A STUDY ON THE EFFECT OF EXTREME RAINFALL INTENSITY ON SLOPE STABILTY USING PHYSICAL BASED MODELLING

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By

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ABSTRAK

Kajian ini memfokuskan penilaian kesan keamatan hujan ekstrem terhadap kestabilan cerun menggunakan model fizikal. Dalam kajian ini, keamatan hujan ekstrem yang telah dikenal pasti telah dimodelkan dalam model fizikal dengan penyukatan kandungan air isipadu berserta sedutan matrik didalam cerun. Keamatan hujan ekstrem yang telah dipilih ialah pada 60 mm/jam di mana ia adalah kadar keamatan hujan tertinggi di Sarawak bertarikh pada 3 Januari, 2016 dan 80 mm/jam di Pulau Pinang pada 10 Oktober 2016. Tempoh simulasi hujan adalah selama 6 jam. Trend keseluruhan pengukuran sedutan matrik dalam setiap kes semakin meningkat dengan beberapa pengecualian daripada tensiometer yang menunjukkan penurunan nilai. Selepas simulasi hujan berhenti, sedutan matrik menurun dengan cepat dan kekal pegun yang kemudiannya jatuh dengan ketara. Untuk kandungan air isipadu, terdapat peningkatan yang sama dalam arah aliran semasa simulasi hujan. Walau bagaimanapun, terdapat perbezaan dari segi nilai awal dan kenaikan dalam kandungan air di bahagian yang berlainan dalam cerun. Untuk bahagian bawah cerun, kandungan air awal adalah lebih tinggi yang pada 60 - 70% dengan kenaikan sebanyak 15 - 20% semasa simulasi hujan. Manakala bagi bahagian yang lebih rendah adalah pada 20 -25% dengan kenaikan sedikit 5-7% dalam simulasi hujan. Untuk semua kes, kegagalan berlaku tetapi pada masa dan jumlah tanah yang berbeza. Ia menunjukkan bahawa peningkatan dalam sudut kecondongan cerun dan keamatan hujan akan menjejaskan kestabilan cerun. Analisis berangka dilakukan untuk dimodelkan kes dalam perisian Geostudio.

ABSTRACT

This study focused on assessing the effect of extreme rainfall intensity to slope stability using a physical based modelling. In this study, identified extreme rainfall intensity are modelled in a physical model with a measurement of Volumetric Water Content and Matric Suction within the slope. Selected extreme rainfall intensity is 60 mm/hr which the heaviest hourly rainfall intensity at Sarawak on 3rd of January, 2016 and 80 mm/hr which in Penang on 10th October, 2016. The simulation is conducted in a 4 different cases and parameter. The duration of the simulated rainfall is 6-hour. The overall trend of the matric suction measurement in each cases is increasing with a few exceptions of tensiometer that shows decreasing value. After the rain simulation stopped, the matric suction decreased rapidly and remain stagnant follow by a significant dropping significantly. For the volumetric water content, there is a similar increase in the trend during the rainfall simulation. However, there is difference in term of initial and increment of water content for different part of the slope. for the lower part of the slope, the initial water content is much higher which at 60 – 70 % with an increment of 15 – 20 % uring the rainfall simulation. While for the lower part are at 20 -25 % with a slight increment of 5-7 % during rainfall simulation. For all cases the failure had been occurred but on a different time and volume of mass wasting. It shows that the increased in slope inclination angle and rainfall intensity would affect the slope stability. Numerical analysis is done to model the cases in Geostudio software.

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LIST OF ABBREVIATIONS

AF	Adjustment Factor
DID	Department of Irrigation and Drainage
FEM	Finite Element Method

FOS	Factor of Safety
GCM	Global Climate Model
LEM	Limit Equilibrium Method
MC	Moisture Content
NEM	North East Monsoon
RIDF	Rainfall Intensity Duration Frequency
RCM	Regional Climate Model
SWCC	Soil-Water Characteristic Curve
SWM	South West Monsoon
TDR	Time Domain Reflectometer
TSM	Tensiometer
VMC	Volumetric Water Content

CHAPTER 1

INTRODUCTION

1.1 Background

In the current state of human civilization, rapid development in massive scale is common to fulfil the needs of development. Usage of advance technology is compulsory in maintaining the momentum of the development. The effect of the development greed is being paid by today global climate dispute. Natural disaster such as heavy snowstorm, extreme heat wave, landslide, floods, tsunami, heavy rainfall and rises of sea level have affecting human security. The occurrence of the natural disaster event has significantly increase the amount of researcher to seek understanding the factor and characteristic of the natural disaster. Landslide, is one of the most frequent natural disaster that been faced all over the world. It is the movement of mass or the earth mass in the downward direction of a slope. Landslide also known as mass wasting, and usually occurs in the slope faces either natural or man-made. The triggering factor of a slope failure has been varying from the slope morphology, groundwater movement, seepage, earthquake etc.

1.1.1 Malaysia Climate

Malaysia is situated near to equator with a tropical climate. With a hot and damp climate nearly every day in a year, Malaysia received wet and dry season instead of the four season like other countries which is far from equator. During the dry season, the natural disaster such as drought usually occur and would affect the human activities, water resources depletion, agriculture, plantation and other food stock farming. During the monsoon or wet season, the abundant rainfall with high intensity and prolonged period had its effect on others calamity. Flood and landslide are some of the most recurring natural disaster in Malaysia. Monsoons in Malaysia which is Northeast Monsoon which start at March and Southwest Monsoon that start at the end of May.

1.1.2 Rainfall-induced Slope Failure

With abundant of rainfall during the monsoon season, the movement of water circulation in the system may be abruptly disturbed. The excessive surface runoff contributes to natural disaster event such as mudflow, debris flow, flood and etc. In landslide and slope failure, there are many triggering factor that would lead to the disaster such as rainfall, groundwater level fluctuation, seepage, and etc. Rainfall-induced slope failure is one of the common type of slope failure. The failure mechanism of the slope usually due to the rainfall characteristic or behavioural. During the rainfall period, the water would seep into the ground water table. This would increase the ground water table level and make it fluctuate. The fluctuation and the downward movement of water into the soil would increase the water content in the soil which also increase the negative pore water pressure in the sub-surface soil. The increase in negative pore water pressure would result in the reduction of the effective stress along the slip surface in the slope. The further reduction of effective stress would reduce the shear strength of soil along the slip surface. When the shear strength along the slip surface reduced lower than the shear stress, the failure would occur in the direction of driving forces along the slip surface.

The factor that causes the slope failure varies according to every cases of slope failure. There is no specific indicator or a series of specific event occur that are similar in each case. There were a few rainfall characteristics such as precedent rainfall, antecedent rainfall, period of rainfall and rainfall intensity that classified as triggering factor of rainfall-induced landslide. In some cases, the precedent and antecedent rainfall have been one of the factor that contributing slope failure. Accumulation of groundwater flow in a very narrow time step causes the ground water table elevate from the normal condition (Kristo et al., 2017). Those characteristic could be observed when the variation of rainfall intensity is presence.

1.2 Problem Statement

Rainfall-induced slope failure has posed a significant impact on the surrounding environment. From the casualties, economic losses, pollution and other impact of landslide had becoming the centre of attention in the society. The development of the landslide hazard and risk assessment is useful as one of the current compatible references in determining the possible occurrence of landslide event. Current landslide hazard map is established using different parameter with a variability in each of it (Jamaludin and Nadzri Hussein, 1993). Nevertheless, this assessment could be enhanced by incorporating the knowledge of slope stability that susceptible to rainfall.

In rainfall-induced slope failure, the characterization of rainfall is varying according to the cases for main contributing factor. The antecedent rainfall, precedent rainfall, duration of precipitation and rainfall intensity are the governing factor that cause the rainfall-induced slope failure (Mukhlisin et al., 2015). However, according to (Kristo et al., 2017) the rainfall intensity variation possess a significant relationship with the slope stability. The increasing trend of rainfall intensity has been showing a nearly linear relationship with the reduction of the slope stability. In addition, the failure mechanism of the slope is also varying in term of the rainfall intensity (Tohari et al., 2007). Thus, the variation of the rainfall intensity would be triggering different failure mechanism with a certain prognosis of linear relationship between increasing rainfall intensity and the reduction of slope stability.

1.3 Objectives

At the end of the study we should be able to:

1. Determine the extreme rainfall intensity based on selected preceding event in Malaysia.
2. Determine the variation of the saturation during the extreme intensity rainfall simulation.
3. Asses the effect of extreme rainfall on slope stability.

1.4 Scope of Work

The scope of work in this research focused on physical modelling of the slope that would be subjected to the extreme rainfall intensity. The rainfall intensity is selected from two cases of extreme precipitation in Malaysia. The selected event is in Kuching, Sarawak (2016) and Pulau Pinang (2016) which received extreme rainfall intensity. The physical modelling will be established by a few measurement instrument to achieve the objective of the study.

1.5 Dissertation Outline

This dissertation includes five main chapters that every chapter explain the different part of this research. Chapter one would focus on the background study, problem statement, research objectives, scope of work to provide a better understanding on this research. Chapter two enlisted the literature review which include the Malaysia seasonal climate, extreme climate change, rainfall induced slope failure physical laboratory model and other relevant topics. Chapter three provide enlisted the stages in methodology and some of the numerical analysis including its procedure. Chapter four shows the results and discussion obtained from the physical model and numerical analysis including the tables, graph and figures. Chapter five is the conclusion and the recommendation for further improvement in the future.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

Global climate changes had a very significant impact towards the environment especially toward the largest group of receptor such as human, wildlife and the environment across the globe. The effect of climate changes directly disturb the natural phenomenon such as the mean sea level and temperature, global temperature distribution and extreme weather event (Tangang et al., 2012). The chain effect of the climate changed result in multiple occurrences of extreme natural event such as extreme precipitation. In Malaysia, seasonal monsoon is highly susceptible toward the climate changes. High precipitation rate could cause various disaster such as the flood and landslide (Suhaila and Jemain, 2012).

Rainfall-induced slope failure is one of the common type of slope failures in Malaysia. The infiltration of rainfall and the fluctuation of water table in the subsurface region of a slope is one of the prominent region of research in geotechnical community. The hydro-mechanical behaviour of rainfall penetration in the soil had been widely studied and discussed due to the complex relationship (Pramusandi et al., 2015). The characterization of rainfall such as the intensity, antecedent rainfall, precedent rainfall and period of precipitation has been studies as the factor affecting the slope stability under the precipitation influence (Mukhlisin et al., 2015).

2.2 Extreme Climate Change

The current global challenge that been faced by every regions is the effect of climate change. The increase in the various temperature had effect in the ecosystem and cause imbalanced in term of sea level, sea temperature, extreme weather event and etc. (Tangang et al., 2012) had showed in the comprehensive study on the climate change in Malaysia that the change in the temperature of the sea and surface has been associated with the unnatural occurrence of highly variation of magnitude for the extreme weather event. This shows that the climate change had the significant impact on the formation of extreme weather variation. From (Zhu, 2013), the increasing frequency of extreme rainfall intensity and period had been spotted across United State Of America by using a Rainfall Intensity-Duration-Frequency (RIDF) method with the Adjustment Factor (AF) on both of the Global Climate Model (GCM) and the Regional Climate Model (RCM). This RIDF analysis from the GCM and RCM have been showing a significant increase in the extreme precipitation event for the historical dataset (1971-2000) and future (2041-2070) with a time step of 30 years. This shows that the climate change in every part of the world had brought a very significant impact to human. The increase in rainfall intensity had caused a lot of undesirable effect that shows the significant of the extreme precipitation toward the surroundings.

2.2.1 Malaysia Seasonal Climate

Malaysia is a country that located at Southeast Asia that were near the equator with a climate to be consider equatorial. Geographically, Malaysia is divided by two main part which is the peninsular and west Malaysia with both having a flatland, mountainous region and costal line with a wide spread of island along the shoreline. The tropical climate in Malaysia typically is hot and humid throughout the year with a wet season.

The wet season or monsoon season in Malaysia is divided by two which is North-East Monsoon (NEM) that usually occur during the month of November to February and the South-West Monsoon (SWM) from the May until August with inter monsoon season between the main monsoon period (Suhaila and Jemain, 2012). During NEM season, the affected area by the monsoon is mainly on the peninsular region of Malaysia while the SWM season would affect the west part of Malaysia. This phenomenon is due to the difference rain formation mechanism by both monsoons (Chen et al., 2012). The formation or contribution of NEM is due to several event which is Madden-Julia Oscillation, Indian Ocean Dipole and the Cold Surges Vortex while for the SWM formation of monsoon is based on the disturbance that originated from the Philippine Sea with a latter disturbance came from the South China Sea (Varikoden et al., 2011). NEM mechanism is propagated from various region while the SWM mechanism were localized. This difference would cause various discrepancy in the characteristic of each Monsoon season.

According to the (Chen et al., 2012), there were a different in term of time and intensity of the NEM and SWM which the NEM having a higher intensity of maximum rainfall the SWM with a time gap between extreme rainfall for each monsoon is 30-day. This could be explained by the different originating mechanism of the monsoon that have been affecting the maximum rainfall.

In Malaysia, past event had showed a significant jumped in the maximum rainfall during certain event. During the 2006-2007 great flood, they were three consecutive extreme precipitation event with a long duration of a month that due to the extremely strong northeast winds from the South China Sea during the NEM period (Tangang et al., 2008). According to the (Suhaila and Jemain, 2012), the current trend of NEM rainfall distribution is in a low frequency but high intensity on the eastern peninsular area. The increment of 200 mm rainfall of a year is detected for the past 15 year in the east coast region (Tang, 2019). The high intensity precipitation trend also could be perceived on the west coast of peninsular Malaysia. In the research by (Varikoden et al., 2011), Kuala Lumpur diurnal variation model had formed a single peak in the trend which categorized as unimodal mean that could be interpreted as the distribution of rainfall having a less frequency but extremely high intensity during the NEM season. The trend of higher intensity rainfall with a less frequency has been seen on a lot of research which show the significant of extreme rainfall intensity with the reduction of wet day frequency (Loo et al., 2015). For future projection on extreme precipitation event, there will be a significant increase on the west coast area compare to the east coast due to the warm convection rain producing mechanism (Figure 2.1 & Figure 2.2) (Abdul Halim et al., 2017).

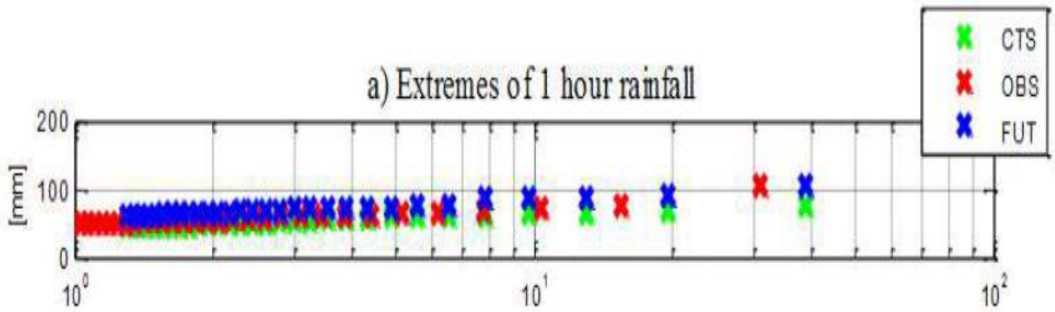

Figure 2.1: Extreme hourly rainfall comparison of Control Simulation Period (CTS), Observation (OBS) and Simulation Future Period (FUT) at Loji Air Kuala Kubu Bharu, Selangor (station 3516022)

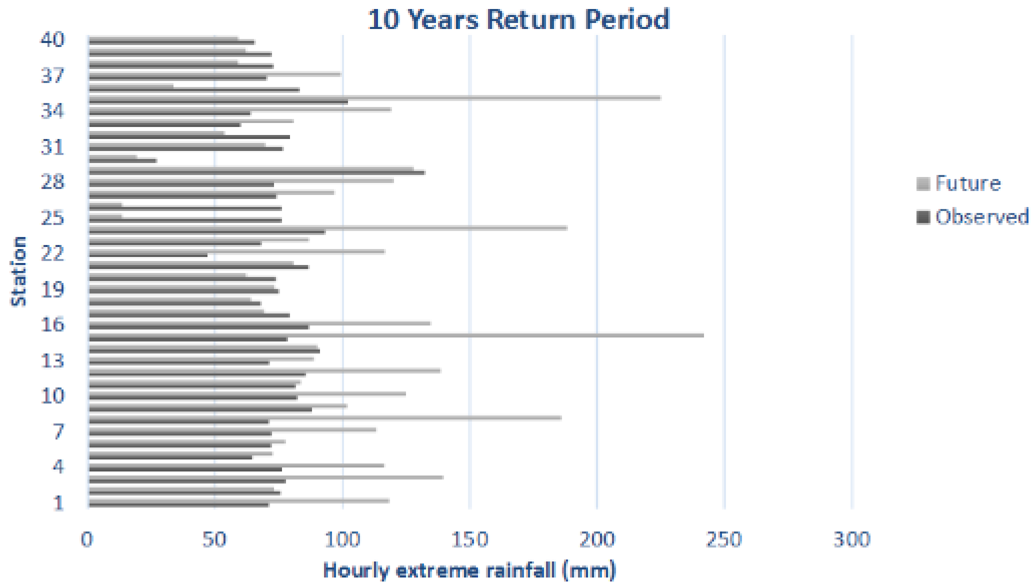

Figure 2.2: Comparison of future and observed extreme rainfall for 40 station (Abdul Halim et al., 2017).

2.3 Rainfall Induced Slope Failure

Rainfall-induced slope failure is a type of landslide or mass wasting that occur due to the influence of rainfall. The current extreme climate change had produced an immense magnitude of rainfall that directly would increase the occurrence of the rainfall-induced landslide (Loo et al., 2015). The association of increase in landslide event had been proved by the presence of extreme precipitation event through studies in Ulu Kelang (Lee et al., 2014, Mukhlisin et al., 2015). With the effect of the rainfall on slope stability is considered as significant, the other rainfall characteristic such as precedent rainfall, antecedent rainfall and the rainfall intensity have to be take into account. Changes in the certain rainfall characteristic such as the pattern, would change the flux boundary condition such as the infiltration and evapotranspiration which would affect the slope stability (Kristo et al., 2017). The variability in the characteristic of rainfall such as the rainfall intensity have been show to affect the overall slope stability.

Rainfall-induced landslide factor has been varying according to the cases by the antecedent rainfall, precedent rainfall, rainfall intensity and the period of rainfall. In the study of the landslide at Ulu Kelang by (Mukhlisin et al., 2015). The main factor of rainfall-induced slope failure is due to the accumulation of rainfall that affecting the water table which could be contribute by the prolonged antecedent and precedent rainfall which also govern by the intensity. According to (Jia et al., 2009), beside the study on the shear strength reduction and the internal pore water pressure change as the instability problems in slope, the fluctuation of boundary condition (ground water table) could be emphasized. The total rainfall which is the total amount of rain in single event despite the period and intensity had been the main cause of the landslide to occur. This is due to the incapability of the slope to restore the initial groundwater table that cause by the complex hydro-mechanical behaviour in result of the three phase (gas-solid-liquid) interaction under rainfall (Pramusandi et al., 2015).

In Malaysia, there are few studies and event that indicate the rainfall-induced slope failure mechanism through high rainfall intensity. In Ulu Kelang, high hourly rainfall intensity had triggered the slope failure at Taman Zoo View (October 2001) which the total hourly rainfall exceeds the antecedent and precedent rainfall (Mukhlisin et al., 2015). The study also recommends the crucial indicator for the prediction of slope failure to be at 70 mm/day. This shows that the extreme rainfall intensity is one of the crucial factor contributing to the rainfall induced slope failure.

2.3.1 Unsaturated Zone

Most of the soil that located before the water table are in unsaturated condition. This unsaturated soil is defined by the degree of saturation which belong at less than saturated condition but more than he dry soil which also known as Vadose Zone. The soil in this state is very complex due to involvement and interaction of 4 phases (pore-air, pore-water, menisci and soil grains) with each other (Egeli and Pulat, 2011). In this soil region, the existence of air and water in the pore would create a different type of pore pressure which is pore water pressure U_w and pore air pressure U_a. The difference between U_w and U_a called the matric suction because the presence of the contractile skin and matric suction, the interaction between the solid, water and air causes a complex hydro mechanical behaviour of the unsaturated soil element (Pramusandi et al., 2015). All the characterization in the unsaturated zone are complex and the relationship is defined in Soil-Water Characteristic Curve.

$$Matric\ suction = Ua - Uw \tag{2.1}$$

According to (Egeli and Pulat, 2011), during the infiltration process of rain water into the soil, the saturation level would increase internally and cause the menisci to dissipate due to the air dissolve in the water from the infiltration process. The absent of menisci enable the water to move in to the soil pores by diffusion state which the direction of movement is irreversible and random that cause the saturation level is diverse throughout the absorption and desorption process.

The different in the water movement path during absorption and desorption phase would cause a lagging effect that affecting the soil particle rearrangement after desorption of process which directly affect the stability of the soil (Egeli and Pulat, 2011). The occurrence of infiltration during the rainfall would raise the pore-air pressure and matric suction, this would disturb the porosity and the seepage properties of the slope due to the change in the effective stress (Sun et al., 2016). From the research above, it is inevitably to presume that (Sun et al., 2016) and (Egeli and Pulat, 2011) have emphasize on the changes of soil particle arrangement due to affected seepage movement as the cause of slope instability under rainfall infiltration.

2.3.2 Soil Water Characteristic Curve (SWCC)

The inconsistency of characteristic of the soil in the unsaturated zone is a problem in determining the condition of the soil for other usage. The changing or inconsistency in the soil is mainly contributed by the change in saturation level or moisture content. This changes are presented by SWCC which governing the change of characteristic with the saturation level. SWCC is presented in term of degree of saturation S, plotted on arithmetic scale and soil suction Ψ is plotted on a log scale (de and Fredlund Delwyn, 2004). The SWCC describes the relation between unsaturated soil moisture content change and the degree of saturation with total suction changes which affect the soil shear strength behaviour (Egeli and Pulat, 2011). This shows the important of SWCC in estimating the unsaturated soil characteristic.

The SWCC is varying depend on the type of the soil which different in the soil texture and pore size distribution. In modelling the SWCC, there few type of model that can be used such as unimodal and bimodal. Unimodal SWCC is developed for the material that follow the normal grain size distribution while the Bimodal is for the gap graded size distribution (de and Fredlund Delwyn, 2004). Figure 2.2 show the different SWCC for each type of soil. In this study, the SWCC is important in determining the characteristic of the unsaturated zone during rainfall infiltration.

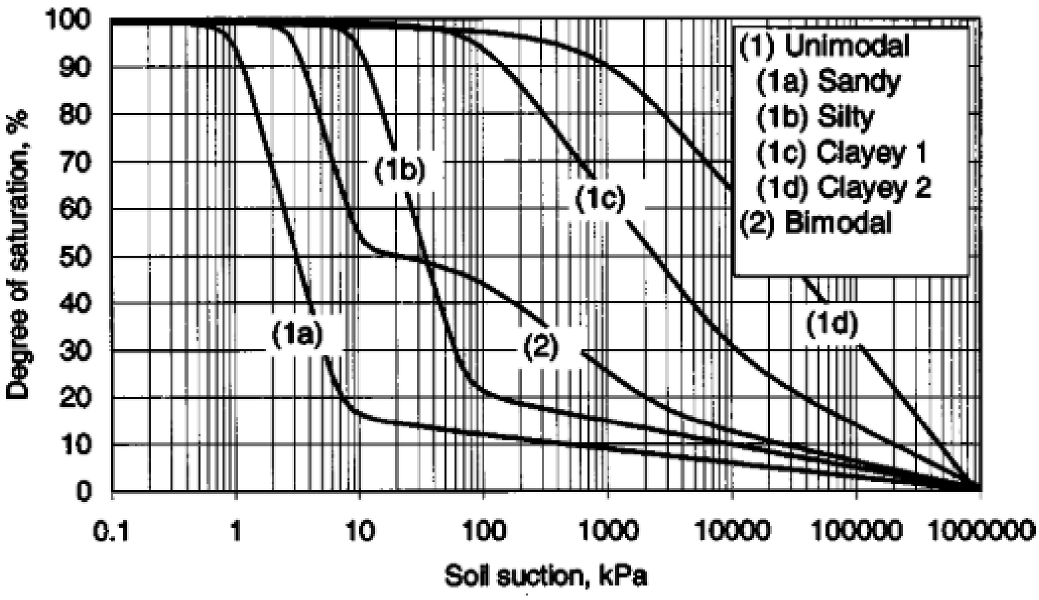

Figure 2.3: SWCC according to type of soil (de and Fredlund Delwyn, 2004).

2.4 Physical Modelling

In assessing the slope stability, physical model is used to model and control the parameter and characterization of variable. It is used to simulate the condition of the site with a controlled environment ensuring the result. There were few types of slope physical model that been used in past research. In the research that be done by (Ling Hoe et al., 2009), the experiment is conducted using the centrifuge model at Columbia University. At the payload of 1,500 kg the centrifuge model could produce a 200 g of acceleration with a nominal radius of 3 metre.in the research that have been done by (Tohari et al., 2007), a landslide tank with a dimension of 2 m x 1 m x 1.5 m with a slope height of 1m is used to simulate the slope morphology. Both studies using a different type of model which a centrifuge and tank model to create the physical slope model.

In the setup process of the physical model, there were a lot of variables that need to be consider. Determination of dependent and independent variable must be done to proceed in term of designing the physical model (Rahardjo et al., 2007). The Factor of Safety (FOS) would be selected and identified as dependent variable that would response to the independent variable such as rainfall intensity, soil properties, slope geometry and initial water table. The initial water table and hydraulic permeability had a very significant impact on the FOS of the slope (Ling Hoe et al., 2009). The permeability characteristic of the soil used in the physical slope modelling also would affect the FOS of the slope (Zhang et al., 2018). There are also significant decrease in the FOS of rock slope with a loose soil and soft rock top layer with the increase in slope inclination (Shinoda et al., 2015). In the experiment conducted by the (Rahardjo et al., 2007), the variable independent factor show a significant effect on the FOS by conducting four series of experiment that having a total of 84 parametric test combination. The results show that variability in the independent variable would affect the outcome of the result.

The reduction of variable independent must be done to produce a controlled result displaying a good array of information with intended parameter (Rahardjo et al., 2007). In the experiment by the (Ling Hoe et al., 2009), the inclination of the slope model is fixed on three value which is 90, 75 and 60 with other independent variable is fixed such as rainfall intensity to demonstrate the effect of different slope angle under the same rainfall intensity. (Jia et al., 2009, Ling Hoe et al., 2009, Rahardjo et al., 2007) had used and recommended a moisture content measurement in the slope physical model to evaluate the boundary change and the variation of saturation level.

2.4.1 Slope Geometry

Beside the rainfall intensity and type of soil, the slope inclination angle is one of the contributing factor in rainfall induced slope failure case. In past research, a series of different slope inclination angle is used to study the effect of rainfall to the slope stability.

However, the failure in the slope only could be seen in at the angle of 35-degree while the 15 and 25-degree inclination angle show no sign of failure (Egeli and Pulat, 2011).

In another study for the large scale model, 45-degree inclination angle is used (Jia et al., 2009). This shows that the high inclination angle is significant in term of slope stability. From the on-site observation, the slope failure common characteristic is having a failure depth at less than 2 metre and the slope inclination angle at 30-50 degree (Chueasamat et al., 2018). For this study, the slope inclination angle would be selected for the range more than 35 degrees to ensure the slope fail.

2.4.2 Rainfall Simulator

To model the rainfall in the physical modelling, a suitable rainfall simulator must be adapted to ensure the similarity of the simulated rainfall tp the natural rainfall. In selecting the rainfall simulation, few desirable characteristics is carefully evaluated (a) accurate reproduction of natural rainfall drop size and energy produced; (b) continuous and uniform application of rainfall over an area; (c) ability to apply various intensity and duration of the rainfall (Abudi et al., 2012).

Rainfall simulator could be divided into two which are pressurized and non-pressurized rainfall simulator. In non-pressurized simulator, the drop is produced by the hypodermic needle under the gravity influenced to reached the terminal velocity. For the pressurized simulator, pressurized nozzles is used with varying ressure to imitate the natural phenomena. However, in the pressurized simulator, soil erosion may occur due to the excess flux created by the pressure while the non-pressurized simulator are capable to control the drop size but require certain height to achieve terminal velocity (Mhaske et al., 2018). In this study, the non-pressurized rainfall simulator is adapted due to capability in control the size and intensity of the raindrop. This to avoid any excessive slope surface erosion that contribute to the decrease in slope stability.

2.5 Numerical Analysis of Slope Stability

In current practice, there are abundant of tools and software that are developed to assist engineer and technical panel to analyse and produce simplified result of any problems. In slope stability and seepage analysis, there a few software that using different mathematical method to solve complex calculation. Although the Numerical Analysis or Finite Element Method (FEM) is the most widely use there a few type of other method which is the Limit Equilibrium Method (LEM), Limit Analysis, Probabilistic Method, Variation Method and others (Batali and Andreea, 2016)

2.5.1 Numerical Analysis in Geostudio

Geostudio is a FEM analysis software that could analyse various process in geotechnical area. This software utilise the FEM to calculate the resultant based on the input parameter (Xu et al., 2012). In this study, two features of Geostudio which is SLOPE/w and SEEP/W is used to solve the numerical analysis. To model the effect of rainfall on the slope stability, multiple analysis has to be utilize to achieve higher accuracy in the result. The combination of SLOPE/W and SEEP/W would produce an analysis which iterate the slope stability according to the change in soil moisture content (Lee et al., 2014, Kristo et al., 2017, Rahardjo et al., 2010)

Numerical analysis of seepage using FEM is initiated by defining the boundary connection at vertical perimeter as nodal flux, Q equal to zero representing the no-flow condition while at the slope surface Q equal to the intended rainfall and with a non-pounding effect to eliminate excessive surface flow (Rahardjo et al., 2010, Kim et al., 2004). For both research, the Soil Water Characteristic Curve (SWCC) were used in the

FEM analysis as the properties of soil in the unsaturated zone. The SWCC usage would provide the analysis of the slope stability and seepage with the permeability and unsaturated shear strength (Rahardjo et al., 2010). According to the research by (Kim et al., 2004), the seepage analysis is used to determine the wetting band at different time step which is simulated in the slope stability to determine the FOS of the slope. this study would adapt the boundary condition according to the physical model and recommendation from the past research.

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter explains the procedure of data analysis, physical modelling analysis and numerical analysis of rainfall induced slope failure under extreme rainfall intensity. For the rainfall data, the selection of rainfall intensity would be based on the past event and data from the rain gauge station in Malaysia. The data analysis will be carried out to determine the intended value of rainfall intensity The data obtained will be use in the physical modelling simulation with variety of slope angle as the parametric study in this research.

Physical modelling would be use as the method to determine the effect of extreme rainfall intensity on the slope. Measurement of volumetric water content and the matric suction during the simulation would be use in the numerical analysis of the slope stability. Soil characterization test would be used to determine the soil characteristic in the numerical analysis. The numerical analysis is used to determine the seepage properties and slope stability.

This research focused on the effect of extreme rainfall intensity on the unsaturated slope stability using physical based modelling and numerical analysis. The flowchart describing the process of this research is given in Figure 3.1.

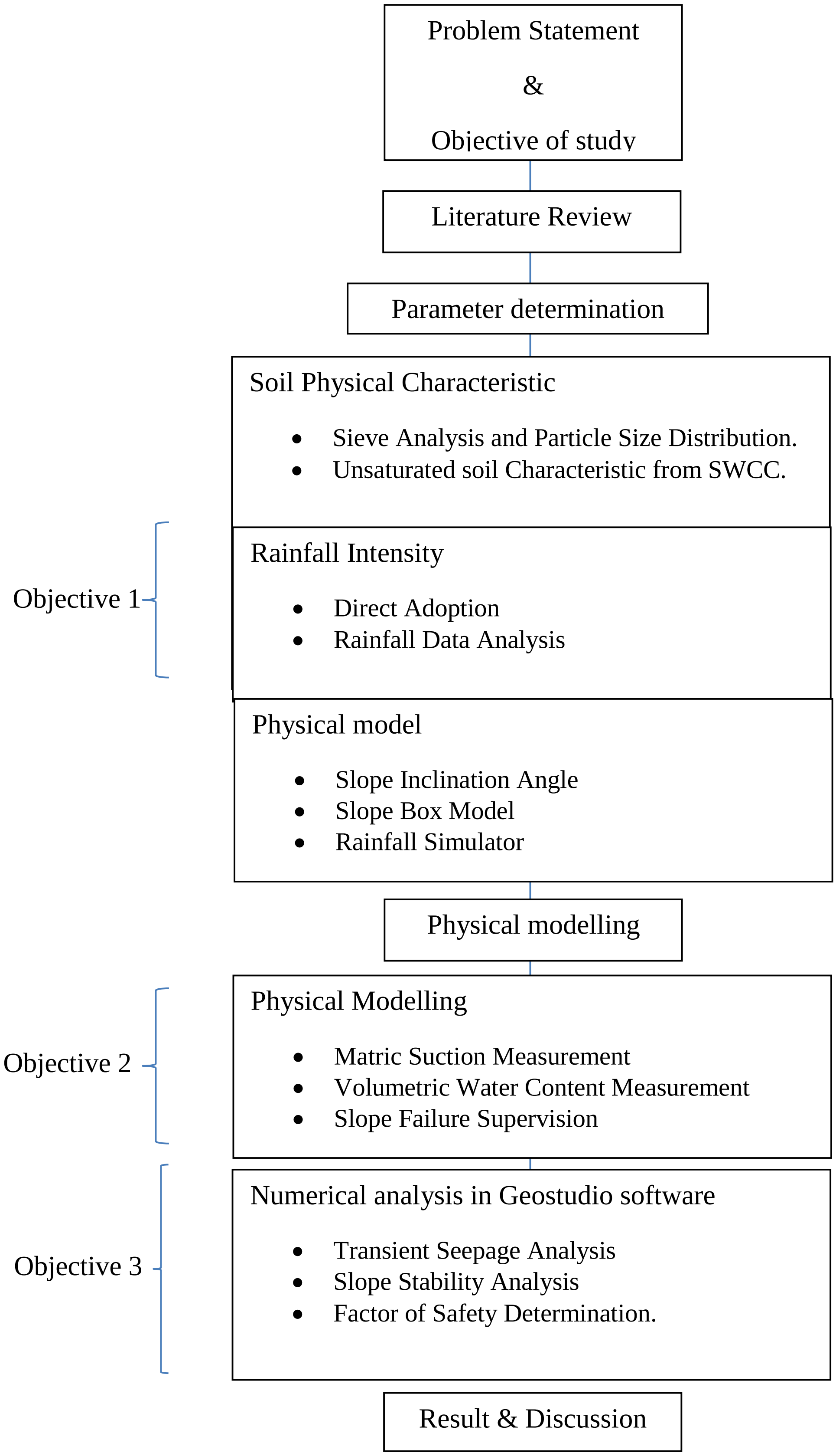

Figure 3.1: Flowchart of the research

3.2 Rainfall Data Analysis

Extreme rainfall or extreme precipitation event is an event of precipitation which the total rainfall and intensity of the rainfall exceeding the previous maximum rainfall. The criteria in selecting the extreme rainfall intensity is to recognised the maximum intensity which significant in term of occurrence any of the natural anomalies such as flood and landslide event alongside extreme precipitation. By considering the intended characteristic, an extreme rainfall intensity may be determined.

In determining the value of the intensity, a base line or lower limit for the rainfall intensity is established by comparing existing classification. The value from the Department of Irrigation and Drainage, Malaysia and from the previous studies (Yakubu et al., 2014), was compared to establish the lower limit of the rainfall intensity criteria as in Table 3.1. Lower value of the extreme rainfall intensity is established at 60 mm/hr. The criteria for selecting the intensity must be more than 60 mm/hr. The intensity than could be determined by using this lower limit.

Table 3.1: Comparison of Rainfall Intensity Classification

Yakubu et al.,(2014)		Department of Irrigation & Drainage, Malaysia. (2017)	
Rainfall Intensity Classification	Rainfall Intensity (mm/hr)	Rainfall Intensity Classification	Rainfall Intensity (mm/hr)
Low	<4	Light	1 < I < 10
Medium	4< I <15	Moderate	10 < I < 30
High	15 < I < 30	Heavy	30 < I < 60
Very High	30< I < 60	Very Heavy/Extreme	>60
Extremely High	> 60		

3.2.1 Direct Adoption Based on Precedent Case

By using the existing rainfall intensity classification, selection of cases with a very heavy rainfall intensity classification would be established. Direct adoption of rainfall intensity in severe cases is use if the rainfall intensity falls into the very heavy or in an extreme intensity classification.

3.2.2 Analysis of Rainfall Series

Hyetograph is the graph of time series with rainfall intensity either hourly, daily, monthly or yearly. The graph show trend of changes in the rainfall intensity according to the time step. This provide an insight of actual series of precipitation with time progression. Hyetograph is very useful in determining the rainfall effect at a wider perspective and the antecedent characteristic of the rain.

In this method, rainfall hyetograph is utilised to obtain the highest rainfall intensity. Rainfall data is obtained from the Pulau Pinang Department of Irrigation and Drainage during the NEM period. The data obtained is from the Kolam Air Bersih rain gauge station in a series of year. Rainfall hyetograph is plotted for the NEM period for 2016 from the month of September to October.

3.3 Soil Physical Characterization

The soil used in the physical modelling is mining sand taken from a mining area in Kampung Kuala Trong, Taiping, Perak. Sample is taken at 0.5 metre depth from the surface of the soil as a disturbed sample. The sand used in the model is sieved and only the sand that passing the 3.35 mm sieve and retain at 2mm sieve is used in the model. All the data for the physical characteristic of the soil is obtained from (Azmi et al., 2016).

To determine the soil physical characteristic, a series of soil physical characterization test must be done.

Physical Characterization test:

- Particle Size Distribution
- Soil Water Characteristic Curve
- Permeability Test

3.3.1 Particle Size Distriburtion

Particle is distribution is an index that express the sizes of the soil with the mass proportion that exist in the sum amount of soil. The particle distribution or sieve analysis allow others to perceive the soil properties based on the content of the certain mass proportion. The most dominant or highest by mass proportion usually govern the engineering property of the soil.

The procedure to conduct sieve analysis is starting with cleaning of 2 mm sand sample. To remove silt and clay particles sample is washed and sand samples are put in oven for 24 hours. The sand sample later are sieved using the following sizes of sieves which are 14 mm, 10 mm, 6.3 mm, 5 mm, 3.35 mm, 2 mm, 1.18 mm, 600 µm, 425 µm, 300 µm, 212 µm, 150 µm, 63 µm and pan accordingly. Those retained in every sieve was weighted. Further calculation was carried out to determine the characteristics of the 2 mm sand sample. The Particle size distribution for the 2 mm sand used in this study is presented in Figure 3.2.

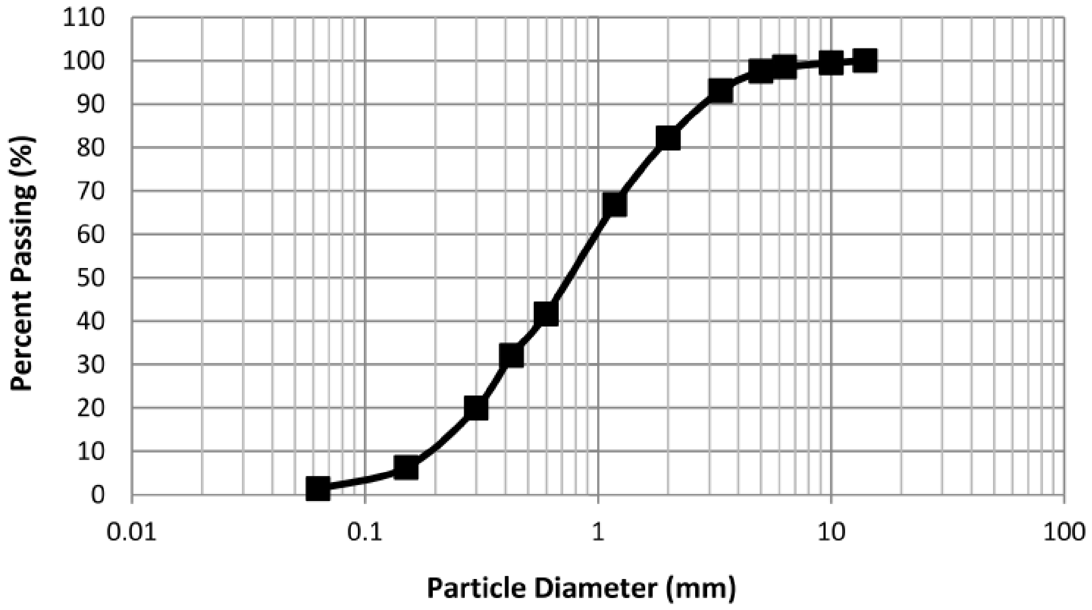

Figure 3.2: Particle Size Distribution graph of 2 mm mining sand (Azmi et al., 2016)

3.3.2 Soil Water Characteristic Curve (SWCC)

Soil Water Characteristic Curve (SWCC) is a relationship that is used to describe the unsaturated soil properties (Leong and Rahardjo, 1997). The state variable in the SWCC is the matric suction and the volumetric water content. The SWCC could provide the characteristic of the unsaturated soil such as the unsaturated shear strength and the permeability characteristic of unsaturated soil. The estimation of the hydraulic function in Geostudio software are by using the Fredlund-Xing-Huang equation. The SWCC is important notably in the numerical analysis of the seepage and slope stability analysis. The SWCC and estimated hydraulic conductivity function for this study is shown in Figure 3.3 and Figure 3.4.