Final Report

Landslide Mitigation Demonstration Project for Patong City

Carried Oct as a Part of the Asian Program for Regional Capacity Enhancement for Landslide Impact Mitigation (RECLAIM II)

Submitted by

Department of Mineral Resources

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Executive Summary

Patong beach is the famous tourist destination. This beautiful beach is surrounded by the mountain. Since the city is expanding, local people and investor try to develop the mountainous area and cause the disturbance to the environment and also trigger landslide. ADPC together with NGI had the responsibility for execution of program RECLAIM which the funding was provided by the Royal Norwegian Embassy in Bangkok. Department of Mineral Resources and Kasetsart University were asked by ADPC to take responsibility for the implementation. The project started by collecting the data that related to the factors that influence the landslide in the area. The factors are slope angle, linearment zone, drainage, land use, slope cutting by road construction, geology and slope factor of safety. The investigation revealed that about 20 percent of the area has high to moderate susceptibility to landslide. The people who lives in the toe of the mountain is in the landslide risky area while people who lives in the plain area stay in the possible flood inundation area. It also found that the flash flood with return period of 10 years expected to give more than 0.3 m of water in the streets in the major area of the city. It is important to keep the water ways open, avoiding barrier for the water in the slopes and the flat land. The geotechnical analyses also found that any construction cutting in the slope with slope angle greater than 17 degree is found to deserve special engineering attention. In order to advise the developer for safe development, several engineering protection solutions have been presented, including guidelines for good excavation and soil filling practice. Furthermore, since most of the landslides in Patong City were triggered by rainfall, a pilot project for early warning of landslides based on threshold values for rainfall that may trigger landslide/debris flow has been implemented. Work has included the establishment of theoretical model as well as installation 10 rainfall stations at selected areas in the city during the data collecting period. The automatic wireless rain gauge system was installed in the selected area, decided based on the mathematical model. The rainfall data will be automatically sent to the computer sever in Kasetsart University while the researchers in Geotechnical Engineering Research and Development Center (GERD) carefully calculate and update the threshold value for landslide warning. The new criteria will then send to Patong municipal for the city engineer who is responsible for landslide warning. The effectiveness of the criteria will be discussed between Patong Municipal and GERD in order to validate the criteria. One PhD student from Kasetsart University will be responsible for updating the mathematical model for the next 2 years. Department of Mineral Resources will be responsible for discussion with local communities and create the activity for community concerned.

During the period of the project, excellent cooperation from the local communities and Patong Municipal has been received. After the landslide hazard map, guidelines booklet and rainfall criteria has been issued to the city, several comments from the city's and communities were received and then adjusted to suite their needs. The lesson learnt is that the interaction with both city's and communities for their needs and their reaction with the hazard map is very important. There is no negative reaction from the people who live in the high hazard area but on the other hand, more concern has been given to option of safe construction methods in that area.

Content

Content (continued)

Chapter 1

Introduction

Title: A Risk-based Assessment for Landslide Mitigation in Patong

Presented for Asian Program for Regional Capacity Enhancement for Landslide Impact Mitigation (RECLAIM II)

Partners
Asian Disaster Preparedness Center (ADPC)
Department of Mineral Resources of the Royal Thai Government
Kasetsart University, Thailand

1.1 Description of the study area (Patong municipality)

Patong city is situated on the west coast of Phuket Island. The city stays in an embayment surrounded by high altitude mountaineous range. Population in the city consists of tourist and local Muslims people due to limit plain over for development. After tsunami incident, land developers attempt to build the buildings in the upper level of the mountain. Landslide is then easily to be triggered by the changing of landform and destroying the land cover. Proper action needs to be done in order to prevent large landslide in the city.

ADPC together with NGI had the responsibility for execution of the program RECLAIM in which the plan was to implement 3 landslide mitigation demonstration projects, one in Thailand, the other two on the Philippines and one on Sri Lanka. Royal Norwegian Embassy in Bangkok, who kindly provided the funding for the project, was decided that patong city was a suitable site for carrying out the demonstration project. Department of Mineral Resources and Kasetsart University was contacted by ADPC and asked to prepare a work plan and take responsibility for the implementation. The present report presents the main activities of this undertaking.

1.2 Justification for the project

A. Patong city stays in the high potential of landslide due to its geographic and geologic condition.

B. Consequences might be high since the city is a tourist attraction area and tourist tends to stay in the high hill in the risky area.

C. After tsunami incident, landslide risk is increasing since developers tend to disturb the stable slope in the upper level.

D. The Department of Mineral Resources and Kasetsert University have done extensive investigation in order to understand the nature of landslide in Patong area. However detail investigation to obtain specific data in the study area is still needed. Some data for landslide mitigation is readily available.

1.3 Objectives

1. To demonstrate implementation of a landslide mitigation project.
2. To determine the landslide acceptable risk of Patong area.
3. To develop guideline for monitoring/warning system.
4. To campaign with information material about landslide hazard warning concept, awareness for the city.

1.4 Project activities

This project include following activities.

A1. Complete the existing landslide hazard map for Patong City by performing extensive geologic and geotechnical investigation and analyzing detail stability analysis. The analysis will be focused on rainfall induced landslide and indicate hazard level.

A2. Prepare a simplified landslide risk map for Patong City where risk classes for selected grids are defined by the following 2 parameters

- a) degree of hazard level and
- b) the consequences have to be estimated from land use data in Patong municipal estimated consequences.

A3. Carry out a water drainage capacity assessment for the major watersheds in Patong City for scenarios of extreme rainfall by the use of a suitable software program such as "Mike 11" or other similar US program. And estimated debris flow path is then indicated by rainfall run off data in the selection risk area.

A4. Workshop with Patong City Authorities for discussion of outcome of A2 and A3 and discuss options for practical mitigation measures.

A5. Geotechnical and geological analysis

- A5.1 Perform geotechnical and geological analysis for target area.
- A5.2 Design the mitigation/warning system for prevention the landslide base on risk analysis results

A6. Implement of Mitigation and Preparedness Measures

- A6.1 Guidelines for construction in slopes
- A6.2 Revision of building by laws
- A6.3 Install 3 rainfall stations and establish threshold rainfall values
- A6.4 Establish procedures for landslide warning based on rainfall triggering.
- A6.5 Land use regulation.
- A6.6 Closing seminar with relevant agencies in the Patong Area.

A7. Public awareness campaign for increased preparedness of communities in collaboration with Patong municipality government

- A7.1 Campaign with information material about landslide hazard and implemented warning concept, awareness building for the city

Table 1-1 shows responsibility in activities.

Activity	KU	DMR	PATONG	ADPC	NGI
A1	1	1			
A2	1				1
A3	2				1
A4	2	2	1	1	2
A5	1	1			
A5.1	1	1			
A5.2	1				1
A6					
A6.1	1				1
A6.2	1	1	1		2
A6.3	1				2
A6.4	1				2
A6.5	1	1			2
A6.6	2	2		1	
A7	2	2		1	
A7.1	2	2		1	

<u>Note:</u> 1 – Major, 2 – Minor.

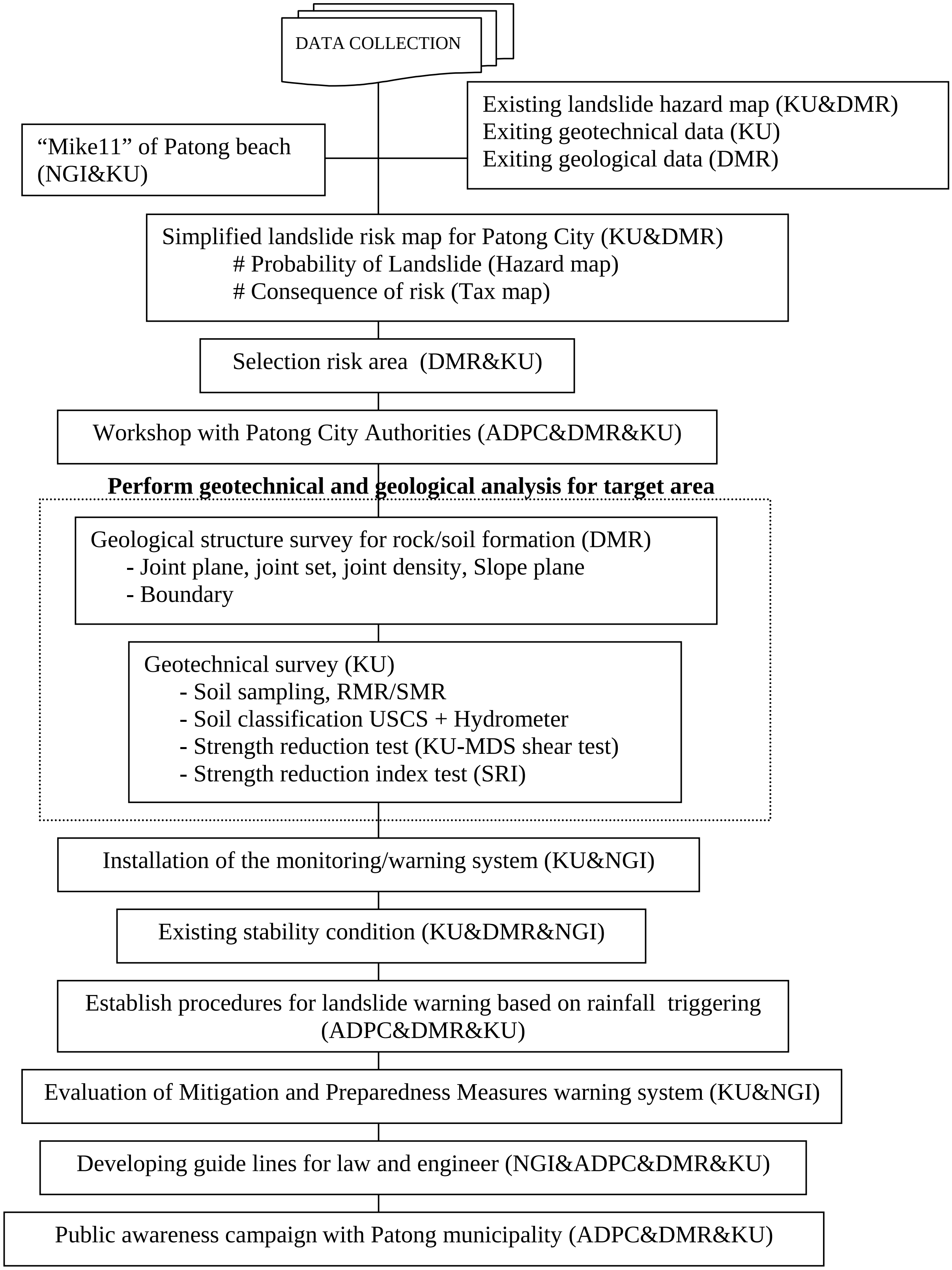


Figure 1 Flow diagrams showing all the methodologies

Chapter 2

Landslide Hazard Mapping

2.1 Factors Considered

The landslide hazard area is determined using weighing factor method. Factor of safety against sliding and slope angle relationship is calculated based on shear strength data. Other factors are also considered after extensive review of the latest literatures and after acquired more information in the target area. Lineament zones were carefully interpreted from arial photo by DMR. 8 major factors are considered and used for assigning landslide hazard area. Those factors are:

1. Factor safety and slope angle relationship
2. Bedding & slope angle relationship (Later neglected)
3. Lineament zone (Revised data)
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.

2.1.1 Factor safety and slope angle relationship (Stability)

According to Geotechnical analysis (Chapter 5), landslide hazard potential in Patong can be divided based on ranges of factor of safety which shown in slope angle ranges as shown in Table 2-1.

Table 2-1 Landslide hazard classification based on factor safety-slope angle relationship

Factor safety and slope angles	Landslide Potential Class
F.S. ≤ 1.3 (≥ 26)	Very high potential
1.3 < F.S. 1.5 (22 ≤ slope<26)	High potential
1.5 < F.S. 1.8 (18 ≤ slope<22)	Medium potential
F.S. >1.8 (<18)	Low potential

2.1.2 Bedding-slope relationship (Stability)

In order to consider the influence of geologic structure, the bedding-slope relationship is considered and landslide hazard area can be classified as shown in Table 2-2. 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 1-4. Therefore, this factor is not used in the analysis.

Table 2-2 Landslide potential classification by bedding & slope relationship

Bedding & slope relationship	Landslide Potential Class
Over dip	Very high potential
Dip	High potential
Under dip	Medium potential
Flat	Low potential

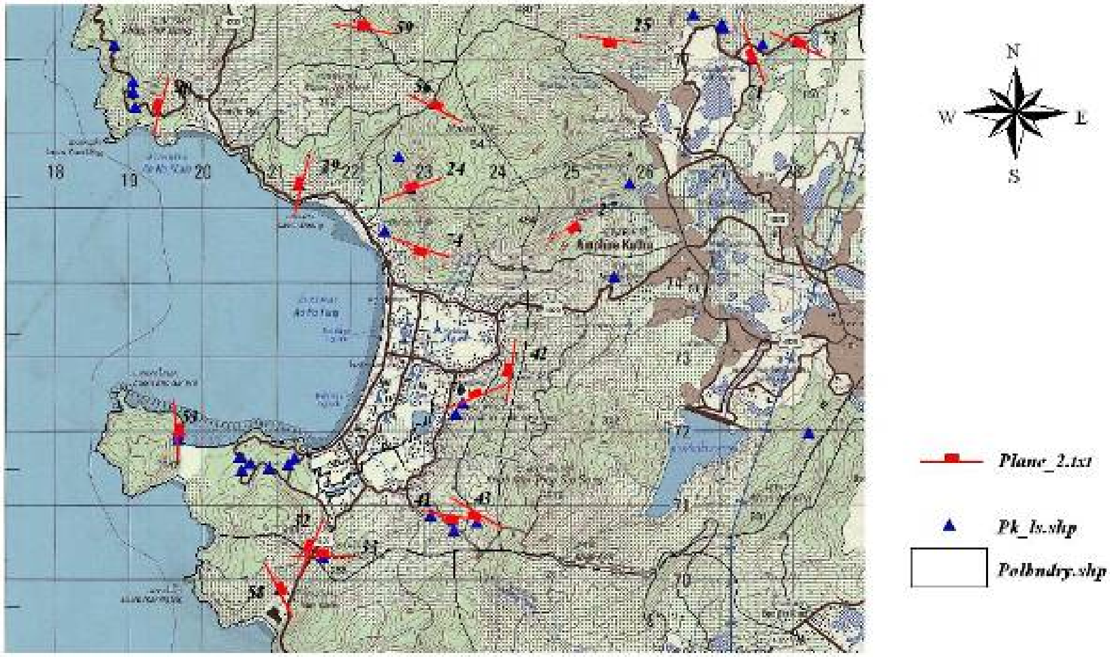


Figure 2-1 Strike and dip directions of rock mass in Patong

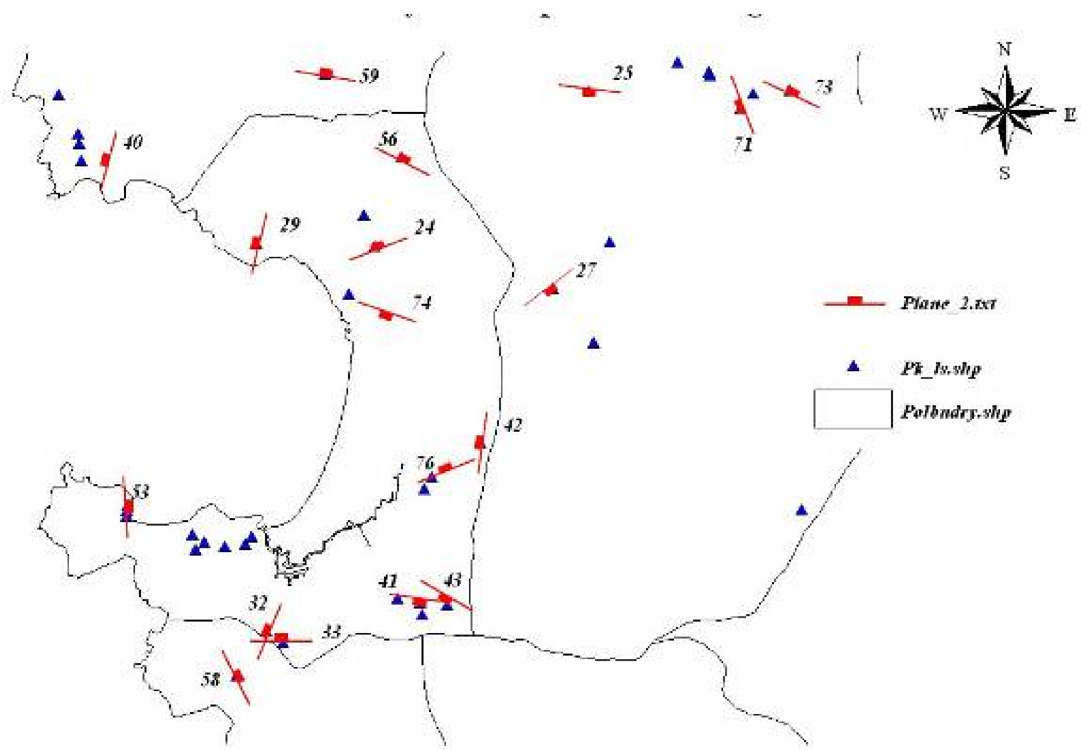


Figure 2-2 Strike and dip direction of rock mass

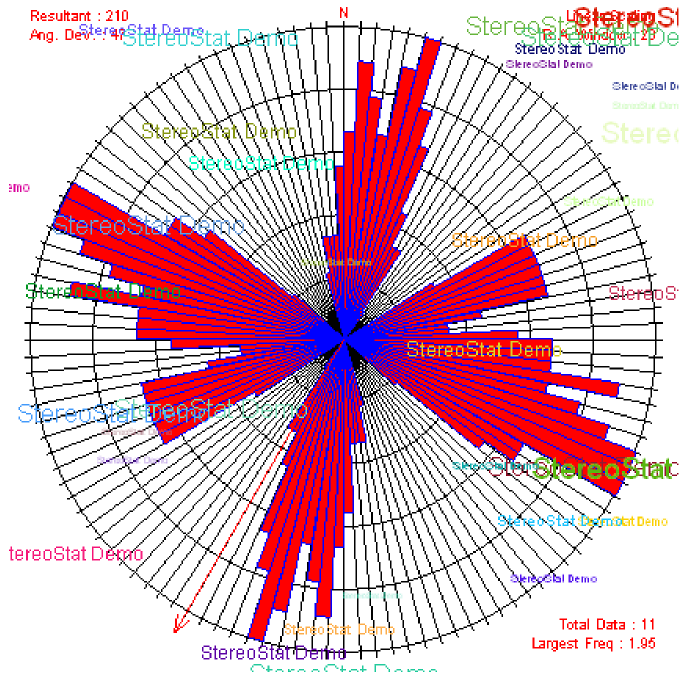


Figure 2-3 Rose diagram of rock fractures in Patong

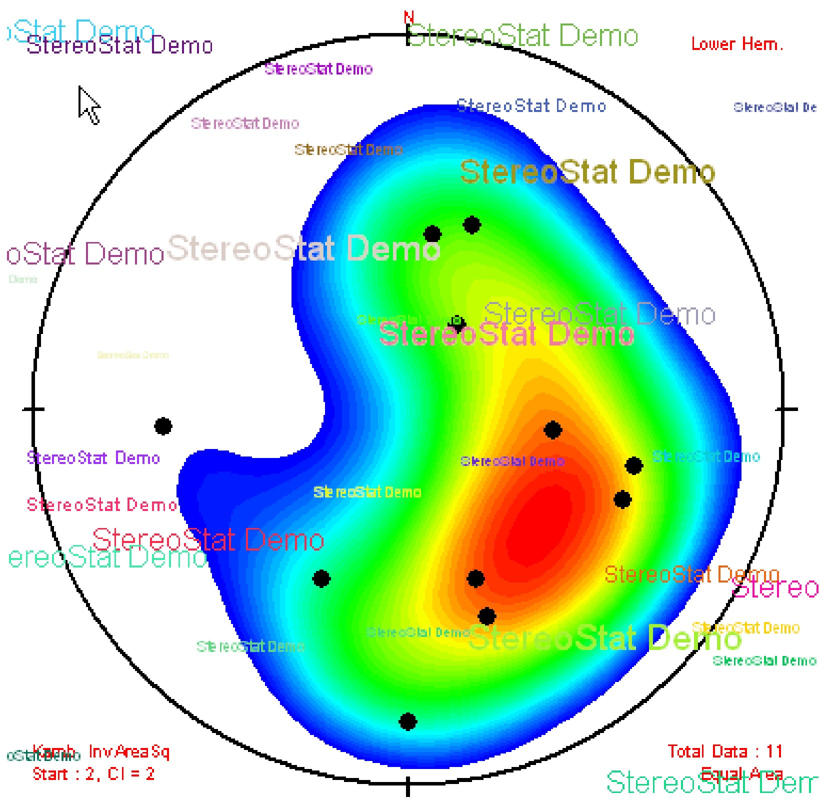


Figure 2-4 Stereo net of rock fractures in Patong

2.1.3 Rock type (Geology)

Rock type is one of the main factors for landslide hazard analysis. Each rock type has different mechanism for landslide. Table 2-3 shows rock group and its dominate rock in the region. However, since rock group in Patong has only one type which is granite (Fig. 2-5), considering this factor in the hazard analysis will not make any different, therefore, it will not be considered in this analysis.

Table 2-3 Potential landslide level of rock series in Southern 6 provinces (By rock type)

Potential landslide level	Satun	Phangnga	Krabi	Trang	Ranong	Phuket	Rock type
Very high	Kgr,Tr Jgr, Trgr	Kgr,Tgr, Jgr	Kgr	Trgr	Jgr,Trgr, Kgr	Kgr	Granite Rock
High	Cb,Ck, SD(C)	EP,CP	CP,Tr	CP,SD (C)	CP	CP	Shale/ Mudstone
Medium	E, SD	JK,DC	Mz,JK,TrJ, T	(S)DC ,JK,T, TrJ	SD		Sandstone/Siltstone
Low	C			C	C		Quartzite, Sandstone and Siltstone
Very low	O,P	P	P	Tr,O,P	P		Limestone/ Dolomite

Note: Tr trang - Dolomite mixed Shale and Gravel stone
Tr Krabi –Shale mixed Clay stone and Siltstone
Source: Department of mineral resource (2006)

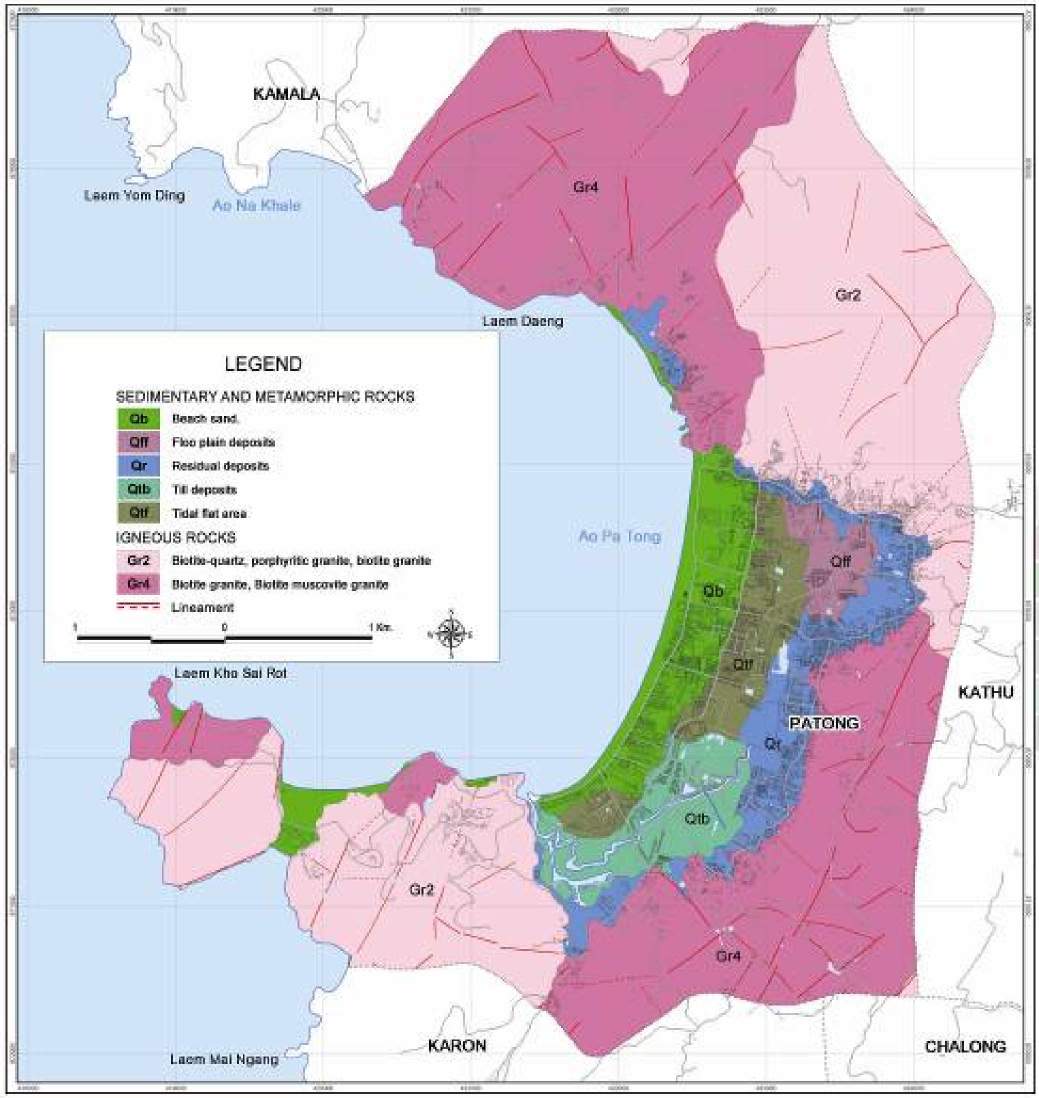


Figure 2-5 Geology Map of Patong

2.1.4 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 as Discussed in Chapter 5. Influencing of lineament zone is buffered 100 meters (Major) and 10 Meters (Minor) from center of lineament line in this analysis. Table 2-4 shows landslide potential classification for this factor.

Table 2-4 Landslide potential classification by lineament zone

Lineament Zone	Landslide Potential Class
Area inside lineament zone Area outside lineament zone	Very high potential Very low potential

2.1.5 Distance from road (Disturbance)

From the analyses in A 5.1 and A 6.1, 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 2-6 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 and classifies landslide potential as shown in Table 2-5.

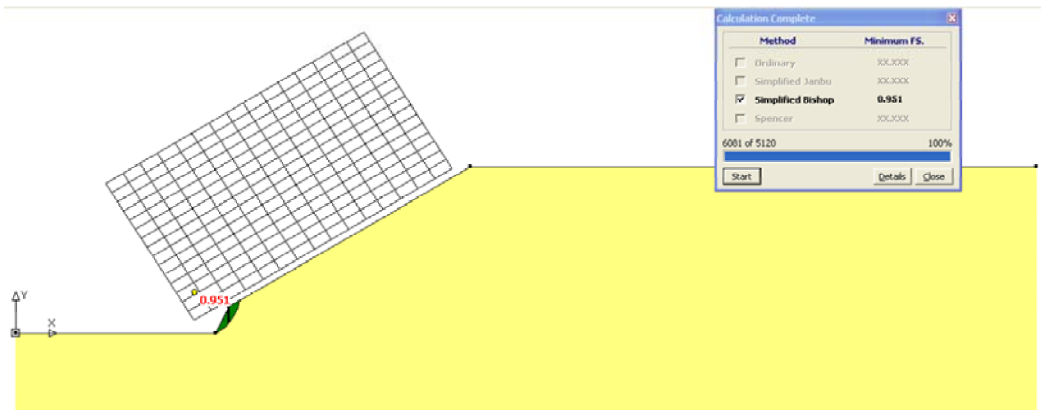


Figure 2-6 Failure plane of cut slope model

Table 2-5 Landslide potential classification by Distance from road

Distance from road	Landslide Potential Class
Area inside road zone Area outside road zone	Very high potential Very low potential

2.1.6 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. Table 2-6 shows the classification of landslide potential based on elevation.

Table 2-6 Landslide potential classified by elevation

Elevation	Landslide Potential Class
Elevation > 80 meters	Very low potential
Elevation 40 - 80 meters	Medium potential
Elevation 0 - 40 meters *	Very high potential

* Not include slope < 10^{O}

2.1.7 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 Factor that caused slope failure (Fig. 2-7) 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. Table 2-7 shows the landslide potential classes by this factor.

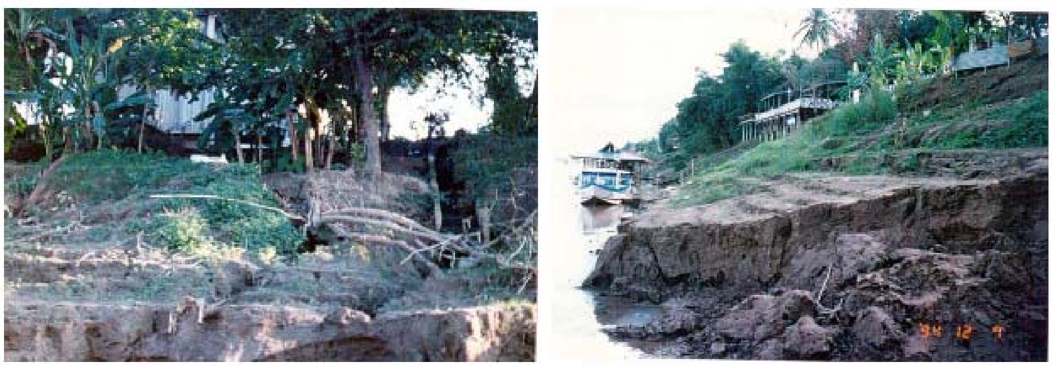


Figure 2-7 Toe Erosion of Slope in the Stream

Table 2-7 Landslide potential classification by surface drainage zone

Surface Drainage Zone	Landslide Potential Class
Area inside Surface drainage zone	High potential
Area outside Surface drainage zone	Very low potential

2.1.8 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. Table 2-8 shows the landslide potential classification based on land used.

Table 2-8 Landslide potential classification by land used

Land Used	Landslide Potential Class
Agriculture area	High potential
Urban and built-up area	Medium potential
Other deforestation	Low potential
Forest area	Very low potential

Finally, 6 factors are used for landslide hazard analyses as described above. Table 9 summarizes the parameters, their weight and their rating score for analyses. Their weight was determined from weighting matrix as shown in Table 2-10. Table 2-11 shows the range of score for each landslide potential level.

Table 2-9 The numerical weight assignment to the parameters influencing the landslide potential in Patong

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) 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 2-10 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 2-11 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

2.2 Processing of landslide susceptibility and hazard map (6 factors)

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 values 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 8 to 13.

The results of processing of landslide susceptibility map considered by weighting factor analysis are shown in Fig 2-14. Plan area was classified by landslide susceptibility class shown in Table 2-12.

Table 2-12 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**

As can be seen from the above table, about 20% of the land area of Patong is characterized as high to moderate landslide susceptible area.

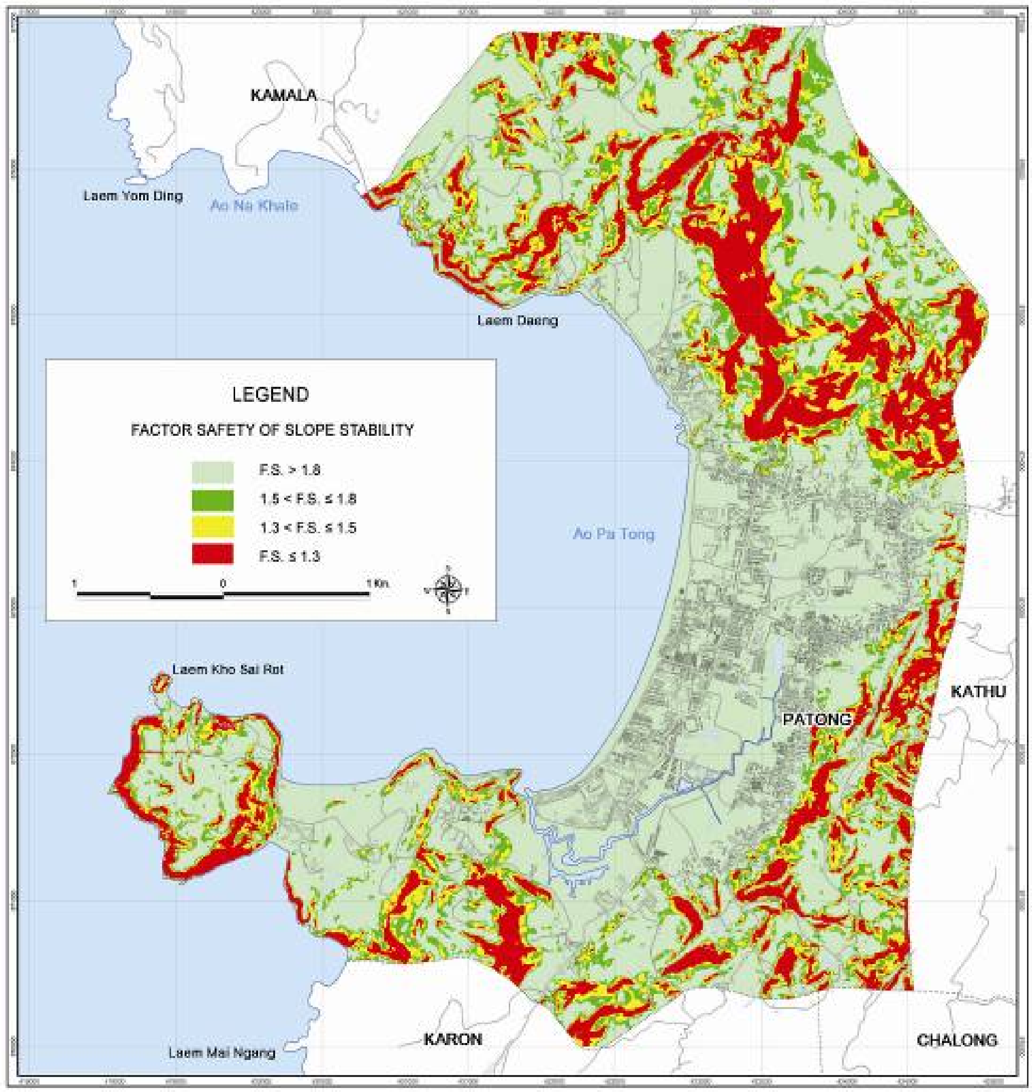


Figure 2-8 Factor safety classification

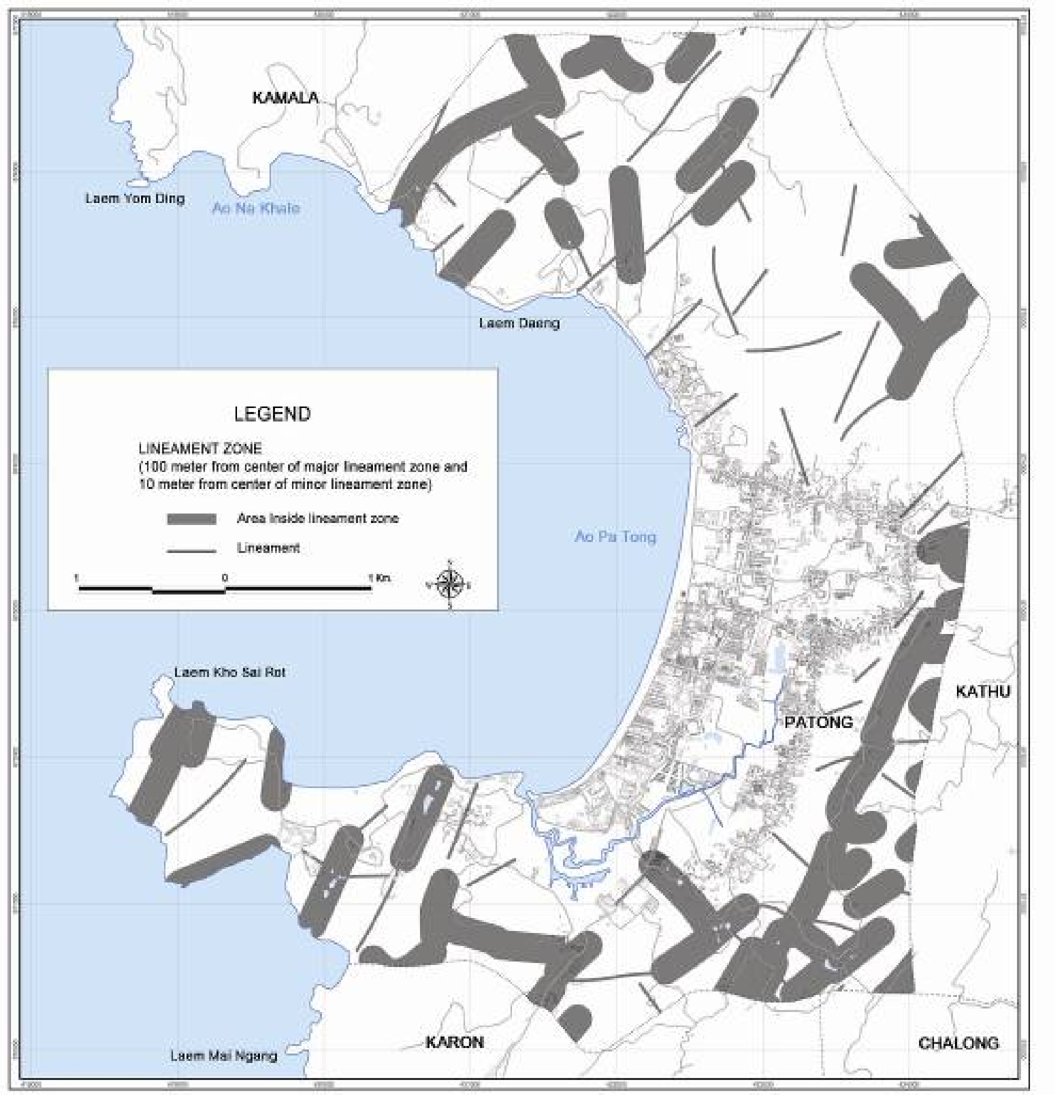


Figure 2-9 Lineament zone

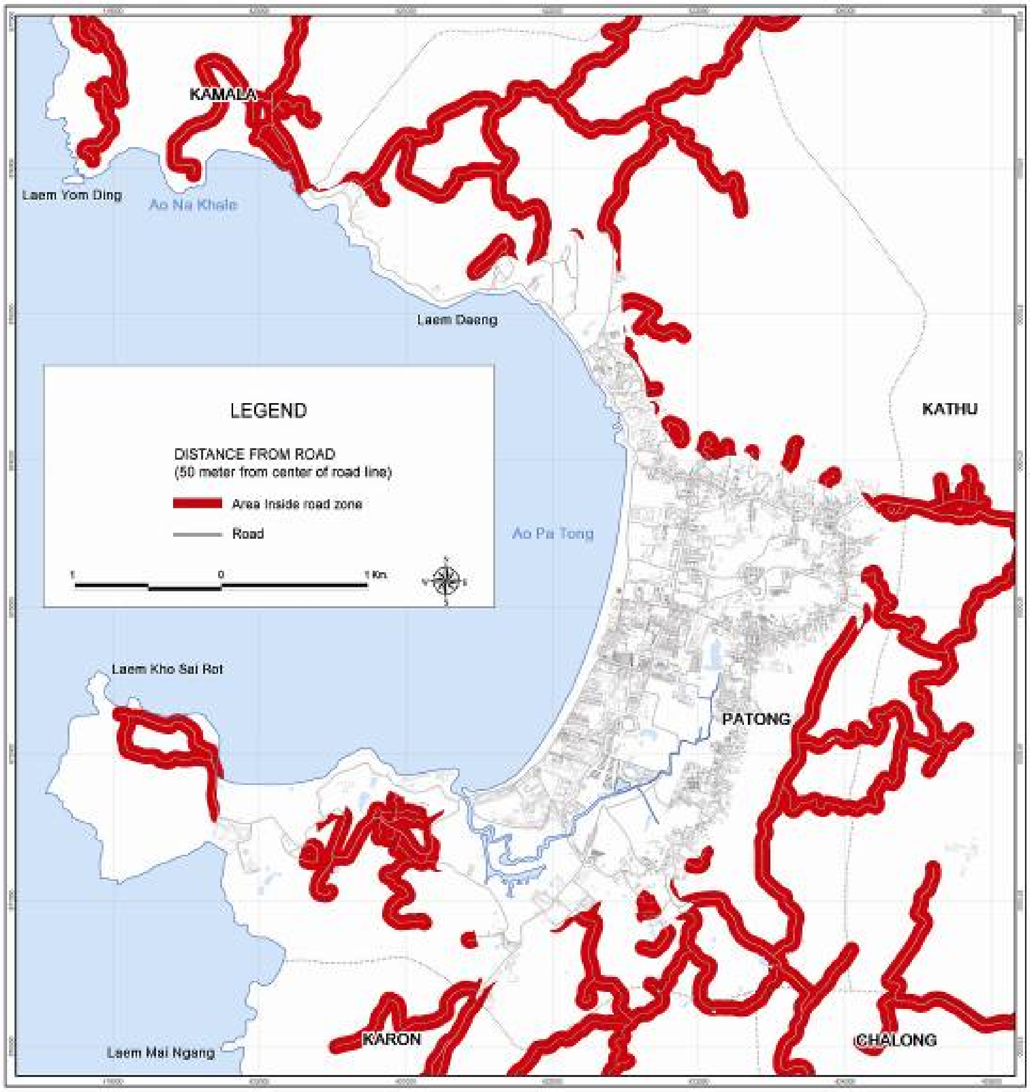


Figure 2-10 Distance from road

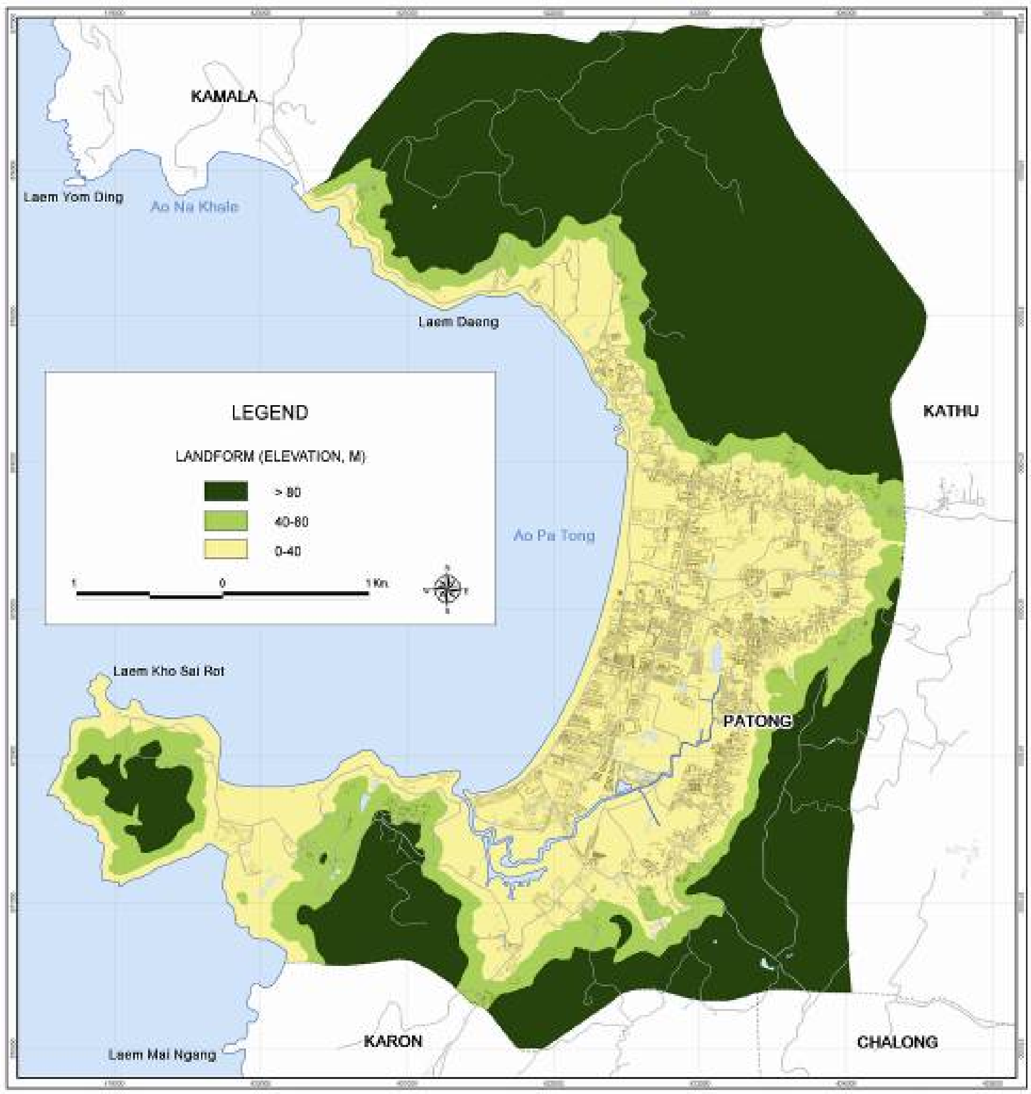


Figure 2-11 Elevation

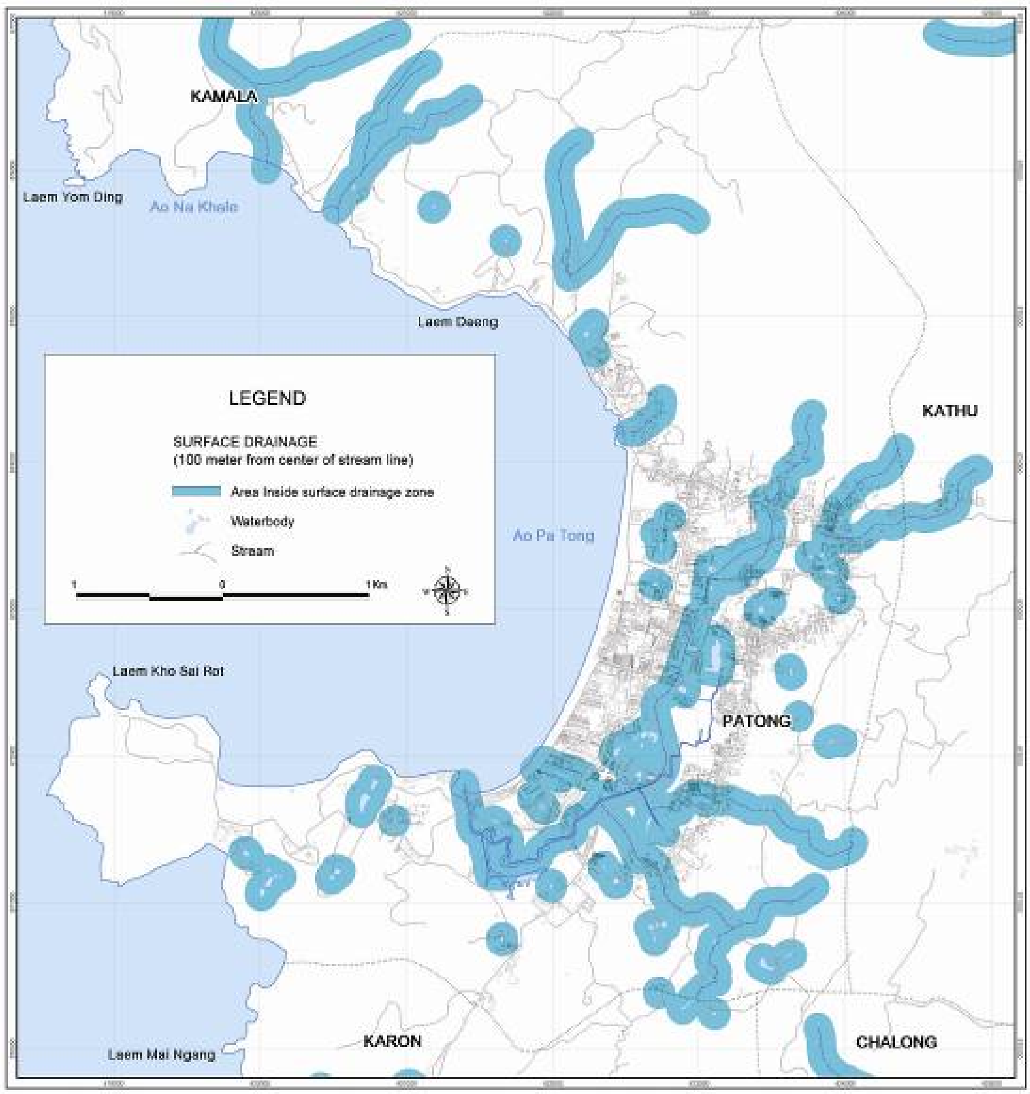


Figure 2-12 Surface drainage area

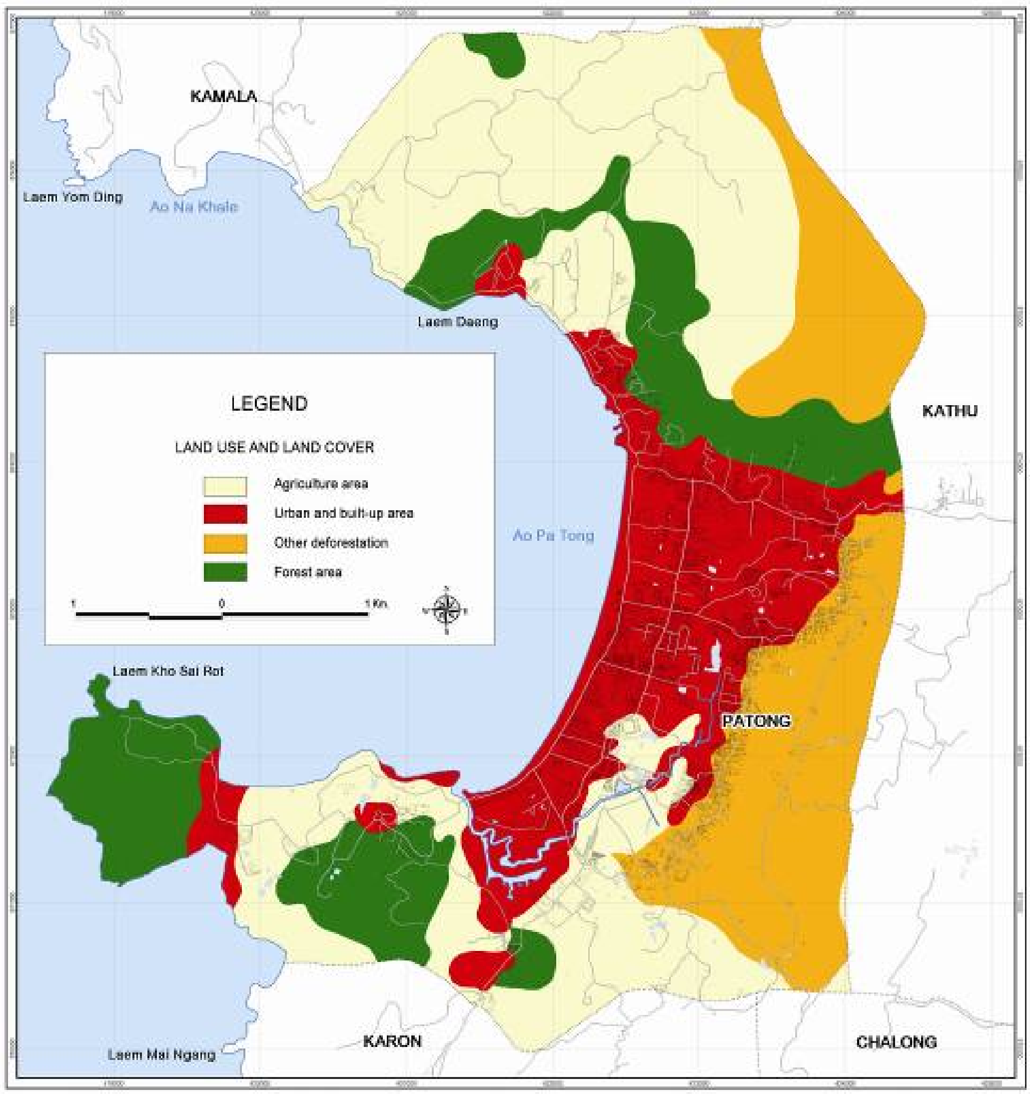


Figure 2-13 Land use and land cover

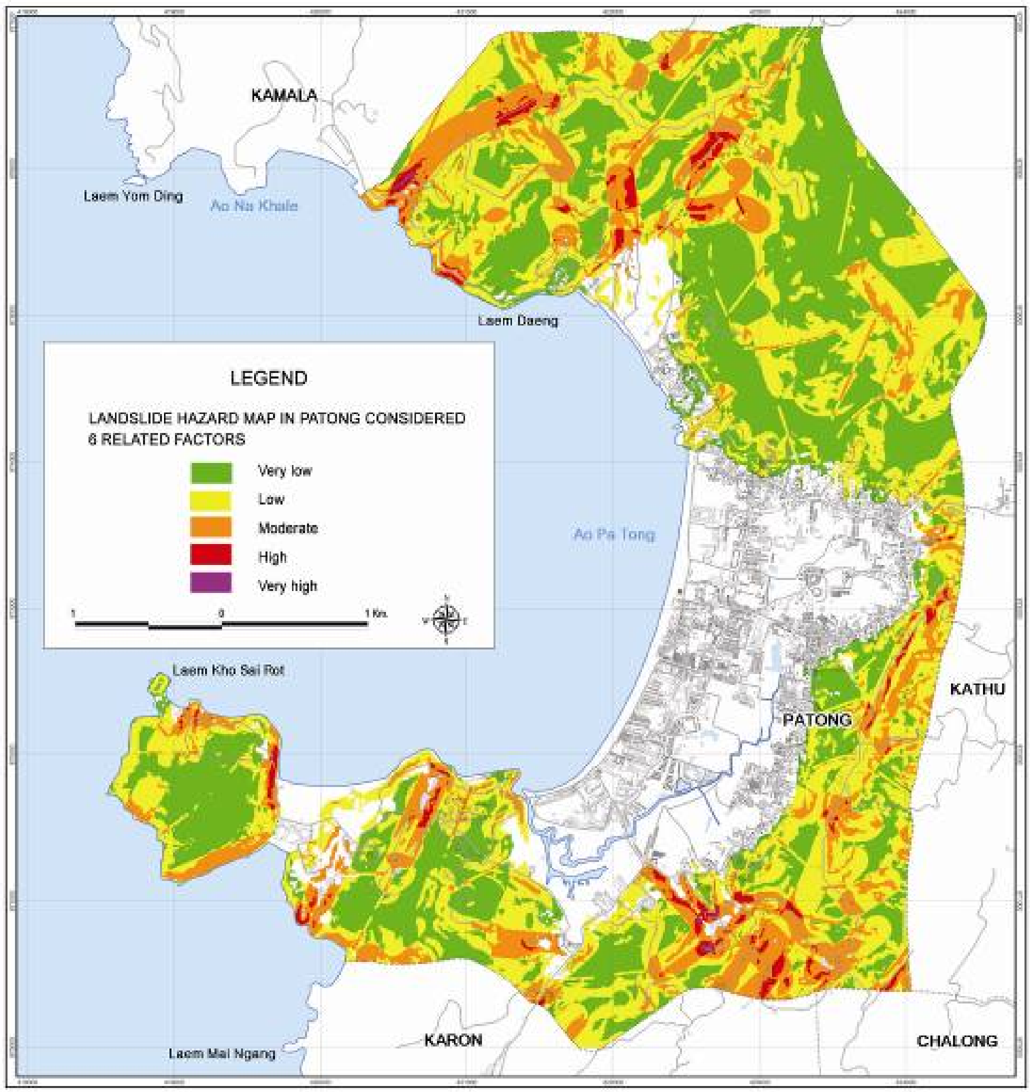


Figure 2-14 Landslide susceptibility map by weighting factor method considered 6 related factors.

2.3 Verification

Landslide susceptibility area is verified by the actual landslide event that occurred in the past as show in Fig 2-15. It clearly shows that the Actual Events Match with the Moderate to High Landslide Hazard Area from the Produced Map.

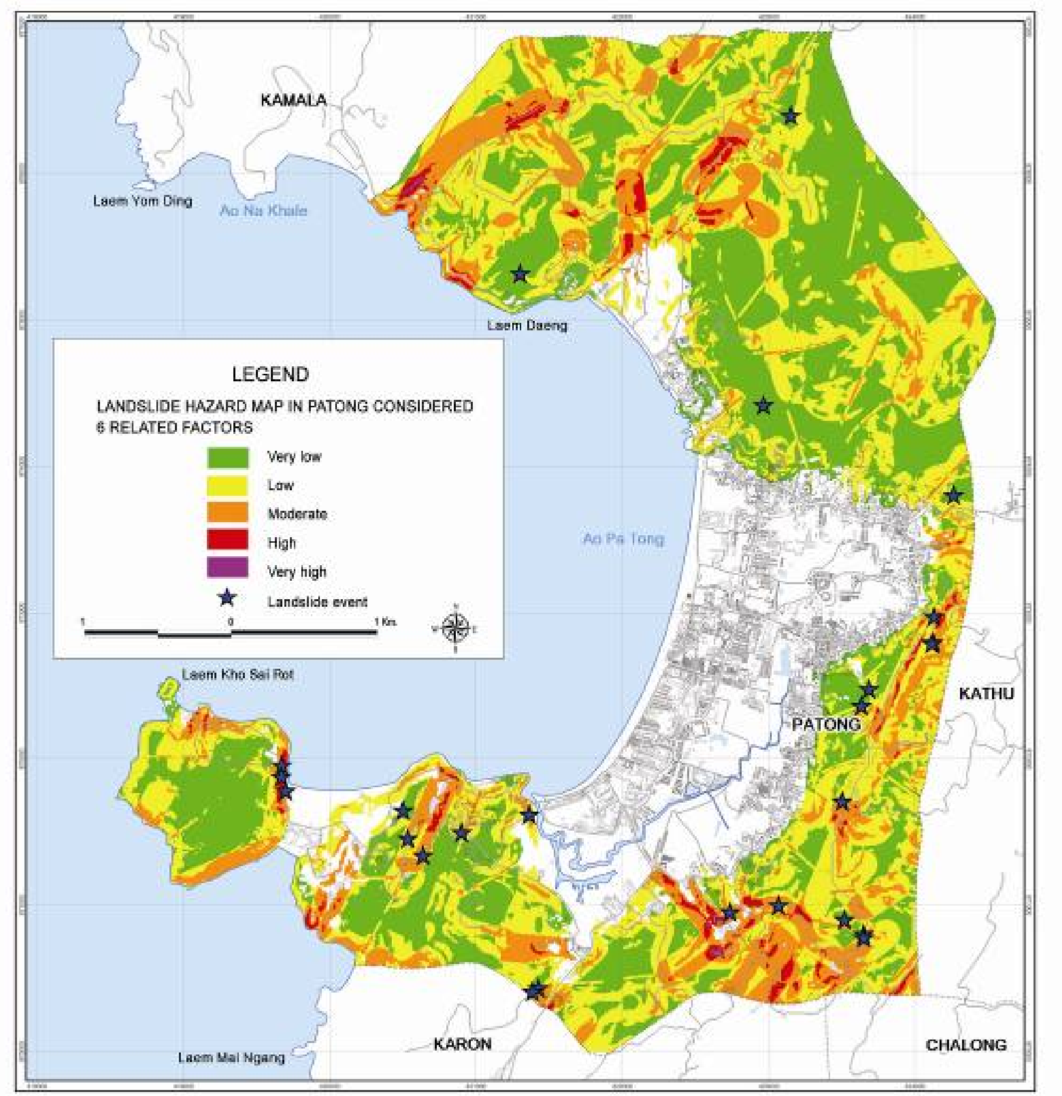


Figure 2-15 Landslide susceptibility area is verified by the actual landslide events.

Chapter 3

Landslide Risk Mapping

3.1 Elements at risk

Element at risk concerned in this project include loss of life population and properties damaged. Number of population and properties value is estimated from the data from taxation map which include type of building and number of storey. Fig. 3-1 shows the taxation map.

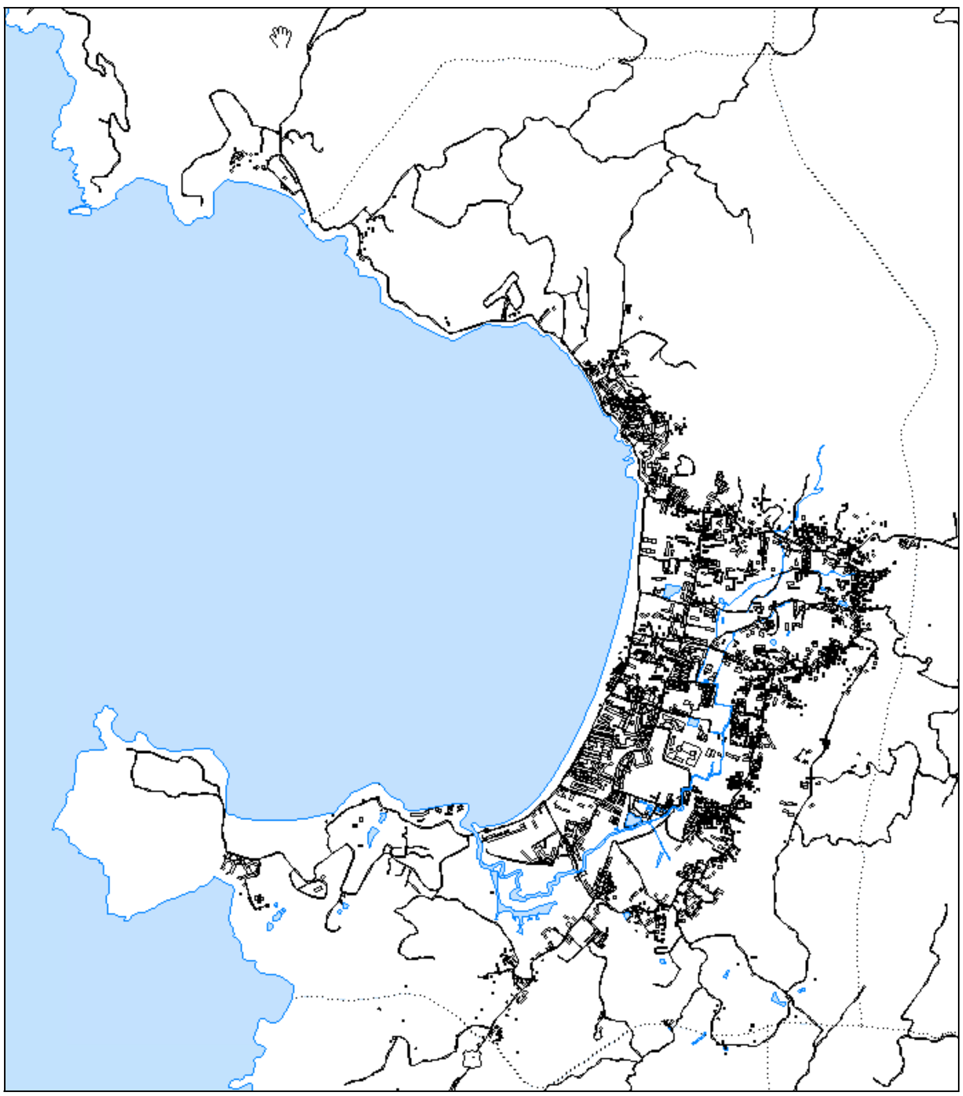


Figure 3-1 Taxation Map
Source: Patong Municipality (2004)

3.2 Estimation of affected area

The affected area is the area including the hazard area and the area that cover by debris or mud flow. The estimation of debris travel distance was planned to be estimated by the method proposed by Finlay et al (1999). However, it can’t be done since lack of record of the debris travel distance from the past events. Up to now, either finding others simplification techniques or collecting data require for Finley’s method need to be done. Advice from NGI would be helpful at this point. Number of population at risk (PAR) is considered to be the same as the number of population who live in the potentially affected area.

3.3 Selected area

Landslide risk map will be done for Pathong city, however two target area will be concentrated in order to demonstrate the detail of mitigation measures. Those target areas are Kalim and Na Nai village. Fig. 3-2 shows the location of the areas. The photos of both areas are presented in Fig. 3-3 to 3-6. Kalim village has population of about 889 people, most of them are Islamic and native. The village area is about 0.50 km by 0.50 km and situates on the lower and toe slope on the northern hillside. The community is considered to be a small community, however surrounding the village, land development seems to be very active. This might be the cause of flooding and debris flow which occured on 14/10/2004 as shown in the Fig. 3-7. As for Na Nai village, the village situate along the lower slope of central hill. The village consists of 2,656 people and rather mixed between local and tourist. The area of the village is a long strip shape with 0.50 by 2.0 km size. The buildings are mixed with residential house apartment and commercial buildings for rent. Flooding and debris flow has occurred on 14/10/2004. The picture is shown in the Fig. 3-8.

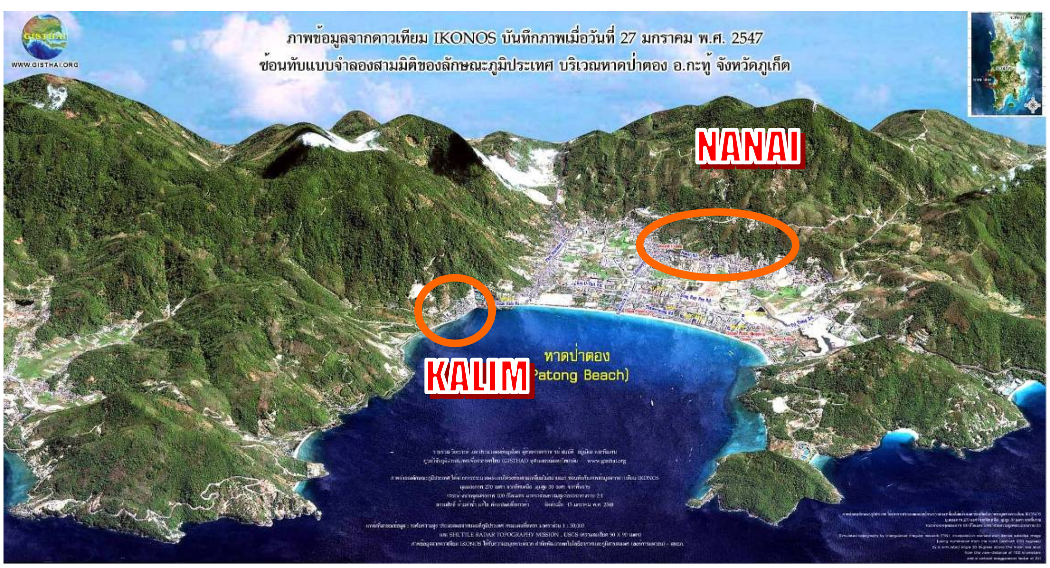


Figure 3-2 The target areas are Kalim and Na Nai village.

Figure 3-3 The general view of Kalim village.

Figure 3-4 The general view of Kalim village.

Figure 3-5 The location of Nanai village.

Figure 3-6 The location of Nanai village.

Figure 3-7 Flooding and debris flow on 14/10/2004 at Kalim village.

Figure 3-8 Flooding and debris flow on 14/10/2004 at Nanai village.

3.4 Building at Risk

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. 3-9 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. Table 3-1 shows number of building in the landslide susceptibility classes. And table 3-2 shows number of building at risk. Number of people live in different susceptibility couldn't certainly analyzed because of missing information.

Table 3-1 Number of building in the landslide susceptibility classes

Landslide Potentials Classes	Number of Building	%
Very high potential	80	0.63
High potential	2,892	22.82
Moderate potential	320	2.52
Low potential	9,412	74.26
Total	**12,674**	**100**

Table 3-2 Number of building at risk

Risk Classes	Number of Building	%
High	22	0.17
Moderate	738	5.82
Low	735	5.80
Non-risk Building	4,911	38.75
No Information	6,268	49.45
Total	**12,674**	**100**

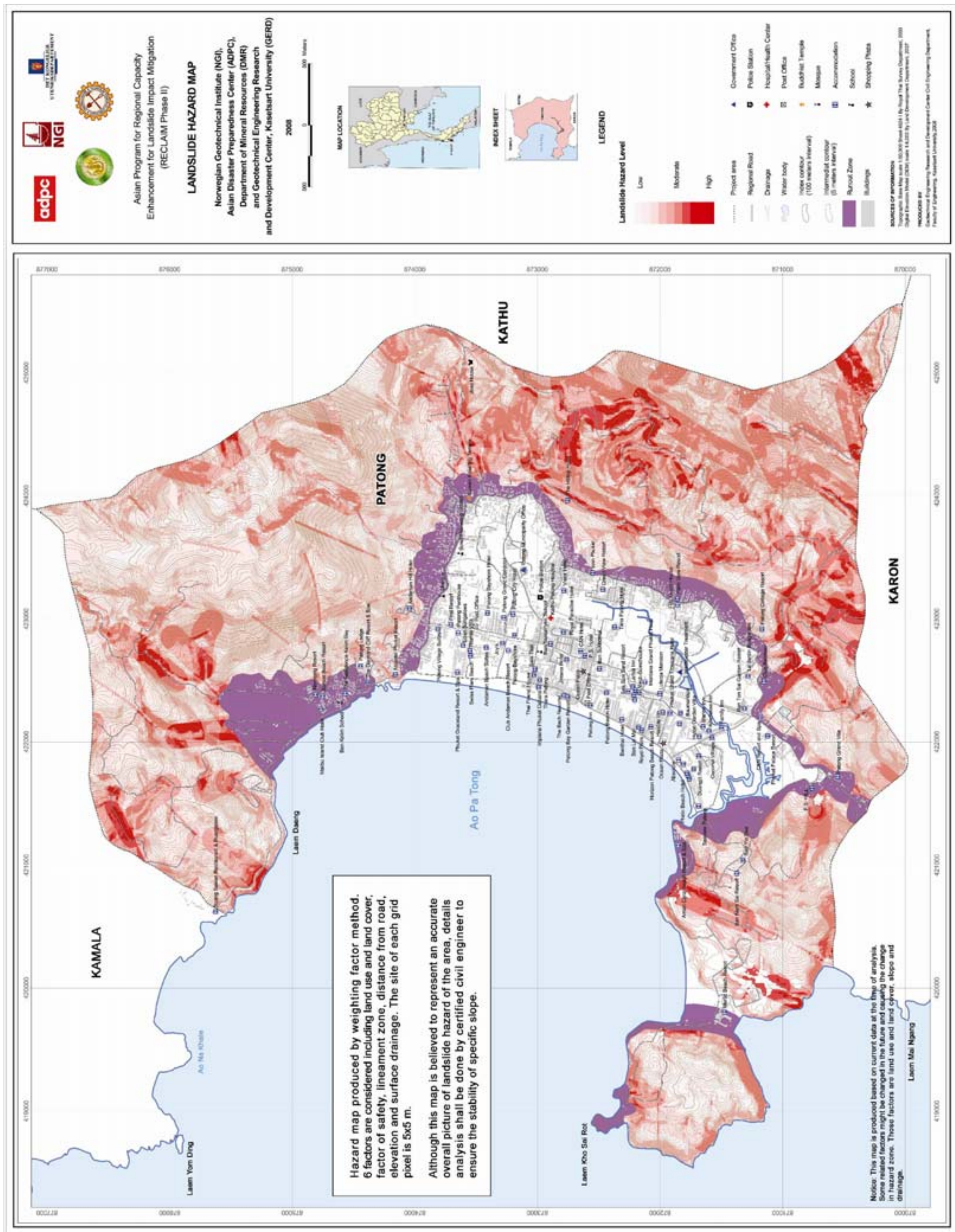


Figure 3-9 The boundary of affected area at the toe of the slope.

Chapter 4

Flood Mapping

4.1 Introduction

Patong City is situated on a floodplain between the Patong Bay and the surrounding hills. Maps showing susceptibility for landslides risk have been produced for the hills. Since Debris flows and flooding are often connected, and it was therefore decided that the flood hazard also needed to be considered in the project. The present study covers the flood inundation on the floodplain. The scope has been to find the danger of inundation in different areas of Patong City. Based on the results, areas likely to be flooded can be identified. NGI kindly offered to assist Kasetsart University on this matter and take the lead for the modeling. The capacity of channels and culverts can be assessed and bottlenecks in the system identified. The photo in Figure 4-1 illustrates the actuality of the problem. The channel is presently being widened and stabilized. The over bank area is turned into developing area. Preparation work for this report was done in connection with a 7 days mission by NGI experts to Patong in April/May 2007. A preliminary report on inundation was presented in July 2007. The input data at that time, especially for topography was however incomplete, and the predicted results were not up to desired standard. This report is prepared on the basis of new and improved data sets for the topography and culverts geometry, received from Kasaret University in July 2008.

Figure 4-1 Channel construction between bridge 6 and 7 (see later description of bridges/culverts)

4.2 Flood Plane Topography

The flood plain is approximately 1.5 wide and 4.0 km long, and the elevation less than five above sea level. Patong has a low raised beach ridge that creates a lower floodplain inside the beach area. At the northern part of the beach, the terrain rise steadily up to about 5 m elevation. Further south, the terrain is lower and the river had originally meandering patterns. The main channel or river runs parallel with the beach southwards along the floodplain and enter the sea at the southern part of the bay. The river is canalized in the upper part. Older map show that the drainage patterns earlier was closer to the beach and more of the interior lowland was wet land. However, the streams and floodplain has been more or less arbitrary has been raised to dry ground. This urbanization has changed the outflow from the area, and further urbanization will continue to increase the peak discharge. Wet land slows down the run-off in an area and makes a sort of natural regulation of river floods. The lower 1 km of the channel is mainly natural, expect that an old meander and flood areas are replaced by a landfill. The flow in this part of the river is sub critical i.e. mainly dependent on sea level. Upstream the water treatment plant, the channel is man-made and probably widened and deepened. The channel is zigzagging in an un-natural manner and a number of culverts and bridges control the flow.

4.3 Hydrologic Modeling

4.3.1 Rainfall analysis

Rainfall has been analysed at six stations on Phuket Island by Mr. Damrong Pungsuwan from Kasetsart University. Figure 4-2 A and B illustrate analysis of extreme precipitation for one of these stations. Figure 4-3 shows these extreme values distributed in time. Table 4-1 shows the cumulative precipitation for the central 24-hours event for 10, 50 and 100 years return period as given in Figure 4.3.

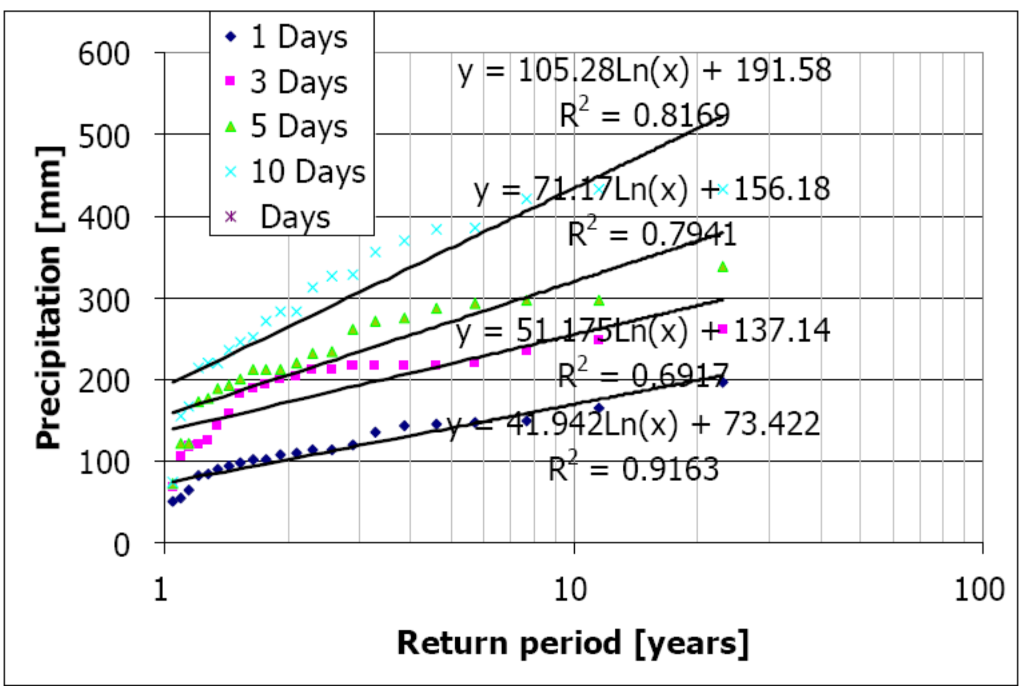


Figure 4-2 A Extreme precipitation analyses for different periods.

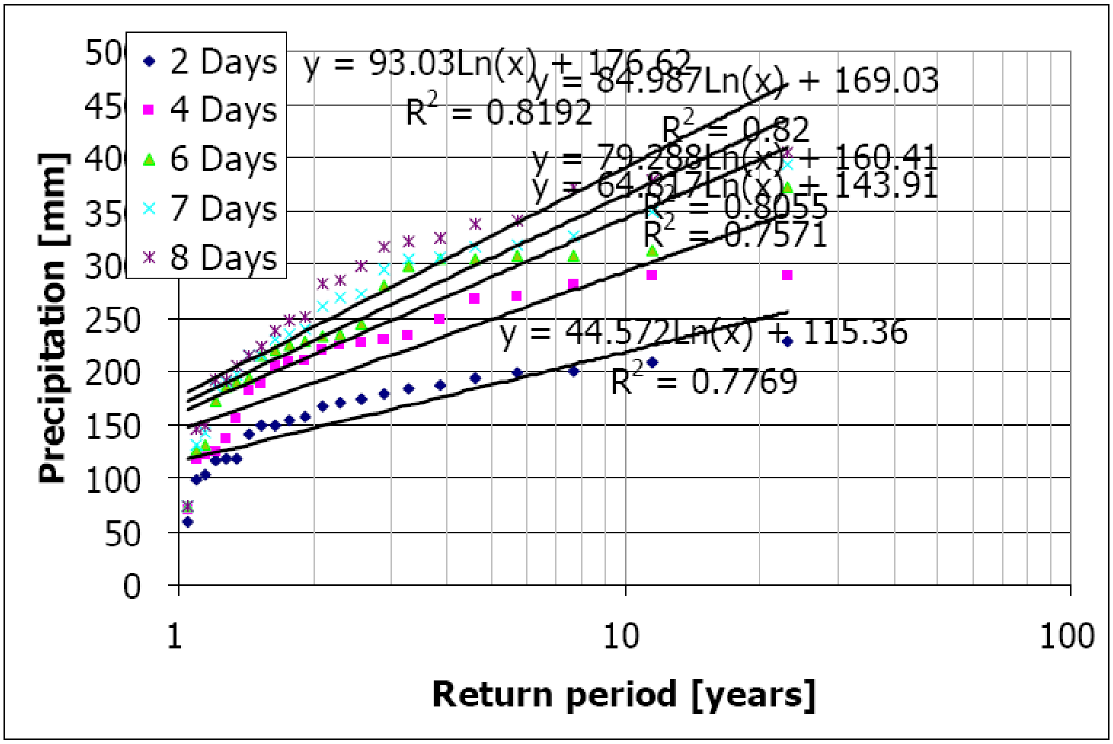


Figure 4-2 B Extreme precipitation analyses for different periods.

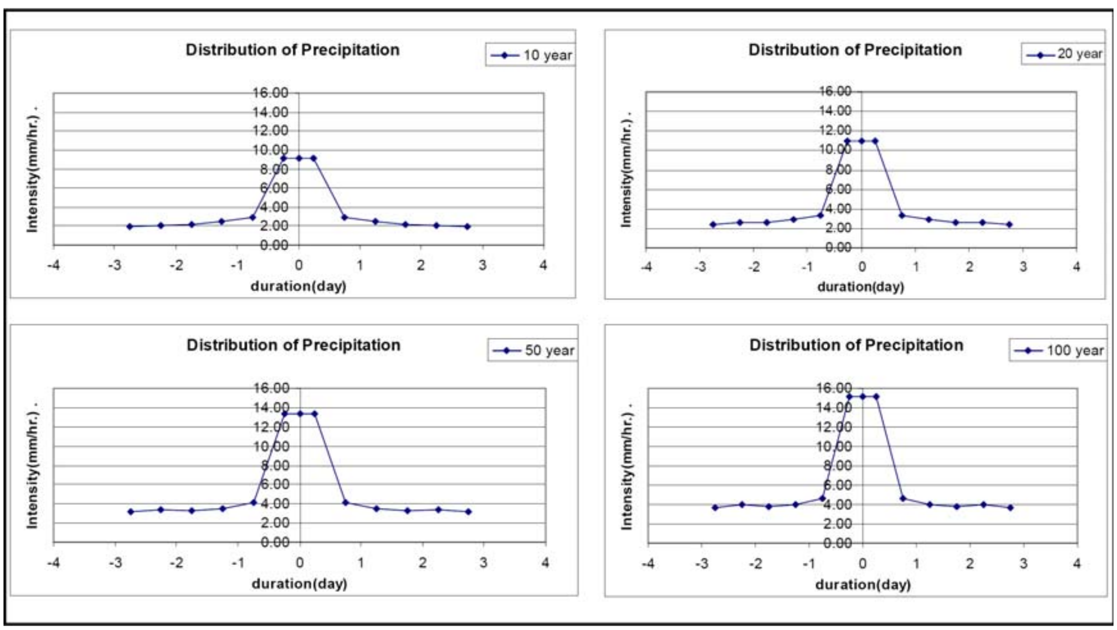


Figure 4-3 Time distributed extreme rainfall events.

Table 4-1 Cumulative 24 hours precipitation for different return periods.

Return period (years)	1	10	20	50	100
Precipitation (mm/day)	62	182	218	266	302

From these 24 hours values and additional 2 and 3 days events, rainfall patterns for 10 and 50 years event are presented as shown in Figure 4. These rainfall patterns have been applied in the hydrological model. Extreme precipitation values for longer durations than approximately 3 days may possibly contain more than one rainfall event and have therefore not been investigated in this study. Figure 4-4 shows some extreme events with high resolution in time (3 hours) for precipitation events at Phuket during the last 6 years. The curves show that 3 hours precipitation can be as high as 150 mm, and that the situation in 2001 is close to the 50-years event in Table 4-1. The intensity was then about 50 mm per hour. The 50 years event in Figure 4-2 is used as an example in the further analysis. The rainfall intensity is about 13 mm per hour during 16 hours.

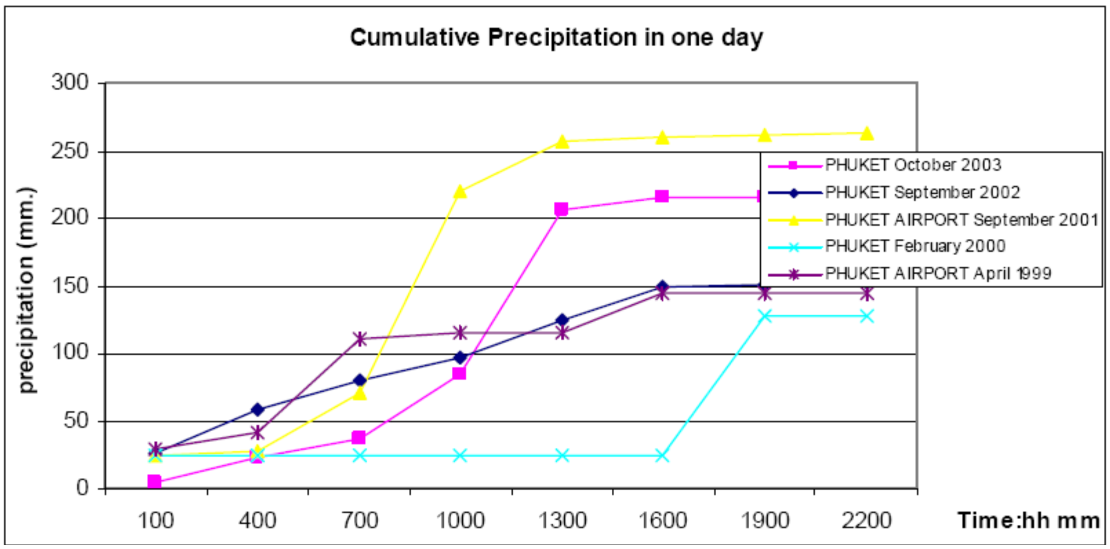


Figure 4-4 Observed precipitation events.

4.3.2 Run-off modeling

The run-off modelling was carried out with the computer program HEC-HMS
The model consists of sub-basins, linked by joints and reaches. Some of the sub-basins represent steep forest area, other more flat and urban areas. Both in the sub-basins and the reaches, the running water is routed in time domain. Based on the terrain model (hereafter called DEM), the catchment area around Patong was defined and further subdivided into 12 sub-basins. Figure 4-5 illustrates the catchment area with sub-basins marked as black bold polygons. Figure 4-6 illustrates graphically the model set up. The hills and city are represented in different kind of sub-basins. The urban city is more impervious than the hills due to asphalt and buildings and the area is flatter. The ground and the threes at the hills retain more of the precipitation compared with the urban areas, but the slopes make faster routing. However, during long prevailing rainfall, the retention per hour decreases due to saturating of the ground.

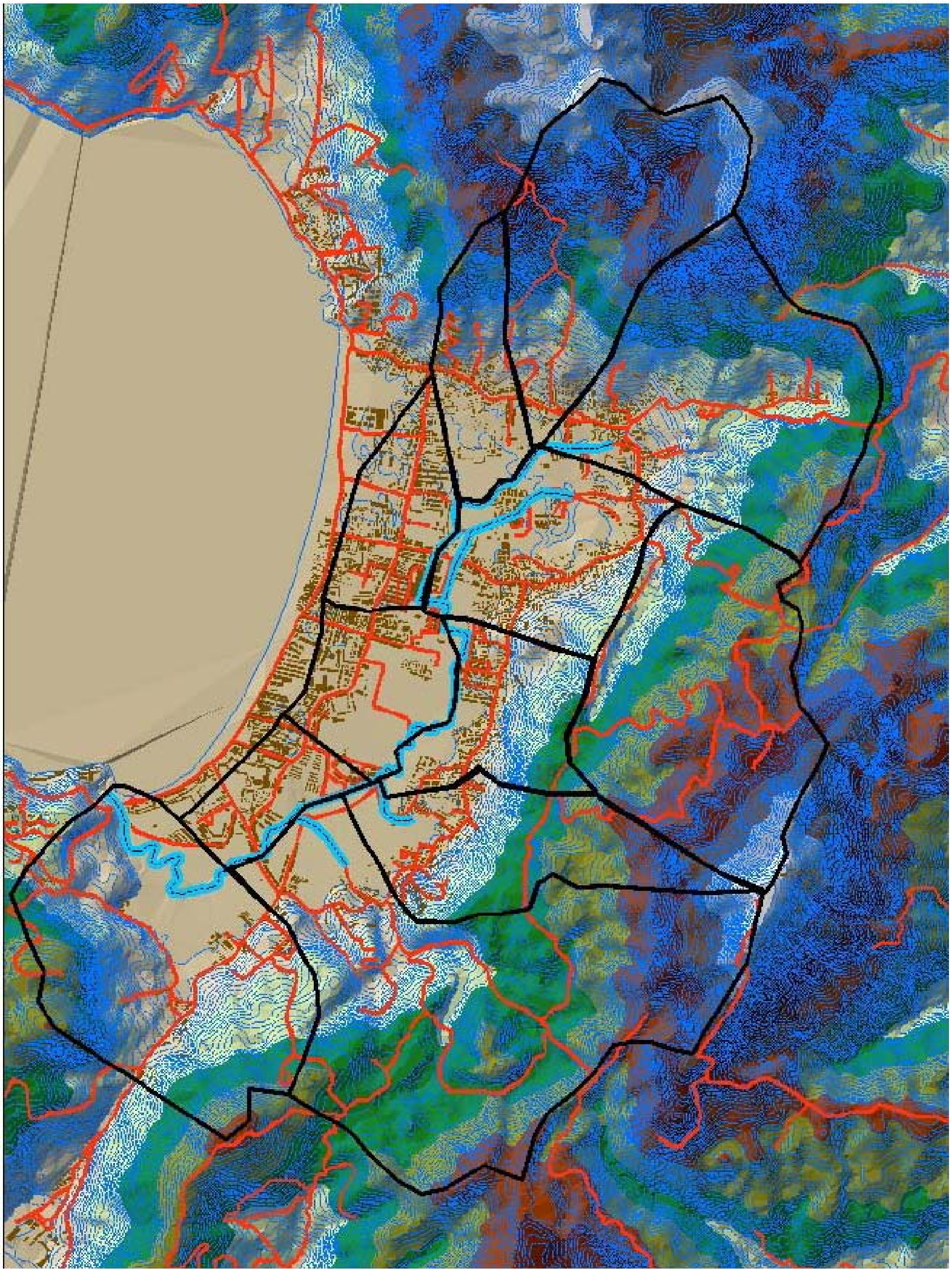


Figure 4-5 Subbasin divisions.

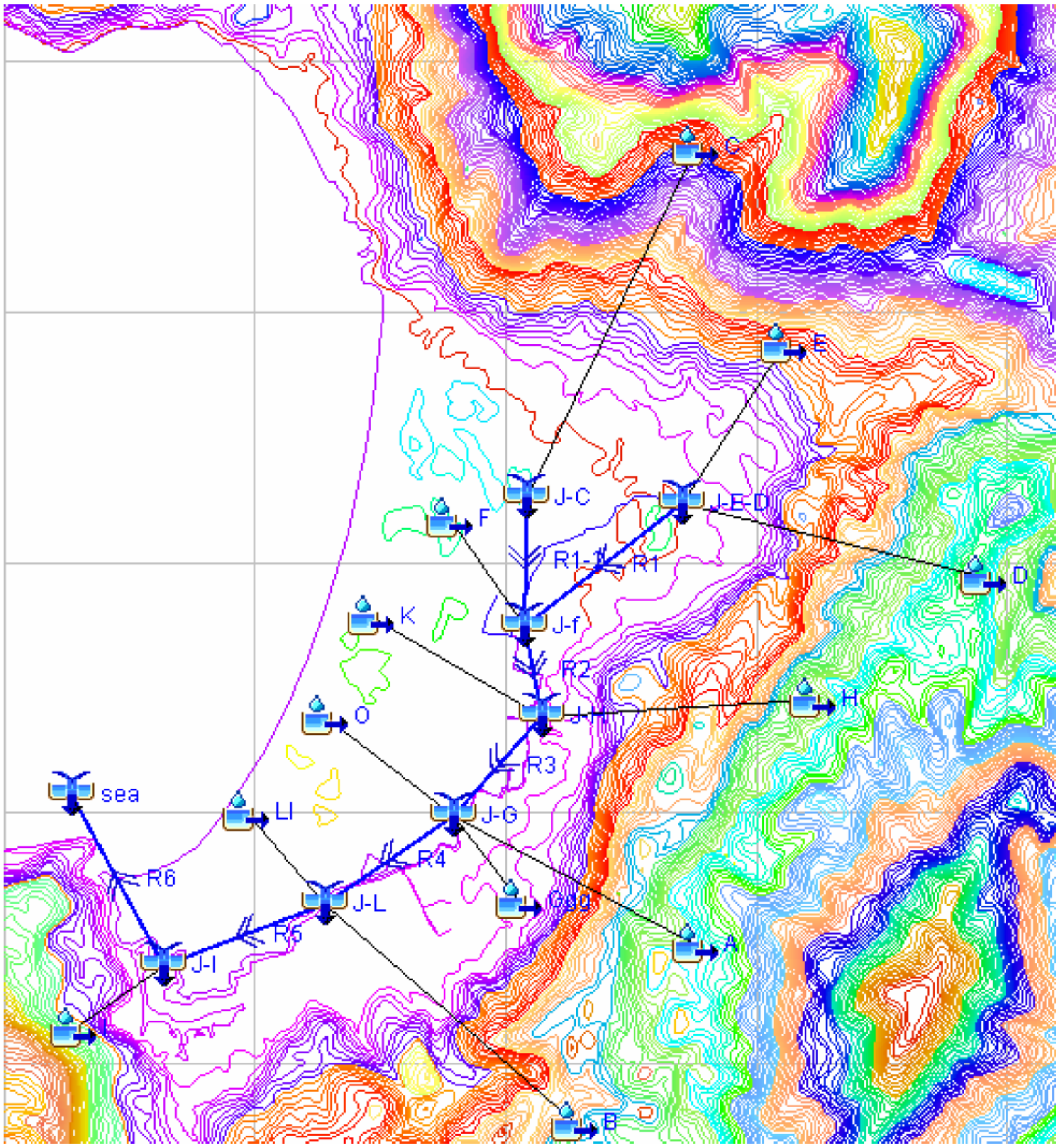


Figure 6 Graphically presentation of the sub-basins and their connections.

Figure 4-7 illustrates the rainfall applied in all sub-basins. The water will be concentrated differently and use different flow time to reach the sea dependent on the sub-basin properties their geographical location. These features are taken care of in the hydrologic model.

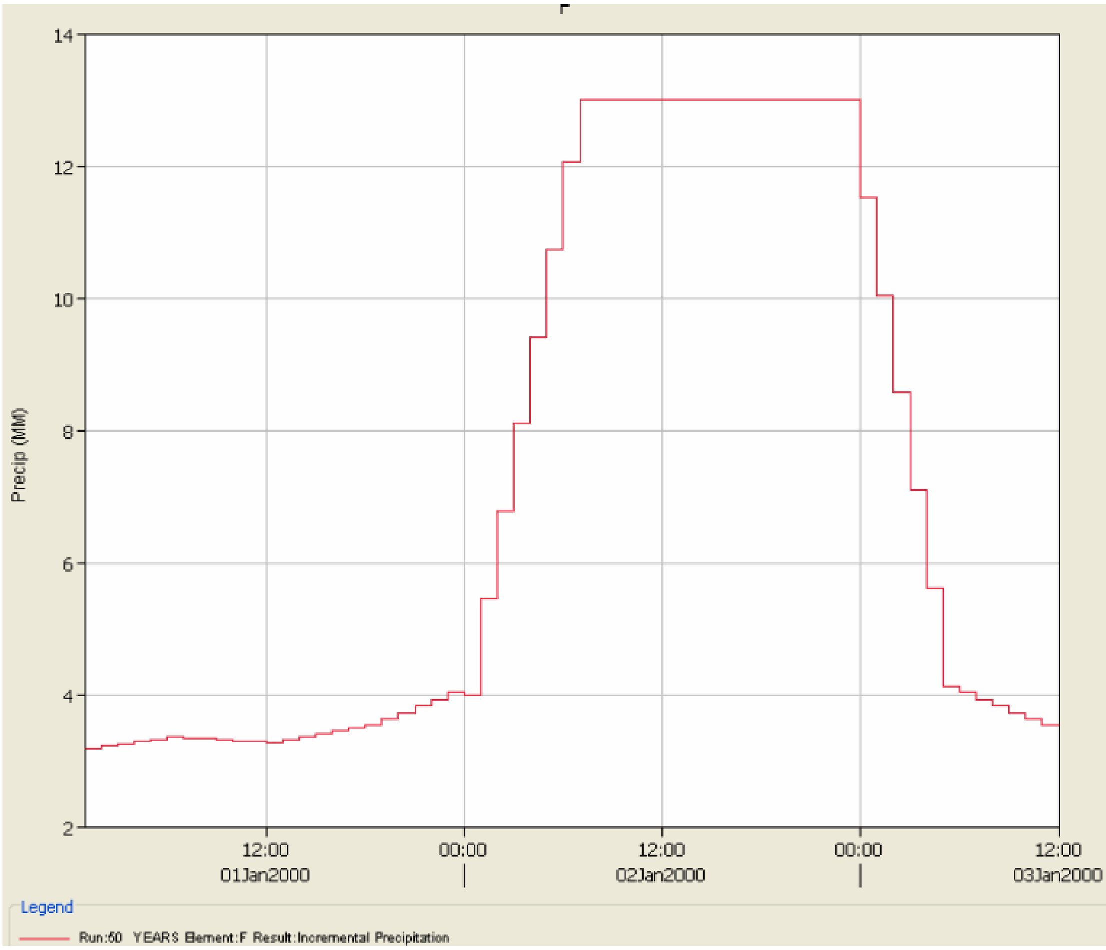


Figure 4-7 Rainfall input (from figure 4-3).

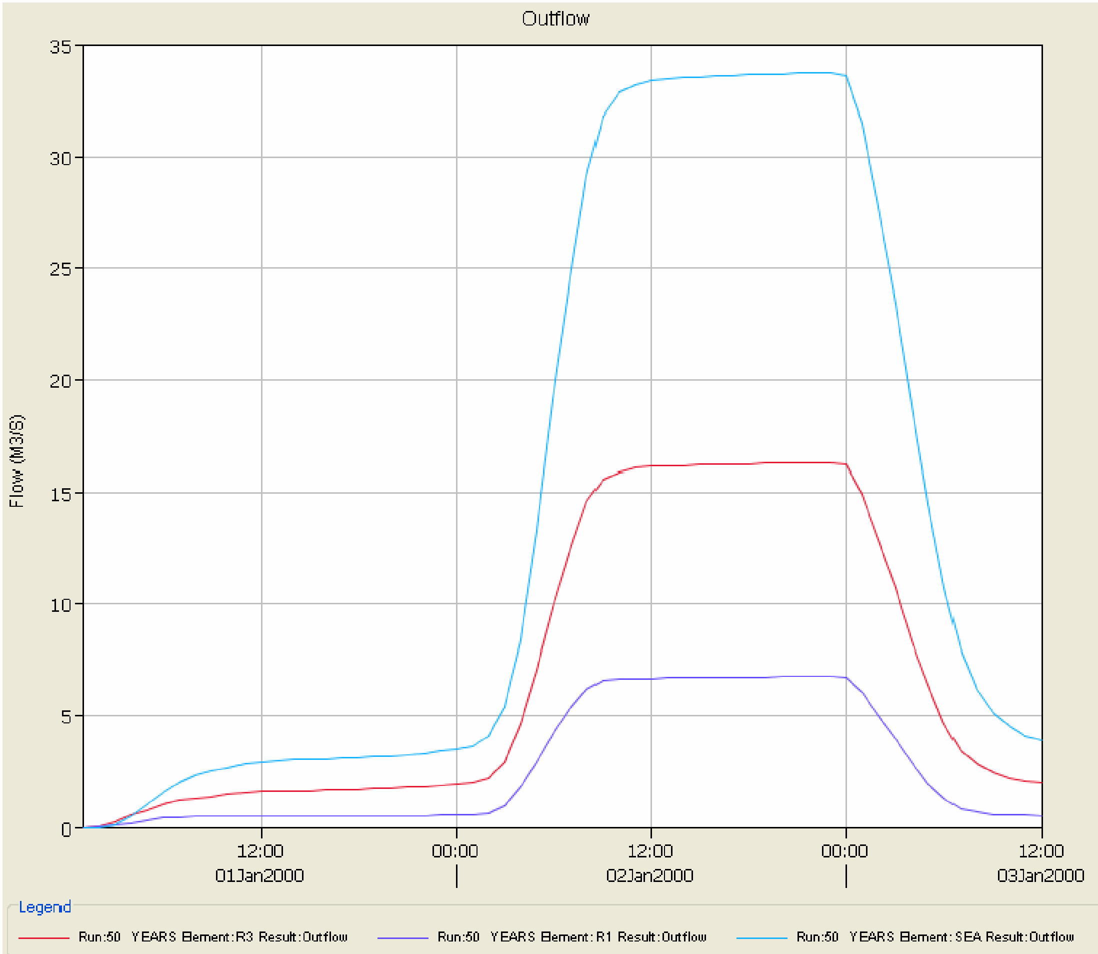


Figure 4-8 Modelled discharges at different location along the channel. The uppermost graph represents discharge into the sea.

Figure 4-8 illustrates runoff at different location along the channel. The upper graph represents discharge into the sea; while the lower curve represent the upper end of the channel modelled in the hydraulic model. Due to the long time with constant intensity, the outflow reaches almost constant discharge. This fact justifies the use of steady state calculations in the hydraulic model. The peak value is rather flat, indicating that the critical selected rainfall values (24 h) are longer than the time of concentration for the catchment area. It might be relevant at a later stage possibly to study the use of a shorter and more intense rainfall. Table 4-2 shows the discharges applied in the hydraulic model. As a verification of these runoff calculations the following estimation are made:

- The Patong catchment area is approximately 12 km^2.
- With a rainfall of 13 mm per hour, this sums up to 156 000 m^3 of water per hour, or 43 m^3/s.
- The difference between this value and the peak values in Figure 4-4, are caused mainly by loss due to infiltration into the ground.

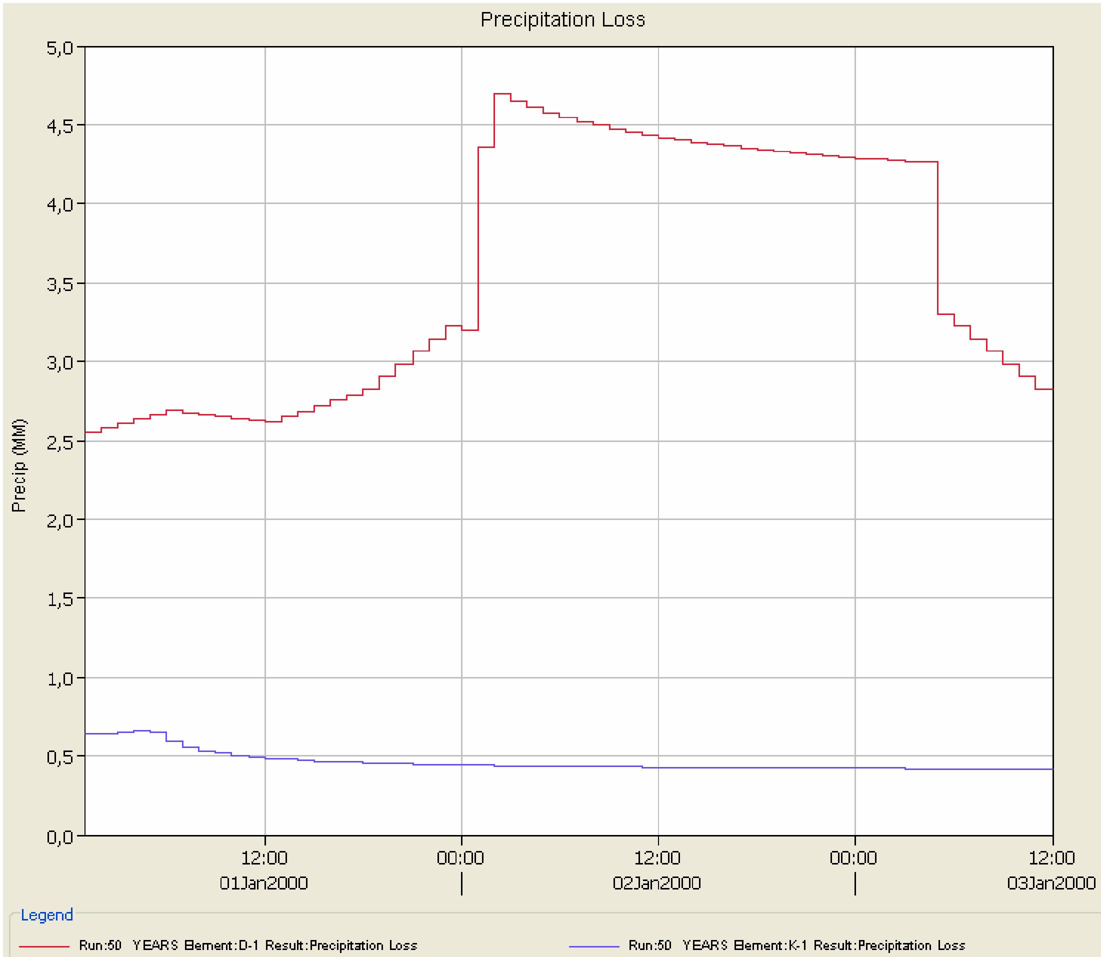


Figure 4-9 Calculated losses in two subbasins; upper graph represent hill areas, lower graph represent city areas.

Figure 4-9 shows precipitation loss in two subbasins. The upper red curve represents loss in an area dominated by forest, while the lower blue one represents an urban sub-basin. In a detail study, these loss functions (Green and Amt is applied) can be calibrated against measured data.

4.4 River Hydraulic Modeling

A hydraulic model calculates water surface elevation at specified point along a channel. In a river environment, the water level depend, either of downstream condition (sub-critical flow), upstream (supercritical flow), or local conditions (critical flow). Critical flow will typical occur at weirs, and it is essential to know the geometry and elevation of invert for these structures.

4.4.1 Geometric input

At the lower part of the channel, up to the water treatment plant, 6 cross sections were measured. Further upstream especially the culverts has been measured. Locations of these culverts or bridges are shown in figure 4-11 and 4-13. Figure 4-15 - 4-21 show pictures of the seven lowermost culverts/bridges in the channel. The distance between the cross section, reach lengths, and structure on the HEC- RAS model is created in ARC GIS by using the HEC-Geo RAS tool. Figure 4-10 illustrates the horizontal geometry of the channel through Patong city

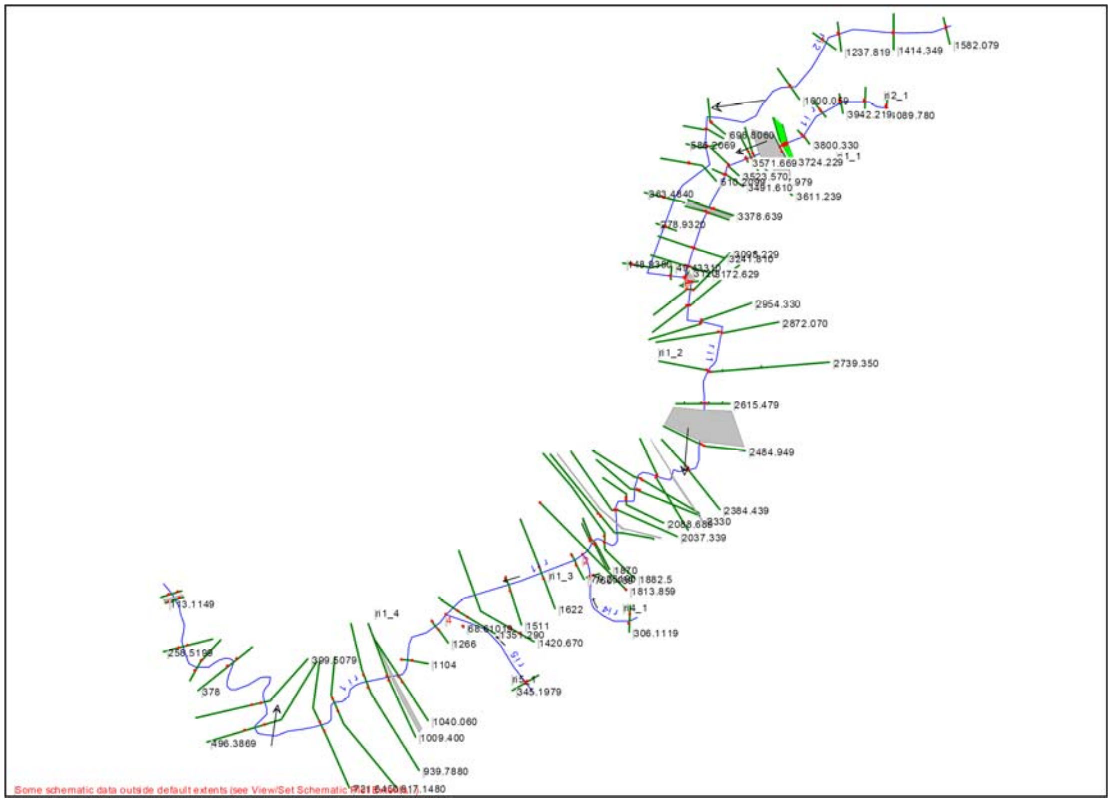


Figure 4-10 Geometrical presentations in HEC- RAS

4.4.2 Boundary conditions

The lower boundary in the model is sea level. It is chosen a sea level of 1.4m that represents spring tide at Phuket City. The upstream boundary condition is set to critical depth. This makes it possible for the model to calculate mixed flow, i.e. shift between sub-critical and supercritical flow within the model. If the model finds sub-critical flow conditions at the upper boundary, the water level is calculated as sub-critical. The inflow to the hydraulic model is taken from the HEC-HMS model. The discharge increases stepwise downstream from the start of the model. Table 4-2 shows these values. These steps represent inflow from side channels and lateral areas. At the lowermost part of the channel, the discharge for a 10 years event is 20 m3/s and 30 m3/s for a 50 years event.

Table 4-2 Statistical discharges along the main channel.

Location (distance from sea) (m)	10 years event (m^3/s)	50 years event (m^3/s)
4000	2.1	3.9
3100	9.6	16.3
1800	13.3	22.0
1200	20.1	29.7

4.4.3 Results

Figure 4-10 show result for a flow representing a 50-years event (~30 m^3/s) and flow with 10 m^3/s. For both of these cases, the culvert from culvert/bridge nr 3 (see Chapter 7, Photo Illustrations) will be drowned, the pipes will be submerged and overflow will occur. Bridge 5 is a bridge that has large effects upstream. The closed part of the river bridge 6 seems two have enough capacity, however the total geometry of this closure is not known, It can also be seen that the tide has influence about 2 km upstream from the sea. These result is depend strongly on correct elevation of the culverts.

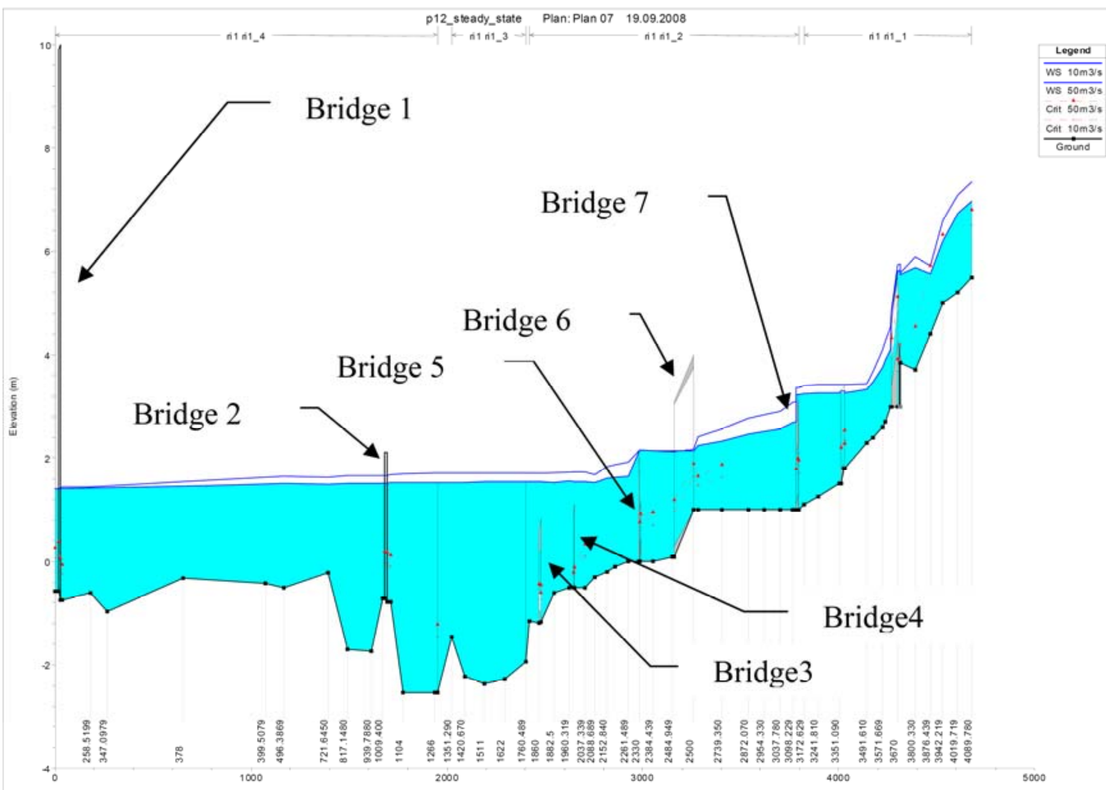


Figure 4-11 Calculated water surface elevations along the channel

Partially blocking of culverts due to debris are not tested at this stage of the model. Attention for improving the model should therefore be on culvert geometry and invert levels. Figure 4-13 typically illustrates the level and geometries that should be measured at each bridge or river crossing.

4.5 GIS Analysis

4.5.1 Methods

The objective with the GIS analysis is to create the final inundation map. The water stages are calculated at cross sections with geographic locations. The lines representing the cross sections are extended across the floodplain or into streets based on hydraulic judgment. These cross section lines have water stages representing different return periods that are used to create a digital elevation model of the water surface. By subtraction the water surface model from digital terrain model, negative values represent water depth in inundated areas. Figure 4-12 illustrates the flood inundation surface model. Figure 4-13 shows the ground surface model. The ground surface model (in figure 4-13) is subtracted from the flood inundation model (figure 4-12) and presented as dark blue cells indicate inundated areas in Figure 4-14. Figure 4-14 shows clearly that there is a difference in vertical datum of the terrain model and the hydraulic model. Below “Bridge 3”, the river bank is well represented in both models (The river bank points along the river is included in the model), but the terrain lowlands along the river are badly represented. The terrain model in southern part of the bay is probably to low. The lower part of the river has 1.4 m as inundation level. Above “Bridge 3” there is a vertical gap between the models. The hydraulic model gives a number of submerged culverts, while this is not visible transformed back to the terrain. Figure 4-15 present the result together with roads and buildings and areas that are believed to be lowland relative to the channel.

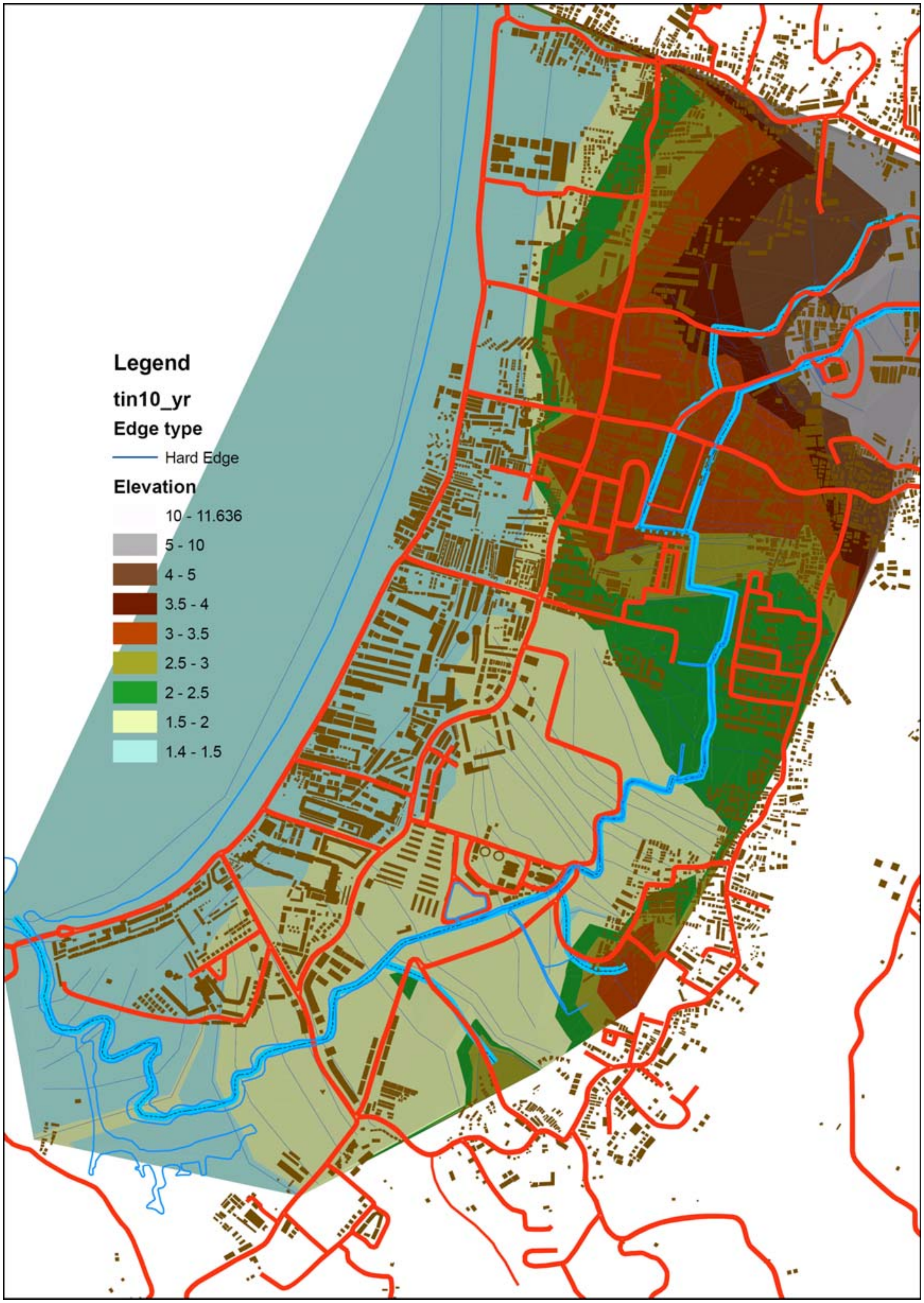


Figure 4-12 Terrain model of 10 years flood water surface.

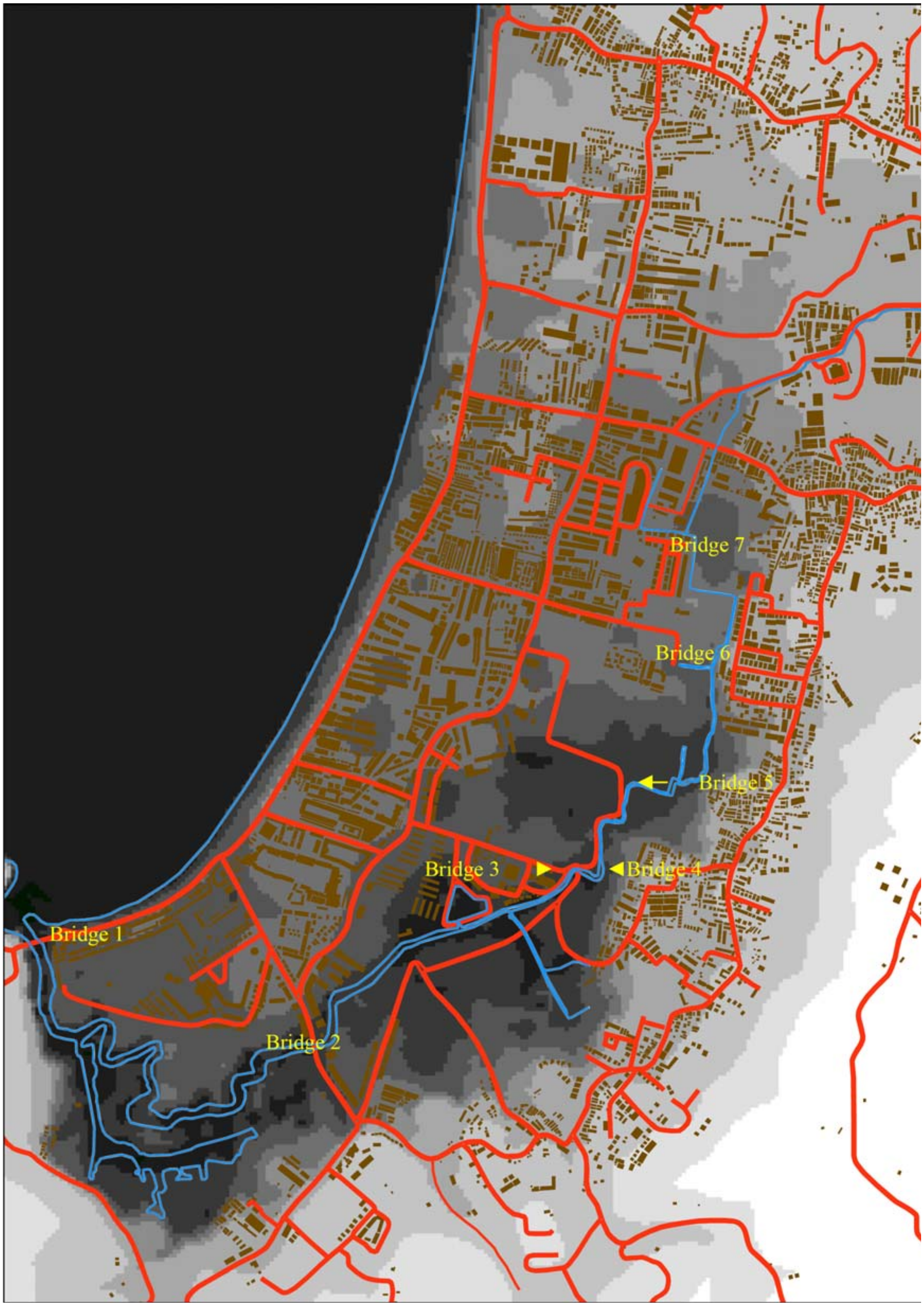


Figure 4-13 Ground surface model and bridge locations. The dark areas represent low laying areas.

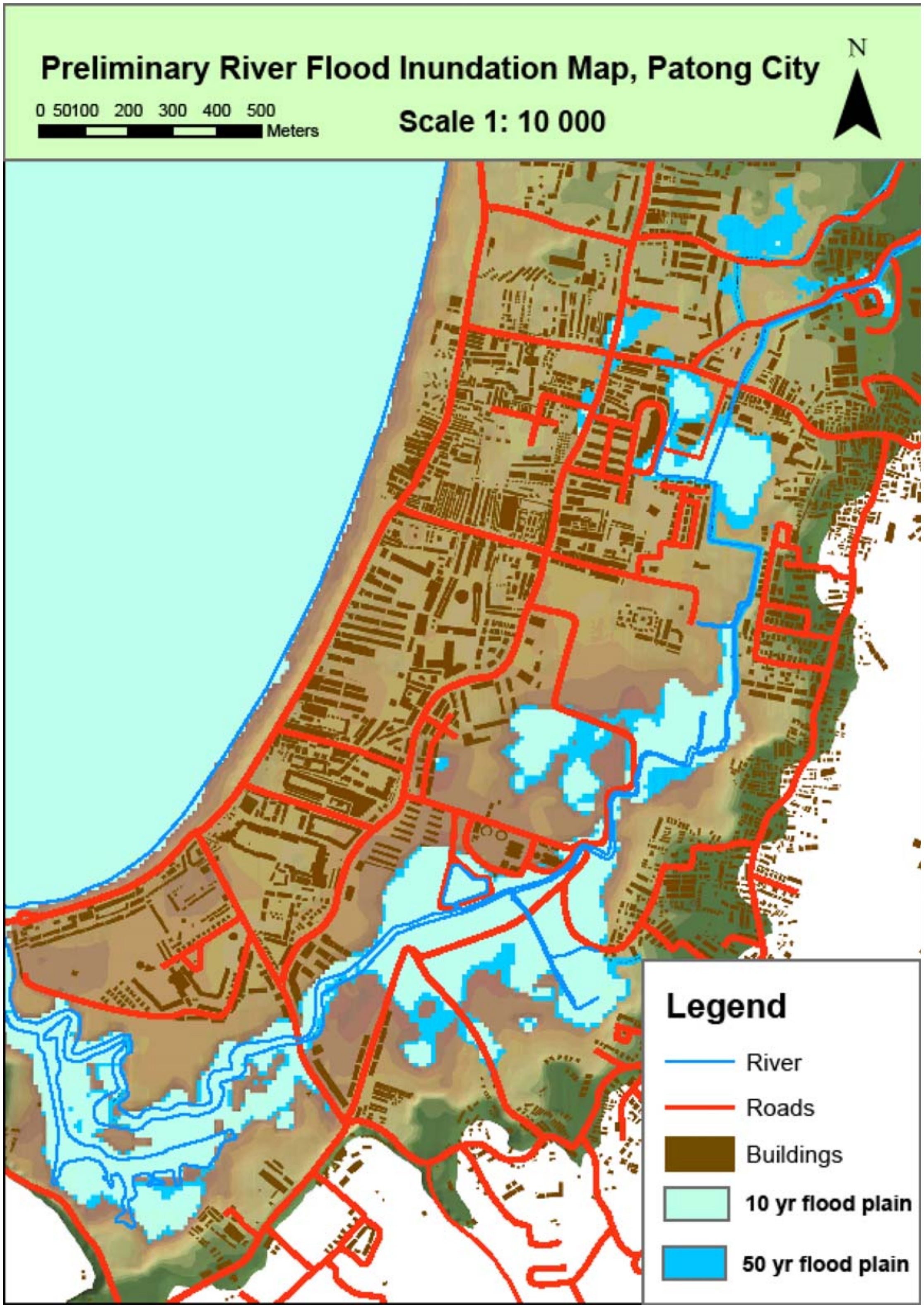


Figure 4-14 Predicted flood inundation for 10 and 50 years rainfall return period.

For this kind of analysis, the accuracy in the terrain model is of great importance important. In a city, it is normally required to have 1 m elevation counters with accuracy for the elevation contours about 1 foot.

4.5.2 Preliminary analysis of inundation areas

Most of Patong city is prone to inundation due to rainfall, and the City should be prepared to experience at least 0.3 meter of water compared with local street level at a frequency less than once in 10 year. The reason is that the streets are relatively flat and the main channel capacity is restricted. The local accumulated rainfall in the city itself will not be drained by its local drainage systems when the channel is completely filled with water. In fact large parts of the city will get inflow from the main channel system, blocking its internal drainage capacity. Only streets with direct falling slopes and surface runoff to the sea will avoid these effects. In some places, backflow gates are installed between the main channel and the pipes, preventing inflow from the main channel. The reviewed terrain model seems to represent the topography of the city at an acceptable manner. Further experience through work with the model, and field observations (flood levels) will improve the map and the use of the area. . The city can simplified be divided into three categories with respect to inundation during flash floods:

1. Areas with streets continuously sloping to the sea
2. Areas with directly connected and dependent of drainage through the main channel upstream of Fresh marked
3. Areas with directly connected and dependent of drainage through the main channel downstream of Fresh marked for situation more frequent than once in 10 year, in area 1, 0.3 m water should be expected. In area 2, 0.3 – 0.5 m of water should be expected relatively to the new main road. Local depressions will increase the water depth. Tide level strongly influence the outflow and water surface level of the area. In area 3) 0.5 m of water should be expected. The outflow is delayed compared to the lower area due to the channel closure. Continuously improvement of the terrain data will improve these judgments.

4.6 Summary

The method of analyse and approach for producing flood inundation maps are presented through a practical study for Patong City. The report contains a description of the hydrologic assumptions, the run-off modelling, the river hydraulic analysis and the final GIS analysis. The study was carried out as a team work between the municipality, Kasetsart University and ADPC with NGI as the lead part. The resulting flood inundation is methodically correctly assessed. This report is a revised and updated version of the Patong flood prediction study. It is based on new and more detailed input data for the topography and other geometries in the low land of the Patong Bay. The study clearly shows that Patong City is likely to be severely flooded even for moderate rainfall situations. Precipitation characteristics for return periods in the range 10 to 50 years have been analysed. Flash flood events with less that 10years return period are found to give more that 0.3 m of water in the streets in major areas of the city. City authorities are advised to keep all existing water ways open and avoid creating new barriers. It is also pointed out that a strengthened flood monitor program might provide valuable input for effective flood management. The maps or its low laying areas are not controlled by field measurements. Likely there are errors in the flood inundation area, however the areas are likely, and it is important to use the map in land use planning both for roads and buildings to reduce problems due to flood inundation.

4.7 Recommendation

For all construction and development work it is important to keep the waterways open, and secure that bridges and culverts do not create barriers. Areas mapped as flood risk areas, should not be developed without making efforts to reduce flood risk damage. Flood risk can be reduced by elevate the areas, improve the channels and culverts capacity. A policy should be established deciding the limits of what is acceptable flood risk in landuse planning. Handling of grey water including its treatment should be included as a theme in the river planning. During flood events, grey water and flood water get easily mixed, creating problems that can be more severe than just the flooding itself. The city should strengthen its flood observation program, including keeping good records of precipitation and associated flooding. Flood management can only be improved by having relevant observation data.

Figure 4-15 Bridge 1 from downstream

Figure 4-16 Bridge 2 from downstream (taken after rainfall)

Figure 4-17 Bridge 3 from upstream

Figure 4-18 Bridge 4 from upstream

Figure 4-19 Bridge 5 from downstream

Figure 4-20 Bridge 6 from upstream closure.

Figure 4-21 Bridge 7 from downstream

Chapter 5

Geotechnical and Geological Analysis

5.1 Geotechnical Engineering 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. 5-1 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 5-2. 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. 5-3 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. 5-4 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.

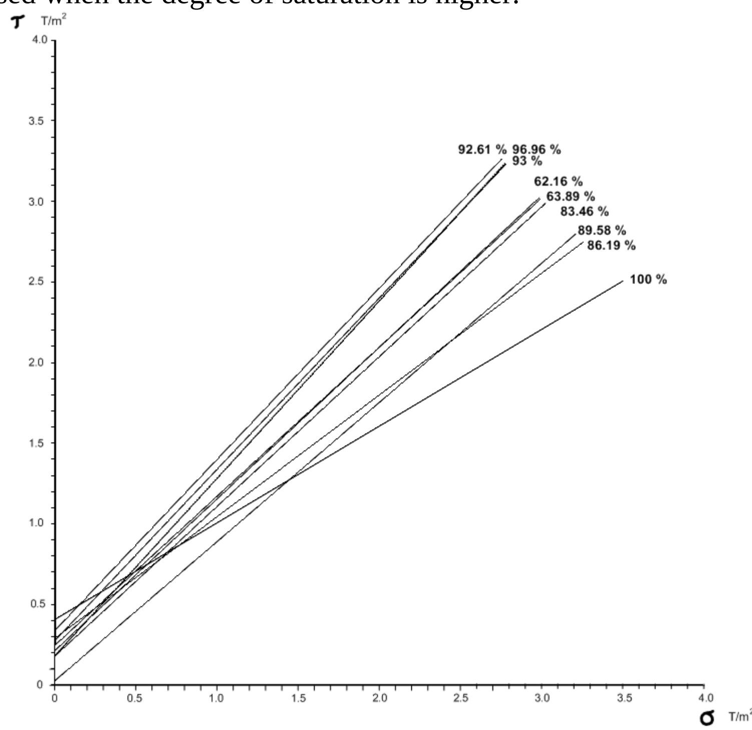
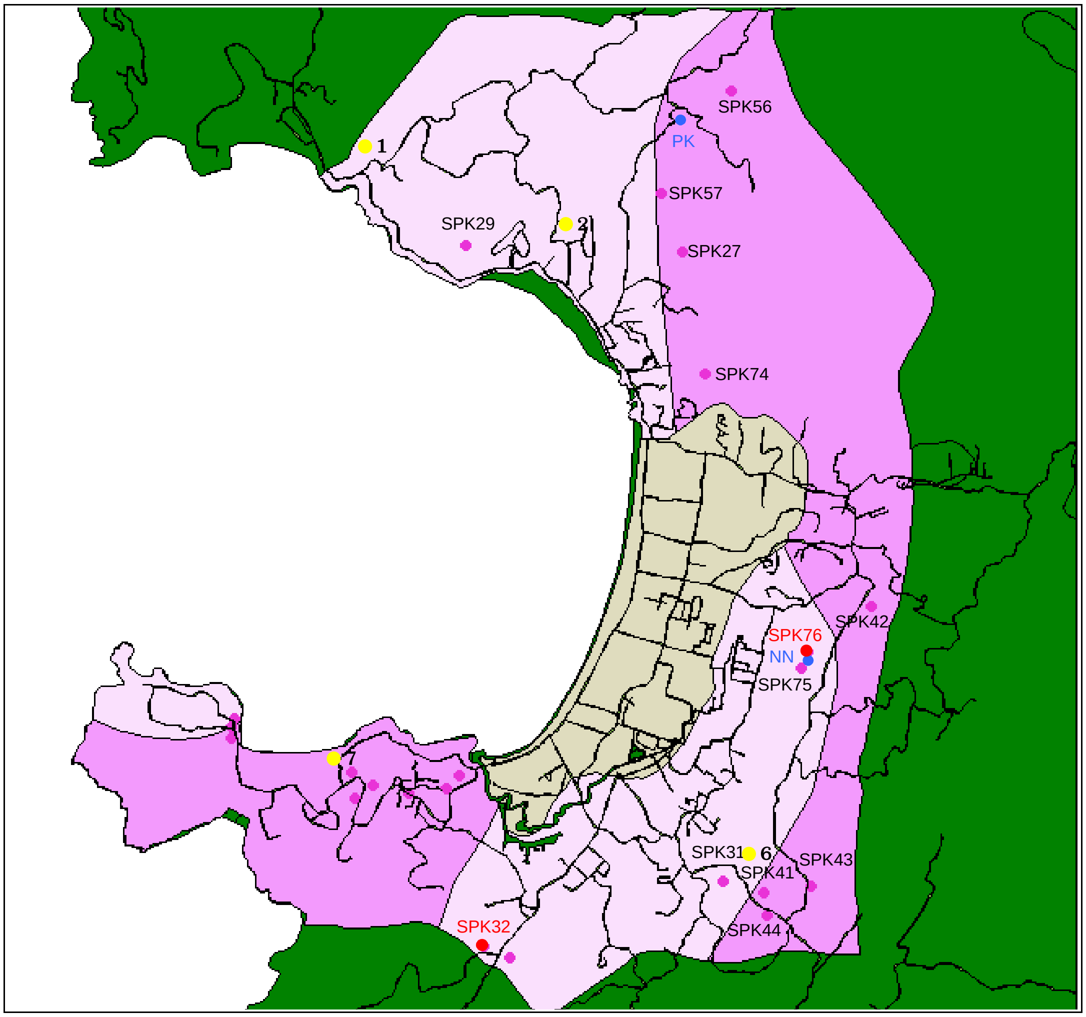


Figure 5-1 Variation of the previous data



ADPC

Previous project #1

Previous project #2

New location

Rock group G2

Rock group G4

Rock group Qb

Figure 5-2 Location of soil samples from various projects

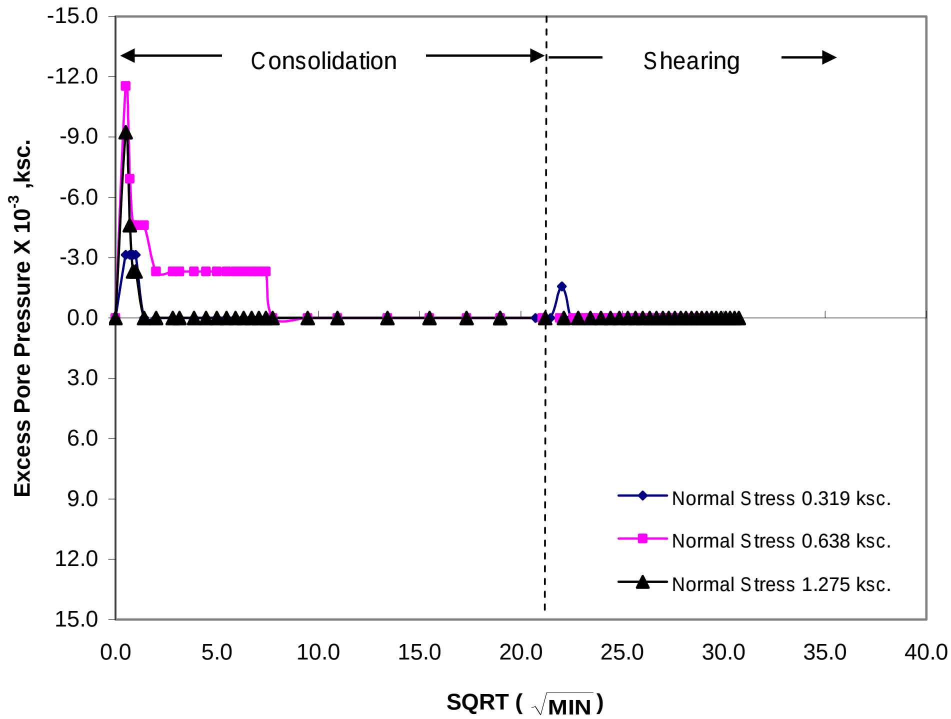


Figure 5-3 Excess pore pressure is exist only during consolidation stage

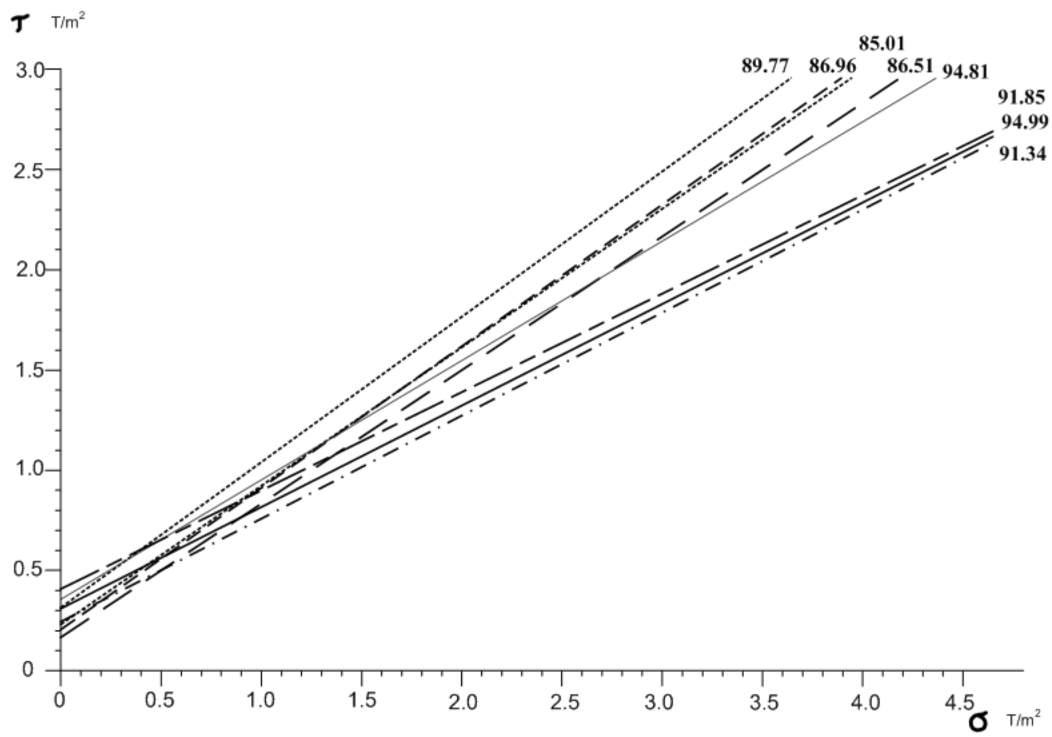


Figure 5-4 c,ϕ data are not vary as the previous

5.2 Geology Analyses

Detail analysis of linerment zone was done by DMR. The analysis is performed by Satellite image interpretation Fig. 5-5 show aerial photo of Patong city and Fig. 5-6 shows the result of the interpretation.

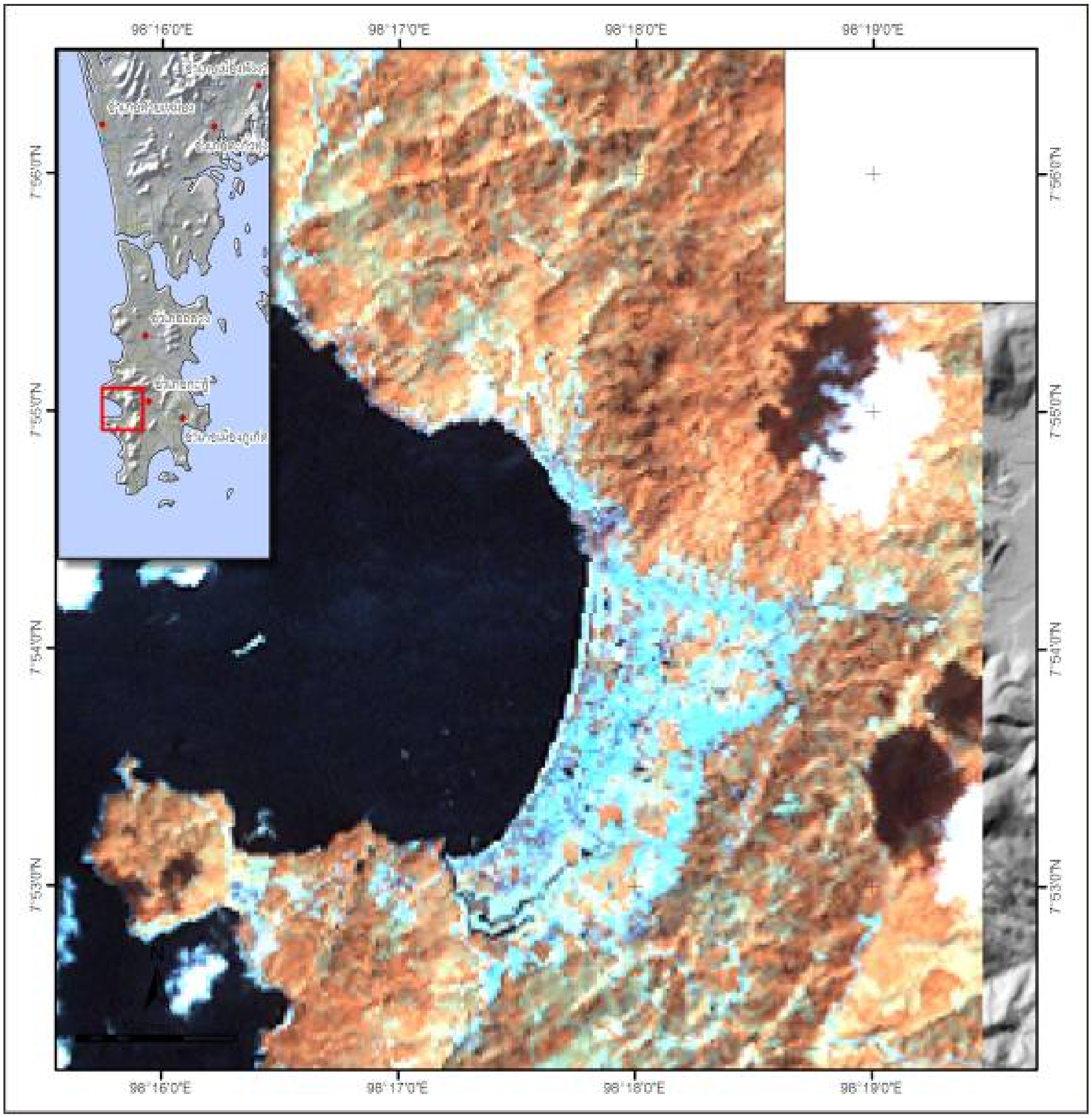


Figure 5-5 Satellite image of Patong city

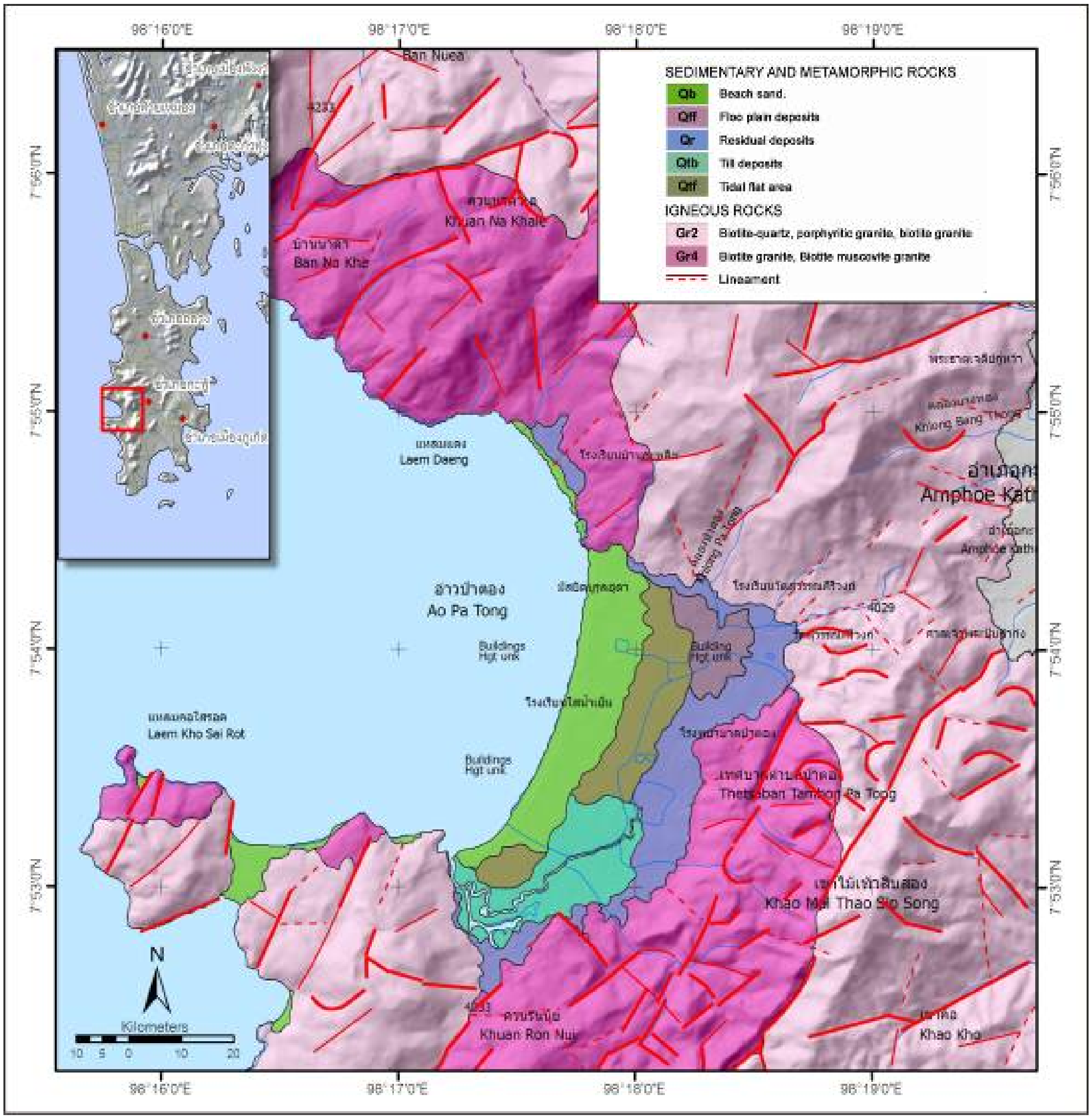


Figure 5-6 The result of the interpretation

5.3 Stability Analysis

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 5-7. Considering the upper hill of Na Nai community, it has a natural bench probably from the ancient sea elevation at the elevation of ELEV. +80.00 m.MSL. The cross section is shown in Fig 5-8.

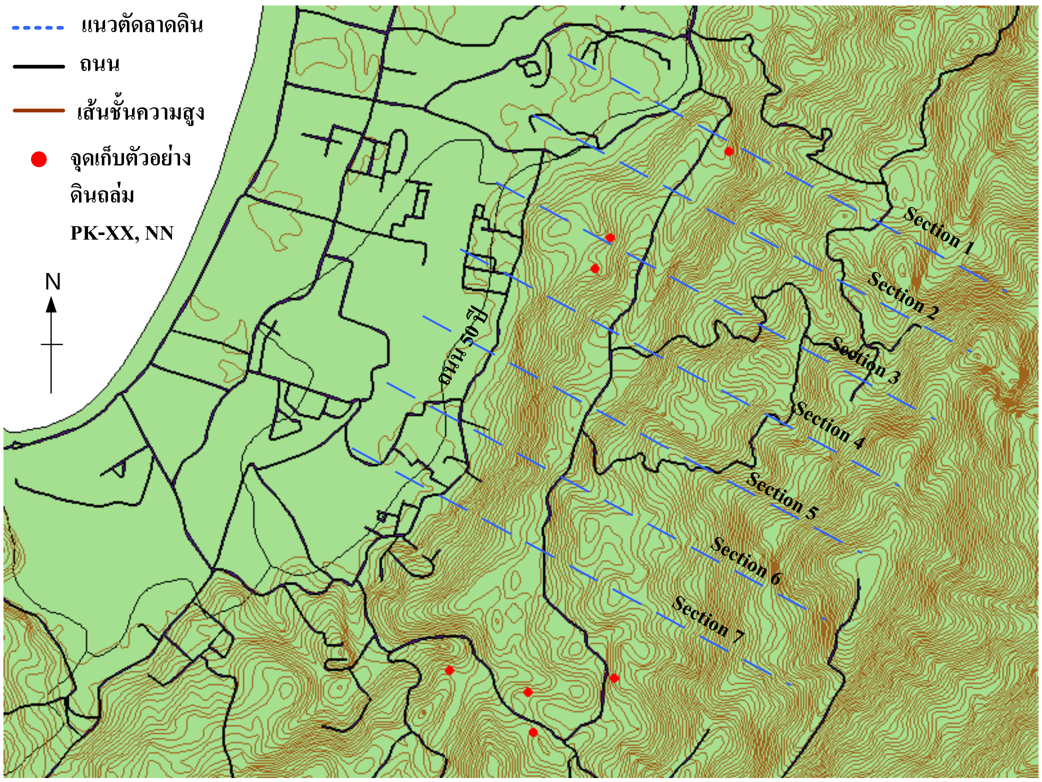


Figure 5-7 Cross section for stability analysis, Na Nai and 50st anniversary road

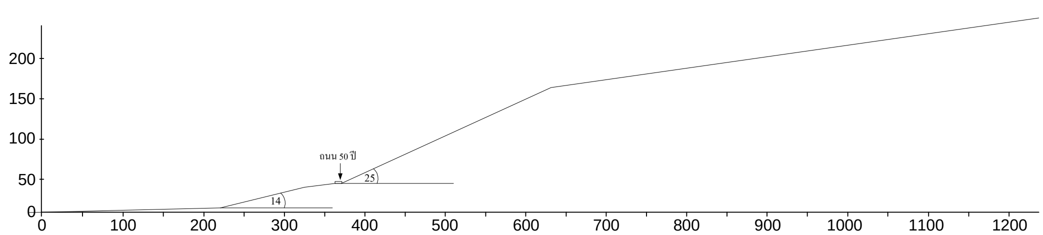
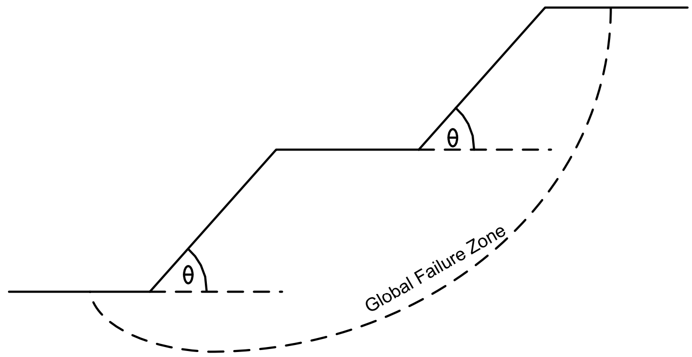
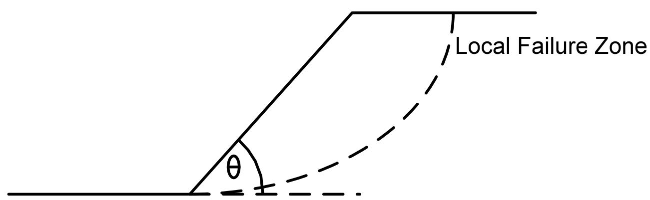


Figure 5-8 One of the cross section of slope over Na Nai community

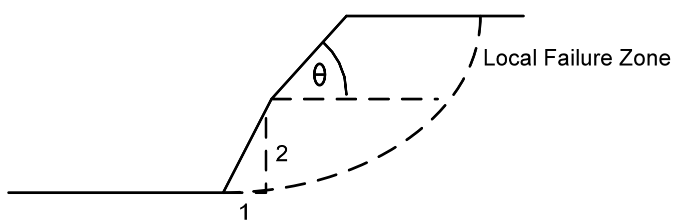
Three kinds of cross section were investigated as shown in Fig 5-9. They are two benching section, local slope in the upper or lower bench and cut slope from road or construction cutting (2H:1X). The preliminary results show that the failure surface doesn't occur through two benching as an overall stability failure but it rather failed at the local slope either lower or upper one.



a) Two benching model



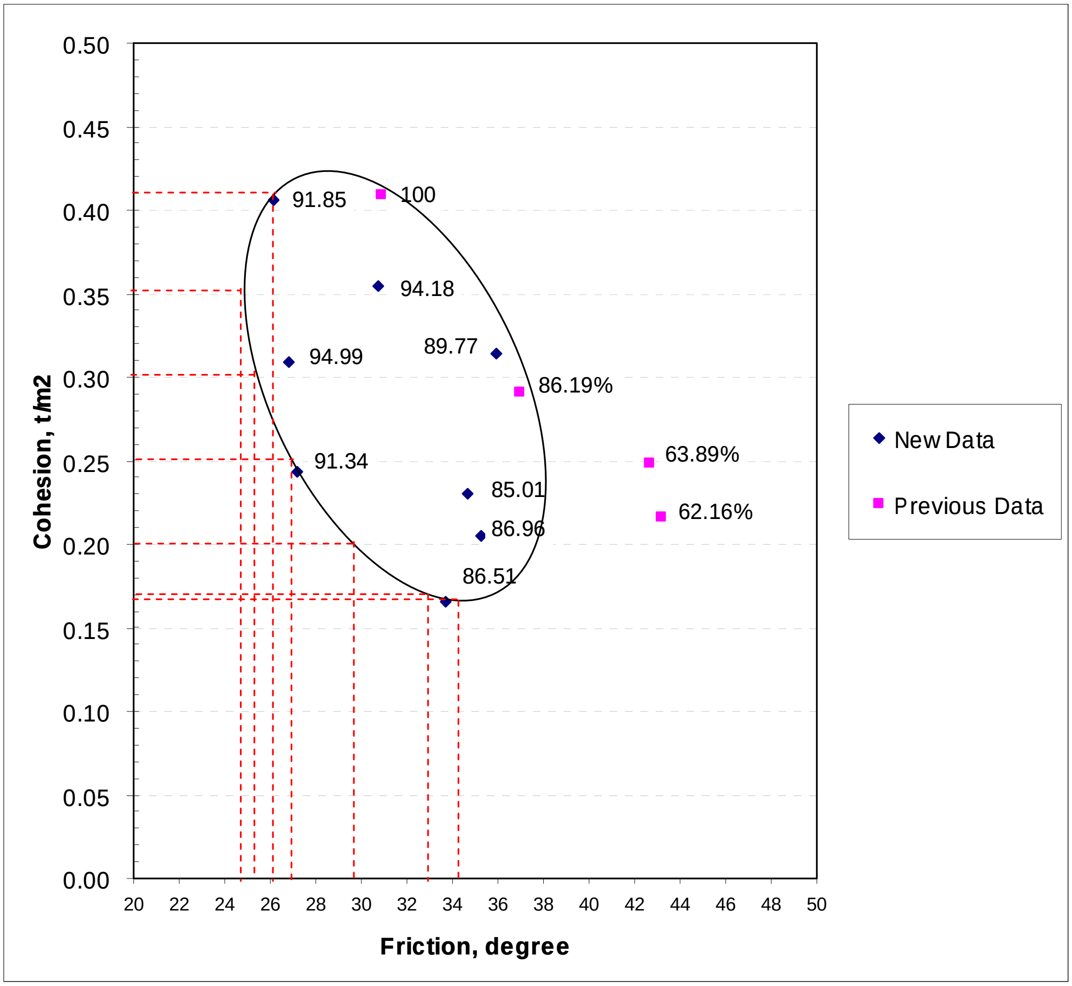
b) One benching model



c) Cut slope model

Figure 5-9 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 5-10. 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. 5-10). The results are summarized in Table 5-1 and Fig 5-11-5-12. 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 according 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 considered the counter measures.



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

Figure 5-10 The analyses were done with various degree of slope from 14 to 40 degrees of both natural (one bench) and cut slope

Table 5-1 Factor of safety from stability analyses

Slope	C, ksc	Friction, degree	Unit Weight, g/cu.mm.	Angle Degree	F.S.
Normal Slope	0.35	24.8	1.78	8	-
				10	-
				12	-
				14	2.29
				16	2.04
				18	1.83
				20	1.67
				22	1.52
				24	1.41
				26	1.31
				28	1.22
				30	1.15
				32	1.08
				34	1.02
				36	0.96
				38	0.92
				40	0.87
Cut Slope 2 : 1	0.17	33	1.78	8	2.87
				10	2.24
				12	1.85
				14	1.64
				16	1.49
				18	1.37
				20	1.32
				22	1.23
				24	1.14
				26	1.07
				28	1.01
				30	0.95
				32	0.93
				34	0.87
				36	0.83
				38	0.79
				40	0.75

Table 5-1(Cont.) Factor of safety from stability analyses

Slope	C, ksc	Friction, degree	Unit Weight, g/cu.mm.	Angle Degree	F.S.
Cut Slope 3 : 1	0.17	33	1.78	8	2.77
				10	2.05
				12	1.72
				14	1.50
				16	1.37
				18	1.26
				20	1.20
				22	1.12
				24	1.05
				26	0.99
				28	0.92
				30	0.87
				32	0.83
				34	0.80
				36	0.77
				38	0.75
				40	0.72

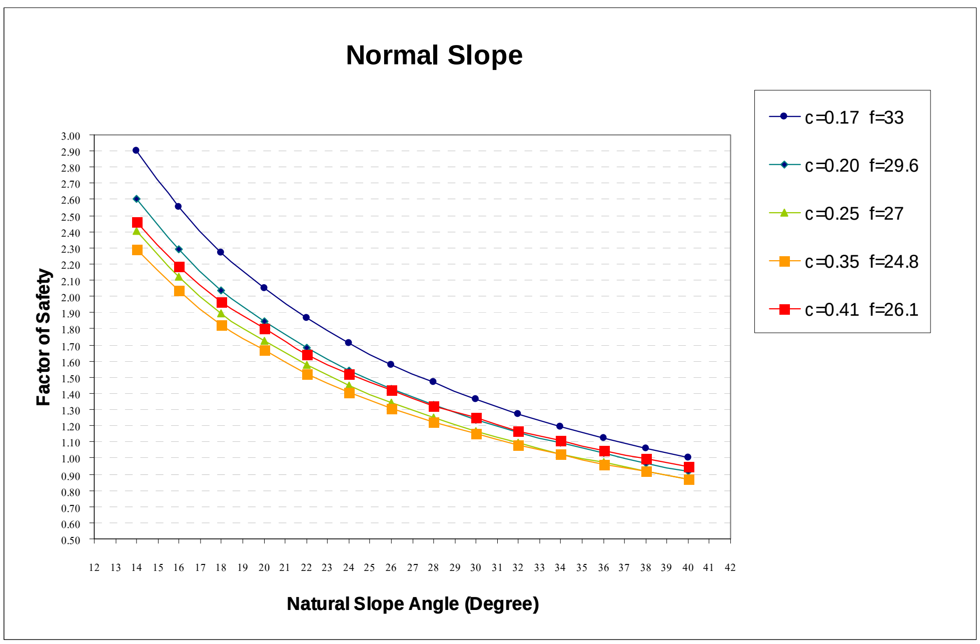


Figure 5-11 Factor of safety with various slope angles

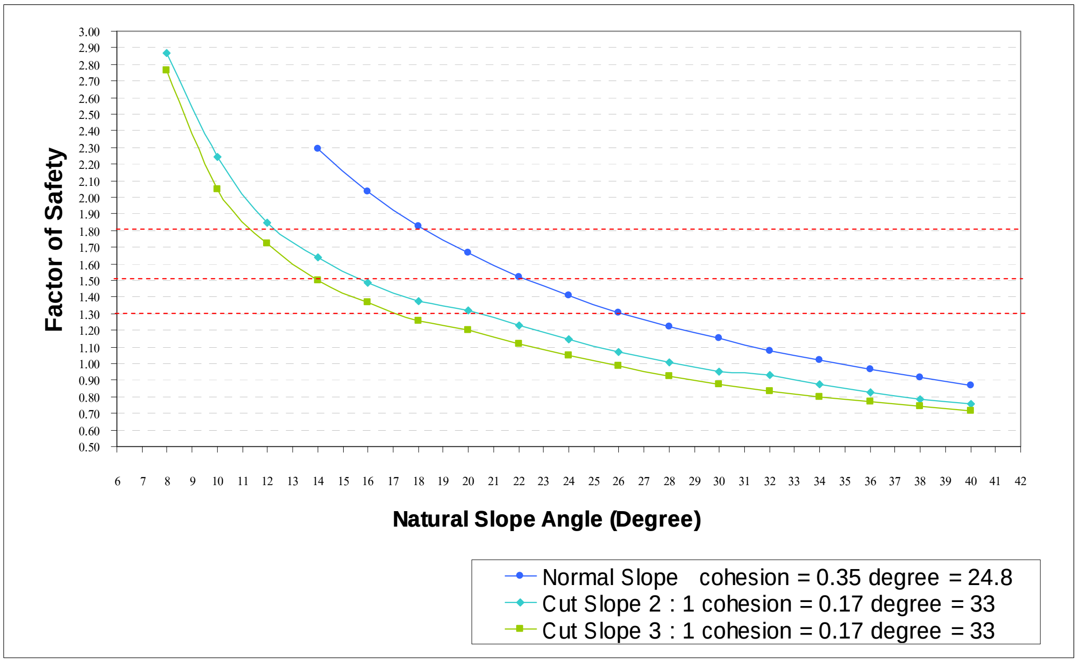


Figure 5-12 Factor of safety with various slope angles

Furthermore, Fig. 5-12 also shows that the disturbance of slope by toe cutting will cause a large reduction of stability of natural slope. The slope stability will significantly be effected if the slope angle less than 30 is disturbed. Table 5-2 conclude that if cutting need to be done with natural slope angle steeper than 20 degree, engineering protection might need to be done.

Table 5-2 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

5.4 Analysis Antecedent Precipitation Index (API) and API map.

In this study, a Antecedent Precipitation Index (API) as an index of profile moisture has been derived which correlates well with rainfall. Daily rainfall data and monthly average data of other weather parameters along with soil moisture holding informations were used to calculate critical API.

5.4.1 Antecedent Precipitation Index (API)

API is a measure of soil moisture condition on the day under consideration & was calculated using Linsely et. al. (1949) model :

$$I_t = K_t * I_{t-1} + P_t$$

Where,

I_t = API on ‘t’ the day (mm)
I_{t-1} = API on ‘t-1’ the day (mm)
P_t = Precipitation on ‘t’ the day (mm)
K_t = recession constant API constant (K =< 1.0 and usually 0.85-0.98)

The value of K in this study has been determined as 0.9 as for tropical region. Again, the recession constant ‘kt’ was calculated following the method given by Chodhury and Blanchard (1983):

$$K_t = EXP\ (-E_t/Wm)$$

Where,

Et = Potential evaporation on ‘t’ th day
Wm = maximum soil moisture available for evaporation (mm)
= WHC/100) * BD * 100 (mm)

Monthly average potential evaporation of Patong station was calculated using Thornthwaite (1948) model as a representative for all stations and presented in Table 5-3. Monthly soil moisture available up to 10 cm top soil available up to 10 cm. top soil for evaporation for different sites were calculated and listed in table 5-4

Table 5-3 Average daily potential evapotranspiration (PET) over Patong station.

Month	PET (mm)	Month	PET (mm)
Jan	5.4	Jul	5.2
Feb	5.4	Aug	5.3
Mar	6.2	Sep	4.8
Apr	5.8	Oct	4.7
May	5.5	Nov	4.6
Jun	5.1	Dec	5.0

Table 5-4 Maximum available soil moisture (Wm) of surface soil (0-100 cm)

Site No	Wm
1	37.8
2	38.2

Table 5-5 gives the average recession constant values for different months using the meteorological data of Patong station.

Table 5-5 Monthly recession constant (Kt) values

Month	PET (mm)	Month	PET (mm)
Jan	0.87	Jul	0.86
Feb	0.87	Aug	0.87
Mar	0.85	Sep	0.88
Apr	0.88	Oct	0.88
May	0.86	Nov	0.88
Jun	0.86	Dec	0.88

5.4.2 Soil analysis

Representative soil samples (0-100 cm depth) from 2 different locust breeding sites were collected for gravimetric moisture (θg), field bulk density and water holding capacity and brought back to laboratory with due care to prevent any moisture loss during transit. Soils were analysed using methods given by Black (1965). Permanent wilting point (WP) was determined at 1.5 MPa metric potential using pressure membrane apparatus.

5.4.3 API map

The antecedent precipitation intensity was analyzed by relationship rainfall data and soil moisture available for evaporation. Critical soil moisture was analyzed by daily rainfall data in Patong. Critical soil moisture content has unit as mm. of water per soil thickness. Small value of critical API is volume of rainfall intensity while slope has unstable. Fig. 5-13 shows critical API contour map in Patong.

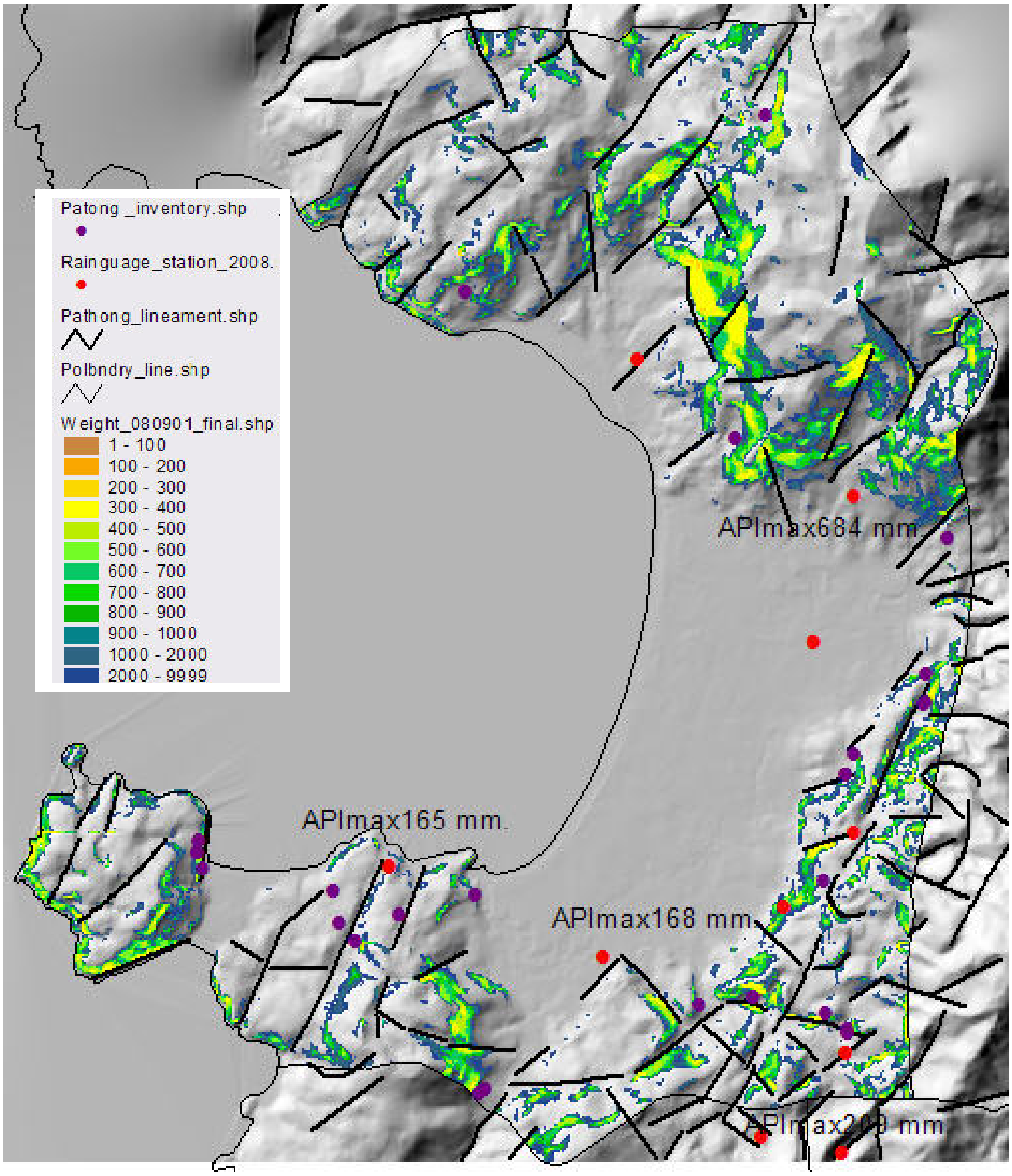


Figure 5-13 Critical API contour in Patong.

The API map shown in Fig. 5-13 shows that the mountain area in the northern part of the bay is vulnerable to create landslide that induced bye rainfall. Therefore, removing of soil cover in those area should be limited.

Chapter 6

Landslide Mitigations

6.1 Introduction

Landslide failures have several patterns. Landslide mitigation should have satisfied for cause of landslide failure. This study proposes several landslide mitigation as guideline for construction in slope, revision of building by laws, landslide warning based on rainfall triggering and land use regulation.

6.2 Guidelines for construction in slopes

6.2.1 Avoidance and regulation

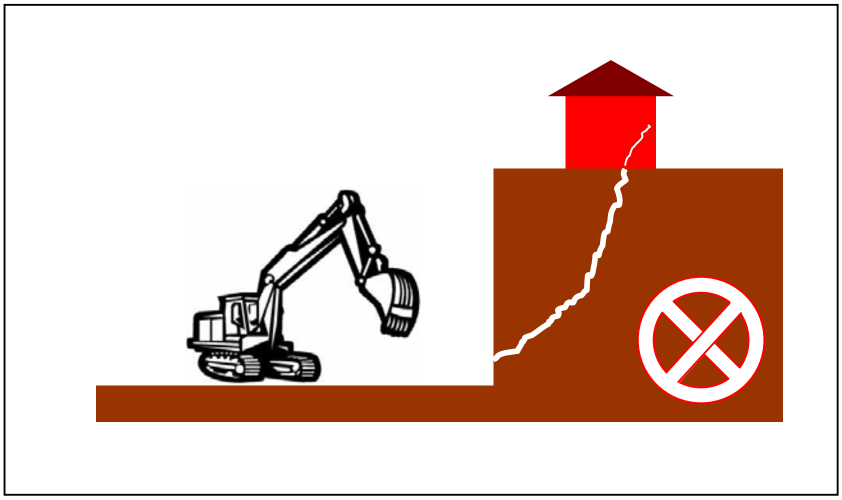
Avoidance in practice which cause slope failure consist of

1. to avoid cut slope against other land authority. Good practice should take satisfied slope. (Fig. 6-1)

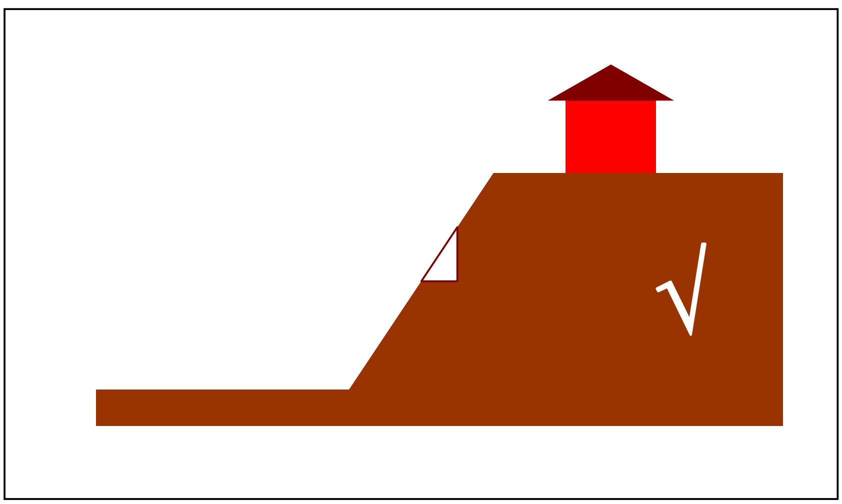
2. to avoid open slope without land cover. Plastic sheet can prevent temporary surface infiltration. (Fig. 6-2)

3. to avoid block off slope drainage at toe slope. Slope drainage should use gabion or rock rap at toe slope for small particle filter. (Fig. 6-3)

4. to avoid surface by use water ditch. The water ditch should locate out of failure boundary. (Fig. 6-4)

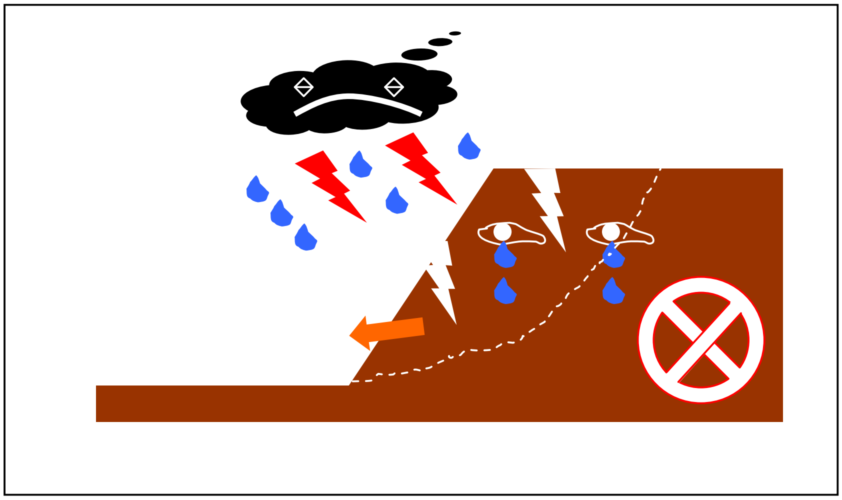


a. Not satisfy cut slope

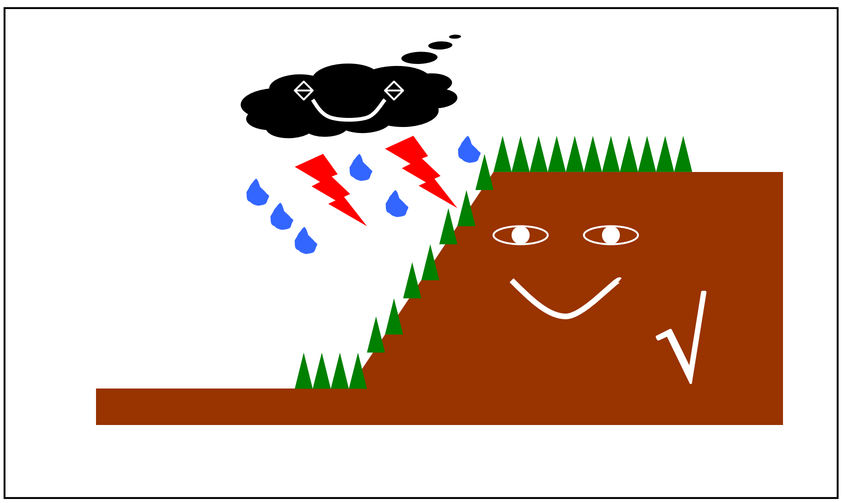


b. Satisfy cut slope

Figure 6-1 Cut slope

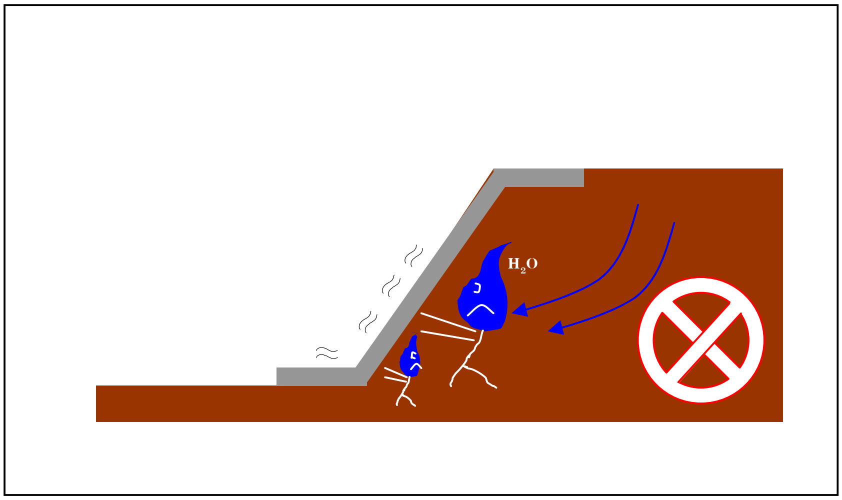


a. Rain fall cause soil erosion and strength reduction

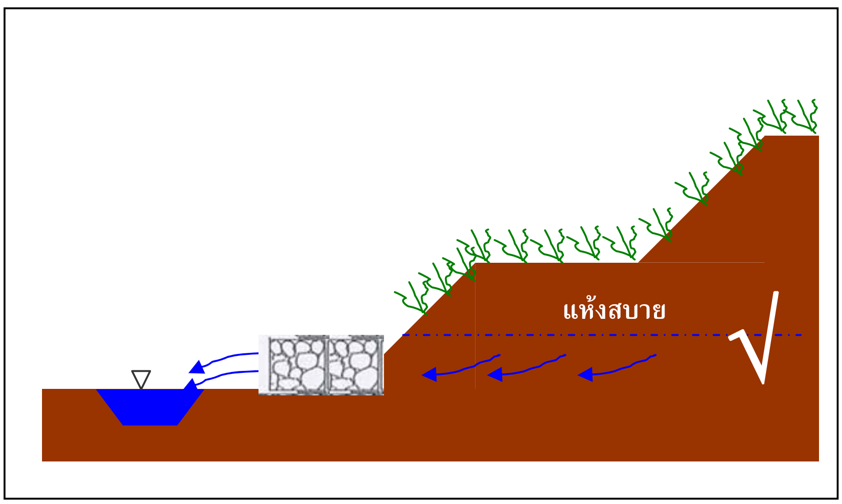


b. Vegetations reduce soil erosion and protect slope stability

Figure 6-2 Land cover

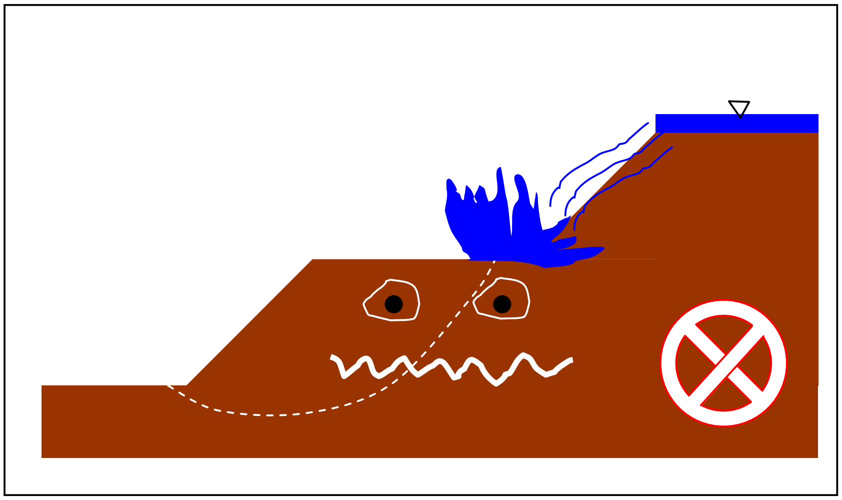


a. Not satisfy slope drainage

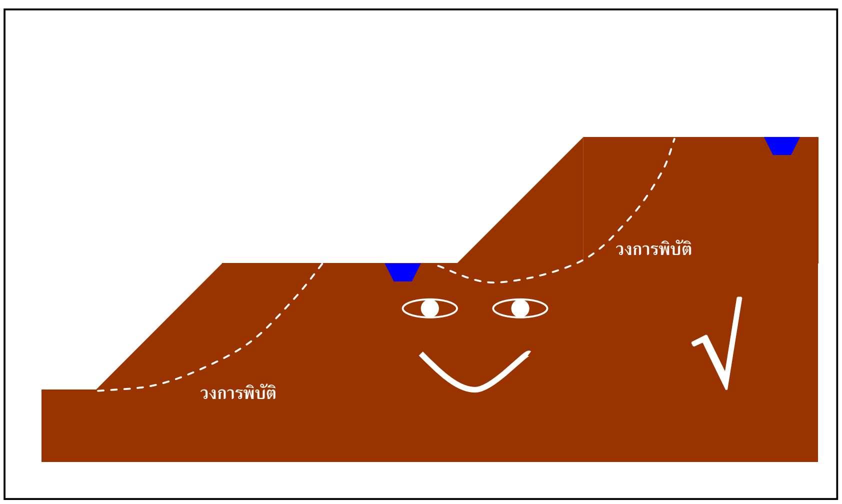


b. Vegetation and Gabion for slope drainage

Figure 6-3 Slope drainage



a. Not satisfied surface drainage



b. Satisfied surface drainage

Figure 6-4 Surface drainage

6.2.2 Engineering slope protection recommendations

6.2.2.1 Every case

Every case must protect surface for erosion and water infiltration reduction by vegetation. Beginner use clay 15 cm. thickness cover slope or use geonet for root connective. Plastic membrane can use temporary cover slope. Surface protection must has slope drainage especial at toe slope. Which use gabion with sand and gravel filter or geotextile to protect fine grain size particle from ground water. In conclusion, slope protection in Patong municipal must has land cover and drainage (Fig. 6-5)

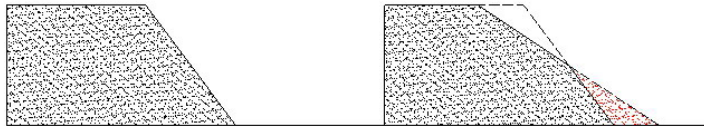
6.2.2.2 for enough area

Excavation reduces steep slope to flat slope call Benching (Fig. 6-6). Should not blasting because of blasting disturb soil and rock structure. Soil reinforcement can use synthetic fabrics such as geotextite in MSE wall for land use reduction (Fig. 6-7), gabion or toe slope counterweight (Fig. 6-8) and fiber reinforcements (Fig. 6-9).

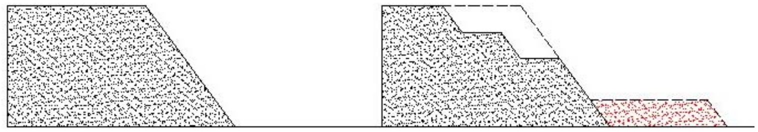
6.2.2.3 for limit area

In limit area have to use engineering structure for resistant earth movement such as retaining wall (Fig. 6-10), soil nail for soil slope protection (Fig. 6-11) and rock bolt/anchor for rock slope protection (Fig. 6-12). Rock bolt dose not satisfy for heavy weathering rock in Patong.

Figure 6-5 Satisfy land cover and slope drainage in residual granite soil

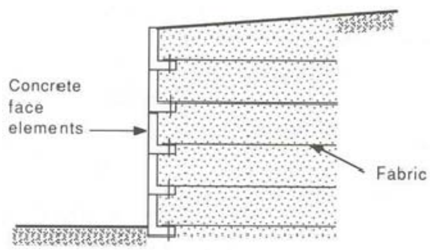


a. Total removal of all unstable materials

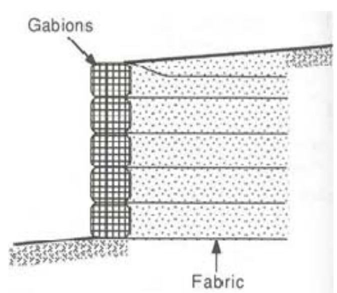


b. Benching of slope

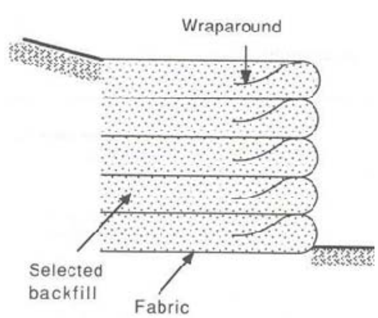
Figure 6-6 Unloading



a. MSE-WALL CONCRETE FACING



b. MSE-WALL GABIONS FACING



c. MSE-WALL WRAPAROUND FACING

Figure 6-7 MSE (Mechanically Stabilize Earth) Walls *(Source: Hausmann, 1990)*

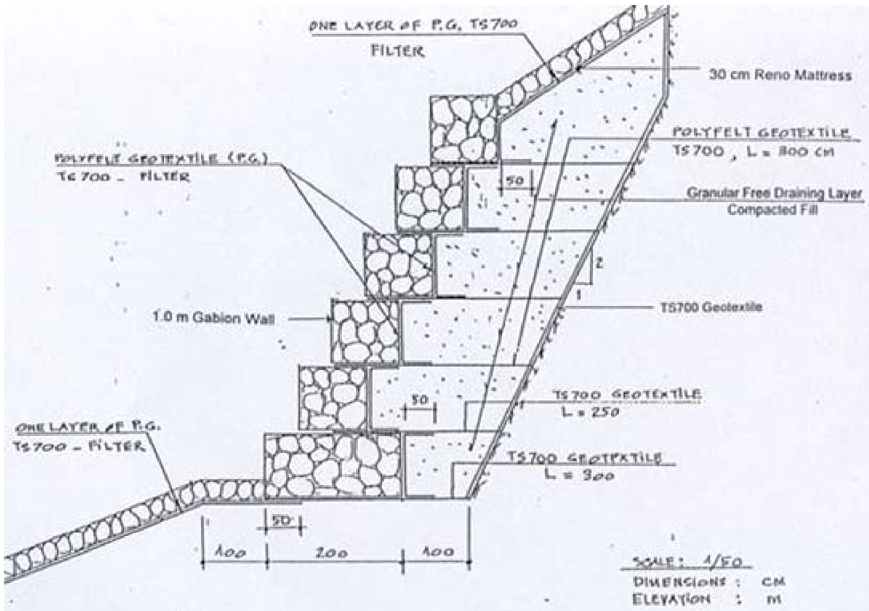
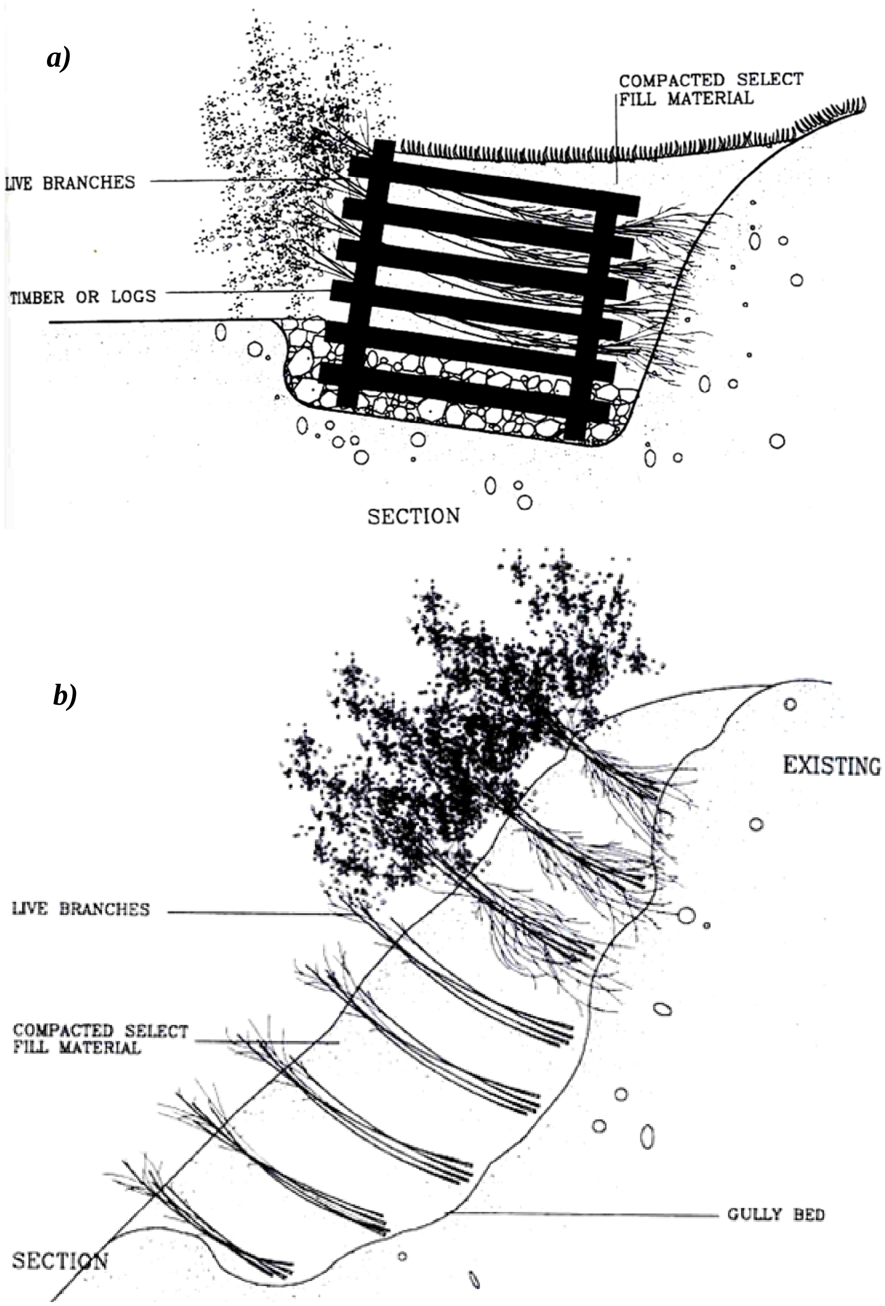


Figure 6-8 Gabion



a) Live Crib Wall b) Live Gully Repair Fill

Figure 6-9 Fiber reinforcements

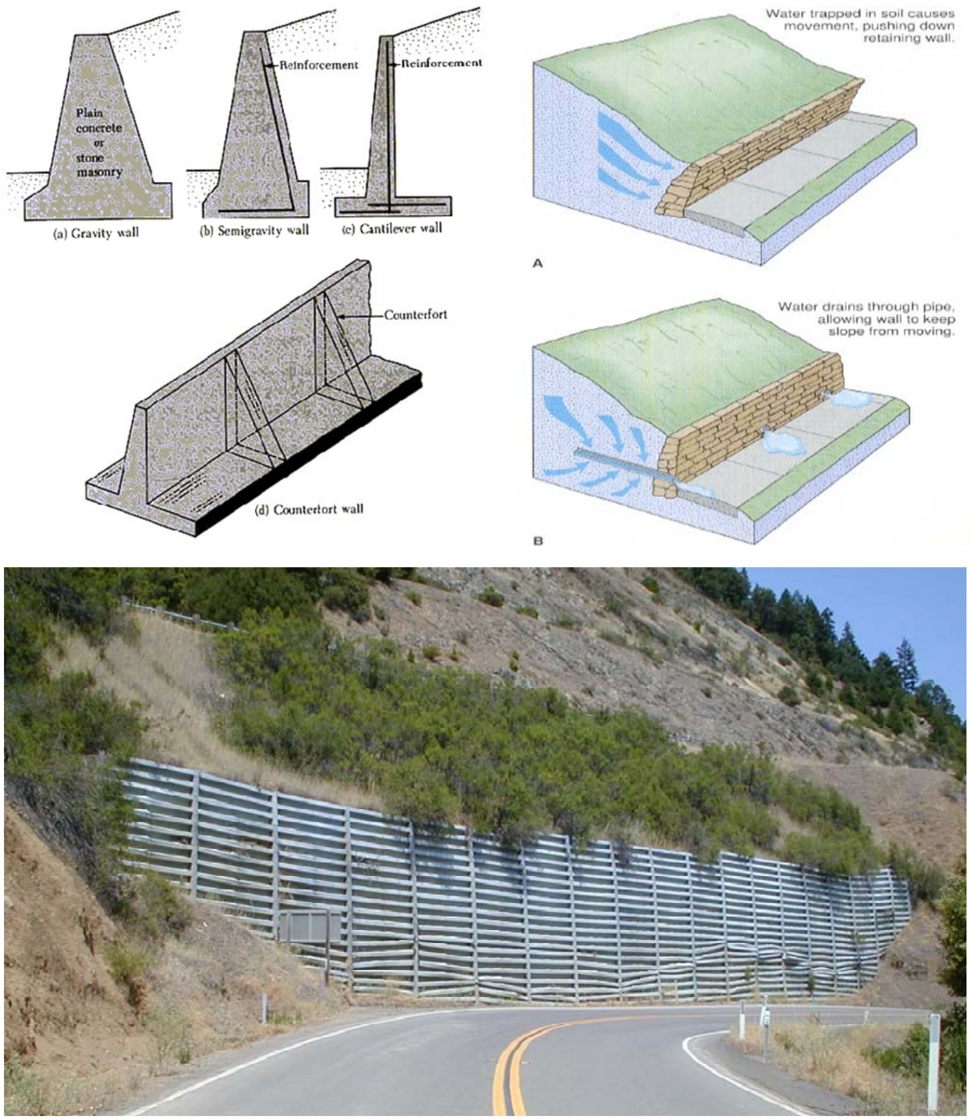


Figure 6-10 Retaining Walls

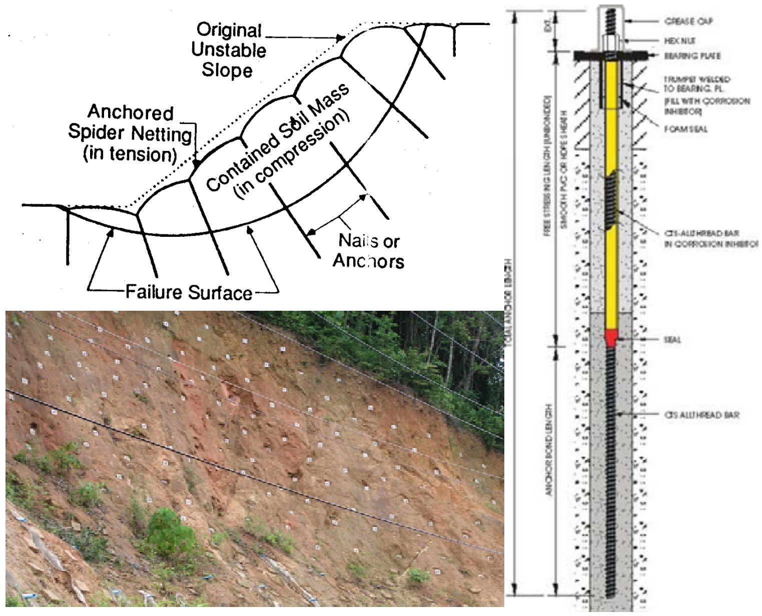


Figure 6-11 Soil nail strength increment

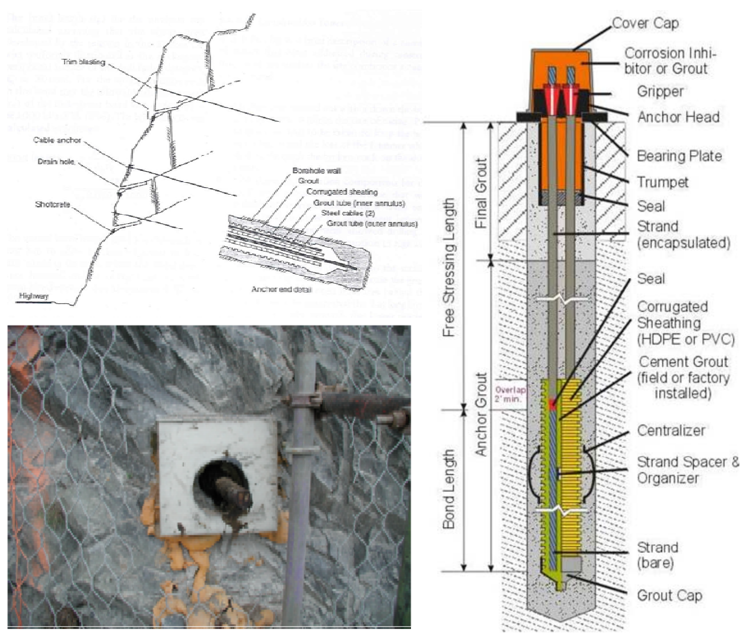


Figure 6-12 Rock Bolt and Anchor (*Source: Koerner and Robins, 1986)*

6.3 Revision of building by laws

Minimum recommendation

This recommendation takes apart from excavation and filling Act B.E.2543 and revises to appropriate Patong area. This recommendation can use as criterion for building.

Soil excavation

1. Soil excavation depth more than 3 meters from existing surface or slope excavation height more than 3 meters must control by civil engineer.

2. Soil excavation areas more than 10,000 square meters must design slope stability and drainage. Have to disturb other land authority.

3. Excavation height more than 3 meter and slope more than natural slope must is far away from other land authority not less than 2 time of excavation depth or excavation height except has slope stability calculation and slope protection by civil engineer.

4. Excavation and filling on natural slope must is far away from other land authority equal half of height but more than 10 meters and space top of filling far away from other land authority equal 1/5 of height but not more than 3 meters (Fig. 6-13).

5. If excavation and filling has slope more than 1 : 2 (V : H) should analysis slope stability and protect slope by civil engineer.

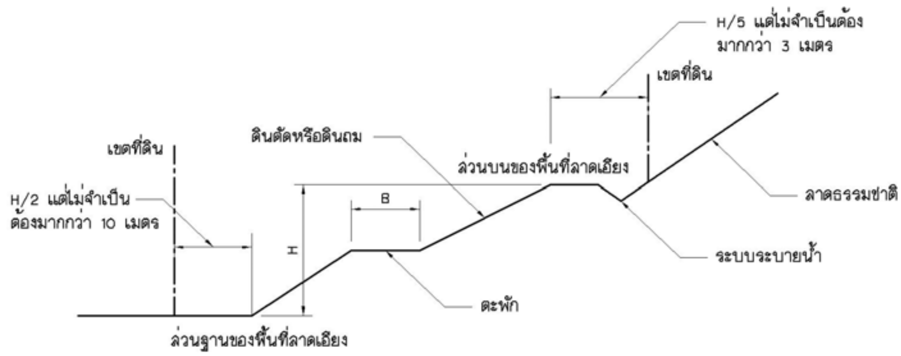


Figure 6-13 Clearing distance for cut slope and embankment

Soil filling

1. Filling height more than 3 meters and higher than around other land authority must has calculation by civil engineer.

2. Filling area more than 2,000 square meters must has slope stability calculation and drainage by civil engineer.

3. Filling height more than 3 meters, toe of slope must is far away from other land authority not less than 2 time of filling height except has slope protection by civil engineer.

4. Filling slope must has slope less than 1 : 1 except has calculate slope stability by civil engineer.

5. Filling on natural slope more than 1 : 2 (V:H) must has calculate slope stability by civil engineer.

6. Filling on natural slope more than 1 : 2 (V:H) and filling height more than 1.5 meters should has shear key 50 cm. depth and > 3 meters width in stiff soil (Fig. 6-14).

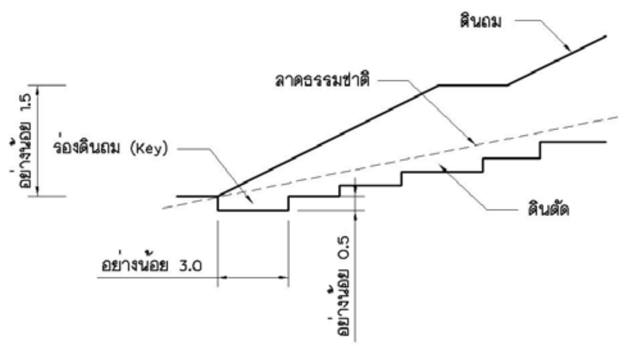
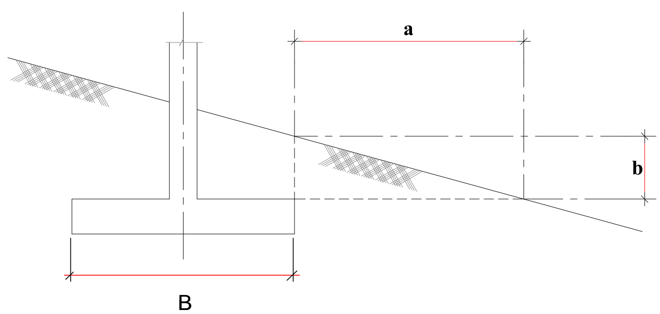


Figure 6-14 Shear key for fill on natural slope

Foundation on slope

Foundation on slope must has minimum edge distance and minimum height of back fill following recommendation (Fig. 6-15) for erosion protection.



Regulation:	Foundation on soil slope	distance	a > 1.5B m.
		distance	b > 0.60 m.
	Foundation on rock slope	distance	a > 0.75 m.
		distance	b > 0.30 m.

Figure 6-15 Foundation on slope

(Foundation work code, Department of Public Works and Town & Country Planning)

6.4 Landslide warning based on rainfall triggering

Install 10 rainfall stations for establish threshold rainfall values. Establish procedures for landslide warning based on rainfall triggering.

Figure 6-16 shows the rain gauge from Department of Mineral Resource. The rain gauges were installed on 18 July, 2007. The installations were participating from municipal officer and head of villages. The head of villages and municipal officer are responsively the record of rainfall intensity. Figure 6-17 shows the study before rain gauge installation. Figure 6-18 shows the location of rain gauge station. Table 1 shows list of rain gauge station.

Figure 6-16 Rain gauge from Department of Mineral Resource

Figure 6-17 The study before installation.

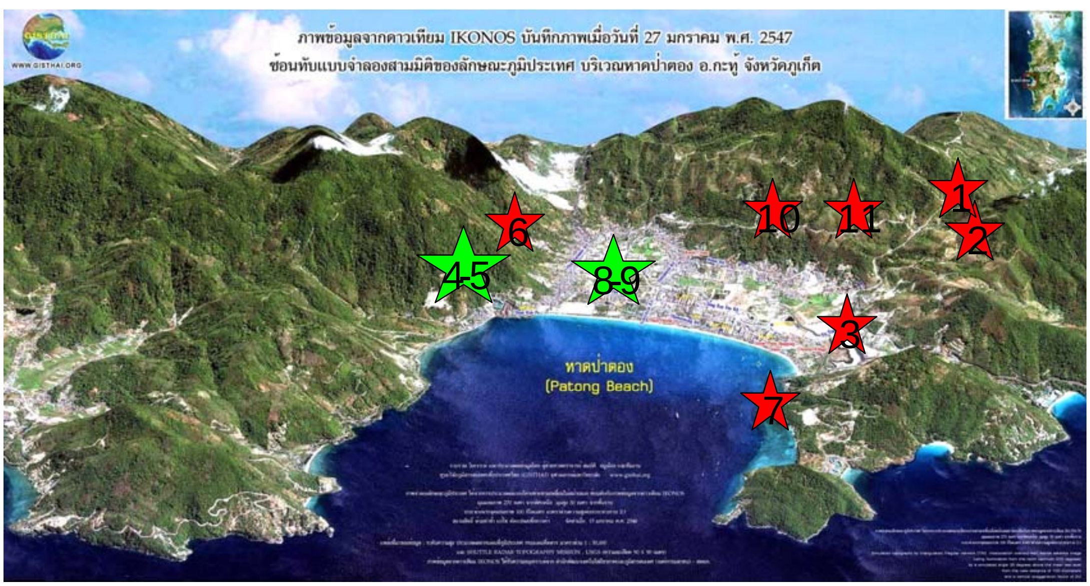


Figure 6-18 The location of rain gauge station.

Table 6-1 List of rain gauge station

Location	Name	Address	Telephone
RSTA01	Ms.Thawadee Boonnaburi	32 Petkhod Rd. Na Nai Vill.	0819702484
RSTA02	Mr.Sumon Saripat	72 Petkhod Rd. Na Nai Vill.	0898722387
RSTA03	Mr.Chuan Rongtong	8 Sirirat Rd. Simon Cabaret	0899706162
RSTA04	Ms.Wascharee Phunchalat	13 Baramee Rd. Kalim Vill.	0818915258
RSTA05	Ms.Wascharee Phunchalat	13 Baramee Rd. Kalim Vill.	(Wireless)
RSTA06	Mr.Manit Kuanyurn	14 Baramee 3 Rd.	0845083598
RSTA07	Municipal officer	Municipal house Tri Trang beach	0819585226
RSTA08	Municipal officer	Patong Municipality	0819585226
RSTA09	Municipal officer	Patong Municipality	(Wireless)
RSTA10	Mrs.Kunyarat Chamit	Ban Suan Hotel	08
RSTA11	Mr.Tipat	Ban rai rom yen fishing	0872819018
RSTA12	Mr.Sitikhan Kanchana	157/11 Na nai Rd. Kanchana Vill.	Miss contact

6.4.1 Landslide warning based on rainfall triggering

After installation 10 rainfall stations, will be install 2 wireless rain gauges for landslide warning. They will be installing in August 2007.

This gauge design eliminates the normal wire connection from the rain gauge to the indoor display. The battery operated transmitter operates up to 300 feet away. Just locate the gauge in an open area and read the rainfall amount on the indoor display. The 8" diameter collector meets NWS specifications for statistical accuracy. Every time the bucket tips, a count is transmitted to the indoor display and the gauge empties. You never have to empty the gauge. Each tip of the bucket shows one hundredth of an inch on the indoor display.

Figure 6-19 The Wireless Rain Gauge.

6.4.2 Establish procedures for landslide warning based on rainfall triggering

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. 6-20. Critical API contour in Pathong is shown in Fig. 6-21.

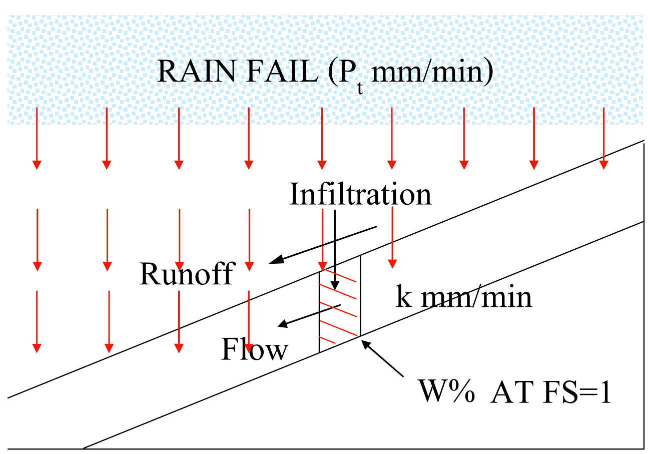


Figure 6-20 The critical API was determined using geotechnical engineering model.

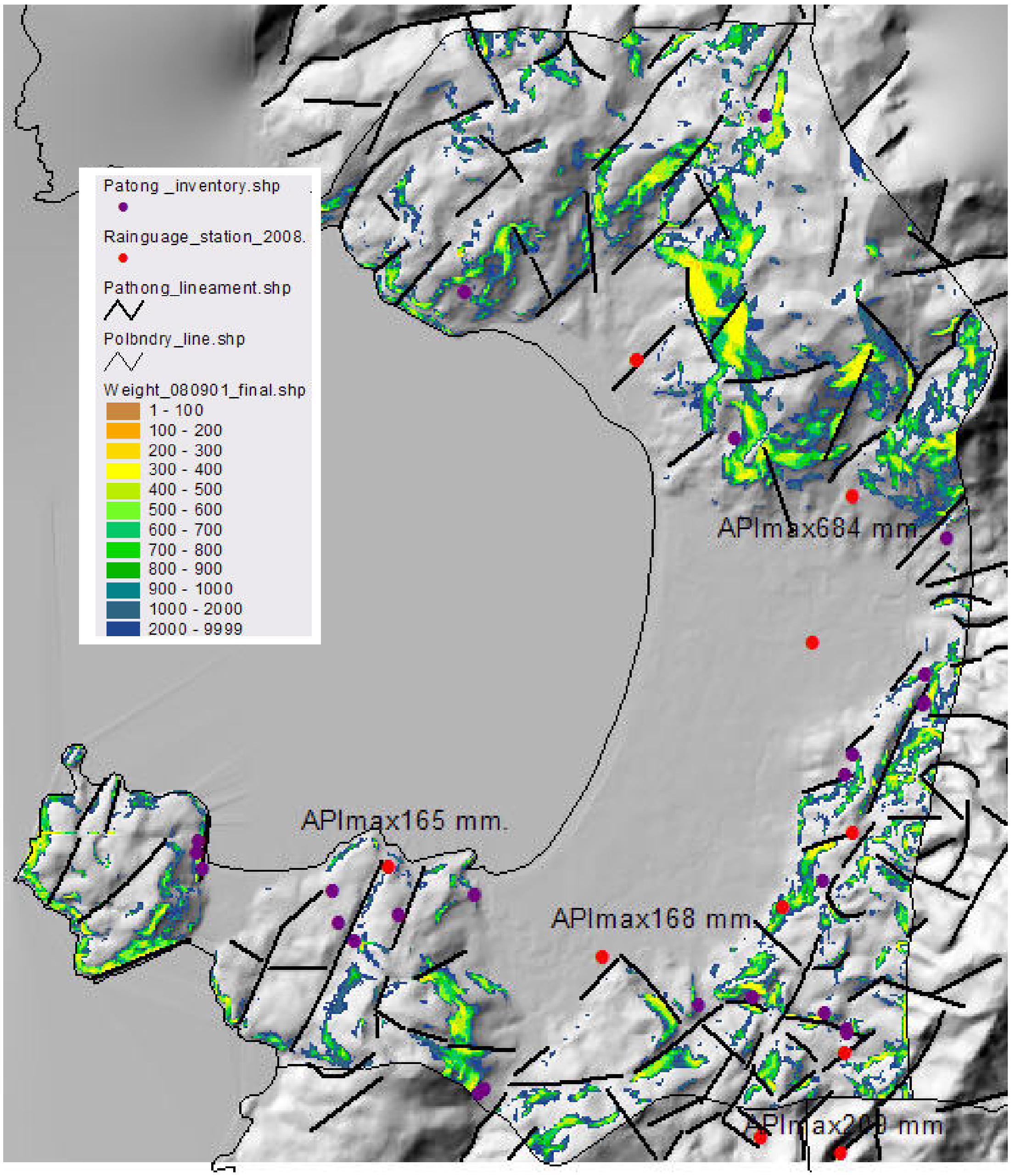


Figure 6-21 Critical API contour in Patong.

Fig. 6-21 shown critical API contour in Patong. The lower API is high landslide hazard area from rainfall.

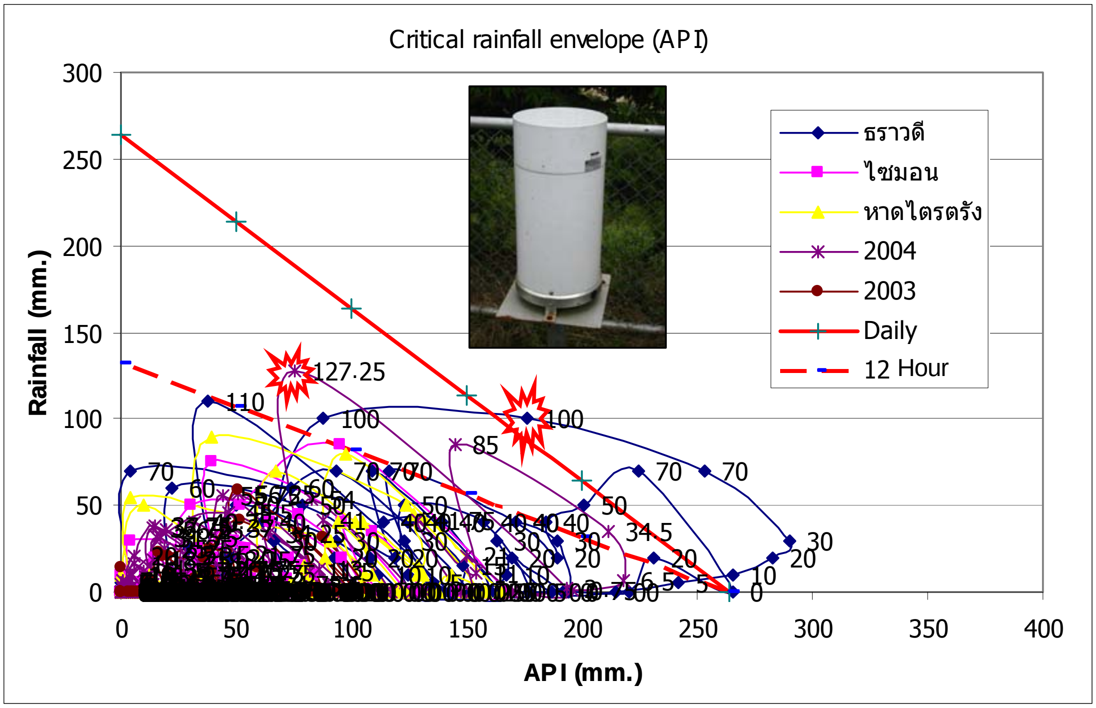


Figure 6-21 Warning by critical antecedent precipitation intensity

Table 6-2 Warning by critical antecedent precipitation index

API (mm.)	Warning by critical antecedent precipitation intensity				Risk Level
	Nanai Village.		Kalim Village		
	mm./Day	mm./Hr.	mm./Day	mm./Hr.	
0	290	12	265	11	**Low**
25	265	11	240	10	
50	240	10	215	9	
75	215	9	190	8	
100	190	8	165	7	**Medium**
125	165	7	140	6	
150	140	6	115	5	
175	115	5	90	4	
200	90	4	65	3	**High**
225	65	3	40	2	
250	40	2	15	1	
265	25	1	0	0	
275	15	1	0	0	
290	0	0	0	0	

The Criteria and warnings method has been discussed with patong municiple's staff who responsible for hazard prevention and warning. It was found that the warning criteria by using method described in Fig.6-21 and Table 6-2 is quite complicated and somehow inconvenient for them.

Therefore, easy to input rainfall data programming in excel worksheet was prepared for them (Table 6-3). This worksheet flows the rainfall input in various range of reading time and also provide the landslide hazard classification at the time of input.

Table 6-3 API warning by excel worksheet

Antecedent precipitation index worksheet on Patong municipality

วัน/เดือน/ปี	ปริมาณน้ำฝน (มม.)	ช่วงเวลา	ค่าดัชนีความชุ่มชื้น API [t-1] (มม.)	ระดับการเตือนภัย	ปริมาณน้ำฝนเสี่ยงภัย		
					มม./วัน	มม./3ชม.	มม./ชม.
API เริ่มต้น	0	24ชม.	0.0	เสี่ยงต่ำ	264.0	33.0	11.0
1 มกราคม 2552	5	24ชม.	5.0	เสี่ยงต่ำ	254.7	31.8	10.6
2 มกราคม 2552	10	24ชม.	14.4	เสี่ยงต่ำ	241.0	30.0	10.0
3 มกราคม 2552	40	24ชม.	52.5	เสี่ยงปานกลาง	176.7	21.4	7.1
4 มกราคม 2552	60	24ชม.	105.7	เสี่ยงปานกลาง	106.1	12.3	4.1
5 มกราคม 2552	50	24ชม.	141.9	เสี่ยงสูง	78.6	9.0	3.0
6 มกราคม 2552	50	24ชม.	173.5	เสี่ยงสูง	47.0	5.1	1.7
7 มกราคม 2552	50	24ชม.	200.9	เสี่ยงสูง	19.6	1.6	0.5
8 มกราคม 2552	0	15นาที	174.8	เสี่ยงสูง	89.2	11.1	3.7
9 มกราคม 2552	0	30นาที	152.1	เสี่ยงปานกลาง	111.9	14.0	4.7
10 มกราคม 2552	0	1ชม.	132.3	เสี่ยงปานกลาง	131.7	16.5	5.5
11 มกราคม 2552	0	3ชม.	115.1	เสี่ยงปานกลาง	148.9	18.6	6.2
12 มกราคม 2552	0	6ชม.	100.1	เสี่ยงปานกลาง	163.9	20.5	6.8
13 มกราคม 2552	0	12ชม.	87.1	เสี่ยงปานกลาง	176.9	22.1	7.4
14 มกราคม 2552	0	24ชม.	75.8	เสี่ยงปานกลาง	188.2	23.5	7.8
15 มกราคม 2552	0	24ชม.	65.9	เสี่ยงต่ำ	198.1	24.8	8.3
16 มกราคม 2552	0	24ชม.	57.4	เสี่ยงต่ำ	206.6	25.8	8.6
17 มกราคม 2552	0	24ชม.	49.9	เสี่ยงต่ำ	214.1	26.8	8.9
18 มกราคม 2552	0	24ชม.	43.4	เสี่ยงต่ำ	220.6	27.6	9.2
19 มกราคม 2552	0	24ชม.	37.8	เสี่ยงต่ำ	226.2	28.3	9.4
20 มกราคม 2552	0	24ชม.	32.9	เสี่ยงต่ำ	231.1	28.9	9.6
21 มกราคม 2552	0	24ชม.	28.6	เสี่ยงต่ำ	235.4	29.4	9.8

The automatic wireless rain gauge system was installed in the selected area, decided based on the mathematical model. The rainfall data will be automatically sent to the computer sever in Kasetsart University while the researchers in Geotechnical Engineering Research and Development Center (GERD) carefully calculate and update the threshold value for landslide warning. The new criteria will then send to Patong municipal for the city engineer who is responsible for landslide warning. The effectiveness of the criteria will be discussed between Patong Municipal and GERD in order to validate the criteria. One PhD student from Kasetsart University will be responsible for updating the mathematical model for the next 2 years. Department of Mineral Resources will be responsible for discussion with local communities and create the activity for community concerned. Figure 6-22 shows automatic wireless rain gauge system with GPRS.

Figure 6-22 Automatic wireless rain gauge system with GPRS

6.5 Land use regulation

Fig. 6-22 shows the landslide hazard area in Patong municipal. Landslide hazard was analyzed from landslide factor. Landslide in Patong was found that lineament zone has more influent. In landslide hazard map divide 4 level (high medium low and very low) which land use regulation should follow landslide hazard level (table 6-4). Table 6-5 shows Maximum natural slopes for safely cut slope.

Table 6-4 Land use regulation for landslide hazard level

Action	Landslide Hazard Level			
	High	Medium	Low	Very Low
Engineer	√	√		
Geologist	√			
Land cover	√	√		
Drainage management	√	√		
Control of cut slope angle	√	√	√	√

Table 6-5 Maximum natural slopes for safely cut slope.

Factor of safety (F.S.)	natural slopes (Degree)
1.3	20.6^{o}
1.5	15.8^{o}
1.8	12.3^{o}

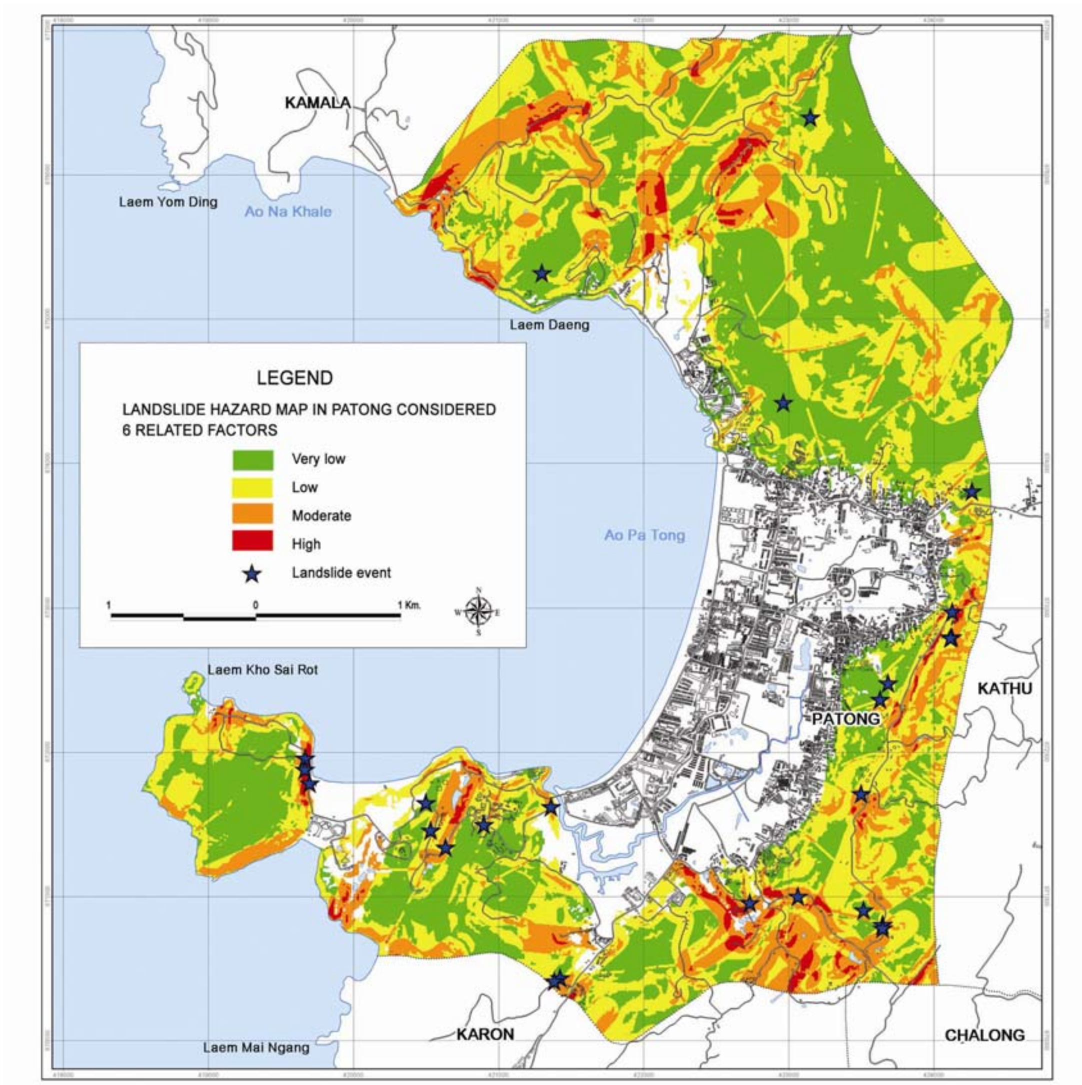


Figure 6-22 Landslide hazard map in Patong municipal Phuket THAILAND

Chapter 7

Workshops

7.1 Introduction

Workshop and seminar have objective to distribute knowledge and awareness. This project was under Asian Program for Regional Capacity Enhancement for Landslide Impact Mitigation (RECLAIM Phase II) to educate Patong municipal officer, other officer in Phuket, villager, other people and land developer. Workshop and seminar were performed three time as workshop with Patong city, seminar 2nd and closing seminar. They are organized mainly bye Department of Mineral Resources.

7.2 Workshop with Patong City

The workshop with Patong City Authorities was done for the discussion of the potential outcome of A2 and A3. The workshop was held on Royal Paradise Hotel, Phuket, Thailand, on 28 April 2007. Table 7-1 shows workshop agenda. Figure 7-1 shows the picture of the workshop.

Table 7-1 Workshop agenda.

08.30-09.00	Registration of Participants	
09.00-09.40	Opening Ceremony	Prof. Warakorn Mairaing, Kasetsart University, Thailand
09.40-09.50	Coffee/Tea Break	
09.50-10.30	Risk Mapping: Case Study from Thailand	Dr. Suttisak Soralump, Kasetsart University, Thailand
10.30-11.20	Excavation and Fill work Law	Prof. Warakorn Mairaing, Kasetsart University, Thailand
11.20-12.00	Use Law in Patong Municipality	Mr.Sompon Kuanyuen Patong, Municipality
12.00-13.00	Lunch Break	
13.00-14.00	Early Warning System	Mr.Charun Noonjun Patong Municipality
14.00-14.40	Water Drainage Capacity Assessment in the Major Watersheds in Patong City with Extreme Rainfall Scenarios	Mr.Evind Hoedal, NGI
14.40-15.00	Coffee/Tea Break	
15.00-15.40	Workshop	Patong Municipality
15.40-16.40	Landslide Hazard Mitigation	Dr. Suttisak Soralump, Kasetsart University, Thailand
16.40-17.30	Concluding Session and Closing Ceremony	Department of Mineral Resources (DMR) Thailand Kasetsart University, Thailand

Figure 7-1 The Patong city demonstration workshop. (27/04/2007)

7.3 Seminar 2nd

The seminar 2nd was done for the education of the potential outcome of this study for officer and villager. The seminar 2nd was held on Patong Resort Hotel, Phuket-Thailand, on 26 October 2007. Table 7-2 shows workshop agenda. Figure 7-2 shows the picture of the seminar 2nd .

Figure 7-2 The Patong city seminar 2nd. (26/10/2007)

Table 7-2 Seminar 2nd agenda.

08.30-09.00	Registration of Participants	
09.00-09.40	Opening Ceremony	Dr.Torsaporn Nuchanong, Department of Mineral Resources (DMR) Thailand
09.40-09.50	Coffee/Tea Break	
09.50-10.30	Landslide Hazard Map	Dr. Suttisak Soralump, Kasetsart University, Thailand
10.30-11.20	Landslide Factor in Thailand	Mr.Somchai Yensaban Department of Mineral Resources (DMR) Thailand
11.20-12.00	Local warning network	Mr.Somchai Yensaban Department of Mineral Resources (DMR) Thailand
12.00-13.00	Lunch Break	
13.00-14.00	Landslide Hazard Mitigation Landslide warning by rainfall	Dr. Suttisak Soralump, Kasetsart University, Thailand
15.00-16.40	Workshop	Patong Municipality
14.40-15.00	Coffee/Tea Break	
15.00-16.40	Workshop	Patong Municipality
16.40-17.30	Concluding Session and Closing Ceremony	Department of Mineral Resources (DMR) Thailand Kasetsart University, Thailand

7.4 Closing Seminar

The closing seminar was done for the education of the potential outcome of this study for officer, villager and land developer. The closing seminar was held on Patong Resort Hotel, Phuket-Thailand, on 22 December 2008. Table 7-3 shows workshop agenda. Figure 7-3 shows the picture of the closing seminar.

Figure 7-3 The Patong city closing seminar 3rd. (26/10/2007)

Table 7-3 Closing seminar agenda.

08.30-09.00	Registration of Participants	
09.00-09.40	Opening Ceremony	Vice Provincial Governor of Phuket ADPC Dr.Adichart Surinkum Department of Mineral resources Prof. Warakorn Mairaing, Kasetsart University, Thailand
09.30-10.00	Coffee/Tea Break	
10.00-10.30	Landslide Hazards and Risk Management in Patong	Dr. Suttisak Soralump, Kasetsart University, Thailand
11.00-11.30	Landslides Warning Network	Mr. Wisut Chotigsatarn Department of Mineral resources
11.30-12.00	Landslide Management in Patong	Mr.Chairat Sukaban Patong, Municipality
12.00-13.00	Lunch Break	
13.00-15.30	Public awareness campaign by landslide hazard and implemented warning concept with relevant agencies in Patong. “Implements Landslide Hazards Mitigation in Patong”	Department of Mineral Resources Kasetsart University, Thailand Patong Municipality
15.00-15.30	Coffee/Tea Break	
15.30-16.30	Group Presentation	Representation of Group
16.40-17.30	Concluding Session and Closing Ceremony	Department of Mineral Resources Kasetsart University, Thailand Patong Municipality

Chapter 8

Participating Organizations and Individuals

Participating Organizations and Individuals

Local Partner:

Patong Municipality Office:	12/3 Patong Beach, Kathu Phuket, 83150 Thailand Phone: (66) 076- 344275, Fax: (66) 076- 342080 , 076-344255 Website: www.patongpatongmunicipality.org
Patong officer:	Mr.Supakorn Meekeaw Tel.: +66 819585226
Head of Na Nai Village:	Mr.Preecha Bonnaburee Tel.: +66 819702484

Participating name on Patong workshop and seminar:

1.Mr.Todsaporn Nuchanong	DMR
2.Mr.Wisut Chotigsatarn	DMR
3.Mr.Suwit Cosuwan	DMR
4.Ms.Nopparat Ratanawigit	DMR
5.Ms.Ladda Arikun	DMR
6.Assoc. Prof. Dr.Warakorn Maireing	KU
7.Assit. Prof. Dr.Suttisak Soralump	KU
8.Mr.Bunpot Kunsuwan	KU
9.Mr.Damrong Pungsuwan	KU
10.Ms.Manunya Seangson	KU
11.Mr.Sirisart Yungsanpu	KU
12.Ms.Suree Sungchareon	ADPC
13.Mr.Muhibuddin Bin Usamah	ADPC
14.Mr.Ovyvind Amand Hoedal	NGI
15.Mr.Chairat Sukaban	Patong Municipality
16.Mr.Sompon Kuanyeun	Patong Municipality
17.Mr.Charun Nuchan	Patong Municipality
18.Mr.Wisit Matasonton	Patong Municipality
19.Mr.Paiton Ponrob	Disaster Prevention officer
20.Mr.Prasit Kitbunyonglerd	Disaster Prevention officer
21.Mr.Prawit Rathanachot	Administrator
22.Mr.Phanit Yongsang	Administrator
23.Mr.Waiyavit Wongpipatchareon	Fireman Patong Municipality
24.Mr.Eakarat Phukdeemai	Disaster Prevention officer
25.Mr.Suppawat Wansangkum	Radio Reporter
26.Mr.Bunleur Yokyong	Driver Patong Municipality
27.Mr.Prakit Tipwadchana	Fireman Patong Municipality
28.Mr.Wirat Changchai	Fireman Patong Municipality
29.Mr.Esamaan Sure	Fireman Patong Municipality

30.Mr.Sorachai Kunkaw	Fireman Patong Municipality
31.Mr.Sittichai Kongmak	Fireman Patong Municipality
32.Mr.Anucha Chantawong	Fireman Patong Municipality
33.Mr.Eakapon Chaiphonrit	Fireman Patong Municipality
34.Mr.Anucha Natipongpisut	Fireman Patong Municipality
35.Mr.Prasert Phuaukrapornpong	Fireman Patong Municipality
36.Mr.Sumat Srithamathon	Fireman Patong Municipality
37.Mr.Chalermpon Chaisit	Fireman Patong Municipality
38.Mr.Punya Yoysang	Fireman Patong Municipality
39.Mr.Sakda Yayee	Fireman Patong Municipality
40.Mr.Phanom Thernthin	Fireman Patong Municipality
41.Mr.Wachira Dhatwon	Fireman Patong Municipality
42.Mr.Sittiporn Kaewbumrong	Fireman Patong Municipality
43.Mr.Eakaluck Phunchalat	Fireman Patong Municipality
44.Mss.Thitiporn Mangchoy	Recorder
45.Mr.Songsuk Songsing	Disaster Prevention officer
46.Mr.Chareon Songsit	Radio Reporter
47.Mr.Pornsak Kumead	Civil Engineering Patong Municipality
48.Mr.Suchatree Kawrit	Civil Engineering Patong Municipality
49.Mr.Aphiwat Suttinun	Fireman Patong Municipality
50.Mr.Wisanu Watano	Fireman Patong Municipality

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