Landslide Problems and Warning by Geotechnical Methods

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ABSTRACT: Landslide is one of the natural disasters cause damage to life and casualties in Thailand every year. A number of factors trigger the landslide including heavy rainfall during tropical monsoon, geological condition, and change of land uses. Prediction and warning by Geotechnical Engineering Method is the direct method for calculating the Factor of Safety (F.S.) of soil slope during heavy rainfall. Since, the strength of unsaturated soil is changed during the water infiltration in soil mass. Metric suction related to the volumetric water content in soil mass can be analyzed for each rainstorm patterns. Field monitoring can be confirmed by using tensiometer for pore pressure and moisture content measurement to verify the infiltration modeling. By applying the infinite slope stability analysis into geographical information system (GIS) approach, the prediction of landslide on Phuket area is given in term of the critical rainfall envelope. This method has the potential application for real time monitoring and warning in the future when the measuring rainfall intensity is reported from the automatic rain gage in the field. Then slopes stability condition can be calculated simultaneously and reported back for the further warning.

1 INTRODUCTION

Landslides are serious natural disasters in many parts of the world. According to Landslide Hazard Team of UNESCO(2000), estimates that landslides claim about 1000 lives and 10-20 billion$ of damages each year. In some area, where the proper landslide management is established, up to 90 % of expected damage can be reduced. Since the past 30 years, rainfall triggered landslides and debris flows had been one of the natural disasters of the country. Resettlement of the people in 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 heavy rain in the region. Rainy season on starts at June on the northern part and ends at December on the southern part of the country as shown on Figure1.

The average annual rainfalls are ranging from 1000 to 1500 mm. for Northern, Northeastern and Central parts. But on the eastern tip and southern peninsular, the higher rainfalls are averaged from 2000 to 3000 mm. The rainfall induced landslides are normally occurred on the mountainous area due to single intent and/or long period rain. In case of prolong rainfall, the flood and debris flow will follow the landslides and cause more damage to the villages along flow passages and on the alluvium plain 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 dilluvial and colluvial fans on mountain foots;
2) the eastern coasts of low mountain range and coastal deposit; the eastern area including rapid development industrial area and deep sea ports;
3) the northeastern part; the high plateau of sandstone, siltstone and shale;
4) the central highlands; the transition area between northeastern and northern region;
5) the northern and western continental highlands, the high mountain ranges formed by granitic rocks, metamorphic rocks, and old alluvium in the valley;

6) 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.

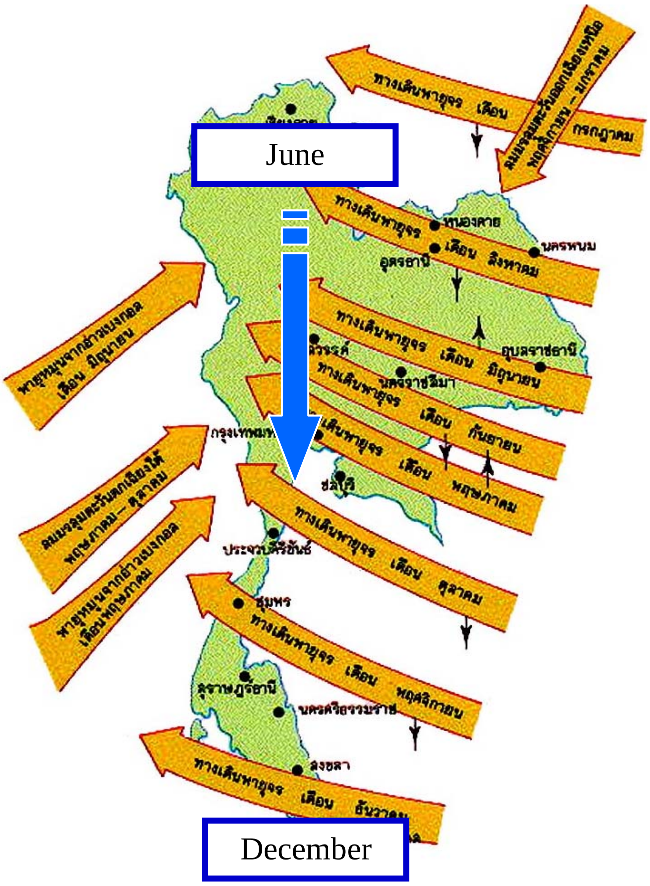


Figure 1 Tropical monsoons and rain storms

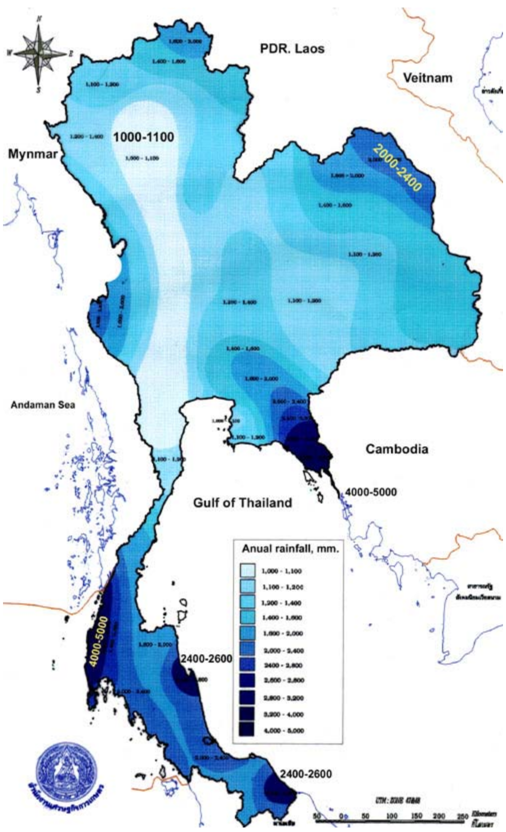


Figure 2 Average annual rainfall

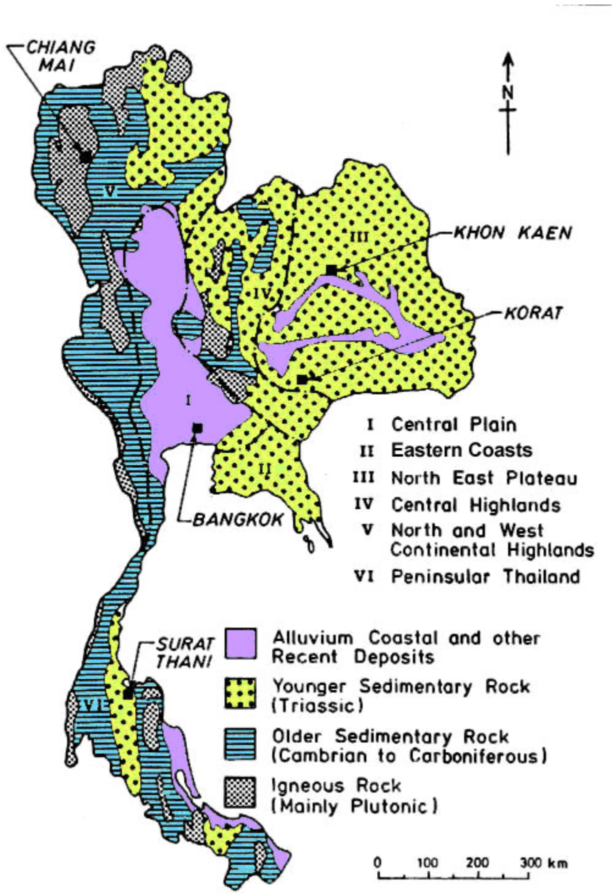


Figure 3 Geomorphology

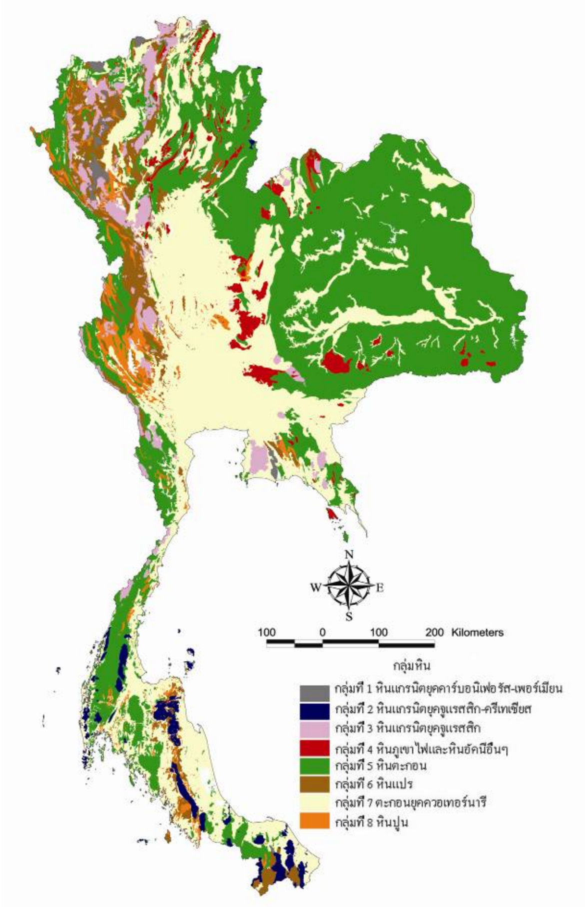


Figure 4 Major Rock Groups , Soralump (2006)

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.

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

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

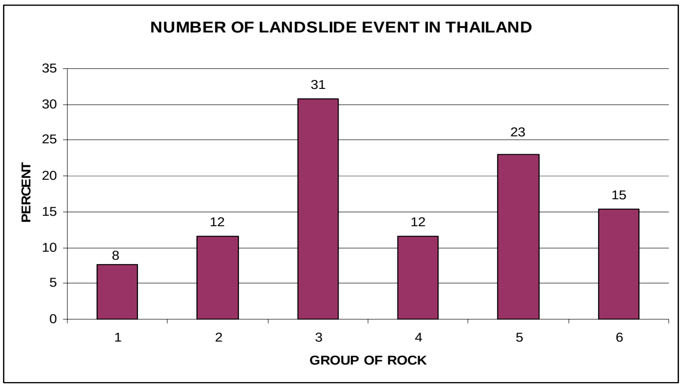
Group 5; sedimentary rocks of sandstone, mudstone, shale, chert and unconsolidated rocks.

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 Figure 5. The granite and granitic soils show the highest potential of landslide. Where on some sedimentary rock groups such as shale, mudstone, and siltstone influencing by geologic structures such as the bedding planes, joints, faults are second highest group.



Group 1 Permo-Carb. granite
Group 2 Jurassic-Cretaceous granite
Group 3 Jurassic granite
Group 4 Volcanic and other plutonic rock
Group 5 Sandstone, shale, mudstone, conglomerate and chert
Group 6 Metamorphic rock

Figure 5 Landslide influenced by rock groups

1.3 *Land uses*

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 extremely draught year. The evidences of large alluvial fans from landslides can be noticed on the west of central plain at Kanchanaburi.

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, infiltration rate and flow regimes within soil profile due to cultivation can also trigger the landslides.

Table 1 Risk of Geology for landslide

Level	Landslide Potential	Rock Groups	Geologic Structure Influence
1	Highest (G.3)	**Granite Dominated:** Highly and deep weathering zone, thick residual soil.	Low
2	High (G.5)	**Shale and Mudstone Dominated:** High weathering rate, shallower residual soil.	High
3	Moderate **(G.5)**	**Sandstone and Siltstone Dominated:** Moderate weathering rate, shallow residual soil.	High
4	Low **(G.5)**	**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

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 6. and on Table 3.

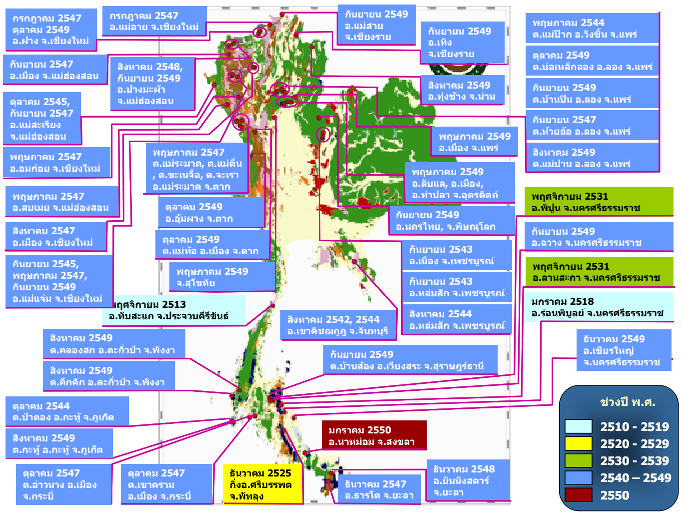


Figure 6 Landslide events in Thailand (GERD, 2006)

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
November 1988	Lansaka, Nakorn Srithumarat	12
August 1999	Kao-kichakud, Chantabuti	1
September 2000	Lumsak-Muang, Phetchabun	> 10
May 2001	Wangchin, Phae	> 30
August 2001	Lumsak, Phetchabun	132
May 2004	Mae Ramad, Tak	5
July 2004	Mae Aye, Cheingmai	1
May 2004	Mae Chame, Cheingmai	1
May 2004	Omkoi, Cheingmai	1
October 2004	Muang, Krabi	3
May 2006	Muang, Uttradit	71
May 2006	Bangtuk, Sukhothai	7
May 2006	Choehae, Phae	5
October 2006	Fang, Cheingmai	8

3 LANDSLIDE ANALYSIS BY GEOTECHNICAL METHOD

The geotechnical engineering method will be described herein as indicated in Figure 7 below.

3.1 *Basic concepts and soil parameters*

3.1.1 *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.

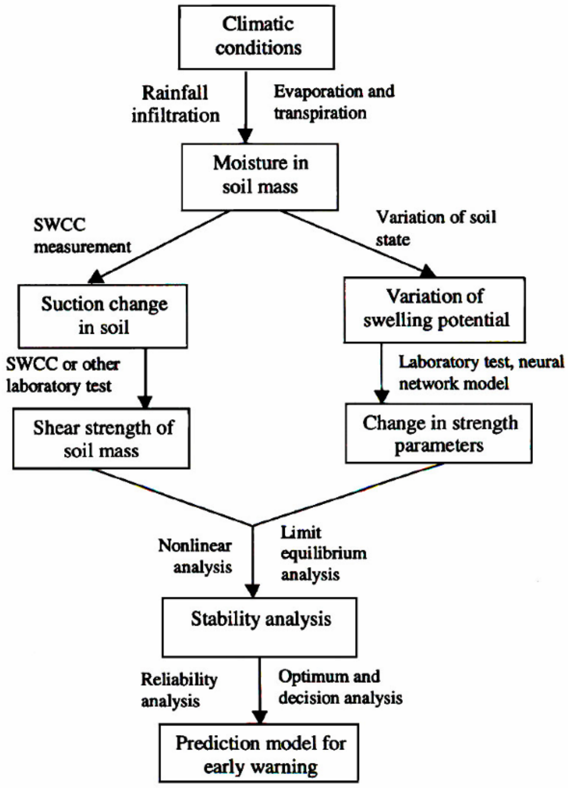


Figure 7 Geotechnical Engineering Method for Landslide Prediction and Warning.

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.

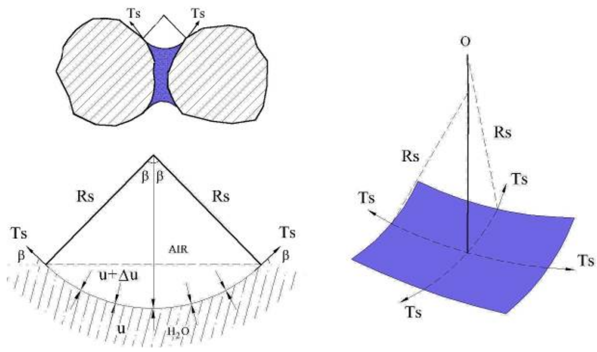


Figure 8 Forces on Contractile Surface (Fredlund, 1993)

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 Figure9.

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

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

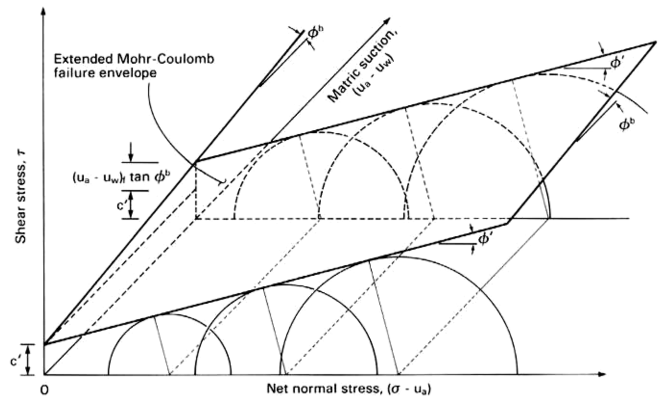


Figure 9 Extended Mohr-Coulomb Envelope for Unsaturated Soil (Fredlund, and Rahardjo, 1993)

3.1.2 *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 10 and 11.

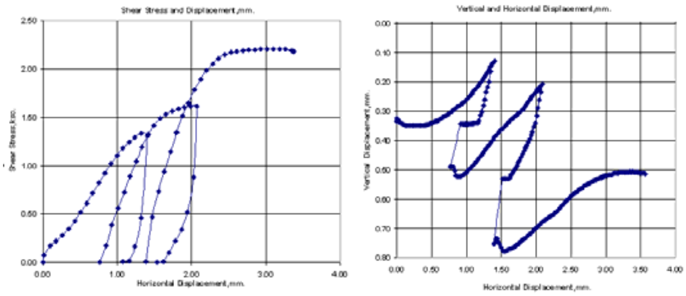


Figure 10 Stress-strain from multi-stage direct shear test.

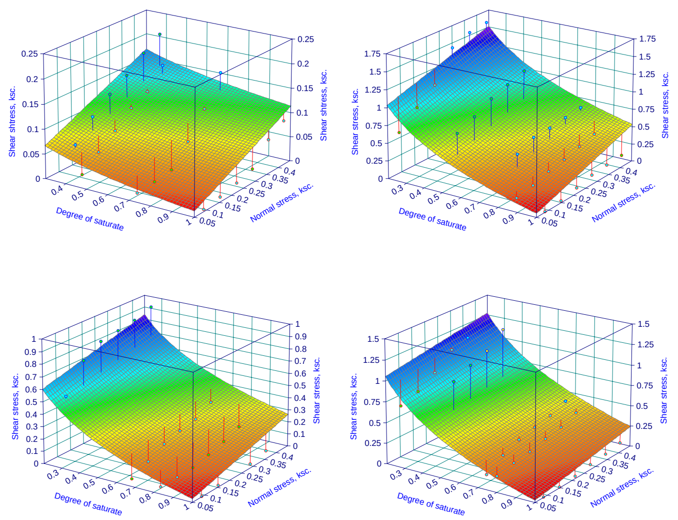


Figure 11 Results from Multistage Direct Shear Test.

3.2 *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 12. 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.

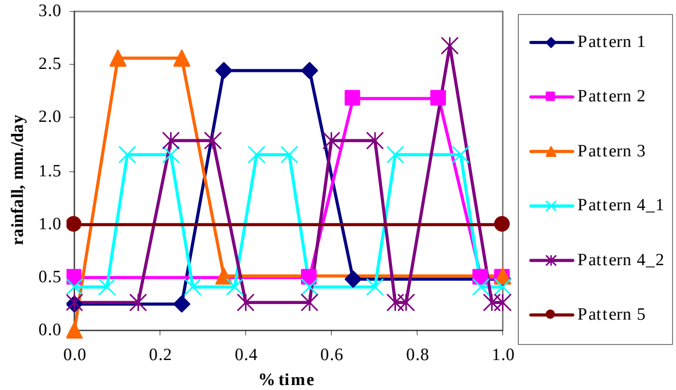
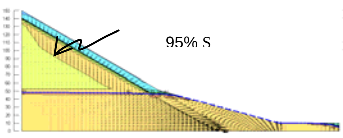
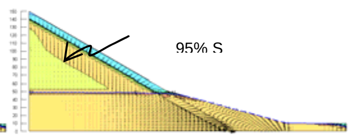


Figure 12 Rainfall Patterns

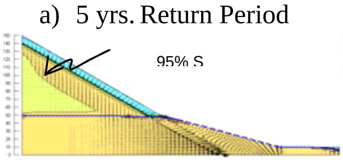
Some of the results from seepage analyses are as shown on Figure 13. The movement of 95% saturation fronts can be the indication of the percolation of water into soil mass at the various elapsed times. However the critical stability condition at different points may not occurred on the same time. The average elapsed time can be selected to represent the critical period.



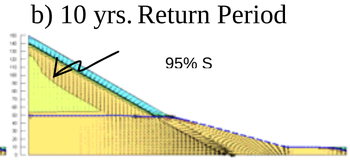
a) 5 yrs. Return Period



b) 10 yrs. Return Period



c) 100 yrs. Return Period



d) 200 yrs. return Period

Figure 13 Seepage Pattern on the 10 th day.

3.3 *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 14. below.

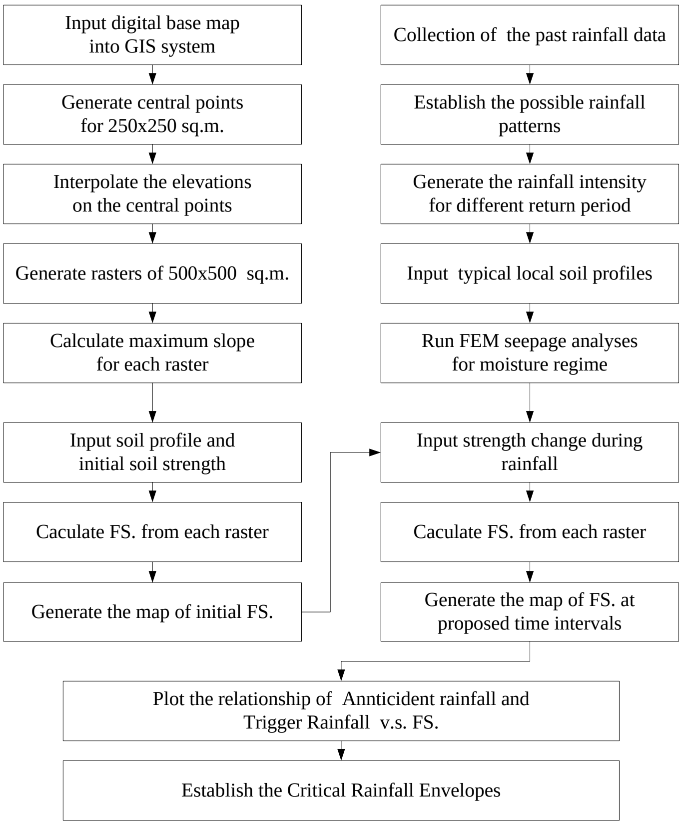


Figure 14 GIS Raster generation

Then the combination of Infinite Slope Analysis as the detail shown on Figure 15. The Factor of Safety for each raster can be calculated at the particular time from the beginning of rainfall until the final stage at of failure or the end of rain storm.

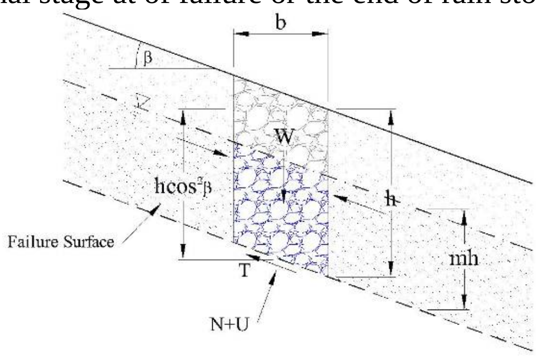


Figure 15 Free Body Diagram Soil Slice on Infinite Slope

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

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

During rainfall, the Factors of Safety(F.S.) from equation (3) at various soil depth and degree of saturation can be performed using GIS programming. On Figure 16. shows the decreasing of F.S. vs. S% until reaching the failure condition at F.S. approach 1.0. At Phuket area, the critical degree of saturations at failure stage are at the range of 91-94 % with good agreement with the field observation.

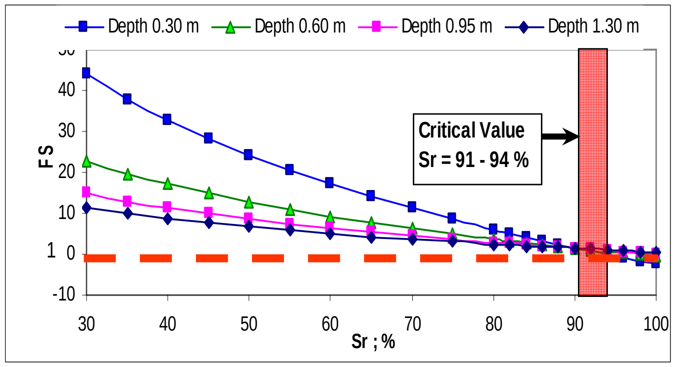


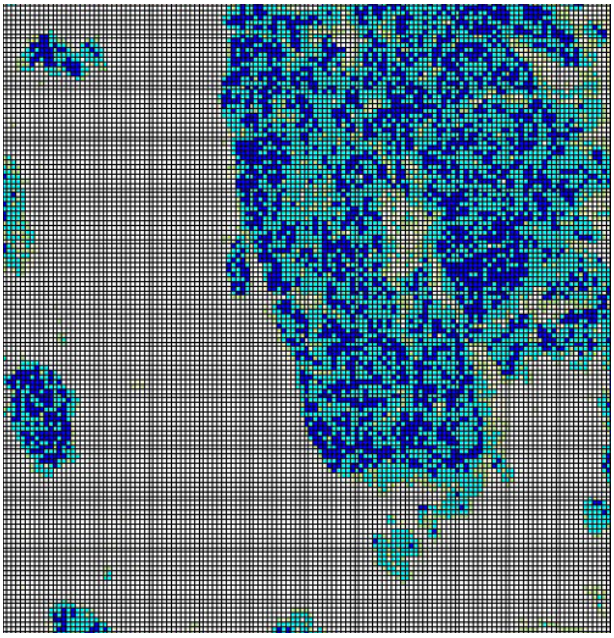
Figure 16 Decreasing of F.S. to Failure Condition.

The GIS technique can extend the stability calculation for the target area and at the near real-time basis. When the observed rainfall is report online to the server, the program can recalculated the new F.S. In case of landslide warning of any heavy rain storm, the forecast rainfall shall be input to the model ahead of time and predicted F.S. will be reported for further active.

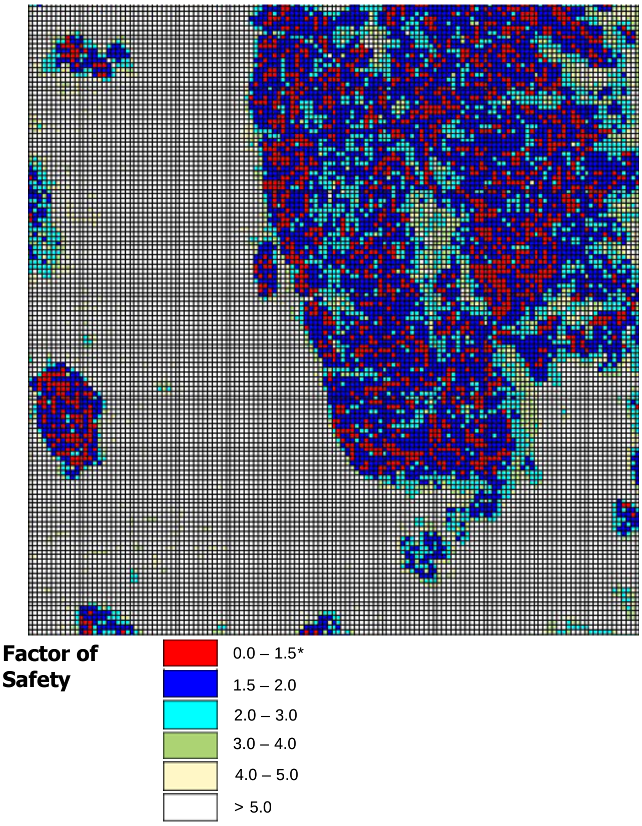
Figure 17. shows the levels of Factor of Safety of each pixel in Chantaburi area before and after heavy rain. On Figure 17 b) the red spots represent the area that F.S. below 1.0 or unstable area.

4 FIELD OBSERVATION FOR VERIFICATION

In order verify the GIS landslide modeling, measuring instruments are installed on the target area. The typical instruments in the observation pit are tensiometers, density and water content sampling windows as shown on Figure 18. The automatic raingage is also set at the representative area in the watershed. On some case, the down slope movement is measured by inclinometer. Figure 19. shows the results of one year observation of the slope on Phuket Area. The peak rainy months are on August, September and October. And the corresponding matrix suctions start to decreased while the degree of saturation increased at every measuring depths. The saturation of soil at shallow depth 0-1.0 m. increases with corresponding to the average rainfall going up and reach the maximum on September and October. This indicated period of the weakest soil condition due to high water content in soil mass.



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



b) After Heavy Rainfall

Figure 17 Distribution of Factor of Safety (Bunpoat, 2005)

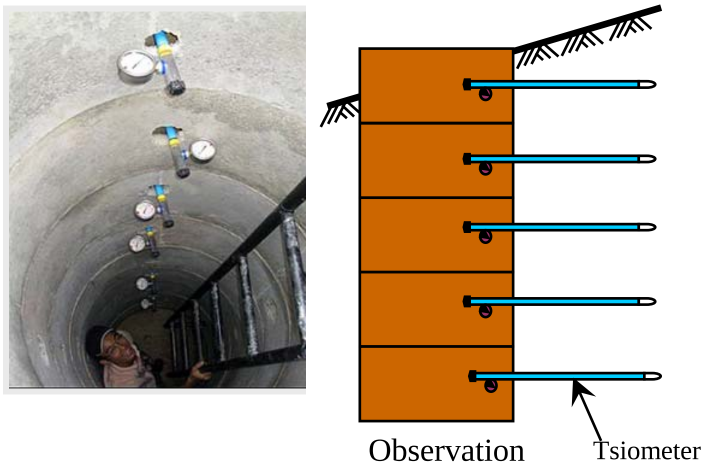


Figure 18 Field Observation Pit

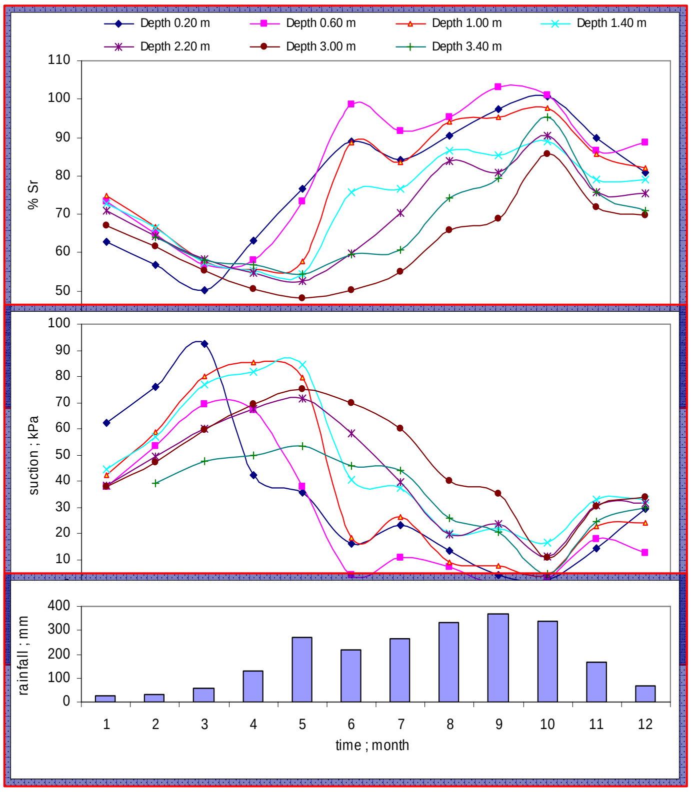


Figure 19 Relation of %Sr, Suction and Rainfall from field observation

5 WARNING LEVELS

The final goal for landslide analysis is the given the proper 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. However, the prediction model has to be calibrated with the known landslide even with some field monitering instruments as mentioned above.

The warning diagrams of the critical rainfall envelopes for Patong-Kamala, Phuket are as shown on Figure 20. The graphs show the relation of 4 days accumulated rainfall vs. daily triggered rainfall when the critical condition with the factor of safety is 1.00. The group of curves indicates the critical condition of different soil slopes. For the particular rain storm, if the path rain fall plot approaching the critical envelope, then landslide is likely to occur.

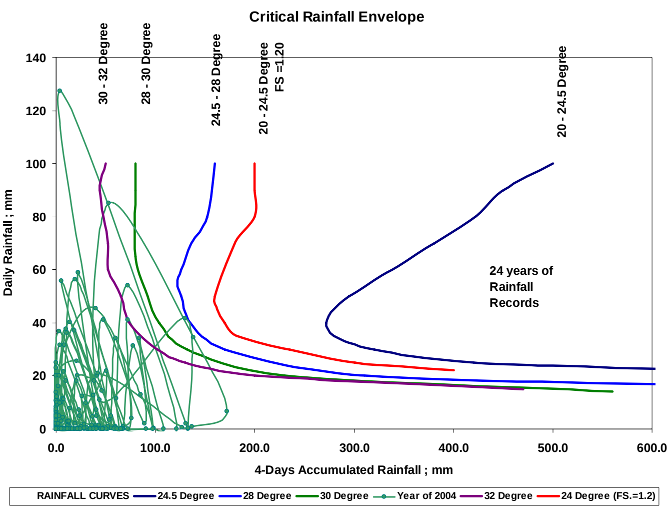


Figure 20 Critical Rainfall Envelope for Phuket Area.

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 and environmental changes. The warning at the present is based on the empirical approach known as “Weight Factors Index”. Direct prediction method using Geotechnnical Engineering Stability Analysis combined with GIS can be done. The unsaturated strength parameters has to be determined by Fredlund’s Model. Past rain fall data 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. However the field monitoring shall be performed to verify the analysis before the public warning can be issued.

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