CASE STUDY ON ANALYSE SLOPE RIVERBANK FAILURE

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FACULTY OF ENGINEERING
UNIVERSITI MALAYSIA SABAH

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ABSTRACT

Slope riverbank failure is a natural event globally in each riverbank, and a drawdown event usually causes slope riverbank failure. This case study aimed to analyze slope riverbank failures by evaluating the seepage and slope stability of the riverbank under slow and rapid drawdown. The riverbank in this case study is located at KM 3.49 Jalan Pantai Luagan in the Sipitang district (N 4° 59' 12.9" E 115° 31' 13.3"). A literature review was conducted to view the current study pattern, then retrieved a methodology based on the current study pattern. The methodology proposed in this study is by analyse the slope riverbank failure under slow and rapid drawdown occurrence using GeoStudio. A data collection was used as input to the software, based on the Boreholes log report and relevant assumptions. The data collection consists of the height of slope, slope angle, fluctuation of water level, shear strength parameter, hydraulic conductivity, and surcharge load. The study's findings are that the riverbank under both drawdowns shows a trend of a slow rate reduction of the phreatic line, indicating a poor permeability of riverbank material. The minimum FOS of the riverbank for slow and rapid drawdown are 1.045 and 0.862, respectively. For slow drawdown, the minimum FOS occurs at 12.8 days, while for rapid drawdown, the minimum FOS occurs at 0.25 days. Furthermore, in the early days, the rapid drawdown reaches its lowest FOS, while the slow drawdown still has a high value in the FOS. However, the slope stability condition for both drawdowns is nearly the same in the long term, and the riverbank takes a long period to achieve a stable condition as before. In conclusion, the drawdown event can cause slope riverbank failure, and the seepage and stability analysis using GeoStudio can view the riverbank condition during the drawdown event.

ABSTRAK

(*Kajian Kes Menganalisis Kegagalan Cerun*)

Kegagalan tebing sungai cerun ialah kejadian semula jadi secara global di setiap tebing sungai, dan peristiwa penarikan biasanya menyebabkan kegagalan tebing sungai cerun. Kajian kes ini bertujuan untuk menganalisis kegagalan tebing sungai cerun dengan menilai resapan dan kestabilan cerun tebing sungai di bawah penarikan perlahan dan cepat. Tebing sungai dalam kajian kes ini terletak di KM 3.49 Jalan Pantai Luagan dalam daerah Sipitang (U 4° 59' 12.9'' E 115° 31' 13.3"). Kajian literatur telah dijalankan untuk melihat corak kajian semasa, kemudian mendapatkan metodologi berdasarkan corak kajian semasa. Metodologi yang dicadangkan dalam kajian ini adalah dengan menganalisis kegagalan tebing sungai cerun di bawah kejadian penarikan perlahan dan cepat menggunakan GeoStudio. Pengumpulan data telah digunakan sebagai input kepada perisian, berdasarkan laporan log Boreholes dan andaian yang berkaitan. Pengumpulan data terdiri daripada ketinggian cerun, sudut cerun, turun naik paras air, parameter kekuatan ricih, kekonduksian hidraulik, dan beban surcaj. Penemuan kajian adalah bahawa tebing sungai di bawah kedua-dua pengeluaran menunjukkan trend pengurangan kadar yang perlahan bagi garis freatik, menunjukkan kebolehtelapan bahan tebing sungai yang lemah. FOS minimum tebing sungai untuk pengeluaran perlahan dan pantas ialah 1.045 dan 0.862, masing-masing. Untuk pengeluaran perlahan, FOS minimum berlaku pada 12.8 hari, manakala untuk pengeluaran pantas, FOS minimum berlaku pada 0.25 hari. Tambahan pula, pada hari-hari awal, pengeluaran pantas mencapai faktor keselamatan terendah, manakala pengeluaran perlahan masih mempunyai nilai yang tinggi dalam FOS. Bagaimanapun, keadaan kestabilan cerun bagi kedua-dua penarikan adalah hampir sama dalam jangka masa panjang dan tebing sungai mengambil masa yang lama untuk mencapai keadaan stabil seperti sebelum ini. Kesimpulannya, peristiwa penarikan boleh menyebabkan kegagalan tebing sungai cerun, dan analisis resapan dan kestabilan menggunakan GeoStudio boleh melihat keadaan tebing sungai semasa acara pengeluaran.

LIST OF CONTENT

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF SYMBOL

α	-	Base inclination
μ	-	Pore-water pressure
W	-	The slice weight
N	-	Base normal
Φ	-	Effective frictional angle
C	-	Effective cohesion
τ	-	Slipping force on sliding plane
F	-	Overall stability safety coefficient
S	-	Anti-sliding force
$S_{resistance}$	-	Shear strength resistance
$S_{mobilised}$	-	Shear stress mobilized
i	-	Slope of available hydraulic head on a gross basis.
k	-	Hydraulic conductivity of soil material.
q	-	The particular discharge through the soil medium
γ_w	-	Unit weight of water.
m_w	-	Slope of the storage slope
k_y	-	Hydraulic conductivity in the vertical y-direction
Q	-	Applied boundary flux i.e. discharge
t	-	Time
h_w	-	Volumetric water content of the soil
k_x	-	Hydraulic conductivity in the horizontal x-direction
H	-	Total available hydraulic head difference

LIST OF ABBREVIATION

FOS	-	Factor of Safety
FEM	-	Finite Element Method
LEM	-	Limit Equilibrium Method
SSR	-	Shear Strength Reduction
USACE	-	United State Army Corps of Engineers
BH	-	Borehole log report

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

Slope failure is a common phenomenon in rivers (Mahbub et al., 2013). Every riverbank on the earth tends to experience the collapse of slope failure. The slope riverbank failure is a significant expression of transverse channel deformation in rivers. It is natural for a riverbank to experience slope failure, which eventually will change the river's shape. The weight of the structure above the ground of a riverbank is one of the factors that cause the slope of the riverbank to fail. The weight of the artificial structure above the slope will decrease the slope stability of the riverbank, which will lead to slope riverbank failure. These slope failures are known as slides (Mahbub et al., 2013). According to Yangui (2013), there are two distinct causes of slope riverbank failure: internal and external. The internal factor contains the bank slope's boundary parameters, such as soil properties and composition, river bending rate, bank slope height, and slope.

In contrast, the external aspect is the dynamic of the river flow, which is mainly based on changes in the river channel's water level. Increased pore water pressure and soil moisture caused by previous and persistent rainfall will lead to slope riverbank failure. Heavy rain is also a significant factor in slope riverbank failure since it affects the shear strength of the soil. Slope failure commonly occurs when the shear strength of the soil is reduced due to decreasing effective stress resulting from pore water pressure increment (Glendinning et al., 2009).

From the perspective of river bed evolution, the riverbank failure phenomena occur throughout the river bed process. They evolve continually following the intrinsic law of distinct river types when the river takes on a particular shape—the interplay between river flow and bank soil results in a riverbank failure. The impact of water flow on the bank will result in steeper and unstable riverbank slopes. However, the riverbank's soil composition and structure can be the factor in manipulating the riverbank's stability. Providing an anti-scouring structure in the soil prevents riverbank failure. Hydrodynamic conditions, particularly the scouring action of longitudinal water flow, are the primary determinants of erosion, sediment transport from the bottom and shore, and sediment form change. Riverbank slope failure results from repeated circulation, which results in the river eroding the bank and causing the bank slope to collapse. After the dirt at the base of the bank slope washed away, the remainder collapsed into the river, and water flow continued to erode and retreat the temporary bank slope (Shen et al., 2005).

Numerous rivers in our country frequently experience bank failure due to a lack of comprehensive control, resulting in numerous unstable river regimes, frequent erosion and siltation changes, and bank erosion and collapse. Riverbed and bank material compositions are complicated, interacting with water movement to generate a complex system. As a result, the shape and degree of bank collapse vary between rivers or portions of the same river. Additionally, due to the dirt on the bank slope pouring into the river channel, the riverbed is scouring and silting due to the unexpected sediment supply (Nagata, 2000; Darby, 1995).

Slope instability or slope riverbank failure can be considered one of the reasons for stagnant economic growth (Jampani et al., 2017). It often results in economic loss for the community. Along with financial loss, there is occasionally a loss of life. Numerous reasons contribute to the failure of a riverbank slope, and these variables are frequently interconnected. Hence, it is crucial to analyze slope riverbank failure. The analysis of slope riverbank failure will provide a clear view of the failure pattern of site location and provide the info needed to propose a solution for slope riverbank failure. An approach can be proposed to treat the slope failure from the analysis. Slope stability analysis can be performed to analyze slope riverbank failure. Slope failure happens due to slope instability; an analysis of slope stability using suitable parameters will better understand the failure pattern based on the Factor of Safety obtained. Through the analysis of slope riverbank failure, valuable data regarding the slope riverbank on-site location can be retrieved, such as a suitable slope gradient for the riverbank. The data retrieved can be used as a reference to design a proper slope embankment or upgrade the initial slope using a relevant approach. More importantly, the analysis will help prevent a future occurrence of slope riverbank failure. The analysis will reveal unfavorable low safety factors, and strengthening steps should be implemented. When a slope fails and remedial work is required, it is critical to conduct a slope failure analysis to ascertain the likely causes. Appropriate remedial design can only be implemented when the failure causes have been identified.

1.2 Problem Statement

Slope riverbank failure is a natural event globally in each riverbank worldwide. The slope riverbank failure is a typical result due to slope instability. Various factors cause slope instability, such as rainfall, a rise in the groundwater table, seepage, rapid drawdown, or a shift in stress conditions. Jaksa et al. (2013) also mention that the rapid drawdown often causes slope riverbank failure during and after flood events or high flow periods.

According to Vanmarcke (1997), Slope instability is one of the significant problems in geotechnical engineering where the loss of life and property can occur. Nalgire et al. (2020) also stated that slope instability problems in both built and natural slopes are common concerns for researchers and professionals. The slope riverbank failure is a significant concern in economics, society, and the environment since it affects all three aspects. It requires a proper strategy to manage the issue properly.

Hence, one of the proper strategies to handle the issue is analyzing slope riverbank failure. Analyzing slope riverbank failure is a preliminary action to a proper remedy to solve the issue of slope riverbank failure. Analyzing slope riverbank failure is an approach to adequately viewing the slope riverbank condition. It can be conducted through various approaches, and many researchers have conducted the study through different methods. Some researchers analyze riverbank stability, studying riverbank soil's physical and mechanical characteristics and the hydrodynamic conditions (Linjuan et al., 2018). In this paper, the approach chosen to analyze slope riverbank failure is by determining the change of pore-water pressure and slope riverbank stability under drawdown conditions. The analysis will be conducted using GeoStudio, modern software that can analyze ever-increasingly complex problems (GEO-SLOPE, 2012). The reasons for choosing GeoStudio are that it can combine analyses using different products into a single modeling project, using the results from one as the starting point for another. These approaches show a clear view of the slope riverbank conditions under drawdown conditions.

1.3 Objectives of Study

This study aimed to analyze slope riverbank failures by conducting the seepage and stability analysis using GeoStudio. The following are the study's objectives in brief:

- To conduct the seepage and slope stability analysis in slow and rapid drawdown conditions.
- To evaluate the change in phreatic line under slow and rapid drawdown.
- To determine the change in factor of safety over time under slow and rapid drawdown conditions.

1.4 Significance of Study

In this paper, an approach to analyzing the slope riverbank failure will be conducted to get a clear view regarding the slope riverbank condition in terms of seepage and stability. The study's benefits contribute to the preliminary study required for the sloping riverbank, which is beneficial to the Geotechnical Engineer and other researchers. A preliminary study in this context is by performing seepage and stability analysis to get data regarding the slope riverbank condition. The analysis is needed to clarify the real issue contributing to the slope riverbank failure. Through the result analysis of this study, it can enhance the understanding of the riverbank condition before proposing a proper remedy.

Then, this study will perform the seepage and slope stability analysis under drawdown conditions. A drawdown condition is a specific event during a flood, or heavy rain often leads to slope riverbank failure. In order to conduct the analysis, a GeoStudio will be used to run the analysis. A GeoStudio is a geotechnical software that can interpret results with visualization & graphics. The software can graphically provide the slope riverbank's condition, enhancing the visualization's understanding.

Furthermore, this study will help increase awareness of using modern software to conduct slope analysis. An increase in awareness may increase the use of modern software in solving slope issues around us. Moreover, modern software such as GeoStudio can solve complex problems that usually become a limitation to geotechnical engineers and researchers.

Last but not least, the study will provide knowledge regarding analyzing slope riverbank failure, especially in conducting the analyses using GeoStudio. This paper will show the procedure to conduct the analyses, which is beneficial to other researchers that want to conduct the analyses in the future.

1.5 Scope of Study

Figure 1.1: The site location of case study 1

Figure 1.2: The location of BH1 and BH2.

The case study will be based on a riverbank located at KM 3.49 Jalan Pantai Luagan in the Sipitang district (N 4 59' 12.9" E 115 31' 13.3"). Figure 1.1 shows the site location of the riverbank along Sungai Mengalong, retrieved by Google Earth Pro. There are two borehole log reports from *Konsultan Azam Sempurna* refer in this case study. BH1 was buried on the road, and BH2 was sunk in the center of the slope, as shown in figure 1.2. The borehole log report will be used to determine the height of slope, slope angle, water level, soil type, shear strength parameter, Etc.

There will be two analyses conducted in this paper: seepage and slope stability analysis. The seepage analysis will be classified into a steady-state and transient analysis. While the slope stability analysis will be performed using the Spencer method from the Finite Element Method (FEM). Then, GeoStudio will be used to run the analysis. The slow drawdown will refer to the water level fluctuation based on BH1 and BH2. In comparison, the rapid drawdown will simulate the water level drop instantaneously.

Furthermore, figure 1.3 shows the flow chart of the research work flow for the entire paper in general. The research workflow is include of the introduction, literature review, methodology, result and discussion, and conclusion and recommendation.

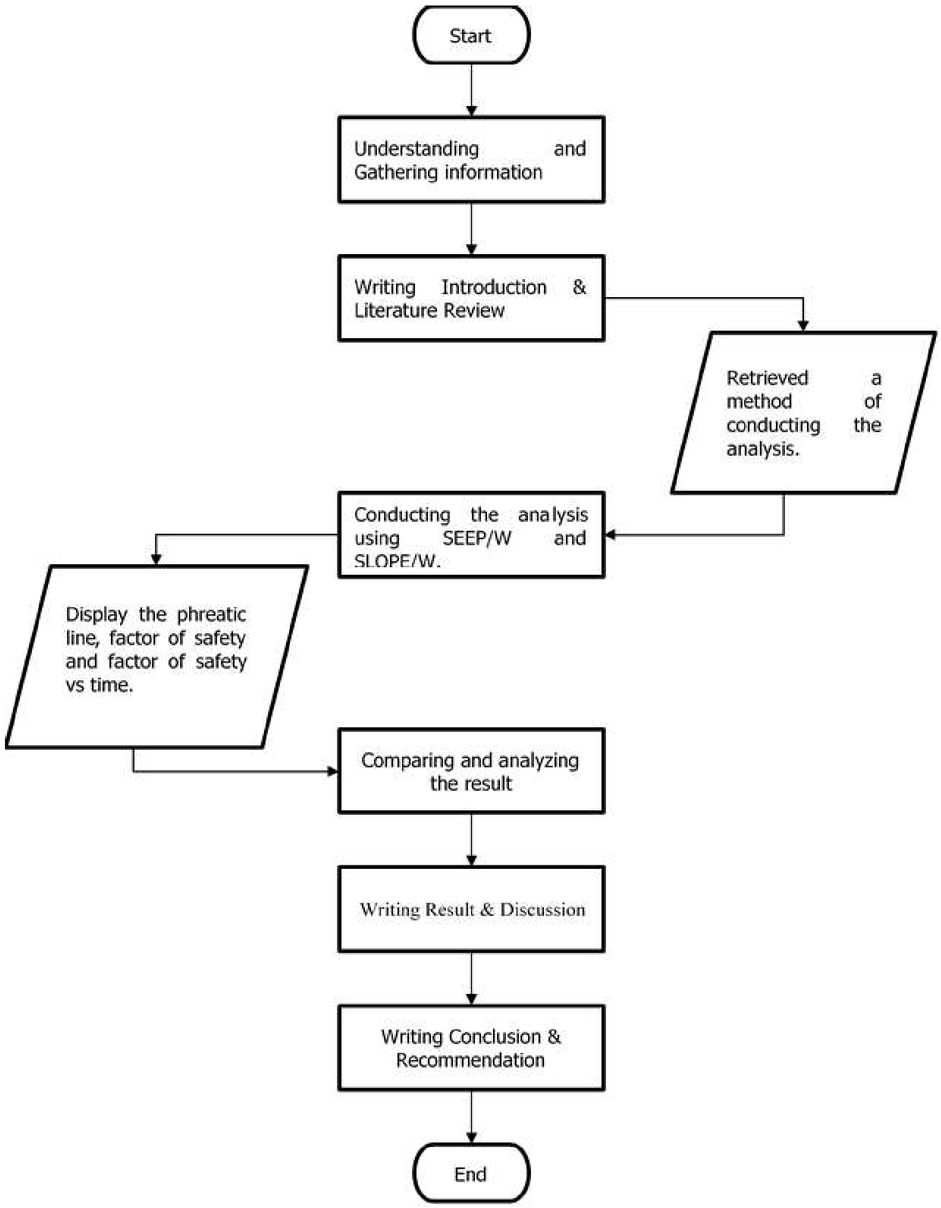

Figure 1.3: Flow chart of overview of the scope study.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter discusses the principles of analyzing slope riverbank failure. It informs the viewers of the riverbank slope failure. This chapter will include several subtopics that will act as a reference and provide vital information for this study. This chapter will also provide the current study pattern on slope riverbank failure to get the most up-to-date methodology, findings, and conclusions of other research. Finally, this chapter includes the theory of the methodology of the analysis.

2.2 Overview of Slope Riverbank Failure

The slope riverbank failure is a natural occurrence of a riverbank. It is a complicated process that requires multidisciplinary investigation. On the one hand, the riverbank slope grows steeper and more unstable due to water flow's effect on the bank. On the other hand, the soil structure and the physical features of the river bank's soil composition influence the river bank's anti-scouring to preserve the bank's stability and resist the development of bank failure (Yu et al., 2008). The interaction between river flow and riverbank soil results in riverbank failure. Major floods always generate significant changes in bank lines despite precautions trying to avoid them. Thus, it is critical to recognize that the issue is not erosion itself but rather the location and rate at which it occurs.

2.2.1 Modes of Slope Riverbank Failure

According to Fiscenich (1989), riverbank failure can be caused by three modes: hydraulic forces, geotechnical instabilities, or a combination of hydraulic and geotechnical forces.

i. Hydraulic Forces

The first slope riverbank failure mode is the hydraulic forces. The hydraulic forces are from the hydraulic flow that usually causes riverbank erosion. The erosion occurs due to the hydraulic flow in the channel producing stress that exceeds the critical shear stress of the soil. Typically, the soil's critical shear stress is surpassed by a tangential shear stress induced by water drag or direct impingement on a bank. Simultaneously, the critical shear stress varies according to the material's type and size. A lack of vegetation, high boundary velocities, and the absence of substantial soil wasting along the bank's toe are often indicators of hydraulic failure (Fiscenich, 1989).

Osman (1998) examined riverbed depth and riverbank scours and estimated slope stability using the safety factor. The study's findings indicate that secondary flow will more than double the average shear stress of water depth (Papanicolaou et al., 2007). Hydraulic forces may transport sediments from the riverbank's bottom and shore and alter their structure. The scenario exists due to longitudinal water flow's scouring impact, which is the principal cause influencing erosion (Linjuan et al., 2018).

Furthermore, Yu (2008) established a relationship between the transverse velocity, the river's width, and the water's depth. It is observed that the more concentrated the nearshore velocity, the greater the nearshore velocities lateral gradient toward the bank, and the steeper the nearshore slope, the more likely the bank slope will lose its stability and collapse (Yu, 2008).

ii. Geotechnical Instabilities

The second slope riverbank failure mode is geotechnical instabilities. It often leads to slope riverbank failure, usually when gravitational forces acting on the