CHARACTERISTICS OF RAINFAILL-INDUCED LANDSLIDES

By

AHMAD LUTFIL HAKIM BIN ABDULLAH

13610

DISSERTATION

Submitted to the Civil Engineering Programme

In Partial Fulfillment of the Requirements

For the Degree

Bachelor of Engineering (Hons)

(Civil Engineering)

AUGUST 2014

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

Table of Contents

List of Figures iii

List of Tables iii

ABSTRACT 1

CHAPTER 1: INTRODUCTION 2

1.1 Background of study 2

1.1.1 Rainfall-induced landslides 2

1.1.2 Early warning system 2

1.2 Problem statement 3

1.3 Objectives 5

1.4 Scope of study 5

CHAPTER 2: LITERATURE REVIEW 6

2.1 General definition of landslide 6

2.2 Rainfall-induced landslides 6

2.3 Early warning system 7

CHAPTER 3: METHODOLOGY 9

CHAPTER 4: RESULT AND DISCUSSION 14

4.1 Introduction 14

4.2 Properties of soil 14

4.2.1 Sieve analysis test 14

4.2.2 Soil density 16

4.2.3 Permeability test 16

4.3 Experimental apparatus 17

4.3.1 The flume setup 17

4.3.2 Rainfall model 19

4.3.3 Soil placement and slope profile 19

4.4 Results 20

4.4.1 Initial readings from Experiment 1 20
4.4.2 Final readings from Experiment 1 21
4.4.3 Initial readings from Experiment 2 22
4.4.4 Final readings from Experiment 2 22
4.5 Early warning system 23
4.6 Reliability 24
4.7 Modification 24
CHAPTER 5: CONCLUSION AND RECOMMENDATION 25
5.1 Conclusion 25
5.2 Recommendation 25
6.1 Key Milestones 26
6.2 Gantt chart 27
References 28
Appendices 30

List of Figures

Figure 1: Generally how rainfall-induced landslides occur 2
Figure 2: Early warning system types 3
Figure 3: Number of fatalities (left) and cost of damage (right) caused by landslides 4
Figure 4: Reported landslides and fatalities (1973-2007) in Malaysia 4
Figure 5: Example of flume test setup (Okura, Kitahara et al. 2002) 7
Figure 6: Example of early warning system (Reid, Baum et al. 2008) 8
Figure 7: General flow of suggested early warning system 9
Figure 8: Side view of the flume 10
Figure 9: Flow meter 10
Figure 10: Rain gauge 11
Figure 11: Piezometer 11
Figure 12: Tensiometer 12
Figure 13: Imko time-domain reflectometer (TDR) 12
Figure 14: UniLog analog logger for piezometer and tensiometer 13

Figure 15: Imko digital logger for time-domain reflectometer (TDR) 13
Figure 16: Flume with installed sensors 14
Figure 17: Sieve distribution Semi-log graph 15
Figure 18: Front view of the flume (old) 17
Figure 19: Front view of the flume (new) 18
Figure 20: Sensors are arranged on a steel plate 18
Figure 21: Flume setup (old) 19
Figure 22: Initial reading of tensiometer versus soil depth 20
Figure 23: Readings of the matric suction during the experiment. 21
Figure 24: Final readings 23
Figure 25: Key milestones 26
Figure 26: Fatal landslides occurred worldwide 30
Figure 27: Flume setup by Okura, Kitahara et al. (2002) 31
Figure 28: Measurement system by Okura, Kitahara et al. (2002) 31
Figure 29: Result from experiment 1 done by (Okura, Kitahara et al. (2002)) 32
Figure 30: Previous researches 33
Figure 31: Previous experiments 34
Figure 32: Previous experiments (cont'd) 35

List of Tables

Table 1: Summary of experimental work 9
Table 2: Initial readings 20
Table 3: Initial readings 22
Table 4: Gantt chart for FYP 1 27
Table 5: Gantt chart for FYP 2 27

ABSTRACT

Rainfall often induced slope to fail. Usually this occurs at steep slopes in the tropics. Parameters often associated with rainfall-induced slope failures are water content, pore-water pressure, and matric suction. These parameters are used to analyse the stability of slope that involve unsaturated soil which directly affected by the infiltration and evaporation at the soil-atmosphere interface. This paper will elaborate on investigation regarding flume testing with different rainfall intensities and soil densities.

CHAPTER 1: INTRODUCTION

This chapter introduces and explains the project topic, "Characteristics of Rainfall-induced Landslides". A background study on this topic is highlighted followed by the problem statement, objectives to be achieved and finally the scope of study.

1.1 Background of study

Landslides are defined as the movement of a mass of rock, debris, or earth down a slope. It is a type of "mass wasting", that categorized any down-slope movement of soil and rock under the unambiguous influence of gravity (Cruden 1991).

1.1.1 Rainfall-induced landslides

The occurrence of landslides can be caused by different factors. The most common factors are rainfall, earthquake and human error. In this paper, rainfall-induced landslide is the main subject. Rainfall-induced landslides are landslides that occur due to the infiltration of rain water into the soil which increases the pore pressures and seepage forces (Terzaghi 1951).

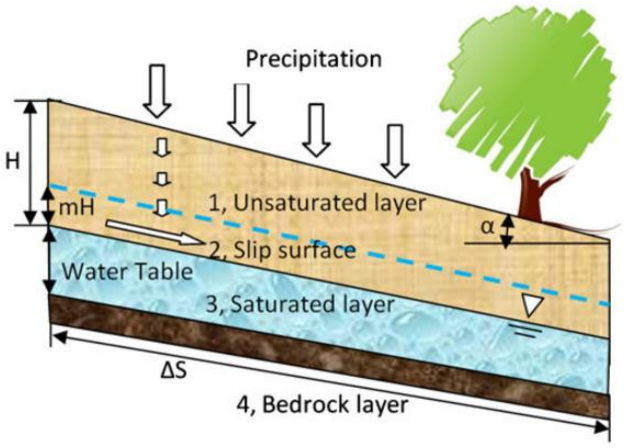


Figure 1: Generally how rainfall-induced landslides occur

Malaysia is exposed to regular rainfall throughout the year because it is located in the tropic region. This rainfall may be more intense during the rainy season and because of that, slopes are exposed to the risk of failure at any time.

1.1.2 Early warning system

In the direction of reducing the danger of active landslides, early warning systems have been developed to monitor the soil. These systems are designed to detect early

warning signs of potentially hazardous landslides and allow mitigation measures to take place before any occurrence of landslides.

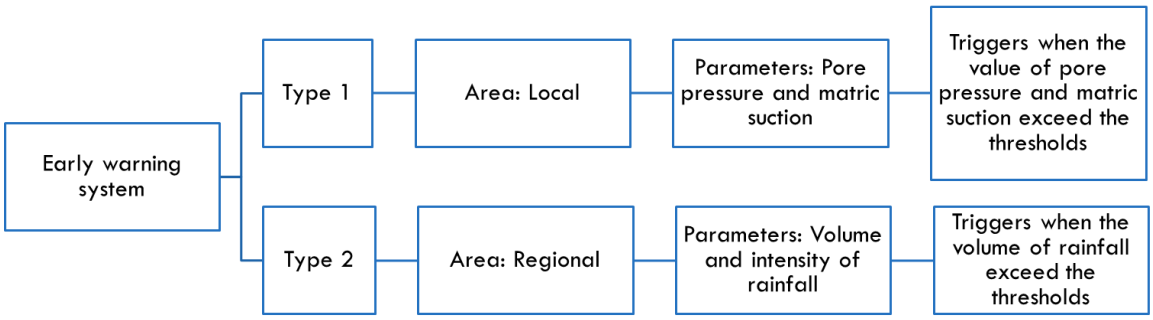


Figure 2: Early warning system types

Generally, there are two types of early warning systems. These two systems monitor different parameters. The first early warning system is designed to monitor a particular slope and the parameters involved are pore pressure, matric suction and water content. The sensors used are piezometer, tensiometer, and time-domain reflectometer (TDR). Piezometer is used to monitor pore poressure while tensiometer is used to monitor matric suction and TDR is used to monitor water content. The system will be triggered when the values of the mentioned parameters exceed the thresholds.

The second early warning system is designed to monitor the rain intensity in a region. Rain gauges are placed in a widespread area nearby a slope that has the potential to fail. This system works by analyzing the rain data from that particular region resulting in the calculation of future rainfalls. Threshold is set at which the rain intensity will most probably trigger the landslide. If the rain intensity met the threshold or the system predicted future heavy rainfall that may induce the landslide, early warning system is triggered.

1.2 Problem statement

Precipitation is regular in a tropic region and affects greatly on the stability of soil in slopes. Rainfall-induced slope failures are caused by the infiltration of rain water into the soil. However, it is uncertain how significant the increase of pore pressure, matric suction, and water content towards the instability of soil.

Throughout the years, landslides have caused fatalities and damage to properties. This shows that landslides have significant impacts to the public. Based on the graph below, America suffered the most fatalities due to landslides while Europe had the highest damage cost.

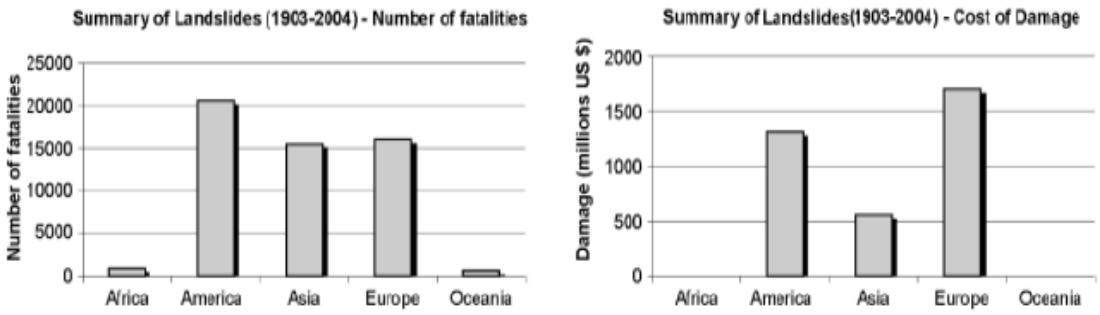


Figure 3: Number of fatalities (left) and cost of damage (right) caused by landslides

1903 to 2004. Source: EM-DAT – The OFDA/CRED International Disaster database.

Meanwhile in Malaysia, the graph below shows the number of landslides and fatalities from 1973 until 2007. The most fatal incidents happened in 1997 where the fatalities are more than 350 and more than 70 landslides occurred.

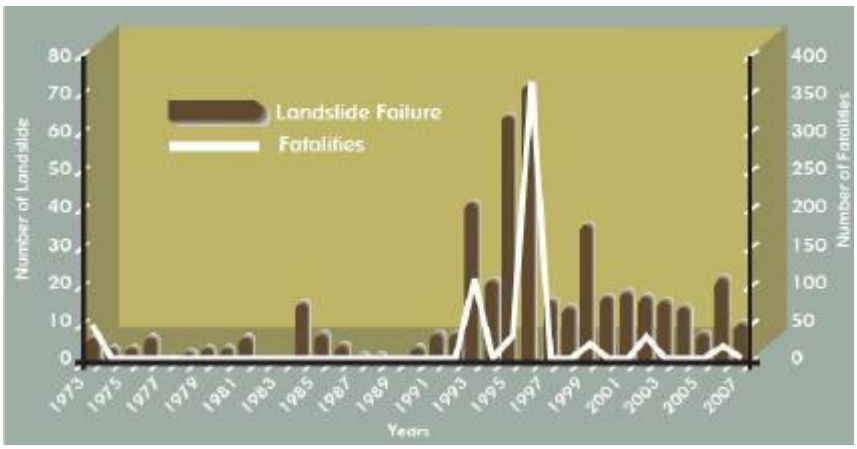


Figure 4: Reported landslides and fatalities (1973-2007) in Malaysia

Source: National Slope Master Plan 2009-2023

Additionally, the value of pore water pressure or matric suction that will be used to trigger the early warning system is still vague. A number of factors will determine the range of value for pore water pressure and matric suction which will trigger the landslide.

1.3 Objectives

1. To conduct experiment in order to determine the patterns of pore pressure, matric suction, and water content within the slope before, during, and after failure.
2. To conduct experiment in order to determine the critical value of pore pressure and moisture content of soil to trigger the early warning system.

1.4 Scope of study

1. The focus of this experiment is to observe failure of slopes due to infiltration of rain water into the soil.
2. The manipulative variables are density of soil and the intensity of rainfall.
3. The responding variables are pore pressure and moisture content of soil.
4. This experiment is to be conducted in a laboratory located at Block J, Universiti Teknologi PETRONAS.

CHAPTER 2: LITERATURE REVIEW

2.1 General definition of landslide

Earth materials have strength that compose the slope and when the gravity force exceeds the strength, slope failure occurs (Acharya 2011). Landslide or mass movement can be slow or sudden and drastic. When stress is applied on soil mass on a slope and exceeds the soil shear strength, landslide occurs. There are known forces of various parameters related rainfall properties, water content of the soil, water table of the soil, land use patterns, lithology, and bedrock geology (Acharya 2011).

2.2 Rainfall-induced landslides

Rainfall-induced landslides occurred due to the infiltration of rainwater. Nonetheless, it is uncertain how the rain water affects the stability of the soil. It is identified that the parameters involved are pore pressure, matric suction, and water content. (Chen, Lee et al. 2004) said that the occurrence of rapid slide flows is due to the reduction of matric suction which is caused by the infiltration of rainwater. Thus, the purpose of this research is to determine the mechanism of failure due to rain water infiltration. Eckersley (1990) used an artificial slope of piled coal layers to demonstrate failure due to pore pressure by supplying water from behind the slope and to induce and examine the landslide. In saturated soil, the pore water pressure of the soil will raise faster compare to in unsaturated soil when the process of rapid compaction is taking place. Major factor is that the void between sand particles absorbs a volumetric shrinkage in unsaturated condition (Okura, Kitahara et al. 2002).

Many times, groundwater table that increases should not be assumed because pore water pressure may be within a soil mass which influenced by the infiltration of rainwater into the soil (Collins and Znidarcic 2004). Therefore, it is inaccurate to assume that the failure of slopes is mainly because of the rising of groundwater table. The rising of pore water pressure is the major affecting factor that causes landslides to occur.

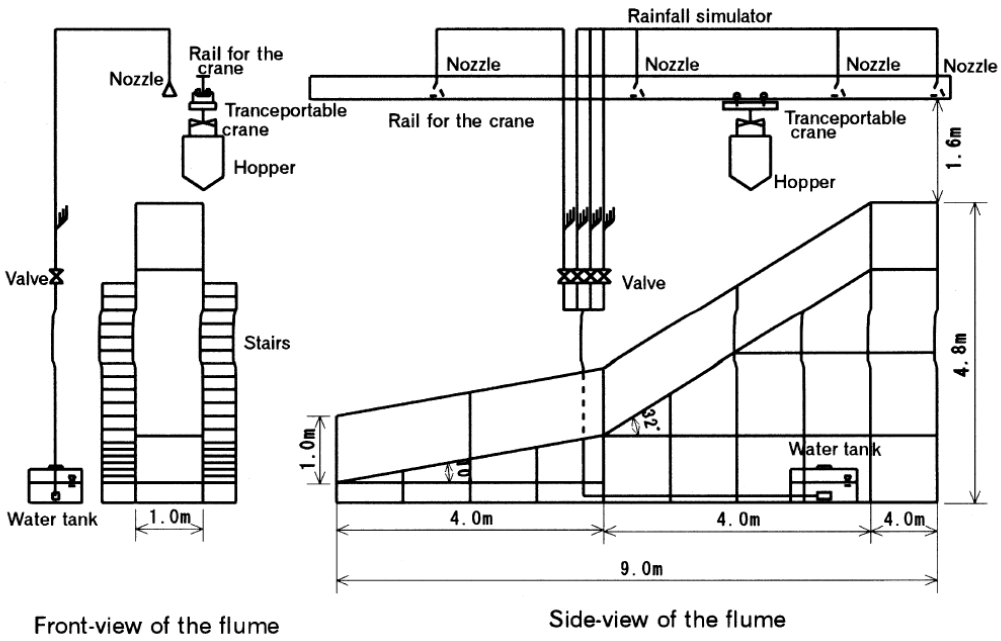


Figure 5: Example of flume test setup (Okura, Kitahara et al. 2002)

For unsaturated soil, there are two independent stress state variables; net normal stress, $(\sigma - u_w)$ and matric suction, $(u_a - u_w)$ where σ is total stress, u_a is pore-air pressure, and u_w is pore-water pressure. However, when the soil is saturated, the pore-air pressure and pore-water pressure are equals. Therefore, the matric suction, $(u_a - u_w)$, equals to zero (Rahardjo, Leong et al. 2002). Flow-type landslides often caused by shallow soil deposits where the rainfall directly infiltrates the slope surface and emerge from the underlying rock resulting failure stage. While for post failure is define as the abrupt acceleration of the failed soil (Cascini, Cuomo et al. 2009).

2.3 Early warning system

Early warning system is invented to prevent or reduce the damage done by the occurring landslides. Its aim is to send early signal or message to the appropriate nearby authorities in order that mitigation measures can be done. Sorensen (2000) said that warning systems are systems that identify approaching disaster, inform involved people and come up with decisions and actions. As simple as it may sound, warning system is a complex system. It links many parties and organizations from the government and private sectors, engineering, technology, media and public. Therefore, to have an effective early warning system, integration between parties, organizations, and medias are crucial. Reid, Baum et al. (2008) emphasize that the

dynamics of active landslides are difficult to analyse unless using real-time or near-real-time monitoring that will produce accurate short-term forecasts of landslide activity. Thus, it is demanded that a comprehensive understanding of current field parameters to monitor such activities.

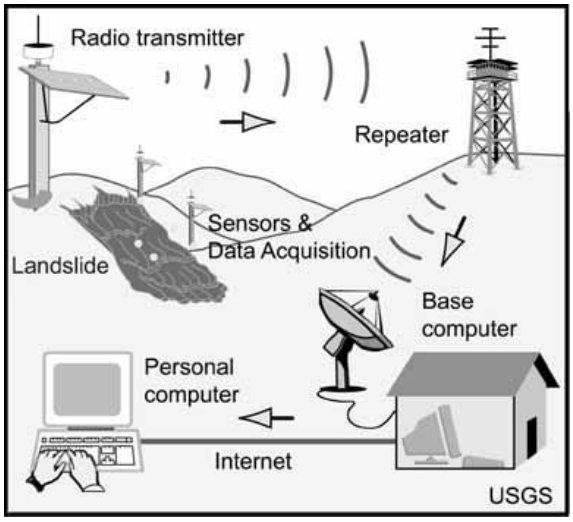


Figure 6: Example of early warning system (Reid, Baum et al. 2008)

However, the most important aspect of an early warning system is the thresholds. Threshold is defined as either the minimum or maximum constant of some quantity required for an activity to take place (Reichenbach, Cardinali et al. 1998). Aleotti (2004) studied the threshold rainfall to be integrated in the warning system. The threshold interests are the minimum or lowest level which could trigger one or more than one landslide.

In this paper particularly, different approach is used. Rather than monitoring the rainfall, the pore pressure of the soil is monitored. This aligned with the first objective which focuses on the pattern of pore pressure and water content influence to the occurrence of landslides. Similar to Eckersley (1990) experiments, pore pressure and water content are analyzed in order to identify the threshold before any landslide will be triggered due to the infiltration of rainwater.

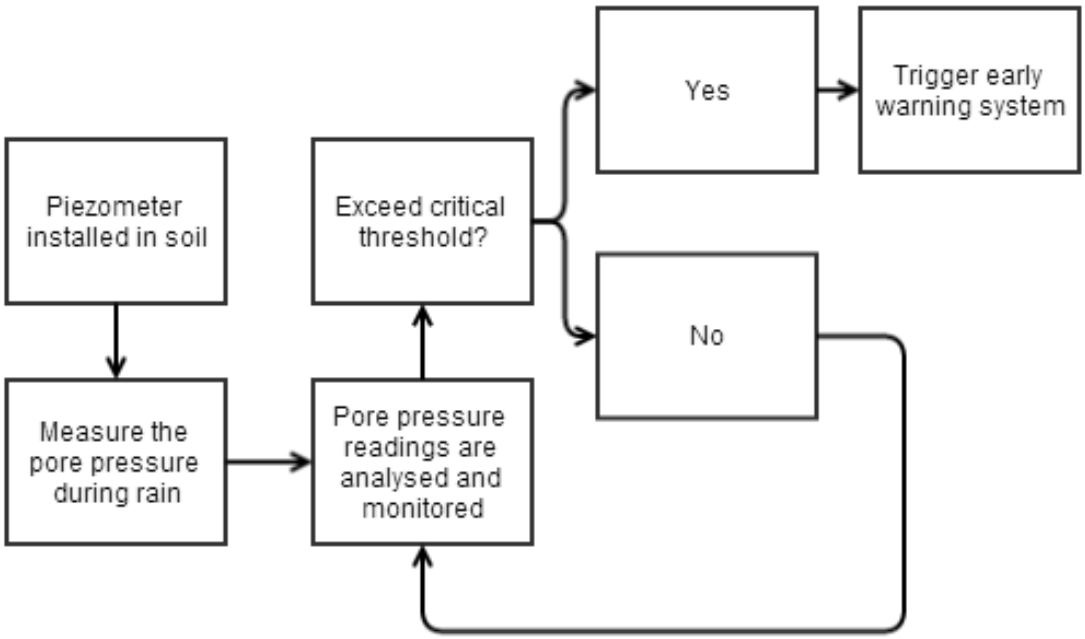


Figure 7: General flow of suggested early warning system

CHAPTER 3: METHODOLOGY

An instrumented flume is employed to investigate rainfall induced flowslide. The flume is equipped with number of sensors for accurate measurements of hydrologic parameters. All the sensors are pre-calibrated prior to installation in the flume. The experiments will be performed on sand under different relative density and rainfall intensities as shown in Table (1).

Test	Type of test	Remarks
Case 1	Rainfall	Rainfall intensity I = 26mm/hr
Case 2	Rainfall	Rainfall intensity I = 50mm/hr

Table 1: Summary of experimental work

For preparation of model, slope soil will be placed in layers in flume and compact each layer to required density under optimum moisture content. During placing of soil layers in flume, sensors will be installed at required depth. Rainfall intensity will be calibrated for different values of flow rate. After preparation of model slope, the experiment will be started by sprinkling the artificial rainfall. Before starting the rainfall simulation, it is necessary to set the initial matric suction, piezometric and

moisture content values at the selected depth along the soil slope. Values will be recorded as soon as rainfall starts. Data will be recorded by the data logger in every test. The positive pore water pressure, matric suction and moisture content will be recorded and the failure behavior will be recorded with a video camera. The duration of each experiment will be determined by the timing and occurrence of failure events.

Figure 8: Side view of the flume

Figure 9: Flow meter

The experiments will be performed in flume with slope inclination of 45˚ and sides of the flume are made of plexis glass. The thickness of the soil will be 50cm and the rainfall will be simulated by sprinkles. In order to measure the rain intensity, three rain gauges are used. The discharge of the water (from sprinklers) will be controlled by a flow meter.

Figure 10: Rain gauge

Figure 11: Piezometer

Figure 12: Tensiometer

Pore pressure will be measured by eight piezometers Model (Sisgeo P235S) and range of piezometer is 100kPa. The diameter of piezometer is 28mm diameter, 200mm in length and 0.5kg of weight. Meanwhile for negative pore water pressure, it will be measured by eight tensiometers, (Model 2100 F Soil Moisture) with range of 0 to 50kPa. The tensiometer has a tiny porous ceramic cup with the dimension of 6mm in diameter and 2.5cm long. It is attached to the tensiometer body via Nylon tubing.

Figure 13: Imko time-domain reflectometer (TDR)

Imko TDR device could measure 3 important parameters; water content, temperature, electrical conductivity and salinity. The moisture content in experiment will be measured by TDR technology sensor Imko Trime Pico 32 which has measuring range of 0 to 100. The TDR technique for measuring soil water content is

established on the relationship between the volumetric water content of a soil, and its apparent dielectric constant, K.

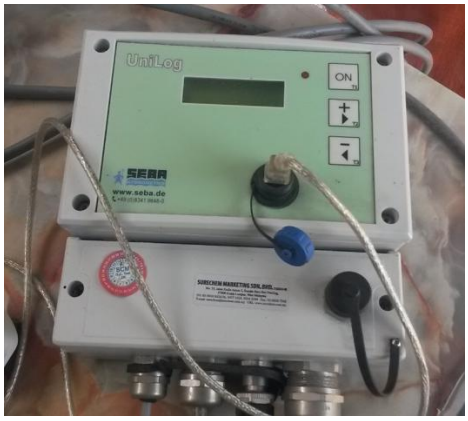


Figure 14: UniLog analog logger for piezometer and tensiometer

Figure 15: Imko digital logger for time-domain reflectometer (TDR)

There are 20 sensors altogether, eight piezometers, eight tensiometers and four TDRs. To process data from these sensors, two data loggers are used. The first one is UniLog analog data logger, used to receive readings from the piezometers and tensiometers. This logger requires a power supply and a USB cable connected to a personal computer. The second data logger is GlobeLog digital data logger, used to receive readings from TDR only. Similar to UniLog, this logger require a power supply and a USB cable connected to a personal computer.

Figure 16: Flume with installed sensors

CHAPTER 4: RESULT AND DISCUSSION

4.1 Introduction

In the process of determining the factors that control initiation of shallow landslide which area is subjected to rainfall and permeable soil, the soil properties of the soil is tested.

4.2 Properties of soil

To determine the soil properties, the soil is tested in the laboratory before the experimental work done. Sieve analysis is done to determine the particle distribution in soil and gradation in soil sample. Specific gravity test is done to determine the density of the soil and lastly permeability test is done to determine the permeability of the soil.

4.2.1 Sieve analysis test

To determine the size range of particles present is soil, sieve analysis is done. Sieve analysis is a type of mechanical analysis that determine the particle distribution in soil and the gradation of sample soil. It is expressed as a percentage of the total dry weight. This test is recommended with particles sizes larger than 0.075mm in diameter.

The result from the laboratory is presented in the Figure 17. based on the graph below, the Coefficients of Uniformity (Cu) and Curvature (Cc) can be determined. In order to calculate the coefficients of uniformity and curvature, it requires grain diameters. From each percent of the soil passing a particular sieve, the grain diameter can be found. For example, 30% of the sample is retained on the No. 20, therefore there is 70% passing the No. 20 sieve.

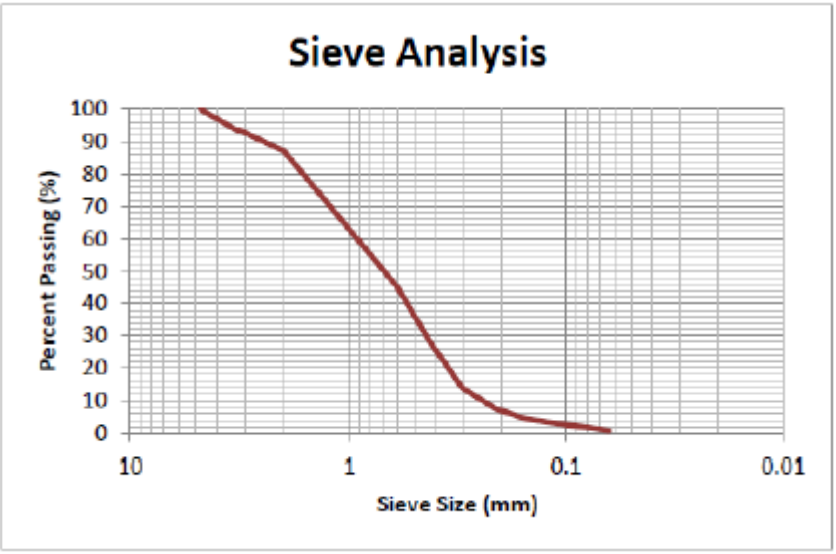


Figure 17: Sieve distribution Semi-log graph

The following equation is used to calculate the coefficient of uniformity, Cu.

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

Equation 1: Coefficient of Uniformity

D_{60} is the grain diameter at 60% passing

D_{10} is the grain diameter at 10% passing

The following equation is used to calculate the coefficient of curvature, Cc which is a shape parameter.

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

Equation 2: Coefficient of Curvature

D_{10} is the grain diameter at 10% passing

D_{30} is the grain diameter at 30% passing

D_{60} is the grain diameter at 60% passing

Therefore, based on the equations, the following values are obtained.

$$C_u = 4.0$$

$$C_c = 0.59$$

Value of Cu is less than 4 and Cc is 0.58 which is less than 3 and more than 1. This indicates the soil sample is a poor graded soil. Most of the soil particles are in the intermediate size group. Small and large size group have small percentage. This type of soil has good drainage properties because there are void spaces that are not filled in the soil.

4.2.2 Soil density

Soil density can be determined by measuring it compare to water. This can be done by using pyknometer method. This method is suitable for soils that are containing particles with medium to low gravel size.

From the laboratory testing it was found that the specific gravity of the soil, G, is 2.61. Normally specific gravity for soils falls between 2.65 and 2.80. The result is lower may be due to the percentage of the coarse-grained soil.

4.2.3 Permeability test

Coefficient of permeability or hydraulic conductivity of soil can be determined by using Constant Head Method. Hydraulic pressure is applied to the soil and the consequent flow rate is measured. The degree of permeability will be able to be determined. Permeability is expressed as velocity and this method is suitable for permeability ranging from 10^{-2} to 10^{-5} m/s.

The ability of soil to transmit water when subjected to hydraulic gradient is known as saturated hydraulic conductivity. The saturated hydraulic conductivity, k for this

sample is 3 x 10^{-4} m/s (0.03 cm/s). The value of k varies greatly between types of soil and this soil falls under coarse sand which is soil with the second highest k value after clean gravel.

4.3 Experimental apparatus

4.3.1 The flume setup

Test experiments were done to see whether the flume work properly or not. All the sensors are working splendidly and the newly acquired TDR gives out accurate readings based on the data obtained from the logger. TDR uses newer technology compare to piezometers and tensiometer. Thus, it is easier to keep track of the results based on the software given by GlobeLog.

In contrary of UniLog, the data received is not clear as there is mix between piezometers and tensiometers. Therefore, precaution measures must be taken so that the data obtained is not wrongly analyzed. That being said, the data obtained is still distinguishable between data from either piezometer or tensiometer. The only issue is that the location of the sensors on the sand (flume).

Figure 18: Front view of the flume (old)

Figure 19: Front view of the flume (new)

The wooden piece was replaced by a sheet of steel and reinforced with a steel bar. This will ensure that the soil will not cause that part to fail under heavy load from the soil. However, leakage still occurs but it is acceptable. The overall setup of the sensors were also have been remade.

Figure 20: Sensors are arranged on a steel plate

Previously, the number of water sprinklers is only four, but new water sprinklers are installed to imitate the rain so that it will be more realistic. This setup will provide even rain on the soil thus avoiding uneven seepage. Each water sprinklers is installed with tap to control the water flow rate. Therefore, it is easier to manipulate the rainfall as to the author's liking and what seems suitable.

4.3.2 Rainfall model

The flume is mainly made of steel and glass. The sides of the flume are transparent and the base is supported by a steel frame. The flume is 1 meter wide, 2 meter long and 2.1 meter high. As shown in the Figure 21. The wooden board has been replaced with steel plate and the water sprinklers have been added as shown in the previous Figure.

Figure 21: Flume setup (old)

4.3.3 Soil placement and slope profile

As landslide usually occurs at slopes with angle 30˚ and 60˚, the flume is made at a 45˚ angle. Two types of layers are considered in this experiment. The first layer is the permeable soil which will be represented by the soil and the impermeable soil or hard rock layer which will be represented by the bottom of the flume. The soil is then placed with two layers. The first layer is 30cm thick and compacted. Then, another 20cm of soil is placed and compacted. The total thickness of the soil is 50cm from the bottom of the soil to the surface of the soil.

4.4 Results

The results are taken from two experiments with consistent readings.

4.4.1 Initial readings from Experiment 1

The Figure below shows the initial reading of tensiometer before the experiment is done.

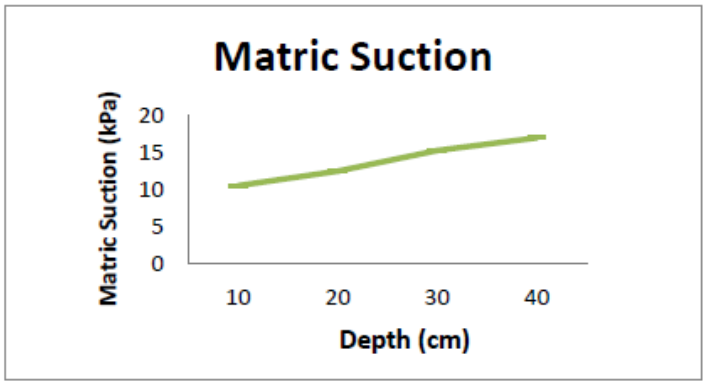


Figure 22: Initial reading of tensiometer versus soil depth

From the Figure we can see that the matric suction increases with depth. Matric suction is a negative pore-water pressure. The increase of matric suction means the permeability of the soil decreases. This is because the pores are already been filled with moisture.

The Table below shows the initial piezometer reading before the experiment is done.

No	Channel	Date/Time	Value	Unit
1	Groundwater 1	19/07/2014	0	kPa
2	Groundwater 2	19/07/2014	0	kPa
3	Groundwater 3	19/07/2014	0	kPa
4	Groundwater 4	19/07/2014	0	kPa
5	Soil moisture 1	19/07/2014	10.8489	kPa
6	Soil moisture 2	19/07/2014	12.8994	kPa
7	Soil moisture 3	19/07/2014	15.9561	kPa
8	Soil moisture 4	19/07/2014	17.1029	kPa

Table 2: Initial readings

The piezometers reading shows that there is no water pressure detected because there is no water in the soil yet. Therefore, no water pressure was exerted inside the soil.

4.4.2 Final readings from Experiment 1

The experiment is started when the rainfall begins. At 10.00AM the experiment started with a low intensity rainfall. The experiment should be done with higher rainfall intensity but due to the water sprinklers unable to produce such intensity, the experiment is done with lower rainfall intensity. The detail of the experiment is as follows:

- Rainfall intensity: 26mm/hr
- Flow meter reading: 12L/min
- Soil type: Silty sand
- Soil inclination: 45˚

The experiment is run for 12 hours. After 12 hours, the condition of the slope is examined to see whether it has failed or not. If it has failed, the experiment is immediately stopped. From this experiment, the failure occurred at 4.45PM. the result is shown in the Figure below.

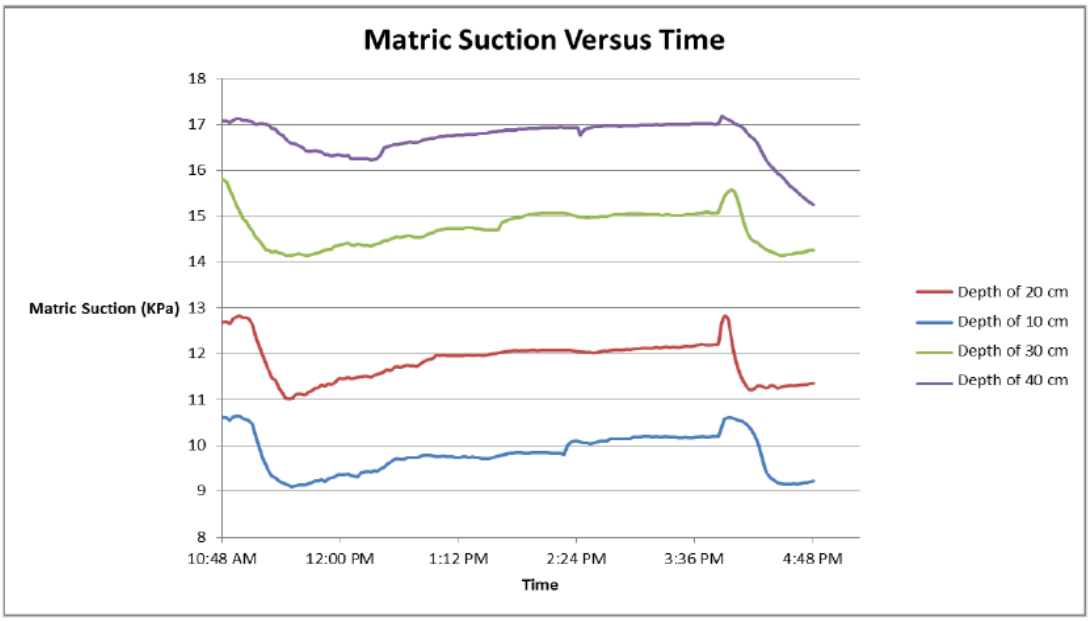


Figure 23: Readings of the matric suction during the experiment.

From the Figure, the value of matric suction increases gradually until at a point where it drops drastically. This is where the failure occurred. The author can say that the soil failed at 10.5kPa of matric suction.

The readings of the matric suction from different sensors are similar due to the depth of the sensor inside the soil. In this case, the sensors were put 40cm inside the soil.

4.4.3 Initial readings from Experiment 2

No	Channel	Date/Time	Value	Unit
1	Groundwater 1	19/07/2014	0	kPa
2	Groundwater 2	19/07/2014	0	kPa
3	Groundwater 3	19/07/2014	0	kPa
4	Groundwater 4	19/07/2014	0	kPa
5	Soil moisture 1	19/07/2014	11.4845	kPa
6	Soil moisture 2	19/07/2014	12.7895	kPa
7	Soil moisture 3	19/07/2014	14.5541	kPa
8	Soil moisture 4	19/07/2014	16.5865	kPa

Table 3: Initial readings

The values of matric suction and piezometers are stated in the above table. It shows zero reading for all piezometers because pore-water pressure is not detected initially. Meanwhile, the matric suction increases as the sensors are placed deeper in the soil.

4.4.4 Final readings from Experiment 2

- Rainfall intensity: 50mm/hr
- Flow meter reading: 20L/min
- Soil type: Silty sand
- Soil inclination: 45˚

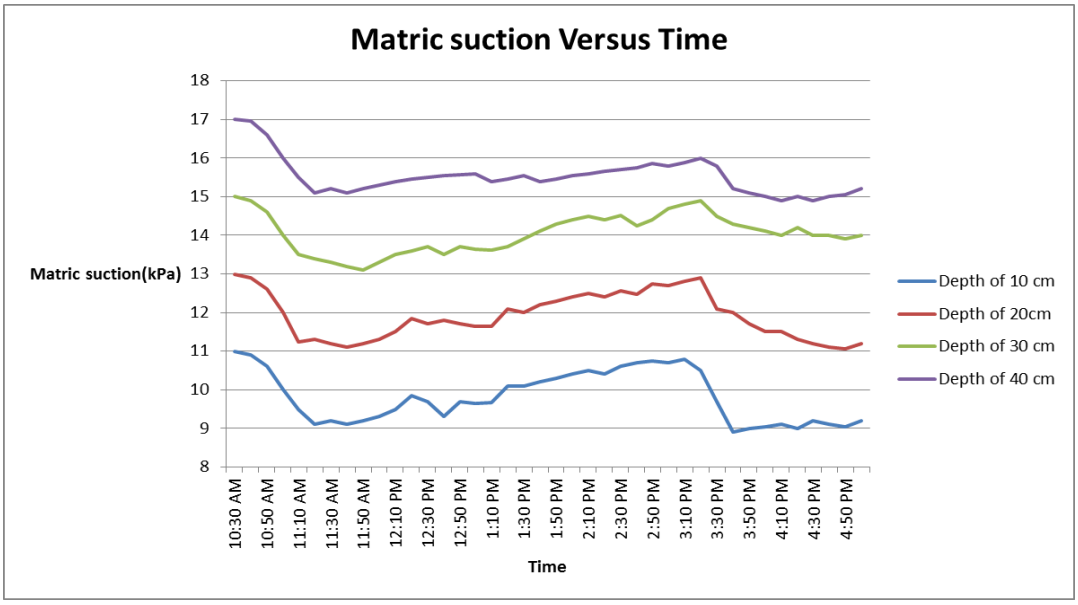


Figure 24: Final readings

10:48am – Rainfall start

11.48am – Rainfall stop

3:48pm – Rainfall begins

4:48pm – Rainfall stops (failure occurred)

The graph shows the tensiometer readings with different depth. The deeper the tensiometer placed, the higher the matric suction value. This means that the shear strength of soil increases with depth. The experiment started at 10:48am and the rain fall stopped at 11:48pm. However, the logger and sensors were still recording data. At 3:48pm, the rain was continued and at 4:48pm failure occurred.

4.5 Early warning system

From the results obtained, it is now possible to create an early warning system. Data obtained will be analyzed and threshold value of pore pressure is identified. This value will be integrated in the system so that when the piezometers installed in situ give out readings exceed the threshold, warning will be triggered and information is distributed to the nearby area.

In order to achieve a systematic early warning system, a comprehensive action plan must be established. The following must be done beforehand;

1. Piezometer sensors are installed in the soil at risky slopes

2. Piezometers are connected to logger
3. Logger is connected to a personal computer
4. Personal computer is used to monitor and analyse readings from the piezometer

Experiment results showed that the soil fail at 10.5kPa for silty sand. Thus, the early warning system should be set to initiate warning before the matric suction reaches 10.5kPa. The reasonable value of matric suction to set off the warning system is 9.5kPa.

4.6 Reliability

1. Water that is coming out from the sprinklers is unlike the real rainfall. The water droplets are uneven and causing some part of the soil to receive more rain water than the other area. This is due to the type of the sprinklers, the location of the sprinklers and the height of the sprinklers from the soil.
2. Water pressure is uneven causing each sprinkler give off different volume of rain. This is due to that the sprinklers are installed in series. The one that is closer to water source give off more water. In this case, the sprinkler located at the top of the slope gushing out more water compare to the sprinklers located at the bottom.
3. As a result, the volume of rain water measured by the rain gauges is significantly different from each other.
4. The soil being compacted unevenly. Due to the lack of tools, it is difficult to compact the soil evenly and the result of the experiment may vary despite using the same intensity of rain.
5. UniLog data logger is unable to identify type of sensors and the location of the sensors. Thus, it is difficult to identify at which point the piezometer or tensiometer is measuring the pore pressure or matric suction.
6. The experiment consumes a lot of time. Therefore, it is difficult to identify when and how the soil will fail.

4.7 Modification

1. More water sprinklers are installed so that the rain produced is evenly distributed.

2. To increase the water pressure, a pump is used. In order for the pump to work properly, a water tank is needed to supply the water needed. If using water directly from the pipe, it might be insufficient.
3. Before running any experiment, it is preferable to test the rain first and observe whether the rain is even or not. Adjust the sprinklers accordingly.
4. A compacting device is fabricated. This tool will help to evenly compact the soil by calculating and different soil density can be obtained by different number of blows.
5. Before conducting the experiment, identify the sensors and mark which sensor is connected to which port.
6. By using a video recorder, it is easier to observer when and how the soil fail without the need to wait long hours to see the soil fail.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

This paper presents the mechanism that induced landslides or slope failures caused by rainfall infiltration. Several uncertainties have been proven by the experiments.

i) The slope failure was caused by the reduction of soil matric suction due to the slope moisture changes for the silty sand investigated in the experiment.

ii) Based on the data obtained, it is observed that a slight change in matric suction will lead to soil failure. Therefore, the role of matric suction as the source of strength for soil cannot be overemphasized.

iii) There was no rise in groundwater table was observed. All the piezometer readings are zero, hence, groundwater table was absent during the experiment.

iv) Multiple slip surfaces were observed. This is common for unsaturated soil slopes that comprises of granular materials (silty sand).

5.2 Recommendation

For the flume design, it can be improved so that it is more user friendly and easier for the user to conduct experiment with more flexibility. The current flume is hard for the user to remove the soil after experiment due to its design. The front part of

the flume should be made removable so that it is more practical to remove the soil after every experiment. The side of the flume is made from tall glass is another aspect that can be improved. It would be better if the glass height is just a little bit taller than the thickness of the soil. This is because, user can easily access the soil if any modification or setting up of sensors that need to be done before, during or after experiment.

6.1 Key Milestones

Figure 25: Key milestones

6.2 Gantt chart

	WEEK													
PROJECT FLOW / TASK	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Title Selection														
FYP Seminar/Talk														
Preliminary Research														
Detailed Study														
Extended Proposal														
Proposal Defence														
Program														
Progress report														
Draft of Interim Report														
Final Interim Report														

Table 4: Gantt chart for FYP 1

	WEEK													
PROJECT FLOW / TASK	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Project Work														
Progress Report														
Pre-SEDEX														
Draft Report														
Dissertation														
Technical Paper														
Oral Presentation														
Final Report(hard bound)														

Table 5: Gantt chart for FYP 2

References

Acharya, G. (2011). "Analysing the Interactions between Water-induced Soil Erosion and Shallow Landslides."

Aleotti, P. (2004). "A warning system for rainfall-induced shallow failures." Engineering Geology **73**(3): 247-265.

Cascini, L., et al. (2009). "Modeling of rainfall-induced shallow landslides of the flow-type." Journal of geotechnical and geoenvironmental engineering **136**(1): 85-98.

Chen, H., et al. (2004). "Causative mechanisms of rainfall-induced fill slope failures." Journal of geotechnical and geoenvironmental engineering **130**(6): 593-602.

Collins, B. D. and D. Znidarcic (2004). "Stability analyses of rainfall induced landslides." Journal of geotechnical and geoenvironmental engineering **130**(4): 362-372.

Cruden, D. M. (1991). "A simple definition of a landslide." Bulletin of the International Association of Engineering Geology - Bulletin de l'Association Internationale de Géologie de l'Ingénieur **43**(1): 27-29.

Eckersley, D. (1990) Instrumented laboratory flowslides. Geotechnique **40**, 489-502

Okura, Y., et al. (2002). "Landslide fluidization process by flume experiments." Engineering Geology **66**(1): 65-78.

Rahardjo, H., et al. (2002). Studies of rainfall-induced slope failures. Slope 2002. Proceedings of the National Seminar, Slope.

Reichenbach, P., et al. (1998). "Regional hydrological thresholds for landslides and floods in the Tiber River Basin (central Italy)." Environmental Geology **35**(2-3): 146-159.

Reid, M., et al. (2008). "Capturing landslide dynamics and hydrologic triggers using near-real-time monitoring." Landslides and Engineered Slopes–Chen et al.(eds.): 179-191.

Sorensen, J. (2000). "Hazard Warning Systems: Review of 20 Years of Progress." Natural Hazards Review **1**(2): 119-125.

Terzaghi, K. (1951). Mechanism of Landslides, Harvard University, Department of Engineering.

Appendices

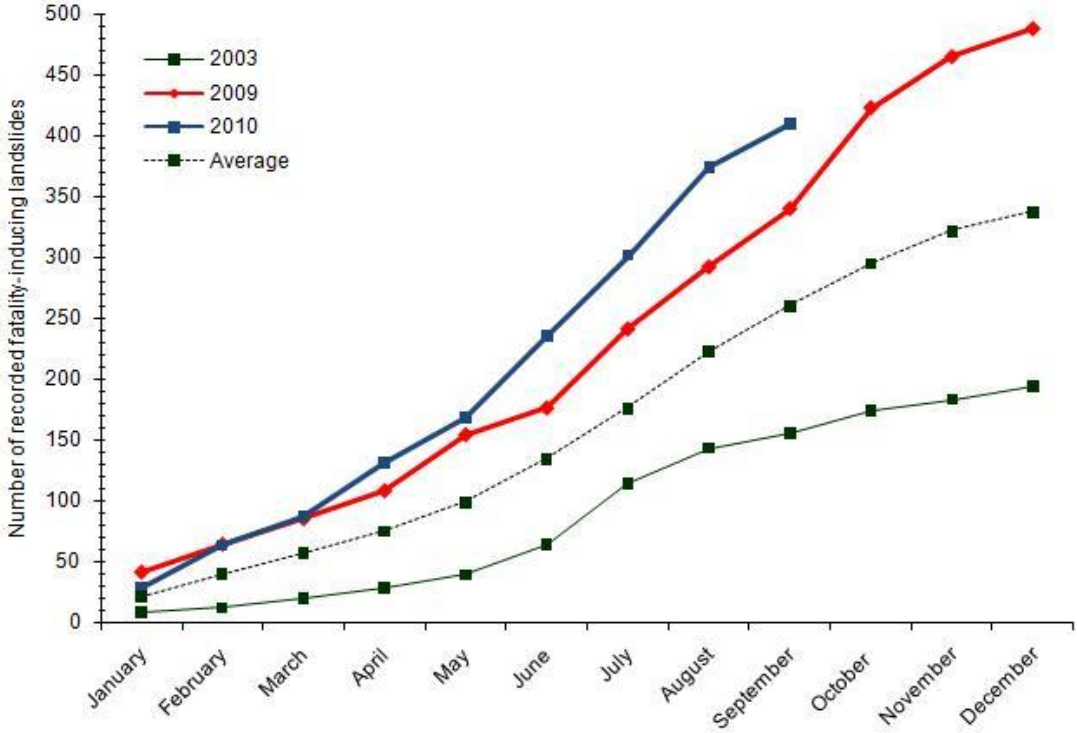


Figure 26: Fatal landslides occurred worldwide

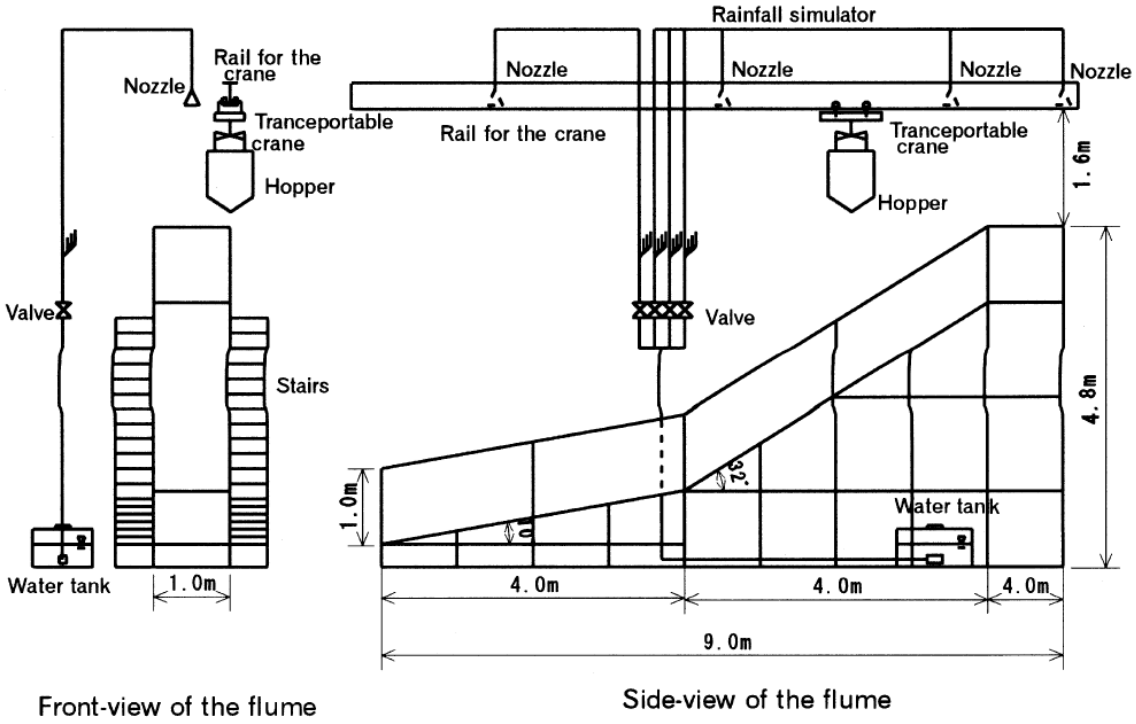


Figure 27: Flume setup by Okura, Kitahara et al. (2002)

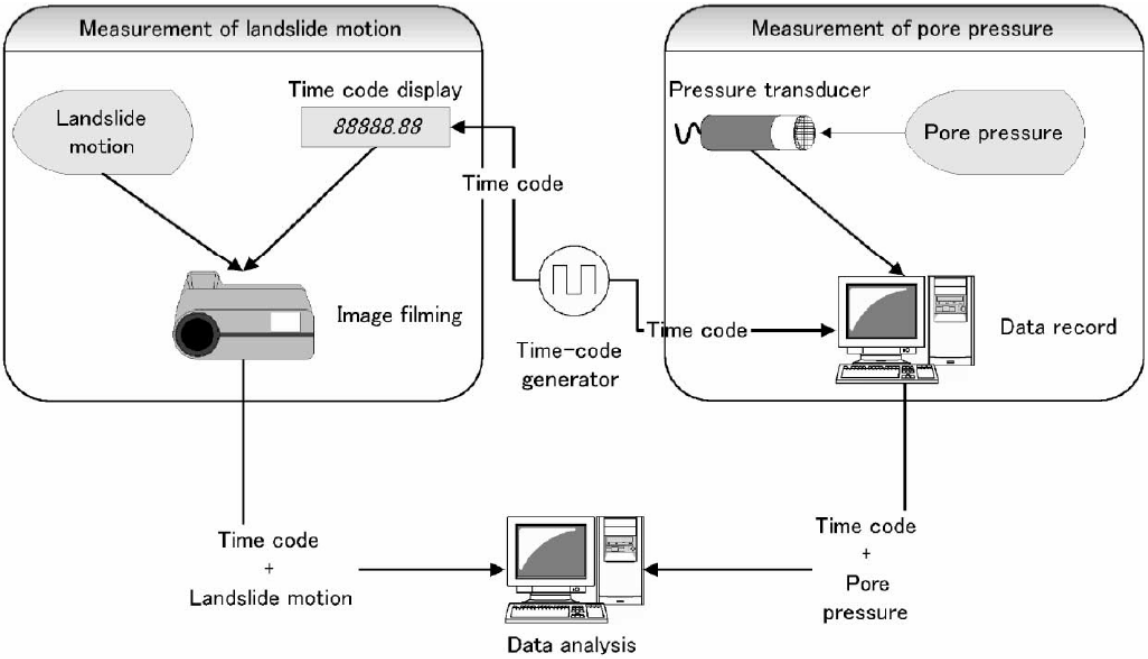


Figure 28: Measurement system by Okura, Kitahara et al. (2002)

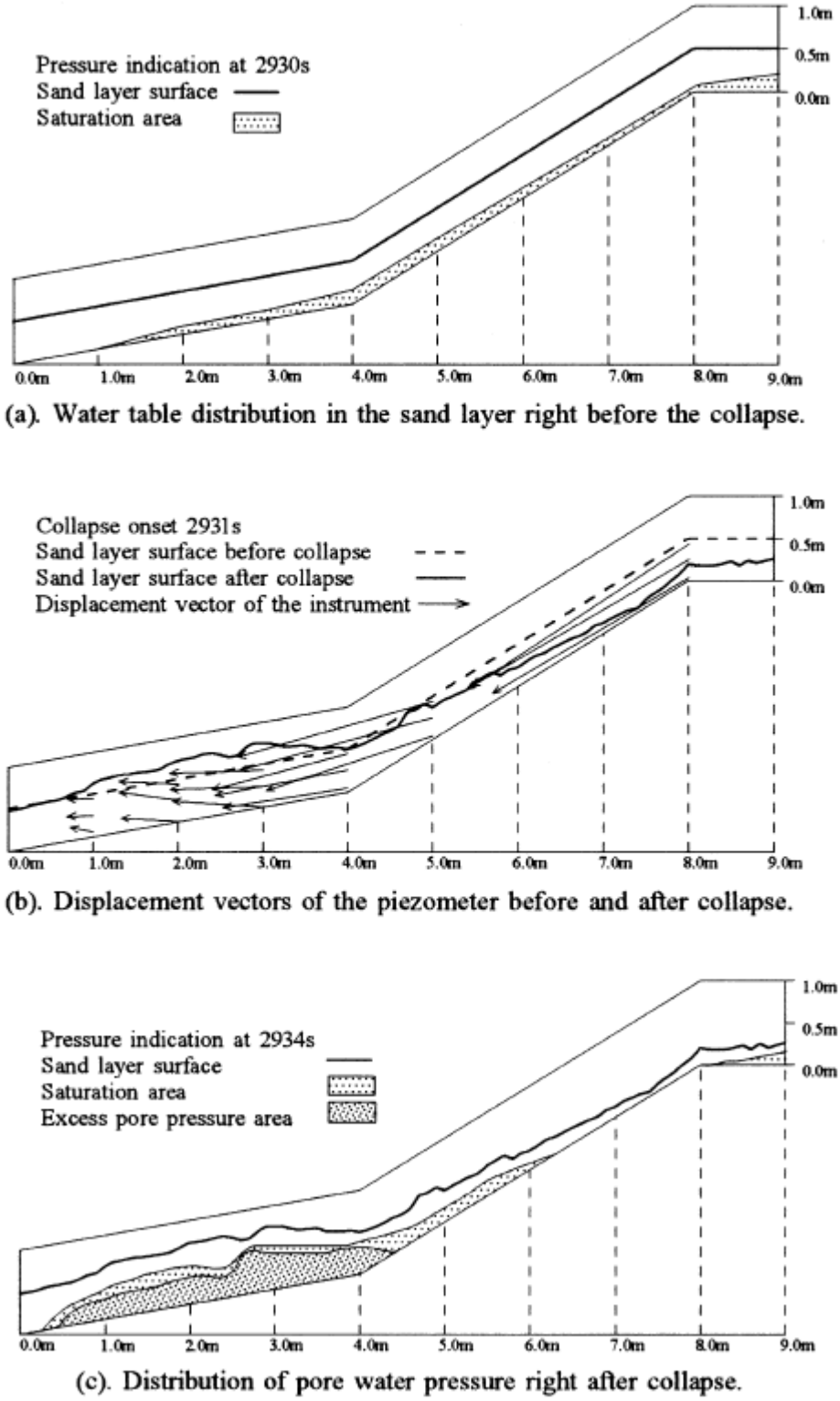


Figure 29: Result from experiment 1 done by (Okura, Kitahara et al. (2002))

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

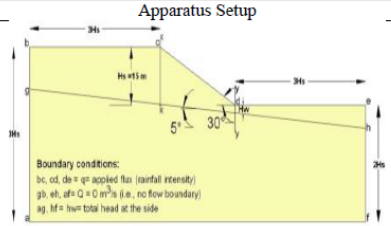
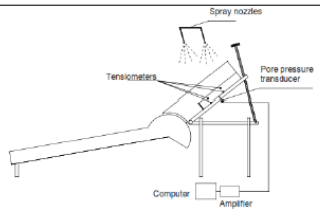
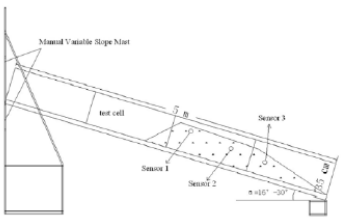
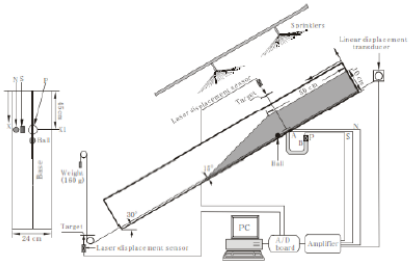
Authors, Year	Objectives	Parameters	Apparatus Setup	Result Enquiry
(Rahimi, Rahardjo, & Leong, 2011)	To find the effect of antecedent rainfall pattern on the stability of slopes.	- identified rainfall patterns used - applied two different type of soil 1. High-conductivity soil 2. Low-Conductivity Soil	 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.

Figure 30: Previous researches

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

Figure 31: Previous experiments

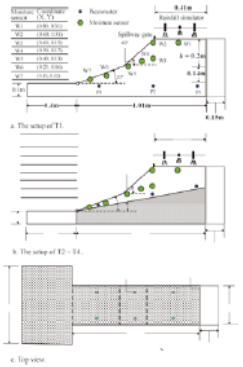
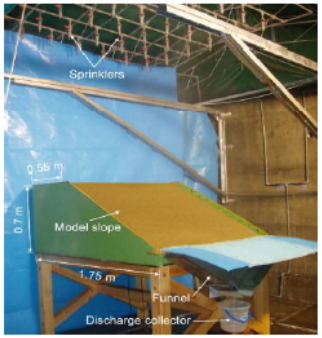
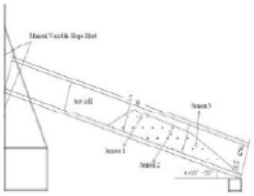
Apparatus Set up				-	-
Result	• Landslide initiated by erosion at shallow depth • The mode of retrogressive failure started from the toe of sandy slope	The internal moisture response, interflow and seepage patterns may be influenced by slope and bedrock configurations	The effective shear strength of 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.	–	–

Figure 32: Previous experiments (cont'd)