BACKANALYSISOF RAINFALLINDUCED LANDSLIDE IN SABAH BY *PERISI* MODEL

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Athesis submitted in fulfillment of the

requirements for the award of the degree of

Master of Engineering (Civil - Geotechnics)

Faculty of Civil Engineering

Universiti TeknologiMalaysia

NOVEMBER 2009

To my beloved dad, mom, brothers and sisters…

ACKNOWLEDGEMENT

Alhamdulillah, thanks to God that give me strength and with His permission, I can complete this study within the time.

First and foremost, I would like to express my sincere gratitude to my project supervisor, Associate Professor Dr. Nurly Gofar for her invaluable supervision, guidance, encouragement, constructive criticisms and friendship throughout the research.All her advices and ideas have contributed to the successful of this project.

I am deeply grateful to all staffs of Department of Irrigation and Drainage (DID) Sabah and Kumpulan Ikram (Sabah) Sdn. Bhd. for giving their contribution and cooperation during data collection being carried out. My deepest gratitude also extends to all lecturers and technical staffs of Department of Geotechnics and Transportation, Faculty of Civil Engineering, Universiti Teknologi Malaysia for their for their advice, support, motivation and guidance in this project.

Last but not least, I warmly thank my family, my dear and close friends of mine, for their love, patience and encouragement during those stressful times. Their views and tips are useful indeed. Without their continued support and interest, this project would not have been the same as presented here.

ABSTRACT

Rainfall has been recognized as the main landslide triggering agent particularly in Malaysia. Therefore, this project focuses on the significance of extreme rainfalls on suction variations and slope stability using *PERISI* (Preliminary Evaluation of Rainfall-Induced Slope Instability) program. Previous study showed that the extreme rainfall is characterized by geographical location. Hence, Intensity Duration Frequency (IDF) curve for Kota Kinabalu was developed in this study for 10 year return period based on 30 year data. *PERISI* was used to study the effect of rainfall infiltration on the stability of the two cases of slope failure in Kota Kinabalu Sabah. The study show that the critical rainfall duration depends on the soil's moisture retention ability and permeability. The soils at Site 1 and 2 are classified as sandy SILT and Highly Plastic CLAY respectively. Analysis showed that combination of 1 day major rainfall and 14 days antecedent was found to cause slope failure in Site 1 while 30 days cumulative rainfall has caused slope instability in Site 2. The comparison between dry and extreme condition in the factor of safety analysis also indicate that rainfall has a great effect on the slope stability.

ABSTRAK

Hujan lebat telah dikenalpasti sebagai agen pencetus utama kepada berlakunya kejadian tanah runtuh khususnya di Malaysia. Oleh sebab itu, kajian ini menumpu kepada kesan hujan ekstrem terhadap taburan sedutan dan kestabilan cerun dengan menggunakan Model *PERISI* (Penilaian Awal terhadap Ketakstabilan Cerun akibat Hujan). Kajian sebelum ini menunjukkan hujan ekstrem dipengaruhi oleh lokasi geografi. Oleh yang demikian, lengkung frekuensi tempoh keamatan (IDF) untuk kawasan Kota Kinabalu dihasilkan dalam kajian ini untuk 10 tahun kala kembali berasaskan data hujan 30 tahun. *PERISI* kemudiannya digunakan untuk mengkaji kesan menyusupan hujan terhadap kestabilan cerun untuk dua kes kegagalan cerun yang telah berlaku di Kota Kinabalu Sabah. Kajian menunjukkan keamatan hujan yang kritikal bergantung kepada keupayaan tanah menahan lembapan dan kebolehtelapan tanah. Jenis tanah untuk Tapak 1 dan 2 masing-masing dikelaskan kepada kelodak berpasir (*Sandy SILT*) dan tanah liat berkeplastikan tinggi (*Highly Plastic CLAY*). Analisis menunjukkan kombinasi hujan utama selama sehari dan hujan selama 14 hari merupakan pencetus utama kepada kegagalan cerun di Tapak 1 manakala hujan selama 30 hari adalah penyebab kepada ketakstabilan cerun di Tapak 2. Perbandingan diantara keadaan kering dan ekstrem didalam analisis faktor keselamatan juga menunjukkan hujan memberi kesan yang nyata terhadap kestabilan cerun.

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A	-	Cross sectional area
A_{ev}	-	Air entry value
C	-	Specific moisture capacity
c'	-	Effective cohesion
e	-	Void ratio
I	-	Rainfall intensity
I_{1-hr}	-	Intensity of 1-hour rainfall
I_{24-hr}	-	Intensity of 24-hour rainfall
I_{30d}	-	Intensity of 30-day rainfall
I_{cr}	-	Critical rainfall intensity
i	-	Hydraulic gradient
I_{acr}	-	Intensity of critical antecedent rainfall
I_f	-	Infiltration rate
I_{mcr}	-	Intensity of critical major rainfall
I_p	-	Infiltrability
k	-	Water coefficient of permeability
k_{sat}	-	Saturated permeability
k_w	-	Hydraulic conductivity of wetted zone
m_w	-	Slope of soil water characteristic curve (SWCC)
n	-	Porosity
P	-	Rainfall amount
q	-	Rainfall unit flux
Q	-	Rainfall total flux
q_f	-	Water flow rate

R	-	Rainfall return period
R_f	-	Surface Runoff
${}^{R}I_t$	-	Averagerainfall intensity for a particular return period
S_r	-	Degree of saturation
S_x	-	Standard deviation of annual maximum rainfall intensities
t	-	Time
t_{a+mcr}	-	Critical combined duration of antecedent rainfall and major rainfall
t_{acr}	-	Critical duration of antecedent rainfall
t_{mcr}	-	Critical duration of major rainfall
t_p	-	Time when surface runoff start to occur
u_a	-	Pore-air pressure
u_w	-	Pore-water pressure
$(u_a - u_w)$	-	Matric suction
W	-	Total weight of soil
W_{ev}	-	Water entry value
X	-	Extreme rainfall intensity for a particular rainfall duration
$\overline{X}$	-	Mean of annual maximum rainfall intensities
Y	-	Gumbel'sreduced variate
$\overline{Y}$	-	Mean of Gumbel'sreduced variates
β	-	Slope inclination angle
χ	-	Parameter related to the soil degree of saturation
ϕ'	-	Effective friction angle
ϕ^b	-	Unsaturated friction angle
γ_d	-	Unit weight of dry soil
γ_w	-	Unit weight of water = 9.81kN/m^3
μ	-	Differences between the volumetric water content before and after wetting process
π	-	Osmotic suction

θ	-	Volumetricwater content
θ_a	-	Average volumetric water content in the wetted zone
θ_i	-	Initial volumetric water content
θ_r	-	Residual volumetric water content
θ_s	-	Volumetric water content at saturation of desorption curve
θ'_s	-	Volumetric water content at saturation of absorption curve
ρ_b	-	Bulk density
ρ_d	-	Dry density
ρ_w	-	Density of water
σ	-	Total normal stress
σ'	-	Effective normal stress
σ_y	-	Standard deviation of Gumbel'sreduced variates
τ_f	-	Shear stress at failure
ψ	-	Suction
ψ_{min}	-	Minimum Suction value
ψ_T	-	Total suction

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CHAPTER 1

INTRODUCTION

1.1 Background of Study

Rainfall has been considered as the cause of the majority of slope failures and landslides in regions experiencing high seasonal rainfalls (Brand 1984, Shaw-Shong 2004). It is well known that the infiltration impairs slope stability but the correlation between rainfall infiltration and slope stability involves many factors. The rainfall infiltration on slope could result in changing soil suction, raising ground water table, as well as increasing soil unit weight and reducing shear strength of rock and soil (Campbell, 1975).

Conventional slope stability analysis is always performed based on the assumption that soil is in saturated condition. This fully saturated condition may be a reasonably good assumption for many cases and is certainly not a restriction. However, recent studies (e.g. Brand 1984, Fourie 1996, and Tsaparas *et al.* 2002) proved that the assumption of saturated conditions cannot be applied successfully for the stability analysis of slopes in unsaturated conditions. The increasing acceptance of unsaturated soil mechanics hence has highlighted the need to correlate the slope failure with rainfall in order to understand the mechanism of rainfall-induced slope failures.

Brand (1984) suggested that the most catastrophic landslides are triggered by major rainfall of more than 70mm/day. His finding was contested by other researchers (e.g: Lumb, 1975; Ng and Shi, 1998; Tsaparas *et al.*, 2002) who focused on the important role of antecedent rainfall instead of the influence of a single rainstorm event for the initiation of slope failure. Antecedent rainfall is defined as rain that falls in the days immediately preceding the landslide event (Rahardjo *et. al.*, 2001). Periods of rainfall with some associated threshold magnitudes that may induce landslide vary from less than 24 hours for shallow debris flows (Wilson & Wieczorek 1995; Larsen & Simon 1993; Caine 1980) to a few months for deep seated slow moving landslides (Flentje 1998). In Hong Kong, Lumb (1975) suggested that antecedent rainfall up to 15 days prior to the failure event should be considered in addition to the intensity of the triggering rainstorm while Ng and Shi (1998) suggested critical rainfall duration of antecedent rainfall between 3 to 7 days only. Meanwhile in Singapore, Rahardjo *et al.* (2001) suggested 5 days of antecedent rainfall as the critical rainfall duration.

Subsequent researches showed that the rainfall induced slope instability is affected by total rainfall and initial condition of the slope (Tsaparas *et al.,* 2003) and also soil permeability and slope depth (Pradel and Raad, 1993 and Lan *et al.* (2003)). Case studies presented on the topic of rainfall induced failure in different geographical regions (Brand (1984), Rahardjo *et al.* (2000), Roslan and Mohd (2005), Tohari and Rahardjo (2006), Gofar *et al* (2007)) have suggested different conclusions on the threshold rainfall condition for the slope failures. Hence, Chowdhury and Flentje (2002) concluded that geographical location has an effect on the occurrence of rainfall induced slope failure. Gofar and Lee (2008) concluded that critical duration of antecedent rainfall is influenced by three major factors i.e (1) the type of soil, (2) the geographical location and (3) the depth of the slip plane. Hence, they developed a model to simplify the effect of rainfall infiltration on slope stability based on statistical rainfall analysis and intrinsic characteristics of soil in Peninsular Malaysia. The model is presented as a computer program named PERISI stands for Preliminary Evaluation of Rainfall Induced Slope Instability (Gofar and Lee, 2009).

1.2 Problem Description

In Malaysia, the study on the rainfall-induced slope failure through the integration of local extreme rainfall is very limited. As mentioned earlier, the rainfall-induced slope failure problem should be treated as a localized problem, in which experiences from different regions of the world would result in different conclusions. Thus, it is necessary to study the mechanism of rainfall-induced slope failure based on the extreme rainfall analyzed from the local historical rainfall data. Since the preliminary evaluation of rainfall induced slope instability model developed by Gofar and Lee (2008) was focused on rainfall and soil characteristics in Peninsular Malaysia only, this project will look at the application of the model for landslide cases in Sabah in order to evaluate susceptibility of rainfall induced landslide for the locations.

1.3 Aim and Objectives of Study

The aim of this study is to generate a statistical extreme rainfall for slope stability analysis in Sabah and to demonstrate the significance of these extreme rainfalls on suction variations and the stability of the slope through case studies. Therefore, the objectives of this study are:

i. To develop rainfall intensity-duration-frequency (IDF) curves for slope stability analysis based on rainfall data from Kota Kinabalu station

ii. To demonstrate the ability of PERISI model to analyze the susceptibility of slope to rainfall induced landslide by using two cases of slope failures in Kota Kinabalu.

iii. To analyse the significance of these extreme rainfalls on the stability of the slope

1.4 Scope and Limitation of Study

The scopes of this study are outlined as follows:

i. Kota Kinabalu rainfall station are considered in the analysis of statistical rainfall using method of Gumbel (1954) for 10-years return period

ii. 30 years record of daily rainfall from Kota Kinabalu station is used and the cumulative rainfall magnitudes are calculated for the following daily rolling periods: 1, 2, 3, 5, 7, 14 and 30 days

iii. Two cases of landslides occurred in Kota Kinabalu areas are selected for slope stability analysis

iv. In the absence of actual data, the soil water characteristic curve (SWCC) and permeability function are predicted based on particle size distribution (PSD)

1.5 Importance of Study

Rainfall-induced slope failure involves a very complicated mechanism that governed by a number of parameters and uncertainties. It is evidenced that beside the contributing factors such as soil strength properties, soil mass and geometry, the factor of safety of slope can be altered by the changes in pore water pressure or suction which in turn greatly influenced by triggering factor of rainfall infiltration. This relationship therefore reveals the importance of this study to understand the dominant factors affecting the failure, the critical rainfall pattern, and the corresponding suction distribution in order to successfully evaluate the effect of rainfall infiltration on the stability of a slope.