

Landslide Problems and Warning by Geotechnical Methods

Warakorn Mairaing



Associate Professor and Head of Civil Engineering Department, Kasetsart University, Bangkok, Thailand, 10900

mairaing@yahoo.com

ABSTRACT

Landslides in Thailand is one of the natural disasters cause damage to life and casualties every year. A number of factors trigger the landslide including heavy rainfall during monsoon season, geological condition, and landuse. Prediction and warning can be done by several methods such as Geomorphology, Weighted Factor Index, Geotechnical Engineering, Risk Analysis Methods. The Geotechnical Engineering Method is the direct method for calculating the Factor of Safety (F.S.) of soil slope during heavy rainfall. The strength of unsaturated soil is changed during the water infiltration in soil mass by Fredlund (1993). Matric suction related to the volumetric water content in soil mass can be analyzed for each rainstorm patterns and can be confirmed by field measurement. By applying the infinite slope stability analysis to geographical information system(GIS), the prediction of landslide at the certain area can be done to establish the critical rainfall envelope.

1. Introduction

Landslides are a serious natural disasters in many countries in the world. According to Landslide Hazard Team of UNESCO(2000) estimates that landslide claim about 1000 lives and 10-20 billion\$ of damages each year. Landslide phenomena are the comparatively easier to predict and issue the warning in advance than earthquake, volcanic eruption or Tsunami. In some area, where the proper landslide management is established, up to 90 % of expected damage is reduced. Thailand has a total land area of 513,115 km² and a population of 65 million people with a growth rate of 1.1 percent annually. Since the past 20 years, landslides and debris flows are the threatening natural hazard of the country. Resettlement of the people in the landslide risk area, deforestation, changes in land-use and rainfall pattern increase the potential damage in recent years. The best estimate of direct and indirect costs of landslide damage range between 1000 – 3000 million baht (38 baht = 1 US.\$).

1.1 Climate

Thailand is located on the warm and tropical climate region. The tropical monsoons and typhoons from both Andaman Sea and

South China Sea contribute to the seasonal heavy rainfalls in the region. A rainy season starts from June on the northern part and moving down to the southern part on December. The general passages of annual monsoons are as shown on Figure1.

The average country annual rainfalls as indicated on Figure 2. are ranging from 1000 -1500 mm. for Northern, Northeastern and Central parts. But on the southern Thailand, the higher rainfalls are averaged from 2000 – 2500 mm. So that the rainfall induced landslides are normally occurred on the mountainous area during the heavy and long period rain. On some watershed area, the flood and debris flow will follow the landslides and cause more serious damage to the villages below.

1.2 Geology

Topography and geology are also the main factors influent landslide. The geomorphology and geology maps are as shown on Figure 3 and 4. Five main geomorphology areas of Thailand are;

- 1) the central plain; the large alluvial flood plain and diluvial-columial fans;
- 2) the eastern coasts; the eastern area including rapid

development industrial area and deep sea ports;

- 3) the northeastern part; the high plateau of sandstone, siltstone and shale;

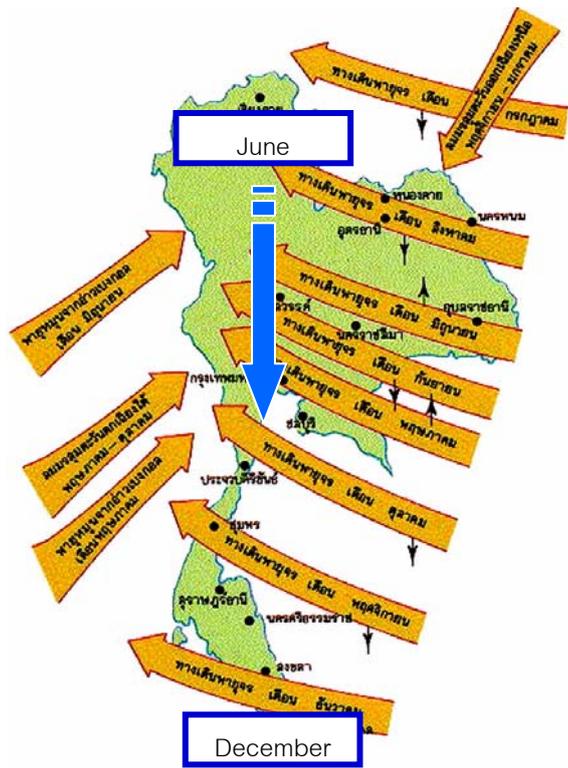


Figure 1 Passages of tropical monsoons over Thailand

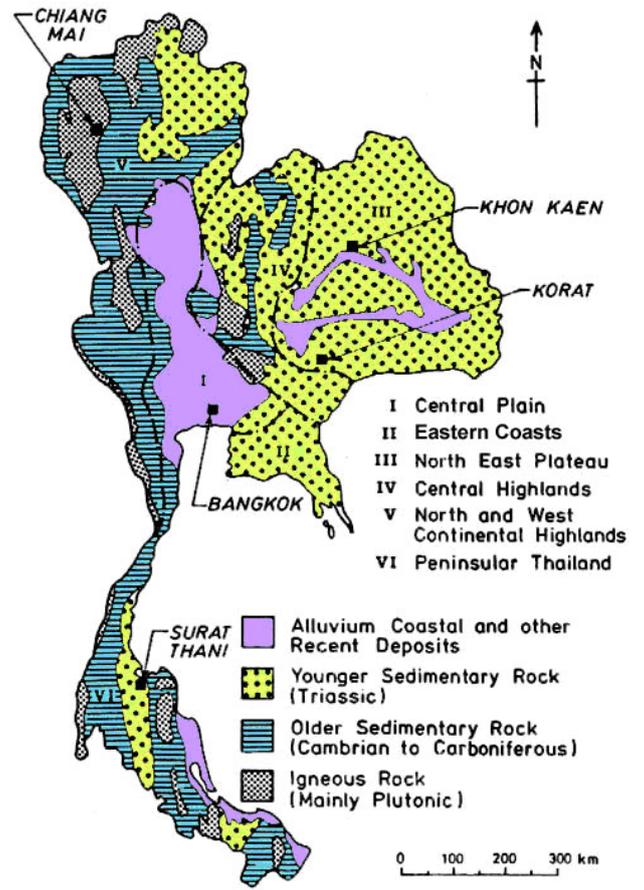


Figure 3. Brief Geomorphology of Thailand

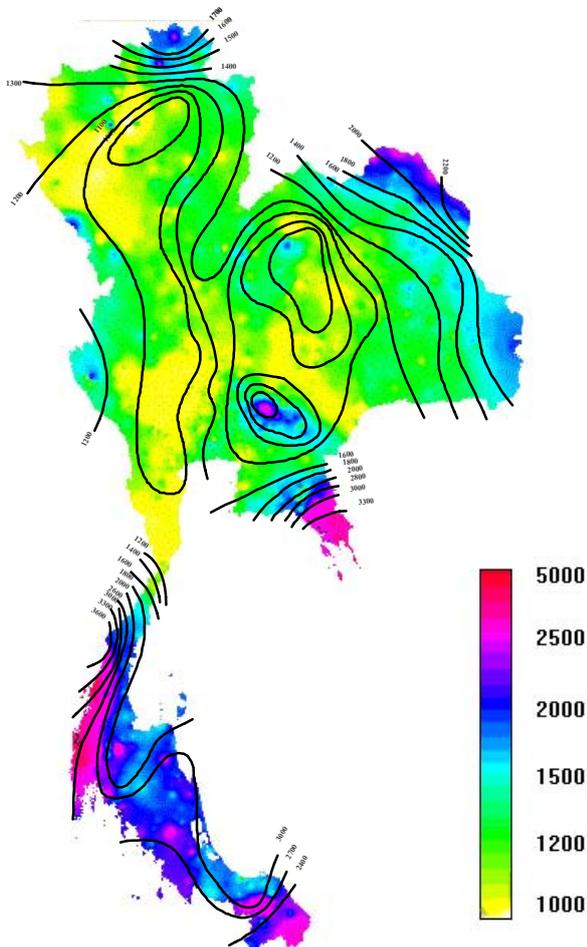


Figure 2. Distribution of Annual Rainfall (mm.)

- 4) the eastern coasts; the eastern area including rapid development industrial area and deep sea ports;
- 5) the northeastern part; the high plateau of sandstone, siltstone and shale;
- 6) the central highlands; the transition area between northeastern and northern region;
- 7) the northern and western continental highlands, the high mountain ranges formed by granitic rocks, metamorphic rocks, and old alluvium in the valley;
- 8) the southern part; the granitic mountain ranges on the west side combined with old and young sedimentation on the central and east sides of the peninsular.

The major rock groups for landslide study can be classified as 8 groups as shown on Figure 4. below.

Group 1; dominate rock is Carboniferous-Permian granite of the northern region.

Group 2; dominate rock is Jurassic-Cretaceous granite of the southern region.

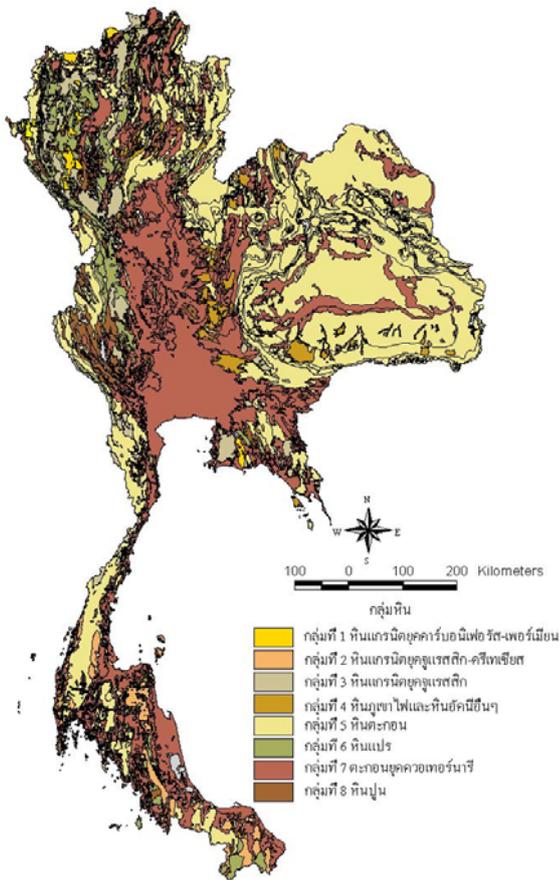


Figure 4. Major Rock Groups of Thailand

Group 3; scattered Jurassic granite mainly on the northern part of Thailand.

Group 4; volcanic and igneous rocks of basalt, andesite, rhyolite, tuff, hornblende.

Group 5; sedimentary rocks of sandstone, mudstone, shale, chert and unconsolidated rocks.

Group 6; metamorphic rocks of gneiss, schist, quartzite, phyllite, marble, meta-tuff.

Group 7; quaternary deposit, alluvial and marine clay deposit.

Group 8; limestone of Ordovician and Permian era.

The past landslide inventories show the potential of landslide according to the rock groups as shown on Table 1. The granite and granitic soils show the highest potential of landslide. Where on some sedimentary rock groups such as shale, mudstone, and siltstone, the geologic structures such as the bedding planes, joints, faults are greatly influence the failure of slopes.

Table 1 Landslide influenced by rock groups

Level	Landslide Potential	Rock Groups	Geologic Structure Influence
1	Highest	Granite Dominated: Highly and deep weathering zone, thick residual soil.	Low
2	High	Shale and Mudstone Dominated: High weathering rate, shallower residual soil.	High
3	Moderate	Sandstone and Siltstone Dominated: Moderate weathering rate, shallow residual soil.	High
4	Low	Quartzite, Sandstone, Siltstone Dominated: Similar to Level 3 but quartzite is stronger to the weathering processes.	Moderate
5	Lowest	Limestone and Dolomite rocks: moderately weathering rate, shallow residual soil.	Low

1.3 Landslide Problems

Landslide problems in Thailand cause by the combined effects of the natural and manmade factors. In the past, when the areas are still in untamed forest, landslide usually occurred after forest fire or draught year. The evidences of large alluvial fans from landslides can be noticed on the west of central plain at Kanchanaburi.



Figure 5. Typical Landslides

Land-use is one of the factor contributing to landslide. The consequences of population growth and demand for agricultural land cause the deforestation and alter the land-use. *Sureeratna L.* (2001) reports that Thailand's forest areas declined from 53.33 percent of the total land in 1961 to 25.02 percent in 1999 as shown in Table 2. The changing of rainfall pattern, the infiltration rate and flow regimes within soil profile from cultivation can also trigger the landslides. However when landslides happen during prolong rain, the sliding mass with water forming soil slurry and debris flows down to the stream channel with destructive energy. This hyper-viscous fluid can carry the large boulders up to several meters in diameter and large tree trunks. When reaching the village, it can destroy the building, bridge or small dam easily.

Although debris flows and floods cause huge damages but they considered to be easier to forecast comparing to others disasters. The effective landslide prediction and warning can reduce the loss up to 90 percent. In order to do so, the basic knowledge of strength parameters, permeability, and ground water flow of unsaturated soil are necessary. And the data of past rainfall intensity and pattern are also relevant.

Table 2. Status of forest area in Thailand

Year	Remaining Forest (rai)	Remaining Forest (%)
1961	171,017,812	53.33
1973	138,578,125	43.21
1975	128,278,755	40.00
1976	124,010,625	38.67
1978	109,515,000	34.15
1982	97,875,000	30.52
1985	94,291,349	29.40
1988	89,877,182	28.03
1989	89,635,625	27.95
1991	85,436,284	26.64
1993	83,470,967	26.03
1995	82,178,161	25.62
1998	81,076,428	25.28
1999	80,242,572	25.02

(12,838,811.6 ha)

1 hectare (ha) equals 6.25 rai (Thai measure)

Sureeratna L. (2001)

2. Some Case History of Landslides in Thailand

During the last 30 years, the landslide cases were fairly well recorded as shown on Figure 4. and on Table 3.

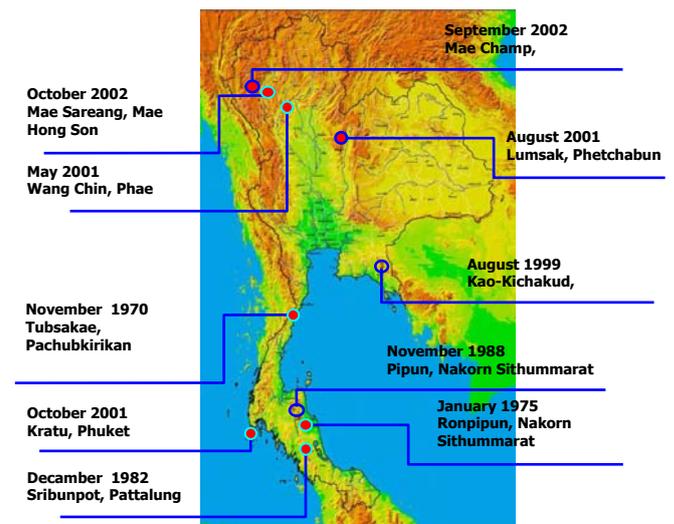


Figure 4. Some Landslide Case History

Table 3. Landslide Records

Year	Locations	Live loss
November 1970	Tubsakea, Prochubkirikan	12
January 1975	Ronpibol, Nakorn Srithumarat	58
December 1982	Sibunpot, Pattalung	4
November 1988	Pipun, Nakorn Srithumarat	> 200
August 1999	Kao-kichakud, Chantabuti	1
May 2001	Wangchin, Phae	> 30
August 2001	Lumsak, Phetchabun	132
May 2004	Mae Ramad, Tak	5
July 2004	Mae Aye, Cheingmai	1
October 2004	Muang, Krabi	3

3. Methods for Landslide Prediction

Landslide prediction in general can be done by four methods starting from the simplest but less accurate to the more complex but quite accurate as follows

1. Geomorphology Method: considering the topography of the area, drainage patterns and configuration of slope.

2. Weighted Factor Index: considering several factors from nature and human. Empirical Index is formulated correlation with some actual landslide occurrences. This method is using in Thailand at the present.

3. Geotechnical Engineering Method: Based on the Factor of Safety (F.S.) from the stability analysis. Normally the infinite slope analysis is applied. The engineering data for the field and laboratory tests is needed.

4. Risk Analysis Method: Combination of Landslide susceptibility with the probability of occurrences and risk cost etc. The risk management can be done after the prediction.

Several government organizations in Thailand are using Weight Factor Index to create landslide risk maps. While Kasetsart University applies Geotechnical Engineering Method for landslide research at the present.

4. Landslide Analysis by Geotechnical Method

The geotechnical engineering method will be described herein as indicated in Figure 5 below.

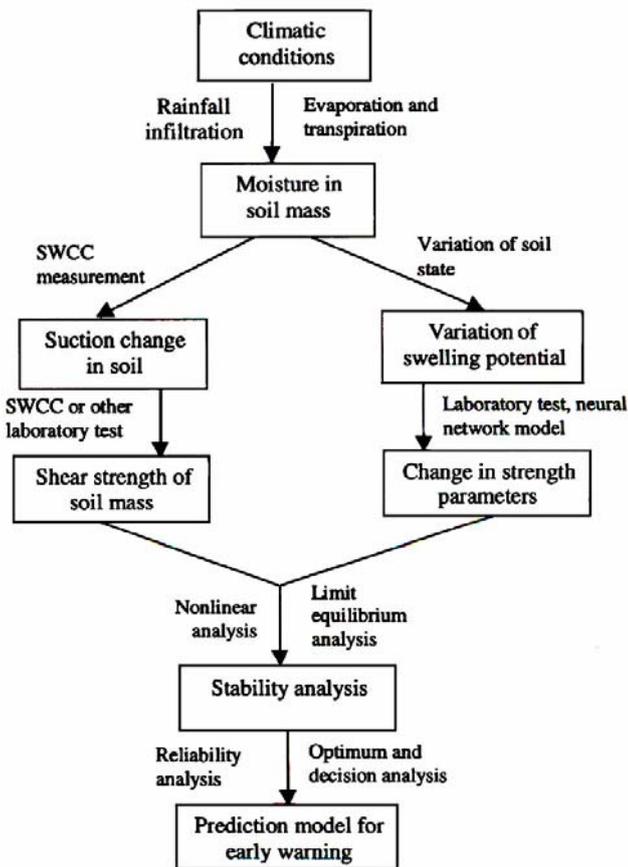


Figure 5 Geotechnical Engineering Method for Landslide Prediction and Warning.

4.1. Basic concepts and soil parameters

4.1.1. Unsaturated soil properties

When natural soil on the slope is in unsaturated condition, it holds the negative pore pressure within soil mass. This behavior can be explained by the forces or surface tension of the contractile skin at the contact points between soil particles (Fredlund, 1993). The effective stress in unsaturated soil mass is increased resulting higher soil strength.



Figure 6. Unsaturated Soil on Steep Slope

This condition is changed when the soil moisture increased due to infiltration from the rain. On the rainy season, the water seeps into soil mass and gradually reduces the strength. On some slope, the failure can occur even before the whole soil mass reach the fully saturated condition.

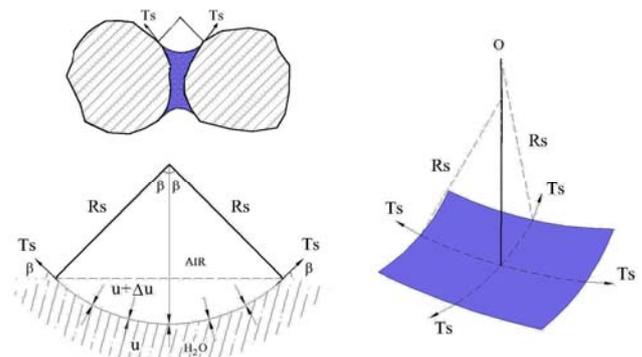


Figure 7. Forces on Contractile Surface (Fredlund, 1993)

Fredlund (1978) propose to modify the classical Mohr-Coulomb's Equation for unsaturated soil as shown on Eq. (1). The strength envelope can be illustrated by 3-D Strength surface as on Figure 8.

$$\tau = c' + (\sigma_n - u_a) \tan \phi' + (u_a - u_w) \tan \phi^b \quad (1)$$

- When c' = effective cohesion at saturated condition
- u_a = pore air pressure
- $\sigma_n - u_a$ = net normal stress
- $u_a - u_w$ = matric suction
- ϕ' = effective angle of internal friction
- ϕ^b = angle of increase rate of strength due to suction

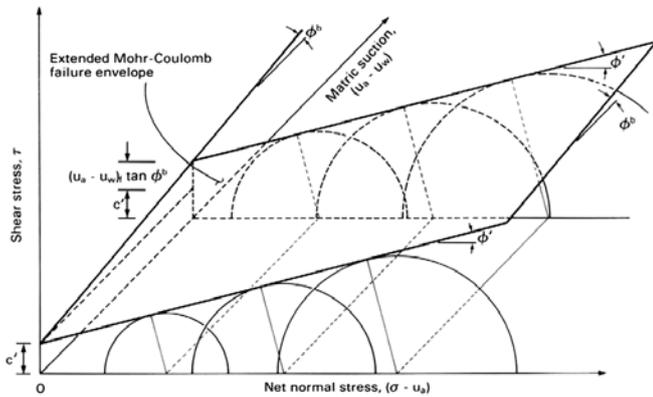


Figure 8. Extended Mohr-Coulomb Envelope for Unsaturated Soil (Fredlund, and Rahardjo, 1993)

4.1.2. Multi-Stage Direct Shear Test

When the soil are sampled directly from the actual or representative failure surfaces. The limited number of sample can be obtained so that the multi-stage direct shear test was used to minimize the testing sample. Only one soil sample with the specified moisture content was applied the initial normal stress close to existing overburden pressure. Then the sample was sheared until approach failure, the first stage was then stop. The higher normal stress was applied and repeat the shearing process similar to the first one. Then, the third or final stage were repeated the same as previous stages. The discrepancy was about 3-5 % on the conservative side between the conventional and multi-stage loading. The typical results from multistage direct shear test with moisture content variation are as shown on Figure 9 and 10.

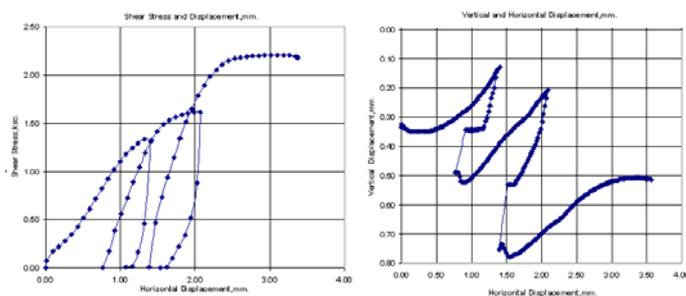


Figure 9. Stress-strain from multi-stage direct shear test.

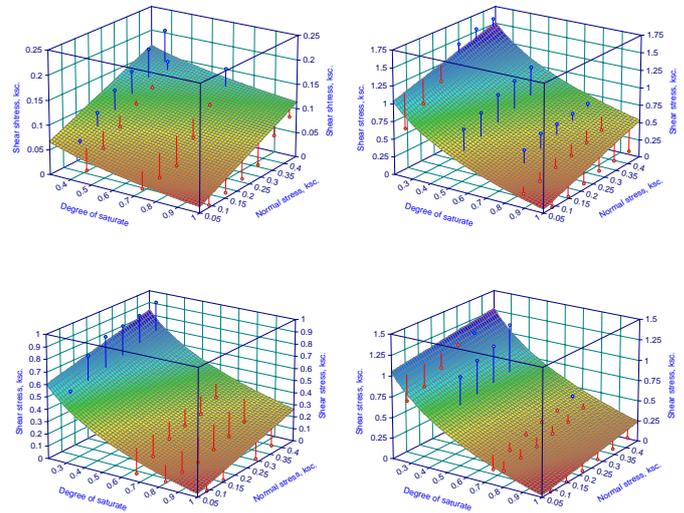


Figure 10. Results from Multistage Direct Shear Test.

4.2. Geotechnical Landslide Analysis

The analysis processes are starting from the field and laboratory results as follows.

1. Digital map of the slope area.
2. Soil profile modeling from field investigation.
3. Unsaturated soil strength parameters.

Then the representative of rainfall patterns are compiled from the past records as the examples shown on Figure 11. These input rainfall patterns are used for FEM seepage analysis on the soil slope. The variation percent saturation on the soil profile with time can be related to the unsaturated soil strength from the laboratory test results.

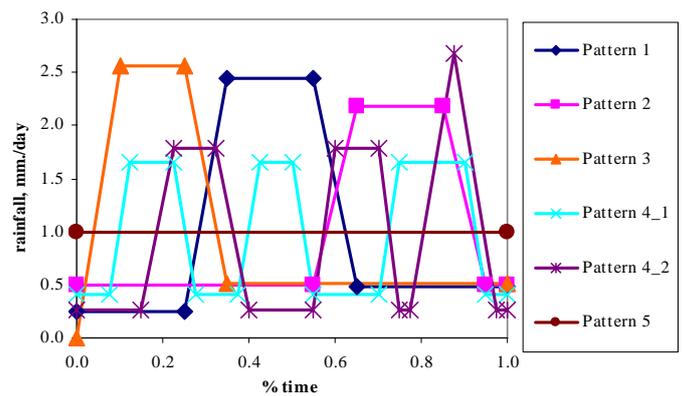


Figure 11. Rainfall Patterns

Some of the results from seepage analyses are as shown on Figure 12. The movement of 95% saturation fronts can be the indication of the percolation of water into soil mass at the various elapsed times. However the critical stability condition at different points may not occurred on the same time. The

average elapsed time can be selected to represent the critical period.

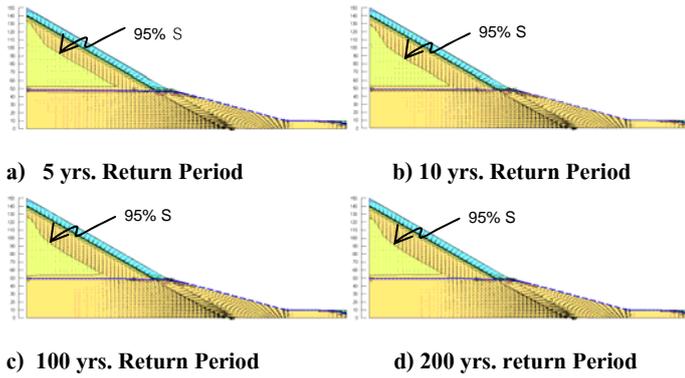


Figure 12. Seepage Pattern on Soil Slope on the 10 th day.

4.2.2. Stability Analysis with GIS Application

The analysis for Factor of Safety on the wide area needs the Geographical Information System. The area is divided into small pixels, each contains the individual information such as slope angle, unsaturated soil strength, soil profile, water table, percent saturation at various time etc. The methods for generation of map raster are as shown on Figure 13. below.

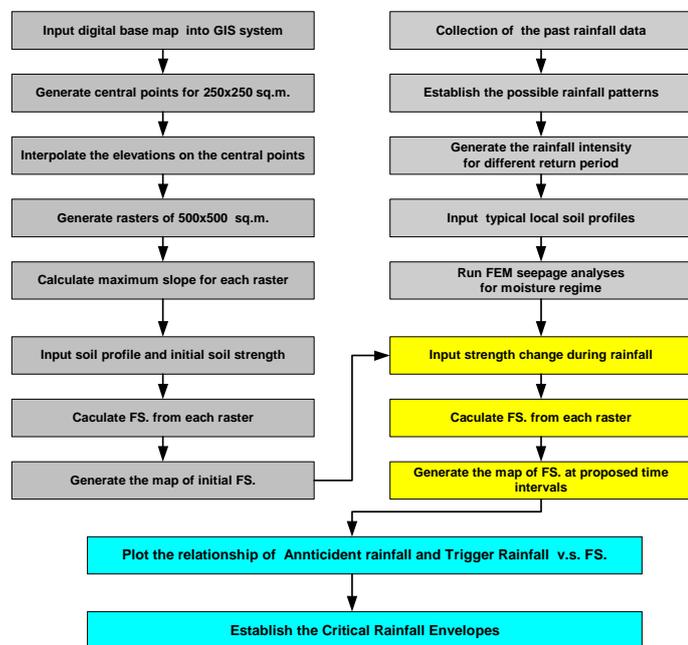


Figure 13. GIS Raster generation

Then the combination of Infinite Slope Analysis as the detail shown on Figure 15. The Factor of Safety for each raster can be

calculated for at the particular time starting from the beginning of rainfall.

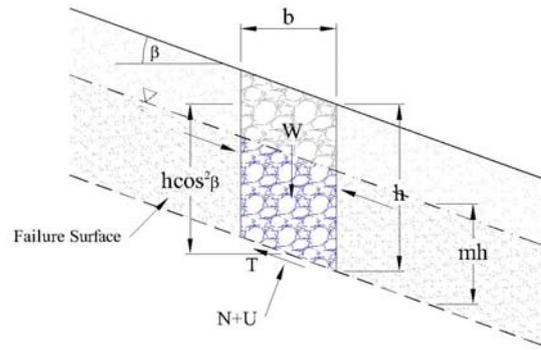
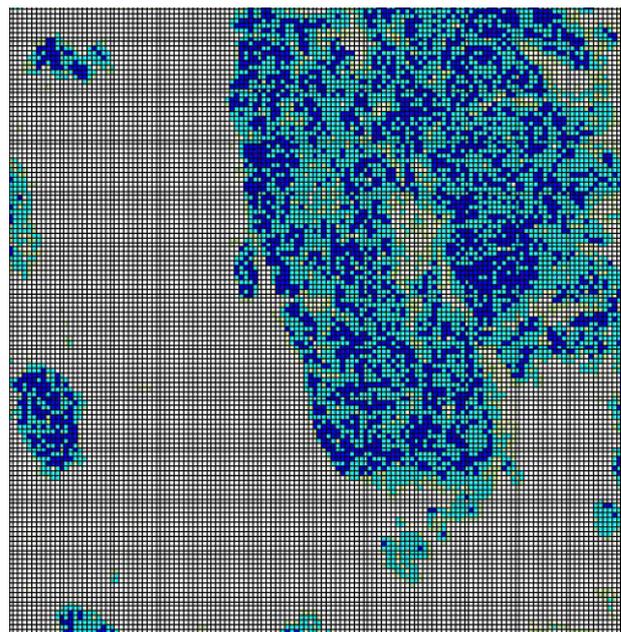


Figure 14. Free Body Diagram Soil Slice on Infinite Slope

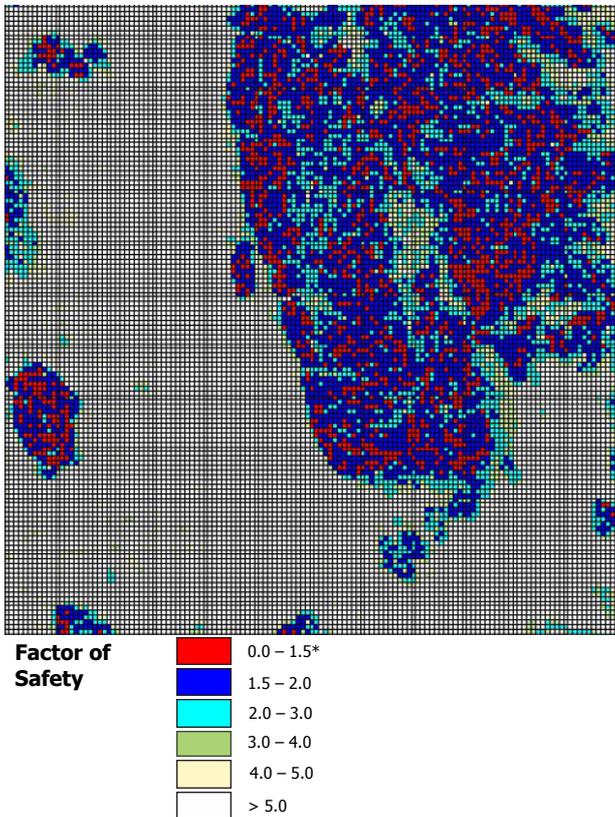
$$F.S. = \frac{c + h \cos^2 \beta \cdot \tan \phi [(1-m)\gamma' + m(\gamma_{sat} - \gamma_w)] + \ln(S) \tan \alpha}{h \sin \beta \cos \beta [(1-m)\gamma' + m\gamma_{sat}]} \quad (3)$$

When

- C = effective soil cohesion
- h = soil sliding depth
- β = soil slope angle
- ϕ = effective soil angle of internal friction
- mh = ground water saturation depth
- γ_{sat} = soil saturation density
- γ_w = water density
- γ' = soil buoyant density
- S = percent saturation
- α = soil unsaturated strength parameter



a) At the initial stage (Natural Water Content before Rainfall)



b) After Heavy Rainfall

Figure 15. Distribution of Factor of Safety (Bunpoat, 2005)

5. Warning Levels

The final goal for landslide analysis is the given the paper warning to the public concerned. In order to do so, we can establish the warning levels from the simple index such as the accumulative rainfall from the field. Or with the GIS technique, the semi-real time calculation of Factor of Safety can be done by computer. However, the prediction model has to be calibrated with the known landslide even with some field monitoring instruments eg. tensiometer, automatic raingage, inclinometer etc.

The warning diagrams of the critical rainfall envelopes for Ban Nam Kor, Chaiyapum and Kao Kitchakud, Chantaburi are as shown on Figure 16 and 17

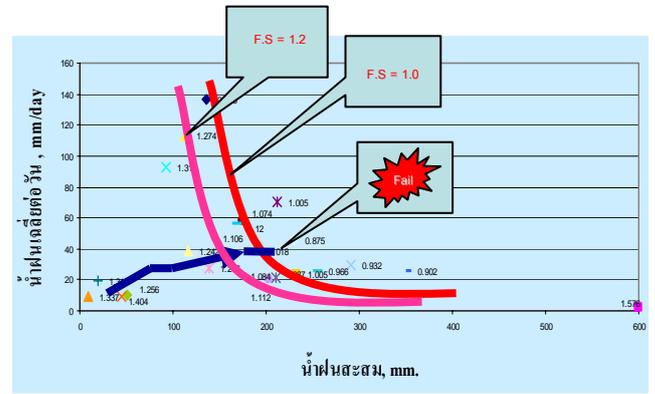


Figure 16. Critical Rainfall Envelope for Nam Kor

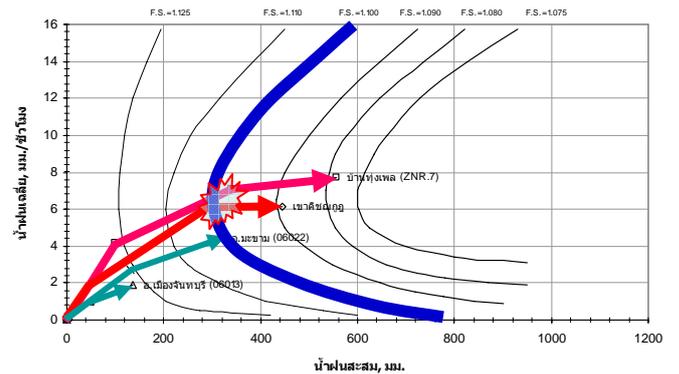


Figure 17. Critical Rainfall Envelope for Kao Kidchakud

6. Conclusion

The landslide problems are one of the natural disasters in Thailand. It is happened long before the historical time but increasing appreciably during the last 20 years due to human factors. The warning at the present is based on the empirical approach known as “Weight Factors Index”. More direct method using Geotechnical Engineering Stability Analysis combined with GIS can be done. The unsaturated strength parameters has to be determined by Fredlund’s Model. The data of past rainfall pattern can be used for seepage analysis to adjust the strength parameters. When GIS digital mapping techniques are applied for infinite slope stability analysis, the distribution of F.S. over the area can be plotted on the map. The semi-real time Factor of Safety distribution or pre-analysis critical rainfall charts after verification can be used for public warning on landslide failure in the future.

REFERENCES

- [1] Mairaing, W. and et.al. 1992 , **The Development of Master Plan for Natural Hazards Related to Landslides**, The Thailand Research Funds, Bangkok. (in Thai)
- [2] Mairaing, W. 1989, **Embankment Dam Engineering**, Civil Engineering Department, Kasetsart University, Bangkok (in Thai)
- [3] Bunpoat Kunsuwan , 2005, **Behaviors of Slope Failures in Chantaburi Watershed Area**, Master Thesis, Kasetsart Unveristy, Bangkok.
- [4] Nonglack Thaicheim-aree, 2003, **Engineering Soil Properties for Stability Analysis of Soil Slopes on Nam Kor, Lumsak, Phetchabun**, Master Thesis, Kasetsart Unveristy, Bangkok. (in Thai)
- [5] Boonrod Kubtitaubhe, 1989. **Study of Appropriate Soil Strength Tests for Huai Pa Thao Dam**. Master Thesis, Kasetsart Unveristy, Bangkok. (in Thai)
- [6] Fleming, H.D. 1952. **Undrained triaxial compression tests on a decomposed pyllite**. pp 112-122. In First Australia New Zealand Conf. Soil Mech. And Found. Eng. Australia.
- [7] Fredlund, D.G. and H. Rahardjo. 1993. **Soil Mechanics for Unsaturated Soils**. John Wiley & Son,INC., New York.
- [8] Kenney, T.C. and G.H. Watson. 1961. **Multiple-Stage Triaxial Test for Determining c' and f' of Saturated soils**. pp.191-195. In 5th Int. Conf. Soil Mech. Vol.1.
- [9] Taylor, D.W. 1950. **A triaxial shear investigation on a partially saturated soil**. pp. 180-191. In ASTM. Spec. Tech. Pub. No. 106.
- [10]Transportation Research Board. 1996. **Landslides Investigation and Mitigation**, National Academy Press, Washington, D.C.
- [11] Sureeratna L.(2001) **Forest Policy and History in Thailand**, Research Centre on Forest and People in Thailand.