Determination of Dominant Factors Controlling Initiation of Shallow Slide

By

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Dissertation submitted in partial fulfillment of

the requirements for the

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(Civil Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the

Civil Engineering Programme

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Approved by,

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January 2014

CERTIFICATION OF ORIGINALITY

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

…………………………………………….

NOORFAZIRA ASHIKIN BINTI ISMAIL

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ABSTRACT

Water-induced landslide process is one of the factors that led to shallow landslide. It is commonly caused by rainfall infiltration due to increase in pore-water pressure and decrease of matric suction within the slope. In order to determine the dominant factors controlling initiation of shallow slide in sandy soil, a few soil properties tests and a model slope subjected to rainfall infiltration was developed and employed to perform experiment on sandy soil. The parameters that the author uses are the intensities of the rainfall. During the experiment, the pore water pressure and the matric suction of the surfaces will be measured. The failure mechanism and the response of pore water pressure and surface tension will be observed and discussed. The failures of the soil happen when the sandy soil had a mark decrease in matric suction during the rainfall drop on the slope surface.

Keywords: shallow landslide, infiltration. Pore pressure, rainfall intensity, rainfall duration

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Shallow landslide is a type of slope failure that usually occurs in humid tropical environment and hilly area. The failure process usually consists of water mixture, soil and debris that initiate on steep slopes during period of intense rainfall. Shallow landslide also can be defined as a movement of materials displaced over a discrete slip surface close to the land surface and the depth is about 4.5 meters or less (Varnes, 1978). Most natural shallow landslide triggered by elevated pore water pressure resulting from combination of high intensity and long rainfall duration or being undercut by stream erosion. The rainfall induced the reducing of matric suction or changing pattern of ground water table where resulting in increasing of pressure head hence increasing the hydraulic pressure through soil. The stability of residual soil slopes is strongly influence by climatic and hydrological changes, such as infiltration, precipitation, evaporation and the transpiration processes. In "Study on Malaysian Urban Rainfall-runoff Characteristics," Leong Chin (2007) writes that Malaysia is one of the tropical countries that experience an extreme rainfall event with long duration and high frequency. Thus, Malaysia is one of the countries that best describe the humid tropical environment that experience shallow slide failure.

1.2 PROBLEM STATEMENT

1.2.1 Problem Identification

Landslides represent a major risk to property, human life, infrastructure and natural environment in most mountainous and hilly regions of the world. Shallow landslides are particular important in terms of natural hazard, as they often translate into rapidly moving debris flows (Iverson et al.,1997) that may affect human life and properties (Sidle and Ochiai, 2006; Keefer and Larsen, 2007). This statement can be proved by figure 1 and figure 2 below.

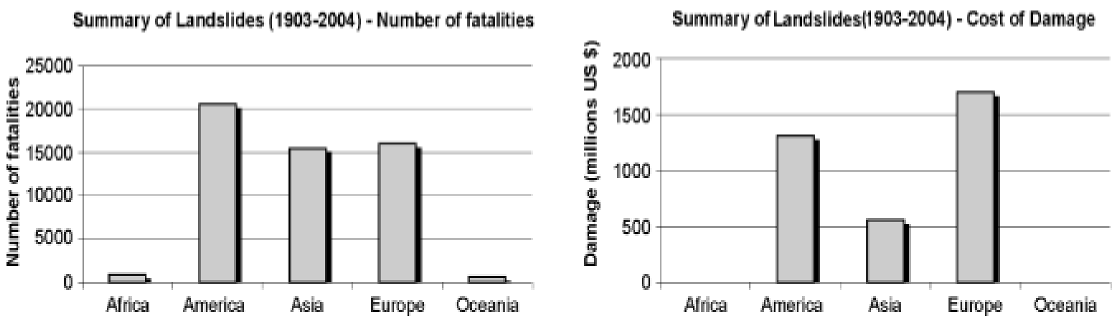


Figure 1: Number of fatalities (left) and cost of damage (right) caused by landslides 1903 to 2004. Source: EM-DAT – The OFDA/CRED International Disaster database.

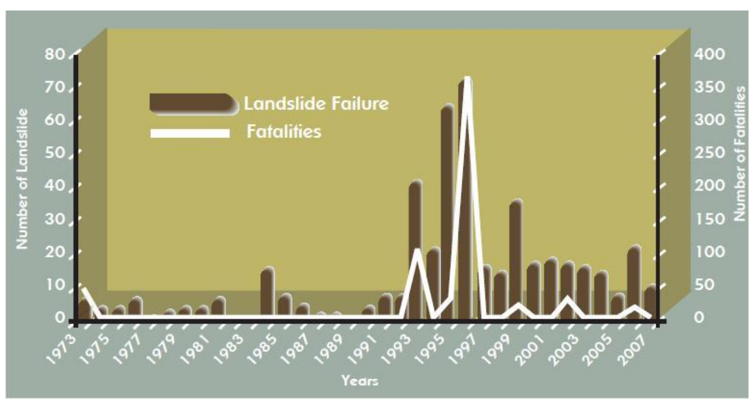


Figure 2: Reported landslides and fatalities (1973-2007) in Malaysia

Source: National Slope Master Plan 2009-2023

Rainfall is certainly one of the most frequent causes of landslides occurrence. Intense storms with high-intensity, long-duration rainfall have great potential to trigger rapidly moving landslides and have been documented as one of the major cause for shallow landslide triggering (Anderson and Sitar 1995; Iverson et al. 1997; Montgomery and Dietrich, 1994; Terlien, 1998; Ng and Shi, 1998; Iverson, 2000; Sidle and Onda, 2004). Thus,an experiment needs to be done to identify the mechanism that triggering slope failure.

1.2.2 Significant of the Project

As landslide failure becomes a problem in tropical and hilly area, the experiment on determining the dominant factors of landslide must be considered. So, the experiment is aimed to foresee the occurrence of phenomenon in two ways of parameters which are long period of rainfall with low intensity and low period of rainfall with high intensity of rainfall.

1.3 OBJECTIVE AND SCOPE OF STUDY

1.3.1 Objective

The objective of this study is to increase the understanding of shallow slide and discover the dominant factors controlling initiation of shallow slide through the rainfall model.

i. To study the soil properties of soil sample
ii. To clarify the nature of pore pressure and matric suction in unsaturated slope.
iii. To define the triggering mechanism of slope failures on relative to the rainfall intensity and rainfall duration

1.3.2 Scope of Study

The study will be focus on the dominant factors or mechanism that controls the initiation of shallow slide. The limitation of this study is based on the fact that most of the shallow slides occur during rainfall and at hilly area.

In this study, the main subjects under investigation are:

i. Hydrology – Rainfall intensity, Pore-water Pressure and matric suction
ii. Geomechanical Landslide Triggering – Mechanism of Triggering Landslide
iii. Geotechnical Engineering – Study Behaviors of Earth Materials

And the aspects being studied are:

i. General features of landslide
ii. Rain intensity
iii. Rainfall duration
iv. Sliding Trigger Mechanism

The details of the scope of study will be discussed in Chapter 2 based on the articles reading. This project is designed to be complete within two semesters. For the first semester is doing some research and data gathering for the study area. For the second semester, which is the implementation part, should include the process in obtaining the hydrologic model for the study area as the output of the project.

1.4 THE RELEVANCY OF THE PROJECT

The high amount and intensity of rainfall, deeply weathered soils and steep slope gradients are generally recognized as the causal factors of slope instability. As the tropical environment has high annual precipitation, the significant of rainwater infiltration as main causal factor for shallow landslide is well thought. Therefore, the shallow landslide is commonly happen in most tropical area particularly during period of intense rainfall. Therefore, this project should be done to study the soil behavior related to the triggering mechanism of failures on relative to the rain intensity and rainfall duration.

1.5 FEASIBILITY OF THE PROJECT WITHIN THE SCOPE AND TIME FRAME

The equipment required for this project are rainfall model, sprinklers, tensiometer, piezometer, flow meter and rain gauges. The software used for this project is data logger developed by SEBA Hydrometrie. It is digitally record the water level or any parameters such as matric suction and pore pressure.

Based on the schedule, the project will be carried out starting week 6. More than that, the project required laboratory work in order to get the data and simulation work. The duration of the project is about eight months which is two whole semesters. The usage of the Gantt chart also will help to manage the time wisely in realization of the project work.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL FEATURES OF LANDSLIDE

The slope failure occurs when the force that is pulling the slope downward (gravity) exceeds the strength of the earth materials that compose the slope (Acharya, 2011). Landslides can move slowly or can move quickly and disastrously, as is the case with shallow landslides. A landslide occurs when stresses acting on soil mass on a hills slope exceed the soil-shear strength. It has generally been recognized that these forces are functions of various parameters relating to lithology, bedrock geology, geotechnical properties, rainfall characteristics (intensity and duration), soil-moisture conditions, water table position, and land-use patterns. (Acharya, 2011)

2.1.1 Shallow Landslide

Shallow landslides are quite often underlain by a plane of weakness lying parallel to it and therefore, shallow landslides are predominant. The term shallow landslide is used to describe movements by which material is displaced over a discrete slip surface close to the land surface and it is a ruptured plan in the upper soil layer only or relatively thin zones of intense shear strain (~ < 15feet) (Acharya 2011). In many cases, the shallow landslides are fast-moving and are extremely destructive and causing problems. A schematic diagram of a shallow landslide is presented in Figure 3

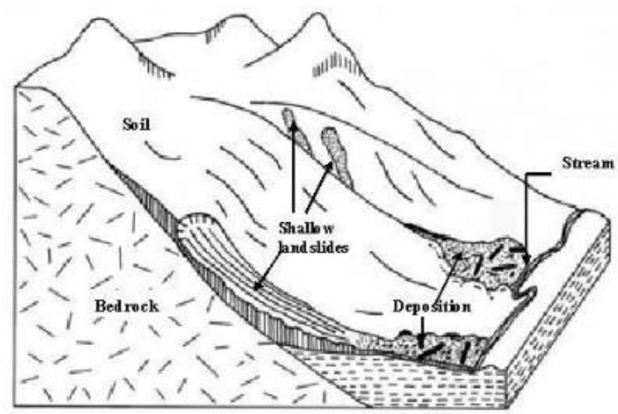


Figure 3: Shallow landslide schematic representation. (Sidle and Ochiai, 2006)

2.2 WATER-INDUCED SHALLOW LANDSLIDE PROCESS

During the rainfall event, the process of water infiltration into the soil will occur. This will increase the pore water pressure in the soil. Pore pressure is the amount of force exerted by water to soil particles. During intense rainfall events, the variations in pore pressures distributed within the soil are highly depending on the soil properties, hydraulic conductivity, and topography. The increasing in pore pressure may be directly related to rainfall infiltration and percolation or may be the result of build-up of a perched groundwater table (Terlien, 1998).

High pore pressures are generated in lower areas of a hill slope (Anderson and Sitar, 1995). Various studies reported that the response of the material involved in the pore pressure development is largely dependent on its hydraulic conductivity. Generation and dissipation of pore pressures during intense rainfall events can be very rapid in high-permeable soil (Johnson and Sitar, 1990). Slopes with different permeability have different hydraulic and mechanic behaviors during the same rainfall process; for example, Lan et al. (2005) state that in a slope with lower permeability, its shallow portion responds rapidly to the rainfall, where the infiltration capacity is quickly reached, resulting in loss of soil suction and increase of pore pressure. This suggests that a lower permeability slope might be more prone to shallow slope failure even in moderately intense rainfall events.

Pore pressure generation is greatly dependent on the initial density of the soil profiles. Iverson et al. (2000) report that sufficient pore pressures required to trigger landslides cannot be generated in dense soil. Wang and Sassa (2001, 2003) relate the pore pressure generation with the relative density. With increasing relative density, pore pressure increases up to a certain value, and thereafter the pressure decreases. The relative density is a term that measures the state of compactness of a natural soil and is expressed as :

$$\textbf{Relative Density} = \frac{(e^{max} - e)}{(e^{max} - e^{min})}$$

Equation 1 Relative Density

Where:

e = void ratio of the soil at natural

e^{max} = loosest state

e^{min} = densest state.

Soils in loose state (high porosity) have greater water holding capacity and therefore higher pore pressures are usually generated.

Generation of high pore pressure may also result in liquefaction which is the soil suddenly loses a large proportion of its shear strength. Landslides instigate when shear stress is greater than the shear resistance of the material (Terzaghi, 1950). Slope instability resulted from either increasing shear stresses or decreasing shear resistance or both. It can be expressed as a ration of shear resistance to shear stress which known as factor of safety, F:

$$\text{Factor of Safety},\ F = \frac{\text{Shear resistance } (\tau_f)}{\text{Shear stress } (\tau)}$$

Equation 2 Factor of Safety

The slope is stable if F>1, but unstable if F<1. Failures will occur if F=1.

$$F = \frac{c' + (\sigma_n - u)\tan\phi'}{\tau}$$

Equation 3 Coulomb Equation

c' = the effective cohesion

σn = the total normal stress

u = the pore-water pressure

ϕ' = the effective angle of internal friction

τ = the shear stress

(σn–u) = the effective stress which is σ'

Terlien (1997) concludes that failure will only take place when the soil becomes saturated from the terrain surface to the depth of the potential slip surface. Slope failure usually occurs at a potential slip surface depth which depends on geotechnical properties of the soil and sloping profile characteristics i.e. slope and depth. This saturation depth is a function of the soil profile, initial soil moisture distribution, and rainfall amount and intensity.

2.3 COMPARISON WITH OTHER EXPERIMENTS

This section explained about details on other tests regarding the rainfall-induced landslide by using flume test method. All the experiments will be vary due to aim of the study, parameters used, type of soil, and method used. The most important issue is that there have been very few experimental studies focusing on how patterns of increasing pore water pressure affect soil behavior. Therefore, more advanced testing focusing on pore pressure variations, which represent different rainfall conditions (intensity and duration of rainfall), is essential and is particularly relevant to the understanding of the behavior of shallow failures on tropical slopes. However, in this study, the parameter of rainfall intensity correlate with rainfall period will be varied. Thus, the parameter is set up for high intensity-short period of rainfall and low intensity-long period of rainfall.

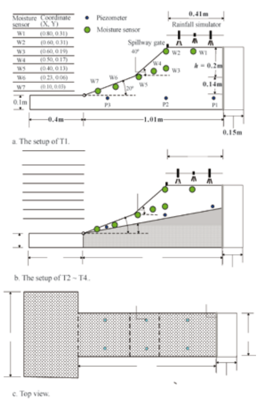
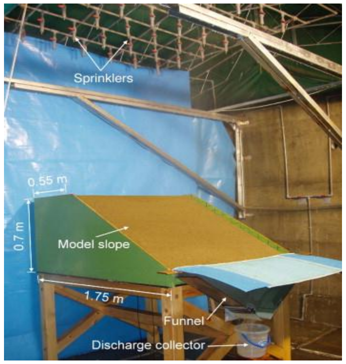
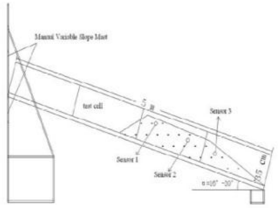
2.3.1 OVERVIEW TABULATION OF OTHER EXPERIMENTS

Previous research on the mechanisms of rainfall-induced landslides has been largely based on experimental studies simulating the field conditions on hill slopes. This section reviews the key laboratory testing approach in finding the factors of shallow landslide, the triggering mechanism and the resulting key issues. Table 1 shows the overview tabulation of other experiments.

Table 1: Overview tabulation of other experiments

Author		**CHEN & CHANG, 2011**	**HUANG, 2008**	**FANG et al., 2012**	**CHENG et al., 2013**	**HUNGCHOU et al., 2012**
Title		Experiment on the stability of granular soil slopes by rainfall infiltration	Internal soil moisture response to rainfall-induced slope failures and debris discharge	Model testing on rainfall-induced landslide of loose soil in Wenchuan earthquake region	Experiment investigation on failure mode of fine-grain rainfall-induced debris flow	Developing processes of rainfall-induced retrogressive landslide by model experiments
Objective		To understand the failure mechanism of granular soil slope subjected to rainfall infiltration was developed and employed to perform experiment in sandy soils.	To gain insight into the rainfall-induced retrogressive slope failure	To investigate the formation process of rainfall-induced landslide for slopes composed of loose soil	To study the interaction of sand and water	To understand the developing process and mechanism of rainfall-induced retrogressive landslide
Variables	**Manipulated**	• Geological condition • Fine contents of drain • Rainfall intensities	• rainfall intensities • geometries condition	• Rainfall intensities	• Rainfall intensities	• Rainfall intensities
	Responding	• Pore water pressure • Water content in soil	• Soil moisture content • Solid discharge	• water content • Pore water pressure	• Pore water pressure	pore water pressure (including matrix suction)
	Constant	Type of soil	• slopes dimension & angle • type of soil • initial dry unit weight	• Type of soil • Slope gradient	• slopes dimension & angle • Type of soil	• slopes dimension & angle • Type of soil
Type of soil		Sand & Silty sand	Sandy soil	the clay content is low and most grain is gravel	Sandy soil	Fine sandy soil
Method	**Approach**	Model test	Model test	Model test	Model test	Model test
	Apparatus	• Sand tank • Rainfall device • Moisture sensor (Delta-T SM200) • Piezometers • CCD Camera	• Water tank • Air compressor • flow meter • plastic pipes • valve • sprinkler	• TRASETDR to measure water content • PSI pressure system to measure water pressure • Video recorder	• Canon 300D to observe water seepage and sliding process • Pore water pressure sensor	• Nozzles • Rainfall simulator • tensiometer

Table 1: Overview tabulation of other experiments (continue)

Apparatus Set up				-	-
Result	• Landslide initiated by erosion at shallow depth • The mode of retrogressive failure started from the toe of sandy slope	The internal moisture response, interflow and seepage patterns may be influenced by slope and bedrock configurations	The effective shear strength of the soil reduces gradually until a critical state, i.e. when the self-weight of the soil is balanced by the pore water pressure, is reached.	The failure process of fine grain impact is sudden and fast as sand in the front of flume model suddenly slid down by the push of posterior sand sample which has significant settlement at the beginning	The soil at the foot of slope was close to saturated owing to the drain and initial landslide was triggered, then the new unstable scarp was increasing during rainfall period, this phenomena caused landslide repeatedly until a stable head scarp was reached
Recommendations	–	More studies are required to validate the present conclusion for various slope configuration and boundary condition	The author suggested that the researchers should take into account the runoff of the soil under excessive infiltration and fine-particle accumulation-induced blocking phenomenon.	–	–

2.4 RELEVANCY AND RECENTNESS OF THE LITERATURE

Literature review is very important in making sure the information gathering and all the data obtained is correct. The information given in the literature also can help in giving guidance to its reader about the topic. For this project, the information from all the articles, books, and journals had given some information about the Shallow landslide triggering mechanism. All the data will be used until the final stage of the project.

CHAPTER 3

METHODOLOGY

3.1 RESEARCH METHODOLOGY

There are a few things that the author does in completing the project. The research methodology will be done in two phases which are during FYP 1 and FYP 2.

3.1.1 Literature Review

The author starts the research with a literature review of the journals, do some reading, data gathering and documentation that relate to the project topic. Literature review is important because the author will get the fully understanding the concept of the project until the project is complete. To achieve the objective, it is important to critically review the literature to identify and describe details on every experimental related with the flume test.

3.1.2 Laboratory and Simulation Work

Laboratory and simulation work will be carried out after enough data are collected. The equipment and apparatus for the lab and simulation work must be prepared before the experiment of project is started. All the data obtain will be analyzed and the evaluation of the result must be based on the requirement and satisfied the lecturer.

3.2 PREPARING SOIL SAMPLE AND RAINFALL MODEL SET UP

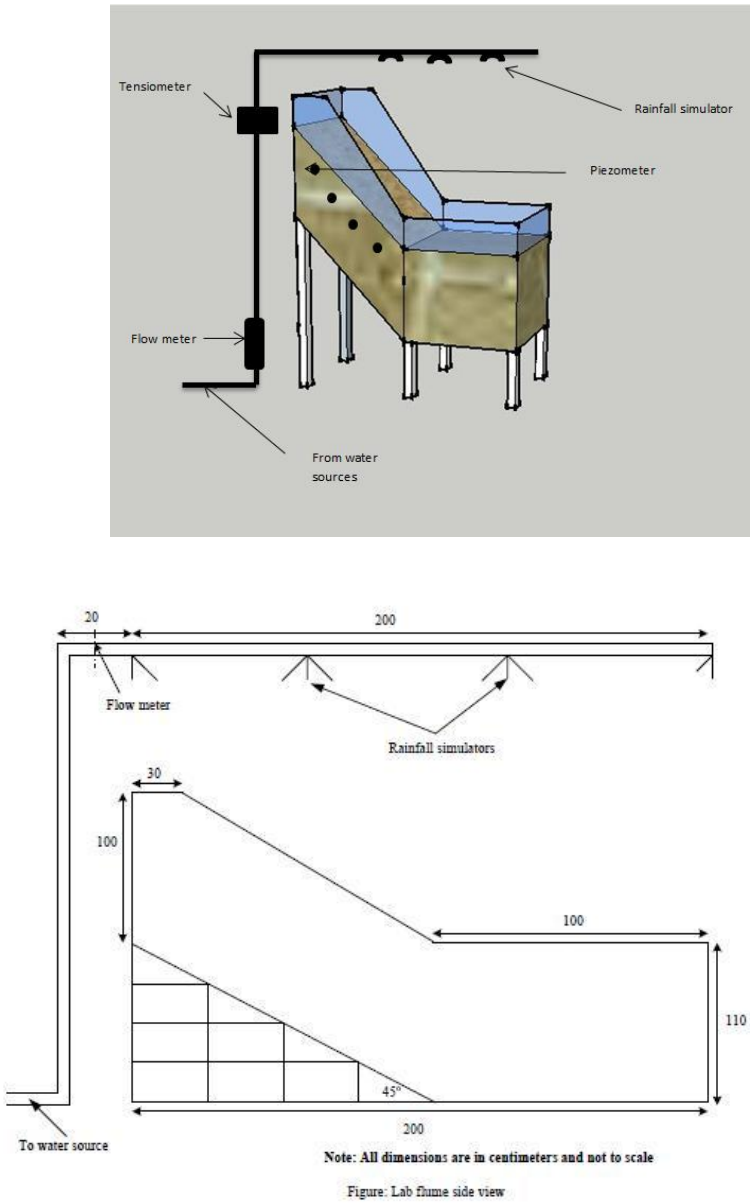


Figure 4 Flume Test Setup& dimension

The method of flume test is testing for the pattern of rainfall in term of its duration or intensity with relating to the ground water table and type of failures observation. The glass at the below soil will act as the bedrock as it is zero permeability. The equipment will be setup as shown in the figure 4 above. Based on monitoring of sliding distance and pore pressures, the process of pore-pressure generation in relation to sliding distance is examined. A set of variables is determined as the controlling parameters. For examples soil type, rainfall intensity, soil hydraulic conductivity. Presence or absence of antecedent rainfall and rainfall duration will be studied setting the relevant parameters according to the Malaysia's reading. The seepage analyses will be conducted as the parameter quantity flow or pore-water pressure will be determined. Instead of that, through the laboratory experiment, the equipment is decided according to the decided parameters. The equipment could be tensiometers, piezometers or any data logger. The result of this experiment will be documented and analyzed through the graphical method or tabulation of data. In this experiment, the sandy soil will be used to construct the experimental slopes. The properties of each soil type determined by laboratory test.

3.3 SOIL PROPERTIES TEST

In order to check the behavior and properties of soil sample, a few soil properties test has been done. Sieve analysis test is to assess the particle size distribution of sample and the soil graded. The specific gravity test is to determine the value of specific gravity of soils by using the large pyknometer method. The last soil properties test is permeability test to determine the coefficient of permeability of sand sample by using constant head method.

3.4 EXPERIMENTAL WORK

In order to identify the dominant mechanism that control initiation of shallow landslide, the data logger developed by SEBA Hydrometrie has been used. This data logger digitally records the water level or any parameters such as water quality, matric suction and pore water pressure.

3.5 PROJECT ACTIVITIES

Figure 5 above shows the flow for the progress of my project work.

Problem Statement and Objective of the project	
Identifying the purpose of this research project	• To obtain soil water characteristic curve from transition of rainwater in the soil from suction to water pore pressure • To define the triggering mechanism of failures on relative to the intensity rainfall and duration rainfall

↓

Literature Review	
Gathering as much information as possible from various sources such as journals and websites	• general features of landslide • water-induced shallow landslide process • experimental studies

↓

Experiment Design
Identifying the subjects that need to be investigated and the experimental procedures, and the collection of results

↓

Data Analysis and Interpretation
The findings obtained are analysed and interpreted critically. Comparison with other literature readings will also be done.

↓

Documentation and Reporting
The whole research project will be documented and reported in detail. Recommendations or aspects that can be further improved in the future will also be discussed.

Figure 5 Progress Flow of Project Work

3.6 KEY MILESTONE

The approach of this project is based on examination and understanding of the scope of work and the timing for the completion of the project. In accordance with the milestones provided in the guideline for final year project, several key milestones have been identified and summarized for FYP I and FYP II in **Table 2** and **Table 3** respectively.

Table 2: Key Milestone for FYP I

Key Milestone	Proposed Week
Submission of Extended Proposal Defence	Week 6
Proposal Defence	Week 9
Submission of Interim Draft Report	Week 13
Submission of Interim Report	Week 14

Table 3: Key Milestone for FYP II

Key Milestone	Proposed Week
Submission of Progress Report	Week 8
Pre-EDX	Week 11
Submission of Draft Report	Week 12
Submission of Dissertation (soft bound)	Week 13
Submission of Technical Paper	Week 13
Oral Presentation	Week 14
Submission of Project Dissertation (hard bound)	Week 15

3.4.1 GANTT CHART (FYP 1)

Table 4 Gantt Chart for FYP 1

NO	DETAIL / WEEK	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Title	■	■													
2	Preliminary Research Work and Literature Review		■	■	■	■										
3	Submission of Extended Proposal Defence						●									
4	Preparation for Oral Proposal Defence							■								
5	Oral Proposal Defence Presentation									■						
6	Detailed Literature Review									■	■	■	■	■		
7	Preparation of Interim Report			■	■	■	■	■		■	■	■	■	■		
8	Submission of Interim Draft Report														●	
9	Submission of Interim Final Report															●

Legend

■	Project Activities
●	Key Milestone

3.4.2 GANTT CHART (FYP 2)

Table 5 Gantt Chart for FYP 2

NO	DETAIL / WEEK	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
1	Project Work Continues																
2	Submission of Progress Report									●							
3	Project Work Continues																
4	Pre-SEDEX																
5	Submission of Draft Report												●				
6	Submission of Dissertation (Soft Bound)													●			
7	Submission of Technical Paper														●		
8	Oral Presentation															●	
9	Submission of Dissertation (Hard Bound)																●

<u>Legend</u>

■ Project Activities

● Key Milestone

CHAPTER 4

RESULT AND DISCUSSION

4.1 INTRODUCTION

In order to determine the dominant factors that control initiation of shallow landslide in area that prone to rainfall and permeable soil, the soil properties of the sample soil is checked.

In determining the trigger mechanism of failure on relative to rainfall intensity and duration, the nature of pore pressure and matric suction for known rainfall intensity is also determined.

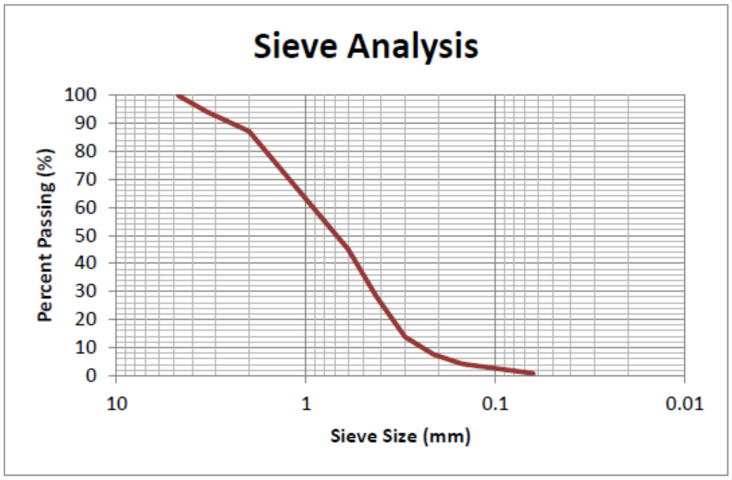
4.2 PROPERTIES OF EXPERIMENTAL SOIL

To check the soil properties, a few tests have been done in laboratory before the experimental work done. Sieve analysis test is to determine the particle distribution in soil and gradation in soil sample. The specific gravity test is to determine the average value of all solid particles present in the soil mass. The permeability test is to determine capacity of soil to allow water through the pore spaces.

4.2.1 SIEVE ANALYSIS TEST

Sieve analysis is a mechanical analysis in determination of the size range particles present in soil, expressed as a percentage of the total dry weight. It is suitable for particles sizes larger than 0.075mm in diameter.

Graph 1 shows the result of the sieve analysis that has been done in laboratory. From the graph below, the Coefficients of Uniformity (Cu) and Curvature (Cc) can be determined. Calculating the coefficients of uniformity and curvature requires grain diameters. The grain diameter can be found for each percent of the soil passing a particular sieve. This means that if 40% of the sample is retained on the No. 20 sieve then there is 60% passing the No. 20 sieve.



Graph 1 Sieve Distribution Semi-log Graph

The coefficient of uniformity, Cu is a crude shape parameter and is calculated using the following equation:

$$C_u = \frac{D_{60}}{D_{10}}$$

Equation 4 Coefficient of Uniformity

Where D60 is the grain diameter at 60% passing, and D10 is the grain diameter at 10% passing

The coefficient of curvature, Cc is a shape parameter and is calculated using the following equation:

$$C_c = \frac{(D_{30})^2}{D_{10} \times \ D_{60}}$$

Equation 5 Coefficient of Curvature

Where D60 is the grain diameter at 60% passing, D30 is the grain diameter at 30% passing, and D10 is the grain diameter at 10% passing

Then,

Cu = D60/D10 = **4.0**
Cc = (D30)2/(D10*D60) = **0.58**

Equation 6 Value of C_u & C_c

Since the calculation shows the value of C_u is less than 4 and C_c is not in the range between 1 and 3, it indicates the soil sample is a poor graded soil. It contains less small and large particles but more particles of intermediate size. Poorly graded soil is a soil that does not have a good representation of all sizes of particles. A poorly graded soil will have better drainage because there are more void spaces in between the soil.

4.2.2 PARTICLE DENSITY / SPECIFIC GRAVITY TEST

The objective of this test is to determine the ratio of the soil density to density of water by using the large pyknometer method. This method is used for soils containing particles up to medium gravel size.

The laboratory result shows that the specific gravity, G of the soil sample is 2.60. The specific gravity of solids for most natural solid falls in the general range of 2.65 to 2.80. The smaller values are for the coarse-grained soils.

4.2.3 PERMEABILITY TEST

Permeability test is to determine the coefficient of permeability or hydraulic conductivity of soil sample by using Constant Head Method. The degree of permeability is determined by applying a hydraulic pressure gradient in sample of saturated soil and measuring the consequent rate of flow. The consequent of permeability is expressed as a velocity. This procedure is suitable for soil having coefficient of permeability in range 10^{-2} to 10^{-5} m/s.

Saturated hydraulic conductivity is a quantitative measure of a saturated soil's ability to transmit water when subjected to a hydraulic gradient. It can be thought of as the ease with which pores of a saturated soil permit water movement. (Saturated Hydraulic Conductivity: Water Movement Concept and Class History) The saturated hydraulic conductivity, k for this sample is 3 x 10^{-4} m/s (0.03 cm/s). The value of hydraulic conductivity (k) varies widely for different soil. Some typical values for saturated soil are given in table 6 below

Table 6 Typical Values of Hydraulic Conductivity of Saturated Soils

Soil Type	k (cm/s)
Clean gravel	100 - 1.0
Coarse sand	1.0 - 0.01
Fine sand	0.01 – 0.001
Silty clay	0.001 – 0.00001
Clay	< 0.00001

Based on table above, it can be conclude that the soil sample is coarse sand. So, the degree of permeability is considered low for unsaturated soil.

4.2.4 INFILTRATION PROCESS

When rain or irrigation water is supplied to a field, it seeps into the soil. This process is called infiltration. The infiltration rate of a soil is the velocity at which water can seep into it. Usually, the infiltration rate of soil depends on factors that are constant, such as the soil texture. It also depends on factors that vary, such as the soil moisture content. Since the soil sample is classified as coarse soils, the rain water will enters and moves more easily into large pores: it takes less time for the water to infiltrate into the soil. In other words, infiltration rate is higher for coarse textured soils than for fine textured soils.

4.3 EXPERIMENTAL APPARATUS

4.3.1 RAINFALL MODEL

The experiments were conducted in a flume tank, with transparent side installed with a rectangular glass, was 1 meter wide, 2 meter long and 2.1 meter high. It is shown schematically in figure 6. To generate an impervious boundary at the end of the slope model, 15mm wooden board, 50cm in height was secured at the slope end. The flume tank structure was rigidly constructed to minimize deflection.

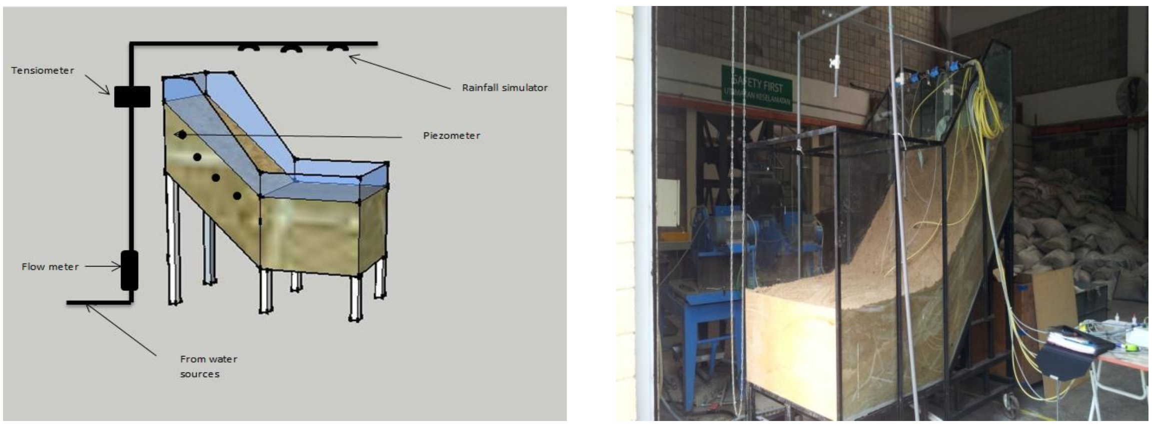


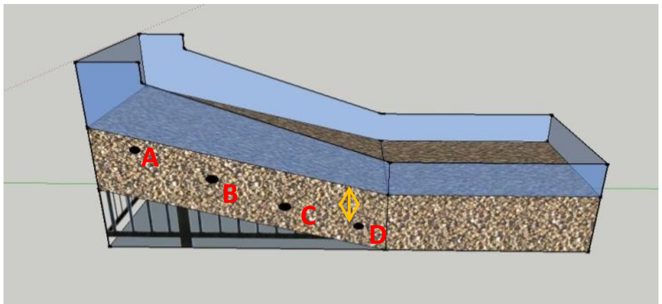
Figure 6 Rainfall model / flume test

4.3.2 SLOPE PROFILE AND SOIL PLACEMENT

The flume angle is made constant for 45^o as the typical angle for shallow landslide to happen in Malaysia is between 30^o to 60^o. There is a consideration of two type layers acting during the test. First layer is the bottom glass which will act as impermeable layer or ground rock layer. Second layer is sample soil layer, silty sandy soil type.at the end of edge of apparatus, a vinyl tube is inserted into the hole with one end where the excess water could flush free. The soil slope was conducted by placing soils in a series of horizontal layers 30cm thick for the first layer and another 20cm for second layer. Meanings the total thickness of the sample soil from bottom is 50cm.

4.3.3 EXPERIMENTAL INSTRUMENTATION

Upon the introduction of water level rise, the moisture content within the slope might be change during slope wetting. To monitor the changes of volumetric soil moisture content throughout the experiment, the model slope were instrumented with four piezometers and tensiometers. Piezometers are wrapped with cotton bag in order to prevent the sand particle contaminate the sensor. Figure 7 below shows the layout for arrangement of the devices in the soil.



Legend
● Piezometer and tensiometer location (parallel location)

Piezometer and tensiometer	Depth from the slope surface
A	0.1 m
B	0.2 m
C	0.3 m
D	0.4 m

Figure 7 Sensors device alignment

To measure the rainfall intensity reading, the using of several rain gauges at random location can help to find the average water drop on the slope. In order to check the water flow rate from the water sources, the small-scaled flow rate has been used.

4.3.4 RAINFALL SIMULATOR

A rainfall simulator was set approximately 0.5m above the model slopes to induce the change in volumetric moisture content and instability in the model slope. Acting as artificial rainfall, two sprinklers is used in order to ensure the whole surface receive the rainfall equally.

4.4 EXPERIMENTAL DETAILS

After the soil characteristic was figure out, the experiment will be started to check on the slope failure mechanism in soil by using rainfall model and data logger developed by SEBA Hydrometrie. SEBA hydrometrie data logger is digitally record the water level or any parameters such as matric suction and pore pressure inside the soil. The features of SEBA Hydrometrie data logger are event-controlled/time-controlled registration, individual control of the connected sensors and alarm management.

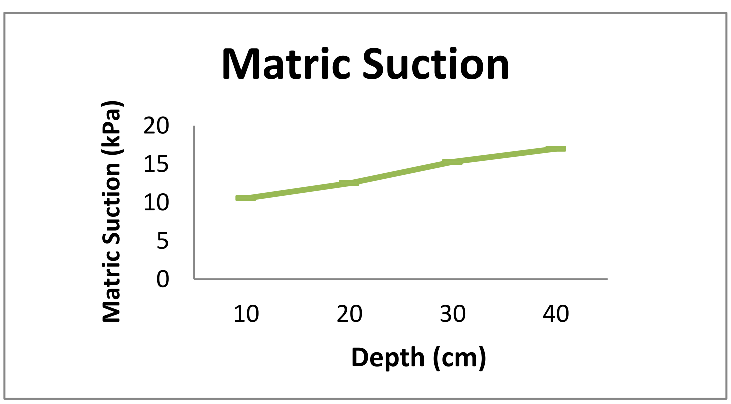
4.5 INFLUENCE OF RAINFALL INFILTRATION

4.5.1 INITIAL READING

The initial reading of piezometer and tensiometer before the infiltration occurs in soil. The readings are shown in the table 7 and table 8. It is to determine the matric suction and pore water pressure behavior in soil at different depths.

Table 7 the initial tensiometer reading

No.	Channel	Depth (cm)	Value (cb)
1	Tensiometer/Soil Moisture 1	10	10.55731
2	Tensiometer/Soil Moisture 2	20	12.50329
3	Tensiometer/Soil Moisture 3	30	15.29001
4	Tensiometer/Soil Moisture 4	40	16.99491



Graph 2 the initial tensiometer reading versus depth of soil

The tensiometer reading represents the value of soil moisture tension or matric suction of the soil. As we can see from the reading above, the matric suction is increasing due to increase in depth of the point of tensiometer in soil.

Matric suction can be defined as a negative pore-water pressure. As the depth increase, the matric suction will be increase. As the matric suction increase, the volumetric water content of the soil will be decreases. This affects the movement of water through soil because there are less water filled spaces available for water flow. As matric suction increase, the permeability of the soil will be decreases.

Table 8 The initial piezometer reading

No.	Channel	Depth (cm)	Value (kPa)
1	Piezometer/Groundwater 1	10	0
2	Piezometer/Groundwater 2	20	0
3	Piezometer/Groundwater 3	30	0
4	Piezometer/Groundwater 4	40	0

The piezometer reading shows the measurement of groundwater pressure. The reading of groundwater pressure is nearly zero and assumed as zero reading for all piezometer because there are no pore water pressure detected at any point during the experiment. The location of piezometer is located at different point. The slope considered has low ground water table.

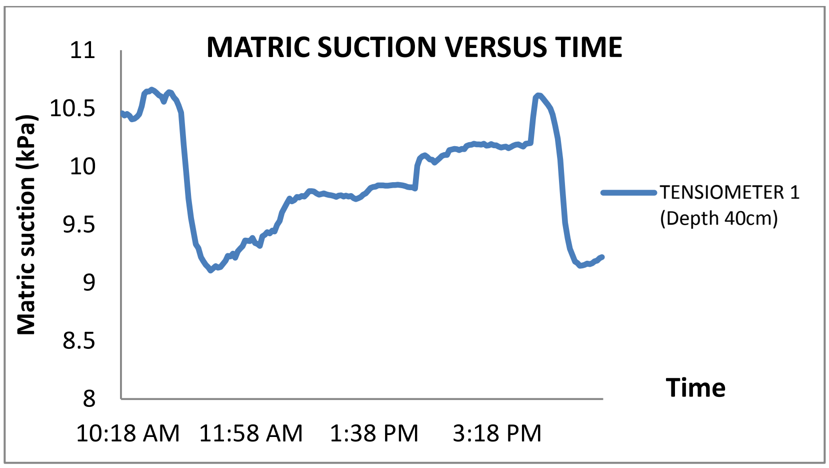
4.5.2 OBSERVATION OF MATRIC SUCTION VARIATION IN SLOPE WITH RESPECT TO RAINFALL DURATION AT HIGH RAINFALL INTENSITY

Graphs 3, 4, 5 and 6 show the matric suction variation in slope for high rainfall intensity. The experiment is started at 10.18 am until the slope failure take place. The type of rainfall simulated on the slope is categorized as delayed rainfall pattern. The readings are for:-

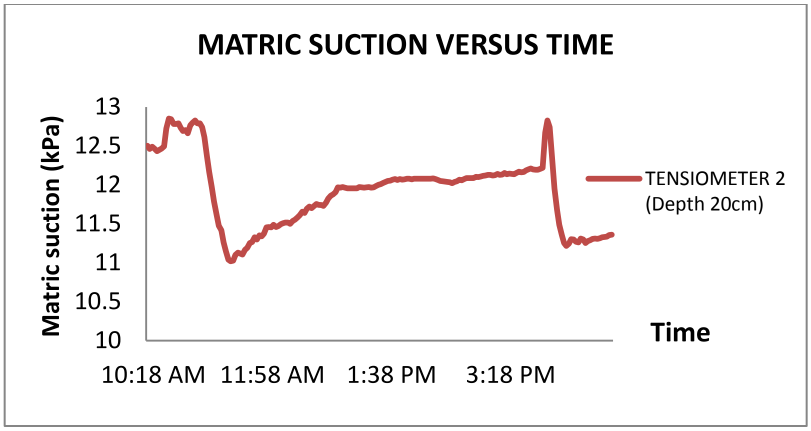
- Rainfall intensity: 26mm/hr (high rainfall intensity)
- Flow meter reading 12 L/min
- Soil Type: Silty Sand
- Soil Inclination: 45^{o}

Table 9 Rainfall pattern of the experiment (during high rainfall intensity)

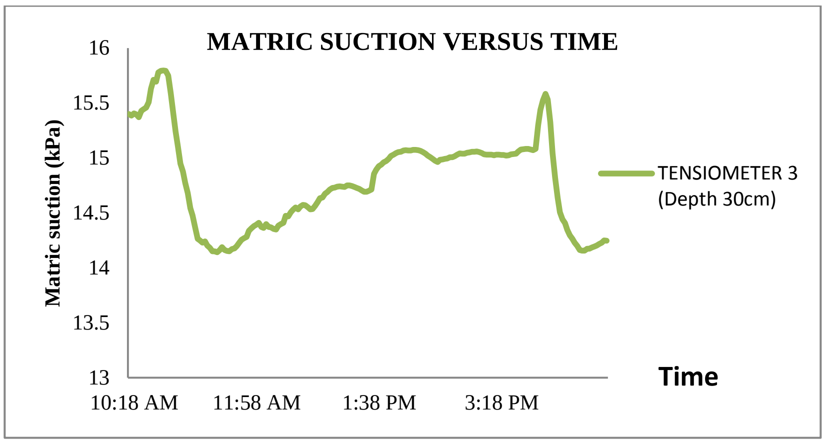
Time (24 hours)	
10.48	Rainfall starts
11.48	Rainfall stops
15.48	Rainfall starts
16.48	Slope failures detected



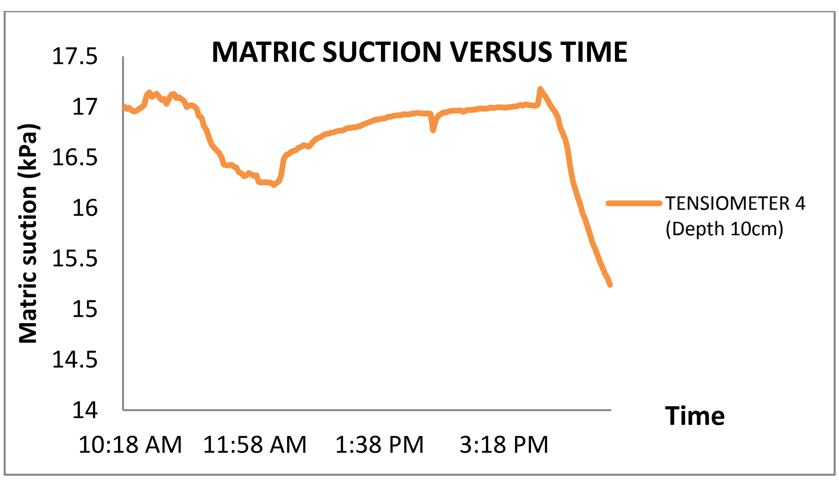
Graph 3 Matric suction variation for tensiometer 1 (high rainfall intensity)



Graph 4 Matric suction variation for tensiometer 2 (high rainfall intensity)



Graph 5 Matric suction variations for tensiometer 3 (high rainfall intensity)



Graph 6 Matric suction variations for tensiometer 4 (high rainfall intensity)

The graphs 3, 4, 5, and 6 above show the matric suction variation during high rainfall intensity at different depth. The patterns are still the same. From the graph, it can be conclude that the infiltration caused a decreased in the matric suction (increase in pore-water pressure) as shown in upward pattern of line from 10.48am until 11.48am (infiltration occurs). The sudden downward shift shows the increasing of matric suction (decrease in pore-water pressure) from 11.48am until 3.48pm (infiltration start to reduce) and the failure triggered at 4.48 pm due to reducing of matric suction.

The readings of tensiometers were automatically recorded up until failure took place. The duration required for failure to take place is 6 hours and 22 minutes of rainfall infiltration into slope.

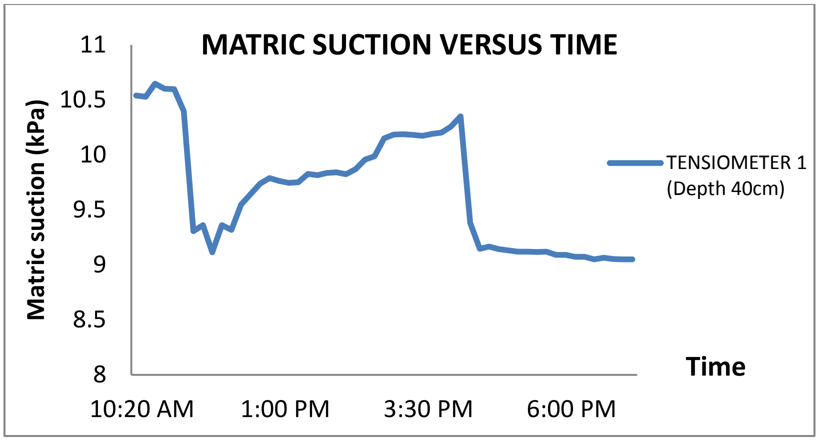
4.5.3 OBSERVATION OF MATRIC SUCTION VARIATION IN SLOPE WITH RESPECT TO RAINFALL DURATION AT LOW RAINFALL INTENSITY

Graphs 7, 8, 9, and 10 show the matric suction variation in slope for low rainfall intensity. The experiment is started at 10.20 am until the slope failure take place. The type of rainfall simulated on the slope is categorized as delayed rainfall pattern. The readings are for:-

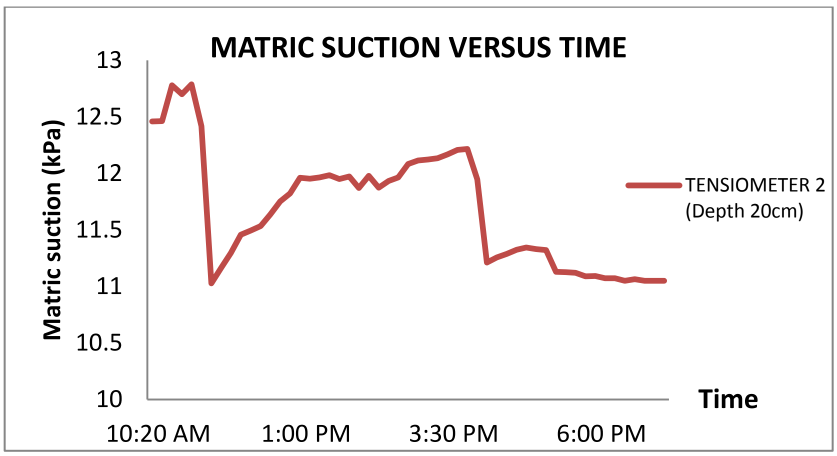
- Rainfall intensity: 7mm/hr (low rainfall intensity)
- Flow meter reading 6 L/min
- Soil Type: Silty Sand
- Soil Inclination: 45^{o}

Table 10 Rainfall pattern of the experiment (during low rainfall intensity)

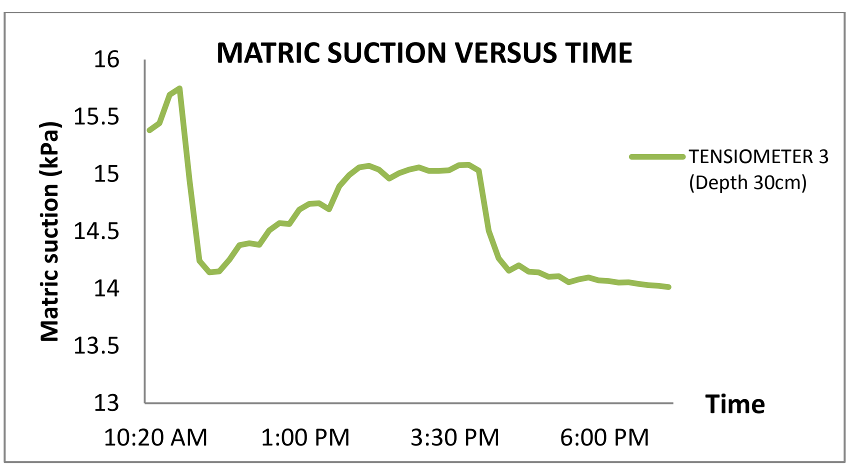
Time (24 hours)	
10.20	Rainfall starts
11.50	Rainfall stops
15.40	Rainfall starts
19.10	Slope failures detected



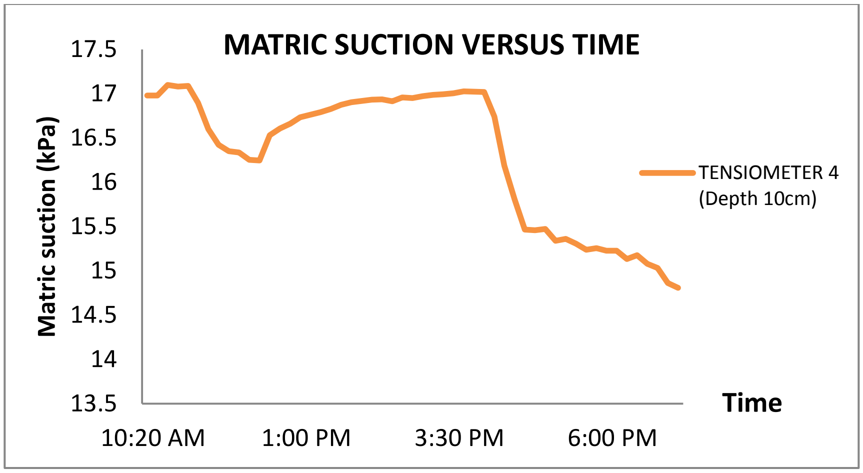
Graph 7 Matric suction variation for tensiometer 1 (low rainfall intensity)



Graph 8 Matric suction variation for tensiometer 2 (low rainfall intensity)



Graph 9 Matric suction variation for tensiometer 3 (low rainfall intensity)



Graph 10 Matric suction variation for tensiometer 4 (low rainfall intensity)

The graphs 7, 8, 9, and 10 above show the matric suction variation during low rainfall intensity at different depth. But the patterns are still the same. From the graph, it can be conclude that the infiltration caused a decreased in the matric suction (increase in pore-water pressure) as shown in upward pattern of line from 10.20am until 11.50am (infiltration occurs). The sudden downward shift shows the increasing of matric suction (decrease in pore-water pressure) from 11.50am until 3.40pm (infiltration start to reduce) and the failure triggered at 7.10 pm due to reducing of matric suction.

The readings of tensiometers were automatically recorded up until failure took place. The duration required for failure to take place is 9 hours and 10 minutes

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

From the results of this study, the following conclusion can be drawn.

Results of both soil properties test and experimental work showed that the infiltration occurs in the soil sample used which the soil is classified as semi-pervious soil with low permeability.

Based on the reading of piezometer, it shows the zero reading. This value indicates that the slope has low ground water table. Thus, infiltration reduces the negative pore pressure (matric suction) above the main groundwater table by an amount depending on the rainfall intensity. However, infiltration does not result in significant rise in the main water table for the range of rainfall intensity considered in this study

On the measurement of matric suction, it appears that the infiltration occurs faster at the nearer to slope surface if compared to deeper location. The infiltration process in slope caused by rainfall reduces matric suction and increases the moisture content and soil permeability in the unsaturated zone. It is found that reduction in matric suction is the dominant mechanism that led to the slope failure during high rainfall intensity & long rainfall duration at the low ground water table condition

The rainfall intensity has a marked effect on the slope stability. The higher the intensity of rainfall, the higher the infiltration rate through the soil. Hence the faster the rate of matric suction to decrease and the shorter the time for slope failure to occur.

5.2 PROBLEM ENCOUNTERS

There are several problems encounter during this study. The result obtained might not be accurate due to some problem and need to be improved in future study. The problems are:

The sensor devices such as tensiometer and piezometer are very sensitive to heat and sunlight which affected the readings and causes confusion in analyzing the data.

The water pressure from the source is too slow. It will limit the variation of water flow rate and rainfall intensity during the experiment. The flow meter used is able to give two values which are the highest and lowest value of flow rates only (highest and lowest rainfall intensity)

Piezometer readings show no raise of groundwater level because there are uncontrolled leakages in rainfall model.

The rainfall simulator did not provide uniformly distributed rainfall type. So, we need several rain gauges to find the average rainfall intensity for the experiment.

5.3 RECOMMENDATION

Below are several recommendations to overcome the problems

i. Run the experiment in the close room to prevent the heat from outside affects the readings.
ii. Provide water pump to increase the water pressure from the source
iii. Avoid any uncontrolled leakage in the rainfall model by using appropriate glue
iv. Use suitable water sprinkler type to simulate uniform distributed rainfall on the slope since it will contribute huge factor to the slope failure

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APPENDICES

PHOTO	DESCRIPTION
	Figure A-1 Flume model set up
	Figure A-2 Flow meter installation

<table>
<tr><td>PHOTO</td><td>DESCRIPTION</td></tr>
<tr><td></td><td>Figure A-3

Slope profile & soil placement</td></tr>
<tr><td></td><td>Figure A-4

Tensiometer & piezometer installation</td></tr>
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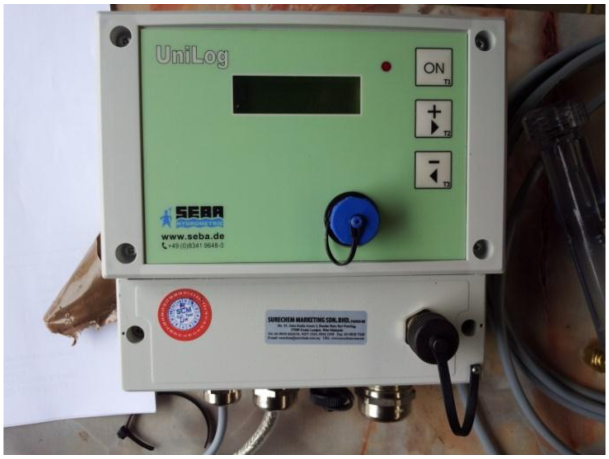
PHOTO	DESCRIPTION
 	Figure A-5 SEBA Hydrometry Unilog
	Figure A-6 Water sprinkler used as artificial rainfall

PHOTO	DESCRIPTION
	Figure A-7 Permeability test using constant head method
	Figure A-8 Sieve analysis test