CHARACTERIZATION OF SHALLOW LANDSLIDE THROUGH RAINFALL MODEL

by

MD. FAZA BIN MOHAMAD RAHIMI

DISSERTATION

Submitted in partial fulfillment of

the requirements for the

Bachelor of Engineering (Hons)

(Civil Engineering)

MAY 2013

Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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Approved by,

……………….......................

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May 2013

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 persons.

……………………………………..
MD. FAZA BIN MOHAMAD RAHIMI

ACKNOWLEDGEMENT

This is dedicated especially to those who have participated in this project from various specialty and those who reviewing this dissertation. Highest praise is to Allah the Almighty, for the blessing of knowledge gain, endurance and perseverance in completing this Final Year Project within the timeframe given. Here I would like gratefully and sincerely thank everyone that have shown commitments and continuously support the whole process of my Final Year Project. Deep sense of gratitude to my own Project Supervisor, Dr. Indra Sati Hamonangan Harahap and his General Assistance, Mr. Lami Boru for the guidance for their continuously support throughout the project. I also would like to thank the following individual for their professionalism and contribution towards the project completion; Mr. Lim Meng Chieh, technical support staff from Surechem Sdn Bhd and Mr. Azwan, technician from UTP Geotechnical Lab including the entire staff of in UTP Civil Laboratory Department. Not to forget, I would like to thanks the Final Year Project Coordinators and UTP IRC fellows for the guidance and hard work in order to keep all the Final Year Student stay in the right track. Last, I would like to thank my parents for allowing me to realize my own potential. All the support they have provided me over the years was the greatest gift.

Thanks

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c' = the effective cohesion

σ_n = the total normal stress

u = the pore-water pressure

ϕ' = the effective angle of internal friction

τ = the shear stress

$(\sigma_n - u)$ = the effective stress which is σ'

ABSTRACT

This study is identifies the characteristics of rainfall-induced shallow landslides. Experimental investigation has been performed by using flume laboratory which signify the real situation of shallow landslide setup through a rainfall model and the variation of the controlling soil parameters under various artificial rainfall conditions. A series of tests was conducted to trigger rainfall-induced landslides. A study on the sample soil is kept going in order to understand its properties which correlate the parameters setup. The variable controls or parameters are the intensity and duration of artificial rainfall. The sample type will be used in the experimental is commercial sand since the shallow landslides occur at this particular type of soil. The landslide triggering mechanism could be described in many ways. Firstly, the large porosity of sand will result high permeability and increase the rate of infiltration hence increase the pore-water pressure and reduced the shear strength of soil in inclination position. In addition the fine particles may condense deep into the sandy soil during the rainfall and create pressure which can cause shallow landslide at surface. Observation of failure phenomena details are taken to show the failure mode of shallow landslides. The results of these objectives will be clarify with the literature readings and analysis on the mechanisms will be compared to the objectives. 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.

Keywords: Shallow landslides, Rainfall Duration, Rainfall Intensity

INTRODUCTION

Landslide is the major destructive constitution threat to lives as well as property including buildings, roads and connections. High statistics of fatalities were recorded related to the shallow landslide. The extensive damage could also endanger the population in term of destruction of communication and supply connectivity. Basically, landslide occurs because of slope failure which is considered as natural disaster. Landslides or slope failure is a natural disaster that occurs in the whole world especially in the South East Asia. This is because this area is surrounded with high hill slope and the structure of the earth materials itself is very subjective. In addition, this area also deals with the tropical environment meanings high annual precipitation in the region. The significance of rainwater infiltration in causing landslides is well thought however many different conclusions came out as to the relative roles of antecedent rainfall to landslides. The steep slope of Malaysia region is dissected by few numbers of shallow landslides due to rainfall. Thus, shallow landslides always occur mainly into forest and grassland. Some of trees were uprooted and leaned due to effect of flowing mass. Along the bed of stream there is a sediment deposition too. Majority of the shallow landslides were found to occur in between 30° - 60° slope angles for Malaysia regions. The steep hilly topography, high precipitation and loosely bounded nature of grains are the prime factors of shallow land sliding. The mechanism that comprise in triggering shallow landslide should be the duration and intensity of the rainfall. A series of parametric studies has been formed by investigation on relative importance of soil properties, initial water table location, rainfall intensity and slope geometry in inducing instability of a homogenous soil slope under different rainfall. The primary factors controlling the instability of the slopes due to rainfall are soil properties and rainfall. It is followed by the initial water table location and slope geometry as secondary role.

CHAPTER 1

PROJECT BACKGROUND

1.1 Background Study

Shallow landslide happens whenever the depth of soil failure is below than 2 meter. It could be happened within various widths as long as it depth is not more than 2 meters or else it will be classified as deep landslide. In addition, the shallow landslide may consist of two types of layers which are top soil and bottom soil. Top soil represent any type of soil which having high permeability and bottom soil is representing low permeability layer.

Due to low permeable soil at bottom layer, water accumulates in the top layer which will raise the groundwater table and increases the pressure head as raining occurs. Therefore, it creates high water pressure and pore-water pressure on top of soil. This scenario will result instability of the soil located with high slope and generate surface movement.

The shallow landslide occurs at two points which are at the upper hill or downhill. At the upper hill, the triggering happens because of suction factor through the infiltration of rainfall in the soil. At the downhill, the triggering happens because of the watering resulted from high water table which create hydraulic water pressure.

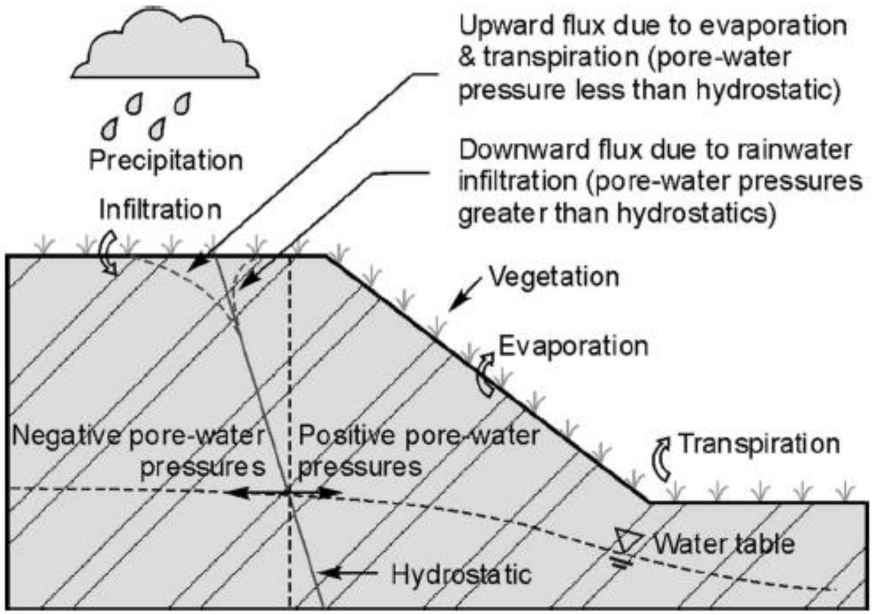


Figure 1 Schematic representation of effects of climatic conditions on pore-water pressure profile near the ground surface of slope

As we know, the slope of failure could be caused by a lot of factors and mainly rainfall. So, to tropical regions are preferred the most for landslide to occur. Shallow landslides mostly covered with agricultural soil and weathered rocks, short period of rainfalls where capable to trigger debris flows and rock falls. Mostly, rainfall-induced shallow landslides relate with the changing pattern of ground water table where the resulting the increasing of pressure head hence increasing the hydraulic pressure through the soil. The stability of residual soil slopes is strongly influenced by climatic and hydrological changes, such as precipitation, infiltration, evaporation and the transpiration processes as illustrated in Figure 1 (Rahardjo, 2007).

Shallow landslides frequently happen in areas that have slopes with high permeable soils on top of low permeable bottom soils. Bottom soils with low permeable trap the water in the shallower thus create high water pressure in the high permeable top soil. Slopes can become very unstable as the top soils are filled with water and become heavy hence slide over the low permeable bottom soils.

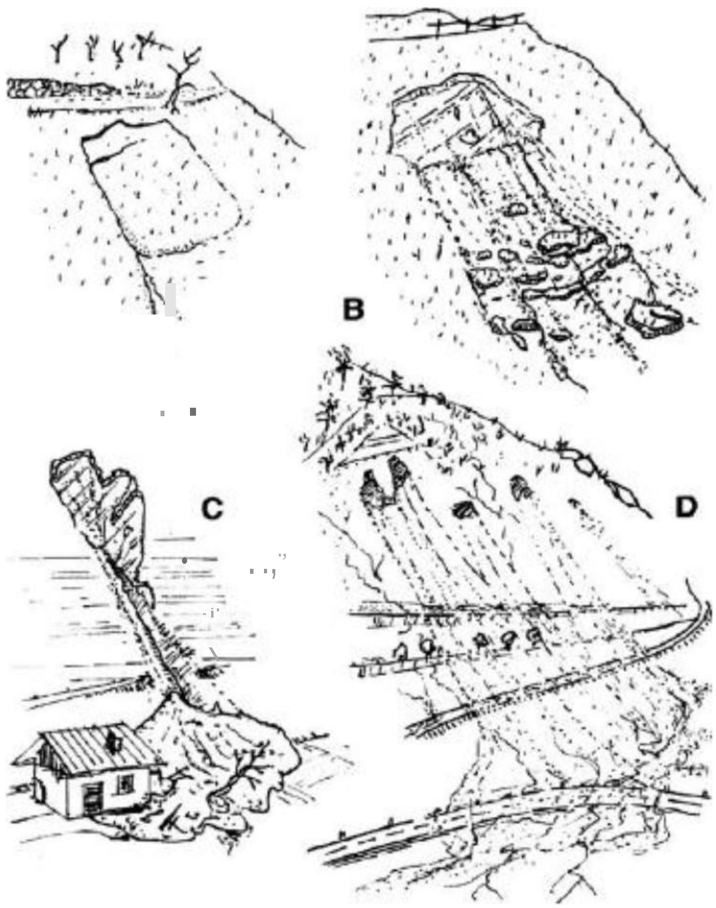


Figure 2 Illustration of kind of shallow landslides

1.2 Problem Statement

Rainfall-induced shallow landslides are becoming ever more frequent all over the world and are receiving a rising interest in consequence of the heavy damage they produce. The most critical part is when the triggering of landslide is unexpectedly as the random characterization of movements. Due to a lot of landslides in the particular area, an experiment will be conducted to characterize the rainfall-induced shallow landslide. The main causes of this phenomenon seem to prolonged rainfalls of medium intensity or very intense rainfalls following relatively wet periods. This rainfall model can foresee the triggering mechanism present at the each mode of duration and intensity of rainfall. So, the experiment is aimed to foresee the occurrence of the phenomenon in two ways of parameters which are long period of rainfall with low intensity of rainfall and low period of rainfall with high intensity of rainfall.

1.3 Objective

The objective of this study is to discover the characterization of shallow landslides through the rainfall model. Other than that, this study is aimed to find the solution on how to avoid the shallow landslides occur before problems arise as stated in the problem statement. So, all the parameters or ranges for determined variables should be discovered first. Moreover the precautions can be made for the potential triggering landslides.

The objective of this study:

- To discover the characterization of shallow landslides through the rainfall model.

- To define the triggering mechanism of failures on relative to the intensity rainfall and duration rainfall.

1.4 Scope of Study

In this study, the main subjects under investigation are:

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

And the aspects being studied are:

i. *Infiltration Concepts*
ii. *Slope Failure Stages*
iii. *The Triggering Mechanism of Rainfall-Induced Landslides*

The details of the scope of study will be discussed in Chapter 2 based on the articles reading.

1.5 Thesis Organization

This thesis consists of five chapters. The first chapter is briefly describes the background, problem statement, objective of the research and scope of study.

Chapter 2 is the literature reviews of the past researches. It includes explanation on the triggering factors of shallow landslides and its soil properties.

Chapter 3 shows the detail of the equipment, devices used and preparation of the experiment. In addition, this chapter also discusses methodology procedure and the apparatus specification for this experiment.

Chapter 4 shows all the results and findings of the research are presented and discussed with the references from the previous studies. The important aspects are discussed in term of its soil properties and parameters decided.

Finally, chapter 5 presents the conclusions of the research and some recommendations for the future study.

CHAPTER 2

LITERATURE REVIEW

2.1 Infiltration concepts

Shallow rainfall-induced landslides of failure on the surfaces is oriented parallel to the slope surface in areas where a collegial soil profile has formed over a bedrock interface. Landslides always occur as shallow even in areas of hill slope topography where ridge and hollow geoforms exist with tremendous spatial variability. The effect of seepage on slope stability can be calculated by using the factor of safety or critical depth for an infinite slope relative to seepage parallel to the slope surface. This concept only applicable for the slope completely saturated. For initially unsaturated slopes, rainfall will affect the slope surface with dramatically different effects. As the infiltrating water moves downward to soil profile, a transition process will occur because of the development of pore water pressure pattern in the soil. The shear strength of the soil mass factor must be considered more detail in order to deal with unsaturated stability analyses. The evolution of the pore water pressure profile also relative to the development of seepage forces in the soil. Pore-water pressure is resulted from the parallel analyses using one-dimensional and two-dimensional infiltration which identical for an infinite slope.

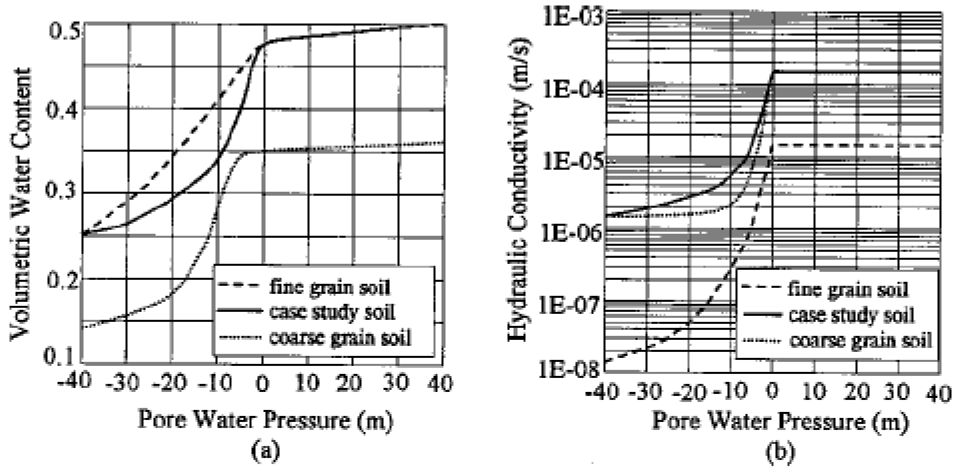


Figure 3 Coarse grain soil, fine grain soil, and case study soil unsaturated characteristic curves.

Analyses for the infiltration of rainfall into typical fine and coarse grain soil were performed using the unsaturated characteristic curves shown in Figure 3.

The evolution of the pore water pressure profile also relative to the development of seepage forces in the soil as shown in the figures below:

a) Starting from the zones around pores, the infiltration through the pores causes the saturation of the surrounding soil.

b) If the rain does not stop, the process continues and greater portions of soil become saturated.

c) If the raining process persists, the saturated portions of soil extend and become continuous, leading to the loss of partial saturation in most of the soil.

2.2 Failure Stages

The failure onset of rainfall-induced shallows landslides is strictly related to the increase of pore-water pressures and the consequent reduction of mean effective stresses (Anderson and Sitar 1995; Alonso et al. 1997). According to Leroueil (2001), drain process is resulted from the failure stage of rainfall-induced shallow landslides of the flow-type in natural slopes which takes account no variation of pore pressures are induced by the soil volume change.

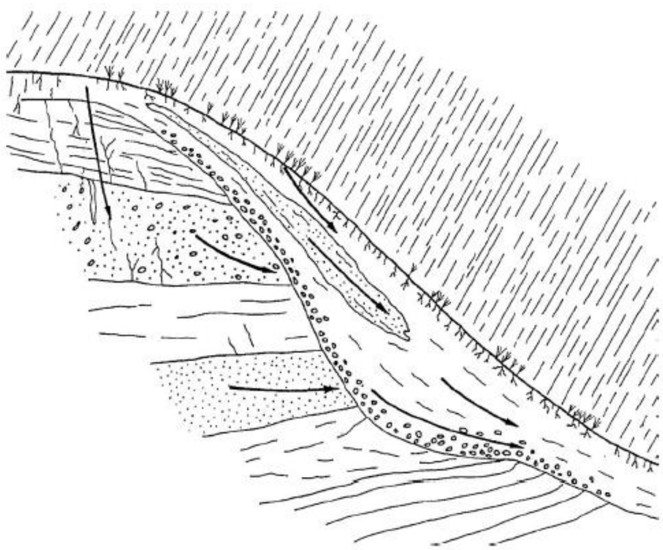


Figure 4 Scheme of ground water circulation inside shallow soil deposits and bedrock (after Johnson and Sitar 1990)

The increase of pore-water pressures can be generated by rainfall inside the shallow soil deposits that directly infiltrate the slope surface and propagate in depth through groundwater flow patterns related to stratigraphical setting of the slope (Ng and Shi 1998). Hydro geological characteristics of the underlying bedrock that forced severe hydraulic boundary conditions at the bottom of shallow deposits affects pore-water pressure regime. For example, the water table arises because of the presence of springs from the bedrock.

2.3 The triggering mechanism of rainfall-induced landslides

2.3.1 Factor of Safety

Landslides instigate when shear stress is greater than the shear resistance of the material (Terzaghi, 1950). Shear stress means the driving force that causes down slope movement of slope materials, or the "external" force meanwhile shear resistance means the resistance of movement, or the "internal" force. 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 1

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 2 Coulomb equation

c' = the effective cohesion

σ_n = the total normal stress

u = the pore-water pressure

ϕ' = the effective angle of internal friction

τ = the shear stress

$(\sigma_n - u)$ = the effective stress which is σ'

The triggering mechanism of rainfall-induced landslide on shallow mostly resulted from the increase of pore-water pressure. According to Terlien (1998), this can be termed as hydrological triggering. Basically, the shear stress related to the rainfall on the slope and seeps into soil by gravity. However, the increase of pore-water pressure causes decrease of normal shear stress of the soil slope. The buoyancy force reduces the shear resistance of the inter-particle friction and turns the factor reaching 1 hence triggers a landslide. The failure can be expressed in Mohr-Coulomb failure envelope.

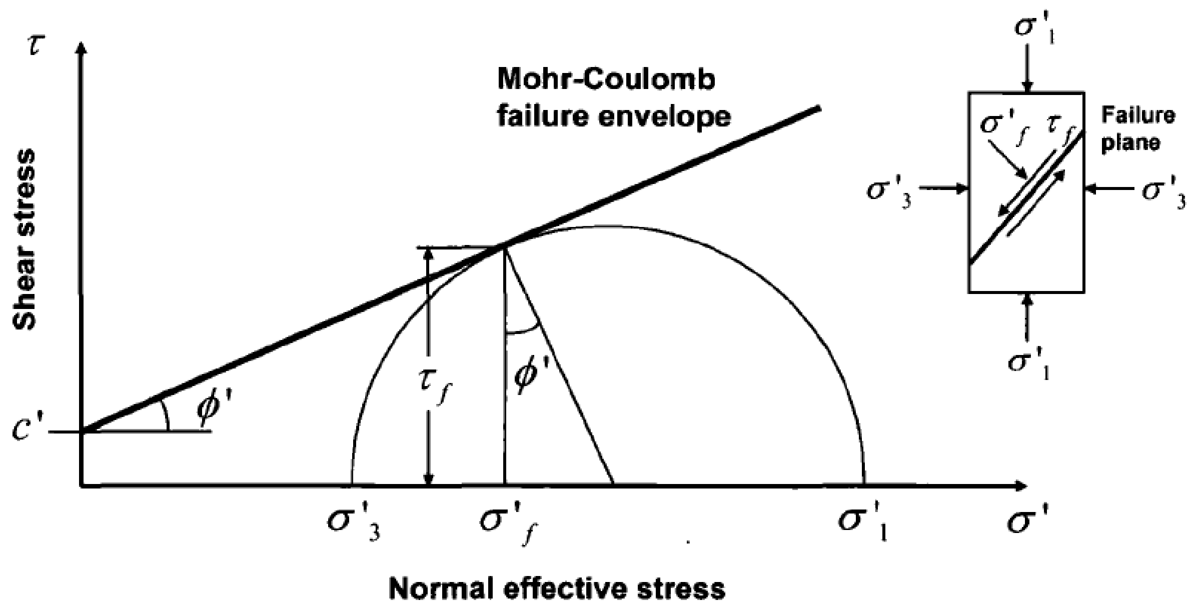


Figure 5 Stress conditions at failure (Craig, 1997)

However, the Mohr-Coulomb criterion cannot determine or explain the landslide kinematics, displacement rates, velocity, the acceleration and the movement style at the shear zone (Qin et al., 2006)

2.3.2 Rainfall Effects

As we know, the rainfall is the main cause of landslide especially shallow landslides. The causes could be:

1. The rainfall penetrates into the potential landslide, increases the soil bulk density, soften the soil, reducing the stabilizing force of the soil.
2. The rainfall increases the pore water pressure rapidly, which diminishes the effective stress and shear strength in the potential sliding surface.
3. The shallow landslides are usually a result of liquefaction, a process during which a high excess pore water pressure is generated, and the soil mass suddenly loses a large proportion of its shear resistance and flows in a manner resembling liquid. Liquefaction of sands due to cyclic loading. (Fang, Cui, Pei, & Zhou, 2012)

2.3.3 Type of Landslides

Most of landslide observed based on three key elements which are the type of movement, kind of material and the rate of movement. (Varnes, 1978) According to many reading materials, we can say that the classification proposed by Varnes (1978) is the most used. The type of landslide includes the falls, topples, slides, spreads and flows. For shallow landslide, it is categorized in flow type of landslides.

Landslide type is classified by (1) the shearing conditions (first time; reactivated) with reference to soil fabric (undisturbed; disturbed) and shear strength parameters (peak; between peak and residual) and (2) pore-water pressure conditions over time (short-time, undrained, partial equalization of excess pore-water pressures; and long term, drained). (Hutchinson, 1988)

(a) Soil fabric (affecting c' and ϕ')	(b) Pore-water pressure on the slip surface (affecting u)
1. FIRST-TIME SLIDES IN PREVIOUSLY UNSHEARED GROUND: soil fabric tends to be random (or partly orientated as a result of depositional history) and shear strength parameters are at peak or between peak and residual values.	1. SHORT TERM (undrained) – no equalisation of excess pore-water pressure set up by the changes in total stress.
2. SLIDES ON PRE-EXISTING SHEARS associated with:	2. INTERMEDIATE – partial equalisation of excess pore-water pressures. Delayed failures of cuttings in stiff clay are usually in this category.
2.1 Re-activation of earlier landslides	3. LONG-TERM (drained) – complete equalisation of excess pore-water pressures to steady seepage values.
2.2 Initiation of landsliding on pre-existing shears produced by processes other than earlier landsliding, i.e.: (a) Tectonics (b) Glacitectonics (c) Gelifluction of clays (d) Other periglacial processes (e) Rebound (f) Non-uniform swelling	Note that combinations of drainage conditions 1, 2, 3 can occur at different times in the same landslide. A particularly dangerous type of slide is that in which long-term, steady seepage conditions (3) exist up to failure but during failure undrained conditions (1) apply, i.e. a drained/undrained failure.
In these cases the soil fabric at the slip surface is highly orientated in the slip direction, and shear strength parameters are or about residual value.	

Table 1 Geotechnical classification of landslides based on soil fabric and pore water pressure conditions

The purpose of this experiment is to find the characteristics of rainfall induced shallow landslides. Based on the geotechnical classification in Table (Varnes, 1978), it shows the mechanisms of slope movements. This experiment examines landslides by simulating the field conditions of rainfall pattern to create pore-water pressure in tropical slope materials.

2.4 Comparison with other experiments

This section explains about details on other tests done regarding to the rainfall-induced landslide with conjunction of flume test method. Hence, the subtopics below are:

(1) Soil properties
(2) Rainfall patterns
(3) Overview tabulation (apparatus setup, parameters, objectives and result enquiry)

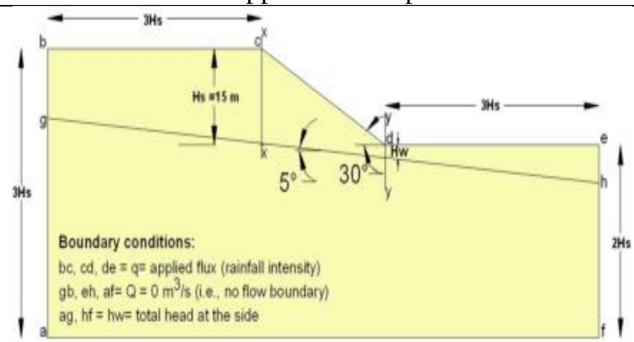
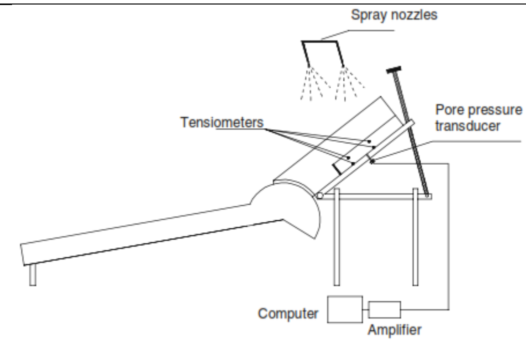
2.4.1 Soil Properties

Experiment done by (Rahimi, Rahardjo, & Leong, 2011) used two types of soil which are high-conductivity residual soil and low-conductivity soil. In addition this experiment used a correction factor, C (φ) = 1 in order to describe the Soil/Water Characteristic Curve (SWCC) while considering the safest mode considered. Shear strength parameters of the soils were kept constant for all cases to ensure that changes in stability of the slope were only attributable to pore-water pressure (or matric suction) changes in the soil. (Rahimi, Rahardjo, & Leong, 2011) A study has been performed in Kyoto Japan by (Wang, Sassa, & Fukuoka, 2003) where they were using silica sand with diameters between 0.057 mm and 0.14 mm as the soil specimen. In Malaysia, we can say that almost type of soil where shallow landslides happen is sandy type. Landslides composed of earthquake-disturbed soil under rainfall condition frequently affected by debris flow and typically the type is wide-grading-gravel-soil. (Fang, Cui, Pei, & Zhou, 2012) The experiment on the totally sandy soil is yet done since there is one experiment quietly similar but the soil type used was find sand and silt. Lorella Montrasio and Roberto Valentino also have done a flume-like test to point out the main characteristics of the physical phenomenon on the basis of the observation of a conspicuous number of soil slips that occurred in 1994 in Piedmont Region (Italy). The soil type used in this experiment are categorized into two layers namely topsoil and subsoil. The topsoil is less homogenous and more permeable than the subsoil. (Montrasio & Valentino, 2007) Based on these experiments, this study will use the sandy soil type as the top layer meanwhile underneath it will be the second layer containing plexiglass as acting the bedrock.

2.4.2 Rainfall Pattern

Experiment performed by (Rahimi, Rahardjo, & Leong, 2011) used three typical rainfall patterns available data collected in the Singapore by online monitoring. There were 3-day, 4-day and 5-day which obviously the 5-day antecedent rainfall caused the worst pore-water pressure profiles in slopes as mentioned by Rahardjo. (Rahimi, Rahardjo, & Leong, 2011) However, the test carried out by (Wang, Sassa, & Fukuoka, 2003) was using constant rainfall intensity which is 1.7 mm/min in all parameters. The test flume by H. Fang was using artificial rainfall device containing a submersible pump, a diversion box, a spray nozzle, a spray pipe and a bracket. The rainfall intensity can be varied by the size of the nozzle which ranges from 5 to 11mm. (Fang, Cui, Pei, & Zhou, 2012) Then, from the rainfall intensity we can define the soil volumetric water content and soil water pressure. In Malaysia, there are two types of monsoon season which affect the rainfall intensity that are Northeast and Southwest Monsoon. However, in this study the parameter of rainfall intensity correlate with rainfall period will be varied. Thus, parameter is set up in between with high intensity-short period of rainfall and low intensity-long period of rainfall. In order to coordinate this parameter, we need to understand the rainfall intensity in Malaysia. The Northeast Monsoon is tends to be wetter than Southeast Monsoon. (Suhaila, Deni, Zin, & Jemain, 2010) In period 1975 to 2004, the maximum Total Amount Rainfall (TAR) recorded was 1200mm to 1500 mm. The minimum is about 300 mm to 600 mm. The highest rainfall intensity record was about 135 mm/day to 165 mm/day which occurrence is in extreme weather. The lowest intensity of rainfall recorded was 45 mm/day to 55 mm/day. (Suhaila, Deni, Zin, & Jemain, 2010)

Overview tabulation (apparatus setup, parameters, objectives and result enquiry)

Authors, Year	Objectives	Parameters	Apparatus Setup	Result Enquiry
(Rahimi, Rahardjo, & Leong, 2011)	To find the effect of antecedent rainfall pattern on the stability of slopes.	- identified rainfall patterns used - applied two different type of soil 1. High-conductivity soil 2. Low-Conductivity Soil	 The inclination angle = 30° Hs = 15m	-Comparison between Factor Safety and elapsed time for each type of soil
(Montrasio & Valentino, 2007)	To verify model capability in matching both the experimental results and the occurrence of the phenomenon in Campania Regin (Italy)	Rainfall pattern: 1. Rainfall intensity was kept constant until failure occur 2. Rainfall intensity differ with differ duration	 The inclination angle = 38° Thickness of sample is kept constant for 0.12 m.	-The value of matric suction is acquired -Observation on every instability occurrences

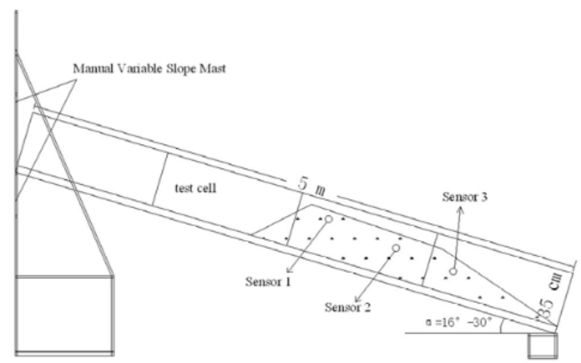
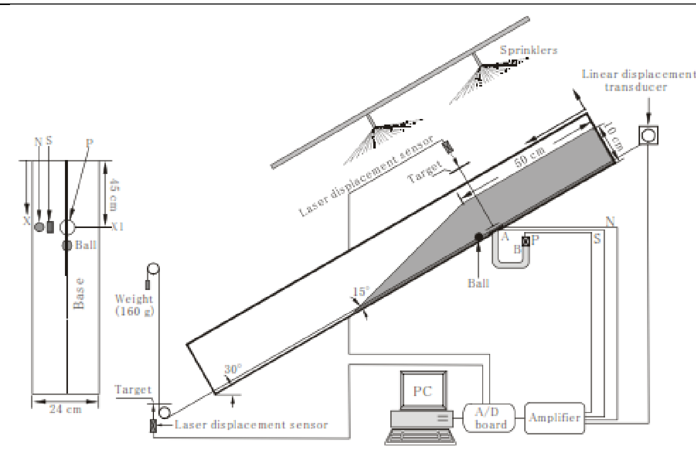
(Fang, Cui, Pei, & Zhou, 2012)	To investigate the initiation process, controlling factors, and mechanism of the landslides for the deposit material under rainfall condition	Three different slope gradients of 16°, 22° and 30°. Constant high rainfall intensity of 84 mm/hour.	 Comprises a rectangular plexiglass flume with dimension of (300 x 35 x 35) cm.	-Water content data is acquired -Pore-water pressure reading is taken -Proposed the deformation-failure model
(Wang, Sassa, & Fukuoka, 2003)	To study those rainfall-induced landslides where silt soils control the triggering and movement of the landslide mass	Rainfall intensity is kept constant Two different fine silica sand samples used		-Pore-water pressure monitored -Movement of the landslide movement landslide is observed.

Table 2 Experimental preview on others study

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

To achieve the objective, it first attempts to critically review the literature to identify and describe details on every experimental related with the flume test. This is because every experiment related to flume has the same objective on finding the mechanism of triggering landslides. Besides, the parameters or variables used are totally different which result and analysis data with different ways. So this study is aiming the characteristics of rainfall-induced shallow landslide using sample of sandy soil type. Besides the sample soil is kept constant and the rainfall duration and intensity will be varied. Through a comparison on each experimental done, this has been yet discovered thus will contribute into understanding of mechanisms triggering shallow landslides in the whole world. Thus, through many readings, the objectives of this study become more significant and helping to find the scope of studies and problem statement.

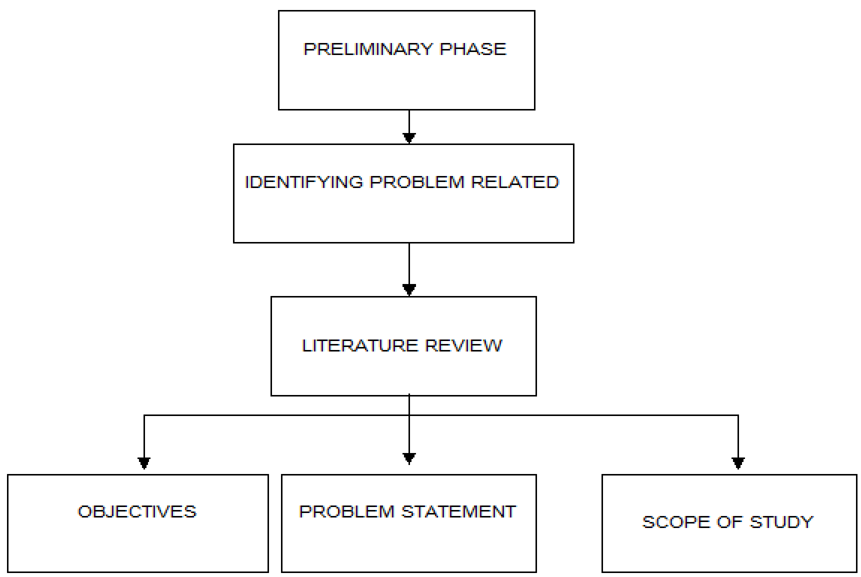


Figure 6 Research methodology

3.2 Data Logger Levellog/Unilog

The data loggers Levellog and Unilog are new product developments from SEBA Hydrometrie which can digitally record the water level or any other parameter such as water quality or rainfall. The implementation of a state-of-the-art serial flash memory enables a relatively high data capacity combined with high data security. The most important features are as follows:

- Event-controlled/time-controlled registration
- Individual control of the connected sensors
- Alarm management

Figure 7 Data Logger

3.3 Key Milestones

Several key milestones for this research project must be achieved in order to meet the objective of this project:

Problem Statement and Objective of the project

Identifying the purpose of this research project

↓

Literature Review

Gathering as much information as possible from various sources such as journals and websites

↓

Experiment Design

Identifying the subjects that need to be investigated and the experimental procedures, as well as the soil properties tests needed and the collection of results

↓

Data Analysis and Interpretation

The findings obtained are analyzed 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.

3.4 Project Activities and Key Milestone

No	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic														
2	Literature Review														
3	Submission of Extended Proposal						O								
4	Preliminary Research Work														
5	Proposal Defense														
6	Setup Apparatus Design (Flume Test)														
7	Preparation of Interim Draft Report													O	
8	Submission of Interim Report														O

Table 3 Project Activities and Key Milestones for FYP 1

Legends

	Project Activity
O	Key Milestone

No	Detail/Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Preparation Apparatus Setup															
2	Lab Test for Soil Properties															
3	Soil Properties Analysis															
4	Submission of Progress Report								O							
5	Trigger Experiment															
6	Result Analysis															
7	Pre-EDX											O				
8	Report Documentation															
9	Submission of Dissertation													O		
10	Submission of Technical Paper													O		
11	Oral Presentation														O	
12	Submission of Project Dissertation															O

Legends

	Project Activity
O	Key Milestone

Table 4 Project Activities and Key Milestones for FYP 2

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

In this study, there is a relationship between the soil-water characteristic curve for the sample soil used and the properties of the unsaturated soil. The soil-water characteristic curve for a soil is defined as the relationship water content and suction for the soil. In other word, this means the amount of water contained within the pores of the soil correlate with suction. Since the soil-water characteristic curve is used the basis for the prediction of other unsaturated soil parameters, such as the permeability and shear.

4.2 Properties of Soil Sample

In order to find the sample properties, three tests have been done in the laboratory. There are:

1) Sieve Analysis Test
2) Particle Density or Specific Gravity Test (Pyknometer method)
3) Permeability Test (Constant Head and Falling Head method)

4.1.1 Sieve Distribution Analysis

Initial soil sample weight 1822.4 g

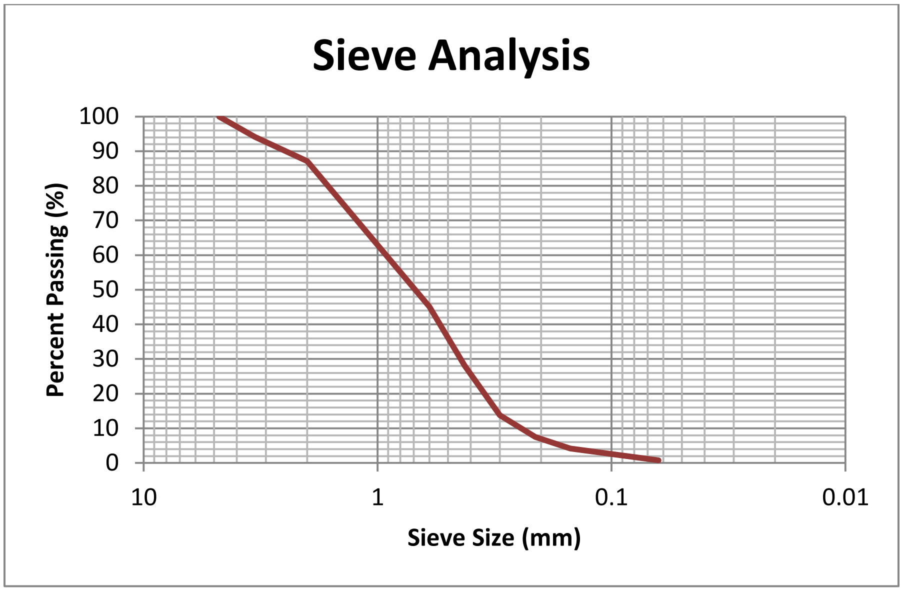


Figure 8 Sieve Distribution Semi-log Graph

Determining the coefficient of uniformity (C_u) and coefficient of curvature (C_c)

D_{60}=1.0

D_{30}=0.38

D_{10}=0.25

Then,

$C_u = D_{60}/D_{10} = 4.0$

$C_c = (D_{30})^2/(D_{10}*D_{60}) = 0.58$

This sample contains less small and large particles but more particles of intermediate size can be described as poor graded. The sample is not suitable as filter as the permeability of the soil could be less with sufficient fine particles may located in the pores of medium size particles. The largest particle size in the smallest 10% of particles is known as D_{10}. Same concept applied where the largest particle in the 30% and 60% are known as D_{30} and D_{60} respectively.

4.1.2 Saturated Hydraulic Conductivity

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 3×10^{-4} m/s. This value can be assumed as semi pervious for its permeability classification. From the observation on test in the lab, we can conclude that the fine particles migrate towards the lower parts filling voids of the sample when the water starts flowing which result less K value.

4.1.3 Soil Particles Density

Soil particles density is the mass of soil particles divided by the volume occupied by the solids. Typical values for the soils range from 2.4 to 2.8 g/cm^3. (Huang, Li, & Sumner, 2012) The particle density for the sample is 2.6×10^3 kg/m^3.

4.1.4 Void Ratio and Porosity

Void ratio is the specific volume and the porosity is all indicators of the efficiency with which the soil particles are packed together. Sands normally have specific volumes in the range 1.3 to 2.0 where void ratio, e is in the range of 0.3 to 1.0. (Powrie, 1997) Void ratio with 0.3 means the sand is well compacted meanwhile the value of one means the sandy type soil is at the maximum loose state. From this, we can assume the void ratio of the sample as the average of the range given which is 0.6 or 60%.

4.2 Flume Test Procedures

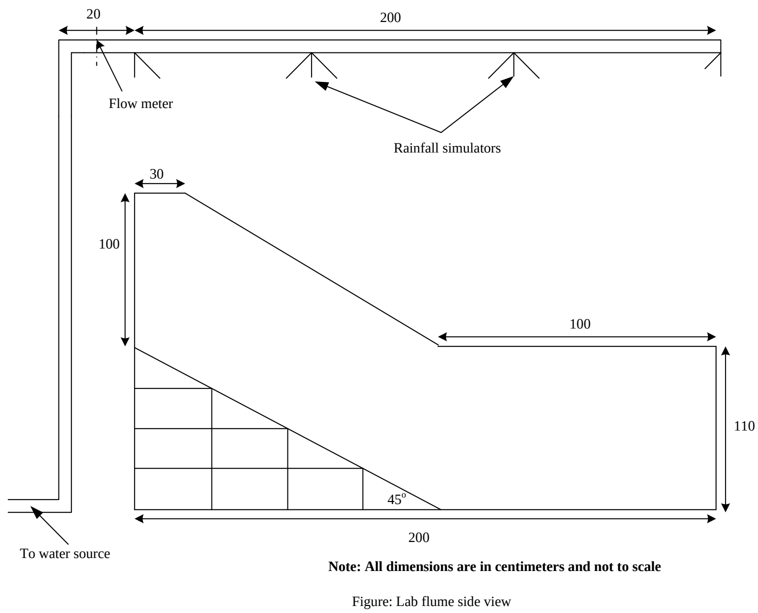


Figure 9 Flume Test Plan Overview

4.2.1 Flume Test Apparatus

Figure above shows the employed experimental apparatus. The flume, with transparent side installed with a rectangular plexiglass, was 1 meter wide, 2 meter long and 2.1 meter high. The flume angle is made constant for 45° as the typical angle for shallow landslides to happen in Malaysia is between 30° to 60°. In this apparatus, there is a consideration of two type layers acting during the test. First layer is the bottom plexiglass which will act as impermeable layer or ground rock layer. Second layer is the sample soil layer, sand soil type. A vinyl tube is inserted into the hole with one end where the excess water could flush free at the edge of apparatus.

4.2.2 Rainfall Model Setup

A flow meter is installed after the water resource. As acting the rain drops, a sprinkler is used and the height from the surface of the soil is adjusted in order to ensure to whole surface receive the rainfall equally.

4.2.3 Sample Setup Procedures

1. The soil sample is transferred into the flume with the thickness of 30 cm parallel to the bottom surface.
2. Then, four sets of tensiometers and piezometers are installed at the inclination surface of soil.

* Piezometer is wrapped with cotton bag in order to prevent the sand particle contaminate the sensor.

* Tensiometer is filled with clean water and should be kept in vacuum.

* Allow the ceramic tip to dry to reduce the water pressure in the sensor and remove any air bubbles that appear.

3. The soil is filled to the second layer with the thickness of 30 cm. Meanings the total thickness of the sample soil from the bottom is 50 cm.

Figure 10 Fitting the soil into flume test

Figure 11 Installation of sensor devices

Below is the layout for the arrangement of the devices in the soil:

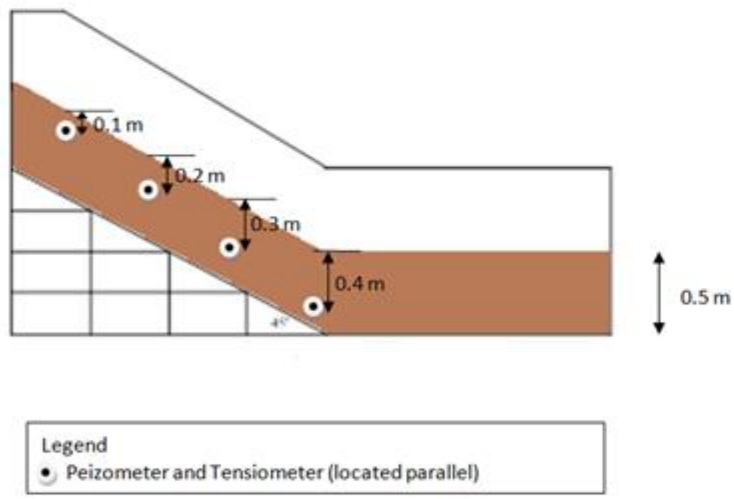


Figure 12 Sensor devices alignment

4.3 Matric Suction Variation in the Slope

4.3.1 Initial Condition

No	Channel	Date/Time	Value	Unit
1	Groundwater 1	23/07/2013	0	kPa
2	Groundwater 2	23/07/2013	0	kPa
3	Groundwater 3	23/07/2013	0	kPa
4	Groundwater 4	23/07/2013	0	kPa
5	Soil Moisture 5	23/07/2013	10.45836	cb
6	Soil Moisture 6	23/07/2013	12.50179	cb
7	Soil Moisture 7	23/07/2013	15.40001	cb
8	Soil Moisture 8	23/07/2013	17.00491	cb

Table 5 Initial Reading

For the initial condition

The reading of the groundwater is nearly zero and assumed as zero reading for all piezometer because there are no pore-water pressure detected during the experiment. The tensiometer reading represents the value of matric suction of the soil. As we can see, the matric suction increasing as the ceramic tips of the tensiometer is located deeper in the soil.

4.3.2 Rainfall Simulation

10:48 am – Rainfall begins

11:48 am – Rainfall stops

03:48 pm – Rainfall begins

04:48 pm – Rainfall stops (as the failures triggered)

Type of rainfall simulated on the slopes is categorized as delayed rainfall pattern.

4.3.3 Matric Suction versus Time

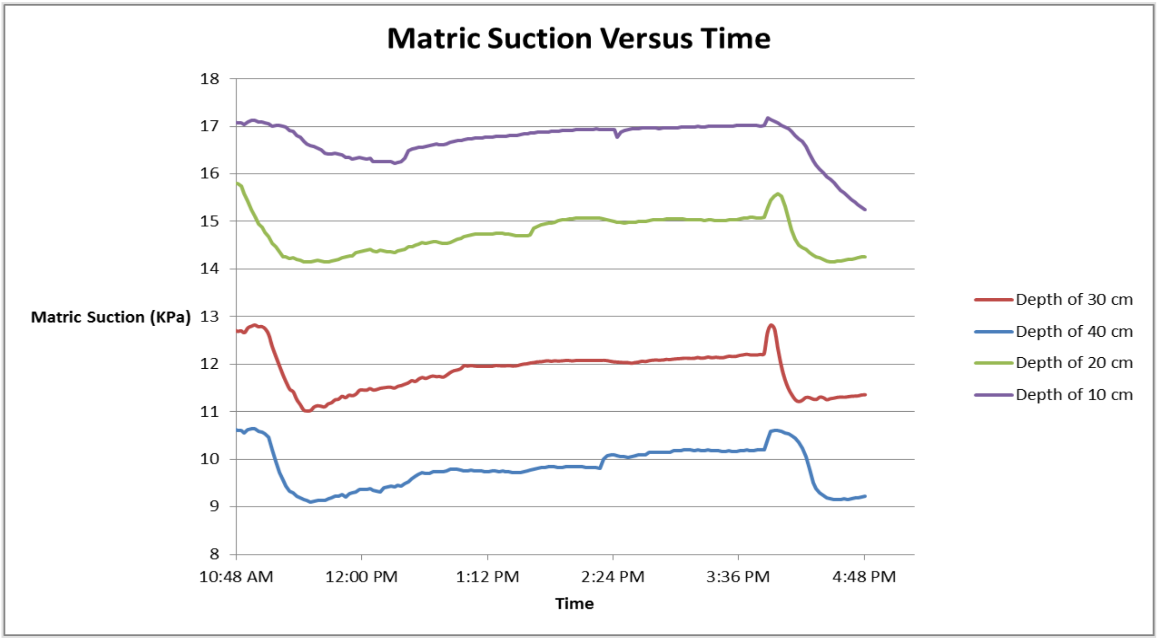


Figure 13 Matric Suction versus Time

The following figures show the instrumentation used. The matric suction readings by the tensiometers and the positive pore-water pressure readings by the piezometers form the basis for the discussions. Both the readings were automatically recorded up until failure took place.

Data:

Soil type: Silty sand

Soil inclination: 45˚

4.4 Observation Phenomena in Flume Test

Movement of slope failure

Type of movement of the landslide depends on the sample properties. Even though the type of soil used differently, the soil still having slope failures due to rainfall and its triggering mechanism could be diverged.

1) Wetting: During wetting period, the water gradually flowed toward the base because the top soil is very high permeability.

2) Drying: This period means that the rainfall is stopped for a few hours. This is done to ensure the seepage force could act as the rainfall water infiltrate through the soil and causes soil slope. Unfortunately, after four hours, there is no sign of slope failure and then the rainfall is started again.

3) Slope failure: After an hour sprinkling the rainfall, the slope failure occurs. This can conclude that the matric suction of the soil is lowered enough to cause the slope stability of the soil. The slope failures can be categorized as multiple slip surfaces.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The present paper outlines the mechanisms that possibly lead to rainfall-induced unsaturated soil slopes failures and has attempted to clarify certain conflicting conclusions in the literature. And as such, the following conclusions can be drawn.

i) The mechanism that led to the slope failure was reduction in soil matric suction as the result of slope moisture changes for the silty sand soil slope investigated in the current experiment

ii) It seems that there was no need for the matric suction to reduce in large amount for the failure to take place. A reduction of matric suction from about 17 kPa to nearly 15 kPa did induce failure. This attests the fact that the role of soil matric suction as a stability-maintaining factor cannot be overemphasized.

iii) Groundwater table (GWT) level rise was not observed in the current experiment because the piezometer readings were all zero, hence showing the effect of the GWT level rise was absent.

iv) There were multiple slip surfaces, all of which were shallow in depth – typical of unsaturated soil slopes made of granular materials.

5.2 Problem Encounters

The result could not be obtained yet as there are several problems encountered during the experiment course that we need to settle first. These problems are:

1. Flow meter scale for the experiment is too large and when water fully flow in device, its value could not reach the minimum scale. So, we did not have the exact value for the rainfall intensity.

2. High sensitivity of the sensor devices like tensiometers due to heat and sunlight affect the readings and causes confusion in analyzing data.

3. Piezometer readings show no raise of groundwater as this factor is one of the triggering mechanisms. This is because at the end of the apparatus is not cover correctly as to ensure there is no water cannot flow out rapidly.

4. Rainfall model is not performing as the real simulation of rainfall at all.

5.3 Recommendation

Below is the recommendation of the above problems:

- ✓ Choose appropriate flow meter which is suitable range of the discharge reading as to identification of the rainfall intensity can be more accurate.
- ✓ Experiment should be run in close door as to prevent the heat from outside affect the readings.
- ✓ The discharge water from the soil slope to the ventilation should adjusted to the correct portion, so that, we can determined the positive pore-water pressure due to high groundwater table.
- ✓ Upgrade the rainfall simulation through more literature study as the rainfall effects on the surfaces also can distribute huge factors to the slope failures.

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APPENDICES A – DATA COLLECTION

Channel 1 – Piezometer 1

Channel 2 – Piezometer 2

Channel 3 – Piezometer 3

Channel 4 – Piezometer 4

Channel 5 – Tensiometer 1

Channel 6 – Tensiometer 2

Channel 7 – Tensiometer 3

Channel 8 - Tensiometer 4

date/time	UNL00946_CH32	UNL00946_CH01	UNL00946_CH02	UNL00946_CH03	UNL00946_CH04
10:18	12.05795	-1.4108	-0.09056	-0.09534	-0.20976
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10:26	12.05795	-3.19814	-0.2812	0.114395	-0.14778
10:28	12.05795	-3.26962	-0.23354	-0.03337	-0.13348
10:30	12.05795	-3.52699	-0.22878	0	-0.17162
10:32	12.05795	-3.63663	-0.20018	-0.02383	-0.22882
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10:36	12.05795	-3.90829	-0.20018	0.081039	-0.24313
10:38	12.05795	-4.02269	-0.17159	0.033371	-0.16208
10:40	12.05795	-3.94167	-0.24785	0.057205	-0.20976
10:42	12.05795	-4.08464	-0.16681	0.057205	-0.17639
10:44	12.05795	-4.06082	-0.21924	0.052429	-0.21928
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10:54	12.05795	-4.1895	-0.24307	-0.00954	-0.14778
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14:16	12.10791	-4.94733	-0.28596	-0.14777	-0.45764
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14:20	12.10791	-4.9807	-0.50522	-0.29553	-0.45764
14:22	12.10791	-5.01883	-0.51952	-0.17636	-0.51962
14:24	12.10791	-4.9521	-0.3241	-0.30029	-0.55775
14:26	12.10791	-5.02835	-0.50046	-0.30029	-0.52916
14:28	12.10791	-5.14275	-0.44325	-0.25262	-0.62926
14:30	12.10791	-5.05219	-0.42419	-0.23833	-0.60066
14:32	12.10791	-5.11415	-1.05333	-0.30029	-0.61496
14:34	12.10791	-5.22853	-0.96277	-0.33366	-0.52438
14:36	12.10791	-5.04265	-0.98184	-0.16206	-0.53392
14:38	12.10791	-5.19041	-0.73399	-0.25262	-0.56729
14:40	12.10791	-5.19518	-1.01044	-0.15253	-0.57205
14:42	12.10791	-5.15228	-0.66727	-0.21449	-0.65311
14:44	12.10791	-5.23807	-1.101	-0.3718	-0.60066
14:46	12.10791	-5.32863	-0.66727	-0.3432	-0.6245
14:48	12.10791	-5.19994	-0.89128	-0.24786	-0.61974
14:50	12.10791	-5.14751	-0.92941	-0.28123	-0.64833
14:52	12.10791	-4.99023	-0.78166	-0.39563	-0.76274
14:54	12.10791	-5.14751	-1.05333	-0.286	-0.70078
14:56	12.10791	-5.02835	-0.97231	-0.32413	-0.70078

14:58	12.10791	-5.13799	-0.97231	-0.25262	-0.62926
15:00	12.10791	-5.11891	-0.71016	-0.28123	-0.62926
15:02	12.10791	-5.06172	-0.9866	-0.3718	-0.60066
15:04	12.10791	-5.19518	-1.03427	-0.2574	-0.68646
15:06	12.10791	-5.11415	-1.12006	-0.3575	-0.79135
15:08	12.10791	-5.25714	-0.99614	-0.18114	-0.67694
15:10	12.10791	-5.09508	-0.9866	-0.41946	-0.6102
15:12	12.10791	-5.08078	-0.65297	-0.3575	-0.70554
15:14	12.10791	-5.13799	-0.66251	-0.40993	-0.62926
15:16	12.10791	-5.2476	-0.91512	-0.44806	-0.68646
15:18	12.10791	-5.25714	-0.84839	-0.46713	-0.65787
15:20	12.10791	-5.22377	-0.86269	-0.4147	-0.56253
15:22	12.10791	-5.28574	-0.9866	-0.34796	-0.56729
15:24	12.10791	-5.34769	-0.94847	-0.4147	-0.58636
15:26	12.10791	-5.23331	-0.78642	-0.33842	-0.68646
15:28	12.10791	-5.28574	-0.96277	-0.40993	-0.70554
15:30	12.10791	-5.22853	-0.72923	-0.39087	-0.70078
15:32	12.10791	-5.2905	-0.92941	-0.2717	-0.73891
15:34	12.10791	-5.28574	-0.78166	-0.49097	-0.7532
15:36	12.10791	-5.2476	-1.0009	-0.43376	-0.77704
15:38	12.10791	-5.36676	-1.04857	-0.40517	-0.70078
15:40	12.10791	-5.40489	-1.1153	-0.48621	-0.58636
15:42	12.10791	-5.29526	-1.13913	-0.48143	-0.72461
15:44	12.10791	-5.35246	-1.17726	-0.52434	-0.7532
15:46	12.10791	-5.26666	-0.90558	-0.3718	-0.72461

15:48	12.10791	-5.19041	-1.0295	-0.49573	-0.79135
15:50	12.10791	-5.2476	-1.04857	-0.40517	-0.6674
15:52	12.10791	-5.32387	-1.01997	-0.37657	-0.6674
15:54	12.10791	-5.34293	-0.72923	-0.41946	-0.78658
15:56	12.10791	-5.48592	-0.78642	-0.56247	-0.70554
15:58	12.10791	-5.47162	-0.23831	-0.56247	-0.70554
16:00	12.10791	-5.2476	-1.04379	-0.4576	-0.71031
16:02	12.05795	0.967545	-1.05811	-0.53386	-0.98203
16:04	12.05795	-0.85315	-1.27258	-0.56723	-0.89145
16:06	12.05795	-1.0867	-1.14389	-0.65303	-0.7532
16:08	12.05795	-1.47276	-1.25351	-0.57199	-0.77704
16:10	12.06628	-2.02563	-1.09622	-0.50526	-0.77704
16:12	12.05795	-2.30208	-1.08192	-0.5863	-0.90099
16:14	12.05795	-2.52609	-1.21538	-0.5148	-0.89145
16:16	12.05795	-2.99796	-0.80072	-0.71024	-0.96297
16:18	12.05795	-3.16953	-1.04857	-0.5434	-0.9868
16:20	12.08293	-3.40784	-1.12959	-0.57199	-0.99156
16:22	12.06628	-3.47934	-1.06763	-0.52434	-0.85332
16:24	12.05795	-3.60802	-0.83885	-0.51956	-0.88193
16:26	12.0746	-3.75101	-1.26305	-0.66257	-0.86285
16:28	12.05795	-3.87494	-0.79118	-0.58153	-0.76752
16:30	12.0746	-4.00839	-0.85791	-0.61014	-0.93436
16:32	12.05795	-4.01791	-1.24399	-0.63873	-1.04401
16:34	12.06628	-4.21333	-1.1153	-0.66733	-0.94389
16:36	12.05795	-4.17998	-1.19632	-0.63397	-0.95343

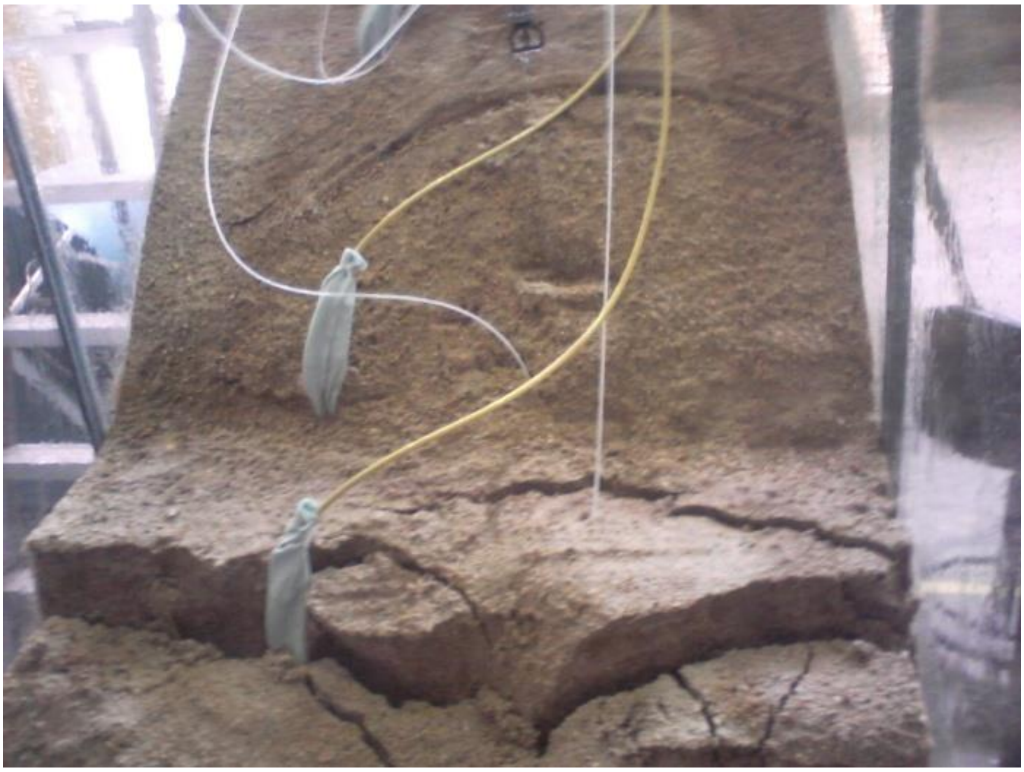
16:38	12.0746	-4.21809	-1.12483	-0.63873	-0.81995
16:40	12.06628	-4.2467	-1.22491	-0.63397	-0.87715
16:42	12.06628	-4.53267	-1.2964	-0.72929	-0.96773
16:44	12.0746	-4.63753	-1.30118	-0.61966	-0.95819
16:46	12.06628	-4.68042	-1.09146	-0.6292	-0.91052
16:48	12.05795	-4.5851	-1.27258	-0.6864	-0.86285

APPENDICES B – PHOTO ATTACHMENT

OVERALL VIEW


FRONT VIEW

SIDE VIEW



SLOPE FAILURE