Analysing of Shallow Slope Failures Triggered by Rainfall using Probabilistic Model: A Case Study of Krabi Landslide in Southern Thailand

Tohoku University Graduate Student ○ Thapthai CHAITHONG
Tohoku University Member Daisuke Komori
Kasetsart University Non-Member Suttisak Soralump

1. INTRODUCTION

Rainfall-induced landslides are serious geological hazards in Thailand. The landslides tend to occur in mountainous areas of Thailand (particularly South and North Thailand) (Jotisankasa and Vathanaukij 2008, Soralump 2010). Thailand has experienced more than 150 landslides related to storms or extreme rainfall during 1970-2018. **Fig 1** shows the number of landslides occurrence in Thailand between 1970 and 2018.

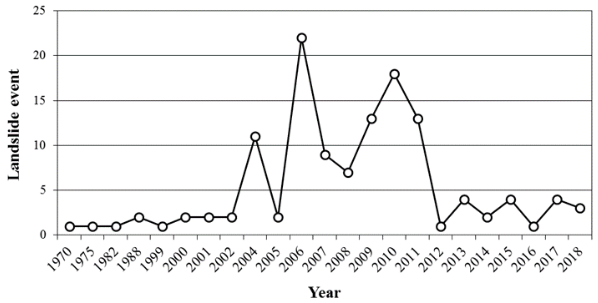

Fig.1. Number of landslides occurrence in Thailand between 1970 and 2018 (after Soralump & Chaithong, 2017)

Generally, prolonged and extreme rainfall events bring about increase in groundwater table or increase in pore-water pressure including, the seepage force is changed. The soil suctions are dissipated due to rainwater infiltration. Shear strength of soil slope is subsequently decreased by rising groundwater table or increasing pore-water pressure until a critical point lead to landslide or slope failure. Based on conservative slope stability analysis, the soil parameters such as friction angle, soil cohesion and unit weight of soil, are assumed to be constant. In contrast, the variability of soil properties in geotechnical engineering affects factor of safety calculations. Hence, the aim of the study is to present the probability analysis of rainfall-induced landslide. The probability analysis uses the simplified first-order second-moment method (SFOSM). The study considers the uncertainties of the soil parameters such as soil cohesion, slope angle, depth of soil, groundwater table, saturated unit weight of soil, total unit weight of soil and friction angle.

2. DESCRIPTION OF STUDY AREA AND 2011 LANDSLIDES AT KHAO PANOM, KRABI PROVINCE, THAILAND

In 2011, the south of Thailand experienced the unseasonably extreme rainfall between 25th and 30th March causing flash floods, landslides, debris flows. Particularly Khao Phanom Mountain, located in the Krabi province, south Thailand. Landslides and debris flows occurred around 28th March 2011. The scars of landslides and debris flow were found surround central of the mountain. The Khao Phanom Mountain was formed by the extrusion of granitic rock through the sedimentary rock, hence, the center area of the mountain consists of granitic rock (Kgr) (Soralump 2011). **Fig 2** shows the location of Khao Phanom Mountain in the south of Thailand.

The accumulated rainfall between 25th and 30th March 2011 amounted to approximately 400 mm, as measured by the Thai Meteorological Department at the Krabi rain gauge. The peak rainfall was approximately 160 mm on 29th March 2011. **Fig 3** shows the daily rainfall and cumulative rainfall during 25th-30th March 2011.

Fig.2. Location of Krabi landslide

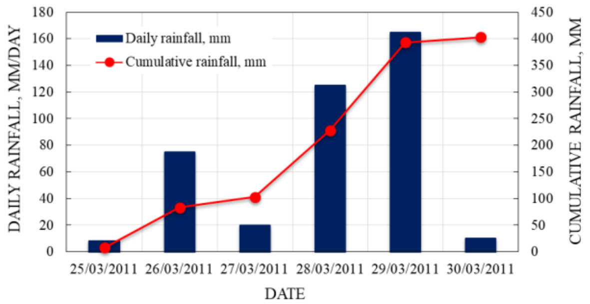

Fig.3. Daily and cumulative rainfall during 25th-30th March 2011

3. METHOD OF ANALYSIS

Fig 4 shows the calculation flow chart for Probabilistic Model. The study uses the infinite slope stability model for calculating the factor of safety and simplified first-order second-moment method for calculating the probability of failure. Equation 1 shows the factor of safety based on the infinite slope stability model. Equation 2 shows the groundwater table prediction equation. Considering the probability of failure calculation, the probability density functions of input parameters are assumed to be normal distribution. In this study, the soil cohesion, slope angle, depth of soil, groundwater table, saturated unit weight of

Keywords: slope failure, extreme rainfall, probability of failure, probabilistic model, landslide

Tohoku University, 6-6-20 Aoba Aramaki, Aoba-Ku, Sendai 980-8579, Japan. Tel & Fax: +81-22-795-7455

soil, total unit weight of soil and friction angle are input parameters are considered uncertainty. Equation 3 shows the simplified first-order second-moment equation (Christian et al. 1994, Haneberg 2004). Equation 4 shows the reliability index. The probability of failure for the normally distributed factor of safety is shown in equation 5.

$$FS=\frac{c'+\left[\left(m\cdot\gamma_{sat}\right)+\left(D-m\right)\gamma_t-\left(\gamma_w\cdot m\right)\right]\cdot\cos^2\beta\cdot\tan\phi'}{\left[\left(m\cdot\gamma_{sat}\right)+\left(D-m\right)\gamma_t\right]\cdot\sin\beta\cdot\cos\beta} \quad (1)$$

where c' is the effective soil cohesion, m is the groundwater table, D is the soil depth, γ_{sat} is the saturated soil unit weight, γ_t is the total soil unit weight, γ_w is the water unit weight, β is the slope angle.

$$m=\frac{A\cdot I}{\eta\cdot b\cdot k\cdot\sin\beta} \quad (2)$$

where m is the groundwater table, I is the rainwater infiltration, b is the channel width, k is the hydraulic conductivity, η is the porosity.

$$V\left[F\right]=\sum_i\left(\frac{\partial FS}{\partial x_i}\right)^2 V\left[x_i\right] \quad (3)$$

where $V[F]$ is the variance of factor of safety, $V[x_i]$ is the variance of the each independent variable.

$$RI=\frac{FS-1}{\sigma\left[F\right]} \quad (4)$$

where RI is the reliability index, $\sigma\left[F\right]$ is the standard deviation of factor of safety.

$$p_f=1-\Phi\left(RI\right) \quad (5)$$

where p_f is the probability of failure, Φ is the cumulative standard normal function.

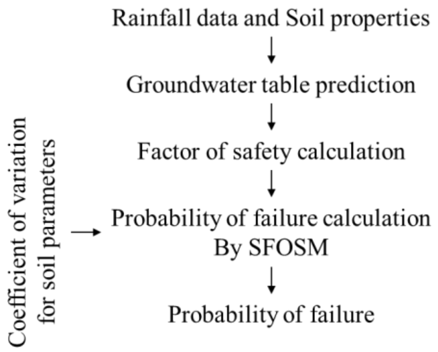

Fig.4. Calculation flow chart for Probabilistic Model.

In analysis, the soil properties are 10.7 kPa for the effective soil cohesion, 27.2 degrees for the effective friction angle of the soil, and 16.3 kN/m^3 for the saturated unit weight of the soil. Moreover, the angle of the soil slope is assumed to 35 degrees, the depth of the residual soil is 3 metres, and the coefficient of hydraulic conductivity is 0.087 cm/hr. The coefficient of variation values are 30% for the effective soil cohesion, 5% for slope angle, 10% groundwater table, 5% soil depth, 3% for saturated soil unit weight, 10% for total soil unit weight, 15% for friction angle (Baecher and Christian 2003, Karam 2005).

4. RESULTS AND DISCUSSION

Fig 5 presents the plots of the daily rainfall and probability of failure. Considering the plot of the probability of failure, it shows that the probability of failure increased from approximately 0.15 to 0.87 as the heavy rainfall passed through. The probability of failure was higher than 0.5 around 27 to 28 March 2011. The predicted landslide occurrence time of the Khao Panom landslide case is in good agreement with the field report.

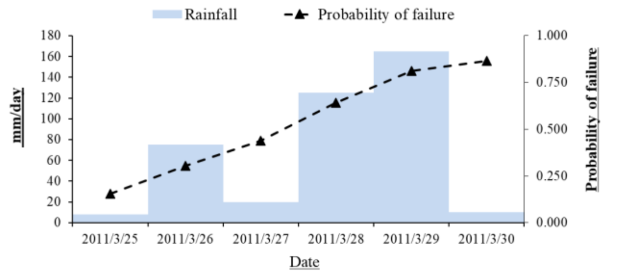

Fig.5. Plots of the daily rainfall and probability of failure.

5. CONCLUSION

The simplified first-order second-moment is capable of estimating the time of landslide occurrence which has been verified by the recorded data on the historical landslide cases in Krabi, Thailand. The estimated occurrence time of landslides using the proposed method is in good agreement with the observations.

ACKNOWLEDGEMENT

The authors would like to acknowledge the Thai meteorological department for rainfall data.

REFERENCES

Jotisankasa A., and H. Vathananukij (2008). Investigation of Soil Moisture Characteristics of Landslide-prone Slopes in Thailand. International Conference on Management of Landslide Hazard in Asia-Pacific Region 11th-15th November, Sendai, Japan.

Soralump S (2010). Rainfall-Triggered Landslide: from Research to Mitigation Practice in Thailand. Geotechnical Engineering Journal of the SEAGS&AGSSEA, Vol 41, Issue. 1.

Soralump S. and T. Chaithong (2017) Modeling Impact of Future Climate on Stability of Slope Based on General Circulation Model. Geotechnical Engineering Journal of the SEAGS&AGSSEA, Vol. 48, Issue 1, pp. 109-116.

Soralump S. (2011) 2011 Disastrous Landslides at Khao Panom, Krabi, Thailand. EIT-Japan Symposium 2011 on Human Security Engineering, Bangkok, Thailand.

Karam K.S. (2005) Landslide hazards assessment and uncertainties. Ph.D. Thesis, Massachusetts Institute of technology.

Baecher G.B. and J.T. Christian (2003) Reliability and statistics in geotechnical engineering. John Wiley & Sons Ltd, England.

Christian J.T., C.C. Ladd, and G.B. Gregory (1994) Reliability applied to slope stability analysis. J. Geotech. Eng. Vol. 120(12) pp. 2180-2207.

Haneberg W.C. (2004) A rational probabilistic method for spatially distributed landslide hazard assessment. Environmental & Engineering Geoscience, Vol. X, No. 1, 27-43.