

Rainfall-Triggered Landslide: from research to mitigation practice in Thailand

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ABSTRACT: Landslide is a serious treat to Thai society. Every 3 to 5 years, large landslide is triggered by heavy rainfall. The northern and southern parts are the most vulnerable parts of the country to landslide hazard. This paper presents the researches carried out by the Geotechnical Engineering Research and Development Center (GERD), of the Kasetsart University, Thailand which concentrates on the determination of the behavior of rainfall-triggered landslide by using Geotechnical method. It is found that it is possible to apply Geotechnical method for landslide risk management in large area with the link of rainfall data from rain gauge or satellite image.

1. INTRODUCTION

Landslide is the natural disaster that affects the society in many ways. Geotechnical Engineering Research and Development Center (GERD), Kasetsart University has developed landslide database of Thailand which contains of almost 40 years of information on landslide events starting from 1970. From the database it was found that there are 2 types of landslide which can be classified based on the extensive of losses namely limited area landslide and large area landslide. Figure 1 shows the characteristic of each type of slide. It was found that more than 95% of limited area landslides are always caused by the disturbance of human activities which causing the change in landform or surface and underground water flow characteristics. On the other hand, large area landslide is natural and mainly caused by unusual large precipitation in the area. However, there are also many evidences that deforestation or agricultural process is the main cause of large area landslide. Figure 2 shows the location of recorded landslide events from the database. It can be seen that the landslide occurred mostly in the northern and southern part of the country. It's also found that the frequency of the landslide event is increasing sharply during the last decade starting from 1996. The assumptions for the cause of increasing number of landslide for the past decade are 1. Landslides naturally occur more often which might be related to the climate change 2. Mismanagement of land use due to the increasing number of population and the needs of land for producing agricultural products, that force people to stay in the landslide hazard areas 3. Combination of first and second reason. Figure 3 shows statistic data of landslide events that caused economic loss of greater than 100 million baht. Furthermore, Table 1 shows the recorded of economic and live losses.



Figure 1. Limited and large area landslide (Department of Mineral Resources)

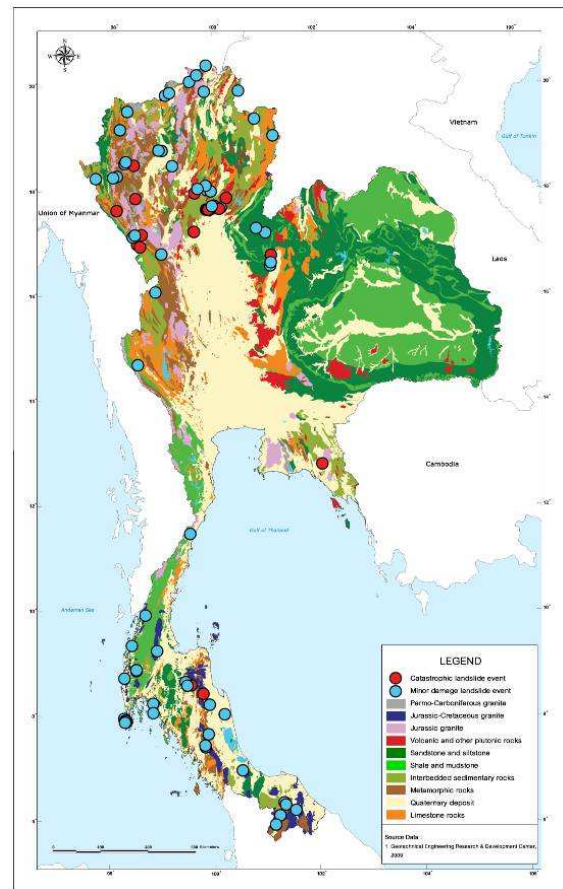


Figure 2. Landslide events in Thailand from 1970-2006 (GERD, 2006)

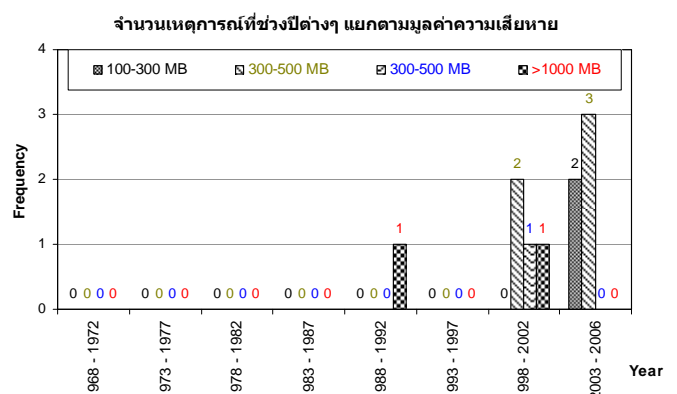


Figure 3. Direct damage cost of greater than 100 million baht from landslide events in Thailand (Soralump, 2007)

Table 1. Number of casualties from landslide events in Thailand since 1970 (Soralump, 2007)

Area	1970-2006		Average lost (37 year)	
	Lives	Economics	Lives	Economics
North	286	2,575,600,000.00	8	69,610,810.81
Central	1	300,000,000.00	0	8,108,108.11
South	247	1,010,000,000.00	7	27,297,297.30
Total	534	3,885,600,000.00	14	105,016,216.22

It is very important to understand the mechanics behavior of residual soil or weathered rock in order to understand the landslide behavior. Therefore, the classification of rock group that specifically related to landslide is needed at the first place. Similar type of rocks, based on their formation, age and statistical recorded of landslide, have been grouped together by Soralump et al. (2007) resulting in 8 rock groups. Soralump et al. (2007) is modified to be more accurate for sedimentary rock group in this paper and result in 10 rock groups instead which are: Group 1: Carboniferous-Permian granite has area of 0.74% Group 2: Jurassic-Cretaceous granite has area of 1.84% Group 3: Jurassic granite has area of 4.55% Group 4: Volcanic rock and other intrusive rock such as basalt, andesine, diorite etc. It has area of 3.04% Group 5: Sedimentary rock mainly sandstone, it has area of 17.55% Group 6 Sedimentary rock mainly shale and mudstone (18.79%) Group 7 Sedimentary rock, combination and interbedded or intercalated (7.17%) Group 8: Metamorphic rock has area of 6.3% Group 9: Quaternary sediment has area of 32.89% Group 10: Carbonate rock mainly limestone has area of 7.13%.

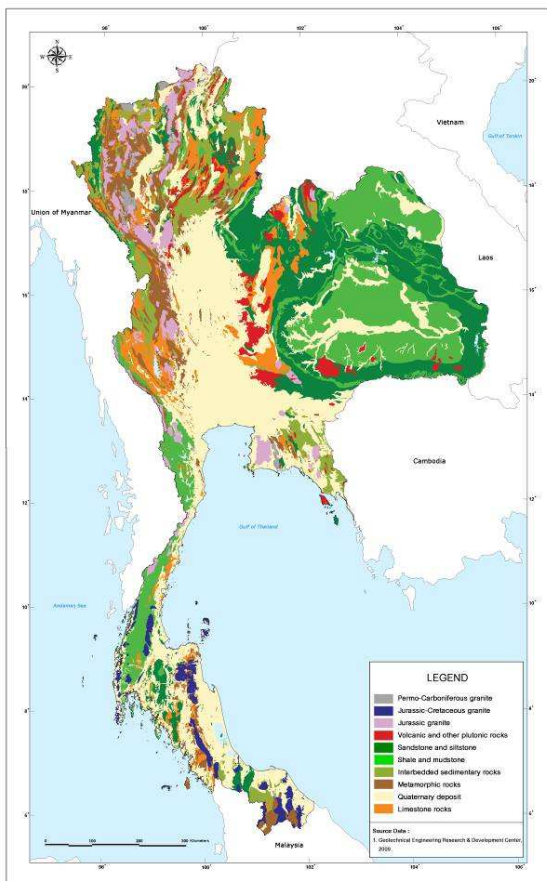


Figure 4. Rock groups related to landslide potential in Thailand

2. RAINFALL TRIGGERED LANDSLIDE-GEOTECHNICAL APPROACH

The behavior of rainfall-triggered landslide in the interested area is very important for landslide real time warning system. The key information that required for analyzing (by Geotechnical method) the changing in slope safety due to the change in soil moisture content from rainfall precipitation are:

1. The model of change in shear strength of soil in unsaturated zone due to the changing in soil moisture content (or metric suction), this characteristics of soil can be determined directly in laboratory by performing the direct shear test to the soil samples with various degree of saturation. Mairang et al. (2005) has proposed this testing technique. In classical way, the above characteristics can be determined based on strength equation for unsaturated soil introduced by Fredlund (1978). This method required the determination of Soil Water Characteristic Curve (SWCC) in additional of effective strength parameters. Jotisankasa (2010) has investigated the unsaturated strength behavior of residual soil in Thailand based this theory.

2. The infiltration model of unsteady flow. The permeability of residual soil in unsaturated condition (K-Function) and also the rough information of underlain base rock permittivity are required. The infiltration behavior can also be determined by directly install tensiometers or moisture probes in various depth of residual soil in the target area in order to record the changing in degree of saturation of soil due to rainfall precipitation. However, many monitoring points may be required to represent the soil moisture behavior for the whole watershed.

3. The rainfall data, which are the rainfall intensity and its pattern, shall be determined. Direct measurement from automatic rain gauge or interpretation from satellite image can be used. With the wireless system, rainfall data from rain gauge can be sent to the monitoring hub for every 15 mins. As for the data from satellite interpretation, more time is required but still in the practical period.

4. In case of infiltration model, the knowledge of absorption and retention characteristic of land cover may be studied and incorporated into the model. This is a challenge in Geotechnical research.

Figure 5 shows the relationship of the analyses described above. The strength reduction characteristics can be used together with infiltration model based on the local rainfall pattern in order to investigate the changing in slope stability with time. Unsteady state flow of unsaturated soil should be considered to represent the more realistic infiltration behavior. Figure 6 shows the example work done by this concept. The rainfall pattern in study area were used in conjunction with the unsteady state flow, strength reduction behavior and stability model. Figure 7 shows the work example used for back analysis of slope failure due to intense rainfall in Ra Island located in the southern part of Thailand. The precipitation is as high as 300mm/day and after 1.5 hr the failure started to begin.

The method described above is suitable for the safety analysis of limited area slope where details slope configuration and engineering soil properties are well known. In order to practice this concept in the wider area to prevent the large area landslide, more afford was done by Soralump and Torwiwat (2009) and Torwiwat and Soralump (2009). Based on landslide rock group as described in last section, undisturbed samples of residual soil located in each rock group have been collected. The total number of over 514 soil samples has been tested for their engineering properties. 307 undisturbed soil samples have been specially tested their shear strength reduction behavior by KU-MDS shear testing method (Soralump and Torwiwat, 2009). Figure 8 shows the example of strength reduction characteristic of 6 rock groups. The critical thicknesses at each degree of saturation of various slope angles are calculated. This critical thickness is then used to calculate the amount of water that could be contained and will give slope safety of 1.0.

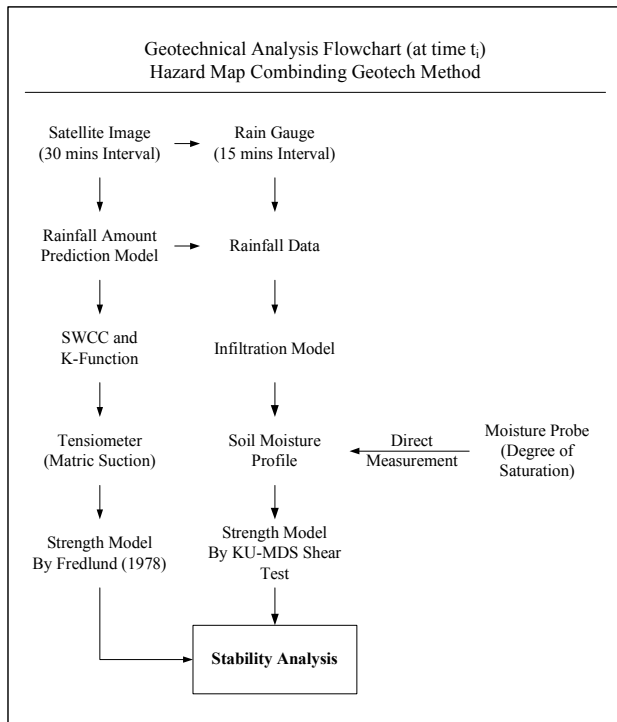


Figure 5. Geotechnical analysis flowchart for supporting the landslide real time warning system

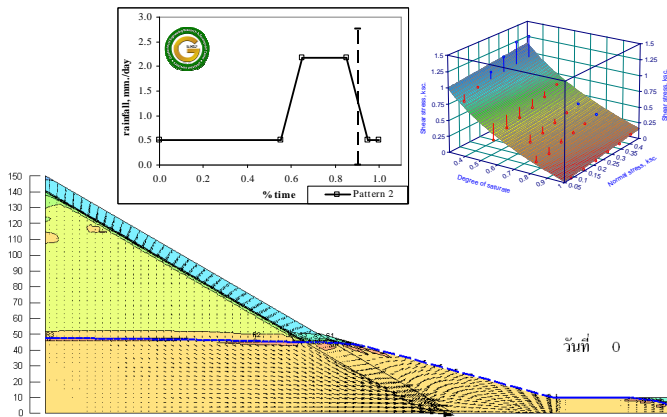


Figure 6. The modeling of rainfall triggered slope failure (Kunsuwan, 2005)

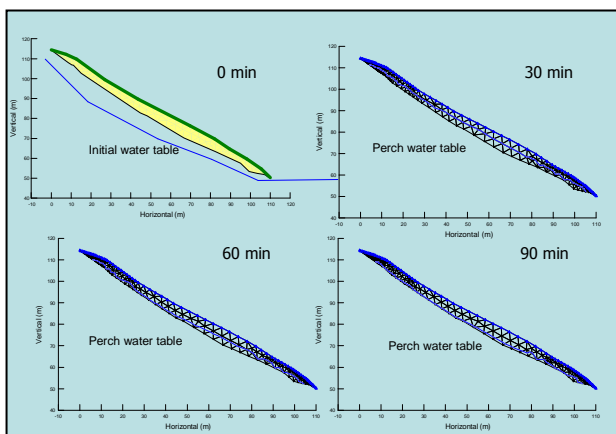


Figure 7. Infiltration model of actual landslide in Ra Island

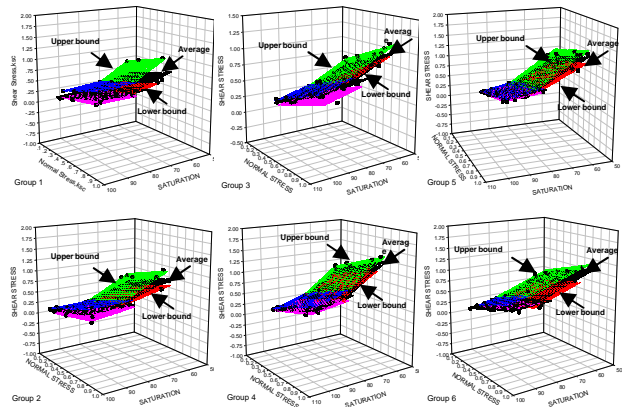


Figure 8. Strength reduction characteristic from increasing of soil moisture content (Soralump and Torwiwat, 2009)

This amount of water is called the Critical Moisture Content (CCM). In order to use this calculated value for landslide warning, CCM can be transformed into the unit of “mm” or the same unit of precipitation and will be used to compare with the Antecedent Precipitation Index value (Linsley et al., 1982) which calculated from rainfall records. The CCM will then be called the critical Antecedent Precipitation Index (API). Figure 9 shows the calculated critical API values for Thailand (DWR, 2008 and Torwiwat and Soralump, 2009). Since the use of API value for landslide and flood warning was initiated by Department of Water Resources, therefore these values are now used in practice for landslide warning in Thailand. However, the reduction of critical API values was used in order to cover various uncertainties. Proper uncertainty analysis using Monte Carlo simulation or FORM is under the research of the author.

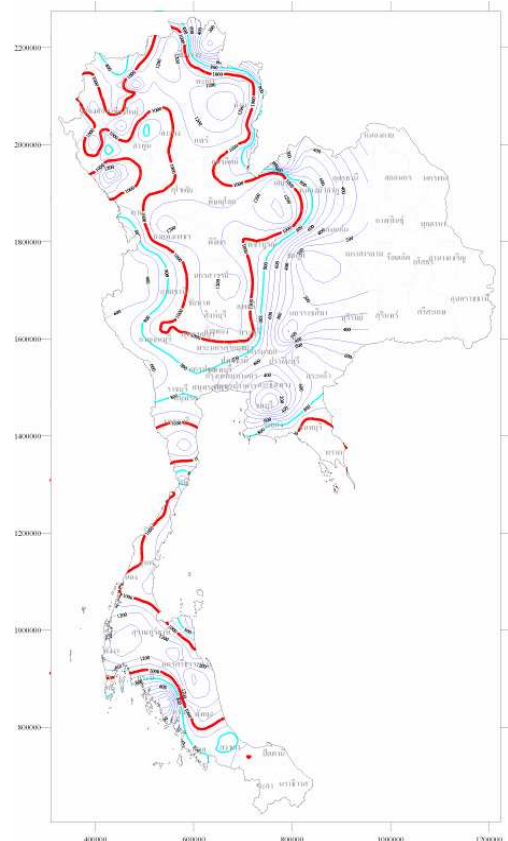


Figure 9. Critical API contour (DWR, 2008, Torwiwat and Soralump, 2009)

application of this approach for Phuket, by using various return period of precipitation, various landslide hazard levels could be produced. Figure 15 shows the contour of 3-day accumulated rainfall analyzed from over 242 rain gauge stations. And with rainfall data date back for almost 40 years, it is possible to analyzed 3-days accumulated rainfall in specified return periods.

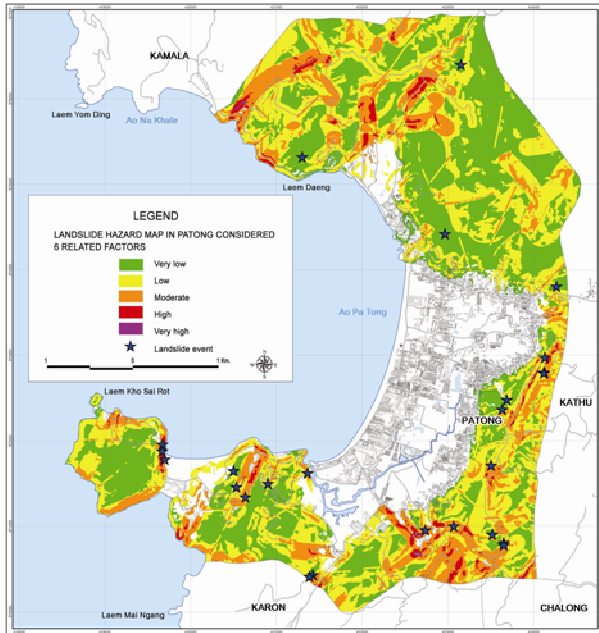


Figure 13. Landslide hazard map of Patong (ADPC, GERD and DMR, 2008)

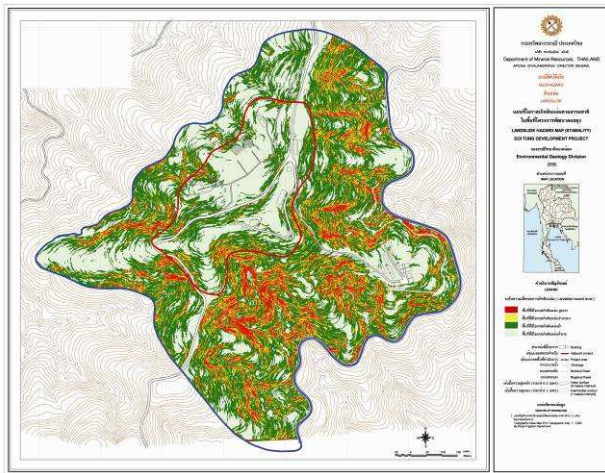


Figure 14. Landslide hazard map, Doi Tung (DMR, 2007 and Soralump et al, 2008)

4. CONCLUSIONS

Rainfall-triggered landslide is proved to be manageable if warning criteria and hazard area can be supplied from research field. In turn, in order to obtain those data for large area, comprehensive geotechnical testing shall be done. Area should be grouped based on geological group, engineering properties of geo-material of each group must be determined. Strength reduction model and infiltration model are important tools to calculate the amount of rainfall that may trigger landslide.

Landslide hazard is sensitive to various factors that might be different in different area. There is no one solution to solve all for this problem. Therefore, the landslide hazard map of Thailand is just a guideline to get the idea of landslide hazard for the whole country.

However, for landslide management, detail analyses are required in specific site. It has been proved that with the scale of 1:4,000, it is possible to apply the detail geotechnical analysis to obtain the hazard area and triggering level of rainfall that might induce landslide.

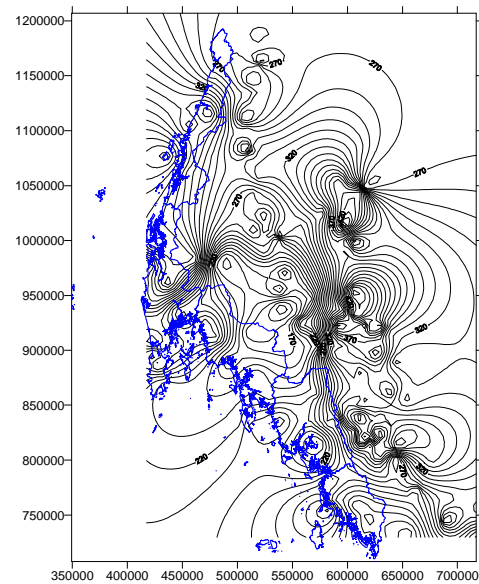


Figure 15. Contour of rainfall precipitation in southern part of Thailand

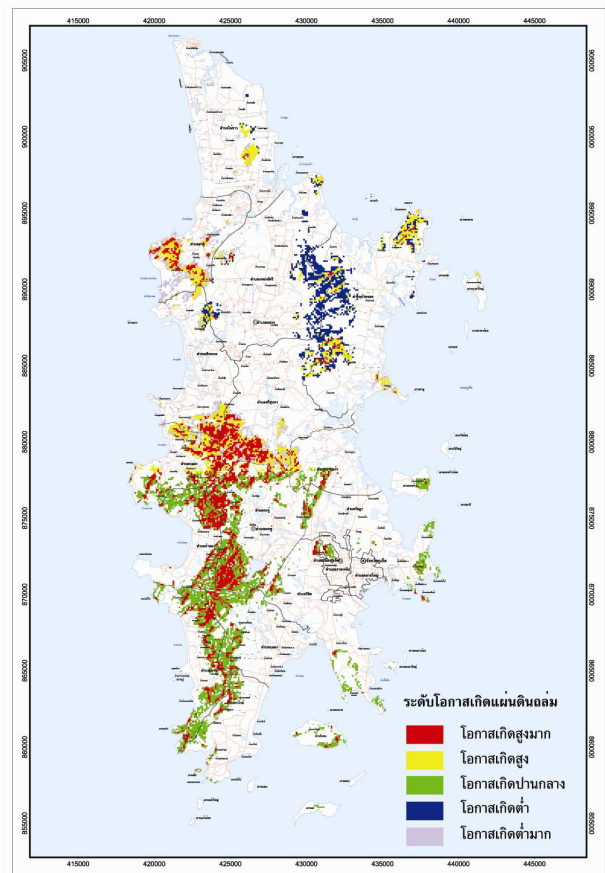


Figure 16. Landslide hazard map using different level of rainfall intensity

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