Landslide Risk Management of Patong City, Phuket, Thailand

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ABSTRACT: The development of Patong city, Thailand is occasionally caused the serious man-made disaster such as flooding and landslide. Geotechnical approach was introduced for producing landslide susceptibility map and landslide risk map. The new landslide causative factor was introduced which are the man made factors such as the affected area by road cutting, the area of prohibition by law and others. Critical API value, which is based on rainfall recorded data, was calculated and the appropriate warning method was adapted for local community based on their current communication scheme. The project is perhaps the first landslide risk mitigation project in Thailand.

Keywords: Landslide, Landslide Susceptibility Map, Landslide Risk Map, Landslide Management, Antecedent Precipitation Index

1 INTRODUCTON

Landslide is one of the natural hazards that affected Thailand. The direct economic lost due to landslide is calculated to be equal to 100 million Baht per year and the return period of large area landslide is once in every 3-5 years (Soralump 2010).

Patong beach, located in Phuket province, is one of the famous tourist destinations in Thailand. This beautiful beach is surrounded by the crescent moon shape mountain range. Since the city is expanding, the use of steep slope area on the mountain is unavoidable. This causes the disturbance to the environment which later on causing the landslide. Asian Disaster Preparedness Center (ADPC) together with The Norwegian Geotechnical Institute (NGI) had the responsibility for execution of Regional Capacity Enhancement for Landslide Impact Mitigation pro-gram (RECLAIM) which the funding was provided by the Royal Norwegian Embassy in Bangkok. Department of Mineral Resources (DMR) and Geotechnical Engineering Research and Development center (GERD), Kasetsart University were asked by ADPC to take responsibility for the implementation the project in which they decided to demonstrate the landslide mitigation in Patong city, Phuget province.

2 STUDY AREA

Patong Municipality is approximately 16 square kilometers in area and located on the west coast of Phuket Island. Population mostly consists of tourists and local Muslim communities. However, after the tsunami event in 2004 the development tends to move higher on the mountain. Improper change of the slope geometry and the land cover are the main causes of the landslide in the area (Figure 1) (Pungsuwan 2006).

Table 1 shows some landslide event records gathered by Patong municipality, it shows that most of the landslide has triggered by excessive rainfall.

Fig. 1 Na Nai roadside landslide on October 25, 2007

Table 1. Landslide records gathered by Patong Municipality.

No.	date	location	Triggering factors
1	October 19, 2001	Various places	Heavy rainfall
2	October 21, 2003	50th anniversary Rd.	Cut slope and heavy rainfall
3	October 14, 2004	Na Nai village	Blockage of drainage and heavy rainfall
4	October 14, 2004	Kalim village	Inappropriate drainage and heavy rainfall
5	October 25, 2006	Na Nai Rd.	Cut slope non protection and heavy rainfall
6	July 15, 2007	50th anniversary Rd.	Construction failure
7	September 5, 2008	50th anniversary Rd.	Drainage
8	September 19, 2009	Kathu-Patong Rd.	Heavy rainfall

3 GEOLOGICAL CHARACTERISTICS

Geological characteristics of Patong include formation of granite in Cretaceous period and modern beach sediments in Quaternary period. Granite rock is found to be in moderately to highly weathered condition with various sets of joint and fracture. Left lateral strike-slip fault has found mostly with their strike lies between north-east to south-west direction. Department of mineral resources has interpreted the satellite image for the geologic structures of Patong as shown in Figure 2 (Department of Mineral Resources 2006).

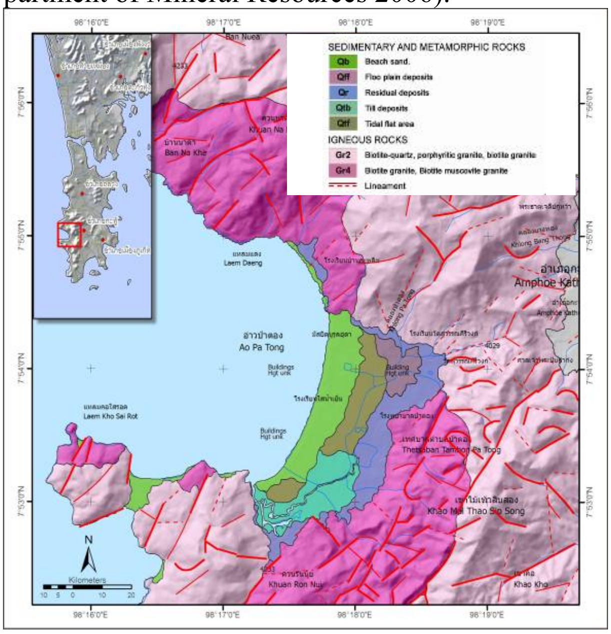


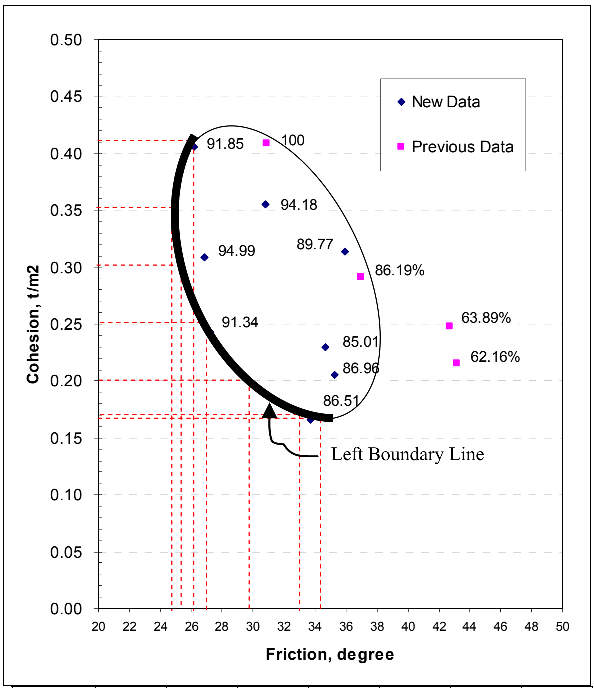
Fig. 2 Geological characteristics, Patong (Department of Mineral Resources 2006).

4 SLOPE STABILITY ANALYSIS

The strength characteristics of residual soil from 12 locations in the study area were used for the stability analysis. The strength parameters of residual soil were obtained by performing the Multi-Stage Direct Shear Test together with the data gathering from the previous studies (Soralump et al. 2007). The drained direct shear tests were done to the soaked (almost saturated) samples. During such test, in order to ensure the drained behavior, the pressure sensor which capable of measuring both positive and negative pore pressure was embedded in the top cap to monitor the change in pore water-air pressure. It was found that the excess pore pressure only exist shortly during consolidation stage, however there was no evidence of positive pore pressure in the shearing stage. This can be concluded that the soil samples were sheared under fully drained condition. The strength parameter values (c’,ϕ’) shown that the cohesion value has tendency of increasing when the degree of saturation is getting higher (Fig.3).

Slope stability analyses were done using KUslope computer program developed by GERD (Isaroranit 2001). The geometry of the mountain slope was studied in order to select the appropriate cross section for the analysis.

The analyses were done by modeling various slope angles from 14 to 40 degrees for both natural (one bench) and cut slope. Since the strength parameters vary through the degree of saturation (Figure 3) and also there are some variation of values among them, therefore the slope analysis were done by using various pairs of strength parameters (c’,ϕ’) along the left boundary line as shown in Figure 3. In order to select a pair that gives the correlation of the lowest calculated FS for various slope angles. The results are concluded in Fig 4 which shows the correlation as such using the selected strength parameters. The results also show that the factor of safety values of the cut slope is generally lower than the natural slope, which is expected to be. Furthermore, it was found that the natural slope angle that the slope cutting might trigger the landslide is found to be 17.1 degree in which corresponding to FS equal to 1.3. This slope angle is generally gentle than the current regulation which prohibits the slope modification that of greater than 19.3 degree (35%). Therefore, it is advised that any construction cutting (1H:2V) done to the natural slope with 17.1 degree angle or more, the proper slope analysis and the counter measures need to be considered in Patong



Cohesion	0.168	0.170	0.200	0.250	0.300	0.350	0.410
Degree	34.5	33.0	29.6	27.0	25.2	24.8	26.1

Fig. 3 Boundary of strength parameters used for the analyses

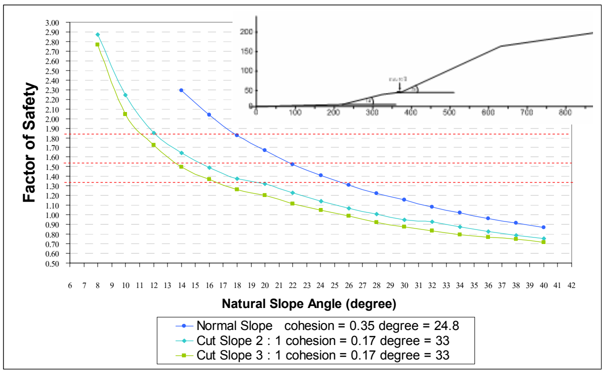


Fig. 4 Factor of safety-slope relationship of cut and natural slope.

5 LANDSLIDE SUSCEPTIBILITY MAP

The landslide susceptibility area in Patong was analyzed using weighting factor method. 8 major factors listed below were considered in the analysis including the safety factor calculated from geotechnical method explained in the previous section.

1. Soil slope stability
2. Rock slope stability
3. Lineament zone
4. Rock type (Later neglected)
5. Distance from road
6. Elevation
7. Land use and land cover
8. Surface drainage zone

The factor related to the rock slope stability which are the rock fractures and slope face orientation were neglected since the detail analysis found that there is less likely that the rock slope instability will be occurred. Furthermore, since there is only one rock type in Patong, the factor of rock type was also neglected. Therefore, the numerical rating for landslide potential is then used 6 related factors. The area of 5x5 square meters grid cells have been employed for the analysis by GIS program. The weight-rating value of each factor was determined in each square grid cell of each derivative map. Table 2 shows the weighting value of each factor, calculating from the weighted matrix based on expert assessments. Finally the scores of weight-rating in each 5x5 square meters grid cell were obtained from the summation of weight-rating values of each derivative map. The levels of score were classified to obtain the landslide susceptibility level of each grid and finally obtain the susceptibility map.

Table 2. Weights and rating values used for the analyses.

Parameter	Weight Value	Rating Value	
	Parameter	Description	Rating (1-5)
1. Factor safety and slope angle relationship	1.875	A. F.S.≤ 1.3 (≥26 degree)	5
		B. 1.3 < F.S. ≤ 1.5 (22≤ slope< 26 degree)	3.66
		C. 1.5 < F.S. ≤ 1.8 (18≤ slope< 22 degree)	2.33
		D. F.S. >1.8 (< 18 degree)	1
2. Lineament zone	1.625	A. Area inside ineament zone	5
		B. Area outside lineament zone	1
3. Distance from road	1	A. Area inside road zone	5
		B. Area outside road zone	1
4. Elevation	1	A. >80 m	1
		B. 40-80 m	3
		C. 0-40 m (Not include slope <10 Degree)	5
5. Surface drainage	1	A. Area inside surface drainage zone	5
		B. Area outside surface drainage zone	1
6. Land use and land cover	1	A. Agriculture area	5
		B. Urban and built-up area	3.66
		C. Other deforestation	2.33
		D. Forest area	1

The results of the analysis are shown in Fig 5. It clearly shows that the actual event locations are mostly located within the moderate to high landslide susceptibility area obtained from the analysis. Considering this, the percentage of map accuracy is determined to be 78.2 percent. Furthermore, Table 3 shows the suggestion for land development act, proposed to Patong Municipal which will be used as a guideline for the future enforcement. This is rather important since most of the landslide in Patong occurred because of the improper practice in design and construction in the slope area.

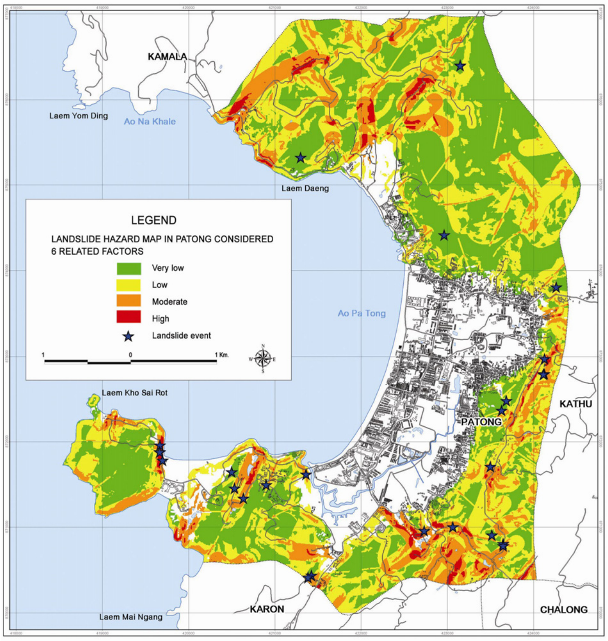


Fig. 5 Landslide susceptibility map (ADPC, GERD and DMR, 2008, Soralump, 2010).

Table 3. Recommendations for slope treatment in various zones of landslide susceptibilities.

Action	Landslide susceptibility Levels			
	High	Medium	Low	Very Low
Geotechnical engineer required	√	√		
Geologist required	√			
Land cover control	√	√		
Drainage management	√	√		
Control of the slope angle for cut slope	√	√	√	√

6 LANDSLIDE RISK MAP

Since risk is a function of hazard and consequence. Therefore, in order to develop risk mapping, the consequence area from landslide need to be estimated. Building locations and their pertinent data were obtained from taxation map provided by Pathong City. The hazard levels were classified based on landslide susceptibility map produced as discussed earlier. The affected area at the toe slope area was estimated to be equal to the height of the slope above the toe based on Finlay et al. (1999). Fig. 6 shows the boundary of affected area at the toe of the slope. The buildings were classified into levels based on their vulnerability from landslide. The number of population at risk (PAR) is estimated from the census data in the taxation map.

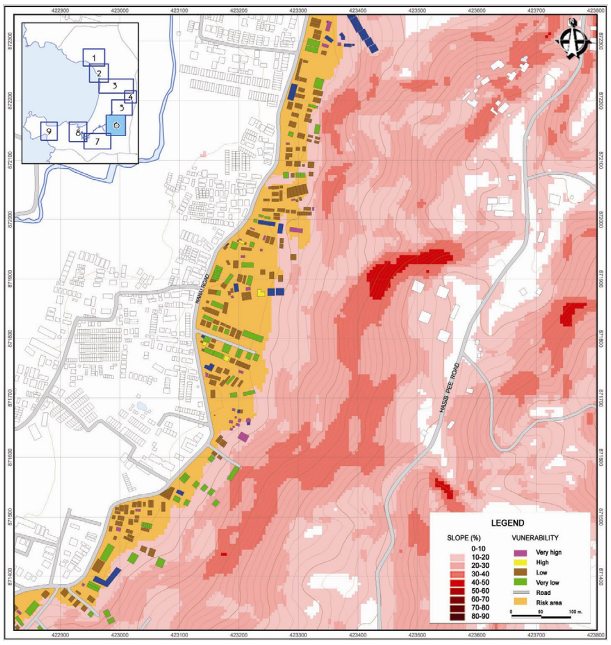


Fig. 6 Landslide risk map in Patong (part).

7 API MAP

Landslide disaster management will be incomplete if lack of the warning system. The past studies found that the accumulated rainfall (or short period rainfall history) and current precipitation has great influence in rainfall-triggered landslide (Soralump 2010). This is consistent with the use of the API concept (Antecedent Precipitation Index). The API represents, presumably, the moisture of the soil at any time using the values measured by rain gauge. The critical API is determined by calculating the critical moisture content in the soil layer that will trigger the failure of soil layer. Factor of safety was analyzed by infinite slope stability method with the soil strength parameters of c' = 0.35 ksc., ϕ' = 24.8o (Figure 5), the unit weight of soil (γ_d) = 1.41 t/m3 , Gs = 2.65, void ratio (e) = 0.89, degree of saturation (Sr) = 93% and the porosity of the soil (n) = 0.471. These soil properties were obtained from the site investigation stage explained earlier. The calculation was done according to equation 1 and the critical thickness is determined from Equation 2. The result of critical thickness based on slope angle are shown in Figure 7. The critical API map is then produced as shown in Figure 8.

$$F.S. = [1 - r_u(1+\tan^2\beta)]\frac{\tan\phi'}{\tan\beta} - \frac{1}{\sin\beta\cos\beta}\frac{c'}{\gamma H_{cri}} \quad (1)$$

When F.S. = factor of safety for infinite slope; r_u = pore pressure ratio $u/\gamma H$; β = Slope angle; γ = unit weight of sliding mass; H_{cri} = critical depth (m.)

$$API_{cr} = n \cdot S_{r,cr} \cdot T_{cr} \quad (2)$$

when API_{cr} = critical API (mm.); n = porosity; $S_{r,cr}$ = percent critical of saturation; T_{cr} = critical depth (m.)

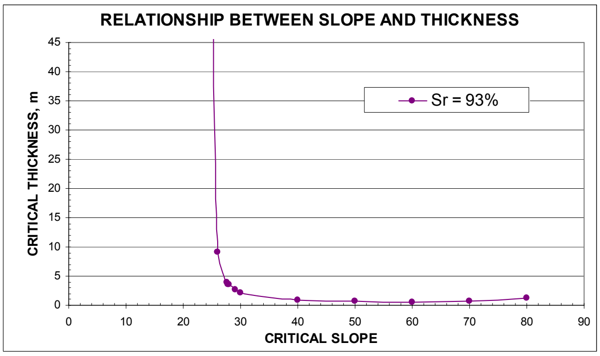


Fig. 7 Relationship between the critical thickness and slope angle.

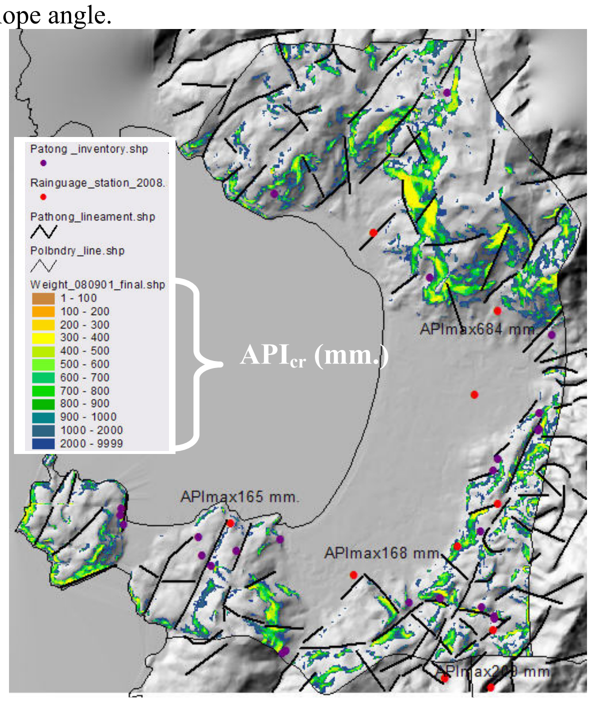


Fig. 8 Critical API map of Patong (ADPC, GERD and DMR 2008, Soralump 2010).

8 WARNING SYSTEM USING RAINFALL DATA

In order to apply the critical API method for landslide warning, it is required to install automatic rain gauge to measure the precipitation in the study area. The rainfall data is used for calculating the API value at time t (API_t) (Equation 3) (Soralump and Thowiwat 2010). Fig.9 to 11 shows the comparison of using the 3 days accumulated rainfall data and the API value for crating the critical envelop. It can be seen that using 3 days accumulated rainfall does not give the pre-warning in some case. However, using API value seems to be more appropriate. However, as seen in Fig.11, it shows that a landslide event occurred before the calculated critical API envelop, this is because of the critical API value was calculated based on assumption of natural landslide. However, the failure is considered to be the man-made landslide. Furthermore, the Alert-Alarm-Action criteria were set as Shown in Figure 12 for practical purpose.

$$API_t = (K_t \times API_{t-1}) + P_t \quad (3)$$

when API_t = API at time 't' (mm.); API_{t-1} = API at time 't-1' (mm); P_t = Precipitation at time 't' (mm.); K = recession constant (K =< 1.0 and usually 0.85-0.98)

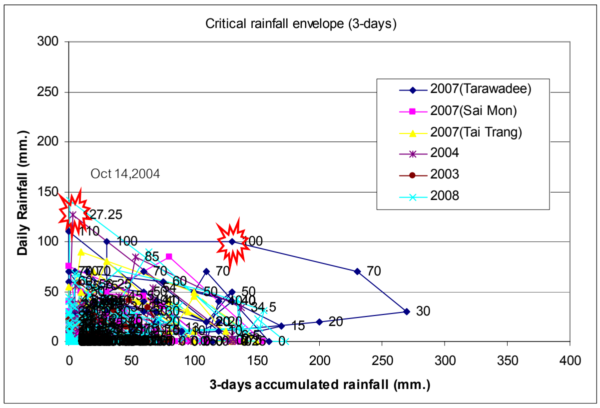


Fig. 9 3 days accumulated rainfall and daily rainfall relationship.

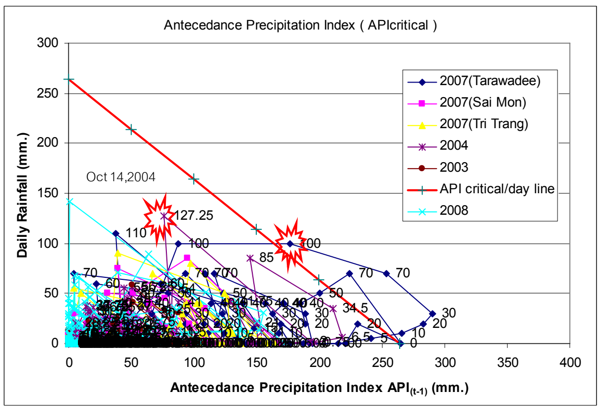


Fig. 10 API value and daily rainfall (Soralump, 2010).

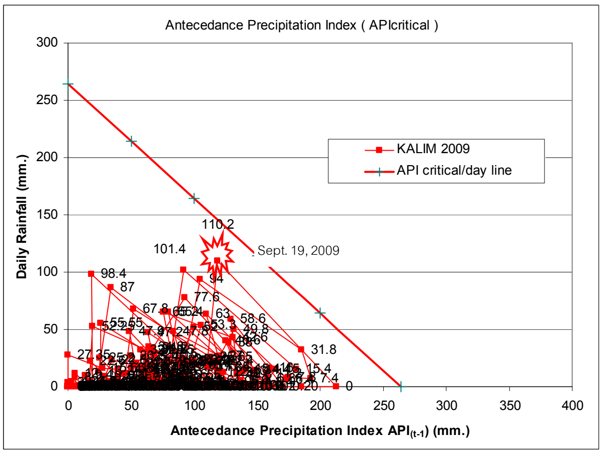


Fig. 11 API graph showing the landslide event in 2009.

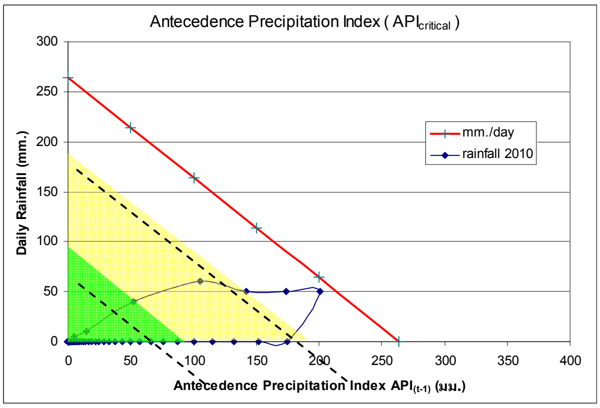


Fig. 12 Alert Alarm Action criteria.

9 CONCLUSIONS

1. Based on verified landslide susceptibility map, it was found that landslide mostly occurred in the lineaments zone.
2. Using API value rather than 3-day accumulated rainfall is much the warnings time.
3. The actual triggering API value seems to be less than the calculated critical API. This is because the geotechnical model used for calculating the critical API is not considered the man-made factors.

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