MATERIALS AND METHODOLOGY

Materials

1. Program spreadsheet (Microsoft Excel)
2. Book reference and thesis
3. Landslide location data
4. Soil strength parameter from parallel study
5. GIS program
6. GPS
7. Geologic investigation equipment (geology hammer, geology campus)

Methodology

This study emphasizes in producing landslide susceptibility map and landslide sensitive area for cut slope in Phuket. The study area is an island that has many development areas which satisfy for study area. This study deals with the application of relatively new tool in landslide hazard zonation: use of computerized system for handling of the geographical data, known as geographic information system (GIS). Eight factors were considered to be related to landslide including Geology (rock type, lineament), Landform (slope, elevation), Surface drainage zone, Land use, Soil characteristic, Engineering properties, Rainfall intensity and RMR or SMR. These factors are used for analyzing landslide hazard location.

The methodology adopted is illustrated on the flow diagram in figure 5. This study improved the accuracy of landslide susceptibility map by including RMR and SMR factors. The map of sensitive area for cut slope was produced by including SMR factors in the analysis which assume the cut slope on soft rock equal to 1:1.2 or 40^o (Japan Society of Engineering Geology, 1992).

The methodology included the following:

1. Data collection (7 factors)
2. Weight factor analysis for landslide hazard area
3. Processing of landslide susceptibility and hazard map (7 factors)
4. Field investigation
5. Weighting factor analysis including RMR value
6. Processing landslide susceptibility and hazard map by considering RMR value
7. Weighting factor analysis including SMR value
8. Processing natural landslide susceptibility map and hazard map by considering SMR value
9. Collect slope condition data form field investigation
10. Failure verification (RMR included)
11. Processing cut slope failure map and hazard map by considering RMR factor included
12. Failure verification (SMR included)

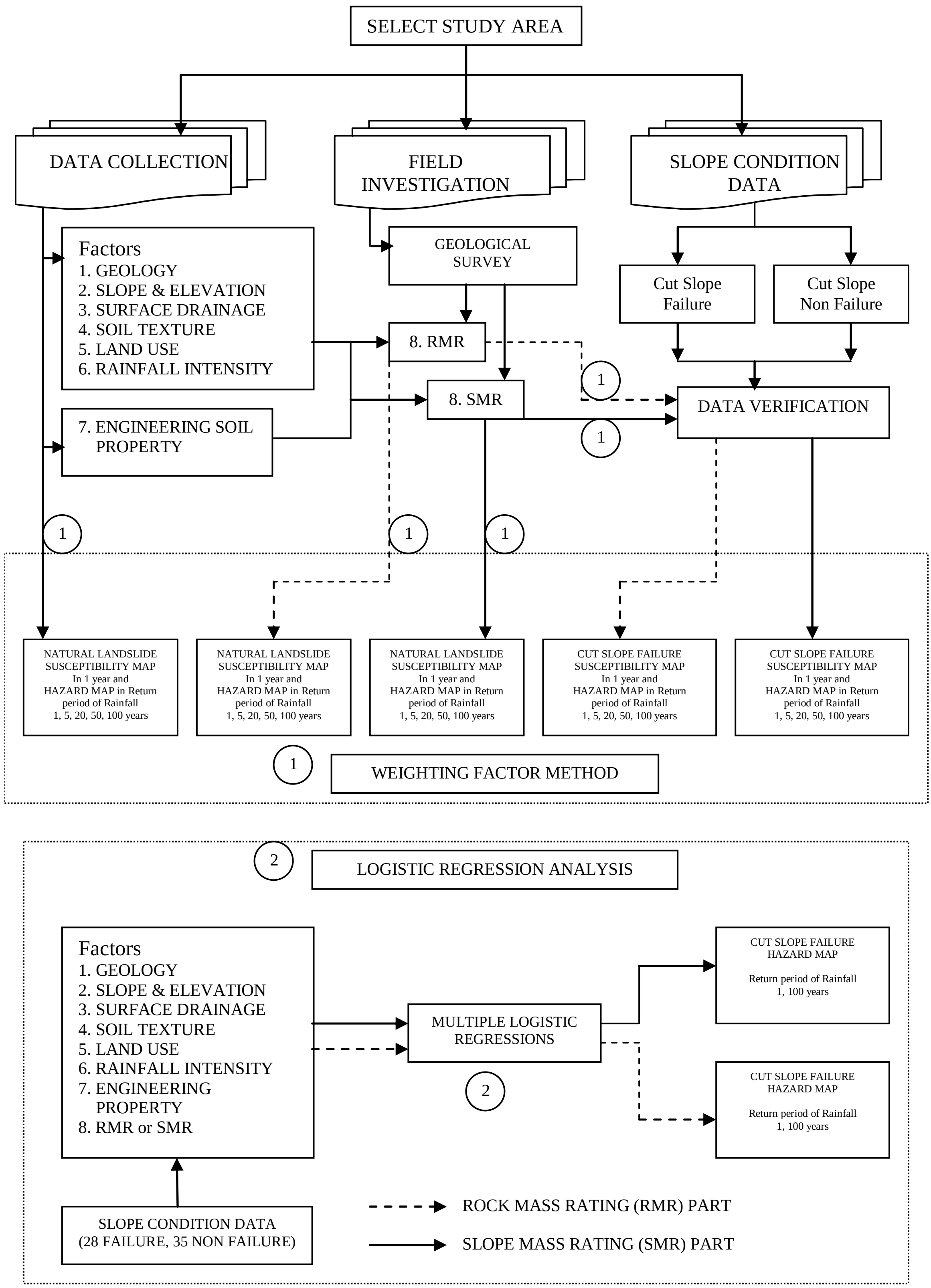

Figure 5 Flow diagrams showing all the methodologies

13. Processing cut slope failure map and hazard map by considering SMR factor included
14. Logistic multiple regression analysis (RMR factors included)
15. Processing cut slope probability of failure map by considering RMR factor included
16. Logistic multiple regression analysis by considering SMR factor included
17. Processing cut slope probability of failure map by considering SMR factor included

Data collection

The collection of fundamental geographic information system (GIS) data was used for analysis of landslide susceptibility. The data used included geology, slope and elevation, surface drainage, soil texture, land cover, rainfall, engineering properties. Table 18 shows GIS data discussed above.

Table 18 Data collection for the analysis of landslide sensitive area

No	Coverage	Organize	Scale Map
1	Province	Topographic map: Royal Thai Survey Department	1:50,000
2	Amphoes	Topographic map: Royal Thai Survey Department	1:50,000
3	Transportation	Topographic map: Royal Thai Survey Department	1:50,000
4	Contour	Topographic map: Royal Thai Survey Department	1:50,000
5	Land used	Land Development Department	1:50,000
6	Geologic Structures	Geology map: Mineral Resource Department	1:50,000
7	Geology	Geology map: Mineral Resource Department	1:50,000
8	Elevation	Topographic map: Royal Thai Survey Department	1:50,000
9	Slope	Topographic map: Royal Thai Survey Department, GERD	1:50,000
10	Streams and rivers	Topographic map: Royal Thai Survey Department	1:50,000
11	Watershed	Environmental Quality Promotion Department	1:50,000
12	Soil series group	Land Development Department	1:50,000
13	Rainfall	Meteorological Department Of Thailand, Royal Irrigation Department, GERD	1:50,000
14	Engineering properties	GERD	1:50,000

Gerd: Geotechnical Engineering Research and Development Center, Kasetsart University.

Evaluation Natural landslide susceptibility map and hazard map

After the data collection of fundamental geographic information system (GIS) maps were complete, which consist of 8 factors map as geology map (rock type and lineament), land form (slope and elevation), surface drainage, soil characteristic, land use, rainfall cumulative intensity 3 days, engineering properties and RMR or SMR factors. These were used to divide grid cell 25x25 meters and were overlaid by using the GIS analysis functions of geoprocessing and analysis menu within ArcView GIS software. The overlay with intersection and union option has been used for GIS analysis and recorded data from all of factor maps. After that, the attributes of intersection from 8 factors was used to calculate score by weighting factor analysis.

The trend of the landslide occurrence was observed from the plotted data. Each of the grid cell had been defined 5 levels of landslide susceptibility, which consisted of very low to nil susceptibility, low susceptibility, moderate susceptibility, high susceptibility and very high susceptibility to landslide.

Field Investigation

Field investigation was used to prepare a slope condition of the cut slope. It was used to compare with susceptibility of landslide map for the cut slope. The prepared landslide distribution and bedrock map as well as other maps e.g. contour, land use, land form map will be verified during the field visit. The existing pattern of cut slope and its magnitude was observed. Eighty seven cut slopes have been surveyed and after completing the field survey, data file was input in GIS map. The study involved field investigation on the geological engineering aspects of rock slopes in Phuket Island, Thailand. Field investigation had been conducted on failure and non failure slopes in development area to understand their recent massive failures.

The methods of investigation for RMR and SMR factors follow as much as practical the methods suggested by the International Society of Rock Mechanics (ISRM, 1981). The collected data include slope geometry, joint condition and orientation, rock conditions, and groundwater condition. The results were used to evaluate rock mass quality for landslide factor on landslide susceptibility map and sensitive area map for slope development.

Rock Mass Rating (RMR) and Slope Mass Rating (SMR) Estimation

Geotechnical data could be easily collected during exploration stages of a new or existing construction project as an integrated approach with investigation data collection. Rock outcrop mapping carried out along all natural outcrops or man-made excavations such as resort projects, river and road-cuts etc. located in close proximity to the surveying site. A typical geotechnical mapping sheet for the collection of pertinent data is shown in Fig 6.

Figure 6 Rock mass rating (RMR) descriptions for field survey sheet (ISRM, 1981)

												VALUE	RATING
Intact rock Strength	PLST	10	8	6.5	5.5	5	4.5	3	2	1	<1		
	UCS,Mpa	250	200	160	140	125	110	75	50	25	<25		
	Field Est.	Chipped by hammer		many blows by hammer to break				single blow		pocket knife			
	RATING	15	14	13	12	11	10	8	6	4	<3		
RQD	J Spacing	>200	40	20	14	10	8	7	6	5	4		
	RQD %	100	90	80	70	60	50	40	30	20	0		
	RATING	20	18	16	14	12	10	9	5	4	3		
Joint Spacing	Js, cm	>200	40	20	14	10	8	7	6	5	4		
	RATING	20	18	16	14	12	10	9	8	7	5		

								Set 1	Set 2	Set 3	VALUE	RATING
							Orientation J Spacing					
Joint Condition	Persistence	< 1m	1- 3m	3 - 10m	10 - 20m	> 20m						
	RATING	6	4	2	1	0						
	Aperture	None	< 0.1mm	0.1-1.0	1 - 5	5 - 10						
	RATING	6	5	4	1	0						
	Roughness	Vrough	Rough	SL Rough	Smooth	Slices						
	RATING	6	5	3	1	0						
	Infilling		Hard infilling		Soft Infilling							
		None	<5mm	>5mm	<5mm	>5mm						
	RATING	6	4	3	2	0						
	Weathering	FRESH	SW	MW	HW	CW						
	RATING	6	5	3	1	0						
							Sub-Total					

Groundwater	Inflow 1/min/10m	None Dry	< 10 Damp	10 - 25 Wet	25 - 125 Dripping	> 125 Flowing		
	RATING	15	10	7	4	0		

Adjustment for Joint Orientation	DIP OF ADVERSE JOINT SET				
	0 - 20	20 - 45	45 - 90		

RMR RATING	80 - 100	60 - 80	40 - 60	20 - 40	0 - 20	
DESCRIPTION	VERY GOOD	GOOD	FAIR	POOR	VERY POOR	
ROCK CLASS	1	2	3	4	5	
Average stand-up time	10 years for 15 m span	6 months for 8 m span	1 week for 5 m span	10 hours for 2.5 m span	30 minutes for 1 m span	
Cohesion of the rock mass	> 400 kpa	300-400 kPa	200-300 kPa	100-200 kPa	<100 kPa	
Friction angle of rock mass	> 45°	35°-45°	25°-35°	15°-25°	<15°	

A description of the pertinent geotechnical data to be included in a logging sheet is presented below. The minimum geotechnical information collected from the mapping of rock outcrops should comprise:

- Rock type description and alteration
- Weathering
- Discontinuity type, orientation, surface conditions, spacing and persistence
- Estimate of rock strength

Estimates of rock strength can be made based on the descriptions presented in Fig 6 and the use of either a pocket knife and/or geological hammer. An average rock strength should be selected per each identified rock type unless significant areas of rock of different strengths were presented within the natural outcrop of man-made excavation.

Photographs were taken of all natural outcrops and/or man-made excavations such as exploration audits or road cuttings in/upon which geotechnical data has been measured and recorded. Both far field and zoom photographs were taken to illustrated the variation of rock types, all joint sets, typical or important joint surfaces as well as joint spacing and persistence. Scales were always being included in each of the photographs.

During the field survey, the rock samples were colleted from each landslide and cut slope. These rock samples were identified for the rock type by geologist and were tested in the laboratory to observe the intact rock strength.

Assumption of estimating slope mass rating was the cut slope located in soft rock, slope direction parallel to slope of mountain and slope dip was 1:1.2 or 40^{o} (Japan Society of Engineering Geology,1992).

<u>Slope Condition data</u>

The slope condition data was defined from field investigation data in which definition of slope conditions were a Fail and a No Fail. The Fail was the failure of the cut slope after excavation and before inspection. The No Fail was the non failure of the cut slope after excavation and during inspection.

<u>Data verification for RMR and SMR factor</u>

The RMR and SMR factors were defined in GIS map depending on rock type and watershed. Before and after weighting factor analysis, RMR and SMR factors were verified. The data verification for RMR and SMR rating before weighting factor analysis, had objective to classify the rang of rating and after that to classify the rang of total landslide susceptibility score. The cutoff score procedure was employed to classify each grid cell as landslide, apparently landslide, apparently non-landslide and non-landslide area.

The cut of score point was defined as the boundary between a landslide, apparently landslide, apparently non-landslide and non-landslide area decision; for example a 89 cutoff score point means that the score of pixel being classified as landslide was equal to greater than 89, while the score less than 89 was classified as non-landslide.

Evaluation Sensitive Area for Cut slope

Evaluation of sensitive area and map production was divided into four steps. The first step produced landslide susceptibility map from 7 factors: geology, landform, surface drainage zone, land use and land cover, soil characteristics, rainfall intensity and engineering soil properties. And RMR factor or SMR factor was included in landslide susceptibility map. The second step produced landslide susceptibility map which depended on return period of rainfall. The third step produced sensitive area map for slope development. In assumption was 1:1.20 or 40^{o} cut slope on soft rock. The fourth step produced probability sensitive area for slope development map from logistic regression modal. Flow chart in Fig 7 illustrates the process of evaluation of sensitive area and map production.

STEP 1 PRODUCTION LANDSLIDE SUSCEPTIBILITY MAP BY WEIGHTING METHOD

STEP 2 PRODUCTION LANDSLIDE SUSCEPTIBILITY MAP BY WEIGHTING METHOD IN RAINFALL 1, 5, 20, 50 AND 100 YEARS RETURN PERIOD

STEP 3 EVALUATING LANDSLIDE SENSITIVE AREA FOR CUT SLOPE BY WEIGHTING METHOD IN RAINFALL 1, 5, 20, 50 AND 100 YEARS RETURN PERIOD

STEP 4 EVALUATING LANDSLIDE SENSITIVE AREA FOR CUT SLOPE BY LOGISTIC REGRESSION IN RAINFALL 1, 5, 20, 50 AND 100 YEARS RETURN PERIOD

Figure 7 Evaluation sensitive areas for cut slope process

Logistic regression

Logistic regression allowed one to from a multivariate regression relation between a dependent variable and several independent variables. The advantage of the logistic regression was that, through the addition of an appropriate link function to the usual linear regression modal, the variables may be either continuous or categorical, or any combination of both types. In present situation, the dependent variable was a binary variable representing the presence or absence of landslides. Where the dependent variable was binary, the logistic link function was appropriate. The logistic regression allows one to form a multivariate regression relation between a dependent variable and several independent variables (Atkinson and Massari, 1998).

The evaluation sensitive of cut slope was developed from field survey data obtained from cut slope in Phuket. Eight independent variables used a multiple regression analysis by Microsoft excel program. The slope condition data (Fail or No Fail) was used to regression analysis for dependent parameter, which assumed of qualitative of slope condition was 2.95 and -2.95 for Fail and No Fail respectively. The assumption Fail or no Fail was the occurrence probability for specific attributes.