RAINFALL THRESHOLDS FOR THE INITIATION OF SLOPE FAILURES AT JELAPANG AND GUA TEMPURUNG AREA

NORISAM BIN ABD RAHAMAN

MASTER OF SCIENCE
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ABSTRACT

For countries located near to the Equator Line, slope failures always associated with the presence of high volume of water due to heavy rainfall. The objective of the study was to find the rainfall threshold that potentially trigger slope failures. These thresholds were to be used as the trigger level to issue Warning Alert and Critical Alert in slope monitoring system. Two (2) study areas were selected i.e. Jelapang area and Gua Tempurung area, as both have substantially large catchments areas with steep natural slopes located beyond the Right-of-Ways (ROW) that feeds into the engineered slopes along the PLUS expressway although they depicted different geology and bedrock underlying the area. The development of Real Time Monitoring System (RTMS) was based on three (3) main elements i.e. complete field stations with sensors (site equipment), central database server and the medium of transmitting the field data to the server at Headquarters. Based on two (2) case studies for both areas and the analysis against rainfall data collected, slope failures occurred during/after rainfall event with intensity of more than 50mm/hour whereby this intensity can be used as the threshold for the RTMS to trigger Warning Alert.

ABSTRAK

Bagi negara-negara yang terletak berhampiran dengan Garisan Khatulistiwa, kejadian tanah runtuh biasa dikaitkan dengan banyaknya jumlah air hujan yeng diterima ketika berlaku hujan lebat. Objektif kajian yang dijalankan adalah untuk mengenalpasti kadar atau jumlah hujan yang boleh menyebabkan berlakunya runtuhan cerun di dalam kawasan kajian. Kadar atau jumlah hujan yang dikenalpasti, digunapakai bagi menentukan Amaran Awal ('Warning Alert') oleh Sistem Pemantauan Cerun. Dua kawasan kajian terlibat adalah kawasan Jelapang dan Gua Tempurung di Perak di mana kedua-dua kawasan kajian ini mempunyai saiz kawasan tadahan yang besar dengan cerun semulajadi walaupun keduanya mempunyai ciri-ciri geologi dan batuan hampar yang berbeza antara satu dengan lain. Sistem Pemantauan Masa Nyata ('Real Time Monitoring System - RTMS') dibangun berdasarkan tiga komponen penting iaitu stesyen di tapak pemantauan (peralatan tapak), pelayan pengkalan data serta kaedah penghantaran data dari tapak pemantauan ke pengkalan data. Berdasarkan kajian kes yang dijalankan di kedua-dua kawasan, kejadian runtuhan cerun berlaku apabila kadar hujan yang turun melebihi 50mm/jam dan kadar ini boleh digunapakai sebagai had kadar hujan bagi amaran berjaga-jaga (Warning Alert).

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APPROVAL

I certify that an Examination Committee has met on **13 October 2014** to conduct the final examination of **Norisam Bin Abd Rahaman** on his degree thesis entitled '**Rainfall Threshold for The Initiation of Slope Failures at Jelapang and Gua Tempurung Area**'. The committee recommends that the student be awarded the Master of Science.

Members of the Examination Committee were as follows:

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Universiti Pertahanan Nasional Malaysia
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Prof. Madya Ir. Dr. Mohammed Alias Bin Yusof
Universiti Pertahanan Nasional Malaysia
(Internal Examiner)

Prof. Dr. Bujang Kim Huat
Universiti Putra Malaysia
(External Examiner)

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DECLARATION OF THESIS

Name	:	Norisam Bin Abd Rahaman
Date of birth	:	22 May 1972
Title	:	Rainfall Threshold For The Initiation Of Slope Failures At Jelapang And Gua Tempurung Area
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LIST OF ABBREVIATIONS / GLOSSARY / TERMS

2G	Second Generation (Wireless telephone technology)
3G	Third Generation (Wireless telephone technology)
BB	Both Bound
DID	Drainage and Irrigation Department
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
GIS	Geographical Information System
GPRS	General Packet Radio Services
GSM	Global System for Mobile Communication
GUI	Graphical User Interface
HQ	Head Quarters
ID	Identification
IFSAR	Interfero-metric Synthetic Aperture Radar
MHA	Malaysian Highway Authority
MySQL	'My' - Structured Query Language
NB	North Bound (travelling from South to North)
NSE	North-South Expressway
NSMP	National Slopes Master Plan
NW-SE	North West – South East
PLUS	Projek Lebuhraya Usahasama Berhad
R.O.W.	Right-of-Way
RTMS	Real Time Monitoring System
SAR	Synthetic Aperture Radar
SB	South bound (travelling from North to South)
SIM Card	Subscriber Identification Module card
TCP/IP	Transmission Control Protocol / Internet Protocol
TEMAN	Total Expressway Maintenance Management

CHAPTER 1

INTRODUCTION

1.1 General Overview

This chapter deals with the overview of rainfall induced slope failures, the system layout for the Real Time Monitoring System (RTMS), the study areas, as well as the process of determining rainfall threshold for any rainfall induced slope failure to occur. The research looked into rainfall data collected using rain-gauges installed within study areas and analysis of rainfall pattern. Data of slope failure records that occurred in the past, within the study areas were also analyzed. And case studies were carried out to determine the threshold level for rainfall to trigger a slope failure. This threshold rainfall level was used to indicate the point for triggering warning alerts to engineers who were responsible for carrying out further investigation on site.

Two (2) focus areas were selected that have substantially large catchments areas located beyond the Expressway's Right-of-Way (ROW). In case of any major slope failure or debris flow occurred within these upstream catchments areas, it will have potential impact towards the Expressway that may cause damages and dangerous to road users. This research also looked into the connection between slope failures occurred within selected study areas and the rainfall received throughout the year within the areas.

Slope failures were common around the world especially in wet tropical region like the South-East Asia. Slope failures were often associated with the rainfall and statistically analyzed with the total amount and/or the intensity of rainfall (Katsuyuki, 1999). Rainfall induced slope failures of unsaturated residual soil slopes occurred when there was an increase in moisture content and a decrease in soil matric suction (Krahn et al, 1989; Lambe, 1996)

Slope failures at hilly terrain can be triggered by many external and internal factors such as earthquake tremors, intense rainfall and stream erosion. These factors can cause increases in the driving shear forces and decreased the existing shear strength of the slope. There were also other long term factors that affecting slope stability such as vegetation covers, drainage conditions, climate and weathering as well as human activities which may lead to slope failures.

Slope failures were the major concern to the Government and the people due to the extent of damages it caused as well as casualties and losses that the people suffered when slope failures occurred. Furthermore, slope failures can lead to economic loses to the country. Despite the efforts of preventing slope failures and mitigating losses due to slope failures, many were caught off-guard when slope failures occurred as there was still no clear indicative threshold that can trigger warning to engineers with regards to potential slope failure.

1.2 Background of the Study

Expressways were built to connect people of an area with other regions, either near or far. Expressways were constructed and maintained to promote economic development as well as commercial activities, to move people and goods around thus facilitating planned and sustainable urban growth.

The North-South Expressway (NSE) was managed by Projek Lebuhraya Usahasama Berhad (PLUS Berhad) formerly known as Projek Lebuhraya Utara-Selatan (PLUS), a subsidiary of UEM Berhad. As the major expressway service operator, PLUS also managing other expressways in Peninsular Malaysia including:

a) The North-South Expressway (NSE) network consists of Expressway Route Number E1, stretching from Bukit Kayu Hitam to Jalan Duta inclusive of the New Klang Valley Expressway (Jalan Duta – Bukit Raja) as well as Federal Highway Route 2. Whereas, at the southern part, the NSE consists of Expressway Route Number E2 stretching from Sungai Besi Toll Plaza to Kempas Toll Plaza in Johor.

b) The North-South Expressway Central Link (ELITE) from Shah Alam Interchange to Nilai Utara Interchange. This expressway linking up both E1 and E2 of the NSE.

c) The Butterworth – Kulim Expressway (BKE)

d) Malaysia – Singapore Second Crossing (MSSC) from Senai Utara Interchange to Tanjung Kupang in Johor before crossing the Strait of Johor via the MSSC Bridge and landed at Tuas in Singapore.

e) Penang Bridge connecting Butterworth area at the mainland of Peninsular Malaysia and Minden at Penang Island.

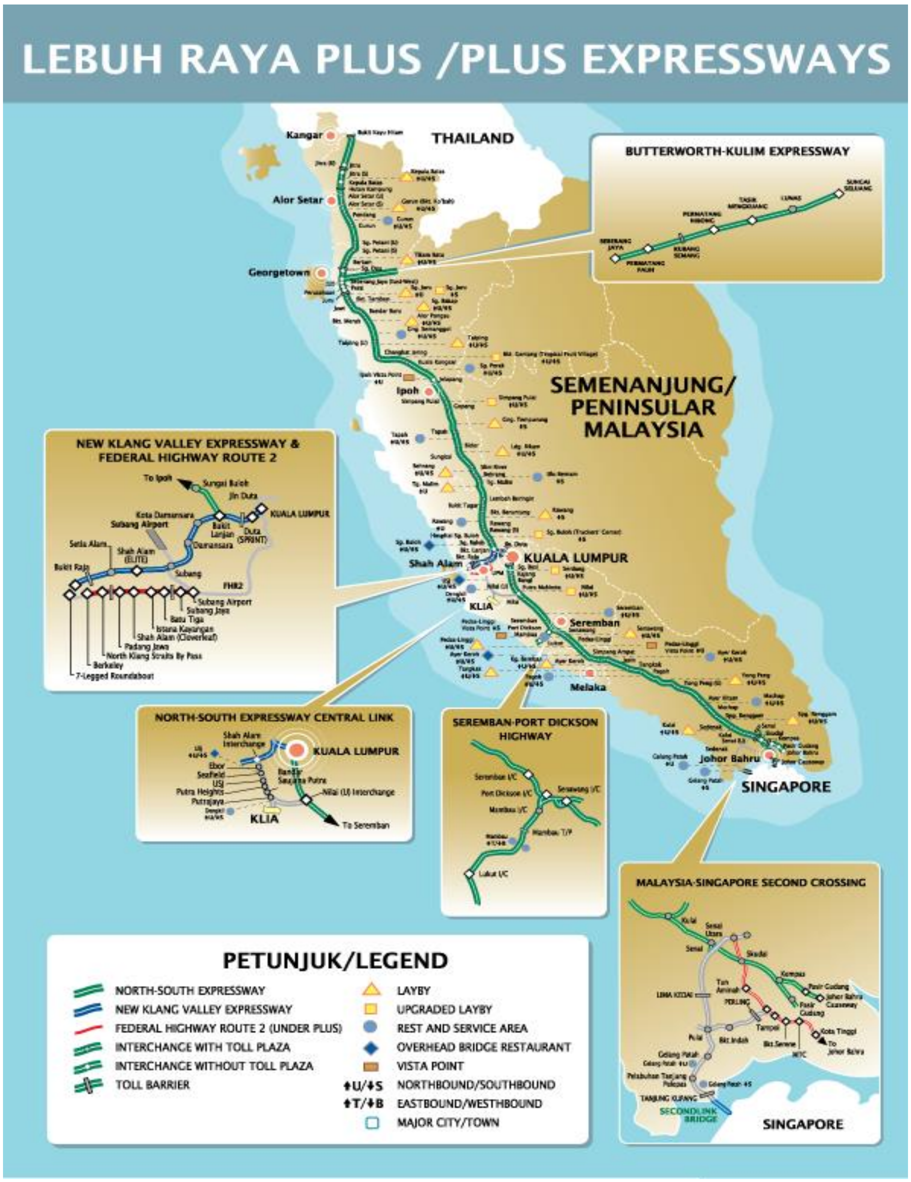

Figure 1.1: Alignment of the Expressways under PLUS (Source from www.plus.com.my)

Figure 1.1 shows the alignment of the North-South Expressway as well as other Expressways under management of PLUS Berhad.

Expressways were designed such that to ease travelling of road users from one place to another. The North-South Expressway (NSE) was built to connect major cities along its route from Bukit Kayu Hitam at the North to Johor Bahru at the South. Therefore, the expressways had been constructed through different terrain from the north of Peninsular Malaysia to the southern tip of Peninsular Malaysia.

While going through different terrains and ground altitudes, the longitudinal gradient have to be kept at the most minimum gradient for safety, riding comfort as well as vehicle control. In order to achieve this with the most optimum construction cost, the expressways were constructed via cut and fill method along the given alignment where the expressway have to cut into hills and mountains as well as crossing valleys on fill embankments. This method of construction resulted in various kind of cut and fill slopes despite other man-made structures forming the expressways mainline i.e. embankments, bridges and tunnels.

Different terrain and geography were observed throughout the expressway's alignment. Flat terrain and soft ground were observed within Kedah and Seberang Perai where the expressway traversing through vast paddy fields. Within the soft ground area where the geology mainly consists of soft marine clay, the expressways were built at minimum embankment height, coupled with several foundation treatments to strengthen the base.

Mountainous terrain were observed within the route in Perak i.e. Jelapang area and Gua Tempurung area. Within Jelapang area, the expressway cut into the rock mass / bed rock while travelling the side terrain of the mountain range before going through tunnels at the highest point. Here, the man-made slopes were consists of high rock cut slopes with shallow soil slope on top. While at Gua Tempurung, the expressway cut through deep regolith / soil mass resulting in high cut soil slopes.

Hilly undulating terrains were observed along the side of the expressway while travelling through majority of Perak, Selangor, Negeri Sembilan, Melaka and Johor area. Within these areas, the expressway was built on cut and fill embankment, thus creating many cut slopes and embankment slopes along the way.

In order to ensure the expressways were secured at all time, these man-made slopes along the expressways were properly monitored, maintained and up-kept. With a vast number of slopes along the expressways, it was unknown which slope going to fail or when a major slope failure may occur. Once a major slope failure occurred, it required huge cost of repair in order to restore the slope to its original condition or to enhance the slope with better engineering solution and stabilization method. Slope failures that affecting an expressway will disrupt major economic supply line and might also involve potential loss of life as well as the victim's economic value.

Monitoring the prominent and active elements that can cause slope failures such as rainfall volume and its intensity, will prepare the Highway Operator to act on the counter measures necessary to prevent or control the potential failures, or at least minimizing the impact for the safety of road users and other expressway's assets in case of unavoidable slope failure. Therefore, it was necessary to have a threshold level for the rainfall as trigger points in issuing warning alert that lead to further necessary action.

1.3 Problem Statement

As Malaysia is located near the Equator Line, it experiences high volume of rainfall as well as a lot of heat from the sun throughout the year. In this wet tropical region, Malaysia experiences high degree of weathering processes and activities in the form of mechanical weathering as well as chemical weathering.

General observation on several slope failures occurred in Malaysia and several other areas around the globe, slope failures normally occurred after certain period of heavy and prolong rainfall or heavy thunderstorms. However, there was no clear indication of any rainfall volume and intensity that can trigger a slope failure.

1.4 Objectives of the Research

Three (3) objectives were identified for the research:

a) To study rainfall pattern for Jelapang and Gua Tempurung area and to identify wet seasons for the areas

b) To study trends of slope failures in mountainous region in Jelapang and Gua Tempurung areas.

c) To determine the threshold of rainfall volume/intensity that could cause slope failures or debris flow within the upper catchments of Jelapang and Gua Tempurung areas.

1.5 Scope of Research

The scope of study for the research can be divided into three (3) major activities. These will involve the following:

a) The research focused on two (2) mountainous regions within the North-South Expressway i.e. Jelapang area and Gua Tempurung area. These areas of concerned located at mountainous region in which large upstream catchments area were formed beyond the expressway's Right-of-Way (R.O.W). The catchments study was carried out based on Interferometric Synthetic Aperture

Radar (IFSAR) data of the respective regions. These involved the processing of raw IFSAR data and satellite images to generate Digital Elevation Model (DEM) using ERDAS Imagine software. The DEM was then processed and analyzed using ArcGIS Software for the slope aspects, slope angle, slope curvature, elevation and hydrology analysis. Based on several major defects and slope failure records obtained from PLUS, comparison and analysis were carried out against the GIS analysis of the catchments area. The ratio analysis indicates which quadrants of catchments areas were susceptible to slope failure.

b) The research also explored the development of Real Time Monitoring System (RTMS) in which the rainfall data recorded on site were transmitted in real time to the Central Server located at PLUS Headquarters for analysis. Based on the rainfall data collected, analysis for rainfall trends were carried out for hourly rainfall, daily rainfall, monthly rainfall as well as annual rainfall. For this study, rainfall analyzed was from the data collected in Year 2011 and 2012.

c) A case study for each area at Jelapang and Gua Tempurung were used to determine the threshold of rainfall that triggered the slope failures. Cross references were carried out with reports on unusual rainfall and flooding from Meteorological Department of Malaysia.

1.6 Limitations

There were many factors that contributed in causing slope instability. This field of research will focus on the effect of rainfall as the main variable over time while other preparatory factors were assumed to be constant.

Verification were based on slope failures recorded by PLUS. However, since the rainfall data collection started from January 2010, while the records of slope failures can be traced back from the time before data collection being activated, there were limitation in comparing the rainfall data and slope failures occurrence in these regions.

CHAPTER 2

THEORY AND LITERATURE REVIEW

2.1 Introduction

Slope failures were one of the hot topics being discussed amongst civil engineers and geotechnical engineers around the globe. Slope failures can occur as long as there were slopes around the area, either engineered slopes constructed by human or natural slopes. Slope failures can be in the form of small scale and localized failures or massive failures and regional in nature. Some of the slope failures may traveled down the terrain if the condition permitted in a form of debris flow, damaging the adjacent populated area that normally located downstream. And for the case of roads or expressways, the damages can cause major disruptions to the trunk line that causing economic loses over a period of time before clearing and rehabilitation works being carried out.

There were many types of slope failures, depends on the properties of soil within the affected areas such as rotational, transitional and rock fall. In addition, there were also many factors that can trigger slope failures such as earthquake, rainfall as well as deterioration due to weathering process.