Warakorn Mairaing, 2006. "Landslide Research Using Geotechnical Method", EIT-JAPAN-AIT 2006 Joint Workshop, Geo-risk Engineering and Geo-exploration, Wednesday 27 September 2006, Bangkok, Thailand

Landslide Researchs Using Geotechnical Method

Warakorn Mairaing [1)]

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. In Thailand, the best estimate of direct and indirect costs of landslide damage range between 1000 – 3000 million baht (38 baht = 1 US.$). Resettlement of the communities in the landslide risk area also increase the potential damage in recent years.

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 averagedfrom 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-coluvial 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;

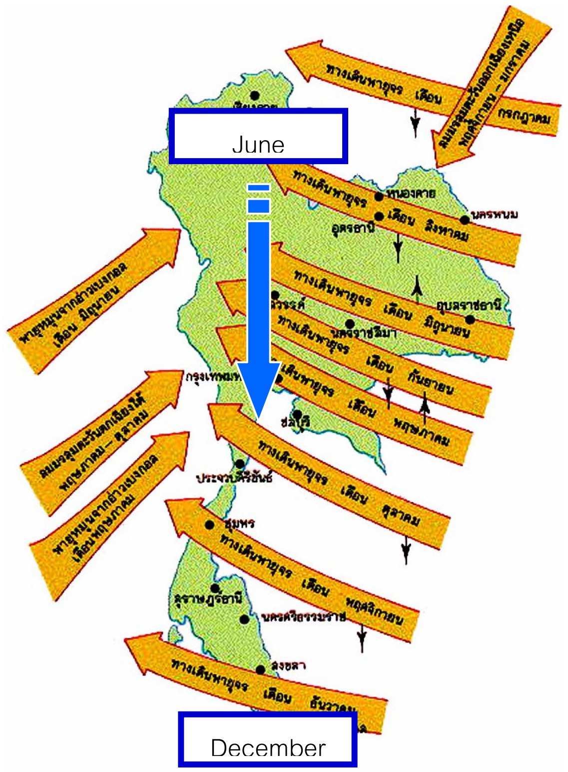


Figure 1 Passages of tropical monsoons over Thailand

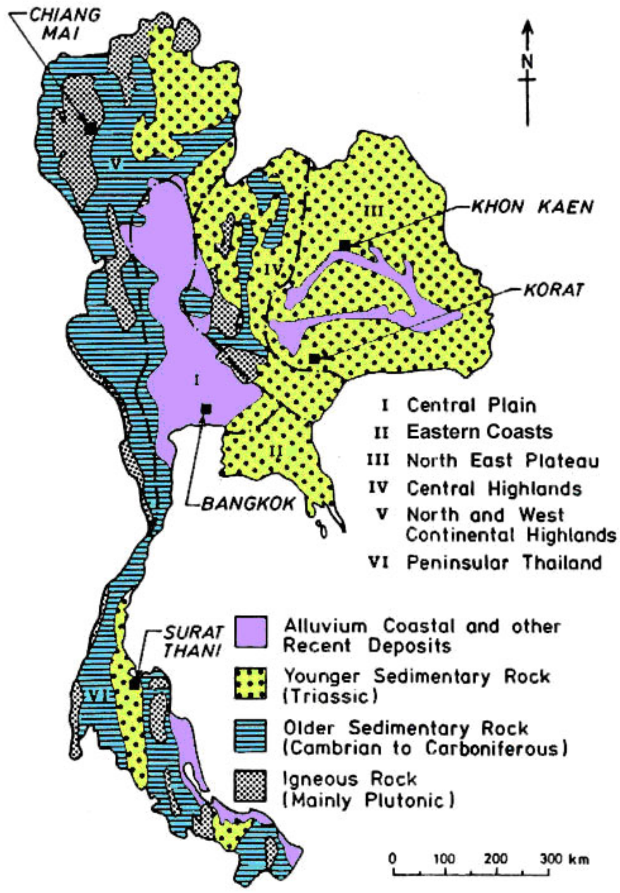


Figure 3. Brief Geomorphology of Thailand

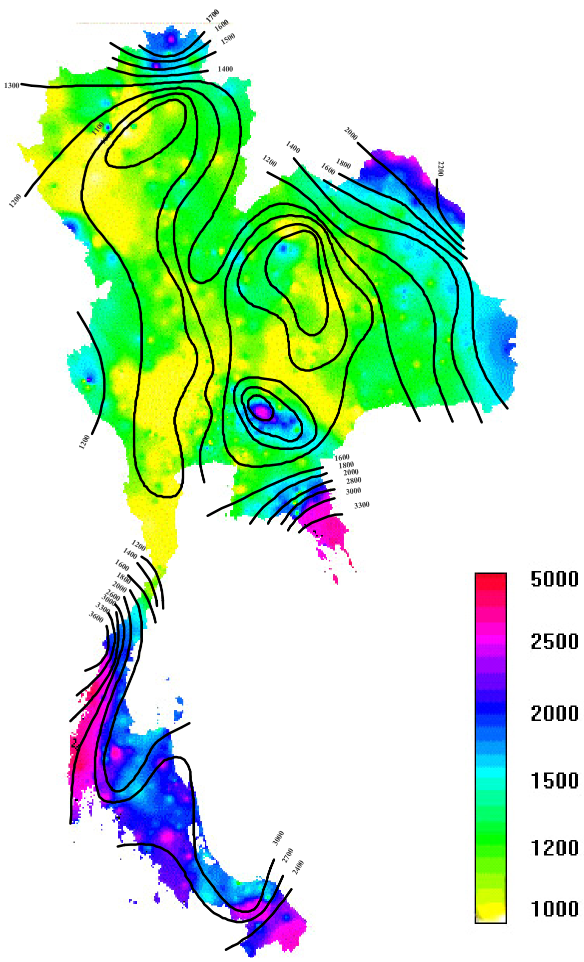


Figure 2. Distribution of Annual Rainfall (mm.)

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 Caboniferous-Permian granite of the northern region.

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

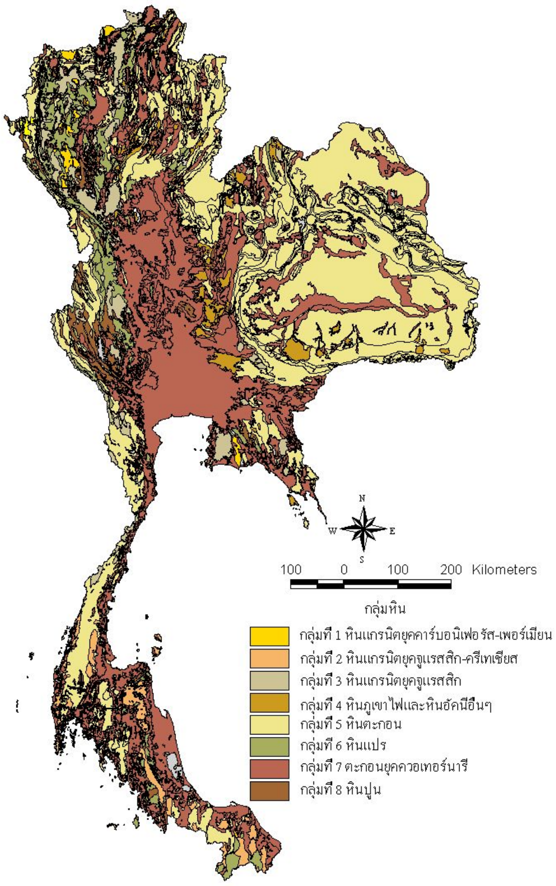


Figure 4. Major Rock Groups of Thailand

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 inventory shows the potential of landslide according to the rock groups as shown on Table 1. In some sedimentary rock groups such as shale, mudstone, and siltstone, the dip angle and other geologic structures greatly influent 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. 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.

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 1.

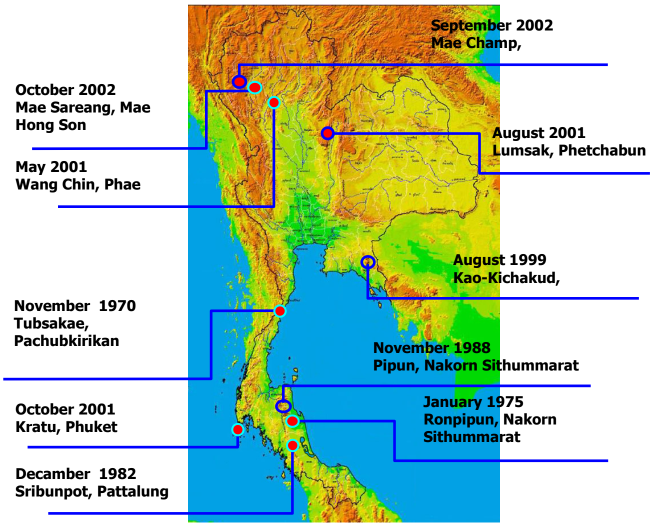


Figure 4. Some Landslide Case History

Table 1. 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.

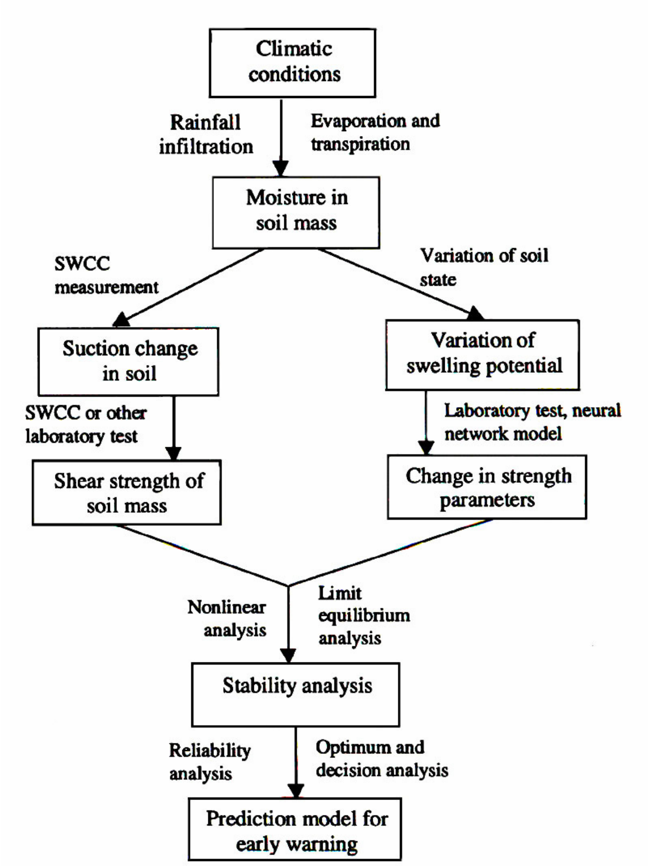


Figure 5 Geotechnical Engineering Method for Landslide Prediction and Warning.

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 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 graduately reduces the strength. On some slope, the failure can occur even before the whole soil mass reach the fully saturated condition.

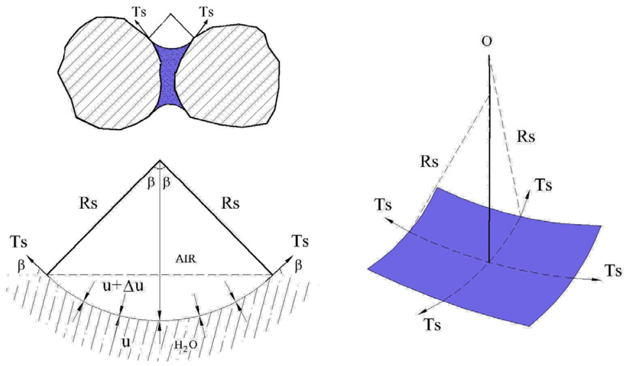


Figure 7. Forces on Contractile Surface (Fredlund, 1993)

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 Figure8.

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

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

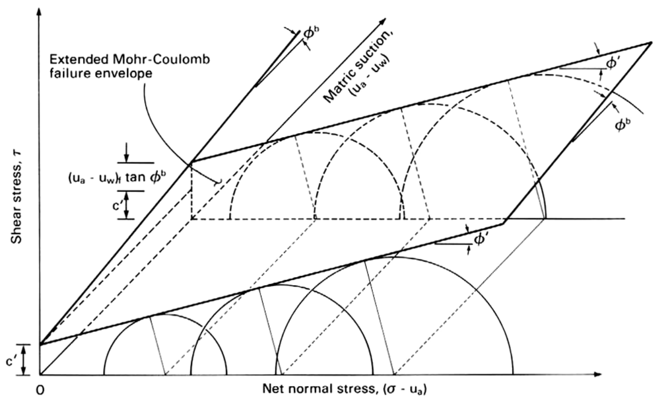


Figure 8. Extended Mohr-Coulomb Envelope for Unsaturated Soil

(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 , the fourth 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.

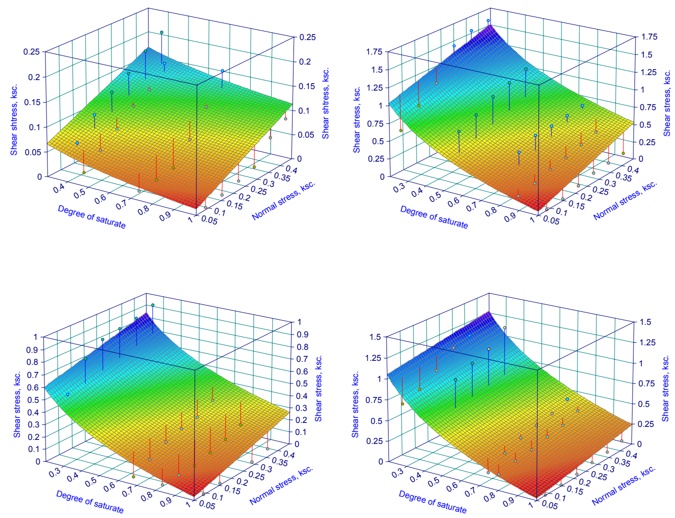


Figure 9. Results from Multistage Direct Shear Test.

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 complied from the past records as the examples shown on Figure 10. 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.

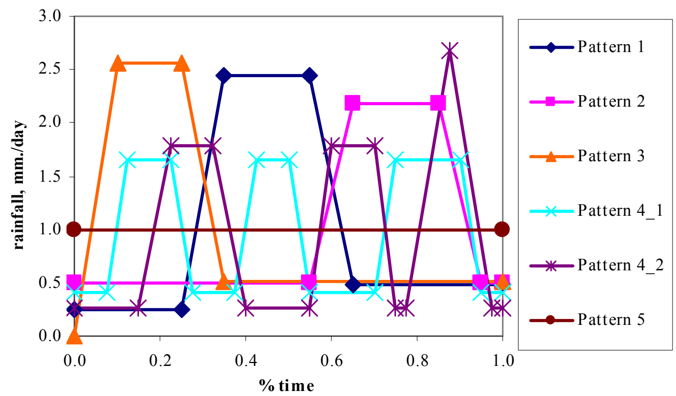
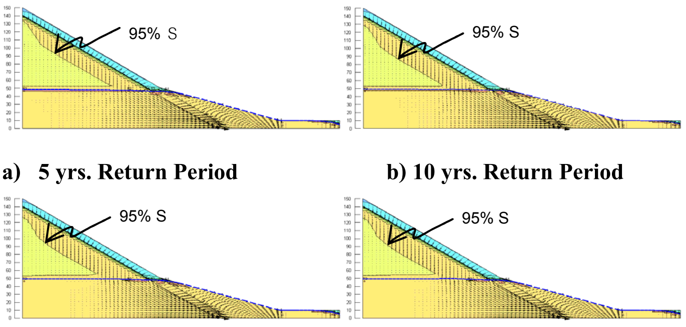


Figure10. Rainfall Patterns

Some of the results from seepage analyses are as shown on Figure 11. 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.



a) 5 yrs. Return Period **b) 10 yrs. Return Period**

c) 100 yrs. Return Period **d) 200 yrs. return Period**

Figure 11. 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 12. below.

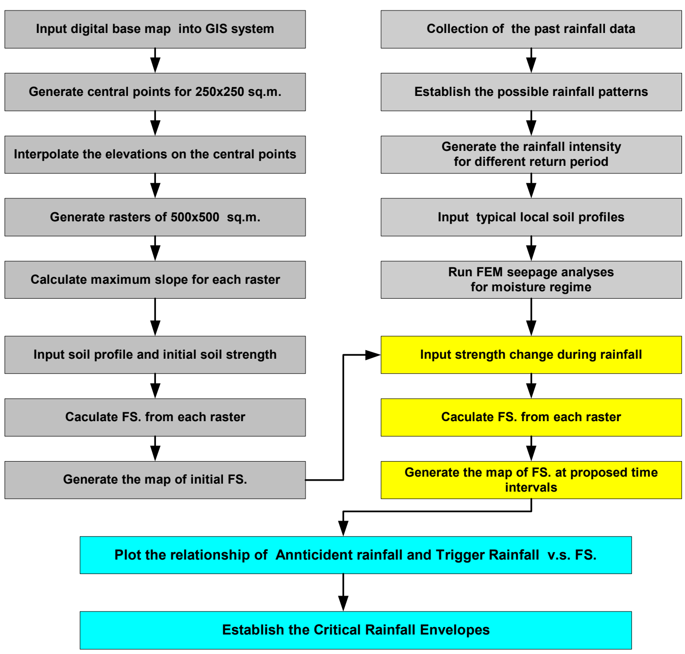


Figure 12. GIS Raster generation

Then the combination of Infinite Slope Analysis as the detail shown on Figure 13. The Factor of Safety for each raster can be calculated for at the particular time starting from the beginning of rainfall.

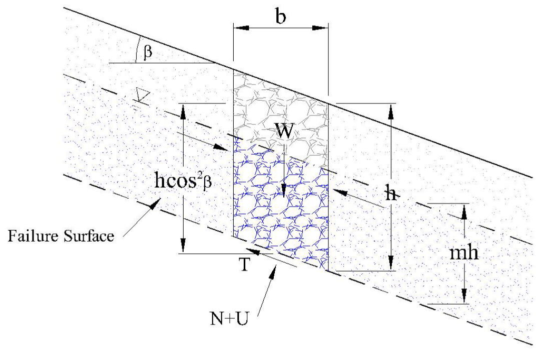


Figure 13. Free Body Diagram Soil Slice on Infinite Slope

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

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

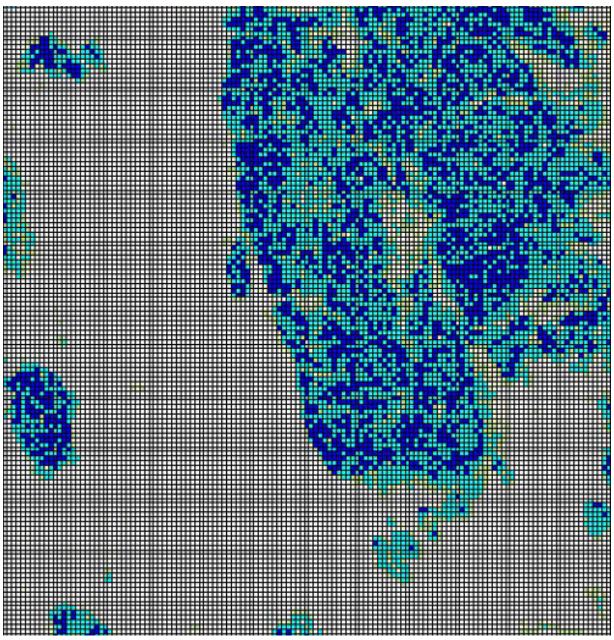
γ_{sat} = soil saturation density

γ_w = water density

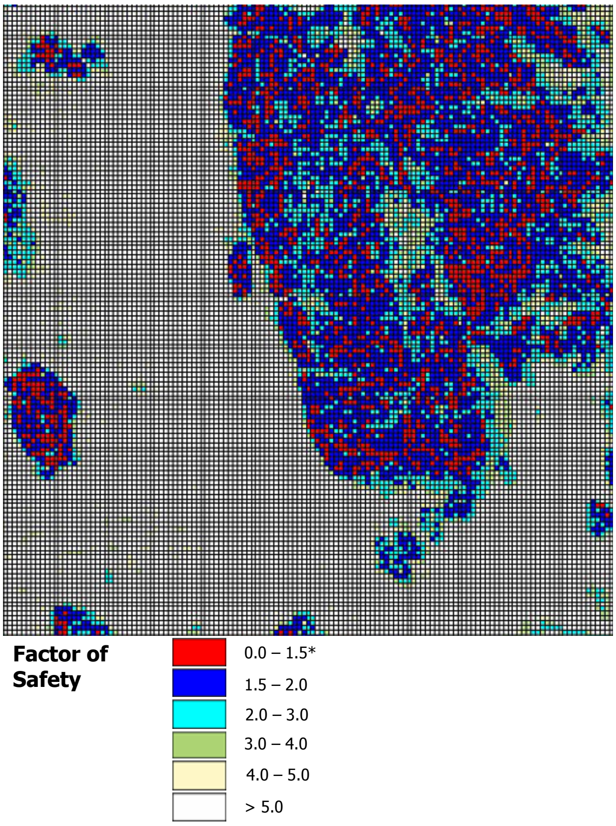
γ' = soil buoyant density

S = percent saturation

α = soil slope angle



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



b) After Heavy Rainfall

Figure 14. Distribution of Facter of Safety (Bunpoat, 2005)

5. Warning Levels

The final goal for landslide analysis is the given the poper 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 monitering 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 15 and 16

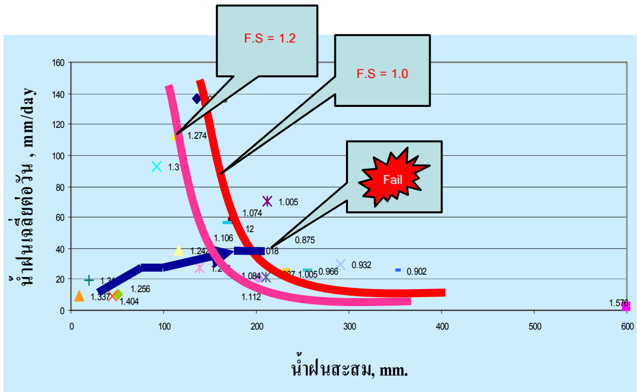


Figure 15. Critical Rainfall Envelope for Nam Kor, Phetchabun

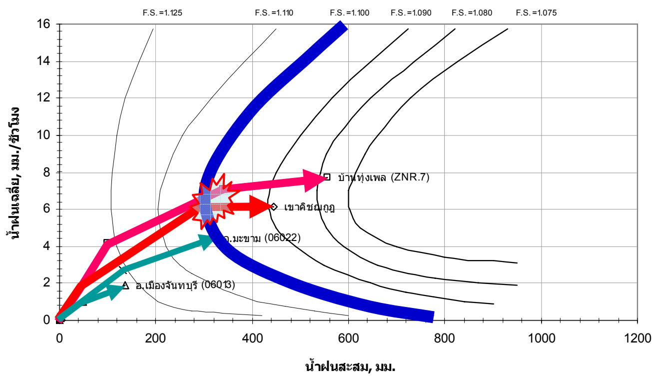


Figure 16. Critical Rainfall Envelope for Kao Kidchakud, Chantaburi

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 30 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 plyllite**. 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.