SIMULATION OF SLOPE FAILURE INDUCED BY RAINFALL ON CLAYEY SOILS

by

AMMAR BIN ZULKIFLLI

16942

Bachelor of Engineering (Hons)

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Supervised by: Dr Indra Sati Hamonangan Harahap

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Simulation of Slope Failure Induced By Rainfall on Clayey Soils

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Ammar Zulkiflli

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____

(Name of Main Supervisor)

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is 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.

AMMAR BIN ZULKIFLLI

ABSTRACT

Landslide is accustomed event in Malaysia and usually occurred during the rainy season and has taken lots of life and destruct million worth infrastructure. This is a geotechnical failure induced either by human activity or weather. Rapid development at the hilly area without supervision of the local authorities and lack of knowledge on soil behavior will leads to the slope to fails. In other hand, in sub-urban area where there are less development, the slope tend to fails due to the heavy rainfall. Water pervade into the soil and change the behavior of the soil and increase the moisture content, pore pressure and mass of the soil. Thus, lead to slope failure.

These research paper aims to study the relationship between rainfall intensity towards the slope failure by simulate 60% of the exact site condition. Author will simulate the maximum rainfall intensity, actual slope surface and type of soil from actual site location. Rainfall intensity data released by Malaysian Meteorological Department will be set as parameter for the study. Meanwhile, soil sample will be tested to examine the soil properties and its behavior. Moisture content and pore pressure will be measured as a parameter of the studies. In other hand, author looking forward for this studies to understand better the factor that leads to this disaster.

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CHAPTER 1

INTRODUCTION

1.1 Chapter Overview

In this chapter, the background pertaining to this research study giving an overview of the effect of the environment towards the slope stability, problem statement highlighting the rainfall induced the slope failure, objective and scope of thus research study are presented. At the end, the arrangement of remaining chapters is given as a reading guideline.

1.2 Background of the Research

In recent year, landslide incident managed to capture attention of the publics and government itself. Recent incident of slope failure has taken many life and destruct million worth of infrastructure. Induced by the heavy rainfall and poor drainage system leads to failure of the slope.

Malaysia is located in southern-east Asia which is lies on equator line. By it characteristic, this region received 2500 – 3000mm rainfall annually. However, Borneo islands which consist Sabah, Sarawak, Brunei and Kalimantan, Indonesia experiencing high intensity rainfall with average 400mm – 1000mm. Meanwhile, based on Malaysia Meteorology Department (MET) stated that peninsular Malaysia less suffered high intensity of rainfall which 200mm - 400mm along January 2015 ("Buletin Cuaca Bulanan", 2015).

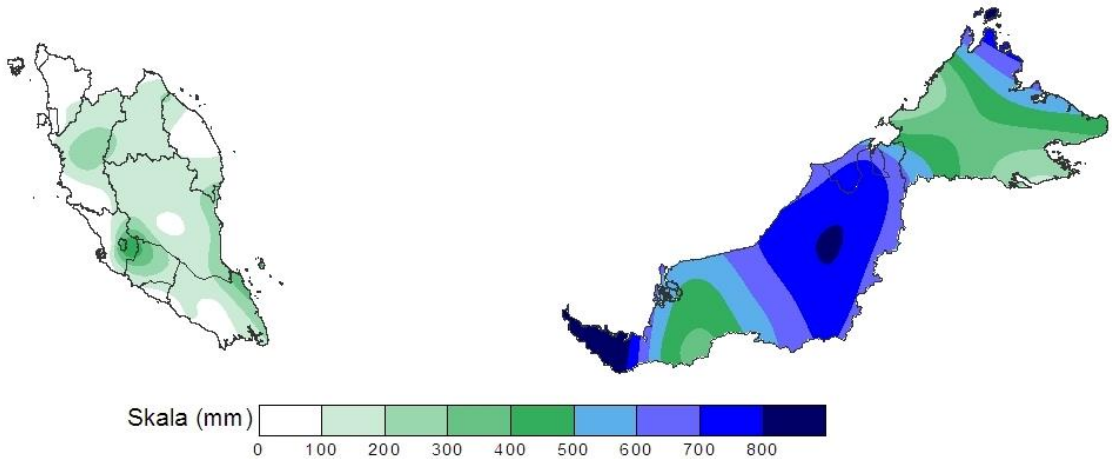


Figure 1: Monthly Rainfall Data

Peninsular Malaysia experiencing heavy rain during monsoon season which is divided in two type; south-east monsoon (May – September) and north-east monsoon (November – March). During the north east monsoon east coast states in Malaysia annually facing high intensity precipitation thus caused annual floods event and slope failure. ("Monsun", 2014)

Slope failure accustomed event in Malaysia and other tropical country involving local population lives and damaged the property which effects the balance of the socio-economic. Landslide or flow slide are indication of slope failure. Landslide occurred due to several factors; (i) human error during slope maintenance (Jamaluddin, T. A, 2003); (ii) environment and weather affects (Sladen et al. 1985); (iii) Concave shape of slope profile (Lee, 1982).

1.2.1 Human Activity

Rapid changes of the soil mechanic, shear strength and properties which affects the slope stability are driven by human activity. (Jamaluddin, T. A, 2003). Uncontrolled development near to slope or hilly area will increase number the probability of landslide. Any development either at top, toe or even on the slope should consider worst case scenario that landslide might occur. Engineering approach needed to tackle this situation by designing a sustained and 'landslide proof' to avoid any unfortunate event harming public safety.

1.2.2 Environment and Weather

Author will emphasize the area of studies regarding to the effects of weather and environment to the slope stability. As mentioned by (Chen, R et al, 2012), high intensity of rainfall gradually increase with period of rain fall would affect the properties of the soil which leads to landslide.

1.2.3 Shape of Slope

(Lee, 1982) claimed the slope profile and hydraulic conductivity of soils are dominant factor for slope stability and report that slopes failure induced by rainfall are commonly in concave shape.

Figure 2: Bukit Lanjan Incident

1.3 Problem Statement

In construction fields, excessive water on site is most challenging part to manage especially during the rainy day. Most of the construction site may not be operated due to heavy precipitation. Earthwork, concreting, soil investigation etc. are example of work progress need to be stop immediately on rainy day to avert difficulty working on soft soil, excessing water in the concrete mixture, disturbed soil sample and etc.

Slope Failures a natural disaster caused loss of life and damage to property. Every year, landslide return in the destruction infrastructure worth millions Ringgit, especially east-coast area in peninsular. As developed country, this annually event of flood and landslides constrain economic development. In Urban area, local authorities provide a guideline for developer to overcome any slope failure by engineering approach. Nevertheless, this in fact does not occur in remote areas where there is less supervision on slope movement or any other factors that may caused the slope failure.

(Chen, R et. al, 2012) claim the mechanism failure of soil slope due to the high intensity of rainfall. In the same journal author mentioned the long period of rainfall allowed the water to pervade easily. Large amount water infiltrate into soil increase the pore pressure thus decreased the shear strength of the soil.

Based on monthly rainfall data collect by Meteorology Department of Malaysia, Perak state received approximately 200mm -300mm rainfall along January 2015 which it is a potential criteria to cause a slope failure apart from slope shape factor and soil properties factor. By rescaling the area of study to investigate the slope stability within 10km radius from Universiti Teknologi Petronas. Author will select a potential slope which shows characteristic to fail.

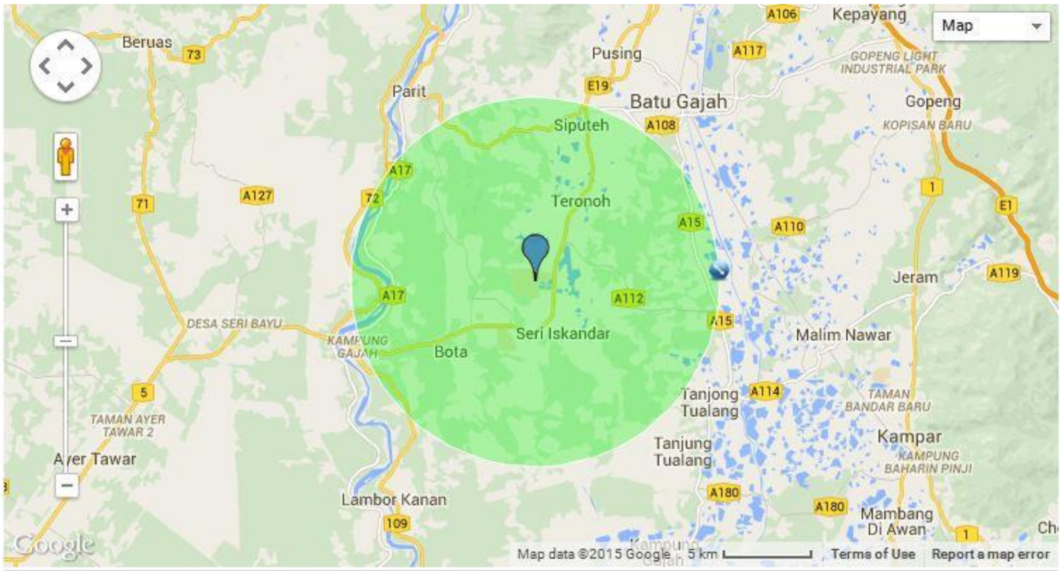


Figure 3: Area of Study

Author is endeavoring to emphasize the effects of rainfall intensity against slope strength. An exact simulation needed to accentuate actual on-site condition. Soil investigation needed to extract on-site soil properties to be examine in the laboratory. Apart from that, slope shape and gradient are need to simulate the actual slope in the flume. Moreover, soil layers data needed if it is available.

1.4 Objective of the Research

The primary objective of this research to simulate 60% of the exact condition of the selected site based on the rainfall intensity and type of soil. This experiment will allow to forecast the slope to fail at certain rainfall condition.

The specific objective of this project is:

- **Determine rainfall intensity for slope to fails.**
- **Observe rainfall period for sample to fail compared to the loose sand.**
- **Analysis the increasing number of moisture content and pore pressure.**
- **Study the soil properties and its behavior which may lead to slope failure.**
-

1.5 Scope of Project

Geotechnical engineering is a branch of civil engineering which study about earth materials and one of the important part in civil engineering and other engineering disciplines. Geotechnical engineering is very wide fields it took years to fully understand and discover things buried underground. Author will scale down the scope of project by looking and investigation regarding how the rainfall effects on the slope strength by simulate into the flume.

This project driven by recent natural event where landslide located at the roadside heading to Parit, Perak. Parit is a sub-urban area located 65 KM from capital city of Perak, Ipoh which is placed 10 kilometers radius from Universiti Teknologi Petronas. It is a good approach for this project to simulate actual on site condition and to be examine in laboratory for further studies.

Studies the soil properties of sample taken from selected slope in Parit. Sample will be tested it bearing capacity ratio, moisture content, type of soil, elasticity etc. Sample will be taken to Universiti Teknologi Petronas Geotechnical Laboratory to be examine. Soil properties data is required to obtain the *'mystery lies beneath'* the slope.

An observation to the rainfall intensity at the site location needed to simulate the flume rainfall. Author tries to simulate 60% from the actual on site condition to forecast the period of landslide to occur. Site visit or visual observation is important to gather some basic information of slope that need to be studied. Topography, level of the location, gradient of the slope, exposed area of slope to the rainfall, and other data need to be taken and study to ensure it effects to the slope stability.

Figure 4: Site Location

CHAPTER 2

LITERATURE REVIEW

2.1 Chapter Overview

In this chapter, a critical review of past research studies related to factor of the slope failure (Gradient, shape, soil characteristic, water content, pore pressure and human activities). At the end, the gaps in literature pertaining to this research study are discussed.

The mechanisms leading to a certain failure mode can be studied by triggering small-scale landslides e.g. in terms of flume tests. Beside numerical tools experiments like flume test can give better understanding of the process of governing landslides by performing flume tests in laboratory.

During the rainfall infiltration the shallow and local slope failures occur due to formation of temporary saturated zone that would leads to reduction of the matric suction. During the rainfall infiltration the shallow soil of landslide mass quickly reaches to saturation and develop the surface runoff, that erode the slope, and seepage field is changed during infiltration of rainfall, as a results moisture content of landslide mass increases. Due to increase in moisture the shear strength is reduced. The shear strength of nearly saturated soil is greater than saturated soil.

The status of moisture content of soil mass strongly related to movement of rainfall induced landslides. The physical index by which soil-water characteristics reflected is volumetric moisture content (Zhang et al., 2014). The moisture is increases after infiltration of the rainfall and modifies the structure of soil and thus lessens or vanish the frictional or cohesive strength of soil (Reddi, 2003).

Infiltration of the rainfall above the ground water table in unsaturated zone induces the slope failure. From the experience it was revealed that numerous slope failures occur during or shortly after rainfall, as water infiltrates into the slope. Landslide that induces by rainfall is varying in depth and the landslide is the deeper, causing greater damages. These types of failures are characterize by shallow sliding surface usually 1–3 m and developed parallel to original slope surfaces. The ground water tables frequently to be found at greater depth below the surface of ground, and there is no any proof that during the rainfall that water table rise significantly that trigger the shallow failures. Instead, due to infiltration of rainfall wetting front get deeper in to the slope attribute the slope failure (Kim et al., 2004; Zhou et al., 2009). There is large deformation in slope failure in which the soil of the slope undergoes significant huge strain.

Then slope will be in new deformed state after the failure, in that movement of toe and settlement at the crest occurs. In tropical and subtropical weathered soils the most of rainfall-induced landslide is occurs above the ground water table (Brand et al., 1984; Mokhtar et al., 2012). Earth slope weakens by rainfall in number of ways. The degree of saturation of soil increases by rainfall infiltration, in that way it breaks the bonds that build by surface tension between particles of soil. The fluid exerts the downhill drag force on the slope when infiltrated volume of water is large enough to mobilize the fluid flow within the soil that produces a destabilizing effect on slope. Due to increase in saturation in the soil, when excess fluid can no longer infiltrate to slope, it discharged as surface runoff and erodes the slope. Rainfall weakens the slope because it decreases the capillary pressure as increase in saturation. Besides, it increase the load on the soil due to generation of frictional drag that created by fluid flow (Borja and White, 2010).

Due to infiltration of rainfall the moisture content is increased and the soil of slope cut and softened thereby increasing the sliding forces (Liu et al., 2013). The failure of slope induced by rainfall is mainly caused by (1) the weight of soil mass increased (2) with the increase in water content decrease in suction of unsaturated soil (3) increase in ground water level (4) erosion of slope surface and lubrication of sliding surface (5) hydrostatic or hydrodynamics pressure (Kitamura and Sako, 2010; Fang and Esaki, 2012).

Flowslide is the slope failure in that sliding mass characterized by general disintegration and development of fluid like motion with rise in pore water pressure (Wang and Sassa, 2001). The most of the shallow slips turns into flow type of failures as reported from Iverson et al. (1997). Rainfall-induced flowslide can occur in natural and also in man-made fill slopes. The rainfall-induced flowslide have a distartous effect on public and nearby communities, because in shallow flowslide the huge saturated soil mass moving at very high speed and causing damages and casualties. Some forms of landside may turn the debris flow, especially in granular soil in that movement like sliding may turn in to the flow. The mechanism of movement is the main difference between the slide and flow like landslides. The sudden increase of pore pressure greater than hydrostatic may leads to decrease in shear resistance and increase the acceleration of movement, in that condition also generates the debris flow (De Wrachien and Brebbia, 2010). The debris flow is intermediate between sediments rich floods and landslides.

Due to probability of events, size and behavior of soil bodies, the landslide risk analysis is not an easy task. But in order to find the good solutions and to tackle the problem strong efforts have been made from the last decades. Some researchers engaged themselves in the improvement of numerical modeling for triggering and movement of landslides, others are concerned with the development of alert and alarm systems for landslide disasters prevention; finally others are engaged in setting the physical models for simulation of landslides initiation and evolutions.

In short time many places affected by heavy rainfall that more often triggers slope failure and declare many casualties and affect the local communities. The effective measure is difficult to find even though the risk of rainfall-induced slope failure widely recognized. The one reason is that more attention is given to bigger events, and in detail small and shallow slope failures have not been studied. Definitely bigger failure can cause more damages to infrastructures and public, and efforts are being made to overcome that problem. The other reason is may be that the shallow slope failure is affected by geology, hydrology and local perception that are relatively difficult to study in detail. The small slope failures occur suddenly and kill the peoples without cautions.

During heavy rainfall the early warning that based on monitoring of the slope is comparatively is an inexpensive way to save the life of the peoples. This practice is however not an easy, because onset slope failure is affected by many factors such as hydrology, geology, topography and perception intensity. There are two approaches are used for early warning system. Proper monitoring not only used for early warning, but also help to better understand the process of landslide.

A physical slope presented. The objective of this research is to study the change in number of precipitation effects the amount of moisture content and pore pressure in the slope.

Three (3) rainfall intensity parameter will be simulated to have a better comparison and each parameter will be tested 3 times for accuracy and consistency.

2.2 Effect of water content

Changes in soil properties induced the change of the behavior of the soil and affect it strength. Saturated soil with rain water may increase the weight of the soil mass which will lead to soil failure. (Yatabe et al. 1986).

(Chen, R et. al, 2012) claim the mechanism failure of soil slope due to the high intensity of rainfall. In the same journal author mentioned the long period of rainfall allowed the water to pervade easily. Large amount water infiltrate into soil increase the pore pressure thus decreased the shear strength of the soil. Permeability of soil also lead to the rainfall infiltration, the higher permeability of soil lead to higher volume of infiltration and vice versa. (R. Schnellman et al. 2010).

` Shearing resistance in soil slopes is mainly governed by shear strength, which in turns is controlled by effective stress. Effective stress is define as total stress minus pore-water pressure. Therefore rising water table increase pore water pressure in the slope, reduce the effective stress consequently decreasing the stability of the slope. (R. Schnellman et al. 2010).

2.3 Shallow Failure

Coarse grained soils of high permeability like sand can result in deep landslide due to rising of water table and increasing pore water pressure at deeper depth. (R. Schnellman et al. 2010). In other hands, reduction in matric suction of the fine grained soil of low permeability can be the triggering factors of shallow landslide during rainfall infiltration.

Shallow failure or ‘soil slip’, is triggered by short duration and intense rainfall, mostly occurs on composed slope with shallow permeable layer and impermeable bedrock. (L. Montrasio, 2007). Campus et al, (1998) stated that soil slips are characterized by a triggering stage and by a sub sequent run out that can develop in different ways. In worst case, he also mention the sliding soil portion flows like liquid down the slope surface, reaching a velocity of more than 9 m/s.

The study of Spickermann et al.(2010) was mainly focused on investigation of hydrological triggering and mode of landslide failure behavior by conducting the flume tests in laboratory, on clayey material as well as on sandy material. The test results showed that, without any visible precursor the failure occurred suddenly in sand with constant but high velocity, but in clay there is slow and constant velocity after that velocity is increased, and failure take place in sand within few minutes while in clay failure take place about weeks, and retrogressive failure occurred in sand connected to fluidization while in clay failure take place progressively and soil slumps and the failure take place without fluidization.

CHAPTER 3

EXPERIMENTAL PROCEDURE

3.1 Chapter Overview

In this chapter, methodology of the studies has been briefed to achieve the main objective of this project. Consist of the site investigation, studies of soil behavior and properties, flume preparation and documentation or data collection. Experimental procedure means to deliver a clear instruction.

3.2 Sample and Soil Testing

Sample were taken from proposed site, located approximately 10 kilometer from University Teknologi Petronas and to be tested in the laboratory. From the visual observation, sample are categorized as sandy clay soil. White boulder, fine grained and chalky sand been identified by the authors. Further studies of the soil properties is needed to obtain more accurate data.

Figure 5: Actual Site Condition

3.3 Model Preparation

Flume is a rectangular box made up from clear view high durable plastic will be used as a container to fill the soil sample. Soil will be compacted inside the flume to give a picture of the real condition on site. Besides, the soil will be shaped by following the actual gradient on site to produce the same runoff surface of the rainfalls. The slope thickness, density and initial moisture content and rainfall intensity were varied to investigate the rainfall-induced slope failure. The rainfall intensity was controlled by flow meter and valves were attached with the body of sprinklers fitting. The compaction was given to slope with 2 kg manual fabricated hammer. The soil was placed parallel to flume bed and compacted.

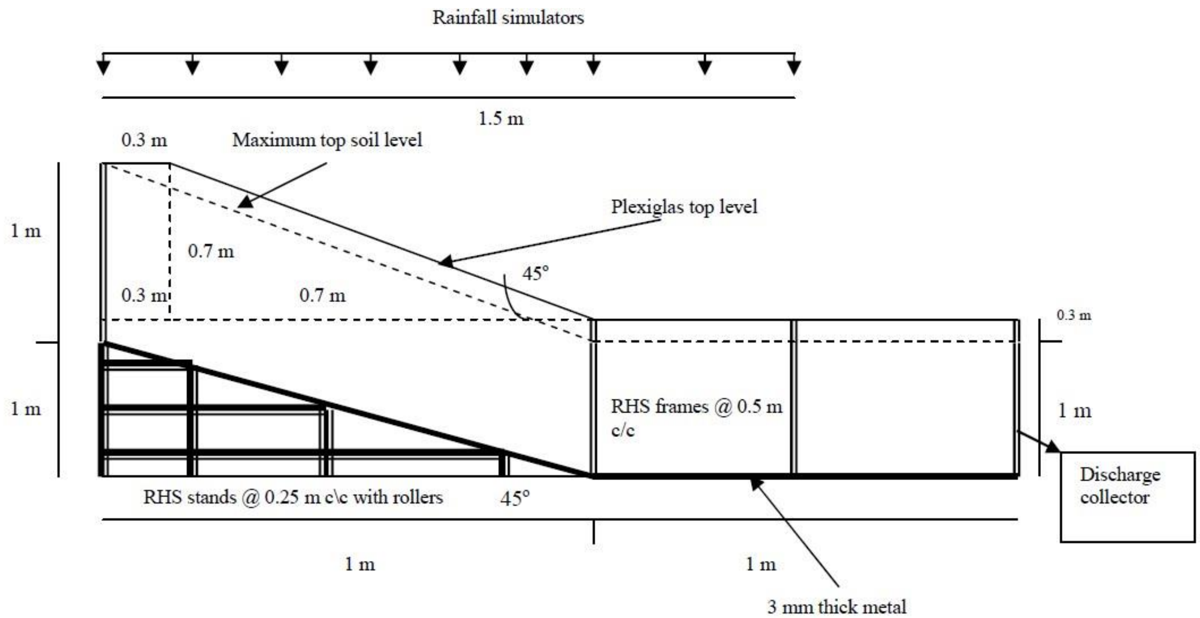


Figure 6 : Flume Dimension

3.4 Sensor

After the preparation of model slope, the sensor such as moisture sensor Imko TDRs and piezometers were installed in soil slope by drilling the holes in soil slope, after that holes were backfilled with moist soil. The pore pressure was measured with electrical piezometer model Sisgeo P235S, with range of measurements from 0 to 100 kPa. The failure in model slope was induced by artificial rainfall through sprinkler.

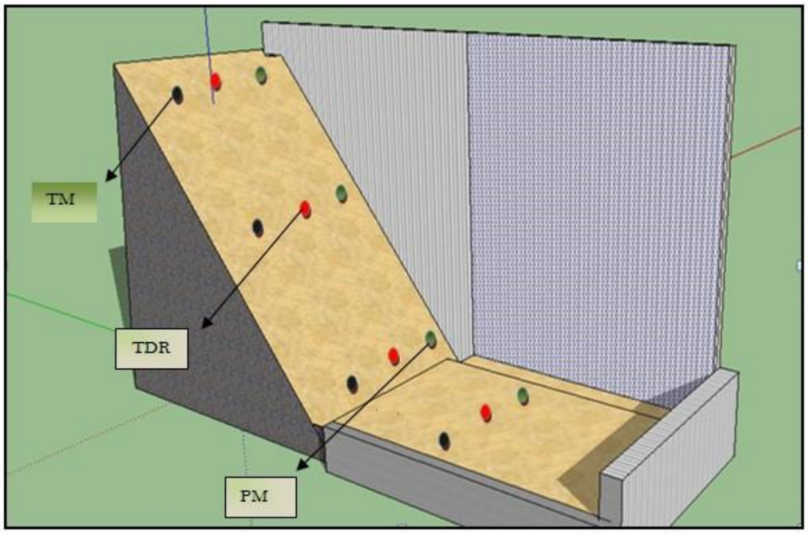


Figure 7 Sensor Location

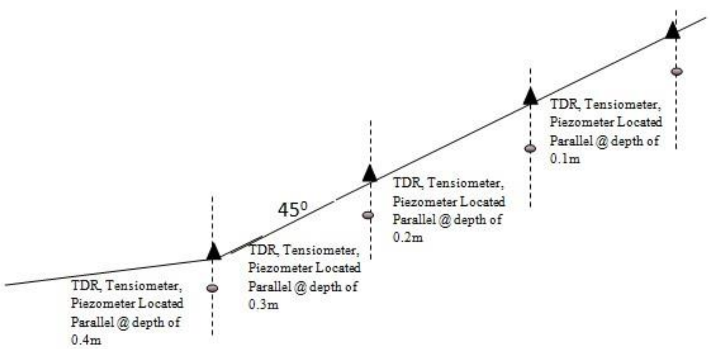


Figure 8 : Side view for Sensor location

CHAPTER 4

RESULT AND DISCUSSION

4.1 Chapter Overview

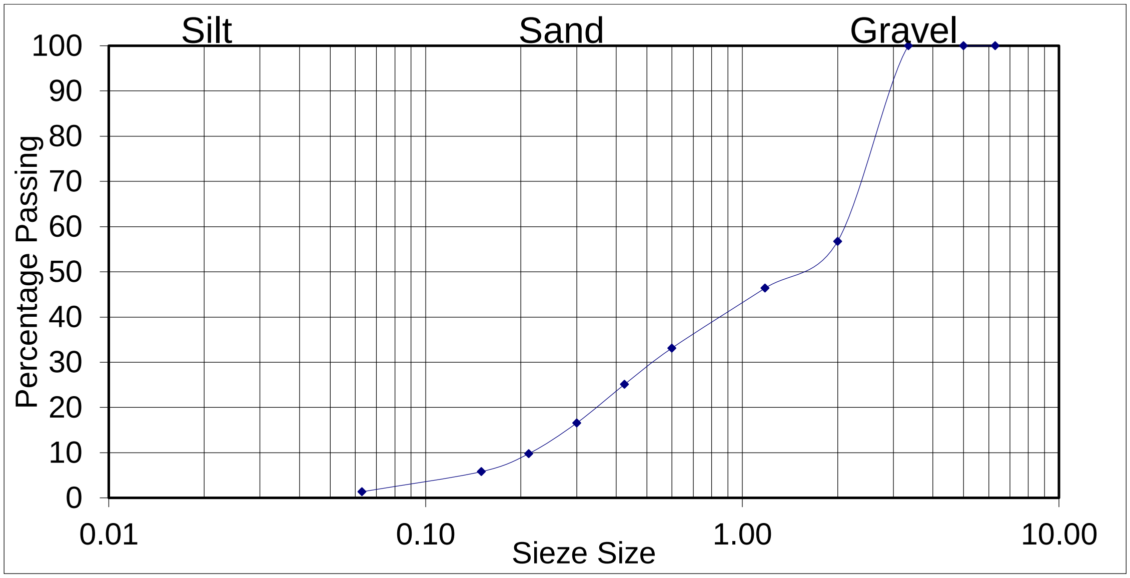
This chapter will elaborate more on the findings gathered of this project. This chapter will perform all the studies and d Based on the result occurred, I would discuss about the slope failure induced by rainfall intensity.

4.2 Result

4.2.1 Soil Propeties

Sample has been tested in the geotech laboratory to determine the soil properties concurrent with soil preparation. Sample been undergo few basic test to obtain the properties such as Liquid limit test and plastic limit test to gather the plasticity index (PI). From this experiment, moisture content of the sample has been achieved. Particle size distribution test are design to determine the type of soil other that hydrometer test.

i) Particle Size distribution



Graph 1 : Particle Size Distribution

Initial Dry mass **m_1**		1000	g	
BS Test Sieve mm	Mass Retained (g)		Percentage retained	Cumulative percentage Passing
	actual	corrected m	(m/m1)100	
6.30	0.000	0.00	0.00	100.00
5.00	0.000	0.00	0.00	100.00
3.35	0.000	0.00	0.00	100.00
2.00	433.040	433.04	43.30	56.70
1.18	103.220	536.26	53.63	46.37
0.600	132.420	668.68	66.87	33.13
0.425	80.400	749.08	74.91	25.09
0.300	85.570	834.65	83.47	16.54
0.212	67.500	902.15	90.22	9.79
0.150	39.980	942.13	94.21	5.79
0.063	44.420	986.55	98.66	1.35
Passing 0.063 m_F or m_E	15.290			
Total (check with **m_6**)	1001.840		**m_1**	

Table 1 : PSD Data

This test is performed to determine the percentage of different grain sizes contained within a soil. The mechanical or sieve analysis is performed to determine the distribution of the coarser, larger-sized particles, and the hydrometer method is used to determine the distribution of the finer particles. Three (3) of 1000g soil sample are used to perform this experiment. From the semi-log graph, the sample was a cohesive less soil, coarse-grained and well graded.

ii) Liquid Limit

The liquid limit (LL) is conceptually defined as the water content at which the behavior of a clayey soil changes from plastic to liquid. However, the transition from plastic to liquid behavior is gradual over a range of water contents, and the shear strength of the soil is not actually zero at the liquid limit.

iii) Plastic Limit

The plastic limit (PL) is determined by rolling out a thread of the fine portion of a soil on a flat, non-porous surface. The procedure is defined in ASTM Standard D 4318. If the soil is at a moisture content where its behavior is plastic, this thread will retain its shape down to a very narrow diameter. The sample can then be remoulded and the test repeated. As the moisture content falls due to evaporation, the thread will begin to break apart at larger diameters. The plastic limit is defined as the moisture content where the thread breaks apart at a diameter of 3.2 mm (about 1/8 inch). A soil is considered non-plastic if a thread cannot be rolled out down to 3.2 mm at any moisture.

iv) Plasticity Index

The plasticity index (PI) is a measure of the plasticity of a soil. The plasticity index is the size of the range of water contents where the soil exhibits plastic properties. The PI is the difference between the liquid limit and the plastic limit (PI = LL-PL). Soils with a high PI tend to be clay, those with a lower PI tend to be silt, and those with a PI of 0 (non-plastic) tend to have little or no silt or clay.

<u>PI and their meanings</u>

(0-3)- Nonplastic

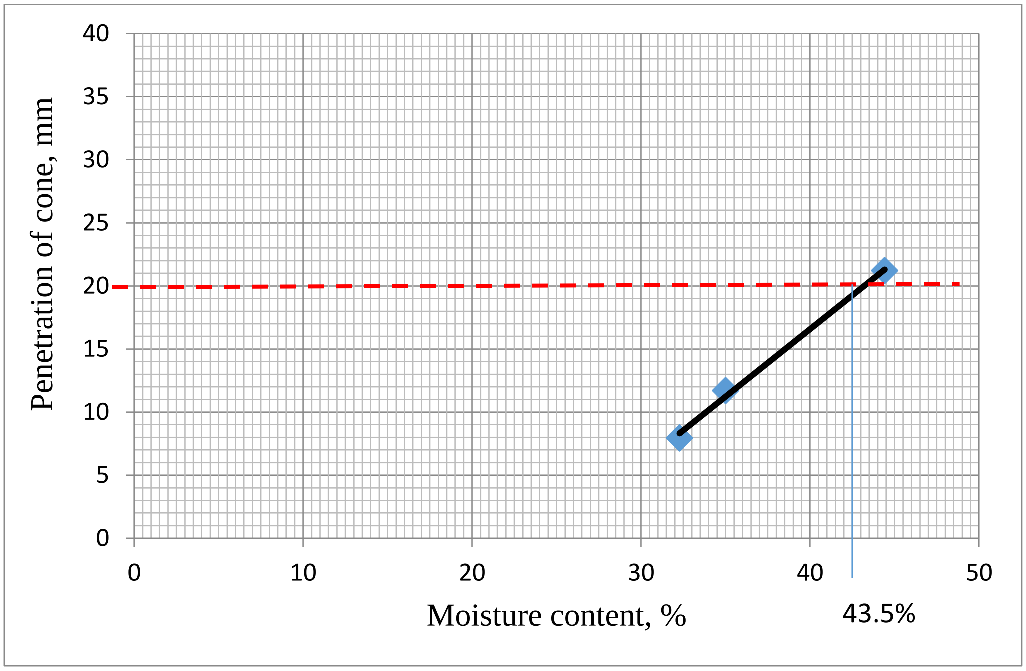
(3-15) - Slightly plastic

(15-30) - Medium plastic

>30 - Highly plastic

v) Liquidity Index

The liquidity index (LI) is used for scaling the natural water content of a soil sample to the limits. It can be calculated as a ratio of difference between natural water content, plastic limit, and liquid limit: LI = (W-PL)/ (LL-PL) where W is the natural water content.



Graph 2 : Moisture Content

PLASTIC LIMIT	Test no.	1	2	3	4	Average
Container no.						
Mass of wet soil + container	g	24.80	25.90	24.10	26.00	
Mass of dry soil + container	g	24.07	25.06	23.12	24.98	22.49
Mass of container	g	20.55	21.15	19.06	20.66	
Moisture content	%	20.74	21.48	24.14	23.61	

Table 2 : Plastic Limit

LIQUID LIMIT	Test no.	1			2			3		
Gauge reading	mm	8	7.9	8.3	11.8	11.6	12	21.1	20.7	21.8
Average penetration	mm	7.95			11.70			21.20		
Container no.		1			2			3		
Mass of wet soil + container	g	49.42			71.84			70.2		
Mass of dry soil + container	g	42.54			58.6			54.38		
Mass of container	g	21.22			20.77			18.76		
Moisture content	%	32.27016886			34.9986783			44.41325098		

Table 3: Liquid Limit

Plastic Limit	22.49	%
Liquid Limit	37.23	%
Plasticity Index	14.73	%

Plastic Limit	22.49	%
Moisture Content	43.50	%
Liquidity Index	1.43	%

Soils Classficiation from AASHTO	Sandy Clay

Table 4: Liquidity Index

Based on the chart and graph shows the average percentage of plastic limit is 22.49%. Meanwhile 37.23% of liquid limit. By using formula PI = (LL – PL), the plasticity index is 14.73%. This define that the sample is slightly plastic.

From the graph plotted, we can determine the moisture content where at 20mm penetration cone shows the moisture content of 43.5%. Furthermore, Liquidity index can be determine by using this formula LI = (W-PL) / (LL – PL).

vi) Group Index

Data collected from series of experiments to study the properties of the soil and its behaviors. ***Plasticity Index*** *(P.I) = L.L – P.L = 37.23 – 22.49 = 14.73.* As less than 35% particles passes sieve 0.075mm thus the soil comes out to be A-1 to A-2 having granular particles. For liquid limit and plasticity index is 37 and 22 respectively as referred to **AASHTO Soil Classification System** table sample soil are classified as A-2-6

General Classification	Granular Materials (35% or less passing the 0.075 mm sieve)							Silt-Clay Materials (>35% passing the 0.075 mm sieve)			
Group Classification	A-1		A-3	A-2				A-4	A-5	A-6	A-7
	A-1-a	A-1-b		A-2-4	A-2-5	A-2-6	A-2-7				A-7-5 A-7-6
Sieve Analysis, % passing											
2.00 mm (No. 10)	50 max	...	...	...	...	...	...	...	...	...	...
0.425 (No. 40)	30 max	50 max	51 min	...	...	...	...	...	...	...	...
0.075 (No. 200)	15 max	25 max	10 max	35 max	35 max	35 max	35 max	36 min	36 min	36 min	36 min
Characteristics of fraction passing 0.425 mm (No. 40)											
Liquid Limit	...		...	40 max	41 min	40 max	41 min	40 max	41 min	40 max	41 min
Plasticity Index	6 max		N.P.	10 max	10 max	11 min	11 min	10 max	10 max	11 min	11 min[1]
Usual types of significant constituent materials	stone fragments, gravel and sand		fine sand	silty or clayey gravel and sand				silty soils		clayey soils	
General rating as a subgrade	excellent to good							fair to poor			

Table 5 : AASHTO Soil Classification System

Now calculate the Group Index;

$$GI = (F200 - 35)\ [0.2 + 0.005(LL-40)] + 0.01\ (F200 - 15)\ (PI-10)$$
$$GI = (60 - 35)\ [0.2 + 0.005(37-40)] + 0.01\ (60 - 15)\ (22-10)$$
$$G.I = 6.72 = 7 \text{ thus}$$

Our soil is A-2-6 (7)

4.2.2 Rainfall intensity against Moisture Content and Pore Pressure

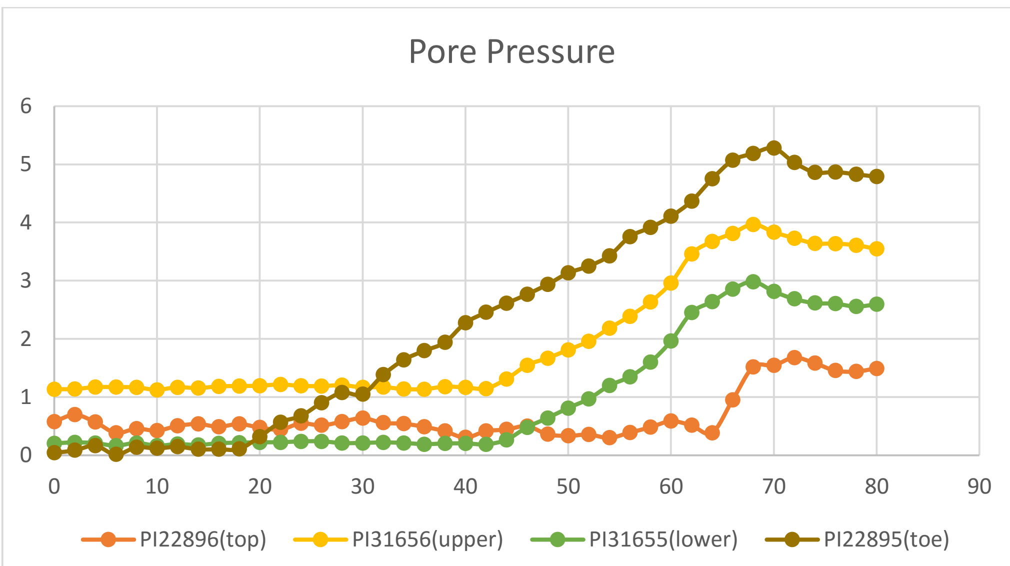
In this current experimental study the numbers of experiments were conducted in flume in order to better understand the mechanism of rainfall induced slope failure. The soil was placed in flume and slope was prepared and the after preparation the moisture and pore pressure sensors were placed at different location and in each figure the sensors position was depicted. In the case of dense slope the soil was placed in flume in layers and each layer of soil was compacted with fabricated hammer sufficiently till achieve the required height.

The failure was induced in the slope by rainfall through small sprinkler installed above the flume. After the starting the rainfall the moisture content was increased and the shallow moisture sensors shows fast response soon after starting of the rainfall, and after the wetting front progressed to base of the slope, initially at the toe of the slope. After the first increase the shallow moisture sensors shows same value, and it increased after the development of water level from the base of the slope. When the wetting front reaches at base of the slope it shows the sudden increments and reaches to saturation, and in the one step fully saturated, however the moisture sensors at shallow depth reaches to saturation in 2 steps.

Figure 9 : Rinsed Precipitation on the Glass

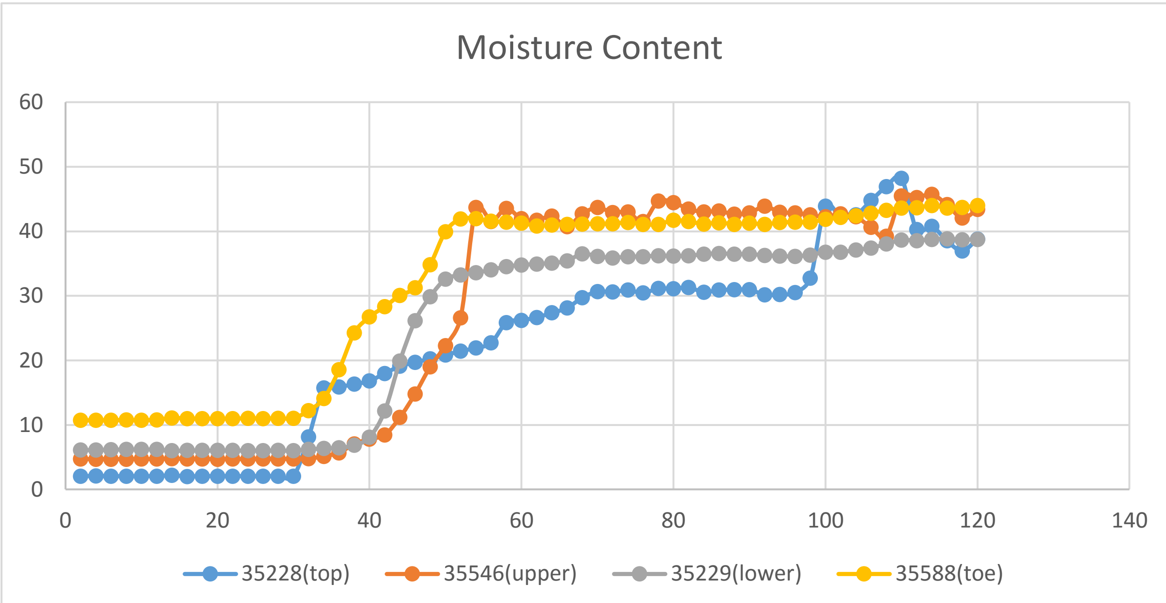
From the visual observation, sample took some time to show any sign of failure. Sample on the side of the flume show an early sign of erosion due to high amount of rainfalls flow on the glass. Basically failure initiated by surface erosion as shown in figure 4 and this allow the precipitation to pervade more to the next layer thus increase chances of being fail. As more rainfall absorb by soil. The mass of the soil also increase which generate lateral force for slope to slide.

Shearing resistance in soil slopes is mainly governed by shear strength, which in turns is controlled by effective stress. Effective stress is define as total stress minus pore-water pressure. Therefore rising water table increase pore water pressure in the slope, reduce the effective stress consequently decreasing the stability of the slope. (R. Schnellman et al. 2010). In this case the more amount of water pervade the layer of soil and accumulate at the toe will increase the pore pressure which lead to failure at the toe. This finding are supported by plotting graph of the pore pressure against time as mentioned earlier.



Graph 3 : Pore Pressure

Based on the graph plotted, shows that the peak of each curve indicate the highest pore pressure, and the failure start to occur a moment after that. All 4 piezometer place at different height as shown in figure 3. PI22895 were place at the toe of the slope where Pore pressure at almost zero at the early stage of experiment. Thenceforth, it gradually increase with time as more water pervade the sample. Meanwhile the PI22896 were installed at top most of the slope having higher initial pore pressure. The reading of pore pressure at the end on experiment is 1.5 which 3 times lower compared to the PI22895 (4.8) where it reinforces the fact that the water stagnant on the surface or saturated inside the sample at the toe does affect its strength. At 68 – 72nd minute, the highest pore pressure been recorded. Within this time range the slope start to fails.



Graph 4 : Moisture Content

Graph above show the graph of moisture content against the time and data were plotted every two minutes.

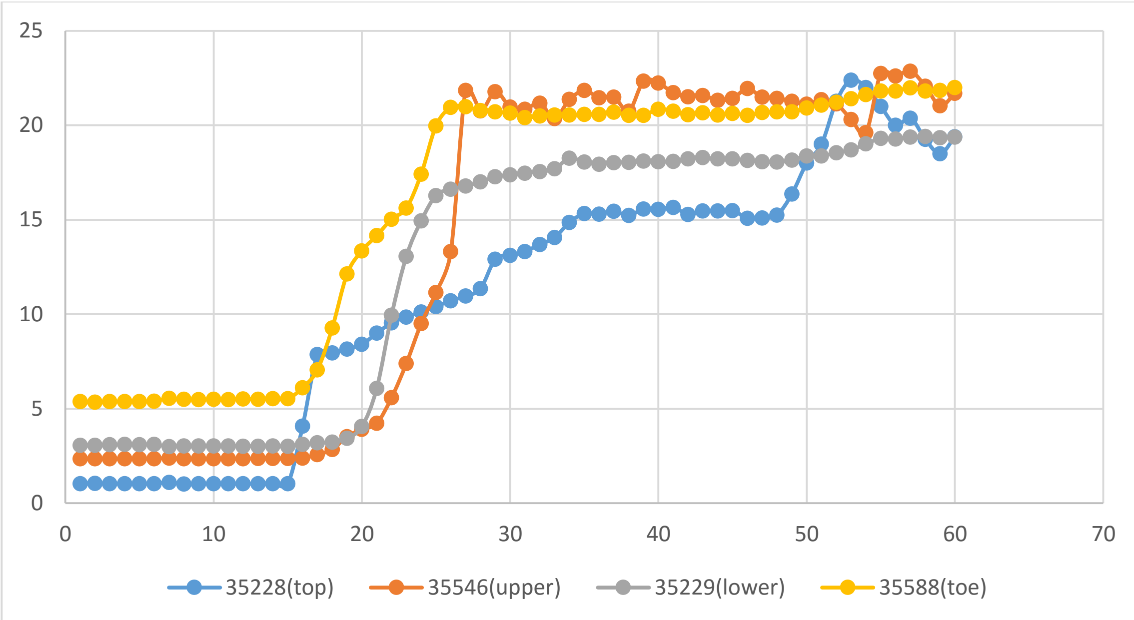
Imko TRDs	Initial Moisture Content,%	Final Reading %
35 228	2.06	38.8
35 546	4.71	43.48
35 229	6.21	38.75
35 588	10.78	44

Table 6 : Percentage of Initial Moisture Content

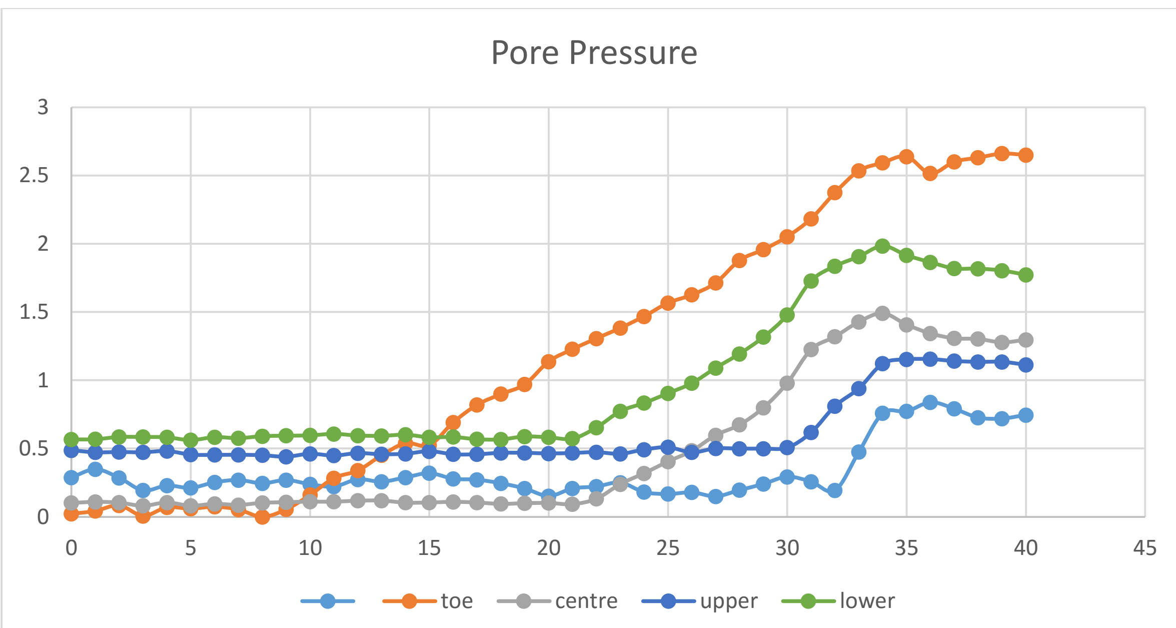
Every sensor show different initial value of moisture content. Pattern was discover by this finding where the location of the sensor and the percentage of moisture content. 35 228 Imko TRDs sensor were located at the top of the slope meanwhile the 35 588 were located at the toe. From this finding, an early hypothesis been made where the moisture content at the toe is higher compare to the top due to the thickness of the sample. At toe 10.78% of moisture content been recorded. The higher volume of soil the higher amount of moisture content because of the saturated rainfalls.

Rapid increase of moisture content shown from minute 30's to 40th for all sensor. Hike of reading indicated the soil start to saturate. When the sample I fully saturated, all sensor show a same and constant reading within range of 38% - 44%. Compare to the sandy soil, the higher number of moisture content on apply at the toe. This finding shows the other way around where the moisture content are about almost the same. The permeability of this two different sample does affect the number of moisture content.

By using the same sample, soil being undergo another simulation against 250ml/sec rainfall intensity, from the second experiment, there is nothing much to say about the pattern of failure, it shows the same shape with approximately same time of failure by half.



Graph 5: Moisture Content for 250ml/sec

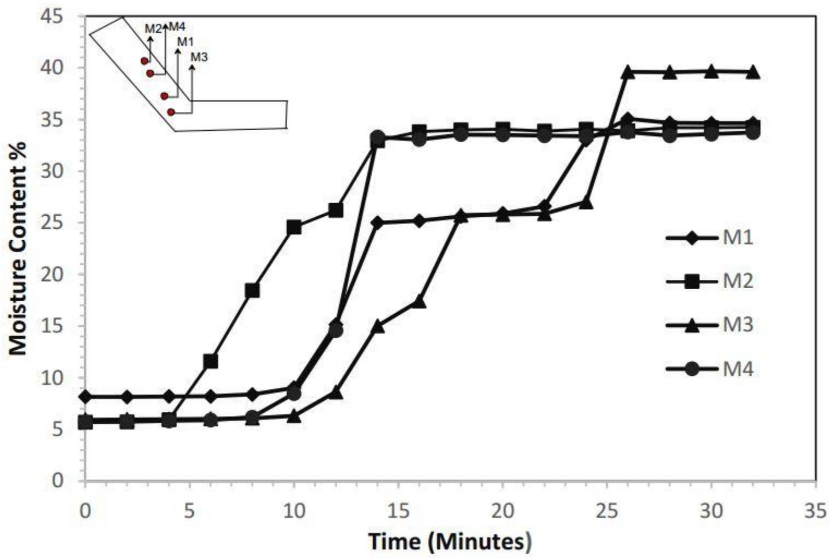


Graph 6: Pore Pressure for 250ml/sec rainfall

From the pore pressure graph, the value is approximately same by half as previous experiment. This shape and the failure occur also almost the same.

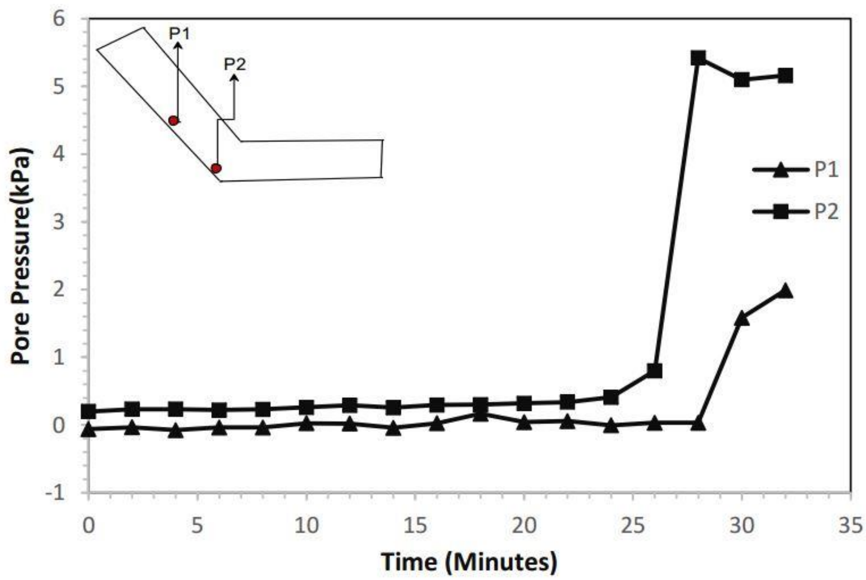
4.2.3 Comparison Sandy Sand vs Clayey Gravel

Previous studie done by M. R. Hakro by using sandy soil said otherwise where the moisture content at the end of experiment show a gap between two sensor at the top and toe. The Toe experience higher value of moisture content compared to the top with 41% and 33% respectively. Just finding justified the rainfall infiltration flow inside of the soil to the toe and accumulated.



Graph 7 : Moisture Content from Previous Studies

From this graph we can observe that the sudden increase of pore pressure may lead to the mechanism of the failure. Compared to the clayey sample the increasing of the pore pressure is gradually and failure occur at the highest point of the pore pressure. Proven that the properties of soil do affect the behavior of the soil against rainfall intensity.



Graph 8: Pore Pressure from Previous Studies

4.3 Discussion

From the previous research, I found out that the major factor of landslide is due to high water content and usually landslide occur during the rainy days. . Numerous amount of water content in the soil major factor that cause the landslide. Once the water pervade the soil, it changes the soil characteristic and its behavior. In additional water content increase the mass of the soil.

Numbers of experiments were conducted apart from discussed above in the flume by measurement of pore pressure, moisture content. Numbers of studies have already been carried out to obtain the characteristics of the pore pressure changes and the deformation characteristics of soil from instrumented slope. During rainfall the changes in pore pressure associated with soil deformation were recorded in instrumented slope.

As mentioned earlier, rainfall intensity used as parameter to study the slope failure. Two intensities will be used for this experiment; 500ml/sec and 250ml/sec. Major movement are visible at 50th minute. Large volume start to shift downward and can be seen at the side of flume through the glass.

For the initiation of the flowslide the development of pore pressure is not important as compared to increase in the moisture content, as in experiments the flowslides were occurred without increase in the pore pressure. According to Eckersley (1990) who conducted the laboratory model test and observed that pore pressure increase is the result rather than cause of flowslide. The sudden increase in pore pressure suggesting that static liquefaction occurring (Damiano et al., 2008). The experiments that were conducted on tight soil (clay) slope demonstrated that moisture content is constant even initial data said otherwise. This is because the clayey soil are saturated because of it properties compared to the sandy soil. During the flowslide the excess pore pressure was observed, this was due to rapid shearing of soil slope. The continuous rainfall infiltration and effect of gravity convert the small failure into flow type of failure. Due to plenty of moisture the failed soil mass shows the high mobility during.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

In this chapter, a brief summary on the research project will be presented. The finding both literature review and simulation rainfall-induced of the slope failure. The finding will help to know better the effects of heavy rainfall intensity towards the behavior, mass and strength that can cause the failure.

The current study was an effort to better understand the mechanism of rainfall-induce slope failure by laboratory experiments in model flume. For investigation of rainfall induced slope failure various approaches are used such as numerical simulation, field studies and laboratory experiments. Form these the laboratory experiments considered as best approach, because field studies are expansive and time consuming, while the numerical simulations requires lot of data and also a problem of reliability.

The purpose of this research project was to determine the rainfall intensity for slope to fails and to observe period of the rainfall takes place to cause the landslide to occur. This might happen due to certain factors. Numerous amount of water content in the soil major factor that cause the landslide. Once the water pervade the soil, it changes the soil characteristic and its behavior. In additional water content increase the mass of the soil, especially in clayey soil which tends to expand if there is existing of water, and shrink under the hot sun.

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As conclusion, the higher rainfalls intensity leads to surface erosion thus expose to more rainfall pervade to net subsoil. Infiltration of precipitation leading to higher moisture content where the soil start to lose its strength between each other plus hike increasing the pore water pressure. When the mass of sample increase, this is where the sliding force generate and failure start to occur.

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