Geotechnical Approach for the Warning of Rainfall-Triggered Landslide in Thailand Considering Antecedence Rainfall Data

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ABSTRACT: Rainfall intensity and its pattern are among the important factor that used for the analysis of rainfall triggered landslide. The concept of using antecedent precipitation index (API) and the finding of critical API will be presented in this paper. The use of API value for landslide hazard warning was introduced by the Department of Water Resources. The critical API values were then calculated and used as a warning criteria for the landslide risk area in the country by the work of Geotechnical Engineering Research and Development Center (GERD). The strength reduction behavior due to the increasing of moisture content of the residual soil from each rock group was investigated. Relationship between critical thickness, critical API of each slope angle were analyzed. The area weighted method was used to identify the representative of critical API in the interested watershed. Some verification of this approach will be presented.

1 INTRODUCTION

Landslide is the natural disaster that affected 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 (mostly deep seated slide) and large area landslide (mostly shallow). 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 is also found that the frequency of the landslide event is increasing sharply during the last decade starting from 1996.

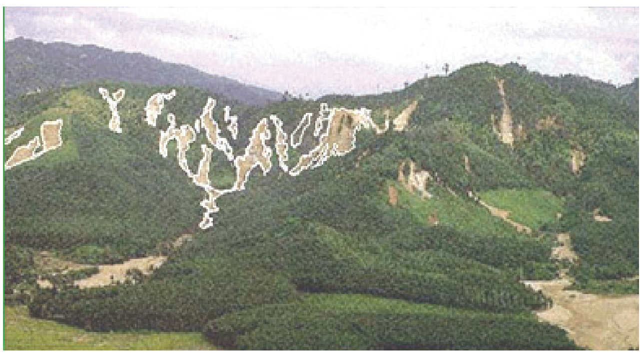

Figure 1: Limited and large area landslide (Department of Mineral Resources).

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 the record of landslide which caused the economic damage of greater than 100 million baht. Furthermore, Table 1 shows the recorded of economic and live losses.

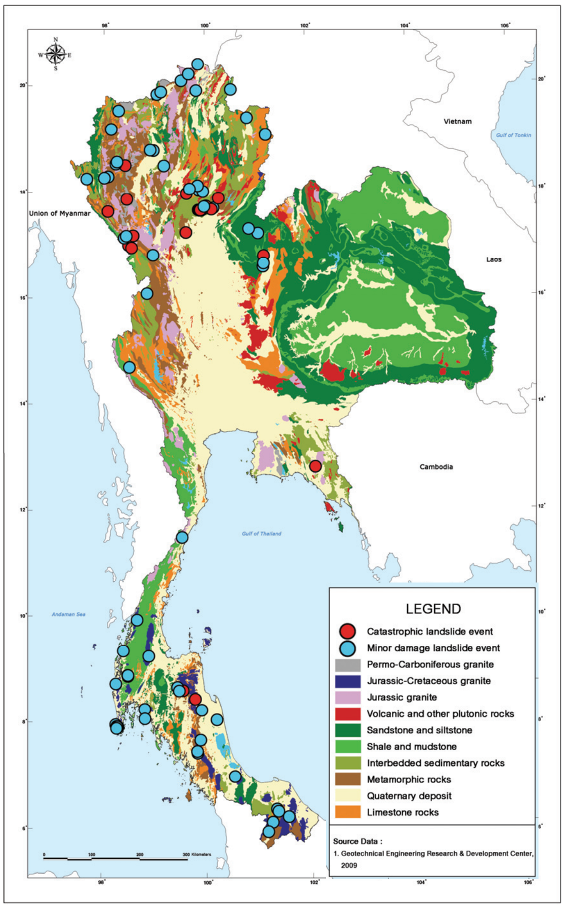

Figure 2: Landslide events in Thailand from 1970-2006 (GERD, 2006).

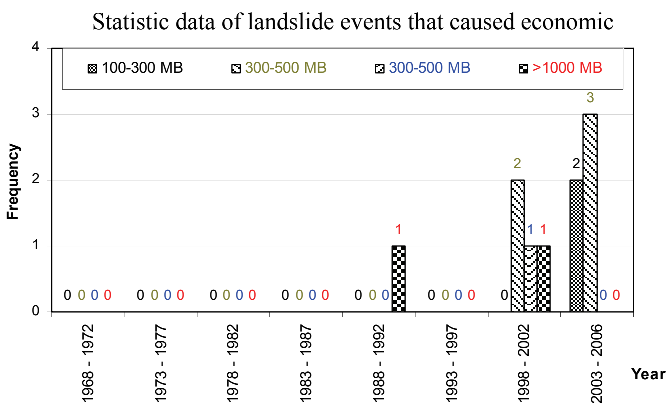

Figure 3: Direct damage cost of greater than 100 million baht from landslide events in Thailand (Soralump, 2007).

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) was modified in this paper to be more accurate for sedimentary rock group result in 10 rock groups (Fig 4.) 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 interbeded or intercalated (7.17%) Group 8: Metamorphic rock has area of 6.3% Group 9: Quantanary sediment has area of 32.89% Group 10: Carbonate rock mainly limestone has area of 7.13%.

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. Mairaing 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 on this theory.

2. The infiltration model of unsteady state 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.

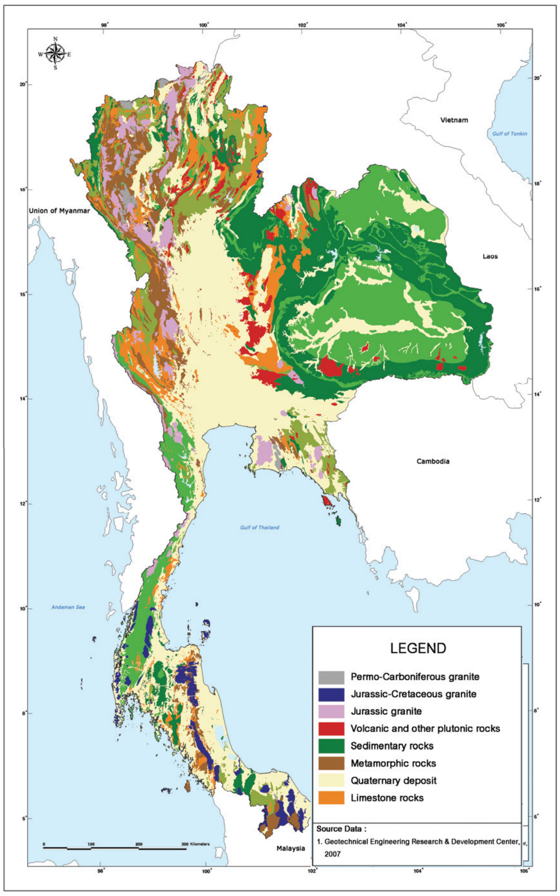

Figure 4: Rock groups related to landslide potential in Thailand.

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.

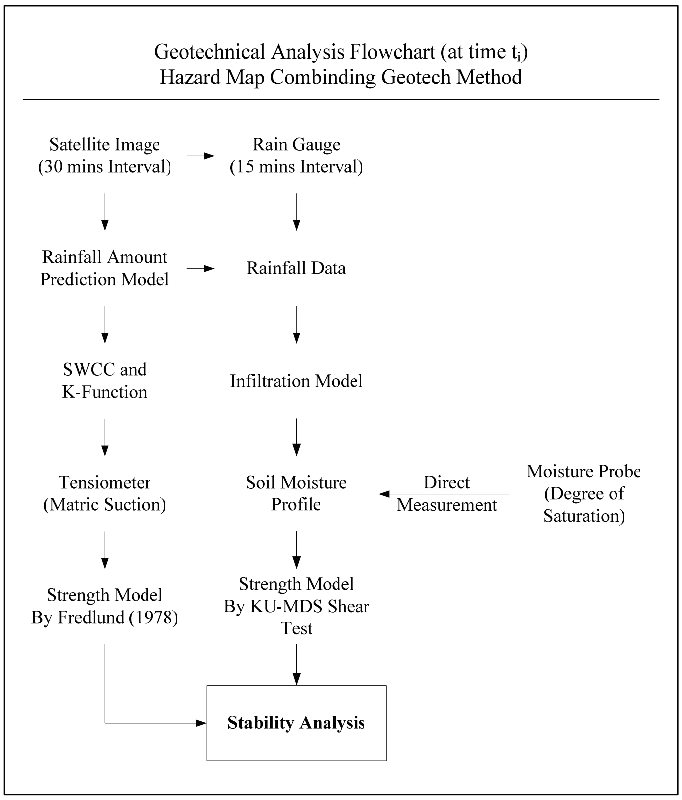

Figure 5: Geotechnical analysis flowchart for supporting the landslide real time warning system.

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 Thowiwat (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 Thowiwat, 2009). Figure 8 shows the example of strength reduction characteristic of 8 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.

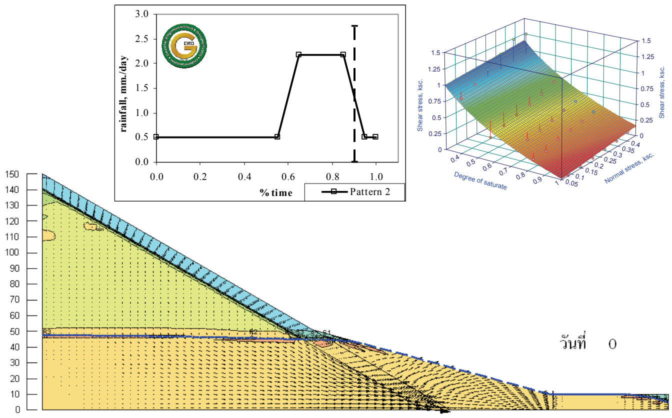

Figure 6: The modeling of rainfall triggered slope failure (Kunsuwan, 2005).

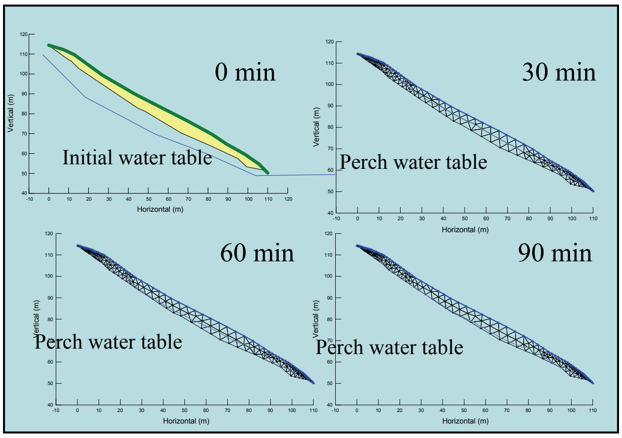

Figure 7: Infiltration model of actual landslide in Ra Island.

This amount of water is called the Critical Moisture Content (CMC). In order to use this calculated value for landslide warning, CMC 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) at any considering time period (API_t) which calculated from rainfall records. The CMC will then be called the critical Antecedent Precipitation Index (API_{cr}). Fig 9 shows the calculated critical API values for Thailand (DWR, 2008 and Thowiwat 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 cove various uncertainties. Proper uncertainty analysis using Monte Carlo simulation or FORM is under the research of the author.

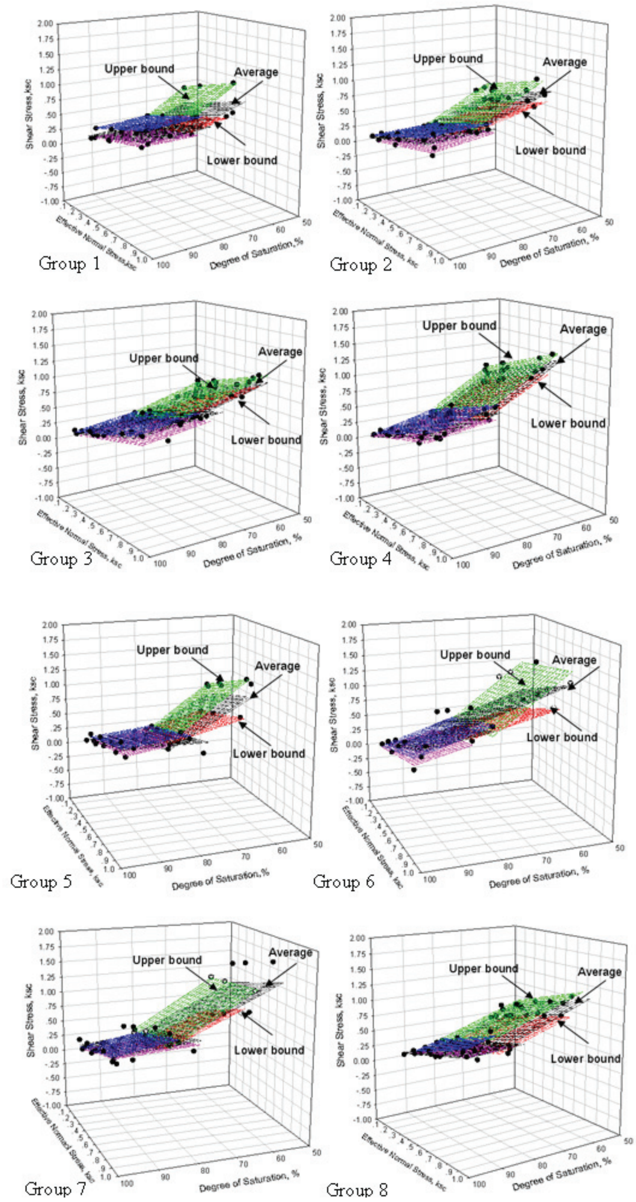

Figure 8: Strength reduction characteristic from increasing of soil moisture content (Thowiwat and Soralump, 2010).

Figure 10 shows the application of the concept described above but done in area with map scale of 1:4,000. The work has been done for Patong Municipality by Asian Disaster Preparedness Center with the corporation with GERD and Department of Mineral Resources (DMR). It has been proved that with this map scale (1:4,000), it is excellence to apply this approach since the detail investigation for engineering soil properties could possibly been done and the scale of topographic map is suitable for stability analysis.

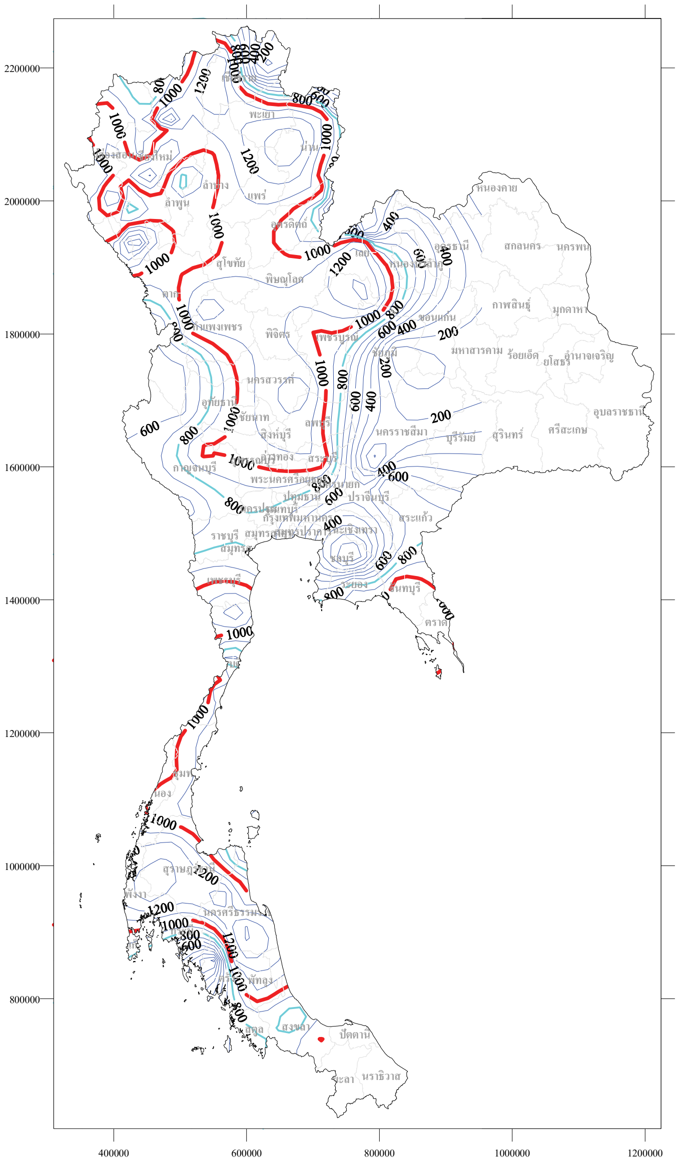

Figure 9: Critical API contour (DWR, 2008, Thowiwat and Soralump, 2009).

The real time monitoring of landslide (and at the same time verification of the critical API value) can be done by using the concept proposed by Okada et al. (1992) as shown in Figure 11. The daily rainfall or shorter period is plotted with the API value which calculated based on the previous amount of rainfall precipitation, soil water holding capacity, evaporation etc. Note that this API value is the present API value at the time of consideration. The critical API value is shown as a red criterion line (Figure 12). If the curve went beyond this line, the landslide is likely to be occurred.

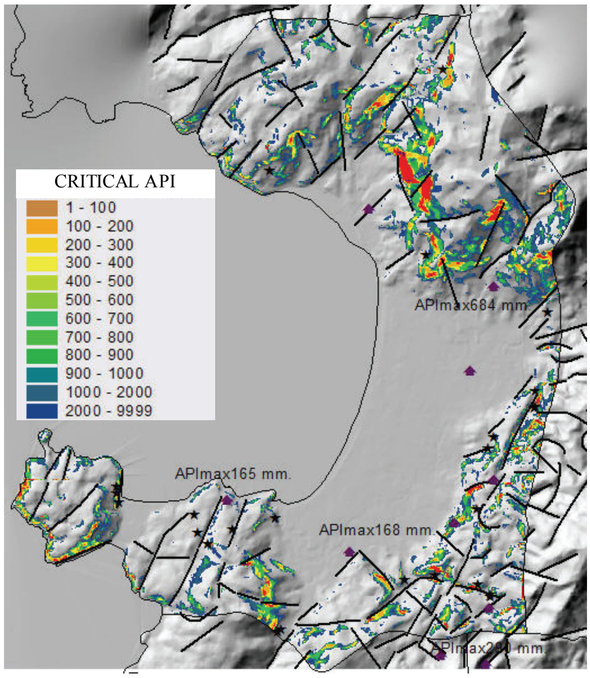

Figure 10: Critical API contour in Patong city, Phuket (ADPC, GERD and DMR, 2008, Soralump, 2009).

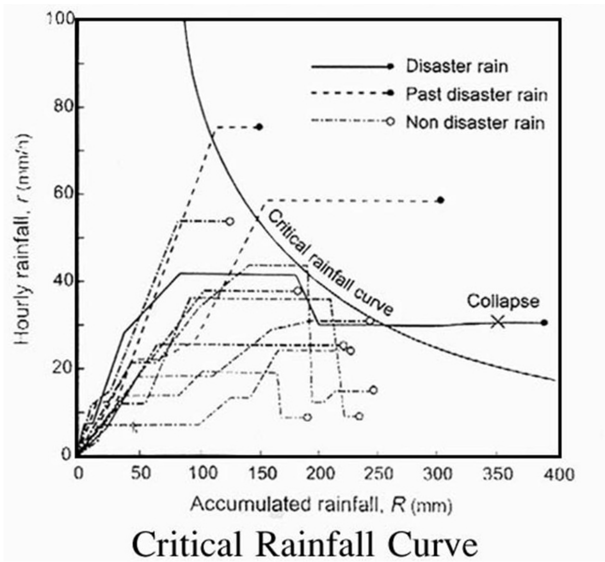

Figure 11: Critical rainfall Curve (Okada et al.,1992).

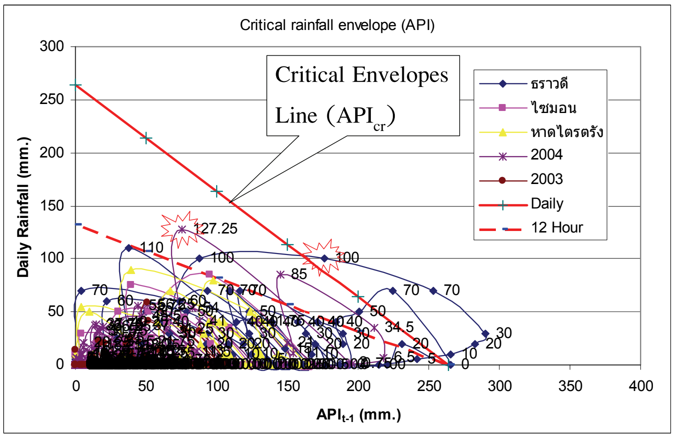

Figure 12: Verification of critical API value.

3 CONCLUSIONS

The near real time landslide warning required extensive type of data such as the Geotechnical properties of residual soil, geologic conditions and the rainfall data. Critical moisture content (CMC) is used for rainfall-triggered landslide warning by comparing with the antecedent rainfall data calculated by API_t. The verification of this approach at Patong shows the satisfy result.

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