Landslide Hazard Mapping and Mitigation Measure in Pathong City

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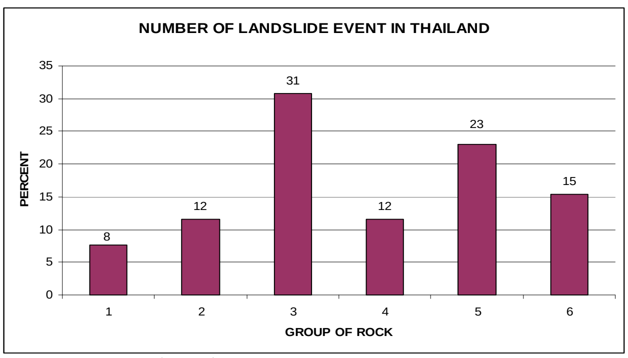
1. Introduction

Landslide is one of natural hazard that affected Thailand. The direct economic lost due to landslide is calculated to be equal to 60 million Baht per year and the return period of large area landslide is once in every 5 years (Soralump, 2006). Fig. 1 shows the geologic map of Thailand which group of rock related with the capability of producing landslide. From recorded data, Soralump (2006) found that Granitic rock in Jurassic era has highest rate of landslide (per unit area) (Fig. 2).

Phuget is one of the provinces that has high potential of affecting by the landslide, Pathong city in particular. Therefore, it is necessary to perform detail analyses in order to provide the suitable regulation and mitigation measures to reduce the risk from landslide. Fig. 3 shows the flow chart of this project.

Fig. 1 Geologic map of Thailand classified by level of landslide hazard (Soralump, 2006)



Group 1 Permo-Carb. granite
Group 2 Jurassic-Cretaceous granite
Group 3 Jurassic granite
Group 4 Volcanic and other plutonic rock
Group 5 Sandstone, shale, mudstone, conglomerate and chert
Group 6 Metamorphic rock

Fig 2 Number of landslide event per area of rock group in Thailand (Soralump, 2006)

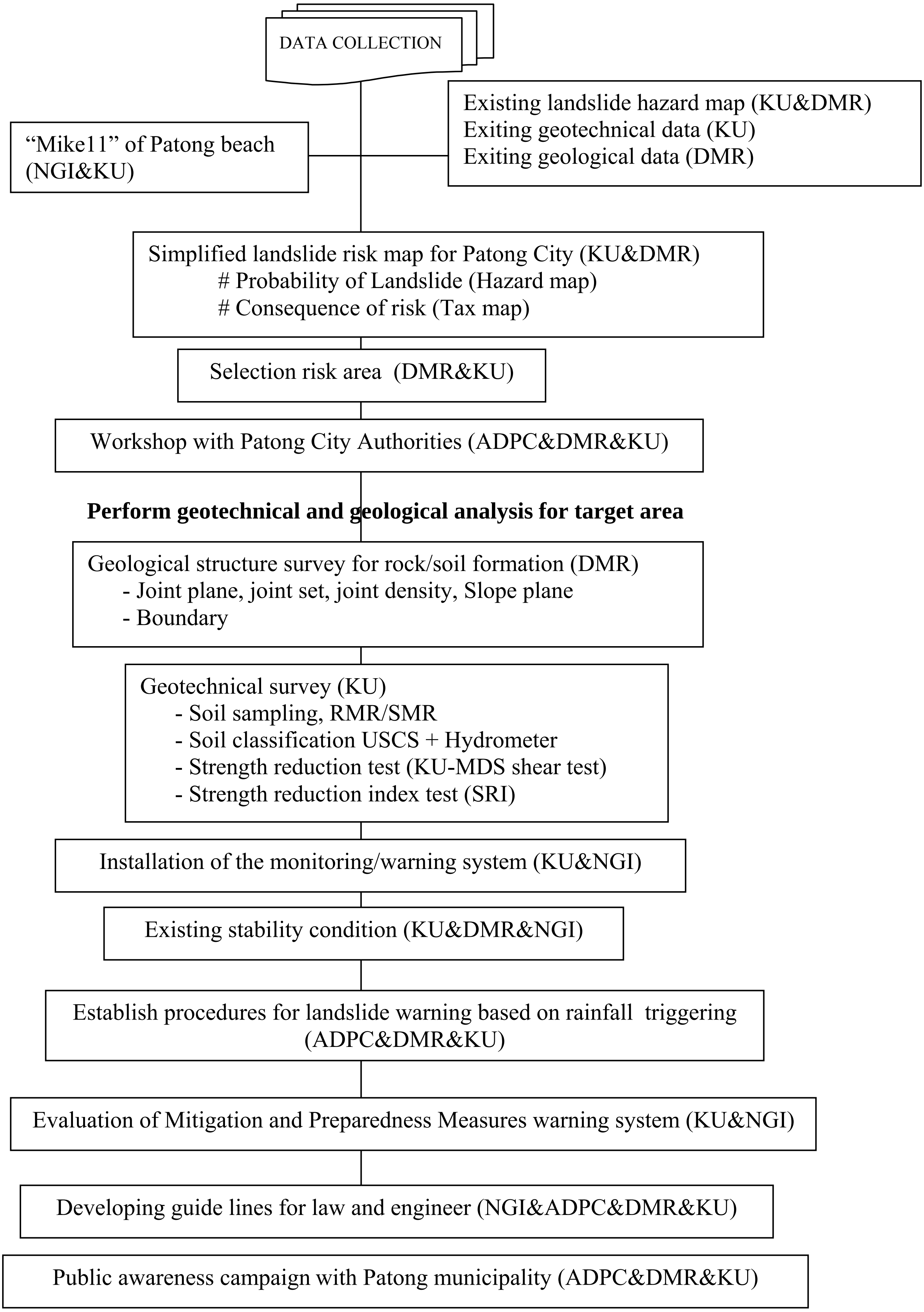


Fig 3 Flow chart of landslide mitigation project in Pathong City

2. Geotechnical Investigation and Analyses

Strength parameters data were acquired from previous research projects both from Geotechnical Engineering R&D Center (GERD), Kasetsart University and from Department of Mineral Resources (DMR). All undisturbed soil samples were collected using KU-Miniature sampler (Warakorn et al, 2004). Strength parameters were determined from direct shear test using both conventional direct shear testing method and KU-MDS shear testing method (Warakorn et al., 2004). However, the data from previous projects shows too much variation with some correlation between strength parameters and degree of saturation. Fig. 4 shows the variation of the data acquired from previous research projects. Therefore, additional soil sampling had to be done in order to reduce the variation of strength parameters. Finally, soil data from 29 locations were used for the analysis in this project as shown in Fig 5. The soil samples were tested by direct shear machine. The drained direct shear tests were done to the soaked (almost saturated) samples. Standard single-staged direct shear was done. In order to ensure the drained behavior, pressure sensor, capable of measuring both positive and negative pressure, was embedded in the top cap to monitor the change in pore pressure. Fig. 6 shows that excess pore pressure is only exist during consolidation stage but not the shearing stage. This can be concluded that the soil sample is sheared under fully drained condition. After carefully done the tests, the test result is satisfied. Fig. 7 shows that c,ϕ data are not vary as the previous and it clearly shows that cohesion will be increased and friction angle will be decreased when the degree of saturation is higher.

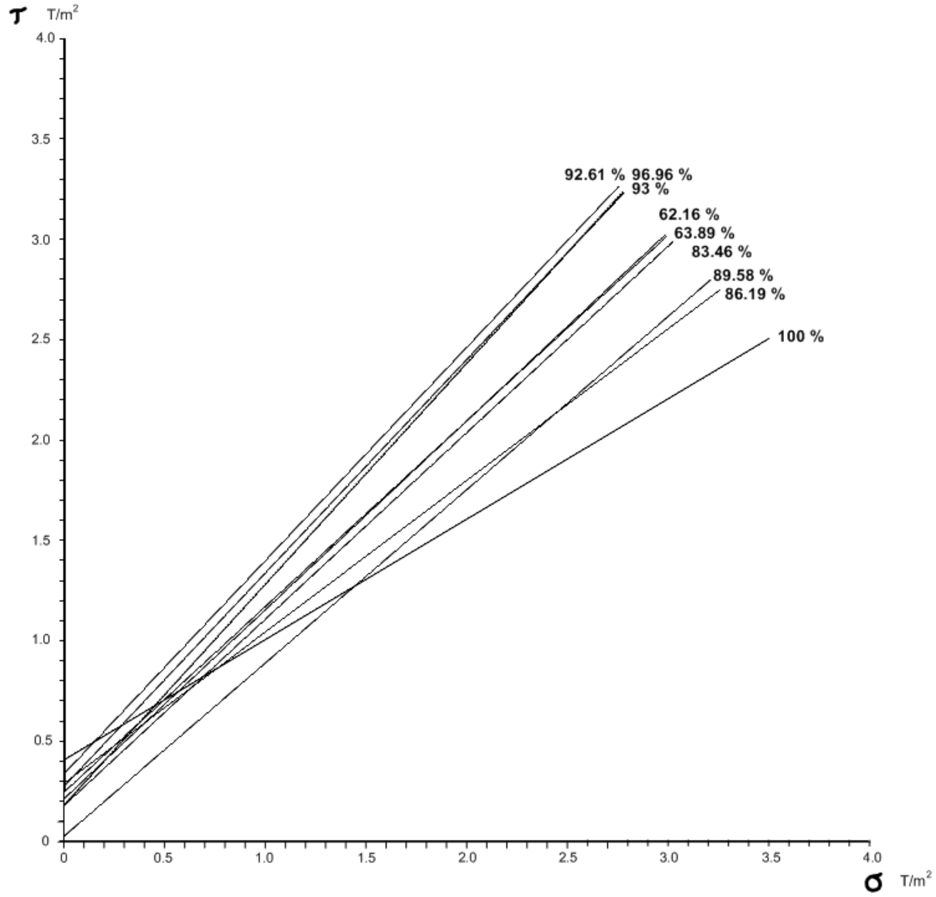
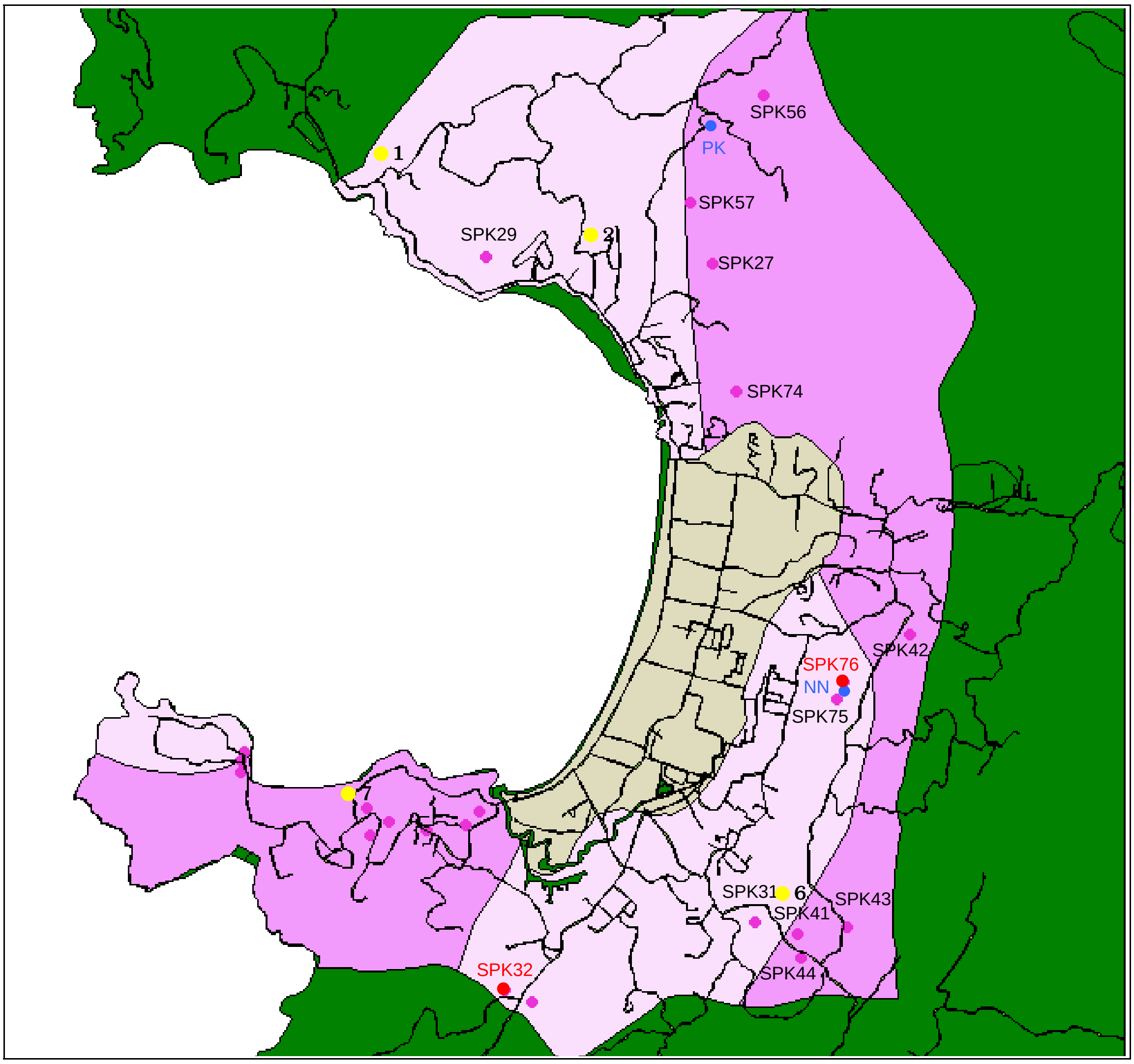


Fig. 4 Variation of strength parameters from previous projects



ADPC Previous project #1

Previous project #2 New location

Rock group G2 Rock group G4

Rock group Qb

Fig. 5 Location of soil samples from various projects

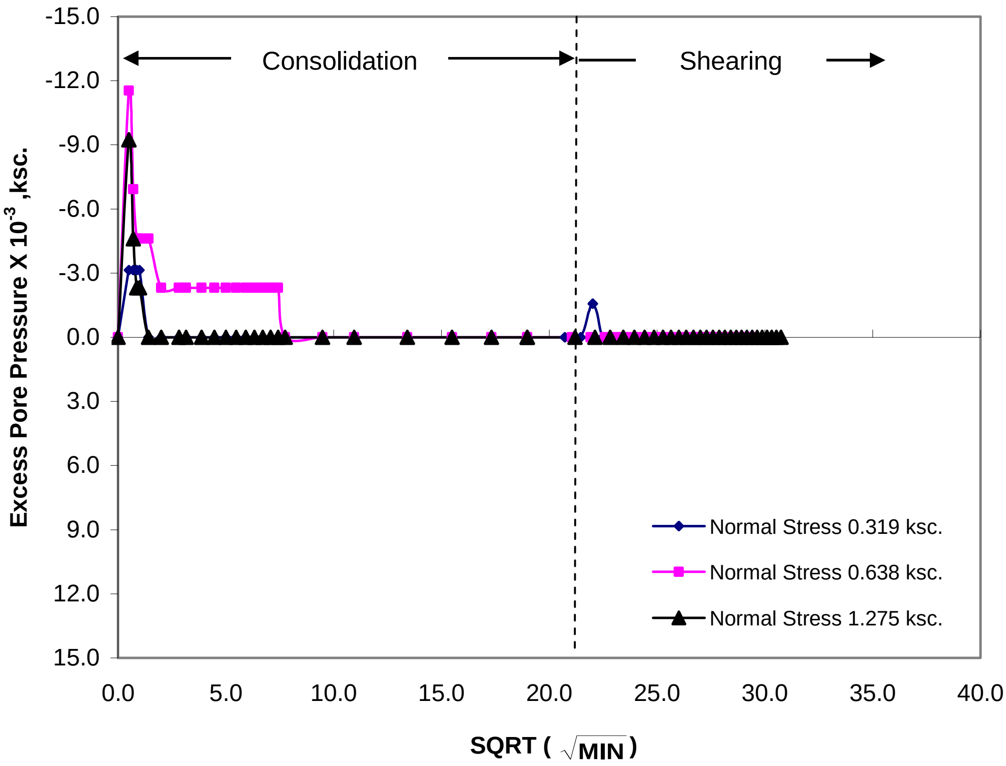


Fig. 6 Excess pore pressure measurement during the tests

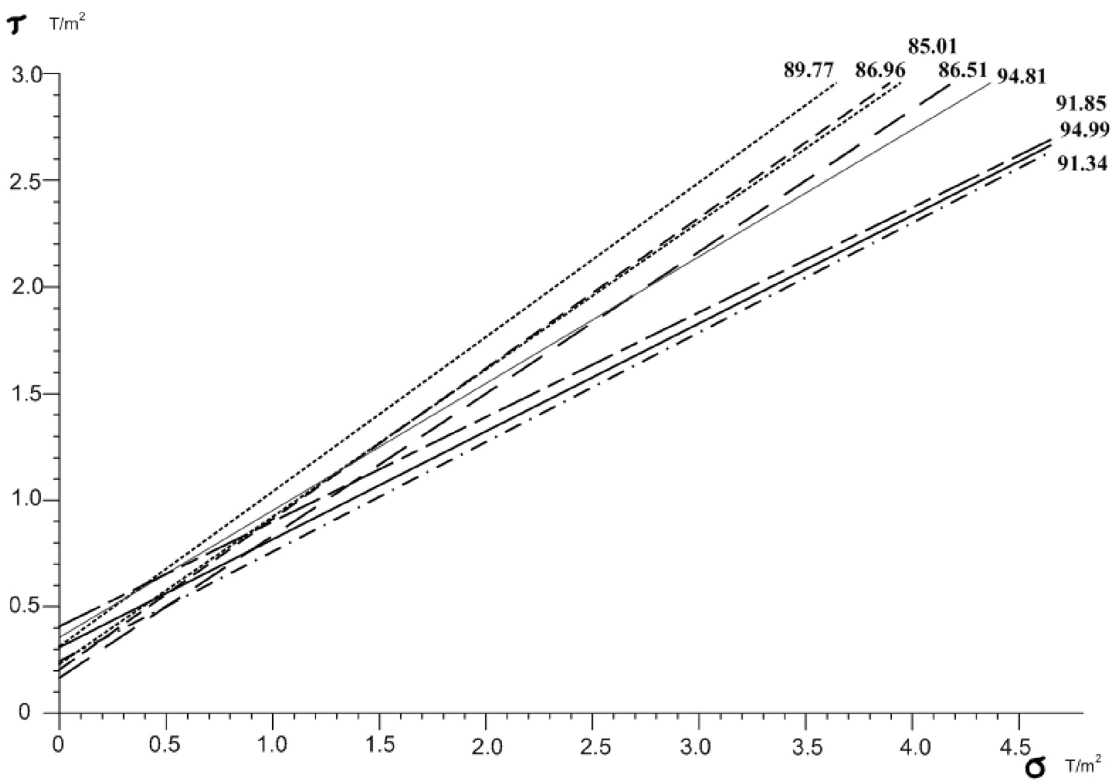


Fig. 7 Strength parameters from drained direct shear test

Slope stability analyses were done by KUslope computer program developed by Kasetsart University. The geometry of the mountain slope was studied to select the appropriate cross section for the analysis. Contour map of Patong city is used to select the cross section for the analyses as shown in Fig 8. The cross section of slope above Na Nai village is shown in Fig 9.

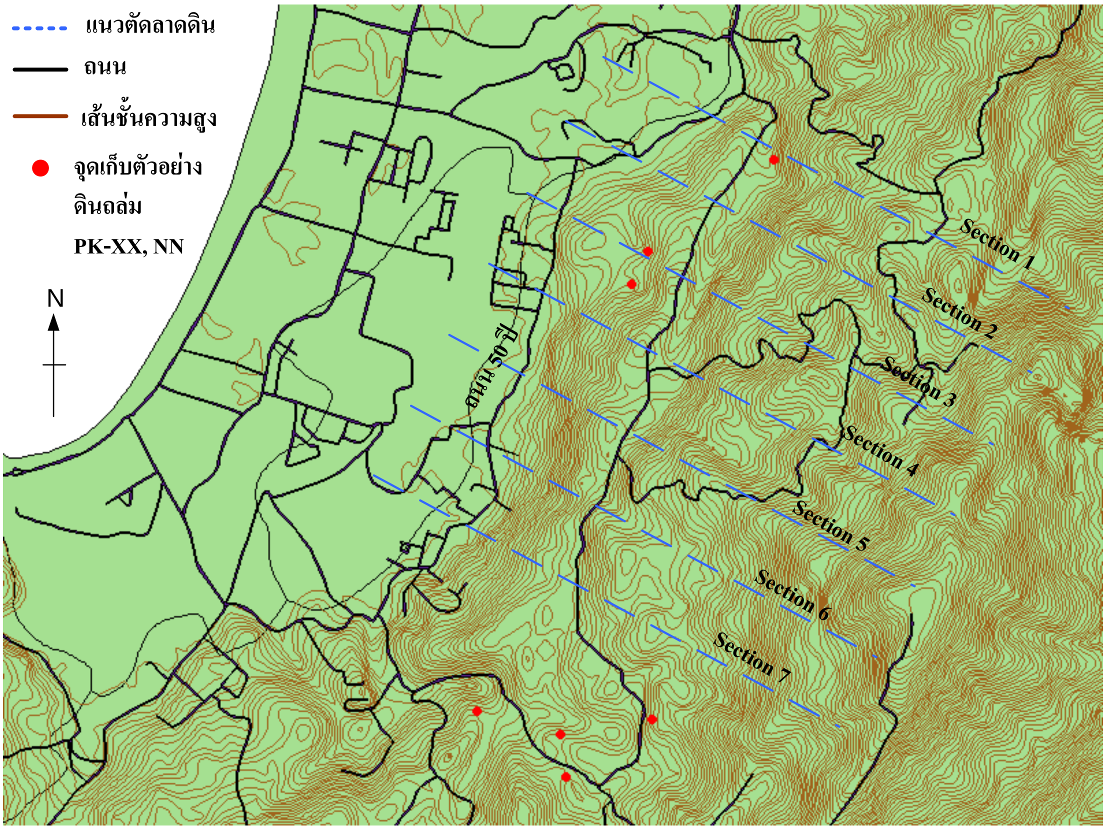


Fig. 8 Cross section for stability analysis, Na Nai and 50st anniversary road

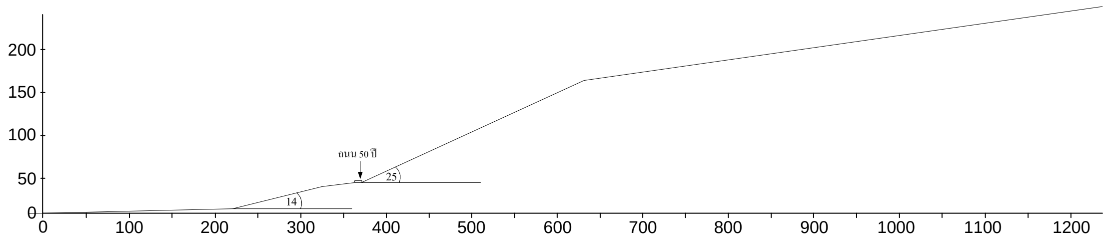
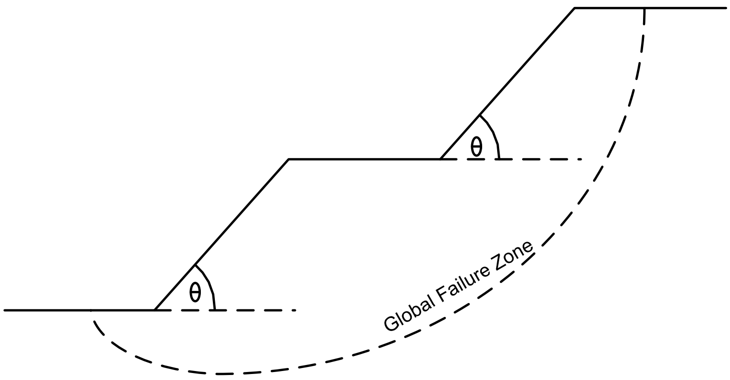
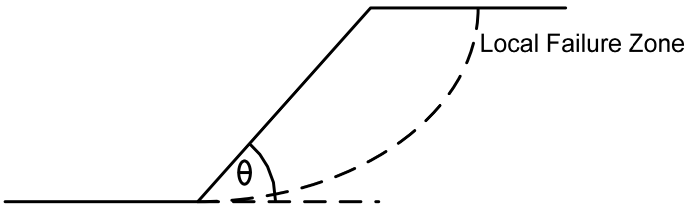


Fig. 9 One of the cross sections of slope over Na Nai community

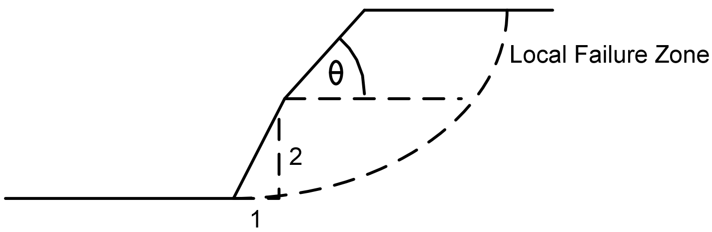
Three kinds of cross section were investigated as shown in Fig 10. They are two benching section, local slope in the upper or lower bench and cut slope from road or construction cutting (2H:1X). The preliminary results show that the failure surface doesn’t occur through two benching as an overall stability failure but it rather failed at the local slope either lower or upper one.



a) Two benching model



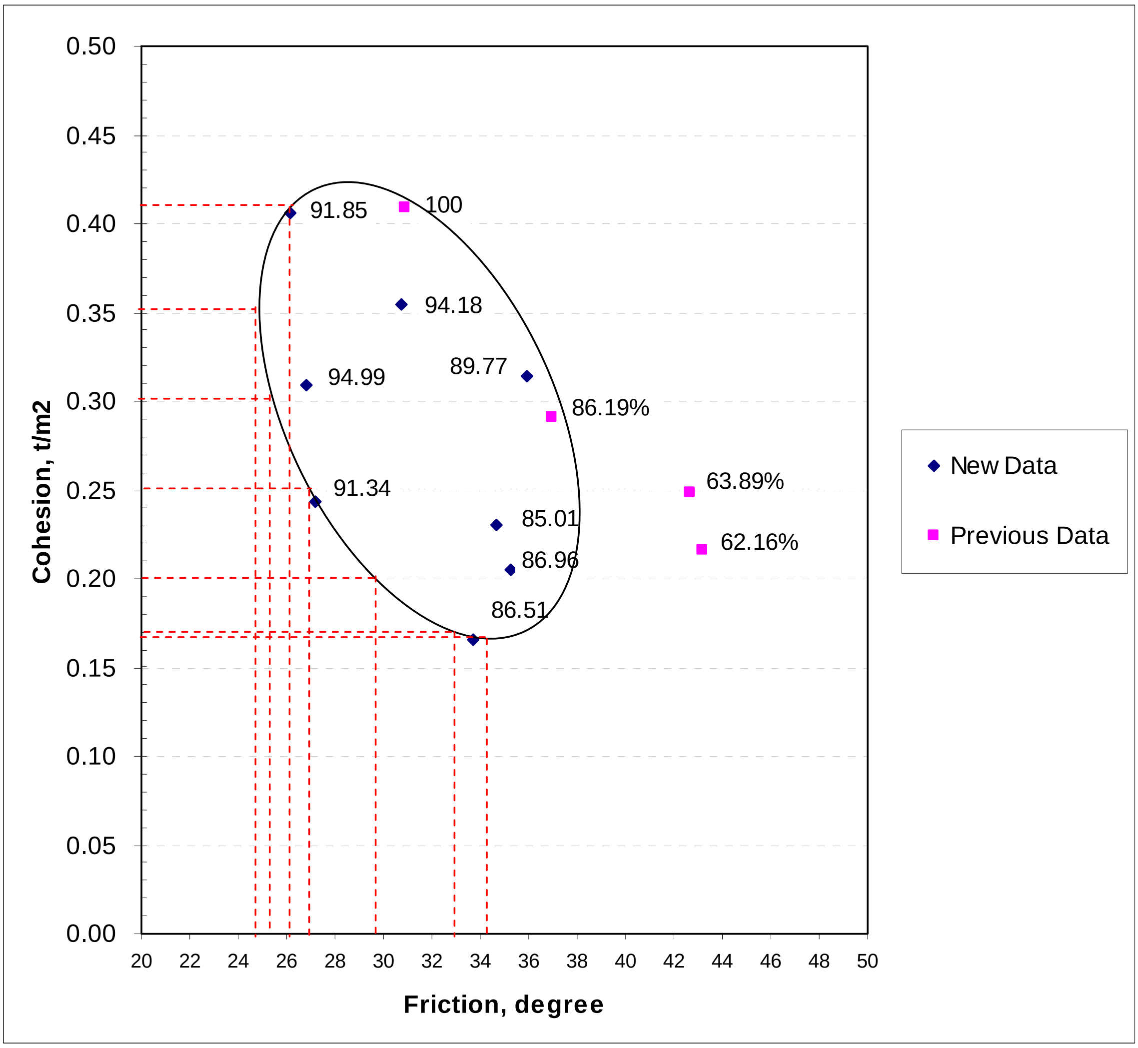
b) One benching model



c) Cut slope model

Fig. 10 Cross section models for stability analyses

The analyses were done with various degree of slope from 14 to 40 degrees of both natural (one bench) and cut slope as shown in Fig 23. Since the strength parameters are vary based on degree of saturation, therefore the slope analysis were done by trial strength parameters along the lower bound line to obtain the possible lowest F.S. (Fig. 11). The results are summarized in Fig 12-13. The results show that the cut slope has lower FS than natural slope as expected. The critical slope angle that cutting will be vulnerable for landslide is 17.1 degree corresponding to FS equal to 1.3. Therefore, any construction cutting in the natural slope with slope angle greater than 17.1 degree, the slope need to be analyzed and the counter measures need to be considered.



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 11 Boundary of strength parameters used for the analyses

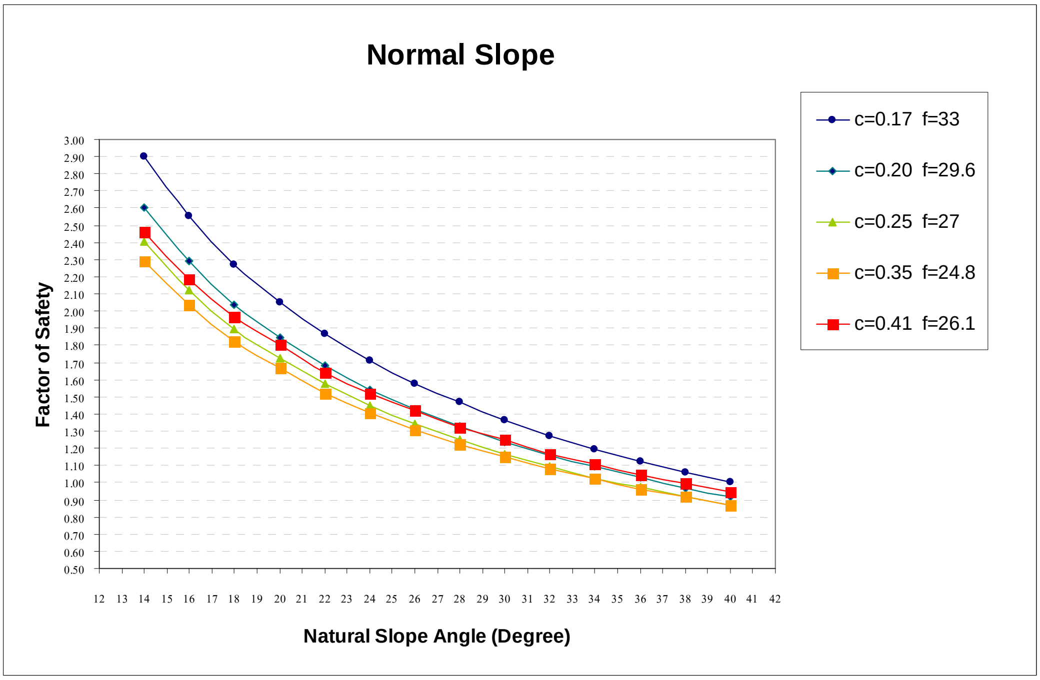


Fig. 12 Factor of safety with various slope angles

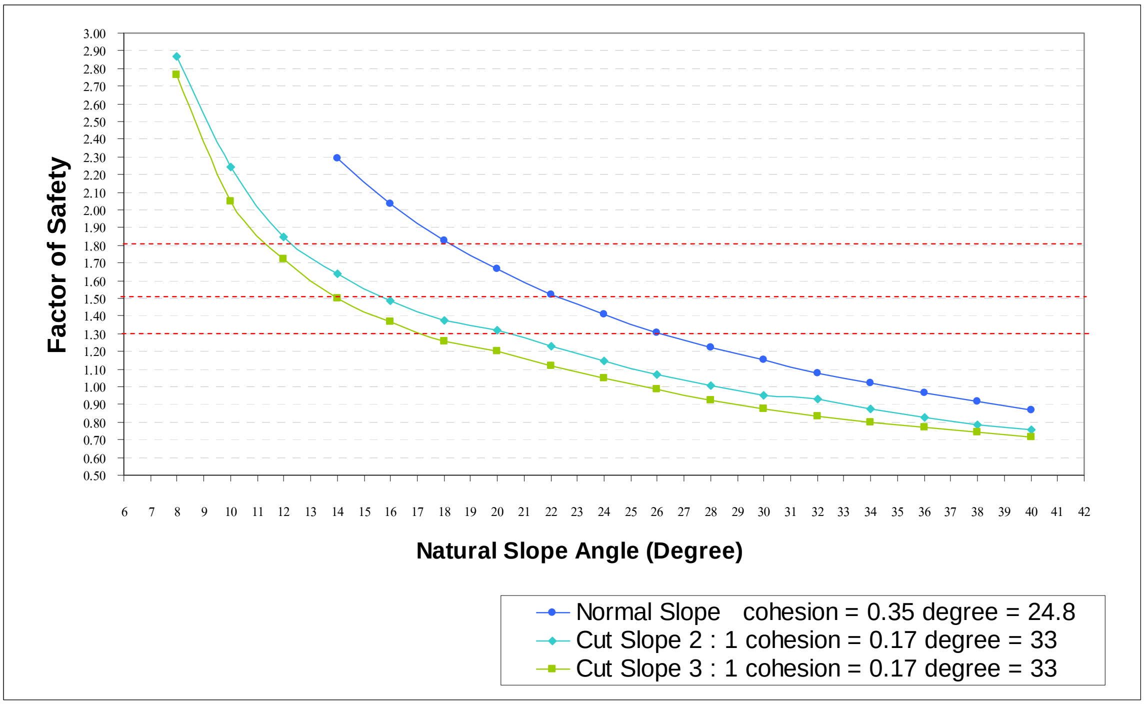


Fig. 13 Factor of safety with various slope angles and cut slope conditions

The slope angles for different limited FS are also show in the Table 1. These ranges of slope angle will be used for indicating landslide hazard area.

Table 1 Slope angle with limited F.S.

F.S.	Normal Slope	Cut Slope (V : H)	
		2:1	3:1
1.3	26.2	20.6	17.1
1.5	22.4	15.8	14.0
1.8	18.3	12.3	11.4

3. Landslide Hazard Analysis

The landslide hazard area is analyzed using weighting factor method. 8 major factors were considered in the analysis.

1. Factor safety and slope angle relationship

2. Bedding & slope angle relationship (Later neglected)

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 detailed descriptions of different rating values of each parameter as well as the weight value are summarized below.

3.1 Factor safety and slope angle relationship (Stability)

According to Geotechnical analysis, landslide hazard potential in Patong can be divided based on ranges of factor of safety which shown in slope angle ranges.

3.2 Bedding-slope relationship (Stability)

In order to consider the influence of geologic structure, the bedding-slope relationship is considered. However, after collecting the rock structure data which are strike and dip direction in various locations in Patong, it found that the rock fractures in Patong area are quite random as shown in Fig 14 and 15. Therefore, this factor is not used in the analysis.

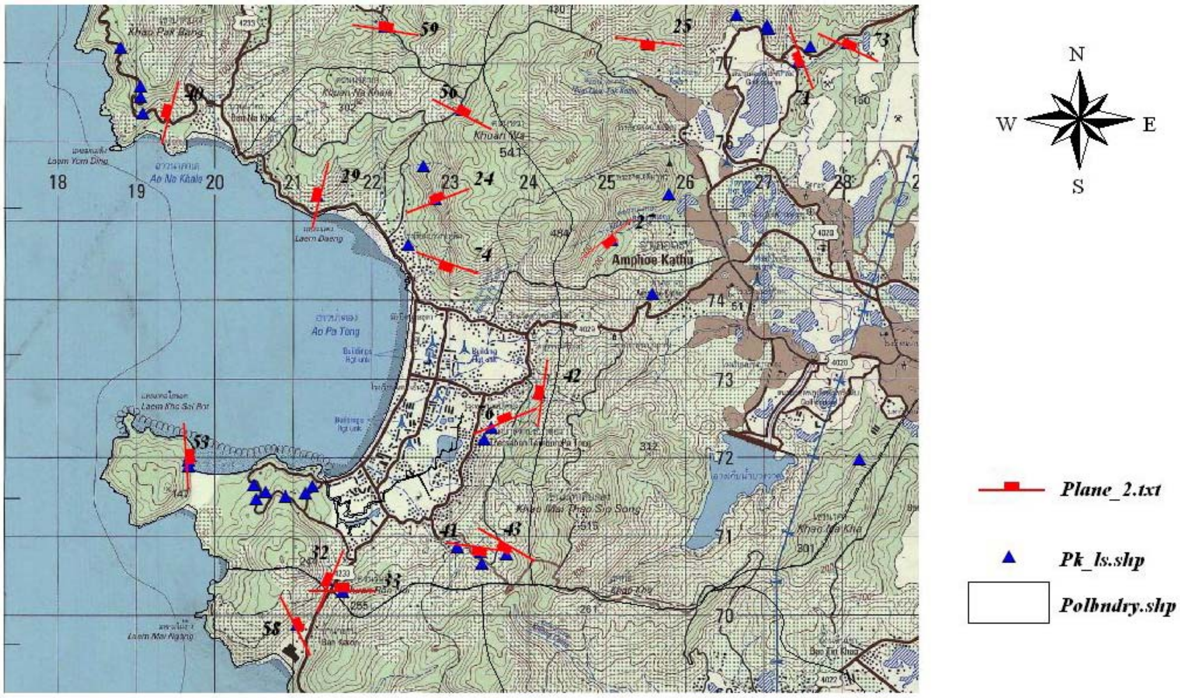


Fig. 14 Strike and dip directions of rock mass in Patong

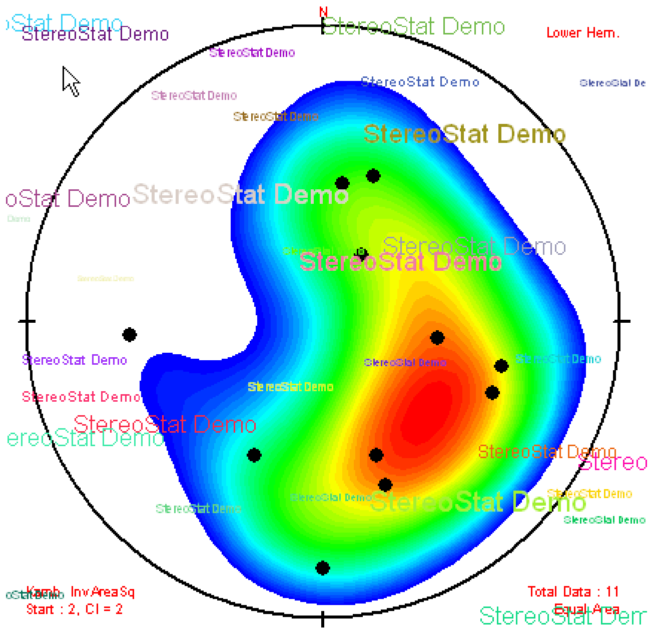


Fig. 15 Stereo net of rock fractures in Patong

3.3 Rock type (Geology)

Since rock group in Patong has only one type which is granite (Fig. 16), considering this factor in the hazard analysis will not make any different, therefore, it will not be considered in this analysis.

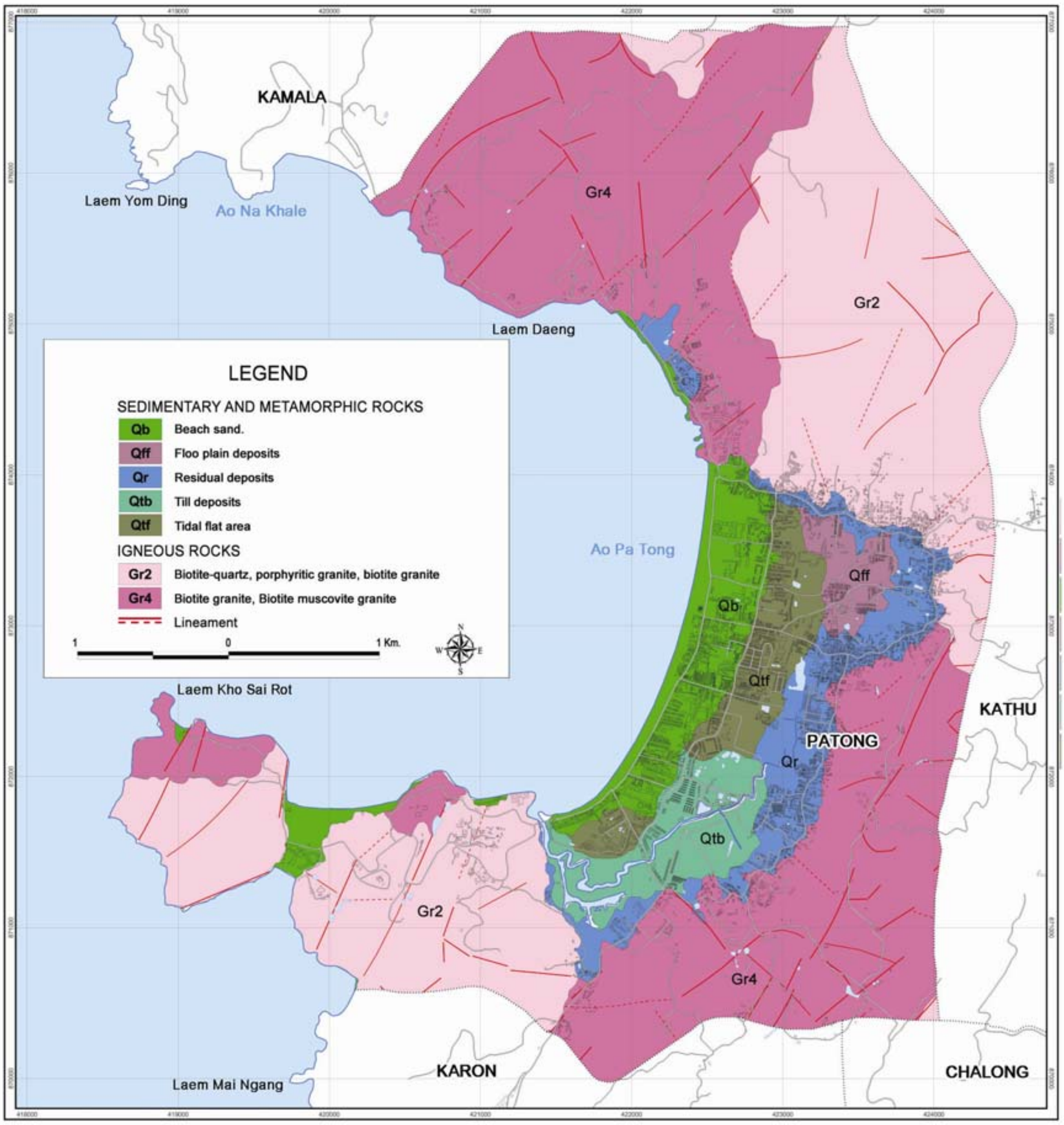


Fig. 16 Geology Map of Patong

3.4 Lineament zone (Geology)

Lineament zone means fault, fracture and joint. Earth movements involve plastic folding and brittle fracture of rocks, as well as uplift and subsidence. These are tectonic features, caused by large scale movements of crustal plates. Groundwater is attracted to a fault zone due to the greater conductivity of the fractured and loosened rock to be found in the fault zone. Faults can act as conduits for flow of water, which explains why rocks adjacent to them are often found to be hydro thermally altered. Replacement of original minerals by clays, zeolites, and silica or calcite, as well as precipitation of these minerals in void spaces, grossly changes the character of the rocks near the fault zones, as a result of which stability problems would ensue (Lee. 1995). Major and Minor Lineament Zones were Interpreted by DMR (Fig. 17). Influencing of lineament zone is buffered 100 meters (Major) and 10 Meters (Minor) from center of lineament line in this analysis.

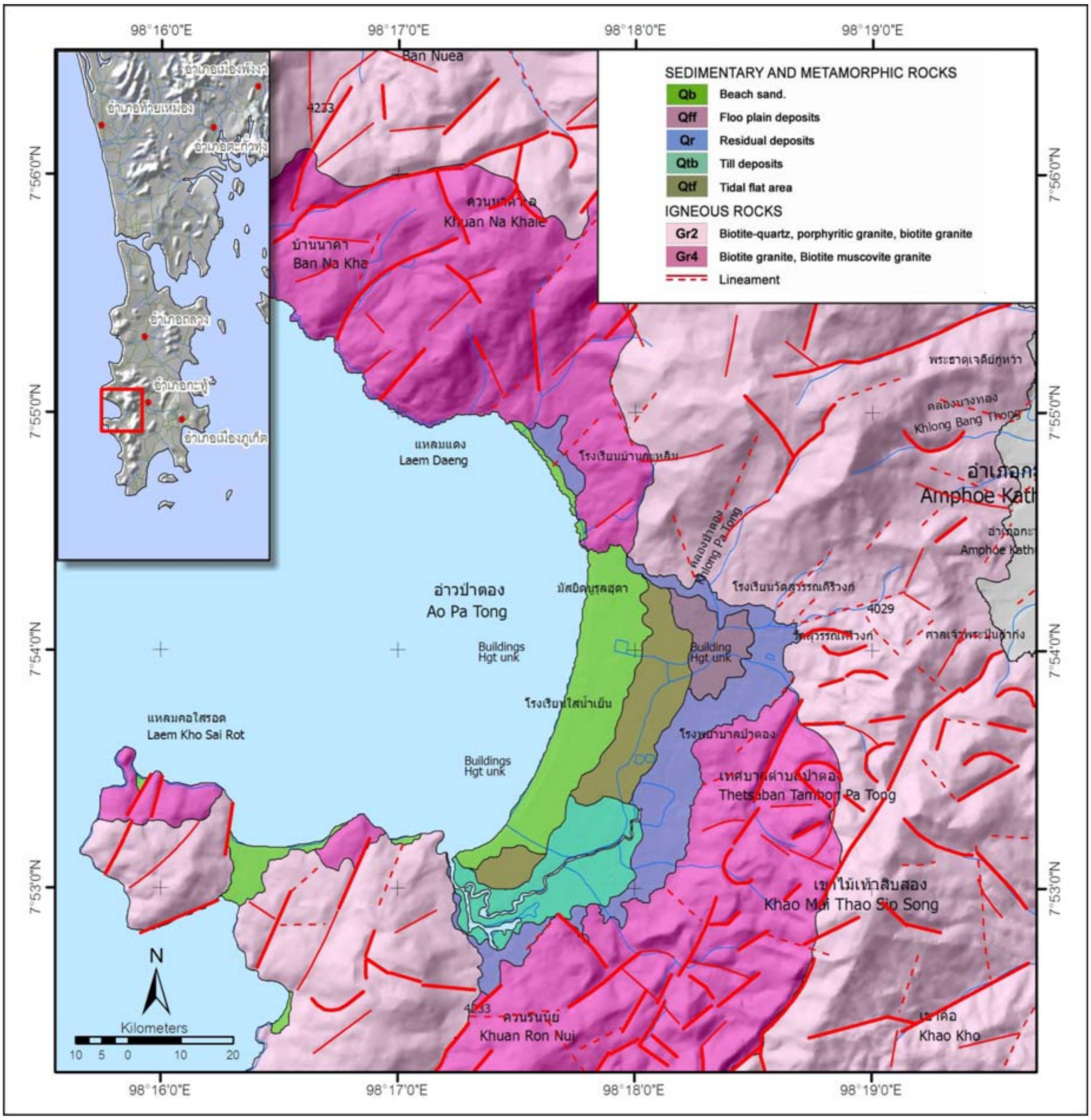


Fig. 17 Lineament zone in Pathong

3.5 Distance from road (Disturbance)

From the geotechnical analyses, it is clearly shown that slope cutting for road construction makes stability of natural slope lower. Therefore, it’s necessary to consider this effect in the analysis. Fig 18 shows one of the failure planes of cut slope section. It found that the failure surfaces from all of the analyses of cut slope section are not go father than 50 meter from its toe. Therefore, this research considers buffering of 50 meters from center of road near or in the hilly area as a disturbed zone from slope cutting.

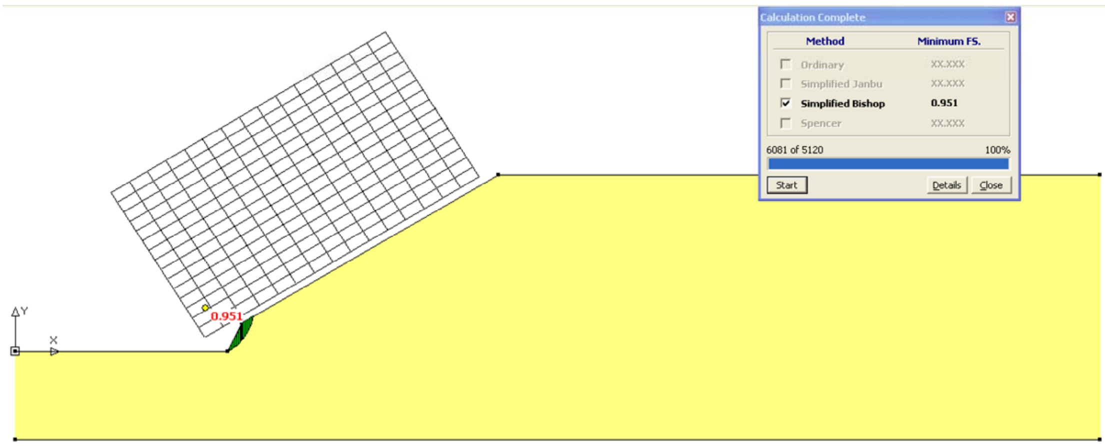


Fig. 18 Failure plane of cut slope model

3.6 Elevation (Disturbance)

The environmental law in Phuget has a regulation of limiting the construction activities in various elevation, elevation of + 40.00-80.00 m.MSL only light structures can be built, above elevation of +80.00 m.MSL no constructions shall be done. Therefore, the disturbance of slope from construction activities can be related to elevation as such.

3.7 Surface drainage zone

Groundwater or stream affects the stability of slopes by generating pore pressures, both positive and negative, which alter stress conditions, changing the bulk density of the material forming the slope, developing both internal and external erosions, changing the mineral constituents of the materials forming the slopes (Lee, 1995). Toe Erosion of Slope in the Stream is one of the major factors that caused slope failure. This research considered the effect zone of surface drainage by buffering off 100m from the center of a stream line as a highly effected zone.

3.8 Land used and land cover

Effect of vegetation on slope stability held reduction energy from rainfall. Root of large tree held slope stable. Other deforestation, urban area and agriculture area was cause of slope failure. Finally, 6 factors are used for landslide hazard analyses as described above. Table 2 summarizes the parameters, their weight and their rating score for analyses. Their weight was determined from weighting matrix as shown in Table 3. Table 4 shows the range of score for each landslide potential level.

Table 2 The numerical weight assignment to the parameters influencing the landslide potential in Patong

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

Table 3 Weighting factor using weight matrix

Factors	1	2	3	4	5	6	Total score	Weight
1		3	3	3	3	3	15	1.875
2	1		3	3	3	3	13	1.625
3	1	1		2	2	2	8	1
4	1	1	2		2	2	8	1
5	1	1	2	2		2	8	1
6	1	1	2	2	2		8	1

Table 4 The landslide potential and the range of total score for 6 factors

Landslide Susceptibility Classes	Range of Score
Very high susceptibility to landslide	35.40-42.15
High susceptibility to landslide	28.66-35.39
Moderate susceptibility to landslide	21.92-28.65
Low susceptibility to landslide	15.18-21.91
Very low to nil susceptibility to landslide	0-15.17

In determining the numerical rating of altogether 6 parameters Affected to the Landslide Potential in Patong, an area of 5x5 square meters grid cell has been employed for the analysis by GIS program. The weight-rating value of each parameter is determined in each square grid cell of each derivative map. Finally, the scores of weight-rating in each 5x5 square meters grid cell is obtained from the summation of weight-rating values of each derivative map to obtain the landslide susceptibility map. The map of each influencing factors is shown in Fig 19 to 24.

The results of processing of landslide susceptibility map considered by weighting factor analysis are shown in Fig 25. Plan area was classified by landslide susceptibility class shown in Table 5.

Table 5 Predicted landslide susceptibility area considering 6 related factors

Score	Landslide Potentials Classes	pixel	Area (m^2)	%
31.6-37.5	Very high potential	408	10,200.00	0.07
25.6-31.5	High potential	13,054	326,218.36	2.27
19.6-25.5	Moderate potential	102,359	2,555,706.73	17.76
13.6-19.5	Low potential	237,269	5,904,230.18	41.03
0-13.5	Very low to nil potential	224,914	5,594,591.66	38.88
	Total	578,004	14,390,946.93	100

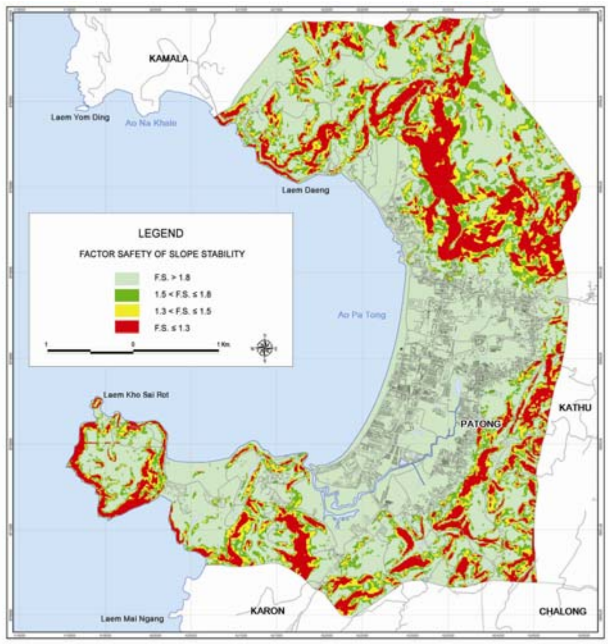


Fig. 19 Factor safety classification

Fig. 20 Lineament zone

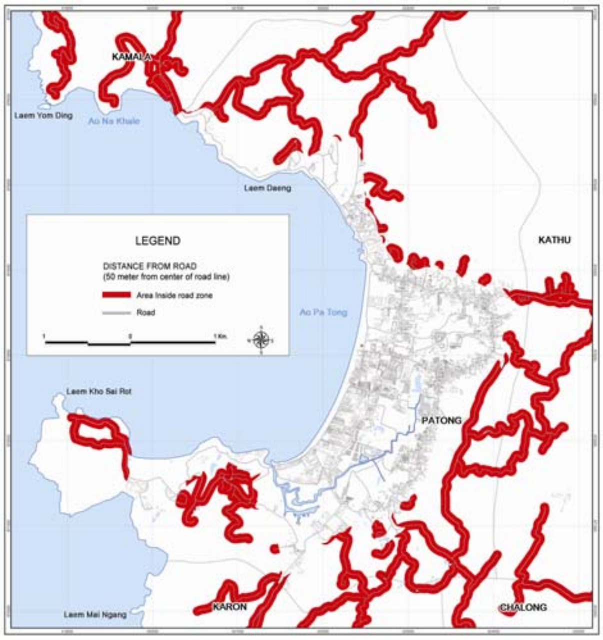


Fig. 21 Distance from road

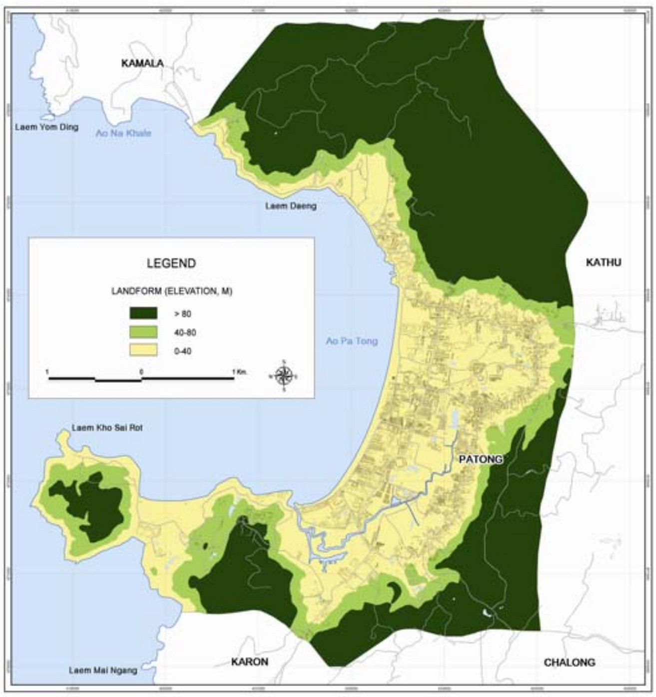


Fig. 22 Elevation

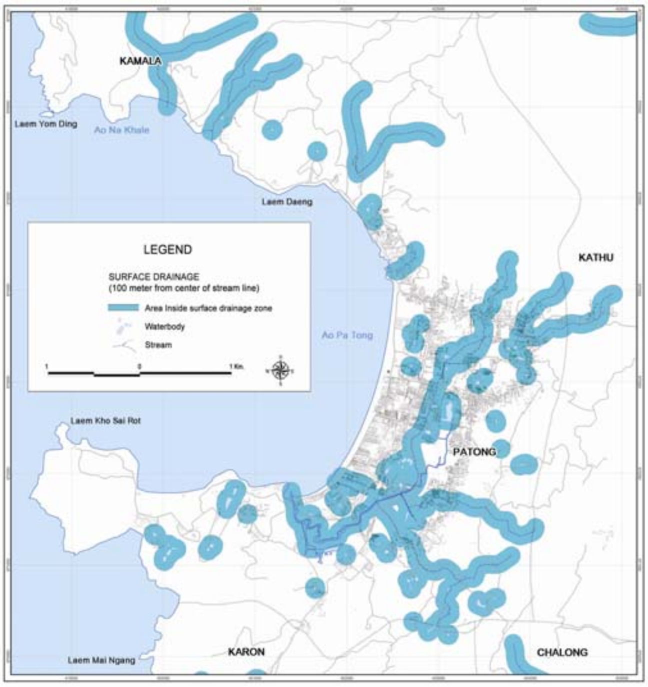


Fig. 23 Surface drainage area

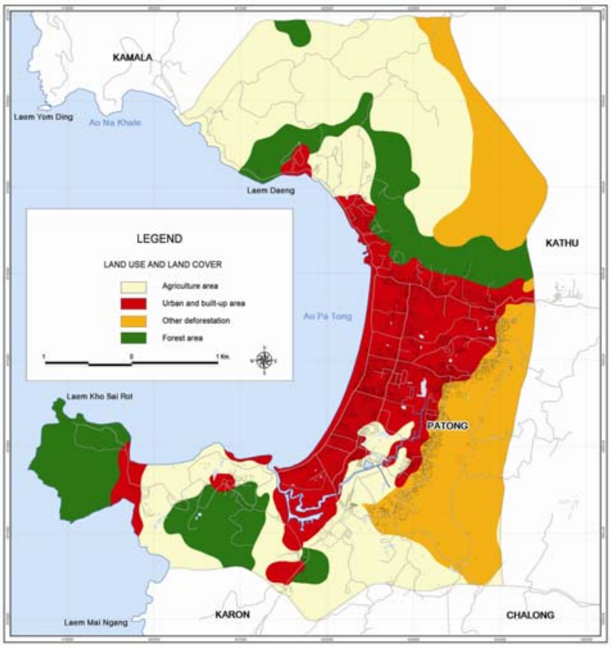


Fig. 24 Land use and land cover

4. Verification

Landslide susceptibility area is verified by the actual landslide event that occurred in the past as show in Fig 25. It clearly shows that the Actual Events Match with the Moderate to High Landslide Hazard Area from the Produced Map.

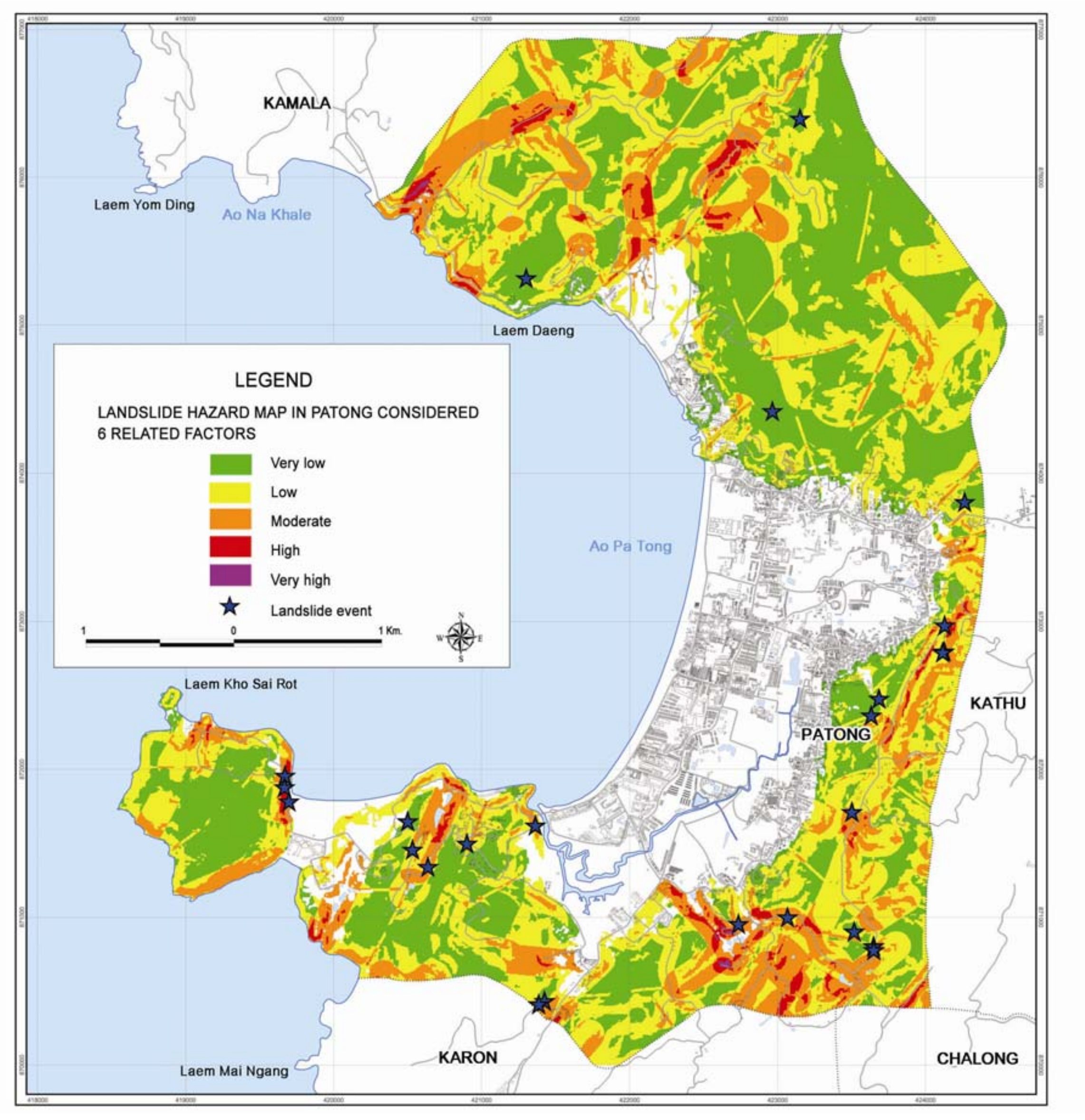


Fig. 25 Landslide susceptibility area is verified by the actual landslide events.

5. Landslide Risk Mapping

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. Buildings location and their data were obtained from taxation map provided by Pathong City. The hazard levels of the buildings were classified based on landslide hazard map produced in this project. However, the hazard map is not cover the toe area where the debris could flow over the buildings. Therefore, the affected area at the toe slope area was estimated to be equal to the height of the slope above the toe. Fig. 26 shows the boundary of affected area at the toe of the slope. The buildings were classified into levels based on their vulnerability due to landslide. The number of population at risk is estimated from the census data in the taxation map.

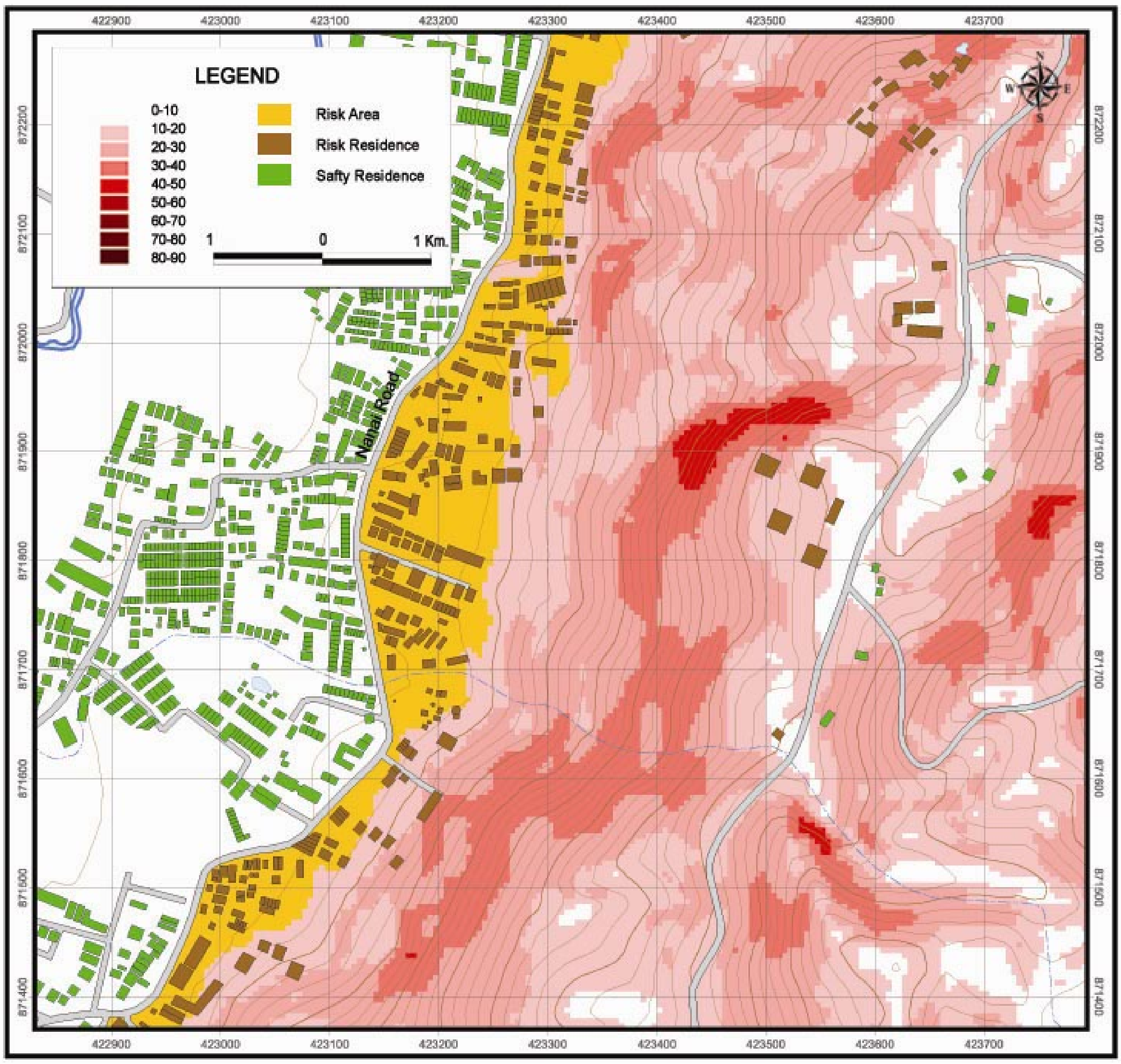


Fig. 26 The boundary of affected area at the toe of the slope.

6. Critical rainfall

The concept of Antecedence Precipitation Index (API) is used for landslide warning based on rainfall precipitation and its accumulation in soil. Critical API was determined in each square grid in the study area. The critical API was determined using geotechnical engineering model as shown in Fig. 27. Critical API contour in Pathong is shown in Fig. 28.

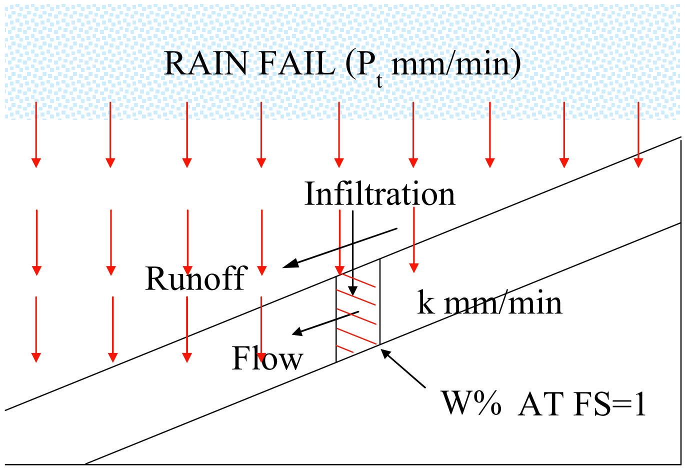


Fig. 27 The critical API was determined using geotechnical engineering model.

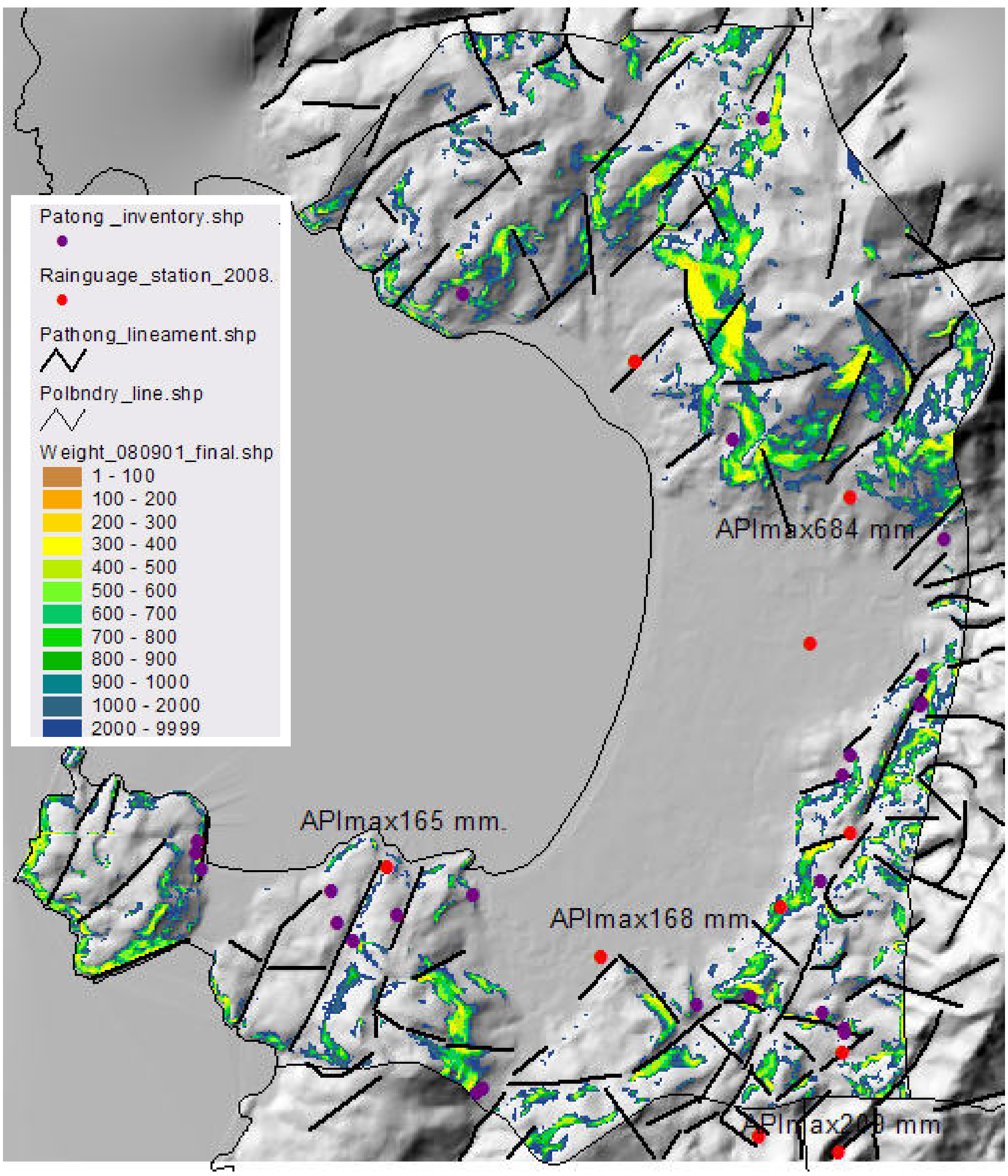


Fig. 28 Critical API contour in Pathong.

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