## CONTENTS

Acknowledgement	c
Abstract in Thai	d
Abstract in English	f
List of Tables	k
List of Figures	1
Chapter 1 Introduction	1
1.1 Disaster scenario of Thailand	1
1.2 Rationale	1
1.3 Research objectives	2
1.4 Usefulness of the research	2
1.5 Definition of landslide	2
1.6 Cause of landslide	3
1.6.1 Geological causes	3
1.6.2 Morphological causes	5
1.6.3 Physical causes	6
1.6.3 Physical causes 1.6.4 Human causes	7
1.7 Landslide classification	8
1.8 Study area rights reserved	8
1.9 Geology	10
1.10 Climate of Chiang Mai area	12

Page	
------	--

Chapter 2 Literature Reviews	15
2.1 Landslide in Thailand	15
2.2 Landslides in weathered granite	17
2.3 Rainfall-triggered landslides	17
2.4 Geotechnical properties of landslide sites	19
2.5 Clay mineralogy of landslide sites	21
2.5.1 Weathering of rocks	22
2.5.2 Clays minerals group	24
2.5.3 Clays minerals of landslide site	26
2.6 Slope stability analysis	28
Chapter 3 Methodology	30
3.1 Field investigation and soil sampling	30
3.1.1 Landslide area	30
3.1.2 Non-landslide area	30
3.2 Geotechnical soil properties	31
3.2.1 Permeability test	31
3.2.2 Grain size analysis (sieve and hydrometer analysis)	33
3.2.2.1 Sieve analysis	34
3.2.2.2 Hydrometer analysis	35
3.2.3 Atterberg limits	40
3.2.3.1 Liquid limit (LL)	40
3.2.3.2 Plastic limit (PL)	42
3.2.4 Shear strength (Direct shear test)	43
3.3 X-Ray diffraction mineralogical analysis	46
3.4 Slope stability analysis using CHASM <sup>®</sup> software	49

Chapter 4 Results and Discussions	52
4.1 Geotechnical soil properties	52
4.1.1 Permeability test	52
4.1.2 Grain size analysis	52
4.1.3 Atterberg limits	54
4.1.4 Shear strength (Direct shear test)	57
4.2 X-Ray diffraction mineralogical analysis	60
4.3 Slope stability analysis (Combined Hydrology And Stability Model)	63
Chapter 5 Conclusions and Recommendations	65
5.1 Conclusions	65
5.2 Recommendations	69
References	71
Appendix	
Appendix A Permeability test	85
Appendix B Grain size analysis	92
Appendix C Atterberg limits	111
	130
Appendix E X-Ray diffraction mineralogical analysis	185
ลี่สสัทธ์บหาวทยาลยเชียงใหม	100
Curriculum Vitae Copyright <sup>©</sup> by Chiang Mai University	204
All rights reserved	

## LIST OF TABLES

Table 1.1	Major types of landslides. Abbreviated version	9
	of Varnes' classification of slope movements	
Table 2.1	Stages in the weathering of minerals in the $< 2 \text{ mm}$ fraction of soils	23
Table 3.1.	Values of effective depth based on hydrometer and	37
	sedimentation cylinder of specific sizes (ASTM E100).	
Table 3.2.	Values of k for use in Equation for computing diameter	38
	of particle in hydrometer analysis (ASTM E100).	
Table 3.3.	Temperature correction factors C <sub>T</sub> (ASTM E100).	39
Table 3.4.	Correction Factors a for unit weight of solids (ASTM E100).	39
Table 4.1	Grain size distribution for the landslide and non-landslide area	52
Table 4.2	Water content, liquid limit, plastic limit and plasticity index	54
	of soils from landslide and non-landslide area.	
Table 4.3	The results of direct shear test.	58
Table 4.4	Semi- quantitative XRD analysis of mineral constituents	62
ລິ	in the soils.	
Table 5.1 C	Method and average value of landslide and non-landslide area.	66

## LIST OF FIGURES

Figure 1.1	Diagram illustrating the major types of	9
	Landslide movement.	
Figure 1.2	Location map of the study area.	11
Figure 1.3	Geologic map of northern Thailand showing the age series	13
	of rocks.	
Figure 1.4	Map of the annual monsoon direction in Thailand.	14
Figure 1.5	Average monthly rainfall in Chiang Mai (1988-2013)	14
Figure 2.1	Stability series for common primary minerals.	22
Figure 2.2	Hydrology model structure.	29
Figure 3.1	Diagram showing precipitation of August in 2011.	31
Figure 3.2	Photographs of study areas A) Landslides occurred at kilometer	32
	53 and location of collected soil sample. B) Non-landslide area	
	at kilometer 50.	
Figure 3.3	3D digital elevation model of landslide and non-landslide areas	32
	with soil sampling locations.	
Figure 3.4	Drilling the borehole by hand auger and performing.	33
	in-situ permeability test.	
Figure 3.5 🖸	The sieve stack in the mechanical shaker.	35
Figure 3.6	Diagram of direct shear arrangement.	44
Figure 3.7	Schematic representation of XRD by regularly spaced	47
	planes of atoms in a crystal.	
Figure 3.8	X-ray powder diffraction (XRD).	48

Page

Figure 3.9	CHASM main page interface.	49
Figure 3.10	CHASM soil property interface.	50
Figure 3.11	CHASM rainfall data interface.	50
Figure 3.12	CHASM visualization of critical slip surface of landslide area.	51
Figure 3.13	CHASM visualization of pore pressure of landslide area.	51
Figure 4.1	The grain size distribution curves for the landslide and non-landslide area.	54
Figure 4.2	Water content, liquid limit, plastic limit and plasticity index with varies depth of soils from landslide and non-landslide area.	56
Figure 4.3	Plasticity chart (USCS) of soil samples in landslide area.	56
Figure 4.4	Plasticity chart (USCS) of soil samples in non-landslide area.	57
Figure 4.5	Variation of clay content with cohesion.	59
Figure 4.6	Variation of clay content with friction angle.	59
Figure 4.7	Shows the representative XRD diffraction pattern from the	61
	soils of landslide sample no. LS_A2 and non-landslide	
	sample no. N-LS_A2.	
Figure 4.8	The variation of factor of safety with time for 48 hours simulation	64
	of landslide and non-landslide area.	
ລິ	้ขสิทธิ์มหาวิทยาลัยเชีย <b>ง</b> ใหม <b>่</b>	
C	opyright <sup>©</sup> by Chiang Mai University	
A	ll rights reserved	