12.15	65	0.085	70.138
550	7.24	12.23	66	0.086	70.715
600	7.89	12.32	67	88.000	71.278
650	8.55	12.41	68	89.000	71.825
700	9.21	12.50	68	0.089	71.308
750	9.87	12.59	67	0.088	69.750
800	10.53	12.68			
850	11.18	12.77			
900	11.84	12.87			
950	12.50	12.97			
1000	13.16	13.07			
1050	13.82	13.16			
1100	14.47	13.27			

APPENDIX E
CONLIDATED DRAINED TRIAXIAL TEST

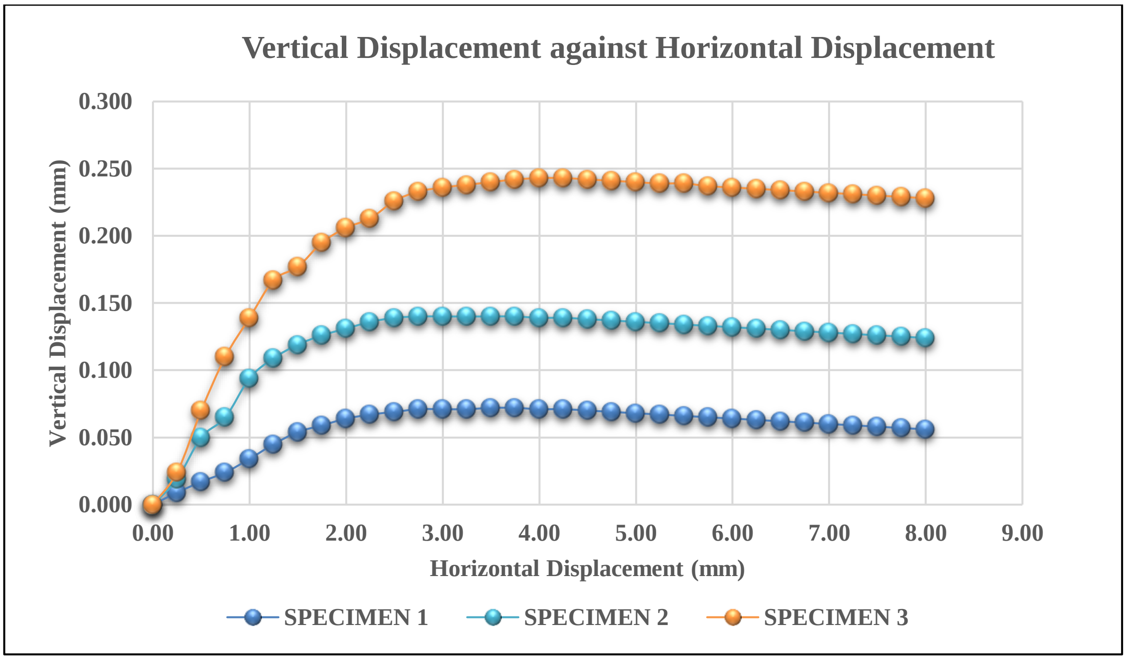
Summary of CD's Result for TP-1

Specimen		1	2	3
Normal Stress	kPa	20	40	80
CONSOLIDATION STAGE				
t100	min	1.44	1.44	1.44
Conso. Settle. (mm)	mm	0.05	0.08	0.15
SHEARING STAGE AT FAILURE				
Calculated Shearing Rate		0.27	0.27	0.27
Shearing Rate	mm/min	0.25	0.25	0.25
Shear Stress	kPa	19.852	33.905	63.055
Displacement	mm	5.25	5.00	6.00
Initial Moist. Cont.	%	20.32	20.32	20.32
Bulk Density	Mg/m^3	1.936	1.936	1.936
Dry Density	Mg/m^3	1.609	1.609	1.609
Specific Gravity		2.64	2.64	2.64
Initial Void Ratio		0.641	0.641	0.641
Degree of Saturation	%	83.70	83.70	83.70
Final Moist. Cont.	%	22.47	22.66	22.53
Bulk Density	Mg/m^3	1.971	1.973	1.972
Dry Density	Mg/m^3	1.609	1.609	1.609
Final Void Ratio		0.640	0.641	0.640
Degree of Saturation	%	92.60	93.30	92.90
SHEAR STRENGTH PARAMETERS	Cohesion, cu		Angle Resistance	
	C' = 9 kPa		**$\phi' = 32^\circ$**	

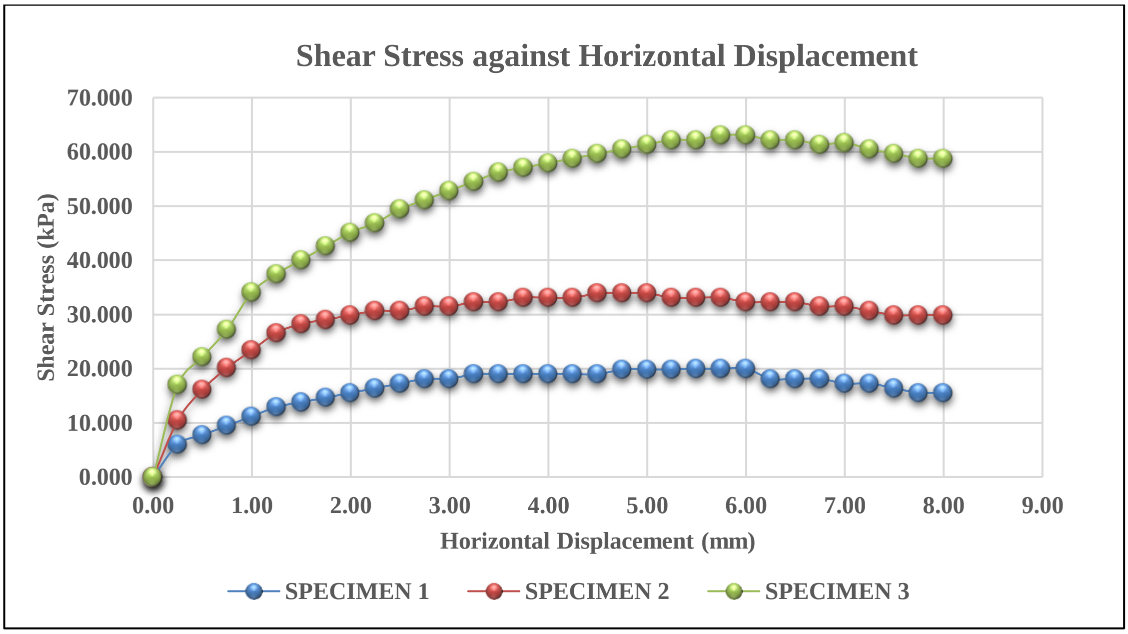
Summary of CD's Result for TP-2

SPECIMEN		1	2	3
Normal Stress	kPa	20	40	80
CONSOLIDATION STAGE				
t100	min	1.44	1.44	1.44
Conso. Settle. (mm)	mm	0.05	0.09	0.15
SHEARING STAGE AT FAILURE				
Calculated Shearing Rate		0.27	0.27	0.27
Shearing Rate	mm/min	0.25	0.25	0.25
Shear Stress	kPa	20.366	34.63	68.4
Displacement	mm	5.50	5.75	6.75
Initial Moist. Cont.	%	17.41	17.41	17.41
Bulk Density	Mg/m^3	2.002	2.002	2.002
Dry Density	Mg/m^3	1.705	1.705	1.705
Specific Gravity		2.65	2.65	2.65
Initial Void Ratio		0.554	0.554	0.554
Degree of Saturation	%	83.30	83.30	83.30
Final Moist. Cont.	%	19.46	19.48	19.44
Bulk Density	Mg/m^3	2.037	2.037	2.036
Dry Density	Mg/m^3	1.705	1.705	1.705
Final Void Ratio		0.554	0.554	0.555
Degree of Saturation	%	93.10	93.10	92.90
SHEAR STRENGTH PARAMETERS	Cohesion, cu		Angle Resistance	
	C' = 8 kPa		**ϕ' = 35°**	

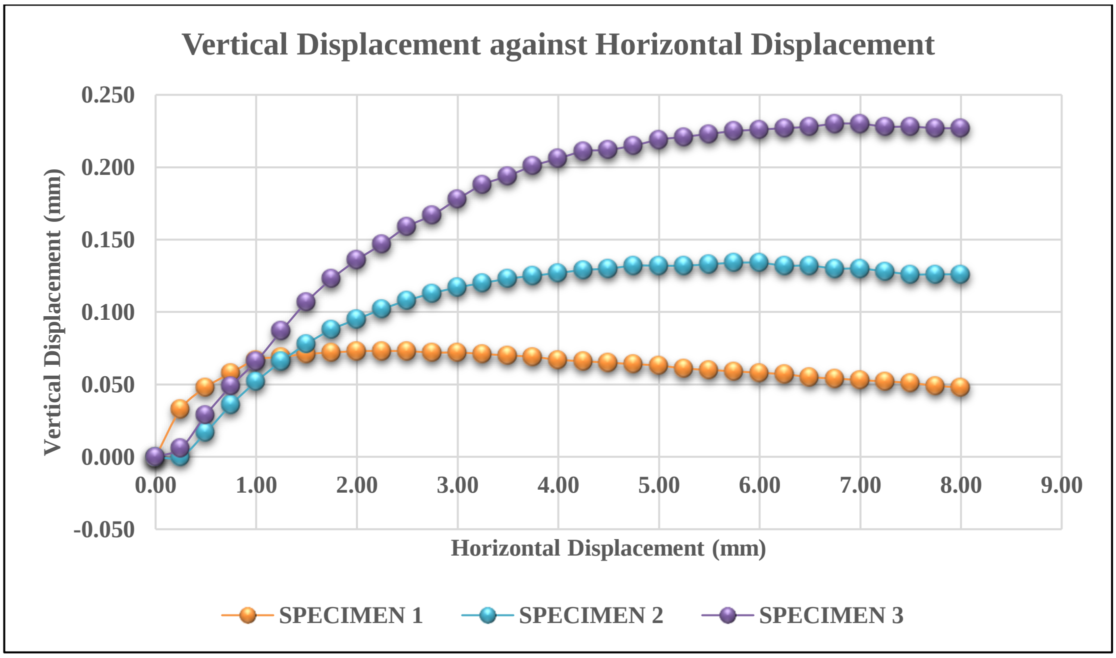
Graph of Vertical Against Horizontal Displacement For TP-1



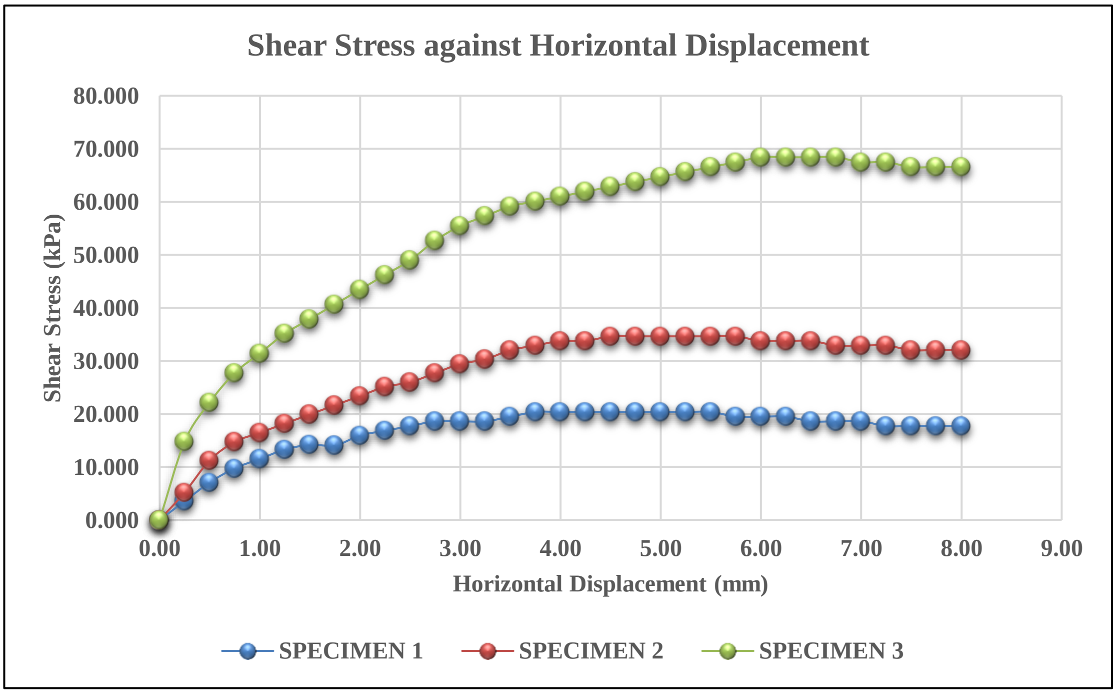
Graph of Shear Stress Against Horizontal Displacement For TP-1



Graph of Vertical Against Horizontal Displacement For TP-2



Graph of Shear Stress Against Horizontal Displacement For TP-2



APPENDIX F
UNIFIED SOIL CLASSIFICATION SYSTEM (USCS)

Unified Soil Classification System (USCS) For BH-1

<table>
<tr><th rowspan="2">BH NO.</th><th rowspan="2">SAMPLE NO.</th><th rowspan="2">DEPTH (m)</th><th colspan="4">SIEVE ANALYSIS (%)</th><th rowspan="2">GROUP SYMBOL</th><th rowspan="2">SOIL DESCRIPTION</th></tr>
<tr><th>GRAVEL</th><th>SAND</th><th>SILT</th><th>CLAY</th></tr>
<tr><td rowspan="8">BH1</td><td>D2</td><td>1.00</td><td>25</td><td>45</td><td colspan="2">30</td><td>SC</td><td>Very Clayey/Silty SAND</td></tr>
<tr><td>D3</td><td>2.00</td><td>28</td><td>45</td><td>26</td><td>1</td><td>SM</td><td>Very silty SAND</td></tr>
<tr><td>D4</td><td>3.00</td><td>31</td><td>49</td><td colspan="2">20</td><td>SC</td><td>Very Clayey/Silty SAND</td></tr>
<tr><td>D5</td><td>4.00</td><td>31</td><td>46</td><td colspan="2">23</td><td>SC</td><td>Very Clayey/Silty SAND</td></tr>
<tr><td>D6</td><td>5.00</td><td>28</td><td>46</td><td>25</td><td>1</td><td>SM</td><td>Very silty SAND</td></tr>
<tr><td>D7</td><td>6.00</td><td>23</td><td>72</td><td colspan="2">5</td><td>SP</td><td>Slightly silty SAND (weathered GRANITE)</td></tr>
<tr><td>C2</td><td>8.70</td><td colspan="5">Rock Test 68.3MPa</td><td>Moderately weathered GRANITE</td></tr>
<tr><td>C2</td><td>10.20</td><td colspan="5">Rock Test 72.4MPa</td><td>Ver strong fresh GRANITE</td></tr>
</table>

Unified Soil Classification System (USCS) For BH-2

BH NO.	SAMPLE NO.	DEPTH (m)	SIEVE ANALYSIS (%)				GROUP SYMBOL	SOIL DESCRIPTION
			GRAVEL	SAND	SILT	CLAY		
BH2	D2	1.00	27	40	33		SC	Very Clayey/Silty SAND
	D3	2.00	21	43	36		ML	Sandy SILT
	D4	3.00	17	30	52	1	MH	Slightly sandy SILT
	D5	5.00	16	29	0	25	CH	Slightly sandy CLAY (weathered GRANITE)
	D6	6.00	20	35	20	25	MH	Slightly sandy SILT (weathered GRANITE)
	D7	7.50	0	77	22	1	SM	Silty SAND (weathered GRANITE)
	D8	9.00	22	46	32		SM	Very silty SAND (weathered GRANITE)
	D9	10.50	27	56	17		SM	Silty SAND (weathered GRANITE)
	D10	12.00	15	56	2	1	SM	Vey Silty SAND (weathered GANITE)
	D11	13.50	21	57	14	8	SM	Very silty SAND (weathered GRANITE)
	D12	15.00	22	46	32		SM	Very silty SAND (weathered GRANITE)
	C3	15.60	Rock Test 66.8MPa					Slightly weathered GRANITE
	C4	17.10	Rock Test 70.2MPa					Slightly weathered GRANITE

Unified Soil Classification System (USCS) For BH-3

<table>
<tr><th rowspan="2">BH NO.</th><th rowspan="2">SAMPLE NO.</th><th rowspan="2">DEPTH (m)</th><th colspan="4">SIEVE ANALYSIS (%)</th><th rowspan="2">GROUP SYMBOL</th><th rowspan="2">SOIL DESCRIPTION</th></tr>
<tr><th>GRAVEL</th><th>SAND</th><th>SILT</th><th>CLAY</th></tr>
<tr><td rowspan="14">BH3</td><td>D2</td><td>1.00</td><td>22</td><td>55</td><td>22</td><td>1</td><td>SM</td><td>Very Silty SAND</td></tr>
<tr><td>D4</td><td>3.00</td><td>25</td><td>69</td><td colspan="2">6</td><td>SM</td><td>Very Silty SAND</td></tr>
<tr><td>MZ1</td><td>4.00</td><td colspan="4"></td><td>MH</td><td>Slightly sandy SILT</td></tr>
<tr><td>D5</td><td>5.00</td><td>28</td><td>59</td><td colspan="2">13</td><td>SC</td><td>Clayey/Silty SAND</td></tr>
<tr><td>D6</td><td>6.00</td><td>21</td><td>40</td><td colspan="2">39</td><td>ML</td><td>Sandy SILT (weathered GRANITE)</td></tr>
<tr><td>D7</td><td>7.50</td><td>0</td><td>41</td><td>42</td><td>17</td><td>MH</td><td>Sandy SILT (weathered GRANITE)</td></tr>
<tr><td>D8</td><td>9.00</td><td>0</td><td>52</td><td>28</td><td>20</td><td>CH</td><td>Sandy CLAY</td></tr>
<tr><td>D9</td><td>10.50</td><td>0</td><td>48</td><td colspan="2">52</td><td>MH</td><td>Sandy SILT (weathered GRANITE)</td></tr>
<tr><td>D10</td><td>12.00</td><td>20</td><td>50</td><td colspan="2">30</td><td>ML</td><td>Sandy SILT (weathered GRANITE)</td></tr>
<tr><td>D11</td><td>13.50</td><td>19</td><td>37</td><td>29</td><td>15</td><td>ML</td><td>Sandy SILT (weathered GRANITE)</td></tr>
<tr><td>D12</td><td>15.00</td><td>0</td><td>59</td><td colspan="2">41</td><td>ML</td><td>Sandy SILT (weathered GRANITE)</td></tr>
<tr><td>D13</td><td>16.50</td><td>28</td><td>33</td><td colspan="2">39</td><td>ML</td><td>Sandy SILT (weathered GRANITE)</td></tr>
<tr><td>D14</td><td>18.00</td><td>21</td><td>66</td><td colspan="2">13</td><td>SC</td><td>Clayey/Silty SAND (weathered GRANITE)</td></tr>
<tr><td>D15</td><td>19.50</td><td>0</td><td>92</td><td colspan="2">8</td><td>SC</td><td>Clayey/Silty SAND (weathered GRANITE)</td></tr>
</table>

APPENDIX G
RAINFALL AND SUCTION DATA

Volume of precipitation from 3/8/2017 to 15/8/2017

Date	3/8	4/8	5/8	6/8	7/8	8/8	9/8	10/8	11/8	12/8	13/8	14/8	15/8
Rainfall (mm)	2.6	0.2	0	15.6	15.6	11.6	0.2	12.4	12.4	0.8	11.8	0	0

Suction of Different Depth from 3/8/2017 to 15/8/2017 on Top, middle and toe of Slope

Top of Slope

		Suction (kPa)												
	Days	**3/8**	**4/8**	**5/8**	**6/8**	**7/8**	**8/8**	**9/8**	**10/8**	**11/8**	**12/8**	**13/8**	**14/8**	**15/8**
Depth (m)	*0.3*	6	8	8	7	6	6	7	6	2	4	1	2	1
	0.45	12	16	14	11	10	8	9	10	5	8	3	5	3
	0.9	14	16	16	15	14	13	15	13	7	10	8	10	9

Middle of Slope

		Suction (kPa)												
	Days	**3/8**	**4/8**	**5/8**	**6/8**	**7/8**	**8/8**	**9/8**	**10/8**	**11/8**	**12/8**	**13/8**	**14/8**	**15/8**
Depth (m)	*0.3*	12	24	30	28	19	24	28	26	18	34	27	26	29
	0.45	13	16	18	16	11	13	15	13	12	20	18	16	17
	0.9	17	17	16	15	15	16	15	16	12	16	14	14	14

Toe of Slope

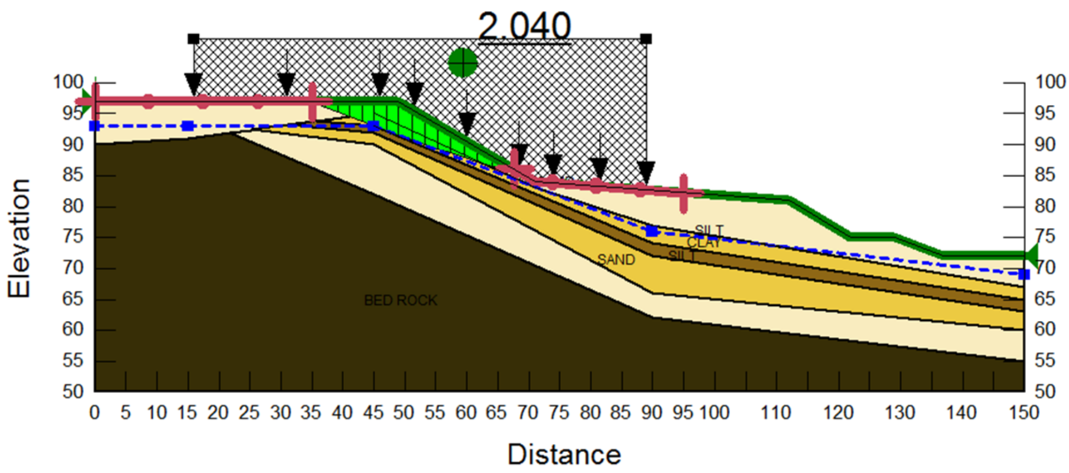
		Suction (cb)												
	Days	**3/8**	**4/8**	**5/8**	**6/8**	**7/8**	**8/8**	**9/8**	**10/8**	**11/8**	**12/8**	**13/8**	**14/8**	**15/8**
Depth (m)	*0.3*	18	18	32	29	22	23	27	26	21	28	19	17	19
	0.45	20	22	26	22	20	25	25	22	20	26	16	15	15
	0.9	19	20	22	18	18	20	22	18	15	25	18	20	20

APPENDIX H
SLOPE DESIGN

Slope Design Description for Top of Slope

SLOPE DESIGN DESCRIPTION	UNIT	REMARKS
Geotechnical Analysis Method		Ordinary
Slip Surfaces Technique		Entry-Exit
Slip Surfaces Direction Movement		Left - Right
Structural Surcharged Load	kN/m3	373.36
Piezometric Level - BH1	M	93
Piezometric Level - BH2	M	93
Piezometric Level - BH3	M	76
Number of Slices		16
Minimum Slip Surface Depth	M	0.1

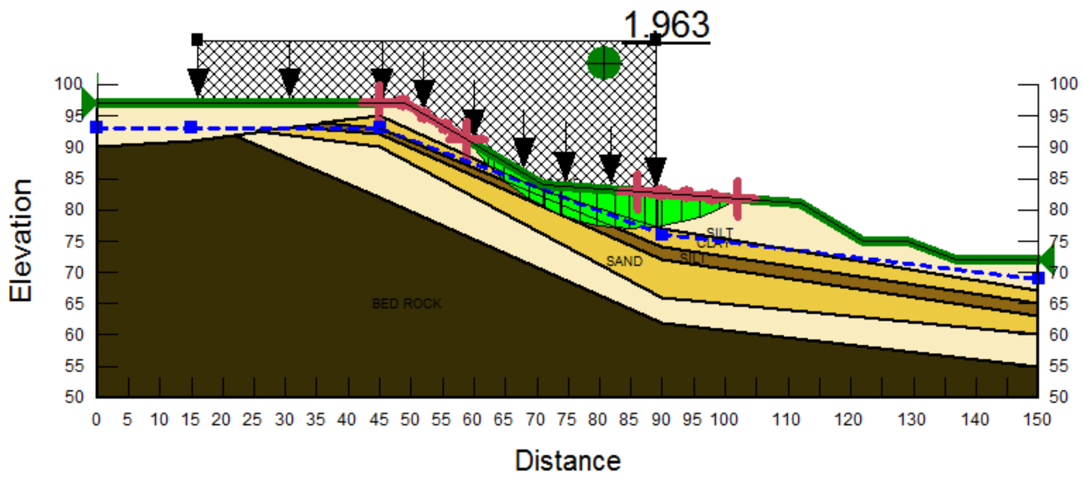
Analysis Result of Critical FOS with Building Surcharged Load on Top of Slope



Slope Design Description for Middle of Slope

SLOPE DESIGN DESCRIPTION	UNIT	REMARKS
Geotechnical Analysis Method		Ordinary
Slip Surfaces Technique		Entry-Exit
Slip Surfaces Direction Movement		Left - Right
Structural Surcharged Load	kN/m3	373.36
Piezometric Level - BH1	M	93
Piezometric Level - BH2	M	93
Piezometric Level - BH3	M	76
Number of Slices		20
Minimum Slip Surface Depth	M	0.1

Analysis Result of Critical FOS with Building Surcharged Load on Middle of Slope



APPENDIX I
SLOPE STABILITY ANALYSIS

Slope Stability Analysis for Top of Slope

Slice No	***z (cm)***	***b (m)***	***W (kN)***	***α (^{0})***	***sinα***	***Wsinα (kN) (4)***	***l (m)***	***ψ (kPa)***	***tanφ'***	***tanφb***	***c'l (kN) (1)***	***Wcosα (m)***	***Wcosαtanφ' (kN) (2)***	***ψltanfb (kN) (3)***
1	42.773	2.0562	17.59	-22.59	-0.384	-6.757	2.227	0	0.700	0.000	17.817	16.240	11.372	0.000
2	127.390	2.0562	52.39	-22.147	-0.377	-19.749	2.220	0	0.700	0.000	17.760	48.523	33.976	0.000
3	210.160	2.0562	86.43	-21.706	-0.370	-31.964	2.213	0	0.700	0.000	17.705	80.298	56.225	0.000
4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	0	0.675	0.000	18.503	104.754	70.658	0.000
5	362.230	1.9158	144.52	-20.872	-0.356	-51.490	2.050	0	0.675	0.000	18.453	135.036	91.083	0.000
6	436.060	2.0000	182.02	-20.456	-0.349	-63.614	2.135	0	0.675	0.000	19.212	170.542	115.032	0.000
7	509.820	2.0000	210.78	-20.032	-0.343	-72.202	2.129	0	0.675	0.000	19.159	198.028	133.572	0.000
8	521.400	2.1180	227.24	-19.596	-0.335	-76.213	2.248	0	0.675	0.000	20.234	214.078	144.398	0.000
9	470.720	2.1180	204.79	-19.149	-0.328	-67.176	2.242	0	0.675	0.000	20.179	193.459	130.490	0.000
10	418.190	2.1180	181.47	-18.704	-0.321	-58.194	2.236	0	0.675	0.000	20.125	171.886	115.939	0.000
11	363.830	2.1180	157.30	-18.259	-0.313	-49.284	2.230	0	0.675	0.000	20.073	149.380	100.758	0.000
12	307.640	2.1180	132.28	-17.816	-0.306	-40.473	2.225	0	0.675	0.000	20.022	125.936	84.945	0.000
13	249.650	2.1180	106.42	-17.373	-0.299	-31.776	2.219	0	0.675	0.000	19.973	101.565	68.507	0.000
14	184.710	2.4722	91.33	-16.896	-0.291	-26.543	2.584	0	0.700	0.000	20.670	87.386	61.188	0.000
15	112.510	2.4722	55.63	-16.382	-0.282	-15.690	2.577	0	0.700	0.000	20.615	53.371	37.371	0.000
16	37.902	2.4722	18.74	-15.87	-0.273	-5.125	2.570	0	0.700	0.000	20.562	18.026	12.622	0.000
Total						***-657.051***					***311.064***		***1268.134***	***0.000***

Slope Stability Analysis for Middle of Slope

Slice No	z (cm)	b (m)	W (kN)	α (^{0})	sinα	Wsinα (kN) (4)	l (m)	ψ (kPa)	tanϕ'	tanϕb	c'l (kN) (1)	Wcosα (m)	Wcosαtanϕ' (kN) (2)	ψltanfb (kN) (3)
1	106.880	3.2060	68.53	-51.512	-0.783	-53.644	5.152	0	0.700	0.000	41.218	42.652	29.865	0.000
2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	0	0.675	0.000	11.114	28.261	19.062	0.000
3	277.860	1.6092	92.18	-42.652	-0.678	-62.457	2.188	0	0.675	0.000	19.693	67.798	45.730	0.000
4	332.850	4.2007	286.57	-35.987	-0.588	-168.389	5.192	0	0.625	0.000	46.726	231.878	144.894	0.000
5	357.630	2.1225	153.13	-29.103	-0.486	-74.480	2.429	0	0.625	0.000	21.864	133.797	83.606	0.000
6	359.850	0.2736	19.81	-26.632	-0.448	-8.879	0.306	0	0.625	0.000	2.755	17.706	11.064	0.000
7	410.710	2.4236	200.68	-23.963	-0.406	-81.506	2.652	0	0.625	0.000	23.870	183.383	114.590	0.000
8	458.420	0.1707	15.80	-21.403	-0.365	-5.767	0.183	0	0.625	0.000	1.650	14.712	9.193	0.000
9	498.890	2.8912	292.43	-18.484	-0.317	-92.712	3.049	0	0.625	0.000	27.437	277.344	173.304	0.000
10	559.570	2.8912	330.47	-13.052	-0.226	-74.632	2.968	0	0.625	0.000	26.711	321.932	201.166	0.000
11	591.570	2.8912	352.74	-7.738	-0.135	-47.494	2.918	0	0.625	0.000	26.260	349.528	218.409	0.000
12	598.280	2.3079	284.93	-3.0173	-0.053	-14.998	2.311	0	0.675	0.000	20.800	284.535	191.921	0.000
13	585.150	2.3079	275.68	1.153	0.020	5.547	2.308	0	0.675	0.000	20.775	275.624	185.911	0.000
14	559.730	1.8428	207.96	4.9065	0.086	17.787	1.850	0	0.675	0.000	16.646	207.198	139.757	0.000
15	543.230	0.1927	20.95	6.7504	0.118	2.463	0.194	0	0.675	0.000	1.747	20.809	14.036	0.000
16	533.010	0.8073	86.06	7.6617	0.133	11.474	0.815	0	0.700	0.000	6.517	85.290	59.721	0.000
17	484.060	3.0000	290.44	11.158	0.194	56.205	3.058	0	0.700	0.000	24.463	284.950	199.524	0.000
18	387.390	3.0000	232.43	16.748	0.288	66.978	3.133	0	0.700	0.000	25.063	222.571	155.846	0.000
19	258.140	3.0000	154.88	22.509	0.383	59.292	3.247	0	0.700	0.000	25.980	143.081	100.186	0.000
20	92.501	3.0000	55.50	28.524	0.478	26.503	3.415	0	0.700	0.000	27.317	48.764	34.145	0.000
Total						***960.208***					***418.604***		***2131.930***	***0.000***

Slope Stability Analysis for Toe of Slope

Slice No	z (cm)	b (m)	W (kN)	α (⁰)	sinα	Wsinα (kN) (4)	l (m)	ψ (kPa)	tanϕ'	tanϕb	c'l (kN) (1)	Wcosα (m)	Wcosαtanϕ' (kN) (2)	ψltanfb (kN) (3)
1	122.280	1.9580	47.88	-52.898	-0.798	-38.190	3.246	0	0.700	0.000	25.971	28.885	20.225	0.000
2	257.750	0.2375	12.29	-49.826	-0.764	-9.391	0.368	0	0.675	0.000	3.313	7.928	5.348	0.000
3	381.480	2.2342	175.11	-46.74	-0.728	-127.524	3.260	0	0.675	0.000	29.344	120.005	80.944	0.000
4	592.630	2.5151	306.78	-41.129	-0.658	-201.787	3.339	0	0.625	0.000	30.054	231.076	144.392	0.000
5	774.260	2.5151	397.13	-35.658	-0.583	-231.505	3.096	0	0.625	0.000	27.861	322.673	201.628	0.000
6	962.570	4.5401	891.46	-28.625	-0.479	-427.076	5.172	0	0.675	0.000	46.552	782.500	527.803	0.000
7	1087.700	1.0000	222.36	-23.299	-0.396	-87.950	1.089	0	0.675	0.000	9.799	204.227	137.753	0.000
8	1147.500	2.9356	689.72	-19.722	-0.337	-232.751	3.119	0	0.675	0.000	28.067	649.262	437.933	0.000
9	1216.600	2.9356	732.72	-14.492	-0.250	-183.359	3.032	0	0.675	0.000	27.289	709.407	478.501	0.000
10	1257.300	2.9356	757.41	-9.3839	-0.163	-123.495	2.975	0	0.675	0.000	26.779	747.274	504.043	0.000
11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	0	0.675	0.000	26.497	762.596	514.378	0.000
12	1259.200	2.9356	755.46	0.64854	0.011	8.551	2.936	0	0.675	0.000	26.422	755.412	509.532	0.000
13	1221.600	2.9356	729.52	5.653	0.099	71.860	2.950	0	0.675	0.000	26.550	725.972	489.674	0.000
14	1166.100	2.3864	565.53	10.223	0.177	100.370	2.425	0	0.625	0.000	21.824	556.552	347.772	0.000
15	1103.500	2.0000	450.37	14.037	0.243	109.237	2.062	0	0.625	0.000	18.554	436.922	273.019	0.000
16	1029.900	0.9185	193.82	16.604	0.286	55.385	0.958	0	0.625	0.000	8.626	185.738	116.062	0.000
17	757.190	4.6420	715.14	21.669	0.369	264.061	4.995	0	0.675	0.000	44.956	664.603	448.280	0.000
18	491.960	0.6144	60.45	26.501	0.446	26.974	0.687	0	0.700	0.000	5.492	54.100	37.881	0.000
19	229.110	3.8251	175.27	30.876	0.513	89.945	4.457	0	0.700	0.000	35.655	150.431	105.333	0.000
Total						**2447.430**					**469.606**		**5380.502**	**0.000**

FOS for Top of Slope with Daily Suction Value for 0.3 m

Date	Slice No	z (cm)	b (m)	W (kN)	α(0)	sinα	Wsinα (kN) (4)	l (m)	ψ (kPa)	tanφ'	tanφb	c'l (kN) (1)	Wcosα (m)	Wcosαtanφ' (kN) (2)	ψltanfb (kN) (3)	FOS
3/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	6	0.675	0.287	18.503	104.754	70.658	3.537	2.272
4/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	8	0.675	0.287	18.503	104.754	70.658	4.716	2.301
5/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	8	0.675	0.287	18.503	104.754	70.658	4.716	2.301
6/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	7	0.675	0.287	18.503	104.754	70.658	4.127	2.286
7/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	6	0.675	0.287	18.503	104.754	70.658	3.537	2.272
8/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	6	0.675	0.287	18.503	104.754	70.658	3.537	2.272
9/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	7	0.675	0.287	18.503	104.754	70.658	4.127	2.286
10/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	6	0.675	0.287	18.503	104.754	70.658	3.537	2.272
11/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	2	0.675	0.287	18.503	104.754	70.658	1.179	2.214
12/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	4	0.675	0.287	18.503	104.754	70.658	2.358	2.243
13/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	1	0.675	0.287	18.503	104.754	70.658	0.590	2.200
14/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	2	0.675	0.287	18.503	104.754	70.658	1.179	2.214
15/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	1	0.675	0.287	18.503	104.754	70.658	0.590	2.200

FOS for Top of Slope with Daily Suction Value for 0.45 m

Date	Slice No	z (cm)	b (m)	W (kN)	α(0)	sinα	Wsinα (kN) (4)	l (m)	ψ (kPa)	tanϕ'	tanϕb	c'l (kN) (1)	Wcosα (m)	Wcosαtanϕ' (kN) (2)	ψltanfb (kN) (3)	FOS
3/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	12	0.675	0.287	18.503	104.754	70.658	7.074	2.359
4/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	16	0.675	0.287	18.503	104.754	70.658	9.432	2.416
5/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	14	0.675	0.287	18.503	104.754	70.658	8.253	2.387
6/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	11	0.675	0.287	18.503	104.754	70.658	6.485	2.344
7/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	10	0.675	0.287	18.503	104.754	70.658	5.895	2.330
8/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	8	0.675	0.287	18.503	104.754	70.658	4.716	2.301
9/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	9	0.675	0.287	18.503	104.754	70.658	5.306	2.315
10/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	10	0.675	0.287	18.503	104.754	70.658	5.895	2.330
11/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	5	0.675	0.287	18.503	104.754	70.658	2.948	2.257
12/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	8	0.675	0.287	18.503	104.754	70.658	4.716	2.301
13/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	3	0.675	0.287	18.503	104.754	70.658	1.769	2.229
14/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	5	0.675	0.287	18.503	104.754	70.658	2.948	2.257
15/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	3	0.675	0.287	18.503	104.754	70.658	1.769	2.229

FOS for Top of Slope with Daily Suction Value for 0.9 m

Date	Slice No	z (cm)	b (m)	W (kN)	$\alpha(0)$	sinα	Wsinα (kN) (4)	l (m)	ψ (kPa)	tanϕ'	tanϕb	c'l (kN) (1)	Wcosα (m)	Wcosαtanϕ' (kN) (2)	ψltanfb (kN) (3)	FOS
3/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	14	0.675	0.287	18.503	104.754	70.658	8.253	2.387
4/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	16	0.675	0.287	18.503	104.754	70.658	9.432	2.416
5/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	16	0.675	0.287	18.503	104.754	70.658	9.432	2.416
6/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	15	0.675	0.287	18.503	104.754	70.658	8.843	2.402
7/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	14	0.675	0.287	18.503	104.754	70.658	8.253	2.387
8/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	13	0.675	0.287	18.503	104.754	70.658	7.664	2.373
9/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	15	0.675	0.287	18.503	104.754	70.658	8.843	2.402
10/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	13	0.675	0.287	18.503	104.754	70.658	7.664	2.373
11/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	7	0.675	0.287	18.503	104.754	70.658	4.127	2.286
12/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	10	0.675	0.287	18.503	104.754	70.658	5.895	2.330
13/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	8	0.675	0.287	18.503	104.754	70.658	4.716	2.301
14/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	10	0.675	0.287	18.503	104.754	70.658	5.895	2.330
15/8/2017	4	288.400	1.9157	112.42	-21.281	-0.363	-40.802	2.056	9	0.675	0.287	18.503	104.754	70.658	5.306	2.315

FOS for Middle of Slope with Daily Suction Value for 0.3 m

Date	Slice No	z (cm)	b (m)	W (kN)	α(0)	sinα	Wsinα (kN) (4)	l (m)	ψ (kPa)	tanϕ'	tanϕb	c'l (kN) (1)	Wcosα (m)	Wcosαtanϕ' (kN) (2)	ψltanfb (kN) (3)	FOS
3/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	12	0.675	0.287	11.114	28.261	19.062	4.249	1.187
4/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	24	0.675	0.287	11.114	28.261	19.062	8.499	1.333
5/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	30	0.675	0.287	11.114	28.261	19.062	10.623	1.407
6/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	28	0.675	0.287	11.114	28.261	19.062	9.915	1.382
7/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	19	0.675	0.287	11.114	28.261	19.062	6.728	1.272
8/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	24	0.675	0.287	11.114	28.261	19.062	8.499	1.333
9/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	28	0.675	0.287	11.114	28.261	19.062	9.915	1.382
10/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	26	0.675	0.287	11.114	28.261	19.062	9.207	1.358
11/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	18	0.675	0.287	11.114	28.261	19.062	6.374	1.260
12/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	34	0.675	0.287	11.114	28.261	19.062	12.040	1.456
13/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	27	0.675	0.287	11.114	28.261	19.062	9.561	1.370
14/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	26	0.675	0.287	11.114	28.261	19.062	9.207	1.358
15/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	29	0.675	0.287	11.114	28.261	19.062	10.269	1.395

FOS for Middle of Slope with Daily Suction Value for 0.45 m

Date	Slice No	z (cm)	b (m)	W (kN)	α(0)	sinα	Wsinα (kN) (4)	l (m)	ψ (kPa)	tanϕ'	tanϕb	c'l (kN) (1)	Wcosα (m)	Wcosαtanϕ' (kN) (2)	ψltanfb (kN) (3)	FOS
3/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	13	0.675	0.287	11.114	28.261	19.062	4.603	1.199
4/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	16	0.675	0.287	11.114	28.261	19.062	5.666	1.236
5/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	18	0.675	0.287	11.114	28.261	19.062	6.374	1.260
6/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	16	0.675	0.287	11.114	28.261	19.062	5.666	1.236
7/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	11	0.675	0.287	11.114	28.261	19.062	3.895	1.175
8/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	13	0.675	0.287	11.114	28.261	19.062	4.603	1.199
9/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	15	0.675	0.287	11.114	28.261	19.062	5.312	1.224
10/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	13	0.675	0.287	11.114	28.261	19.062	4.603	1.199
11/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	12	0.675	0.287	11.114	28.261	19.062	4.249	1.187
12/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	20	0.675	0.287	11.114	28.261	19.062	7.082	1.285
13/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	18	0.675	0.287	11.114	28.261	19.062	6.374	1.260
14/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	16	0.675	0.287	11.114	28.261	19.062	5.666	1.236
15/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	17	0.675	0.287	11.114	28.261	19.062	6.020	1.248

FOS for Middle of Slope with Daily Suction Value for 0.9 m

Date	Slice No	z (cm)	b (m)	W (kN)	α(0)	sinα	Wsinα (kN) (4)	l (m)	ψ (kPa)	tanϕ'	tanϕb	c'l (kN) (1)	Wcosα (m)	Wcosαtanϕ' (kN) (2)	ψltanfb (kN) (3)	FOS
3/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	17	0.675	0.287	11.114	28.261	19.062	6.020	1.248
4/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	17	0.675	0.287	11.114	28.261	19.062	6.020	1.248
5/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	16	0.675	0.287	11.114	28.261	19.062	5.666	1.236
6/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	15	0.675	0.287	11.114	28.261	19.062	5.312	1.224
7/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	15	0.675	0.287	11.114	28.261	19.062	5.312	1.224
8/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	16	0.675	0.287	11.114	28.261	19.062	5.666	1.236
9/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	15	0.675	0.287	11.114	28.261	19.062	5.312	1.224
10/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	16	0.675	0.287	11.114	28.261	19.062	5.666	1.236
11/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	12	0.675	0.287	11.114	28.261	19.062	4.249	1.187
12/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	16	0.675	0.287	11.114	28.261	19.062	5.666	1.236
13/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	14	0.675	0.287	11.114	28.261	19.062	4.957	1.211
14/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	14	0.675	0.287	11.114	28.261	19.062	4.957	1.211
15/8/2017	2	232.530	0.8617	40.50	-45.742	-0.716	-29.003	1.235	14	0.675	0.287	11.114	28.261	19.062	4.957	1.211

FOS for Toe of Slope with Daily Suction Value for 0.3 m

Date	***Slice No***	***z (cm)***	***b (m)***	***W (kN)***	$\alpha(0)$	***sinα***	***Wsinα (kN) (4)***	***l (m)***	ψ ***(kPa)***	***tanϕ'***	***tanϕb***	***c'l (kN) (1)***	***Wcosα (m)***	***Wcosαtanϕ' (kN) (2)***	ψ***ltanfb (kN) (3)***	***FOS***
3/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	18	0.675	0.287	26.497	762.596	514.378	15.196	9.584
4/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	18	0.675	0.287	26.497	762.596	514.378	15.196	9.584
5/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	32	0.675	0.287	26.497	762.596	514.378	27.014	9.788
6/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	29	0.675	0.287	26.497	762.596	514.378	24.482	9.744
7/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	22	0.675	0.287	26.497	762.596	514.378	18.572	9.643
8/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	23	0.675	0.287	26.497	762.596	514.378	19.417	9.657
9/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	27	0.675	0.287	26.497	762.596	514.378	22.793	9.715
10/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	26	0.675	0.287	26.497	762.596	514.378	21.949	9.701
11/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	21	0.675	0.287	26.497	762.596	514.378	17.728	9.628
12/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	28	0.675	0.287	26.497	762.596	514.378	23.638	9.730
13/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	19	0.675	0.287	26.497	762.596	514.378	16.040	9.599
14/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	17	0.675	0.287	26.497	762.596	514.378	14.351	9.570
15/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	19	0.675	0.287	26.497	762.596	514.378	16.040	9.599

FOS for Toe of Slope with Daily Suction Value for 0.45 m

Date	Slice No	z (cm)	b (m)	W (kN)	α(0)	sinα	Wsinα (kN) (4)	l (m)	ψ (kPa)	tanϕ'	tanϕb	c'l (kN) (1)	Wcosα (m)	Wcosαtanϕ' (kN) (2)	ψltanfb (kN) (3)	FOS
3/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	20	0.675	0.287	26.497	762.596	514.378	16.884	9.613
4/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	22	0.675	0.287	26.497	762.596	514.378	18.572	9.643
5/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	26	0.675	0.287	26.497	762.596	514.378	21.949	9.701
6/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	22	0.675	0.287	26.497	762.596	514.378	18.572	9.643
7/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	20	0.675	0.287	26.497	762.596	514.378	16.884	9.613
8/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	25	0.675	0.287	26.497	762.596	514.378	21.105	9.686
9/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	25	0.675	0.287	26.497	762.596	514.378	21.105	9.686
10/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	22	0.675	0.287	26.497	762.596	514.378	18.572	9.643
11/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	20	0.675	0.287	26.497	762.596	514.378	16.884	9.613
12/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	26	0.675	0.287	26.497	762.596	514.378	21.949	9.701
13/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	16	0.675	0.287	26.497	762.596	514.378	13.507	9.555
14/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	15	0.675	0.287	26.497	762.596	514.378	12.663	9.541
15/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	15	0.675	0.287	26.497	762.596	514.378	12.663	9.541

FOS for Toe of Slope with Daily Suction Value for 0.9 m

Date	***Slice No***	***z (cm)***	***b (m)***	***W (kN)***	*α(0)*	***sin*α**	***Wsin*α *(kN) (4)***	***l (m)***	*ψ* ***(kPa)***	***tan*ϕ'**	***tan*ϕb**	***c'l (kN) (1)***	***Wcos*α *(m)***	***Wcos*αtanϕ' *(kN) (2)***	*ψ*ltanfb ***(kN) (3)***	***FOS***
3/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	19	0.675	0.287	26.497	762.596	514.378	16.040	9.599
4/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	20	0.675	0.287	26.497	762.596	514.378	16.884	9.613
5/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	22	0.675	0.287	26.497	762.596	514.378	18.572	9.643
6/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	18	0.675	0.287	26.497	762.596	514.378	15.196	9.584
7/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	18	0.675	0.287	26.497	762.596	514.378	15.196	9.584
8/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	20	0.675	0.287	26.497	762.596	514.378	16.884	9.613
9/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	22	0.675	0.287	26.497	762.596	514.378	18.572	9.643
10/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	18	0.675	0.287	26.497	762.596	514.378	15.196	9.584
11/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	15	0.675	0.287	26.497	762.596	514.378	12.663	9.541
12/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	25	0.675	0.287	26.497	762.596	514.378	21.105	9.686
13/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	18	0.675	0.287	26.497	762.596	514.378	15.196	9.584
14/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	20	0.675	0.287	26.497	762.596	514.378	16.884	9.613
15/8/2017	11	1271.200	2.9356	764.80	-4.3507	-0.076	-58.019	2.944	20	0.675	0.287	26.497	762.596	514.378	16.884	9.613