CHAPTER 5

Conclusions and Recommendations

5.1 Conclusions

In general, landslides in Thailand occurred under the condition of heavy rainfall of more 100 mm/day and cumulative rainfall exceeding 300 mm/3 days. But in this study, the landslide at kilometer 53 on Highway 1095 (Mae Ma Lai - Pai) occurred after a light rainfall of 30 mm/day and cumulative rainfall of 40 mm/3 days. This observation suggests that the failure of slope depends on a number of factors, not only rainfall. Even though it is the main trigger to slope failure. Therefore, this research is aimed to investigate factors that control the occurrence of landslide in this area. The study consists of field survey, field test, and laboratory tests of soil samples from landslide and non-landslide area. The non-landslide area chosen for comparison has similar topography, elevation, slope angle and geology with those of the landslide area. Both areas are characterized by weathered granite. The landslide site is underlain by weathered granite rocks with the elevation ranging between 870 to 950 m MSL and slope angle of 25°to 32°. The non-landslide site is also underlain weathered granite rocks with the elevation ranging between 750-900 m MSL and slope angle of 26°to 34°. Due to the fact that slope made up of weathered granite rocks under the condition of tropical climate are known to be susceptible to slide. And as highly weathered granitic rocks, are composed mainly of clay minerals which are the weathering products of their principle mineral. The focus of this research is to investigate the role of clay minerals on rainfall triggered landslide. This study involves the determination of soil physical properties such as soil permeability, grain size distribution, Atterberg limits, shear strength , X-ray diffraction and analysis of slope stability using the CHASM software. The methods used in this study and the results of landside parameters are shown in Table 5.1.

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Table 5.1 Method used in this study and average values of parameters in landslide and non-landslide areas.

Method		Soil samples from landslide area	Soil samples from non-landslide area
Permeability test (cm/s)		1.32×10^{-5}	9.11×10^{-6}
Grain size distribution	Gravel (%)	5.05	3.51
	Sand (%)	86.15	80.19
	Silt (%)	3.48	6.61
	Clay (%)	5.32	9.69
Atterberg limits	Water content (%)	25.4	19.7
	Liquid limit (%)	23.3	29.6
	Plastic limit (%)	12.0	17.1
	Plasticity index (%)	11.4	12.5
Direct shear test	Cohesion (kPa)	4	8.2
	Friction angle (°)	44.4	32.9
XRD analysis	Quartz (%)	32.3	80.7
	Feldspar (%)	18.0	9.4
	Muscovite (%)	23.7	7.6
	Kaolinite (%)	7.8	4.7
	Illite (%)	12.9	-
	Montmorillonite (%)	8.8	-

It was apparent that the landslide occurred in the study area a shallow slide is accompanied by a debris slide. Distance from crown to toe is measured at 210 m. The slope in landslide and non- landslide areas are made up of soils with low permeability which are difficult to drain water and hence are rapidly saturated after a short period of rainfall. Generally, slopes with lower hydraulic conductivity are most prone to shallow

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failures due to the significant pore water pressure response to the rainfall. Forth low permeability soils, antecedent rainfall can be important in reducing soil suction and increasing the pore-water pressure.

Landslide and non- landslide areas consist of gravels, sands, silts and clays with a significant amount of sand (about 80%). Soils of both areas are well-graded sands with clays. Soils of the non-landslide area are higher in the amount of finer particles than the landslide area. It is generally explained that rainfall-triggered landslides in coarse grained soils are caused by increasing pore pressures, and seepage forces, during a periods of intense rainfall. Liquid limits of the landslide soils are lower than the non-landslide soils, where the increasing moisture content reaches a certain value the soils become liquid and start to flow. Hence, the soils from the landslide area is more susceptible to slide than the soils from non-landslide area during rainfall.

The shear strength of soils is characterized by the angle of internal friction and cohesion. The average cohesion of landslide soils is 4.0 kPa and the average friction angle is 44.4^{o}. The soil samples from non-landslide have the average cohesion and internal friction angle of 8.2 kPa and 32.9^{o}, respectively. Relatively, the soil samples from the landslide area have low cohesion and high internal friction angle. The cohesion decreases with decreasing clay content whilst the friction angle increases with decreasing clay content. The soil samples from the landslide areas have lower percentage of clay content than that of the non-landslide areas. This indicates that the clay contents play an important role on the shear strength of the soils. The internal friction angle and cohesion from the tests are used to calculate the factor of safety using the CHASM software. The results show that the position of groundwater table, soil friction angle, soil cohesion, rainfall intensity and rainfall duration have significant effects on the instability of the slopes. Groundwater table position and soil strength properties are found to be the primary factors controlling the instability of the slopes, while rainfall intensity plays a secondary role. The soil shear strength is reduced as moisture content changes from unsaturated to saturated condition after a period of wetting by rainfall. On the other hand it is shown that increasing soil saturation, which is a direct effect of rainfall accumulation, leads to the decrease in the factor of safety. For the landslide area, the calculated factor of safety is less than 1 indicating that the slope is unstable and hence slump occurs. In the non-

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landslide area, the factor of safety tends to decrease, but is still greater than 1, indicating a relatively stable slope. The factor of safety of slope decreases due to the decrease in shear strength of soils while the shear stress increases. The shear strength of the soils decreases with increasing water content. This implies that the slope in the non-landslide area will possibly be failed of the rainfall continues to increase over time.

Regarding the role of clay minerals in controlling the slope instability, discussion on weathering and clay mineralogy should be made. Granite is made up of quartz, mica and feldspar. As quartz is resistant to chemical weathering, it may be removed only as mineral grains of quartz. Feldspars and micas are susceptible to chemical weathering and break down to form clay minerals. The X-ray diffraction study showed that the soils from landslide and non-landslide areas consist of quartz, feldspar, muscovite, kaolinite, illite and montmorillonite. Thus, clays may be composed of mixtures of finer grained clay minerals and clay-sized particles of other minerals such as quartz, carbonate, and metal oxides. Quartz, feldspar and muscovite are the primary minerals indentified by the XRD data and the important clay minerals are kaolinite, montmorillonite and illite. Quartz is identified by its typical 3.34 Å peak. Muscovite can be identified by the 9.9 Å and 4.9 Å, feldspar by 3.24 Å, kaolinite by 7.1 Å, illite by 10 Å, and montmorillonite can be identified by the 15 Å,peaks respectively. Quartz, feldspar, muscovite are present in the clay fraction in all soil samples. Feldspar minerals such as albite and microcline are abundant after quartz. Clay minerals detected in this study induce illite, kaolinite and montmorillonite. Semi-quantitative mineral analysis indicated the proportions of 6.2% to 17.8% for montmorillonite in landslide area and none for the non-landslide soils. Kaolinite does not absorb water and does not expand when it comes in contact with water. However, their overall structure is soft and weak, when soaked up with water, and it may contribute to landslide. The most important aspect of the montmorillonites is the ability for H_2O molecules to be absorbed between the sheets. The force of bonding between cations and the sheets is not very strong and depends on the amount of water present. In dry montmorillonites, the bonding is relatively strong. The montmorillonites are expanding clays when they become wet, because of water enters the crystal structure and increases the volume of the mineral. The water has virtually no strength, almost any load will cause layer to slide easily over other layer. Montmorillinite can expand by several times its original volume when it comes in contact with water. Montmorillonite

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in particular was rapidly lose strength in wet conditions. It reduces the cohesion in a soil and greatly a lower affects its strength behavior. Soils in the granite areas where landslides took place have clay mineral content relative to those from non-landslide areas. The clay minerals in the landslide soils are high in montmorillonite and kaolinite. It is believed that this area is much more vulnerable to landslides when compared with other areas because of its high content of montmorillonite and kaolinite. Therefore, this suggests that montmorillonite and kaolinite play important role in slope failure, even in the case of light rainfall.

This landslide occurred after a light rainfall (30 mm/day) in rainy season. The landslide areas is made up of weathered granite with low permeability which is difficult to drain water and soils can be rapidly saturated after a short period of rainfall. The increased groundwater discharge after the rainfall. The water is an important factor in slope stability, contributes both to high shear stress and low shear strength. The soil samples from the landslide areas have a low cohesion and a high content of montmorillonite and kaolinite. Therefore, clay mineral content can serve as the sensitive factor influencing landslides, together with physical properties and rainfall triggering effect landslide.

5.2 Recommendations

5.2.1 Generally, the preparation of landslide hazard map of Thailand takes into account the four factors, including geology, geomorphology, rainfall and land use. To improve the accuracy of the landslide hazard map, the other factors should also be considered and emphasized .These factors include are slope aspect, permeability of soil, geotechnical properties of soil and types of clay minerals as these responsive to rainfall.

5.2.2 Thailand should establish a landslide inventory map. Landslide inventory map records the location, cause of landslides, characteristic of landslide, intense and prolonged rainfall. A map of existing landslides serves as the basic data source for understanding conditions contributing to landslide occurrence. Landslide inventory map is helpful in understanding about landslide and hazard assessment for the area.

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5.2.3 Base on the result of this study, clay mineralogy which depends on the composition of granitic rocks and the degree of weathering, is also a factor controlling landslide in the area under the condition of a tropical climate. Hence, detailed study on other rainfall-triggered landslide in Thailand should be reviewed. The effects of clay mineralogy to landslides could be better understood if a sufficient number of studies are conducted

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