

**ANALYSIS OF SLOPE DEFORMATION DUE  
TO THE EFFECT OF VARIOUS RAINFALL  
PATTERNS**

**ASFARINA BINTI MAIDIN**

**FACULTY OF ENGINEERING  
UNIVERSITI MALAYSIA SABAH**

**2022**



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**ANALYSIS OF SLOPE DEFORMATION DUE  
TO THE EFFECT OF VARIOUS RAINFALL  
PATTERNS**

**ASFARINA BINTI MAIDIN**

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**UMS**  
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## CERTIFICATION

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## ABSTRACT

Formation is a geological process that occurred through time. As it related to the movement of the soils, thus instantly it also correlated to the slope stability. There are many formations that existed in Sabah such as Crocker Formation, Trusmadi Formation, Kudat Formation, Garinono Formation, and many more. Therefore, this thesis is focus on the analysis of slope deformation due to the effect of various rainfall patterns at Garinono Formation which more specifically at Location P, Sandakan, Sabah. On top of that, the purpose of this research is to interpret the geotechnical properties of the critical slope, to analysis the change in porewater pressure due to the effect of various rainfall patterns, and to examine the deformation and stability of unsaturated soil due to the effect of varying rainfall patterns. In this research, secondary data which consist of soil investigation report and rainfall tabulation data were obtained from Kumpulan (IKRAM) Sabah Sdn. Bhd. and *Jabatan Pengairan dan Saliran (JPS)* Sabah respectively. The manipulated variable in this research is the pattern of rainfall which is short-intense (i.e., 2-Hours Rainfall Event) and prolonged (i.e., 48-Hours Rainfall Event). The method of analysis in this research is using Finite Element Method (FEM); numerical simulation conducted using GeoStudio software. Three analyses conducted in this research which consist of transient analysis using SEEP/W, deformation analysis using SIGMA/W, and stability (Factor of Safety) analysis using SLOPE/W. The result shows that, prolonged rainfall presented the significant effects on porewater pressure changes, slope deformation, and factor of safety rather than short-intense rainfall. The porewater pressure change according to the amount of rainfall intensity and the duration of rainfall. Then, both short intense and prolonged rainfall experience large deformation at vertical displacement which deform 1.7 m from the ground surface. In addition, the stability of slope triggered when the rainfall intensity more than saturated hydraulic conductivity values; Layer 1 (i.e., Ksat: 0.2 mm/hr) and Layer 2 (i.e., Ksat: 0.7 mm/hr).



## **ABSTRAK**

### **(Analisis Ubah Bentuk Cerun Akibat Kesan Daripada Pelbagai Corak Hujan)**

*Formasi adalah proses geologi yang berlaku sepanjang masa. Oleh kerana formasi berkaitan dengan pergerakan tanah, maka ia juga berkaitan dengan kestabilan cerun. Terdapat banyak formasi yang wujud di Sabah seperti Formasi Crocker, Formasi Trusmadi, Formasi Kudat, Formasi Garinono, dan banyak lagi. Oleh itu, tesis ini tertumpu kepada analisis ubah bentuk cerun akibat kesan pelbagai corak hujan di Formasi Garinono. Selain itu, tujuan penyelidikan ini adalah untuk mentafsir sifat geoteknikal cerun kritikal, menganalisis perubahan tekanan air pori akibat kesan pelbagai corak hujan, dan mengkaji ubah bentuk dan kestabilan tanah tak tepu akibat kesan daripada pelbagai corak hujan. Dalam penyelidikan ini, data sekunder yang terdiri daripada laporan penyiasatan tanah dan data penjadualan hujan diperolehi daripada Kumpulan (IKRAM) Sabah Sdn. Bhd. dan Jabatan Pengairan dan Saliran (JPS) Sabah. Pembolehubah yang dimanipulasi dalam penyelidikan ini ialah corak hujan yang bersifat pendek (iaitu, 2-Jam Peristiwa Hujan) dan berpanjangan (iaitu, 48-Jam Peristiwa Hujan). Kaedah analisis dalam penyelidikan ini adalah menggunakan Kaedah Elemen Terhingga (FEM); simulasi berangka yang dijalankan menggunakan perisian GeoStudio. Tiga analisis yang dijalankan dalam penyelidikan ini terdiri daripada analisis sementara menggunakan SEEP/W, analisis ubah bentuk menggunakan SIGMA/W, dan analisis kestabilan (Faktor Keselamatan) menggunakan SLOPE/W. Hasilnya menunjukkan bahawa, hujan yang berpanjangan menunjukkan kesan ketara terhadap perubahan tekanan air liang, ubah bentuk cerun, dan faktor keselamatan berbanding hujan lebat yang singkat. Tekanan air pori berubah mengikut jumlah intensiti hujan dan tempoh masa hujan. Kemudian, kedua-dua hujan lebat pendek dan hujan berpanjangan mengalami ubah bentuk besar pada anjakan menegak yang berubah bentuk sedalam 1.7 m dari permukaan tanah. Di samping itu, kestabilan cerun dicetuskan apabila intensiti hujan lebih daripada nilai kekonduksian hidraulik tepu; Lapisan 1 (iaitu, Ksat: 0.2 mm/jam) dan Lapisan 2 (iaitu, Ksat: 0.7 mm/jam).*





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# CHAPTER 1

## INTRODUCTION

### 1.1 Background of Study

The Garinono Formation is a formation located at Sandakan, Sabah. The Garinono Formation phenomena formed a regional soil layer with weak strength and could contribute to the occurrence of some events such as landslides and soil erosion (Radeano et al., 2017). In historical geology, the east region of Sabah is classified into two deep sedimentations; the central Sabah sub-basin and the Sandakan sub-basin. The Garinono Formation, the Sandakan Formation, and Volcanic Facies vary from recent Quaternary alluvial materials which are still being deposited. These rock units are dissected by numerous lineaments with complex structural styles developed during a series of regional Tertiary tectonic activities. Rapid urbanization activities have caused changes in land use. Urbanization processes may contribute to the exposure of impervious surfaces, loss of vegetation cover, modification of slope gradient and drainage systems. The last decade has seen slope failure, flash floods, and erosion events, which have claimed lives, damaged properties, and increased the cost of maintenance. Thus, further research on the Garinono Formation, especially in the technical part, is important for future safety and reference.

Rainfall is expected to be the most common cause of landslides worldwide. Rainfall-induced slope failures are common in unsaturated soils in a variety of geological settings, including pyroclastic deposits, severely weathered residual soils, and colluvial weathered deposits (Rahardjo et al., 2013; Prahdan, 2015; Sorbino, 2013). As severe rains grow more common, a greater number of rainfall-induced slope failures may occur (Rahardjo et al., 2013; Zhang et al., 2019). Slope failure occurs when rainwater infiltrates into the residual soil slope, causing a decrease in matric suction inside the unsaturated zone of the residual soil slope (Comegna et al.,

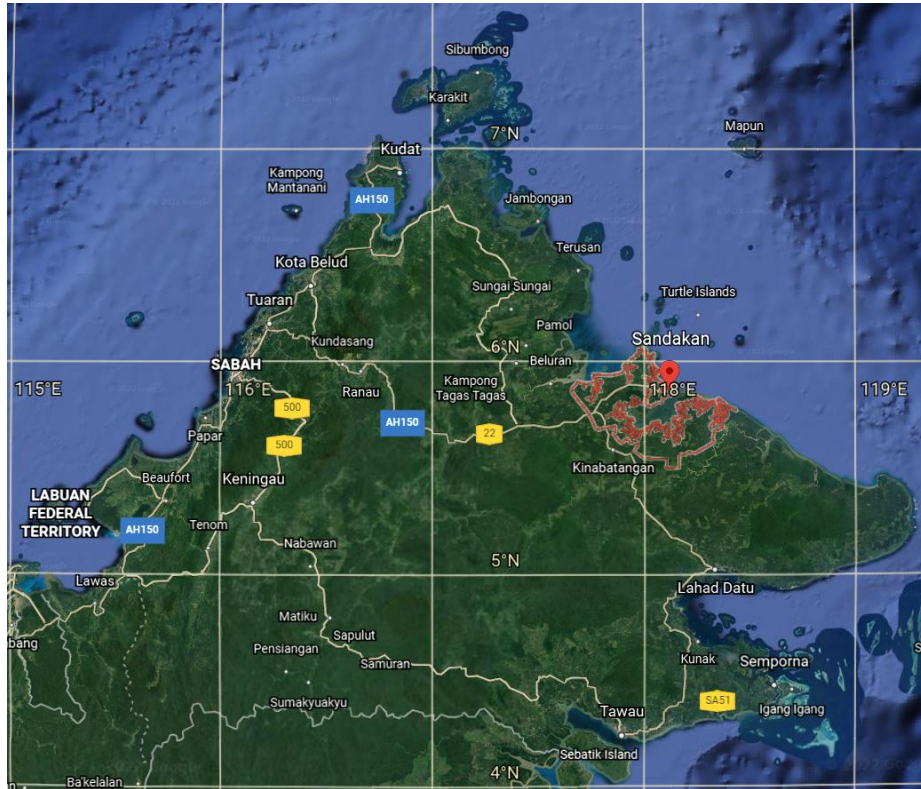


2016). Various studies have shown that the behaviour of an unsaturated zone has a complex nature. Many geotechnical issues relating to soil moisture interaction in the vadose zone have been reported in recent years. Thus, understanding the hydraulic properties of unsaturated soil from Sabah's geological formation is critical and useful in solving geotechnical problems and applications.

Soil slope stability has been a common subject of study in geotechnical engineering whether related towards its factor of occurrence, applications, or etc. In addition, slope deformation has been a common occurrence around the world for a long time, either due to natural factors or human actions. This incident is related to slope stability, where when the safety factor of the slope becomes weak, then settlement will occur and cause slope deformation. The Factor of Safety, or better known as FOS, is the most widely used parameter in the study of slope stability.

This research will examine the slope deformation and its stability that is influenced by different rainfall patterns. This study also evaluated the effects of rainfall patterns on changes in pore water pressure and slope deformation and stability by considering the hydro-mechanical properties of unsaturated soils as a result of varying rainfall patterns. Following that, the analysis was conducted through numerical simulation using the software-based Finite Element Method (FEM) of SEEP/W, SIGMA/W, and the Limit Equilibrium Method (LEM) of SLOPE/W from Geoslope. Previous research (Morgenstern and Price, 1965; Fredlund and Krahn, 1977; Zhou and Cheng, 2013; Rafiei Renani and Martin, 2020) concludes that the limit equilibrium analysis is the most straightforward and widely used technique for calculating factors of safety (FOS).





**Figure 1.1: Sandakan area on the Sabah Map**

Source : Google Earth.

## 1.2 Problem Statement

Rainfall is expected to be the most common cause of landslides in Sabah. Slope failures are a common occurrence in which significant quantities of soil flow downslope due to gravity. It happens when the shear stress on the slope surpasses the slope's shear strength. Specifically, changes in rainfall patterns will affect the pore water pressure beneath the ground's surface. Changes in pore water pressure may diminish the effective stress and shear strength of soil, which may lead to rainfall-induced slope failures. This might be devastating and result in several deaths. Understanding the variance in rainfall intensity, which can be used to predict future rainfall patterns, is one method for preventing these unwanted slope failures caused by rainfall. Limited research has been conducted on the effect of rainfall intensity variation on slope stability in Sabah. Consequently, the purpose of this study aims to evaluate the deformation and stability of a soil slope in Sandakan, Sabah, under

different rainfall patterns. In addition, seepage, deformation, and slope stability analyses were conducted to detect the differences in the safety factor caused by variations in rainfall intensity.

### **1.3 Objectives of Study**

Below are the objectives of this study:

- a) to interpret the geotechnical properties of the critical slope formation.
- b) to analyse the change in pore water pressure due to the effect of various rainfall patterns.
- c) to examine the deformation and stability of unsaturated soil due to the effect of varying rainfall patterns.

### **1.4 Scope of Study**

This study is focused on the analysis of slope deformation and its stability due to the effect of various rainfall patterns at the Garinono Formation areas, which are located at Sandakan, Sabah. Based on the findings of the site investigation report, the slope geotechnical characteristics of the study area were examined in relation to the geology and topography, the type of soil, and the hydro-mechanical properties. On the basis of soil physical properties, soil hydraulic properties parameters, such as the Soil-Water Characteristics Curve (SWCC) and hydraulic conductivity function, were estimated. The analysis is using the Finite Element Method (FEM) in GeoStudio software.

- a) Transient seepage analysis using SEEP/W, boundary conditions (i.e., 2-Hours Rainfall Event and 48-Hours Rainfall Event)
- b) Deformation analysis using couple-stress/PWP in SIGMA/W, boundary conditions is observing both XY-displacement. The SEEP/W in (a) becomes the parent analysis. Then, the material model is set as elastic-plastic.
- c) Slope stability analysis using ordinary in SLOPE/W, the SIGMA/W analysis in (b) is the parent analysis and PWP conditions from SEEP/W analysis in (a).

### **1.5 Significant of Study**

The importance of this study lies in the fact that it will allow for a better understanding of the factors that cause slope failure in parts of Sabah that have slope problems. The findings of this study can assist engineers, local authorities, or landowners in resolving issues that are related to slopes, and they can also facilitate the implementation of mitigation strategies to guarantee the safety of slopes. This study is necessary to ensure the continued viability of Sabah, particularly in Sandakan, and to prevent the occurrence of casualties in the future that are brought on by slope failures.



## CHAPTER 2

### LITERATURE REVIEW

#### 2.1 Current Research Trend on Formations in Sabah

Table 2.1 below shows the summary of the current research trend on formations in Sabah. The current research trend on Formation in Sabah below is the collection of publication papers that were published from 2012 until 2021, which means in the range of 10 years. The purpose of this table is to determine the limitation on the research study about formations in Sabah. Therefore, it can be observed that the Garinono Formation is the least studied of all the formations in Sabah.

**Table 2.1: Current Research Trend on Formations in Sabah**

Year	Title	Topic	Method of Analysis	Formation	Source
2012	Rock Cut Slope Stability Evaluation of The Crocker Formation Along Jalan Ums, Kota Kinabalu, Sabah	Slope Stability	Geological mapping, discontinuity survey, kinematic analysis	Crocker	(Mohd Zaki et al., 2012)
2013	Geo-Electrical Resistivity Characterization of Sedimentary Rocks In Dent Peninsular, Lahad Datu, Sabah	Geo-Electrical Resistivity Characterization	Vertical Electrical Sounding (VES)	Sabahat, Ganduman, Togopi	(Saleh & Samsudin, 2013)



2014	Slope Stability Assessment of The Temburung Formation Along Beaufort-Tenom Railway, Sabah	Slope Stability	Geological mapping, discontinuity survey, kinematic analysis, prescriptive measure	Temburung	(Abd Rahim, 2014)
2015	Stratigraphic Succession and Depositional Framework of the Sandakan Formation, Sabah	Sedimentary Facies	Facies analysis and interpretation	Sandakan	(Khor et al., 2015)
2016	Sedimentary Facies of the West Crocker Formation North Kota Kinabalu-Tuaran Area, Sabah, Malaysia	Sedimentary Facies	Geological mapping and sedimentology logging	West Crocker Formation	(Mohamed et al., 2016)
2017	Facies And Sandstone Characteristics of The Kudat Formation, Sabah, Malaysia	Facies and sandstone characteristics	Facies analysis and interpretation, Scanning Electron Microscope (SEM) analysis, XRD analysis	Kudat	(Tahir et al., 2017)

2017	Slope Stability Study Around Kampung Kuala Abai, Kota Belud, Sabah, Malaysia	Slope stability	Engineering geological mapping, kinematic analysis, kinetic analysis, dry density analysis, adjustment factor, stereographic measurement	Crocker	(Abd Rahim & Raffee Usli, 2017)
2018	Engineering Geological Assessment (EGA) On Slopes Along The Penampang To Tambunan Road, Sabah, Malaysia	Engineering Geological Assessment	Field mapping and laboratory analysis	Crocker	(Roslee & Tongkul, 2018)
2019	The Geology of Kudat Peninsula, Sabah: New insights from field geology and subsurface interpretation	Subsurface interpretation (Geology)	Observation and interpretation	Crocker, Kudat	(Mohamed Zainuddin et al., 2019)
2019	Stability Assessment of Pinousuk Gravel Slopes from Mesilou, Kundasang, Sabah	Slope stability	Fellenius slicing method	Trusmadi, Crocker	(Erfen et al., 2019)
2020	Swelling Clay Minerals and Slope Cut Failures in The Garinono Formation	Soil index properties	X-ray diffraction analyses	Garinono	(Raj, 2020)