# EVALUATION OF ROCK S LOPE STABILITY ALONG SOME HIGHWAYS USING GEOGRAPHIC INFORMATION SYSTEM

**Kiattisak Artkhonghan**

**A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Master of Engineering in Geotechnolgy**

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**Academic Year 2012**

# การประเมินเสถียรภาพของความลาดเอียงมวลหินตามแนวถนนทางหลวงโดยใช้ระบบสารสนเทศภูมิศาสตร์

นายเกียรติศักดิ์ อาจคงหาญ



วิทยานิพนธ์นี้เป็นส่วนหนึ่งของการศึกษาตามหลักสูตรปริญญาวิศวกรรมศาสตรมหาบัณฑิต
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# EVALUATION OF ROCK SLOPE STABILITY ALONG SOME HIGHWAYS USING GEOGRAPHIC INFORMATION SYSTEM

Suranaree University of Technology has approved this thesis submitted in partial fulfillment of the requirements for a Master's Degree.

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เกียรติศักดิ์ อาจคงหาญ : การประเมินเสถียรภาพของความลาดเอียงมวลหินตามแนวถนนทางหลวง โดยใช้ระบบสารสนเทศภูมิศาสตร์ (EVALUATION OF ROCK SLOPE STABILITY ALONG SOME HIGHWAYS USING GEOGRAPHIC INFORMATION SYSTEM) อาจารย์ที่ปรึกษา : อาจารย์ ดร.ปรัชญา เทพณรงค์, 125 หน้า.


วัตถุประสงค์ของงานวิจัยนี้คือการประเมินเสถียรภาพของความลาดเอียงมวลหินตามแนวทางหลวงด้วยระบบสารสนเทศภูมิศาสตร์ (Geographic Information System, GIS)โดยไม่มีการออกภาคสนาม ซึ่งพบว่าการพังของความลาดเอียงที่เกิดขึ้นส่วนใหญ่เป็นรูปแบบโค้ง เนื่องจากงานวิจัยนี้เป็นการรวมแนวคิดของระบบสารสนเทศภูมิศาสตร์และระบบผู้เชี่ยวชาญเข้าไว้ด้วยกัน ดังนั้น เสถียรภาพที่ประเมินได้จึงไม่ได้อ้างอิงตามสมการทางกลศาสตร์หินเพียงอย่างเดียว แต่อ้างอิงจากประสบการณ์และวิจารณญาณของผู้เชี่ยวชาญด้วย ซึ่งค่าที่ประเมินได้อยู่ในรูปของร้อยละของความน่าจะเป็นที่จะเกิดการพังในรูปแบบโค้ง (Probability of Failure, PF) โดยทำการเก็บตัวอย่างจากความลาดเอียง 15 แห่ง ที่แตกต่างกันในด้านของเสถียรภาพ ผลจากการประเมินเมื่อเปรียบเทียบกับผลจากภาคสนามและผลจากแบบจำลองทางคณิตศาสตร์ แสดงให้เห็นว่าระบบสามารถประเมินเสถียรภาพของความลาดเอียงได้ใกล้เคียงและสอดคล้องกับความเป็นจริง การใช้ระบบสารสนเทศภูมิศาสตร์สามารถหาพื้นที่เสี่ยงภัยต่อความไม่มีเสถียรภาพในพื้นที่ขนาดใหญ่ได้ ความแม่นยำในการประเมินจะมากขึ้นหากข้อมูลที่ใช้ประกอบมีความละเอียดและทันสมัย




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| สาขาวิชา เทคโนโลยีธรณี | ลายมือชื่อนักศึกษา ________________ |
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KIATTISAK ARTKHONGHAN : EVALUATION OF ROCK SLOPE STABILITY ALONG SOME HIGHWAYS USING GEOGRAPHIC INFORMATION SYSTEM. THESIS ADVISOR : PRACHYA TEPNARONG, Ph.D., 125 PP.

GIS/EXPERT SYSTEM/DEM/PROBABILITY OF FAILURE

The objectives of this study are to detect potential circular failures on rock slopes along highways without field surveying and to locate instability areas along the road cuts by using Geographic Information System (GIS). The circular failure mostly occurs in the study area. This research combines both GIS and expert systems; therefore, the calculation of slope stability is not only based on the known analytical solutions, but also the experience and inference procedure of a slope expert supported by his rationale and logic. The slope stability resulted from this study is represented in the form of probability of failure (PF). The predictive capability of the proposed system has been verified by comparing with 15 actual rock slopes under variety of stable- and unstable conditions. The factor of safety obtained from field investigation is performed to compare with GIS method. The results from GIS method agree well with the traditional one. Using GIS method is able to detect instability risk area in large scale. The accuracy of the result depends on input data which should be updated and real time.

School of Geotechnology Student's Signature______________________

Academic Year 2012 Advisor's Signature______________________

# ACKNOWLEDGEMENTS

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Kiattisak Artkhonghan

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# SYMBOLS AND ABBREVIATIONS

| | | |
|---|---|---|
| AI | = | Artificial Intelligence |
| DEM | = | Digital Elevation Model |
| DStM | = | Digital Structural Model |
| ES | = | Expert System |
| FS | = | Factor of Safety |
| GIS | = | Geo Informatics System |
| $I_n$ | = | Influencing factor for the corresponding parameter |
| KBS | = | Knowledge Base Systems |
| LDD | = | Land Development Department |
| PF | = | Probability of Failure |
| $P\{f\}$ | = | Probability of Failure |
| $R_n$ | = | Rating for each parameter |
| SMR | = | Slope Mass Rating |
| TIN | = | Triangulated Irregular Network |
| TINs | = | TIN Triangle |
| UCS | = | Uniaxial Compressive Strength |

# CHAPTER I

# INTRODUCTION

## 1.1 Research Objectives

The objectives of this study are to detect potential circular failures on rock slopes along highways without field surveying and to locate instability areas along the road cuts by using Geographic Information System (GIS). The research combines both GIS and expert system. The calculation of slope failure stability is not only base on the known analytical solutions or theories, but also based on the experience and inference procedure of a slope expert supported by his rationale and logic. The stability is presented in the form of probability. The probability of failure (PF) is presented on a potential map.

## 1.2 Problem and Rationale

When slope failure is occurred on a road cut, it is unfavorable because it can cause a serious damage to the road and the local traffic. Many hazards have been reported from several highways such as Lomsak-Chumpae highway, Phetchabun province. The problems of slope failures along the road cuts have repeatedly occurred on some locations. The failures brought down both earthen and installed materials, and obstructed the traffic for several hours. This has posed severe economic impacts on the commercial and tourism of the regions (Thongthiangdee, 2003).

Applications of GIS in mountain areas have been relatively slow in developing. By the late 1980s, the potential of GIS to model slope instabilities was still being discussed in the literature. Stocks and Heywood (1994) accredit this tardiness to characteristically poor baseline data and a general lack of funding.

Through the 1990s, however, GIS has been increasingly applied to a wide range of hazards from forest fires to snow avalanches (Walsh et al., 1994). Some research on integrating GIS and deterministic models for slope failure zonation has been conducted. Examples include GIS-based infinite-slope stability models (Kamai, 1991; Terlien, 1996; Pack et al., 1998, 2001), GIS–infinite-slope seepage model (Dietrich et al., 1993; Montgomery and Dietrich, 1994; Montgomery et al., 1998), GIS– probabilistic infinite-slope models (Hammond et al., 1992; Fannin andWilkinson, 1995; Fannin et al., 1996) GIS–infinite-slope probabilistic seismic landslide model (Jibson et al., 1999; Luzi et al., 1998; Khazai and Sitar, 2000), Preliminary rock slope susceptibility using GIS and SMR (Irigaray, 2003), GIS based stability analysis of rock cut slope (Kim et al., 2004)

In other areas this hazard has been investigated. Studying of slope damage triggering factors of their hazards could help effectively in reducing their damages. But some areas are difficult to accesses. To determine a potential of slope failure, this research used the Geographic Information System (GIS) to resolve a problem. It is convenient, economical and safety. The result of this research is show in potential map. It is a primary analysis of slope stability to detecting risk areas without a field work operation.

## 1.3 Scope and Limitation of Research

Evaluating of rock slopes stability by used GIS is not base on analytical solutions. Because of the resolution of data, GIS method cannot identify discontinuity structure on the rock slope such as: discontinuity orientation, joint spacing, joint aperture, number of discontinuity. Circular failure mode is emphasized in the research. The rock slope should have single benched and rock grade is not over R2.

## 1.4 Research Methodology

The research is divided in to six tasks (Figure 1).

1) Literature review: The objective of the literature review is to collect and examine the previous studies on the geological conditions of the sites, the evaluated rock slope stability base on expert system, and the case studies from the published papers (journals, proceedings, and conferences).

2) Field investigation: Field investigation will be conducted along highway. The purpose of field investigation is to obtain geological engineering data of the sites. The study criteria follow as much as practical the methods suggested by the International Society of Rock Mechanics (Brown, 1981). The data include slope geometry, joint conditions and orientation, intact rock strength, performance of the existing rock supports (if any), modes of failure, rock conditions, and groundwater conditions. The data obtained from fieldwork will be used for kinematics analysis and computer simulation.

3) Determination of rock slope stability using numerical method: The numerical computer simulation is to calculate the factor of safety (FS) for circular failure mode. Several values of properties are assumed in the computer simulation, which eventually gives safety factors close to the actual field condition. The FLAC SPLOE program will be used in the analysis.

4) Determination rock slope stability using GIS method: The system classifies each factor considered in the stability evaluation into small ranges or sub-divisions, mainly to convert the input slope characteristics into quantitative form. Data input included: Digital Elevation Model (DEM), geologic unit map, land-use map, and road map. The results of stability are show in term of probability of failure.

5) Auditing and verification: Comparison between GIS and result from numerical method. This section is to verify an appropriate factor for predicting further slope failures by GIS.

6) Thesis writing: All research activities, methods, and results will be documented and compiled in the thesis. The contents or findings may be published in the conference, proceedings, and journals.

## 1.5 Thesis Content

The first chapter introduces the thesis, by identifying the research objective, and briefly describing the problems and rational, the scope and limitation of research, and the research methodology. The second chapter describes the literature review. Detailed rock slope analysis, mechanical analysis, expert system, and Geographic Information System. Relevant literatures including those in journals, proceeding, and reports have been reviewed. Chapter three describes the field investigation and case history. This chapter contains field investigation, and case history reviews. Expert system is presented in chapter four. This chapter describing the rock slope stability analysis by using expert system. Chapter five is data preparations. This chapter explains the data formation for rock slope stability analysis includes DEM to slope geometry, land use to vegetation maps, highways map to vibration zone maps, and geologic maps to influencing factor maps. Chapter six describes the analysis method for the site. Chapter seven provides the discussions, conclusions, and recommendations for future studies.

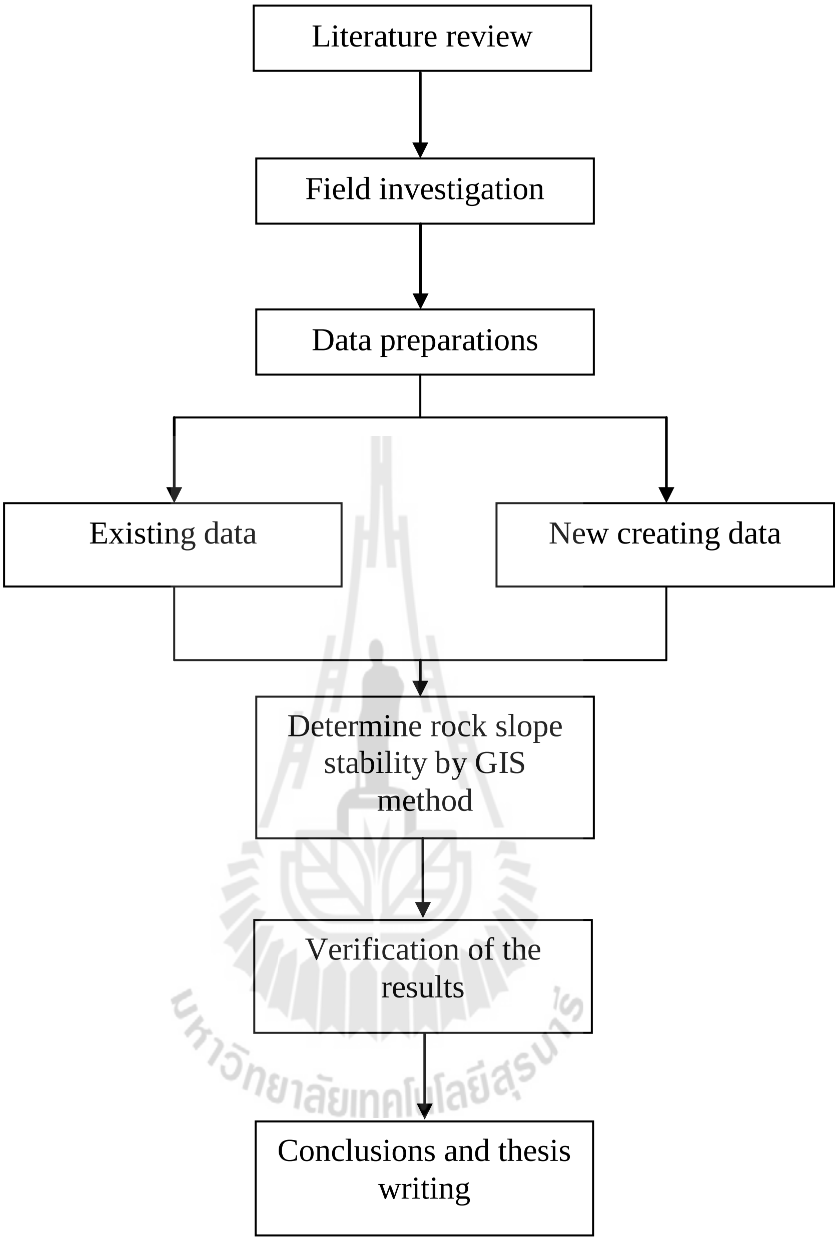


**Figure 1** Research methodology.

# CHAPTER II

# LITERATURE REVIEW

This chapter presents result of the literature review on the relevant methods of slope stability analysis, including mechanical method, numerical method, expert system, and GIS method.

## 2.1 Rock slope analysis

The problem of evaluating the stability of slopes in jointed and weathered rock masses remains as major challenge in the practice of rock engineering. The stability of structure depended on strength and deformability of rock masses. The rock masses are typically heterogeneous and anisotropic because the different of rock types and properties. The most universally occurring anisotropic characteristic of all rock masses is the presence of distinct breaks, or discontinuities, in the physical continuity of the rock. These include bedding surfaces, joints, and fault, etc. the water can reduce rock strength from pervasive chemical weathering. The presence of discontinuities in rock mass is the primary controlling factor of rock mass strength and deformability. Discontinuities also have a dominant role in defining rock mass properties. The slope geometries have become important on stability evaluation. Hoek and Bray (1981) and Goodman (1989) have classified the mode of slope failure into four types; plane and wedge sliding, topping and circular failure (Figure 2.1).

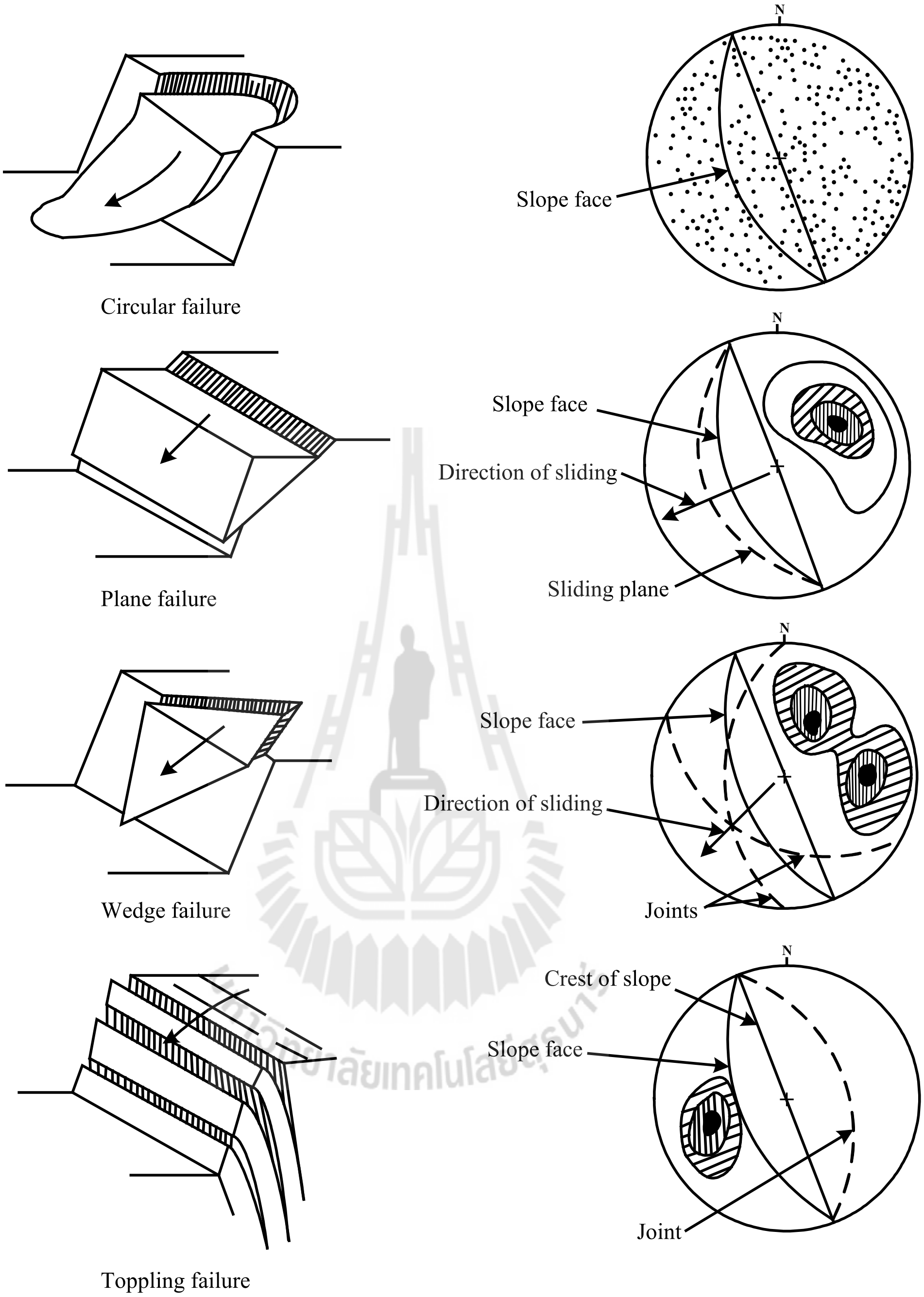


**Figure 2.1** Mode of rock slope failure and comparison with dip direction and dip angle in form of stereoplots (after Hoek and Bray, 1981).

Plane failure occurs when a geological discontinuity, such as bedding planes, strikes parallel or nearly parallel (within approximately ± 20 degrees) to slope face. The plane must daylight in the slope face that means the dip of the plane is smaller than the dip of the slope face. Moreover, the dip of the failure plane must be greater than the friction angle of the plane.

Wedge failure occurs when two discontinuities strike obliquely across the slope face, their line of intersection daylights in the slope face, and the line of intersection inclines at an angle larger than the angle of internal friction of the rock.

Toppling failure may result in an abrupt falling or sliding, but the form of movement is tilting without collapse. Toppling failure has traditionally been regarded as occurring in two modes: block toppling and flexural toppling. The former occurs when the center of gravity of a block of rock lies outside the outline of the base of the block, with the result that a critical overturning moment develops. The latter occurs under certain circumstance when a layered rock mass outcrop at a rock slopes, and the principal stress parallel to the slope face. Apart from these, inter-layer slip causes the intact rock to fracture and the resulting blocks to overturn.

For a circular failure, rock body is divided into a discontinuous mass. The failure path is normally defined by one or more discontinuity. In case of soil slope, the individual particles are very small compared with the size of the slope, and a strongly defined structural no longer existed. Then the failure paths are in the circular form.

## 2.2 Mechanical Analysis

The mechanical method is classical and simple method that use for rock slope stability evaluation. It is summation of force (force balance) on the discrete block. There two types for force summation, as 1) the summation of driving forces, such as rock weight, pore pressure and vibration, and 2) the summation of resisting forces, such as the friction force and existing support. The slope geometry and rock discontinuity are the parameters that use for calculation. This is advantage of mechanical method.

There are very few cases in which the application of the mechanical analysis has been verified against actual observations of failure. The complexities of slope geometry, joint orientation and block volume are basic disadvantage of this method.

## 2.3 Expert System

The development of the Artificial Intelligence (AI) and Expert System (ES) software has begun about 20 year ago (Rich and Knight ,1990). AI and ES are the neural networks or the evaluation process for solving the complex problems, complex parameter and decision making. AI and ES use the decision network to solve the difficult problems. AI and ES are not database. Moula et al.(1995) compile the name of several expert systems and Knowledge Base Systems (KBS) that have been developed for the analysis and design geotechnical engineering. Wharry and Ashley (1986) introduce one of the earliest KBS to address the problem of determining the required level of geotechnical investigation. This is based on the requirements of proposed structure and the level of information known about the site. The aim is to reduce the risk involved with the subsurface to an acceptable level. Smith and Oliphant (1991) develop a KBS to assist in the planning stages of a site investigation. The system provides suggestions as to the next stage of a site investigation (e.g. desk study, site reconnaissance, ground investigation etc.). The information obtained from the subsoil exploration stage is also used to create a 2-D visual representation of the soil layers. Alim and Munro (1987) present a very simple prototype KBS for soil identification that uses rather simplistic textbook knowledge. It provide judgment concerning the most likely foundation type under given soil and loading conditions ,based on visual and physical observation of soil characteristics.

Rock mass classification systems make use of a set of reasonably defined well rules, therefore ideally suited implementations as knowledge based systems. A number of systems have been developed in geotechnical engineering, some of which have been reviewed by Zhang et al.(1988). Ghosh et al.(1987) describe an ES for deciding on rock bolt length and spacing for supporting coal mine roofs. Moon et al.(1995) have developed the software that is artificial neural-network integrated with expert system for preliminary design of tunnels and slopes.

There are some expert systems that have been developed for analysis and design of the rock and soil slope. Grivas and Reagan (1988) describe a KBS (called STABCON) for evaluating slope instability and recommending appropriate types of treatment for soil slope. It is similar to the analytical methods for calculating slope stability. Faure et al. (1991, 1995) develop of the software called Expert Systems for Slope Stability for assisting in slope stability analysis. It assist in diagnosing the type of landslide on the basis of information about the geology, vegetation, geomorphology, and hydrogeology. Hao and Zhang (1994) describe a KBS for stability analysis of rock slopes. It uses fuzzy sets for representation of joint sets. Ozgenoglu and Ocal (1994) propose SEVDER, a KBS for slope stability analysis rerating to mining operations.

Adeli (1988) has described the advantages of expert system and knowledge-based systems, for example the inference mechanism knowledge base is more explicit, accessible, and expandable. One can find a similarity between expert systems and the human reasoning process. It can be gradually and incrementally developed over an extended period of time. A general system with one inference mechanism can be developed for different types of applications simply by changing the knowledge base. The same knowledge may be used in different problems by possibly employing different inference mechanism. An ES can explain its behavior through an explanation facility and can check consistency of its knowledge entities or rule and point out the faulty ones through a debugging facility. ES does not make cursory or irrational decisions. It uses a systematic approach for finding the answer to the problem. The limitations of ES and KBS are that they do not learn, lack common sense and intuition. Their performance degenerates fast near the boundaries of their expertise. Most expert systems today lack a user-friendly natural language interface and are not easy to use by non-experts. Different experts often give more or less different design recommendations.

Even thought there are several design and field engineering who pose extensive skill an experience in rock slope analysis and design, the existing expert system in this discipline is extremely rare. The need in preservation of their knowledge and skill is increasingly important, as the relevant geological engineering project become more complex in terms of geological conditions engineering requirements, and economic constraints. It is however possible that many private firms in the developed countries could have developed and implemented some kind of intelligent systems for assisting in the analysis and design of rock slope. Application of such systems is normally for the internal use only. Such systems therefore have not been widely used, and hence have not been scrutinized by the public at large. In Thailand, in particular, no expert system on rock slope design publicly exists. The need in such systems becomes ever more crucial as the development of the infrastructures of the country must continue under the economic constraints.

## 2.4 Geo Informatics System

The Geo Informatics System (GIS) is a general-purpose computer based technology designed to capture, store, manipulate, analyze and display diverse sets of spatial or geo-referenced data. Godchild (1993) states that the GIS technology has the ability to perform a variety of task: (1) preprocessing of data from large stores into a form suitable for analysis exemplified by reformatting, change of projection, resampling, and generalization, (2) supporting analysis and modeling: forms of analysis, calibration of models, forecasting, and prediction (3) post-processing of result through reformatting, tabulation, report generation, and mapping. The overlay operation commonly applied within in the GIS is useful in both heuristic and statistical approaches (Gupta and Joshi 1989; Carrara and others 1991,1995; Wang and Unwin 1992; Mark and Ellen 1995; Van Westen and others 1997; Fernandez and others 1999).

David and Dudycha (1998) show case studies of slope stability in Phewa Tal watershed, Nepal. The findings of this research suggest that the use of geomorphology significant terrain units extracted from a digital elevation model (DEM), using regular grid cells. In particular, the terrain units facilitated the use of logistic regression, and significantly decreased the amount of computing costs. Dai and Lee (2001) used GIS database to compile primarily from existing digital maps and aerial photographs, to describe the physical characteristics of landslides and the statistical relations of landslide frequency with the physical parameters contributing to the initiation of landslides on Lantau Island in Hong Kong. The database include slope gradient, lithology, elevation, slope aspect, and land-use are statistically significant in predicting slope instability, while slope morphology and proximity to drainage lines are not important and thus excluded from the model. The data are imported back into the GIS to produce a map of predicted slope instability. The results of this study demonstrate that slope instability can be effectively modeled by using GIS technology and logistic multiple regression analysis.

Omar et al. (2002) show case studies of geological factors contributing to slope failure along Selim highway, Malaysia. Based on the study, eight geological factors contributing to cut slope failures are identified. The factors are geology, weathering, joints, faults, orientation, aperture, persistence, and spacing. Fiorillo (2003) analyzed a slope along a stretch of the Adriatic coast, near Petacciato (Molise, Italy). He reported that several re-activations occurred in the past century, involving the zone between the build-up area and the sea, along a coastal slope over 2000 m long and 200 m high.

Irigaray et al. (2003) Using GIS and Slope Mass Rating (SMR) to enables the preliminary assessment of the susceptibility of rock slopes to failure. The SMR index is obtained from Bieniawski's basic RMR (Rock Mass Rating). The method is applied automatically by a GIS. Data have been gathered from the DEM data, and by the statistical analysis of the parameters measured on the slopes. The methodology has been applied to the slopes along the N-340 road between Arraijana beach and Castell de Ferro (Granada, Spain). Zhou et al. (2003) produced a spatial probabilistic modeling of slope failure using a combined GIS, infinite-slope stability model and Monte Carlo simulation approach. A DEM data for the study area has been created at a scale of 1:2500. Calculated results of slope angle and slope aspect derived from the DEM are discussed. The research integrating an infinite-slope stability model and Monte Carlo simulation with GIS, and applying spatial processing, a slope failure probability distribution map is obtained for the case of both low and high water levels.

Ghosh et al. (2010) was discussed a GIS-based methodology for rock slope instability assessment based on geometrical relationships between topographic slopes and structural discontinuities in rocks. The methodology involves (a) regionalization of point observations of orientations (azimuth and dip) of structural discontinuities in rocks in order to generate a digital structural model (DStM), (b) testing the kinematical possibility of specific modes of rock slope failures by integrating DStMs and DEM-derived slope and aspect data and (c) computation of stability scenarios with respect to identified rock slope failure modes. The study demonstrates the usefulness of spatially distributed data of orientations of structural discontinuities in rocks for medium- to small-scale classification of rock slope instability in mountainous terrains. Baillifard et al. (2003) describes 5 criteria: a fault, a scree slope within a short distance, a rocky cliff, a steep slope, and a road. These criteria were integrated into a GIS using existing topographic, geomorphological, and geological vector and raster digital data. The proposed model yields a rating from 0 to 5, and gives a relative hazard map. Kim et al. (2004) applied GIS to analyze the stability of rock cut slope. GIS is the effective tool to deal with the widely scattered and the enormous number of data. Various factors affecting on the slope stability analysis, such as the structural domain, the orientation and dip angle of the cut slopes, and the friction angle of discontinuities, were considered as the input parameters for GIS. By overlaying input data layers and using the developed computer algorithm, the FS values, as an index of slope stability were calculated for each failure mode, which considered for stereographic analysis and limit equilibrium analysis simultaneously. In this research, the factors of safety for each failure mode are evaluated and the minimum factor of safety is also evaluated in the divided small area. In order to verify the developed analysis method, the results of the cut rock slope stability were compared with actual failure modes and locations in the study area. This approach has the advantages that the slope stability analysis of the regional area can be carried out easily without time consumption in many repeated FS calculation for widely scattered slopes at the preliminary survey stage of design. In addition, the analysis results can be easily expressed and visualized using GIS.

# CHAPTER III

# FIELD INVESTIGATION AND CASE HISTORY

The main objectives of field investigation and case history review are to obtain data base for use in the stability analysis and design, and to use some of field investigation to verify the predictive capability of the GIS system. This chapter summarizes the result of the field investigation routes and of the case history review. More details are given in Appendices A.

## 3.1 Highway number 304 route

The highway number 304 route is located between Nakhon Ratchasima and Prachinburi province. The route consists of three slopes (Figure 3.1). The group of hard-soft interbedded rock mass. The hard formation is sandstone. It has 0.3 to 1.0 meter in thickness. The soft formation is shale. It is 0.1 to 0.7 meter thick. The slope height are varied from 5 to 10 meters. The slope face angle is varied from 55 to 75 degrees. The rock has three joint sets. The failure is secondary toppling of vertical joint in massive sandstone. The failure is initiated by the erosion of the lower soft shale bed which results in the collapse of the hard sandstone bed above.

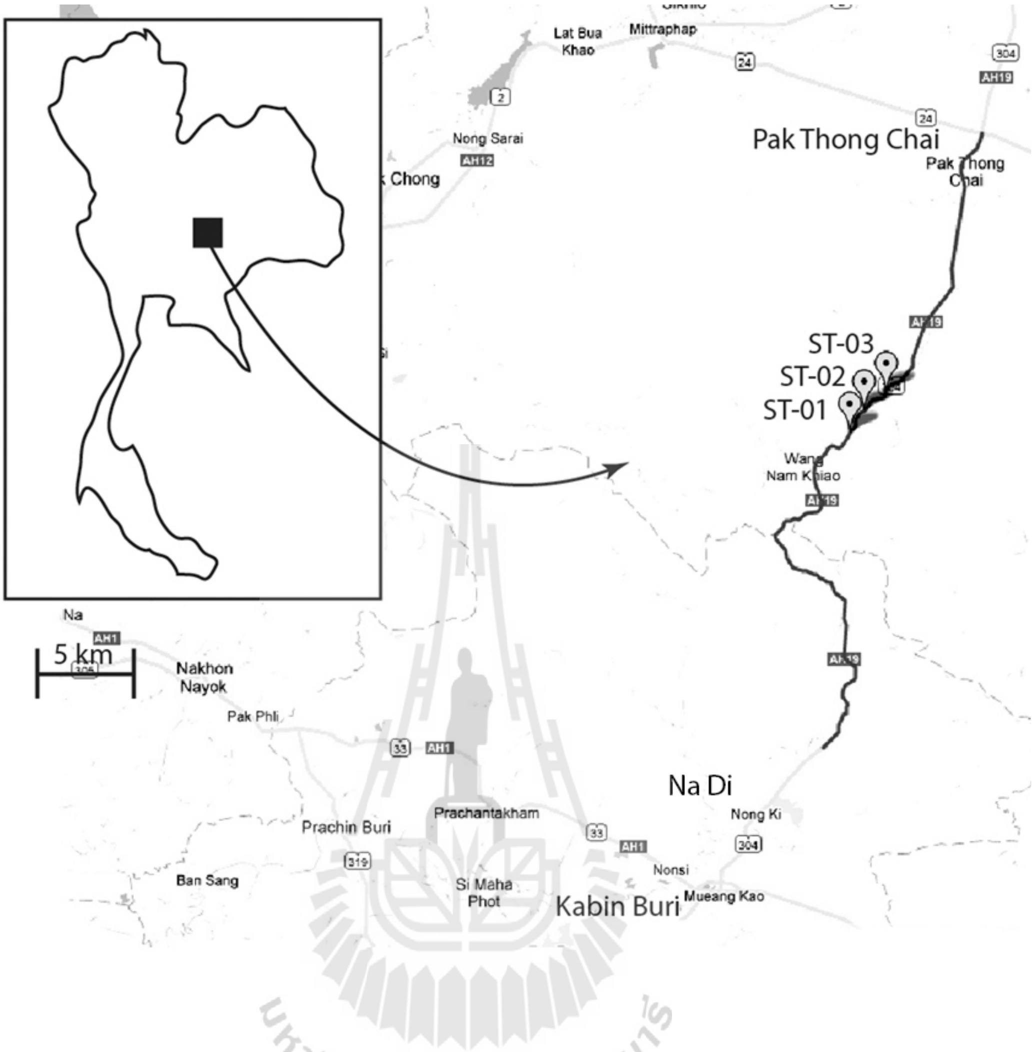


**Figure 3.1** Study locations on highway 304 at Pak Thong Chai to Na Di. The route includes three slopes.

## 3.2 Highway number 12 route

Lomsak-Chumpae highway was constructed over 20 years ago to shorten the distance from the northeast of Thailand. It is 120 kilometers long, cutting across Phetchabun and Khon Kaen provinces (Figure 3.2). The route of Highway number 12 is located between Ban Pak Chong and Phu Kaw Kow, Phetchabun provinces. The slope failures along the road cuts have repeatedly occurred on some locations. The field investigation was conducted on five unstable and four stable rock slopes along the highway during October 2010 and February 2011 (dry season). The route is 15 kilometers in distance. The rock masses exposed along this route are reddish-brown shales of the Nam Duk formation (Middle Permian in age). Most of failures are of circular mode but some locations are stable. The circular failures usually occur in highly weathered rocks. The overall slope height is over 30 meters. The slope face angles vary from 55 to 65 degrees. The uniaxial compressive strength of intact rock is between 5 and 25 MPa (Thongthiangdee, 2003).



## 3.3 Highway number 11 route

The route of Highway number 11 (Figure 3.3) is located between Ban Nam Khrai and Ban Khao Plueng, Uttaradit province. The route includes three slopes. Rock slopes are classified as heavily jointed rock. Slope height is 30 to 50 meters. Circular failure mode is occurring on top of slope, new slope cuts fail before installation of shot create. The failures are usually caused by groundwater after heavy rain fall. The uniaxial compressive strength of intact rock is less than 25 MPa (Kamutchat, 2004).

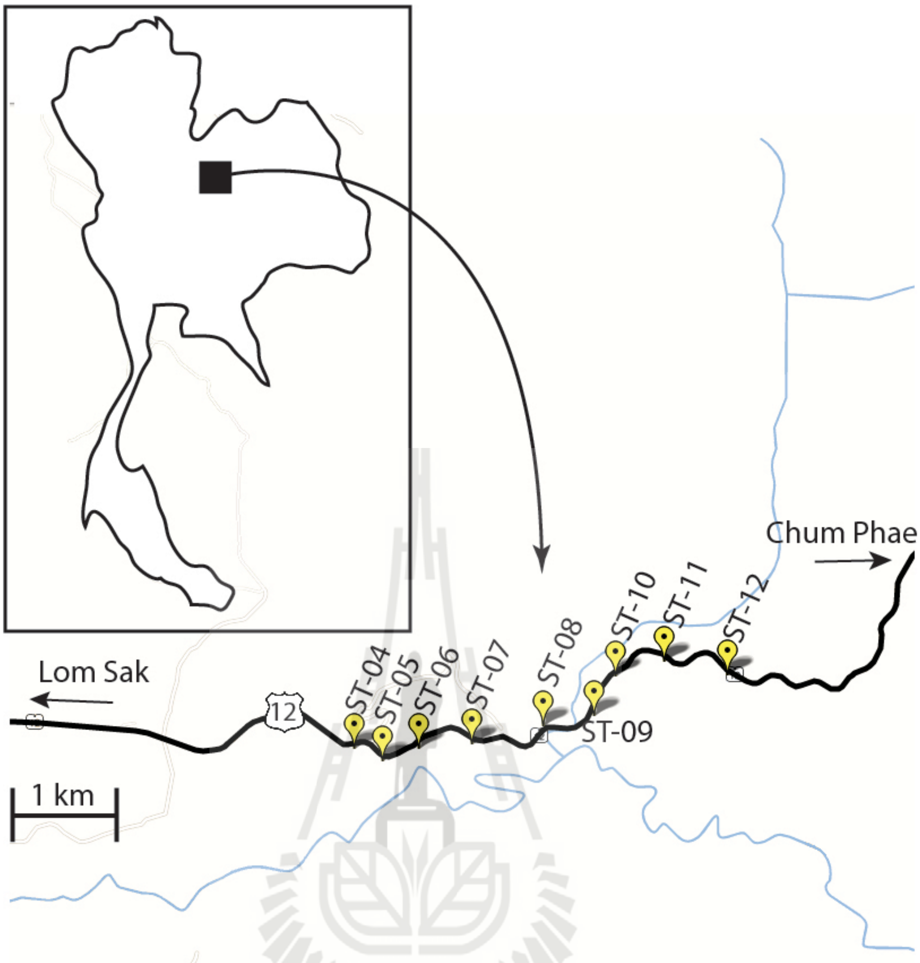


**Figure 3.2** Study locations on highway 12 at Ban Pak Chong to Pu Kaw Kow. The route includes 9 slopes.

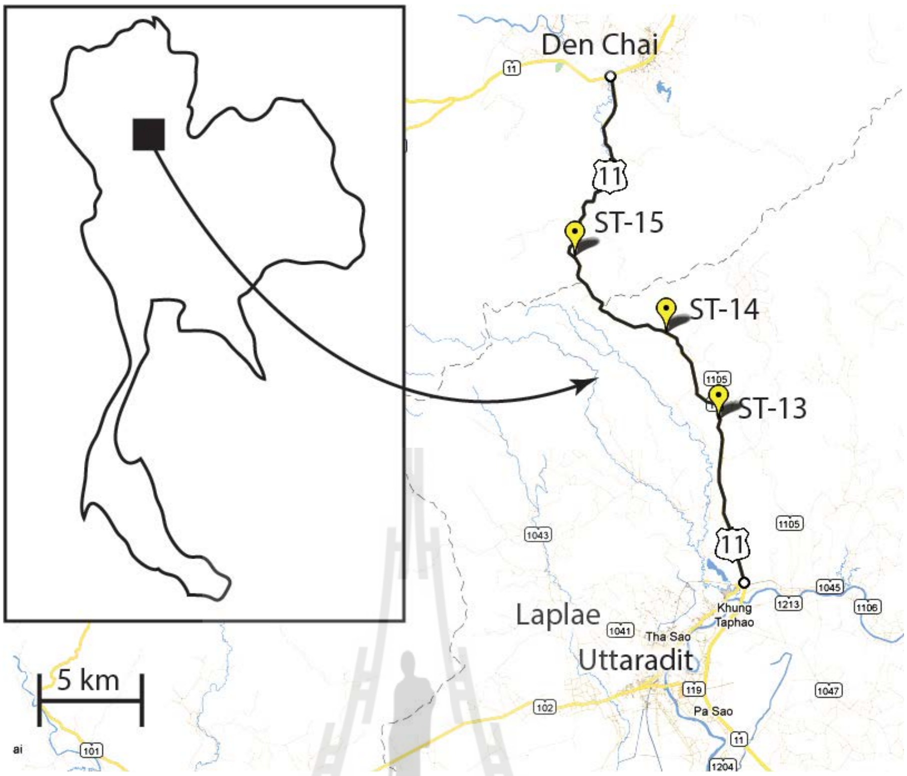


**Figure 3.3** Study locations on highway 11 from Ban Nam Khrai to Ban Khao Plueng. The route includes three slopes.

# CHAPTER IV

# EXPERT SYSTEM

The system classifies each factors considered in the stability evaluation into small ranges or sub-divisions mainly to convert the input slope characteristics into quantitative form. The classification follows as practical the suggested methods by the International Society of Rock Mechanics (Brown, 1981). A set of rating is then assigned to these parameters for each failure mode considered. Recognizing that the significance of these parameters can be at different degrees for different conditions of rock mass, a set of influencing factors is also defined as multiplying factors for the corresponding parameter. The probability of failure *P{f}* in percent for each mode can then be calculated by equations:

$$P\{f\} = \sum\left(R_n \times I_n\right) \tag{4.1}$$

Where $R_n$ is rating for each parameter, $I_n$ is the influencing factor for the corresponding parameter, and "*n*" represents type or number of the parameters considered for each slope (varying from 1, 2, 3, 4…n). Table 4.1 and 4.2 list the rates and influencing factors to calculate the probability of the circular failure. In this case, the value *n* equals to 8. To correlate the probability of failure to the factor of safety, the system defines that the factor of safety is 1.0 when *P{f}* equals to 50%. The system recommendations also compare the calculated *P{f}* against the degrees of safety required for types of engineering application. For Type A where the slope toe is nearby residential structures or power plant facilities, *P{f}* should be less than 10%. Type B is for the slope along main highways, railroads, and large bridges, which requires the *P{f}* less than 30%. Type C is for the slope along the small roads and reservoirs, which requires the *P{f}* less than 50%. Type D requires *P{f}* less than 70% which is defined for the temporary access or small roads in open pit mines.

**Table 4.1** The parameters for calculated for circular failure (Fuenkajorn 2003).

| **Slope height** | | **Slope face angle** | | **Groundwater** | | **Degree of weathering** | |
|---|---|---|---|---|---|---|---|
| **(m)** | **Rate** | **Degrees** | **Rate** | **(%)** | **Rate** | **Conditions** | **Rate** |
| <7 | 1 | <25 | 0 | 0 | | Fresh | 2 |
| 7-10 | 5 | 25-30 | 1 | 25 | | Slightly | 4 |
| 10-15 | 8 | 30-35 | 2 | 50 | | Moderately | 6 |
| >15 | 10 | 35-40 | 3 | 75 | | Highly | 8 |
| | | 40-45 | 5 | 100 | | Completely | 10 |
| | | 45-50 | 6 | Unknown | *5 or 10 | Unknown | 5 |
| | | 50-55 | 8 | | | | |
| | | 55-60 | 9 | | | | |
| | | 60-65 | 9 | | | | |
| | | 65-70 | 10 | | | | |
| | | >70 | 10 | | | | |

| **Vegetation** | | **Number of discontinuity** | | **Vibration** | | **Average discontinuity spacing** | |
|---|---|---|---|---|---|---|---|
| **Conditions** | **Rate** | **(Sets)** | **Rate** | **Conditions** | **Rate** | **(mm)** | **Rate** |
| No vegetation | 10 | ≤ 2 | 1 | Near Blasting site, earthquake | 10 | < 20 | 10 |
| Only grass | 7 | 3 | 8 | Near main highway | 5 | 20-60 | 7 |
| Grass with small trees | 5 | ≥ 4 | 10 | No vibration | 0 | 60-200 | 5 |
| Full grown trees | 0 | Unknown | 5 | Unknown | 5 | >200 | 0 |
| Unknown | 5 | | | | | Unknown | 5 |

***5 for arid climate, 10 for tropical climate**

**Table 4.2** The influencing factors to calculate the probability of the circular failure (Fuenkajorn 2003).

| Rock grade | Slope height | Slope face angle | Groundwater | Degree of weathering |
|---|---|---|---|---|
| R0 | 2.0 | 2.0 | 3.1 | 0 |
| R1 | 1.7 | 1.8 | 2.2 | 0.2 |
| R2 | 0.1 | 0.1 | 1.2 | 0.4 |
| **Rock grade** | **Vegetation** | **Number of discontinuity** | **Vibration** | **Average discontinuity spacing** |
| R0 | 0.5 | 0 | 2.4 | 0 |
| R1 | 1.1 | 0.4 | 0.5 | 2.1 |
| R2 | 2.0 | 1.2 | 0.1 | 4.9 |

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# CHAPTER V

# DATA PREPARATIONS

This chapter explains how to create the necessary parameters for evaluated probability of failure (PF). The “ArcGIS” version 9.2 is used for analysis. It is used for creating and using maps, compiling geographic data, and analyzing mapped information. The existing data includes: Digital Elevation Model (DEM), Geologic maps, Land use maps, and Thai highway maps. The uniaxial compressive strength of intact rock (UCS) is adopted from Thongthiangdee (2003), and Kamutchat (2004).

## 5.1 DEM to Slope Geometry Maps

DEM is a computer representation of the earth's surface, and as such, provides a base data set from which topographic parameters can be digitally generated. This study used DEM at scale 1:4,000 (Figure 5.1). It is provided by Land Development Department (LDD) Ministry of Agriculture and Cooperatives, Thailand. DEM is represented as a raster from grid of squares. The data resolution is 5×5 meters per pixel and the data accuracy is 95%. Triangulated Irregular Network (TIN) derived from DEM in 3D Analysis Tools menu (Figure 5.2). A TIN comprises a triangular network of vertices, known as mass points, with associated coordinates in three dimensions connected by edges to form a triangular tessellation. But TIN have not attribute data. Then convert TIN to TIN Triangle (TINs), vector-based representation of the physical land surface (Figure 5.3). Using a TINs in analysis is more advantage than raster DEM. It is distributed variably based on an algorithm, determines which points are most necessary to an accurate representation of the terrain. The geometries parameters of slope such as slope face angle and slope height are produced from TINs.

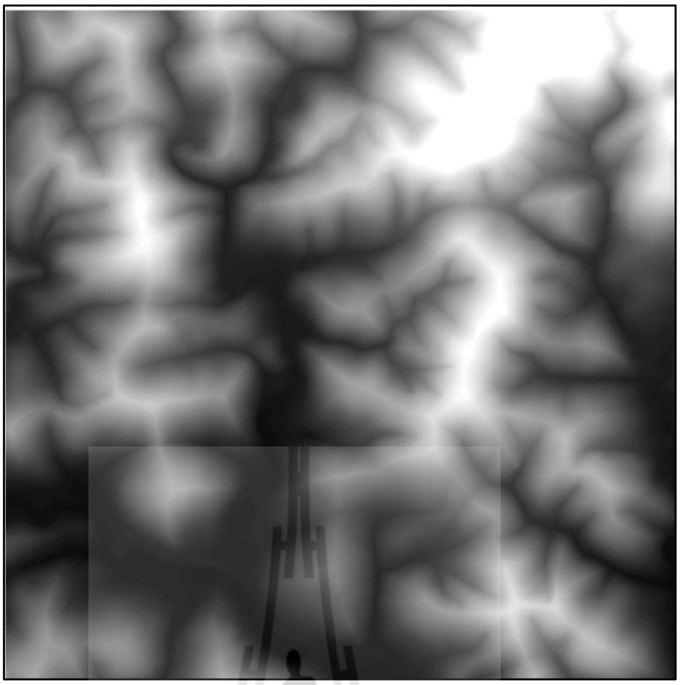


**Figure 5.1** A 400×400 grids Digital Elevation Model (DEM) at scale 1:4,000. The elevation increased from white to dark color.

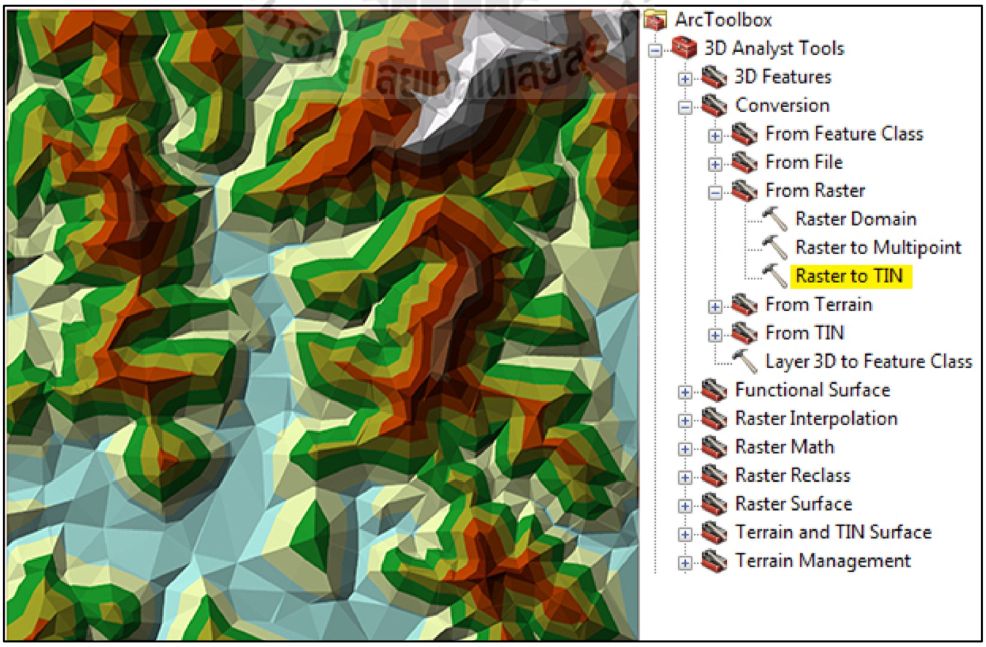



**Figure 5.2** Triangulated Irregular Network (TIN) derived from DEM.

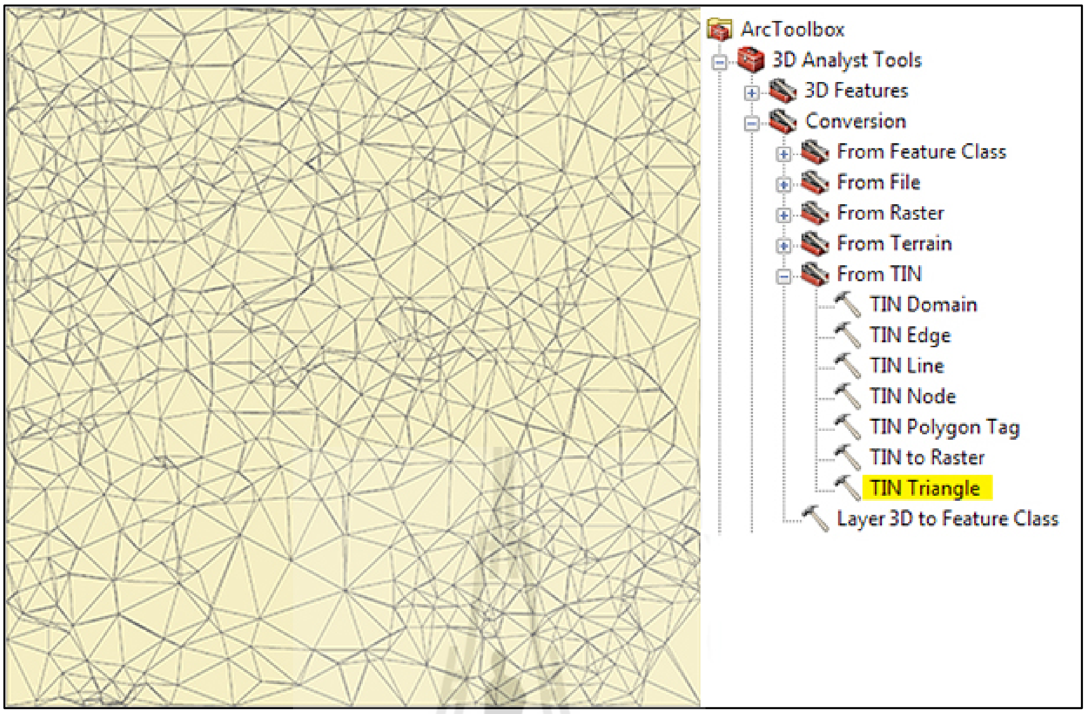



**Figure 5.3** TIN Triangle (TINs) converted from TIN. TINs contained attribute data includes slope area, aspect, angle, and number.

### 5.1.1 Slope face angle maps

An angle of slope face are containing in attribute table of TINs. The angles are divided in to 11 levels (Figure 5.4). All levels are rating in attribute table followed table 4.1. Many degrees of slope angle from TINs are slightly less than the actual. It is significant to insert appropriate tolerance value on TIN creation (Figure 5.5). The Z Tolerance is between 2 to 10 meters, 2 to 5 for only steeply hill and 5 to 10 for flat terrain with hill.

### 5.1.2 Slope height maps

Slope height can determined from difference of maximum and minimum elevation of TINs nodes (Figure 5.6). Both of them can produce by Spatial Analysis Tools in Zonal Statistics submenu (Figure 5.7). Go to Math in Spatial Analysis Tools to calculate the

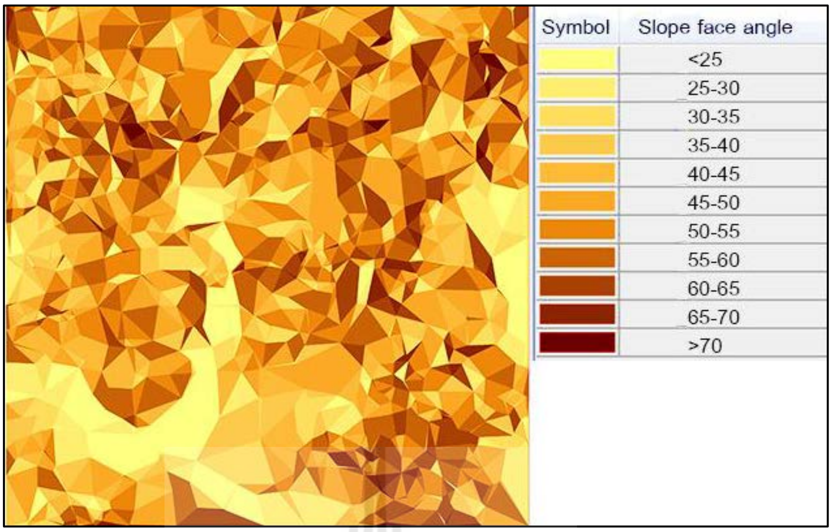



**Figure 5.4** Slope face angle maps produced from TINs.

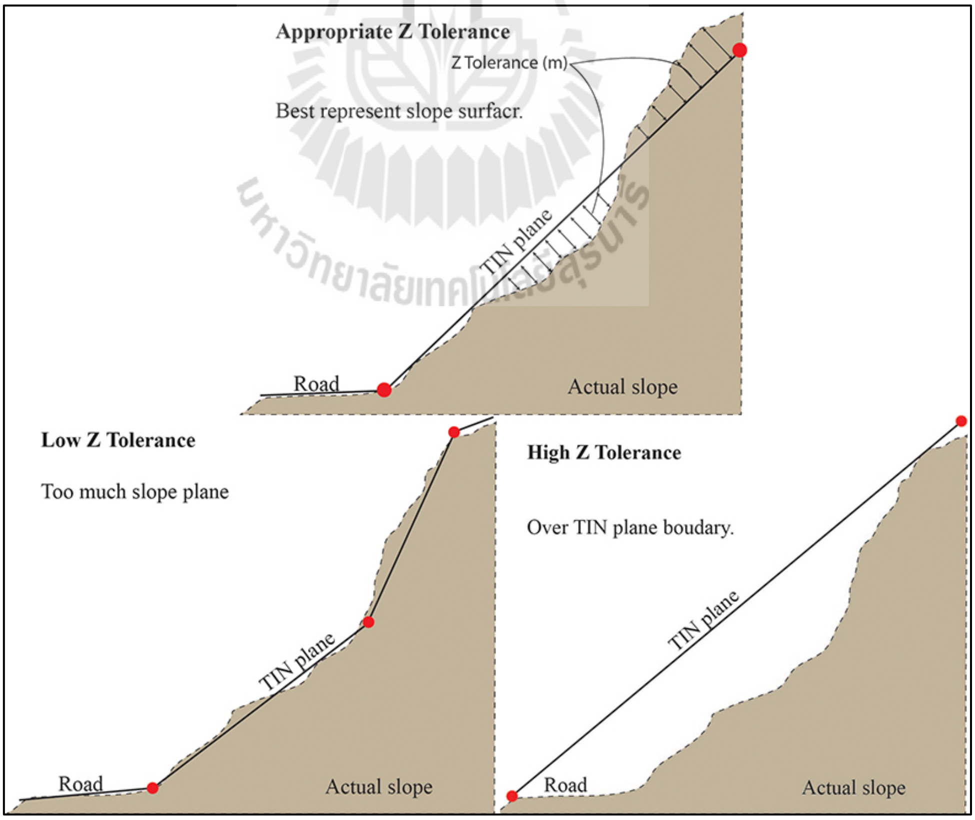



**Figure 5.5** Schematics of rock slopes with varied Z Tolerance for triangulated irregular network (TIN) applied in GIS method.

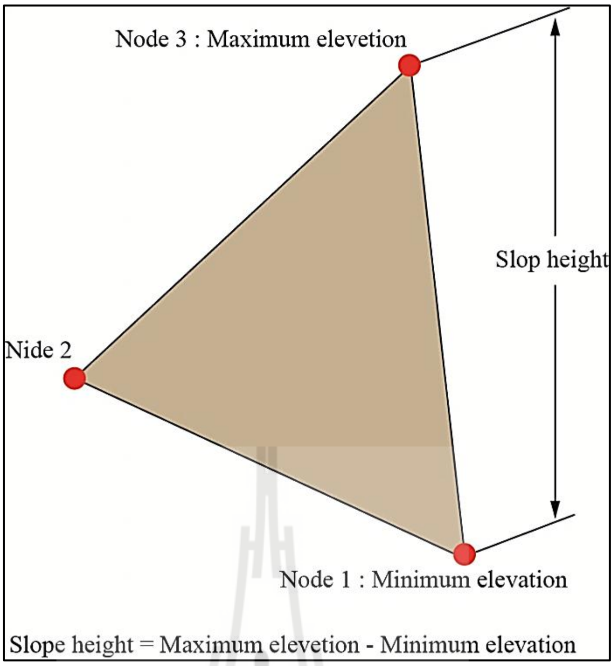



**Figure 5.6** Concept for determined slope height of TINs surface.

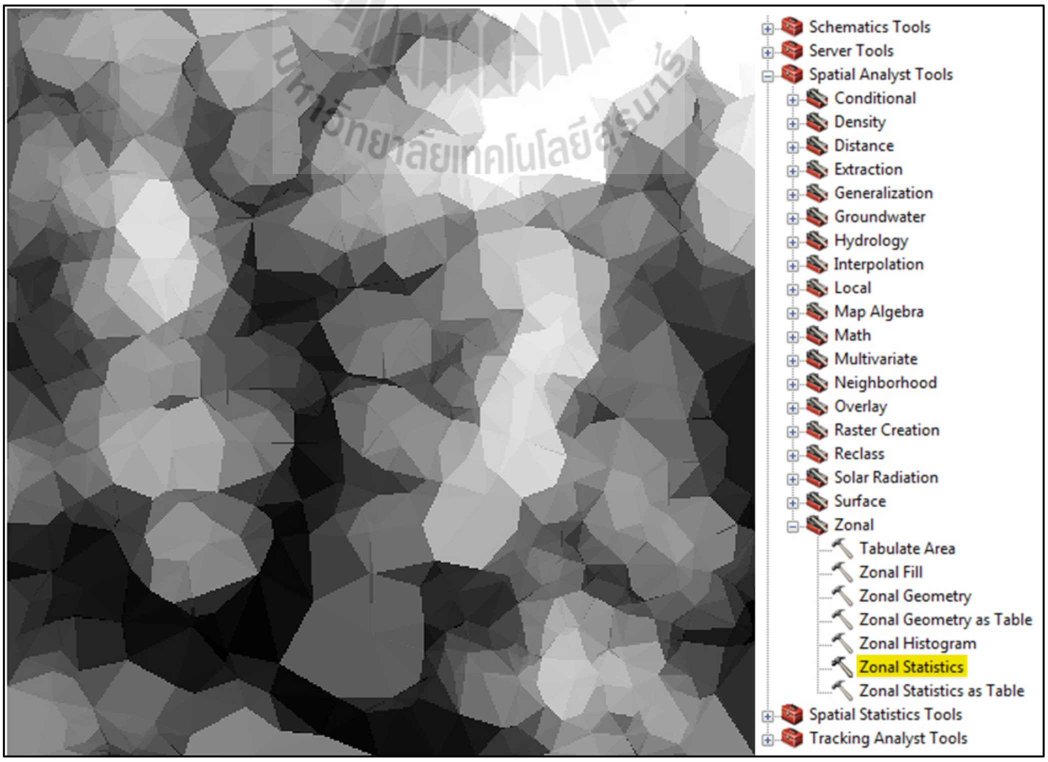



**Figure 5.7** Maximum and minimum elevation created from TINs.

difference between maximum and minimum elevation (Figure 5.8). Convert them to integer value and using Conversion Tools create raster to polygon. The slope height containing in attribute table and divided in to four levels (Figure 5.9). All levels are rating in attribute table followed table 4.1.

## 5.2 Land Use to Vegetation Maps

Land use maps in vector file scale 1:50,000 provided by LDD. The data can be used to classify type and amount of vegetation. Attribute data contain category of land use (Figure 5.10). The interpretation classifies four type of vegetation as follows.

1) No vegetation if field related reservoir, natural water, and Huai.
2) Only grass if field related rice paddy, farm, and village.
3) Grass with small trees if field related scrub.
4) Full grown trees if field related rain tree, park, and perennial plant.

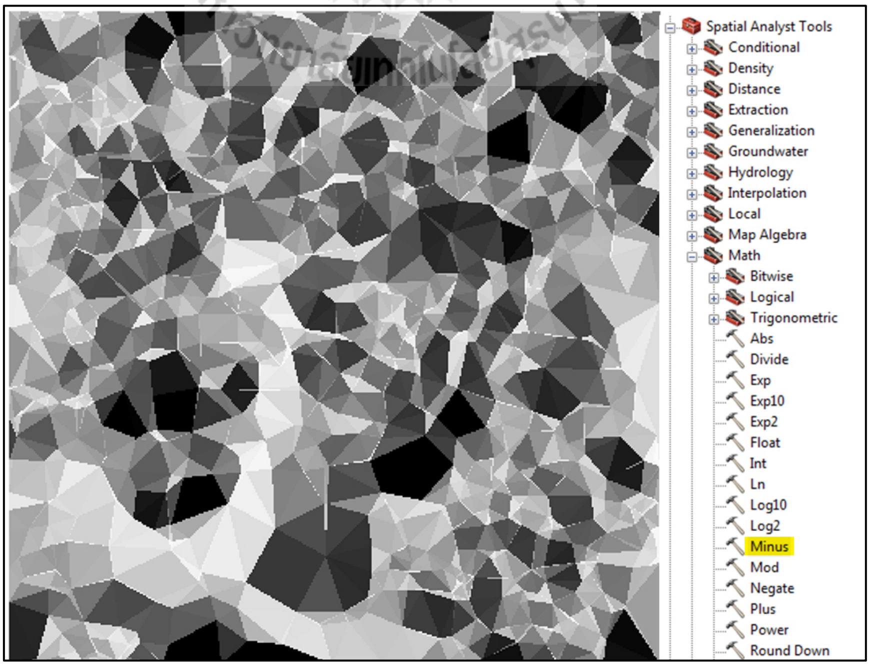



**Figure 5.8** After Minus command the slope height is appear but lack of attribute data.

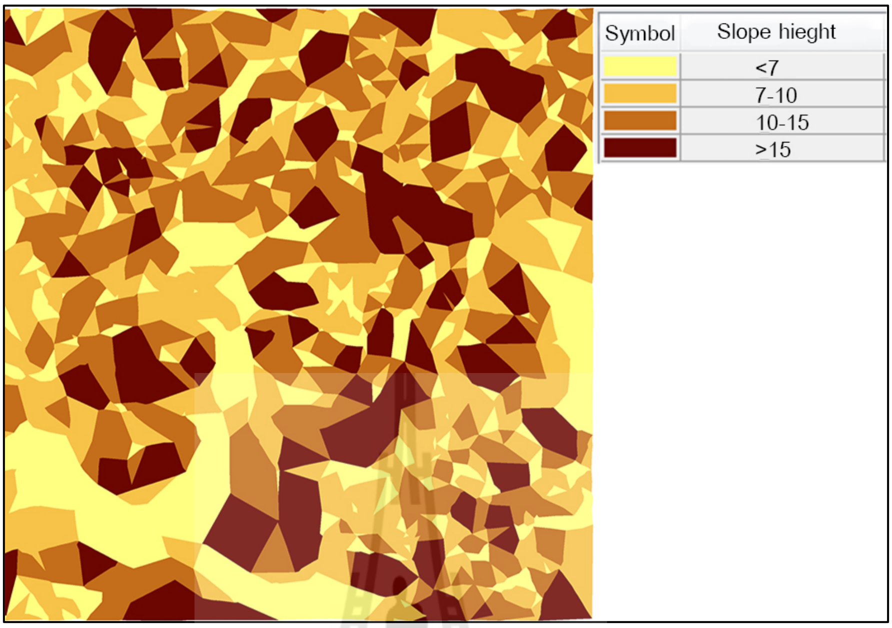



**Figure 5.9** Slope height maps produced from TINs.

Attributes of shape_phare50_final_new

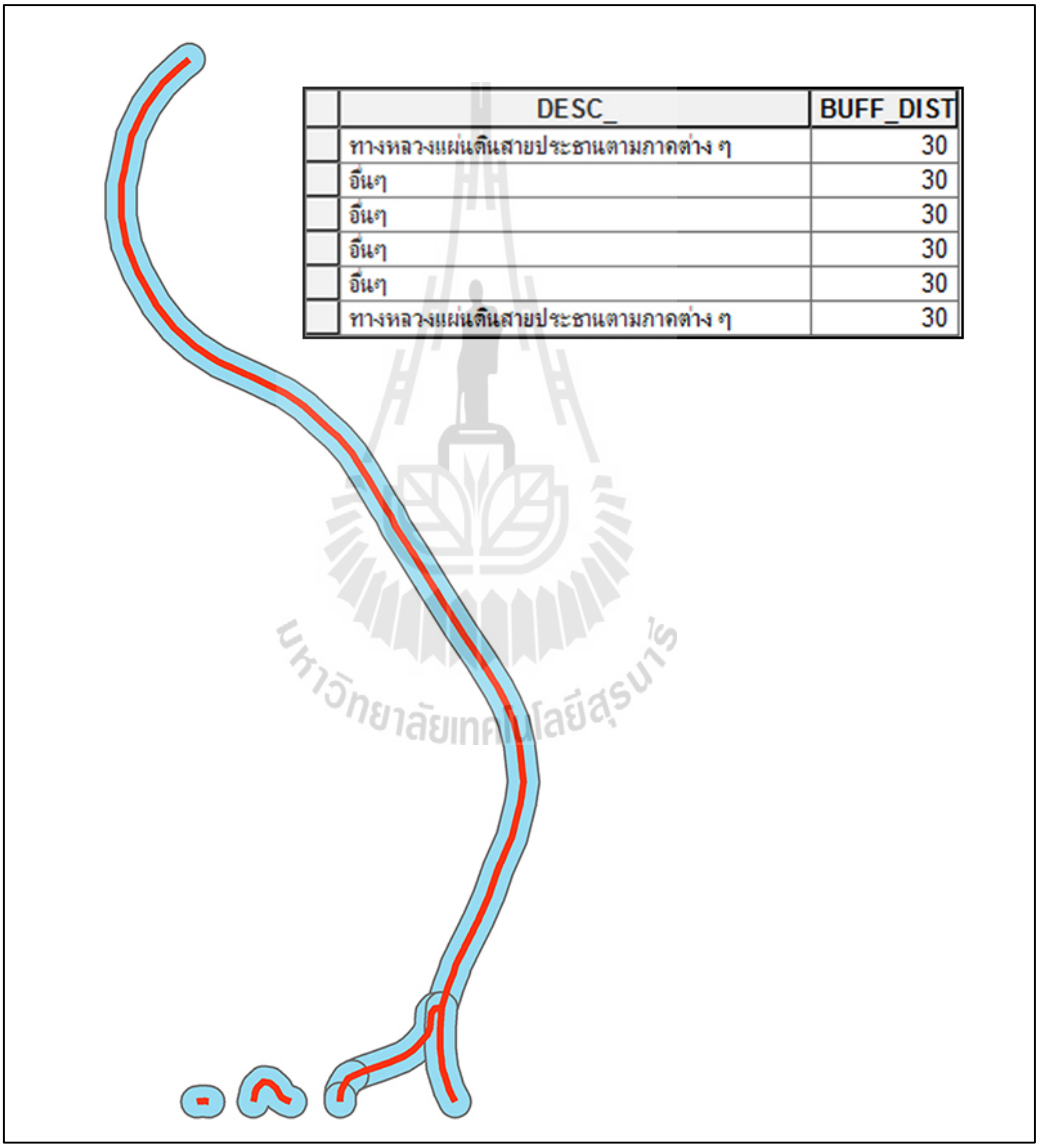
| FID | Shape * | AREA | DES_EN | RAI | ACRES | LU_CODE |
|---|---|---|---|---|---|---|
| 0 | Polygon | 66644.485618 | Reservoir | 42 | 1.53 | W201 |
| 1 | Polygon | 44478.840721 | Rice paddy | 28 | 1.021 | A101 |
| 2 | Polygon | 4504.848441 | Farm pond | 3 | 0.103 | W202 |
| 3 | Polygon | 14458.164036 | Natual water | 9 | 0.332 | W102 |
| 4 | Polygon | 52776.157077 | Nong Mai | 33 | 1.212 | W102 |
| 5 | Polygon | 12899.730389 | Reservoir | 8 | 0.296 | W201 |
| 6 | Polygon | 555087.295636 | Rice paddy | 347 | 12.743 | A101 |
| 7 | Polygon | 48020.352416 | Ban Daen Chon | 30 | 1.102 | U201 |
| 8 | Polygon | 13880.568937 | Huai Khwian | 9 | 0.319 | W101 |
| 9 | Polygon | 8527.591777 | Reservoir | 5 | 0.196 | W201 |
| 10 | Polygon | 15321.840205 | Scrub | 10 | 0.352 | M102 |
| 11 | Polygon | 4758.200803 | Huai Rong Hang | 3 | 0.109 | W101 |
| 12 | Polygon | 95894.952014 | Scrub | 60 | 2.201 | M102 |
| 13 | Polygon | 3439.546418 | Village | 2 | 0.079 | U201 |
| 14 | Polygon | 7723.859015 | Village | 5 | 0.177 | U201 |
| 15 | Polygon | 10064.460872 | Nong Klang | 6 | 0.231 | W102 |
| 16 | Polygon | 63472.573617 | Ban Nong Klang | 40 | 1.457 | U201 |
| 17 | Polygon | 8879.619382 | Rice paddy | 6 | 0.204 | A101 |
| 18 | Polygon | 16199.359933 | Rain tree | 10 | 0.372 | A318 |
| 19 | Polygon | 8553.93014 | Longan | 5 | 0.196 | A413 |

Record: 0 Show: All Selected Records (0 out of 18425 Selected)

**Figure 5.10** Field description in attribute table of Land use data.

## 5.3 Highway Map to Vibration Zone Maps

A vector data of highway map of Thailand is scale 1:1,000,000. Zone of vibration can be generated as a buffer zone about 30 meters from the Highways (Figure 5.11). Rating of the buffer zone equal 5 point and zero for outside.



| DESC_ | BUFF_DIST |
|---|---|
| ทางหลวงแผ่นดินสายประธานตามภาคต่าง ๆ | 30 |
| อื่นๆ | 30 |
| อื่นๆ | 30 |
| อื่นๆ | 30 |
| อื่นๆ | 30 |
| ทางหลวงแผ่นดินสายประธานตามภาคต่าง ๆ | 30 |



**Figure 5.11** Zone of vibration maps about 30 meters from highways.

## 5.4 Geologic Maps to Influencing Factor Maps

Hard copy of geologic maps scale 1:50,000 were scanned to computer. The image data was digitized in ArcGIS program. Set the georeferencing to UTM zone 47 WGS84. Insert rock grade to attribute table of geologic maps. The rock grade converted from UCS followed as Brown (1981) (Table 5.1). Figure 5.12 is shown the geologic map after digitized and add attribute data. A set of influencing factor is also defined as multiplying factors for the corresponding parameter (Table 4.2).

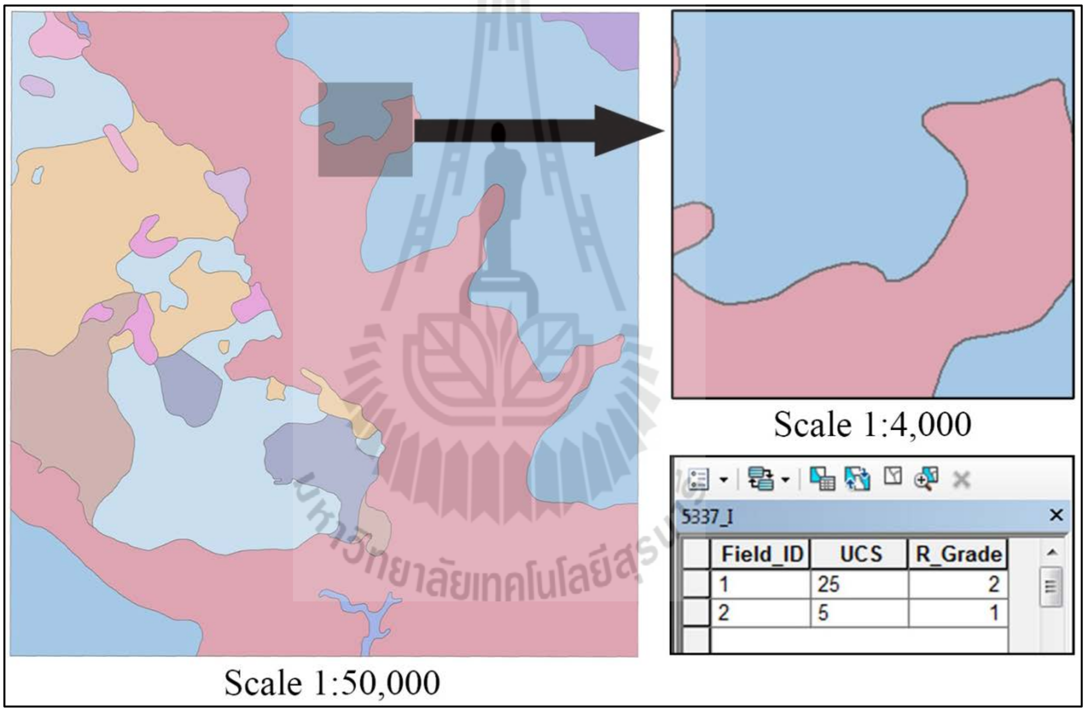



**Figure 5.12** Influencing maps depended on rock grade was prepared for multiplying factors for the corresponding parameter

**Table 5.1** Field estimates of uniaxial compressive strength of intact rock (Brown, 1981).

| Rock Grade | Uniaxial Compressive Strength (MPa) | Field Estimate of Strength | Examples* |
|---|---|---|---|
| R6 | > 250 | Rock material only chipped under repeated hammer blows | fresh basalt, chert, diabase, gneiss, granite, quatzite |
| R5 | 100 - 250 | Requires many blows of a geological hammer to break intact rock specimens | Amphibolite, sandstone, basalt, gabbro, gneiss, granodiorite, limestone, marble rhyolite, tuff |
| R4 | 50 - 100 | Hand held specimens broken by a single blow of a geological hammer | Limestone, marble, phyllite, sandstone, schist, shale |
| R3 | 25 - 50 | Firm blow with geological pick indents rock to 5mm, knife just scrapes surface | Claystone, coal, concrete, schist. shale, siltstone |
| R2 | 5 - 25 | Knife cuts material but too hard to shape into triaxial specimens | chalk, rocksalt, potash |
| R1 | 1-5 | Material crumbles under firm blows of geological pick, can be scraped with knife | highly weathered or altered rock |
| R0 | 0.25 - 1 | Indented by thumbnail | clay gouge |

# CHAPTER VI

# ANALYSIS METHOD

This chapter shows step to determined PF on rock slope. The procedure divided in to three stages: (i) convert the input slope characteristics in to quantitative values, (ii) recognizing the significant of the parameters, and (iii) summation and creating potential maps

## 6.1 Considered Parameters to Quantitative Form

The system classifies each considered parameters in the stability evaluation into small ranges mainly to convert the input slope characteristics into quantitative form. The classification follows as Fuenkajorn (2003). For circular failure the system can constructed four parameters includes: slope face angle, slope height, vegetation, and vibration.

### 6.1.1 Primary parameters

All considered parameters from chapter V have been edited, add new field to attribute table for get rating value. Setup the field type to integer for stored quantitative values. Selected similar attribute and respective add rating values to each range. The values insert to new created field that nominate "_Rating" must be short integer (Figure 6.1).

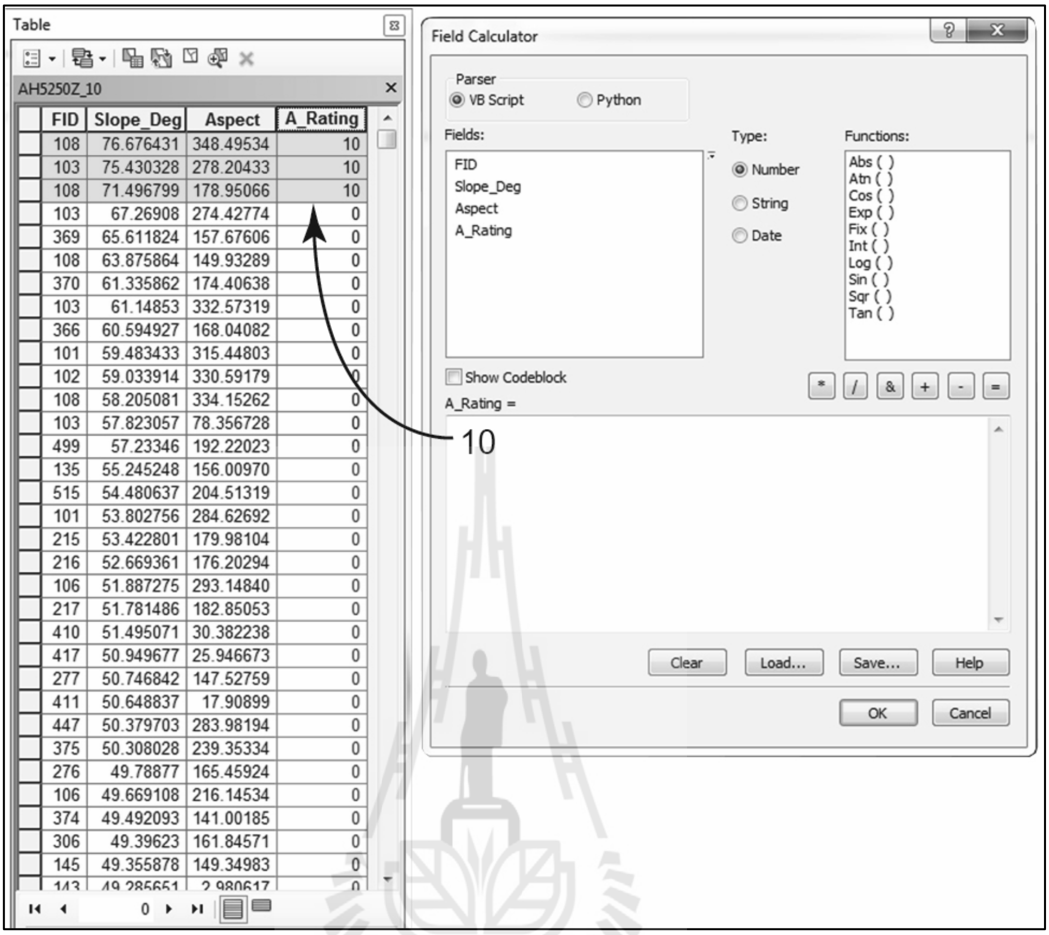



**Figure 6.1** Rating insert in attribute table. The considered attribute (Slope_Deg) have been divided into sub-divisions and add rating to new field (A_Rating).

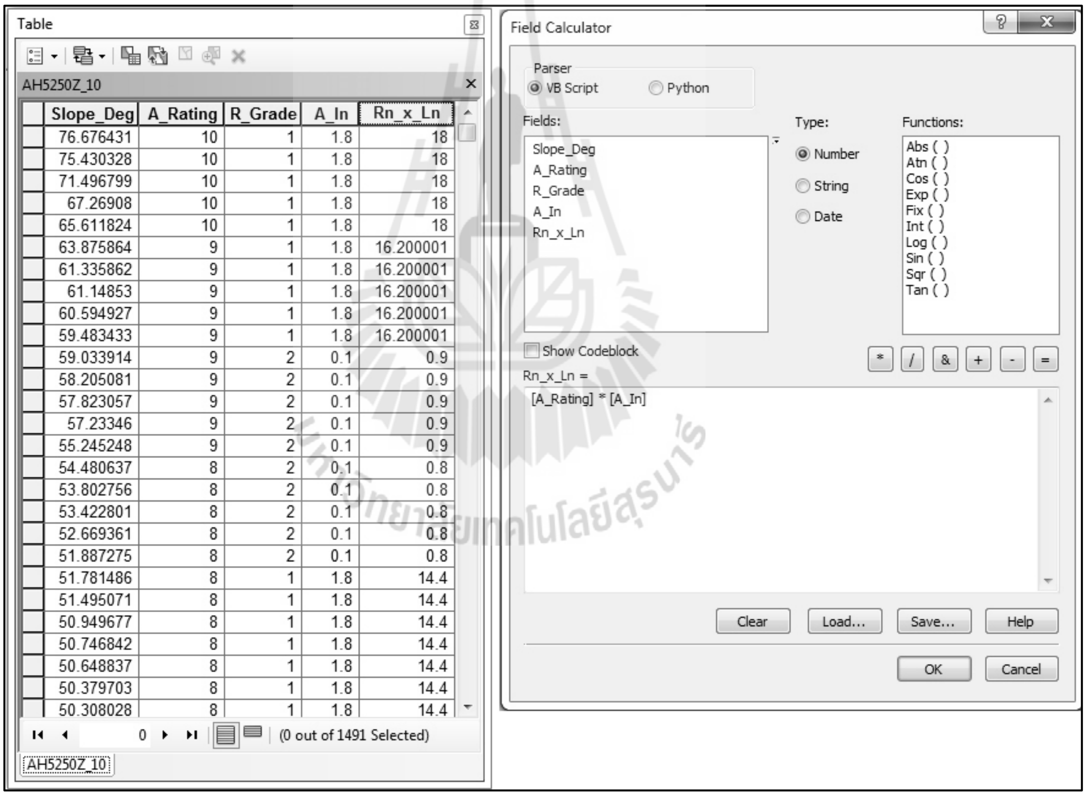
### 6.1.2 Secondary parameters

Secondary parameters are supplementary information for completed the analysis. Those considered parameters cannot create in GIS system. The system suggests assuming condition as follows.

1) Groundwater conditions are 25% for arid and 100% for tropical climates.
2) Degree of weathering is rated as five point.
3) Number of discontinuity is rated as five point.
4) Average discontinuity spacing is rated as five point.

## 6.2 Parameters Adjustment

The calculations of PF use 8 parameters. After convert them to quantitative value, each parameter has been adjusted. The union of all GIS vector layers which are considered parameters map and geologic map resulted in the layer. The layer containing polygons with identical combination attributes of considered parameters and geotechnical properties of materials. A set of influencing factor is also defined as multiplying for the corresponding parameter (Figure 6.2). The attributes of the layer were performed using equation (4.1) and result in additional attribute name “Sum_PF” (Figure 6.3).




| Slope_Deg | A_Rating | R_Grade | A_In | Rn_x_Ln |
|---|---|---|---|---|
| 76.676431 | 10 | 1 | 1.8 | 18 |
| 75.430328 | 10 | 1 | 1.8 | 18 |
| 71.496799 | 10 | 1 | 1.8 | 18 |
| 67.26908 | 10 | 1 | 1.8 | 18 |
| 65.611824 | 10 | 1 | 1.8 | 18 |
| 63.875864 | 9 | 1 | 1.8 | 16.200001 |
| 61.335862 | 9 | 1 | 1.8 | 16.200001 |
| 61.14853 | 9 | 1 | 1.8 | 16.200001 |
| 60.594927 | 9 | 1 | 1.8 | 16.200001 |
| 59.483433 | 9 | 1 | 1.8 | 16.200001 |
| 59.033914 | 9 | 2 | 0.1 | 0.9 |
| 58.205081 | 9 | 2 | 0.1 | 0.9 |
| 57.823057 | 9 | 2 | 0.1 | 0.9 |
| 57.23346 | 9 | 2 | 0.1 | 0.9 |
| 55.245248 | 9 | 2 | 0.1 | 0.9 |
| 54.480637 | 8 | 2 | 0.1 | 0.8 |
| 53.802756 | 8 | 2 | 0.1 | 0.8 |
| 53.422801 | 8 | 2 | 0.1 | 0.8 |
| 52.669361 | 8 | 2 | 0.1 | 0.8 |
| 51.887275 | 8 | 2 | 0.1 | 0.8 |
| 51.781486 | 8 | 1 | 1.8 | 14.4 |
| 51.495071 | 8 | 1 | 1.8 | 14.4 |
| 50.949677 | 8 | 1 | 1.8 | 14.4 |
| 50.746842 | 8 | 1 | 1.8 | 14.4 |
| 50.648837 | 8 | 1 | 1.8 | 14.4 |
| 50.379703 | 8 | 1 | 1.8 | 14.4 |
| 50.308028 | 8 | 1 | 1.8 | 14.4 |

**Figure 6.2** Adjustment of considered parameters defined as multiply with influencing factor.

Table

AH5250Z_10

| Rn*In_1 | Rn*In_2 | Rn*In_3 | Rn*In_4 | Rn*In5 | Rn*In_6 | Rn*In_7 | Rn*In_8 | Sum_PF |
|---|---|---|---|---|---|---|---|---|
| 10.8 | 1 | 5.5 | 0.5 | 0.25 | 2 | 2 | 5.1 | 27.15 |
| 10.8 | 1 | 0 | 0.5 | 0.25 | 2 | 2 | 5.1 | 21.65 |
| 10.8 | 13.6 | 0 | 0.5 | 0.25 | 2 | 2 | 5.1 | 34.25 |
| 10.8 | 13.6 | 0 | 0 | 0 | 2 | 2 | 5.1 | 33.5 |
| 10.8 | 13.6 | 0 | 0 | 0 | 2 | 2 | 5.1 | 33.5 |
| 9.72 | 13.6 | 5.5 | 0 | 0 | 2 | 2 | 5.1 | 37.919998 |
| 9.72 | 1 | 5.5 | 0 | 0 | 2 | 2 | 5.1 | 25.32 |
| 9.72 | 1 | 5.5 | 0 | 0 | 2 | 2 | 5.1 | 25.32 |
| 9.72 | 1 | 5.5 | 0 | 0 | 2 | 2 | 5.1 | 25.32 |
| 9.72 | 1 | 5.5 | 0 | 0 | 2 | 2 | 5.1 | 25.32 |
| 0.54 | 1 | 11 | 2.5 | 1.25 | 6 | 0 | 10.5 | 32.790001 |
| 0.54 | 1 | 11 | 2.5 | 1.25 | 6 | 0 | 10.5 | 32.790001 |
| 0.54 | 13.6 | 11 | 2.5 | 1.25 | 6 | 0 | 10.5 | 45.389999 |
| 0.54 | 13.6 | 11 | 2.5 | 1.25 | 6 | 0 | 10.5 | 45.389999 |
| 0.54 | 13.6 | 5.5 | 2.5 | 1.25 | 6 | 0 | 10.5 | 39.889999 |
| 0.479999 | 13.6 | 5.5 | 0 | 0 | 6 | 0 | 10.5 | 36.080002 |
| 0.479999 | 13.6 | 5.5 | 0 | 0 | 6 | 0 | 10.5 | 36.080002 |
| 0.479999 | 1 | 5.5 | 0 | 0 | 6 | 0 | 10.5 | 23.48 |
| 0.479999 | 1 | 5.5 | 0 | 0 | 6 | 0 | 10.5 | 23.48 |
| 0.479999 | 1.7 | 0 | 0 | 0 | 6 | 0 | 10.5 | 18.68 |
| 8.64 | 1.7 | 0 | 0 | 0 | 2 | 0 | 5.1 | 17.440001 |
| 8.64 | 1.7 | 0 | 0 | 0 | 2 | 0 | 5.1 | 17.440001 |
| 8.64 | 1.7 | 0 | 0 | 0 | 2 | 0 | 5.1 | 17.440001 |
| 8.64 | 1.7 | 0 | 0 | 0 | 2 | 0 | 5.1 | 17.440001 |
| 8.64 | 1 | 5.5 | 0.5 | 0.25 | 2 | 0 | 5.1 | 22.99 |
| 8.64 | 1 | 5.5 | 0.5 | 0.25 | 2 | 0 | 5.1 | 22.99 |
| 8.64 | 1 | 5.5 | 0.5 | 0.25 | 2 | 0 | 5.1 | 22.99 |
| 6.48 | 1 | 0 | 0.5 | 0.25 | 2 | 0 | 5.1 | 15.33 |
| 6.48 | 0.8 | 0 | 0.5 | 0.25 | 2 | 0 | 5.1 | 15.13 |
| 6.48 | 0.8 | 0 | 0.5 | 0.25 | 2 | 0 | 5.1 | 15.13 |

0 (0 out of 1491 Selected)

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**Figure 6.3** The result of PF were performed using equation (4.1).

## 6.3 Numerical Models

The numerical computer simulation is aimed to calculate the FS of the rock slopes and to compare with the results from using GIS method. The circular failure is emphasized because it is a typical failure mode which occurs on the field. The estimation of shear strength parameters is adopted from the back analysis (Hoek & Bray, 1981), and previous researches (Changsuwan, 1984; Wannakao, 1985). For soil properties, it is considered that the friction angle probably ranges from 15 to 25 degrees for disturbed material. The cohesion ranges from 0.04 to 0.1 MPa for weathered soft rock and 0.1 to 0.2 MPa for soft rock. The unit weight of intact rock is between 22 and 26 kN/m$^3$ (Changsuwan, 1984). These parameters are fed into the FLACslope4.0 program to calculate the FS. The results of numerical models are given in Appendices B.

## 6.4 Resulting Maps

The results of GIS method and computer modeling comparing with actual conditions of the studied road-cut slopes are showed in Table 6.1. Figure 6.4 to 6.8 shows the potential maps of all locations. The results of GIS method show that among 15 locations, eight are subjected to the circular failure and seven are stable. The circular failure is supposed to occur when the PF is over 40%. The results are verified by comparing with the actual conditions; thus, they indicate that GIS method can predict the stability conditions similarly to the actual slope behavior. The prediction from the GIS trends to be conservative; that is, the probability of failure obtained by this method is higher than the actual condition in most cases. After comparing with FS, the GIS method provides 80% of reliability.

**Table 6.1** Summary results of 15 slopes evaluation using numerical method (FLAC4.0) and GIS method (ArcGIS9.2).

| ***Station*** | ***FS.*** *(FLAC Slope 4.0)* | ***PF(%)*** *(ArcGIS 9.2)* | ***Actual Conditions*** |
|---|---|---|---|
| 01 | 4.87 | 14 | Stable |
| 02 | 2.36 | 18 | Stable |
| 03 | 3.96 | 15 | Stable |
| 04 | 1.12 | 48 | Circular failure |
| 05 | 1.38 | 36 | Stable |
| 06 | 1.57 | 28 | Stable |
| 07 | 1.08 | 50 | Circular failure |
| 08 | 1.20 | 41 | Circular failure |
| 09 | 1.57 | 34 | Stable |
| 10 | 1.48 | 39 | Stable |
| 11 | 1.21 | 55 | Circular failure |
| 12 | 1.03 | 45 | Circular failure |
| 13 | 0.66 | 62 | Circular failure |
| 14 | 0.96 | 56 | Circular failure |
| 15 | 0.86 | 63 | Circular failure |

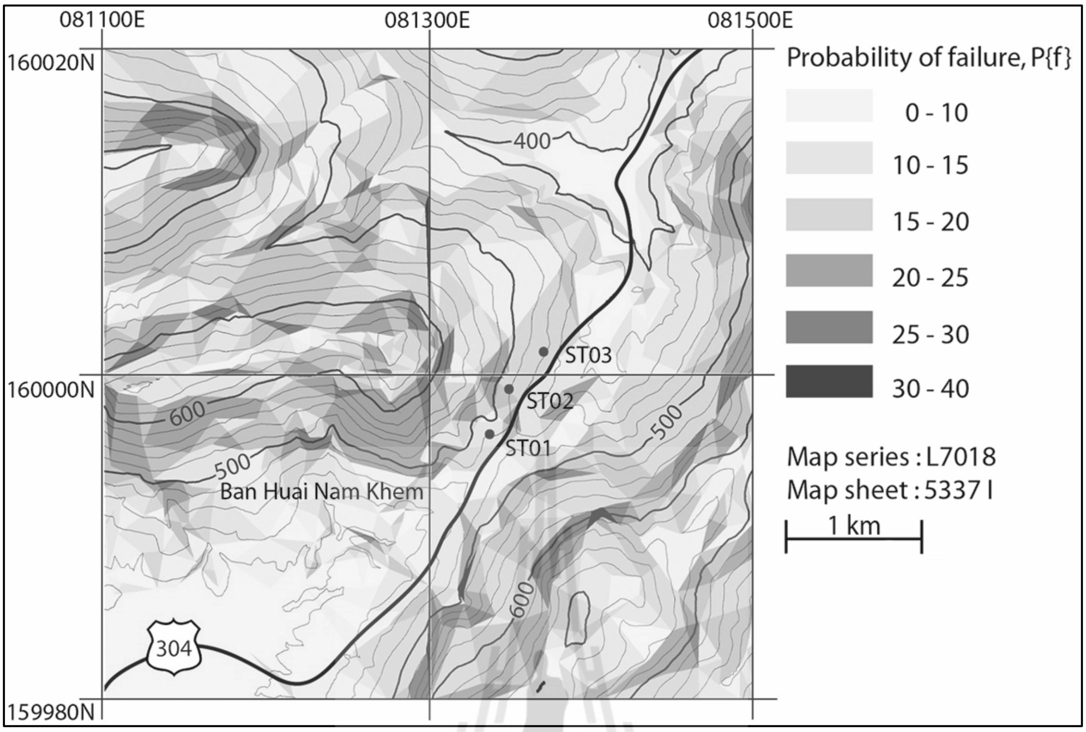


**Figure 6.4** Potential maps of highways 304 route.

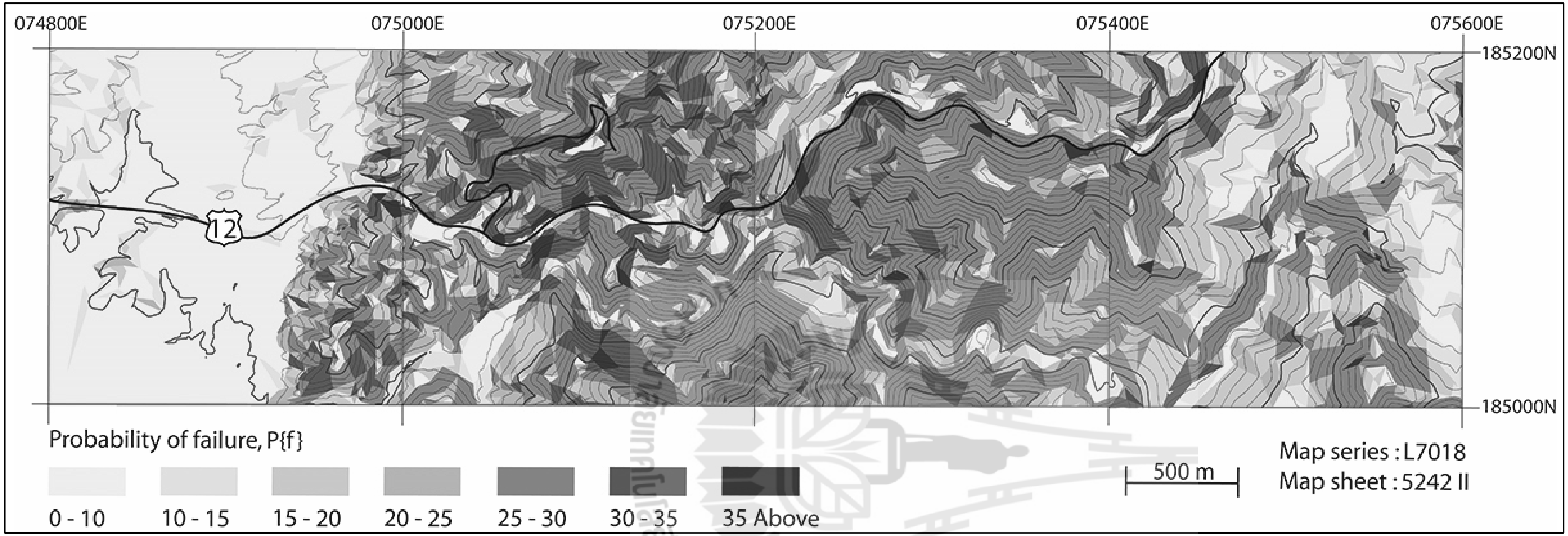


**Figure 6.5** Potential maps of the highway no. 12 route.

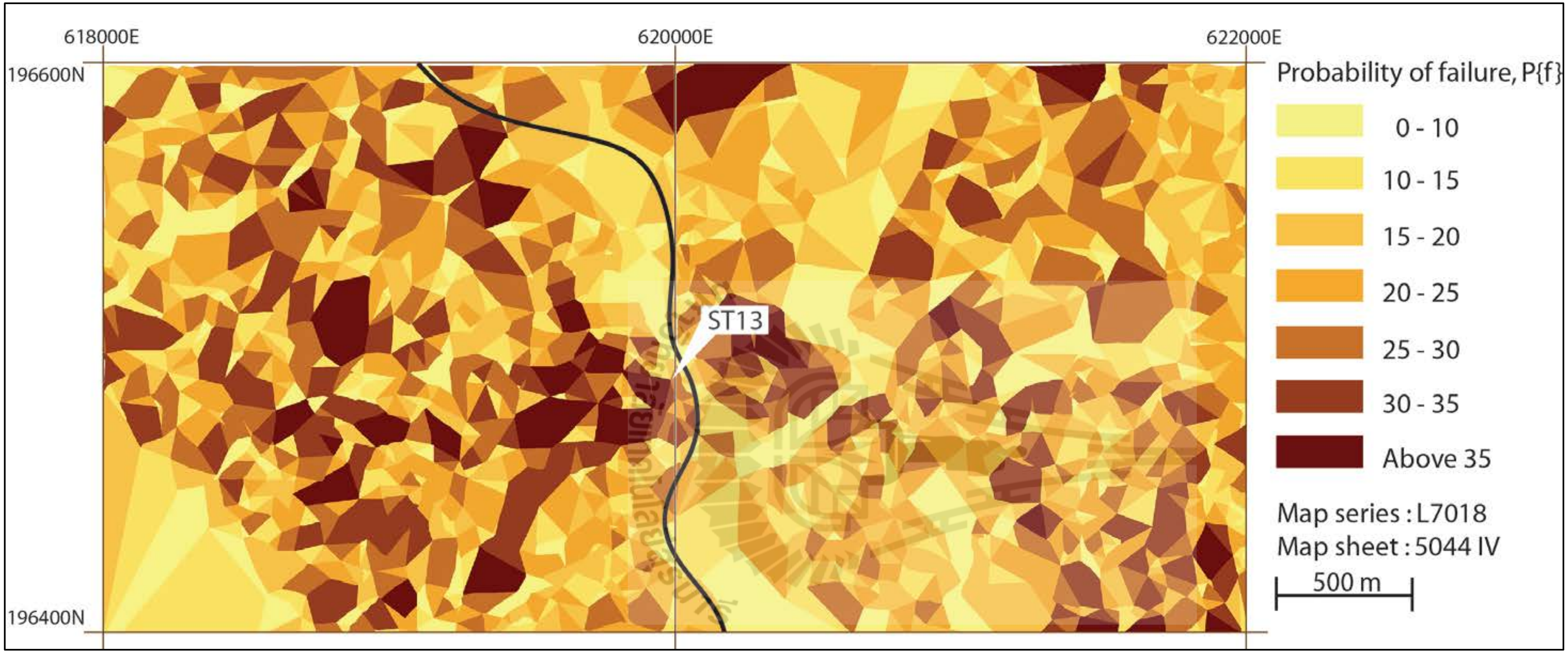


**Figure 6.6** Potential maps of the highway no.11 route, station 13.

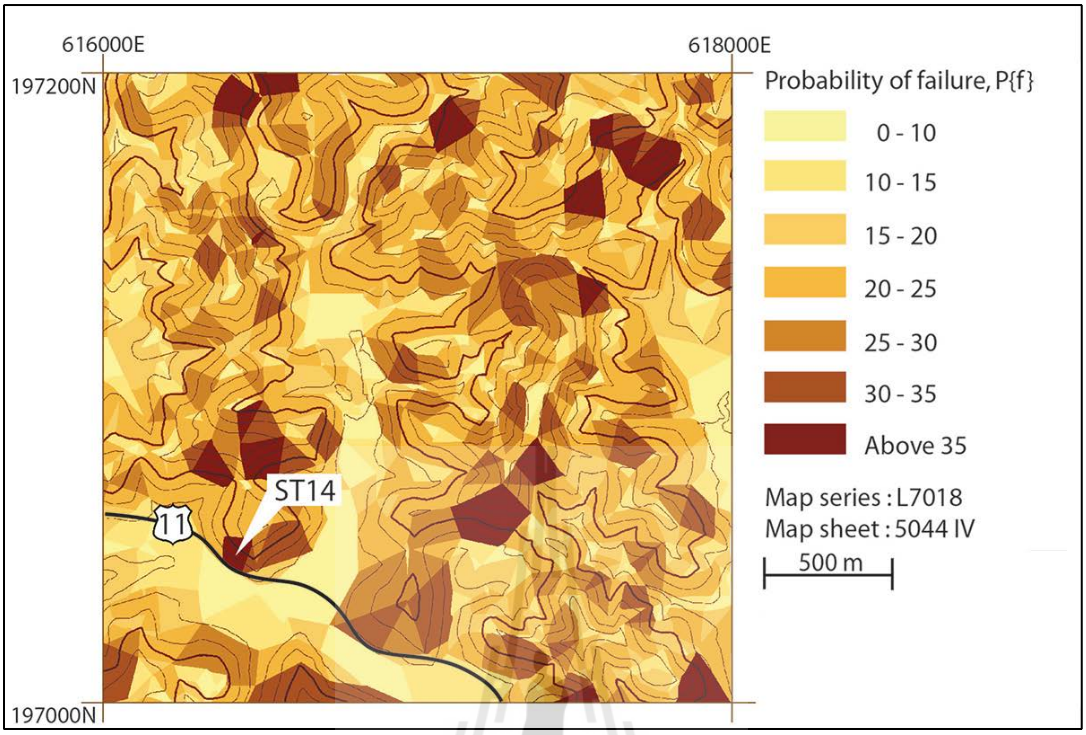


**Figure 6.7** Potential maps of the highway no. 11 route, station 14.

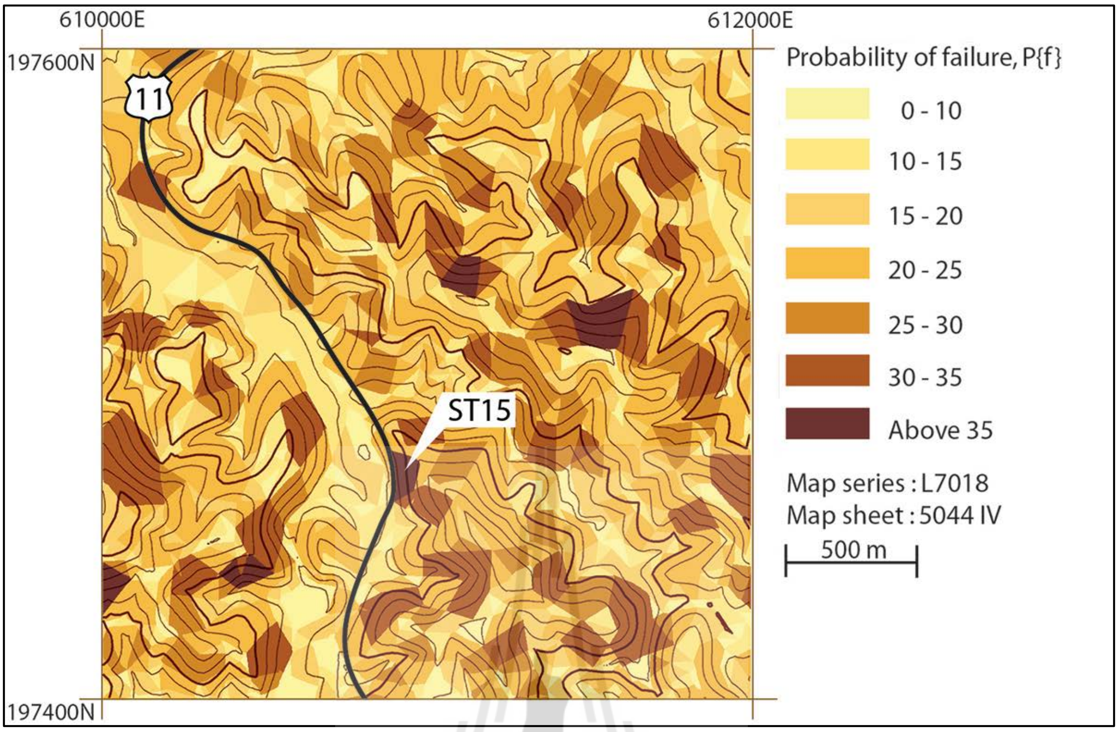


**Figure 6.8** Potential maps of the highway no. 11 route, station 15.

# CHAPTER VII

# DISCUSSIONS AND CONCLUSIONS

## 7.1 Discussions and conclusions

The probability of failure has been determined in this study. DEM with a scale 1:4,000 performed to simulated slope geometry. GIS method with expert system together can detect the risk area in large scale. The major parameters in GIS method are agreed with Fuenkajorn (2003). Some parameters such as degree of weathering, discontinuity spacing and number of discontinuity cannot detect in the GIS because the data resolution is lacking. The diversity of actual slope failure in the field investigation is similar. This is the reason why this study aims to circular failure. The critical PF from GIS method is 40%, factor of safety equal 1.0. But the expert system from Fuenkajorn (2003) limited PF as 50%. The slope height and slope angle decrease on operation in the second stage of method. The Z Tolerance controls the slope aspect. When the slope height and angle drops it reduces the rating of PF.

## 7.2 Recommendation for Future Studies

In fact, the type of failure is not only circular mode. The evaluation should be considers in the other failure mode. The slope stability depended on both slope characteristics and rock mass properties. The orientation and discontinuity of the slope are necessary. The results in this study can be improved to increase the accuracy by using proven and new GIS data. Users can adjust rating and influencing factors in order to improve the predictability of the system. The user can add more variable into the system, if appropriate. The experience users should however be familiar with the system function before improving the system. Frequent verification of the system with the actual field condition should be performed.

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# APPENDIX A

# FIELD INVESTIGATION

# FIELDS INVESTIGATION

## A-1 Highway number 304 route

The route consists of three slopes located between Nakhon Ratchasima and Prachinburi province.

### A-1.1 Station 01

The station 01 is located on highway 304 (Figure A1), Pak Thong Chai district, Nakhon Ratchasima province. The slope location is 47Q 0812549 and UTM 1599772 of GPS system. The slope is classified as hard-soft interbedded rock. The hard formation is sandstone. It has 0.6 to 1.0 meters in thickness. The soft formation is shale. It has 0.2 to 1.0 meters thickness. The slope height is 5 meters. The slope face angle is 70 degrees. The slope is stable. The rock has three joint sets (Figure A2), as follows.

Joint set 1 (bedding plane) has strike 271 degrees, with 25 degrees dip angle. The joint are filled with clay.

Joint set 2 has a strike of 165 degrees, with 75 degrees dip angle. Joint spacing is 27 centimeters. Joint aperture is 0.5 millimeters. JRC is estimated as 5. The joints are filled with clay.

Joint set 3 has strike of 75 degrees, with 60 degrees dip angle. Joint spacing is 25 centimeters. Joint aperture is 5 millimeters. JRC is estimated as 5. The joints are filled with clay.

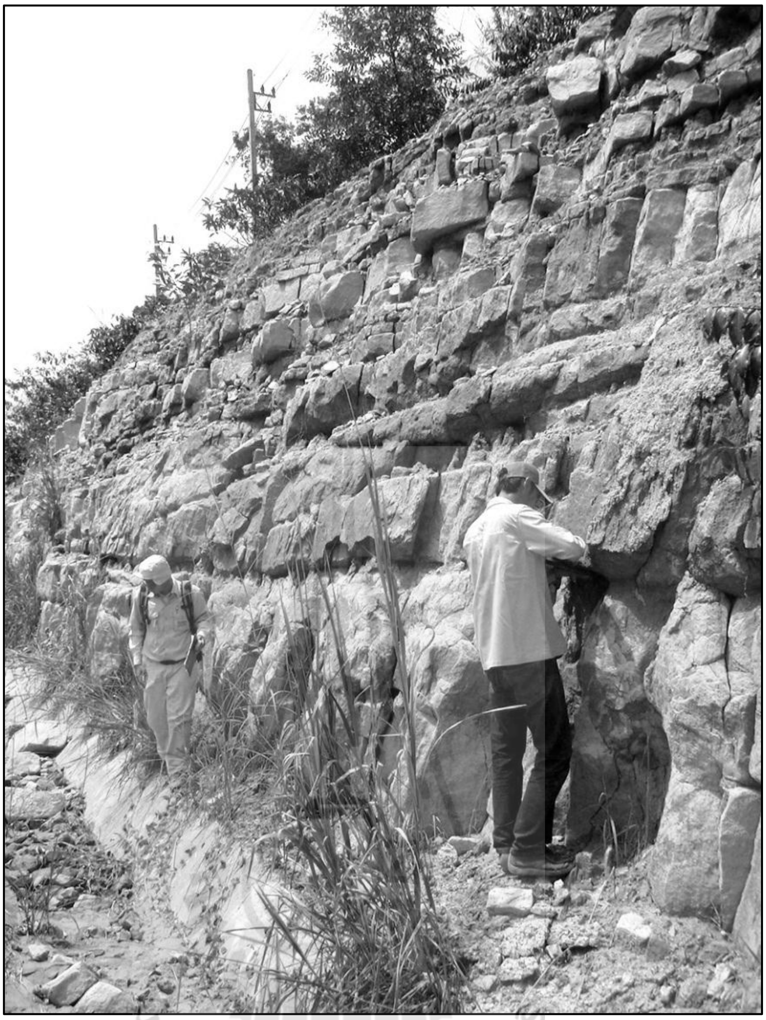
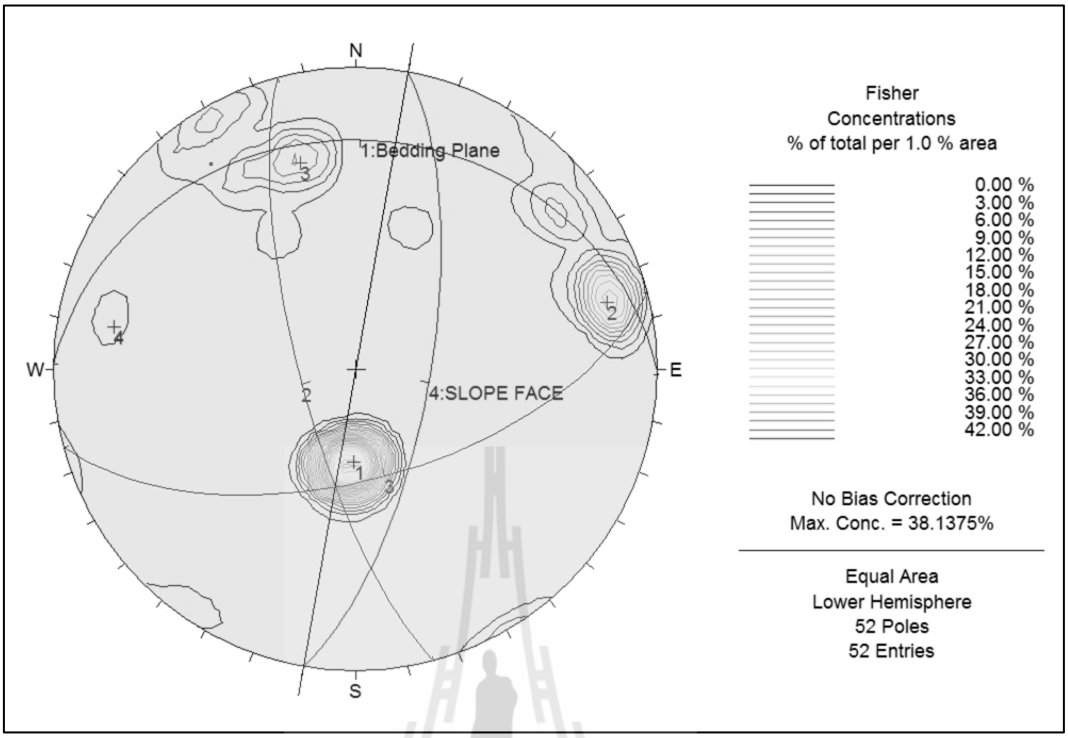


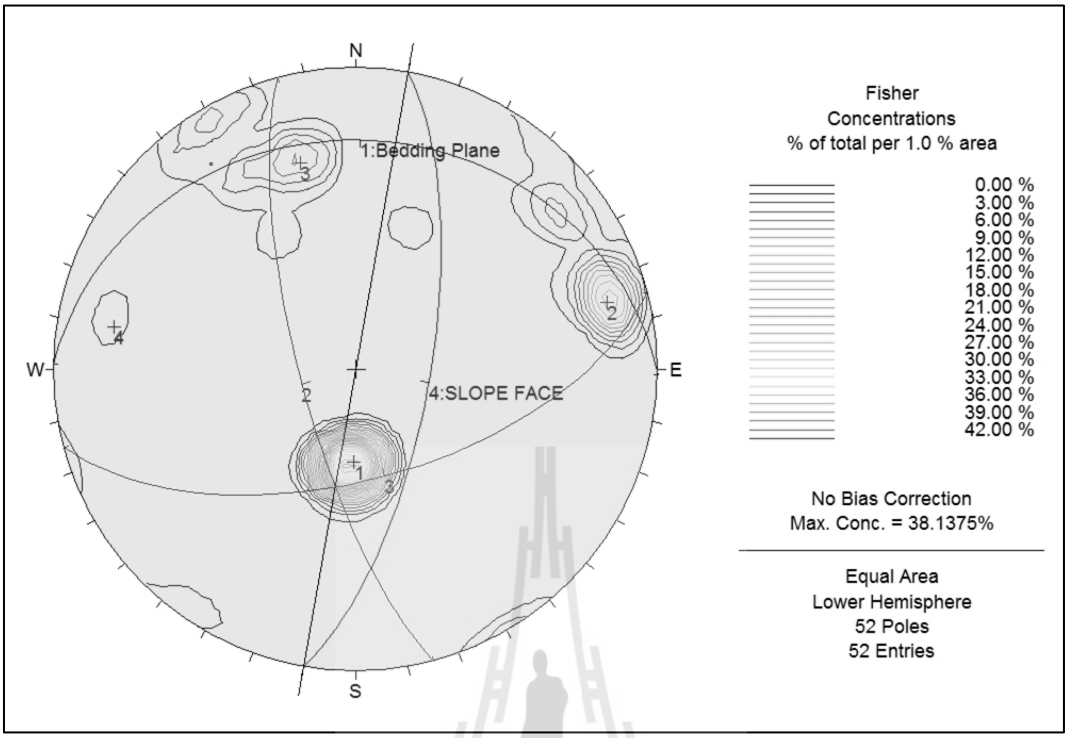


**Figure A1** Slope location at km 67+650 of 304 highway, Pak Thong Chai district, Nakhon Ratchasima province.




| ID | TREND/PLUNGE | STRIKE/DIPR | LABEL |
|---|---|---|---|
| 1 | 181/65 | 271/25 | Bedding Plane |
| 2 | 75/15 | 165/75 | Joint#2 |
| 3 | 345/30 | 75/60 | Joint#1 |
| 4 | 280/20 | 10/70 | SLOPE FACE |

**Figure A2** Representative plane of discontinuity set of station 01.




| ID | TREND/PLUNGE | STRIKE/DIPR | LABEL |
|---|---|---|---|
| 1 | 181/65 | 271/25 | Bedding Plane |
| 2 | 75/15 | 165/75 | Joint#2 |
| 3 | 345/30 | 75/60 | Joint#1 |
| 4 | 280/20 | 10/70 | SLOPE FACE |

**Figure A2** Representative plane of discontinuity set of station 01.

### A-1.1 Station 02

The station 02 is located on highway 304 (Figure A3), Pak Thong Chai district, Nakhon Ratchasima province. The slope location is 47Q 0812744 and UTM 1600070 of GPS system. The slope is classified as hard-soft interbedded rock. The hard formation is sandstone. It has 0.6 to 1.0 meters in thickness. The soft formation is shale. It has 0.2 to 1.0 meters thickness. The slope height is 5 meters. The slope face angle is 70 degrees. The slope is stable. The rock has four joint sets (Figure A4), as follows.

Bedding plane has strike 210 degrees, with 9 degrees dip angle. The joint are filled with clay.

Joint set 1 has a strike of 159 degrees, with 85 degrees dip angle. Joint spacing is 27 centimeters. Joint aperture is 0.5 millimeters. JRC is estimated as 5. The joints are filled with clay.

Joint set 2 has strike of 342 degrees, with 87 degrees dip angle. Joint spacing is 15 centimeters. Joint aperture is 3 centimeters. JRC is estimated as 5. The joints are filled with clay and soil.

Joint set 3 has strike of 60 degrees, with 78 degrees dip angle. Joint spacing is 25 centimeters. Joint aperture is 5 millimeters. JRC is estimated as 5. The joints are filled with clay and soil.

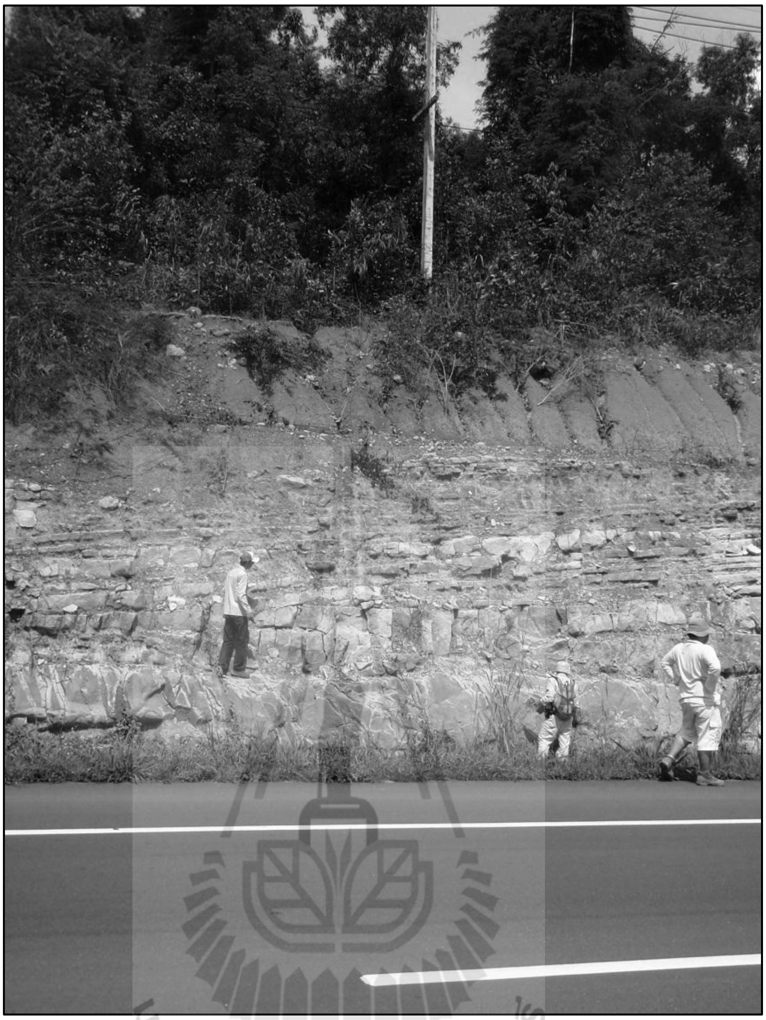
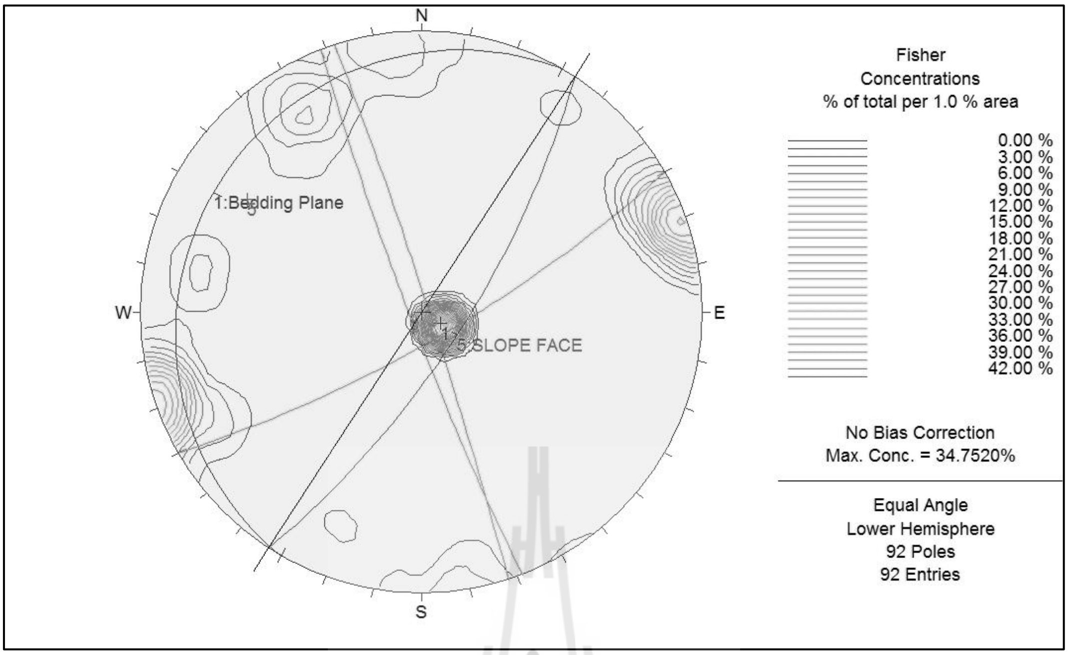




**Figure A3** Slope location at km 63+500 of 304 highway, Pak Thong Chai district, Nakhon Ratchasima province.




| ID | TREND/PLUNGE | STRIKE/DIPR | LABEL |
|---|---|---|---|
| 1 | 120/81 | 210/9 | Bedding Plane |
| 2 | 69/5 | 159/85 | Joint#1 |
| 3 | 252/3 | 342/87 | Joint#2 |
| 4 | 330/12 | 60/78 | Joint#3 |
| 5 | 303/17 | 33/73 | SLOPE FACE |

**Figure A4** Representative plane of discontinuity set of station 02.

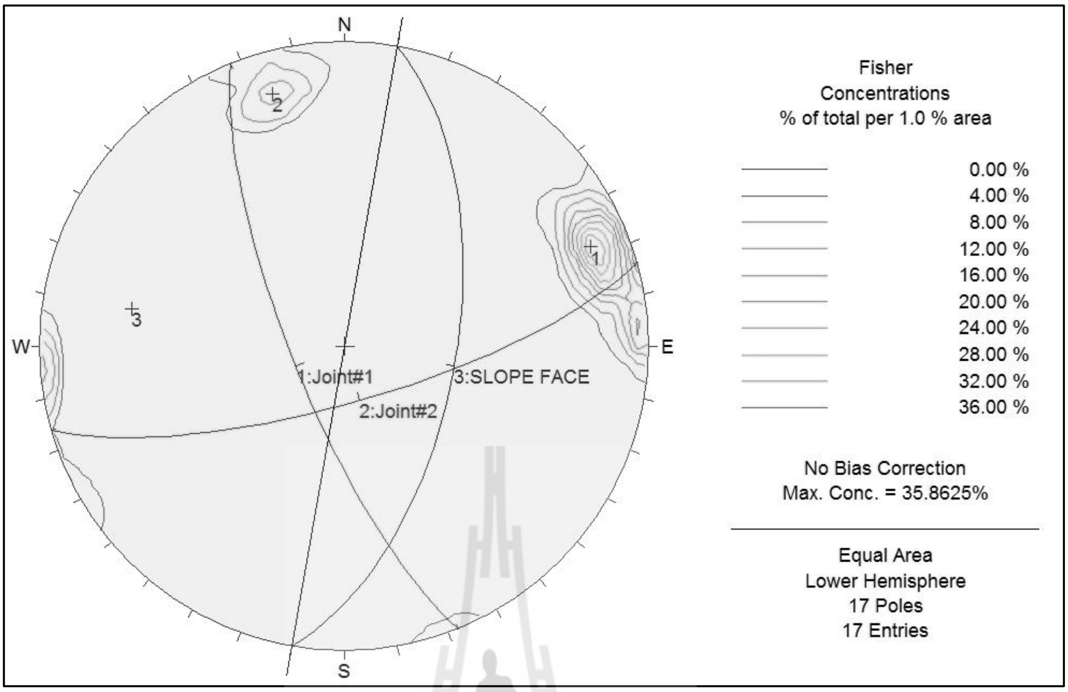
### A-1.1 Station 03

The station 03 is located on highway 304 (Figure A5), Pak Thong Chai district, Nakhon Ratchasima province. The slope location is 47Q 0812617 and UTM 1599907 of GPS system. The slope is classified as highly weathered rock. The slope height is 5 meters with 60 degrees of slope face angle. The slope is stable and has two joint sets (Figure A6), as follows.

Joint set 1 has strike 158 degrees, with 76 degrees dip angle. The joint are filled with clay.

Joint set 2 has a strike of 158 degrees, with 76 degrees dip angle. Joint spacing is 27 centimeters. Joint aperture is 0.5 millimeters. JRC is estimated as 5. The joints are filled with clay.

**Figure A5** Slope location at km 65+700 of 304 highway, Pak Thong Chai district, Nakhon Ratchasima province.




| ID | TREND/PLUNGE | STRIKE/DIPR | LABEL |
|---|---|---|---|
| 1 | 68/14 | 158/76 | Joint#1 |
| 2 | 344/15 | 74/75 | Joint#2 |
| 3 | 280/30 | 10/60 | SLOPE FACE |

**Figure A6** Representative plane of discontinuity set of station 03.

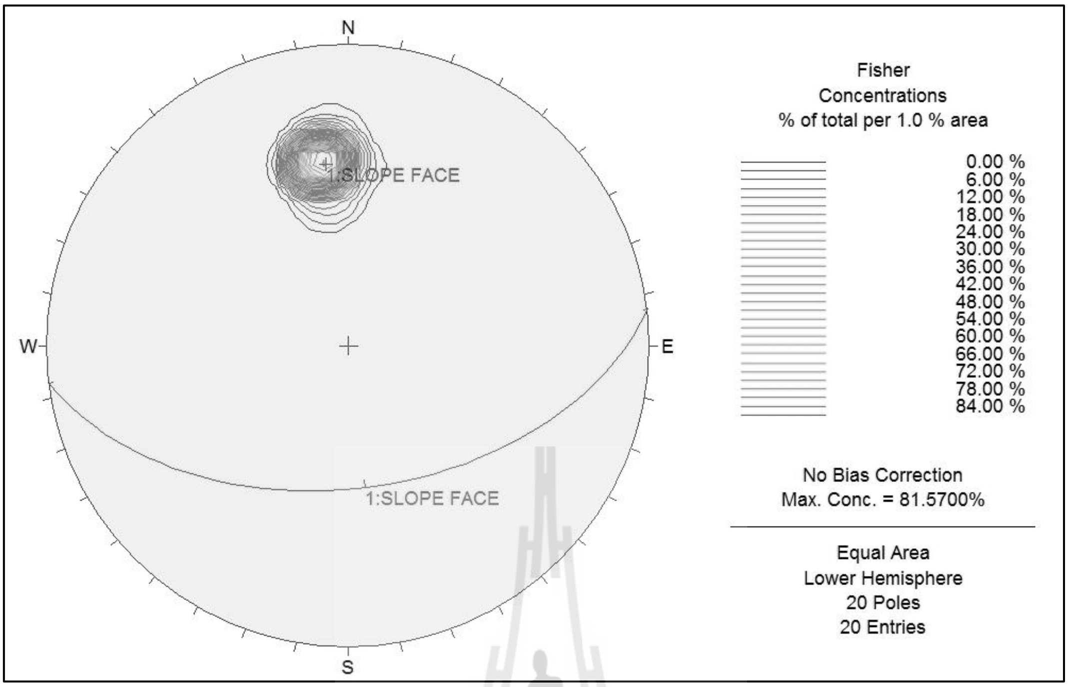
## A-2 Highway number 12 route

Lomsak-Chumpae highway was constructed over 30 years ago to shorten distance from the north to the northeast of Thailand. It is 120 kilometers long, cutting across Phetchabun and Khon Kaen province. The slope failure along the road cut have repeatedly occurred on some locations. The slope can be classify into three groups are bedded rock, heavily joint rock and soft rock. The most failure is circular mode.

### A-2.1 Station 04

The station 04 at km 16+200 is located on Lonsak-Chumpae highway (Figure A7). The slope location is 47Q 0750300 and UTM 1850998 of GPS system. The slope is classified as moderately weathered rock. The slope height is 20 meters and length is 150 meters. The strike and dip angle of slope face is 83 and 51 degrees. The rock type is shale. The slope was fail in circular mode. The representative plane has shown on figure A8.

**Figure A7** The circular failure mode on station 04. Plant and grass are generally covered on the slope face.




| *ID* | *TREND/PLUNGE* | *STRIKE/DIPR* | *LABEL* |
|---|---|---|---|
| 1 | 353/39 | 83/51 | SLOPE FACE |

**Figure A8** Representative plane of slope face of station 04.

**A-2.2  Station 05**

The station 05 at km 17+000 is located on Lonsak-Chumpae highway (Figure A9). The slope location is 47Q 0750788 and UTM 1850988 of GPS system. The slope is classified as bedded rock. The slope height is 50 meters and length is 150 meters. The strike and dip angle of slope face is 55 and 78 degrees. The rock type is slaty-shale. The slope is stable. The rock mass has four joint sets (Figure A10), as follows.

Bedding plane has a strike of 168, with 82 degree dip angle. The joint spacing is 0.02 to 0.2 meters. The joint aperture is 0.5 centimeters. The JRC is estimated as 2. The joints are filled with clay.

Joint set 1 has a strike of 27, with 29 degrees of dip angle. The joint spacing is 0.01 to 0.4 meters. The joint aperture is 0.3 to 1 centimeters. The JRC is estimated as 2. The joint are filled with clay.

Joint set 2 has a strike of 255, with 79 degrees of dip angle. The joint spacing is 0.015to 0.4 meters. The joint aperture is 0.1 to 0.5 centimeters. The JRC is estimated as 2. The joint are filled with clay.

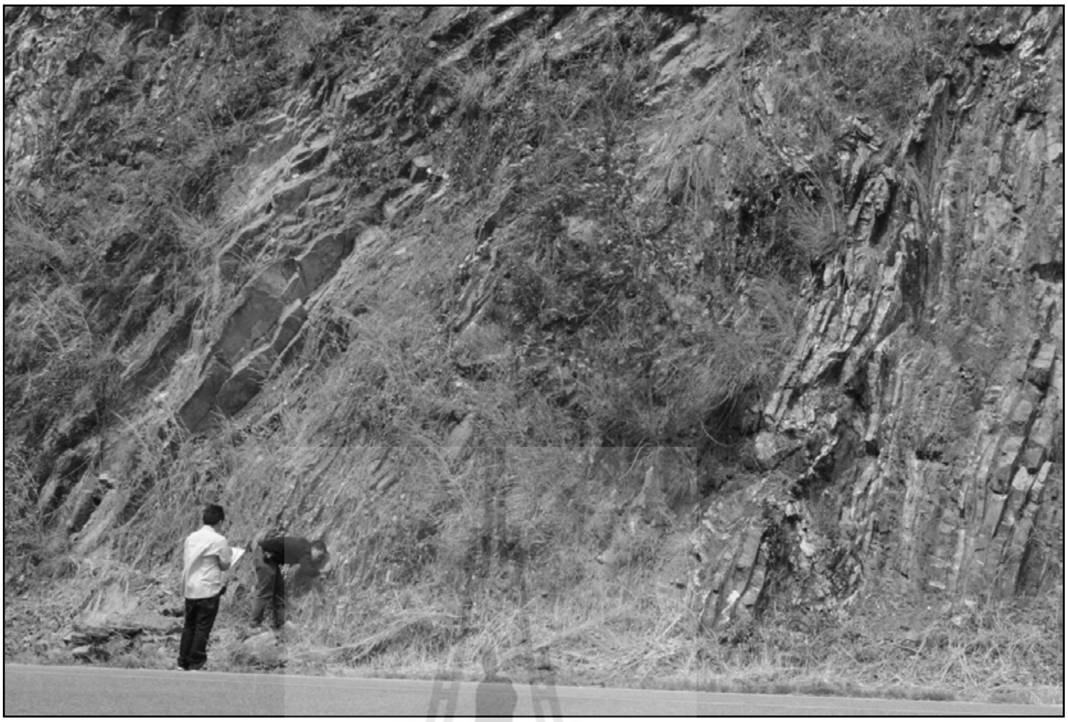
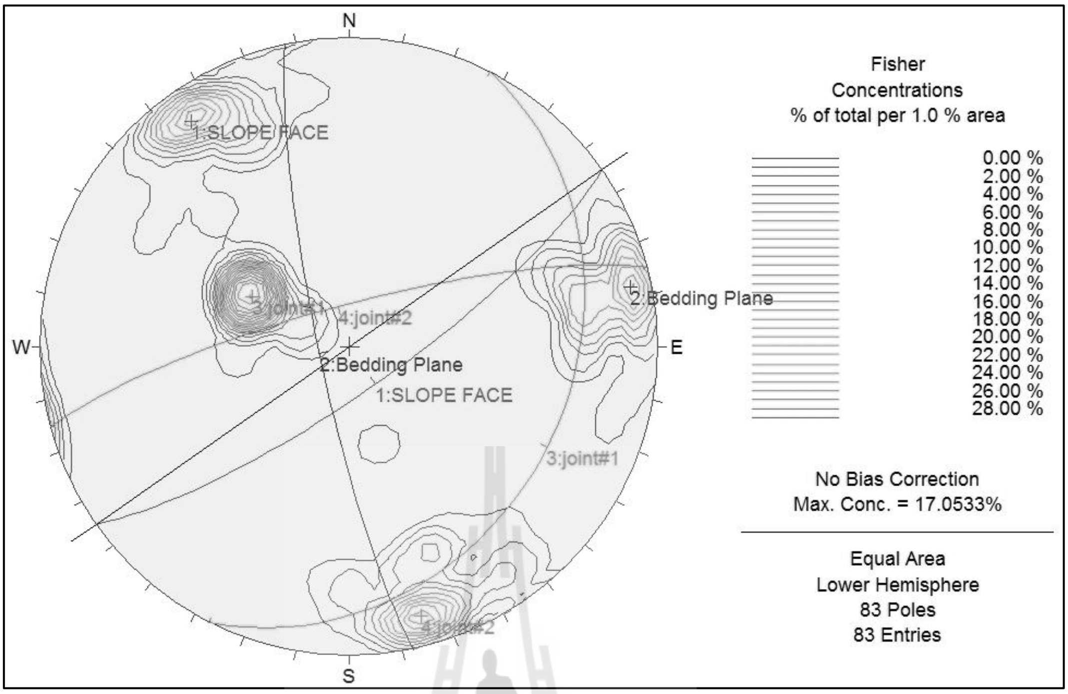


**Figure A9** The bedded limestone slope is located at km 17+000 of highway 12.




| *ID* | *TREND/PLUNGE* | *STRIKE/DIPR* | *LABEL* |
|---|---|---|---|
| 1 | 325/12 | 55/78 | SLOPE FACE |
| 2 | 78/8 | 168/82 | Bedding Plane |
| 3 | 297/61 | 27/29 | joint#1 |
| 4 | 165/11 | 255/79 | joint#2 |

**Figure A10** Representative plane of slope face of station 05.

**A-2.3 Station 06**

The station 06 at km 17+500 is located on Lonsak-Chumpae highway (Figure A11). The slope location is 47Q 0752709 and UTM 1851671 of GPS system. The slope is classified as bedded rock. The slope height is 25 meters and length is 205 meters. The strike and dip angle of slope face is 213 and 72 degrees. The rock type is Bedded limestone. The slope is stable. The rock mass has four joint sets (Figure A12), as follows.

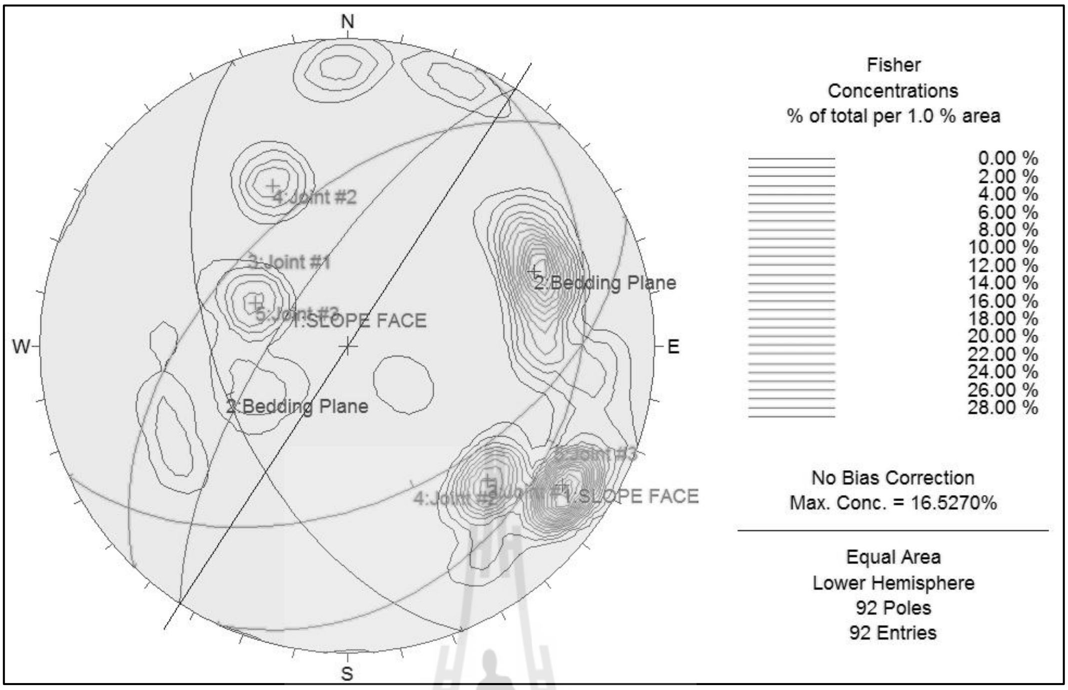
Bedding plane has a strike of 158, with 55 degree dip angle. The thickness of bedding is 0.5 meters. The joint aperture is 0.5 centimeters. The JRC is estimated as 2. The joints are filled with clay.

Joint set 1 has a strike of 224, with 53 degrees of dip angle. The joint spacing is 0.4 meters. The joint aperture is 3 to 10 centimeters and has not material infilling. The JRC is estimated as 4.

Joint set 2 has a strike of 65, with 48 degrees of dip angle. The joint spacing is 0.65 meters. The joint aperture is 1 centimeters and has not material infilling. The JRC is estimated as 4.

Joint set 3 has a strike of 25, with 27 degrees of dip angle. The joint spacing is 0.5 meters. The joint aperture is 1 centimeters and has not material infilling. The JRC is estimated as 4.

**Figure A11** Slope location at km 17+500 of highway no.12, Lom Sak district, Petchabun province.




| ID | TREND/PLUNGE | STRIKE/DIPR | LABEL |
|---|---|---|---|
| 1 | 123/18 | 213/72 | SLOPE FACE |
| 2 | 68/35 | 158/55 | Bedding Plane |
| 3 | 134/37 | 224/53 | Joint #1 |
| 4 | 335/42 | 65/48 | Joint #2 |
| 5 | 295/63 | 25/27 | Joint #3 |

**Figure A12** Representative plane of slope face of station 06.

### A-2.4 Station 07

The station 07 at km 17+800 is located on Lonsak-Chumpae highway (Figure A13). The slope location is 47Q 0750515 and UTM 1850928 of GPS system. The slope height is 16 meters and length is 200 meters. The slope is convex shape and unstable. The small circular failure occurred. The representative plane has shown on figure A14.

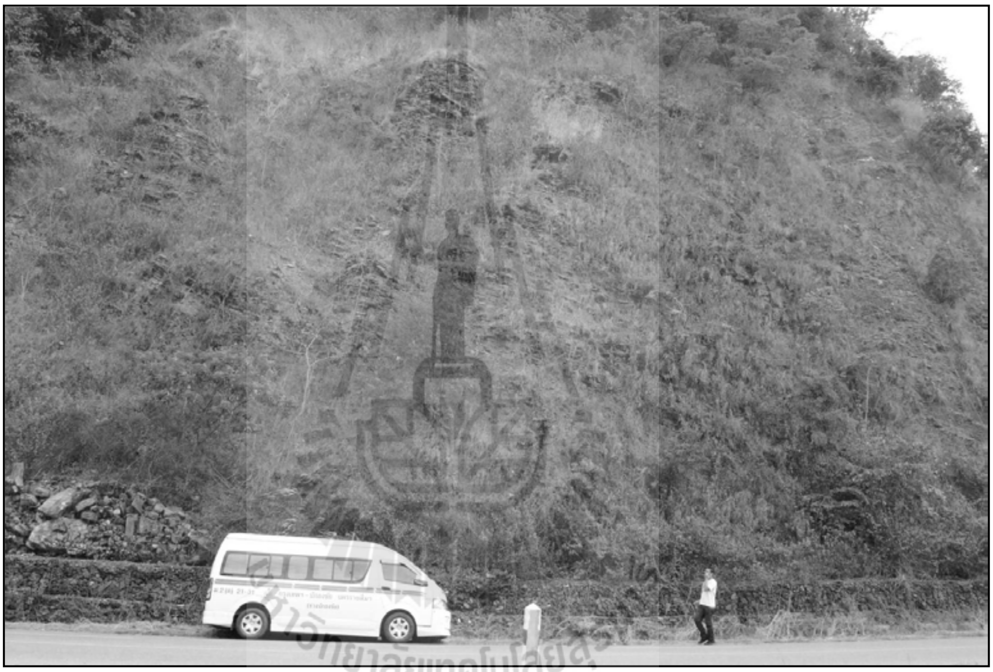
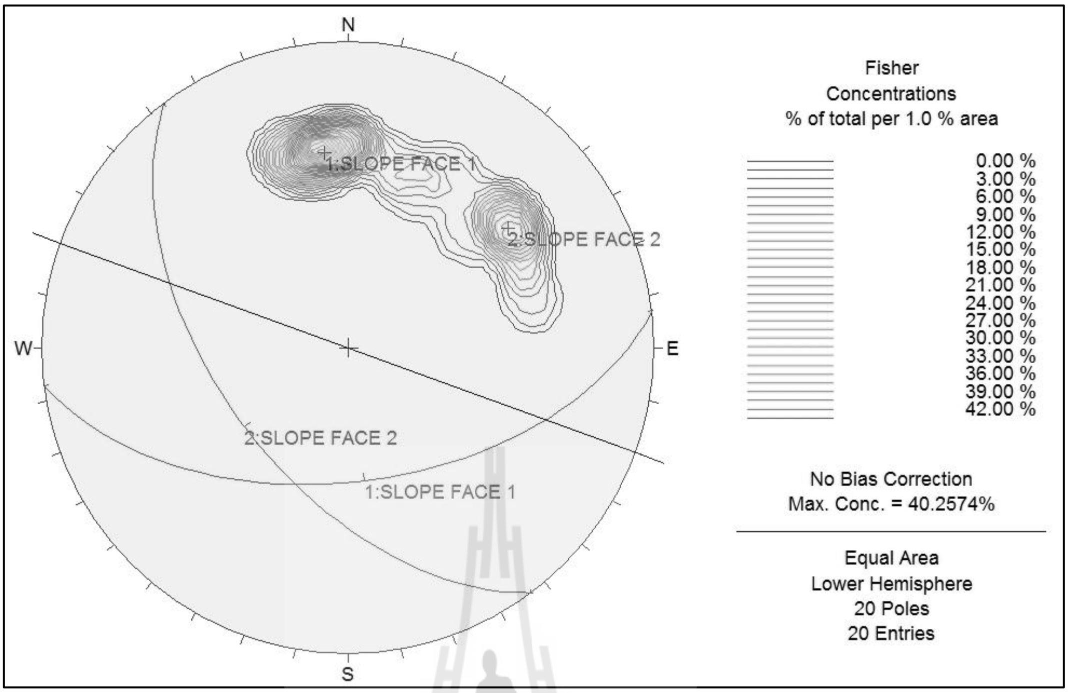


**Figure A13** The shale slope is located on station 07 of highway no.12, Lom Sak district, Petchbun province.




| ID | TREND/PLUNGE | STRIKE/DIPR | LABEL |
|---|---|---|---|
| 1 | 353/36 | 83/54 | SLOPE FACE 1 |
| 2 | 53/35 | 143/55 | SLOPE FACE 2 |

**Figure A14** Representative plane of slope face of station 07.

**A-2.5  Station 08**

The station 08 at km 18+550 is located on Lonsak-Chumpae highway (Figure A15). The slope location is 47Q 0752188 and UTM 1851244 of GPS system. The slope height is 50 meters and length is 150 meters. The slope classified as heavily joint rock. The dip angle is 50 degrees. The rock type is weathered shale. The slope is unstable, failed in circular mode. The rock mass has four joint sets (Figure A16), as follows.

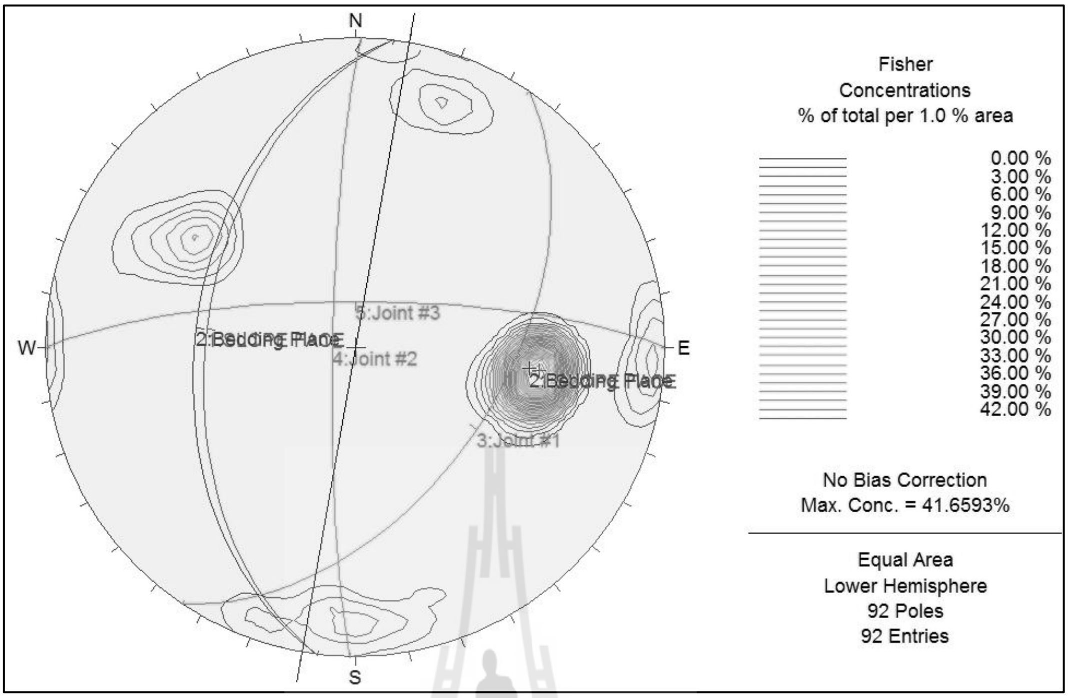
Bedding plane has a strike of 187 degrees, with 47 degrees dip angle. Bedding thickness is 20 centimeters. The joints are filled with clay.

Joint set 1 has a strike of 34 degrees, with 51 degrees dip angle. Joint spacing is 20 centimeters. Joint aperture is 0.5 millimeters. JRC is estimated as 5. The joints are filled with clay.

Joint set 2 has a strike of 181 degrees, with 84 degrees dip angle. Joint spacing is 10 centimeters. Joint aperture is 0.5 millimeters. JRC is estimated as 5. The joints are filled with clay.

Joint set 3 has a strike of 270 degrees, with 78 degrees dip angle. Joint spacing is 25 centimeters. Joint aperture is 0.5 millimeters. JRC is estimated as 5. The joints are filled with clay.

**Figure A15** Slope of station 08 on highway no.12. the circular failure was occurred on the top of the slope.




| *ID* | *TREND/PLUNGE* | *STRIKE/DIPR* | *LABEL* |
|---|---|---|---|
| 1 | 97/40 | 187/50 | SLOPE FACE |
| 2 | 97/43 | 187/47 | Bedding Plane |
| 3 | 304/39 | 34/51 | Joint #1 |
| 4 | 91/6 | 181/84 | Joint #2 |
| 5 | 180/12 | 270/78 | Joint #3 |

**Figure A16** Representative plane of slope face of station 08.

**A-2.6 Station 09**

The station 09 at km 26+250 is located on Lonsak-Chumpae highway (Figure A17). The slope location is 47Q 0752819 and UTM 1851742 of GPS system. The slope is classified as bedded rock. The slope height is 30 meters and length is 225 meters. The strike and dip angle of slope face is 154 and 73 degrees. The rock type is bedded limestone. The slope is stable. The rock mass has three joint sets (Figure A18), as follows.

Bedding plane has a strike of 187, with 57 degree dip angle. The thickness of bedding is 0.7 meters. The joint aperture is 0.5 centimeters. The JRC is estimated as 2. The joints are filled with clay.

Joint set 1 has a strike of 48, with 50 degrees of dip angle. The joint spacing is 0.55 meters. The joint aperture is 0.5 millimeters. The JRC is estimated as 5. The joint are filled with calcite.

Joint set 2 has a strike of 268, with 49 degrees of dip angle. The joint spacing is 0.25 meters. The joint aperture is 0.7centimeters. The JRC is estimated as 5. The joint are filled with clay.

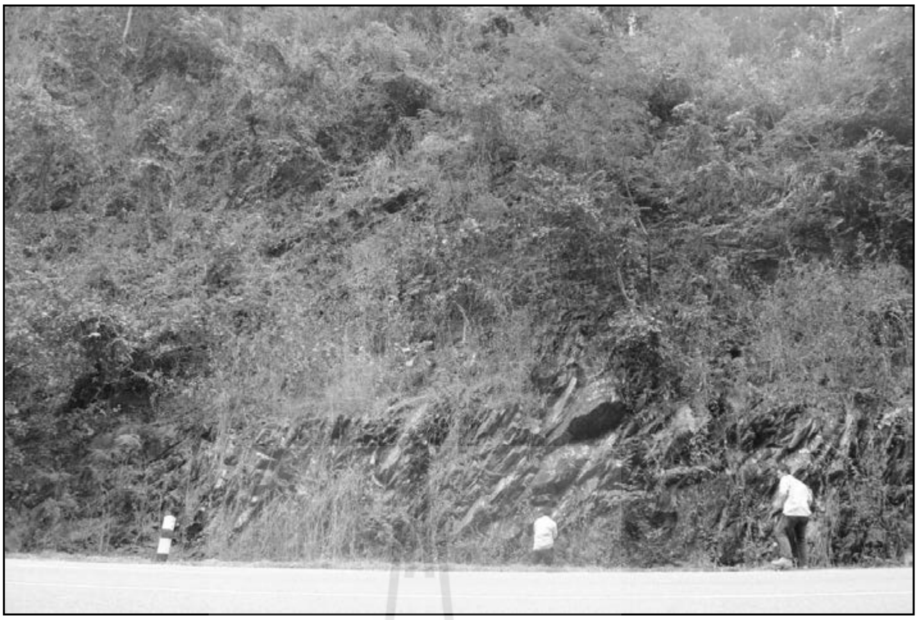
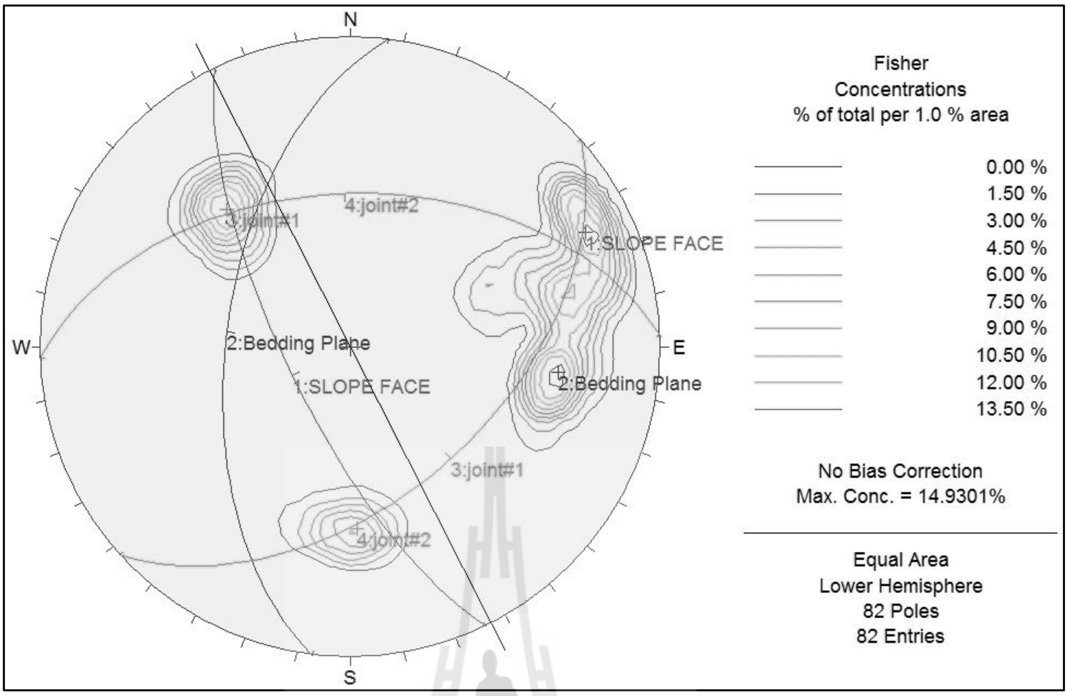


**Figure A17** Slope location at km 26+250 of highway no.12, Lom Sak district, Petchabun province.




| ID | TREND/PLUNGE | STRIKE/DIPR | LABEL |
|---|---|---|---|
| 1 | 64/17 | 154/73 | SLOPE FACE |
| 2 | 97/33 | 187/57 | Bedding Plane |
| 3 | 318/40 | 48/50 | joint#1 |
| 4 | 178/41 | 268/49 | joint#2 |

**Figure A18** Representative plane of slope face of station 09.

**A-2.7 Station 10**

The station 10 at km 27+950 is located on Lonsak-Chumpae highway (Figure A19). The slope location is 47Q 0784092 and UTM 1847995 of GPS system. The slope is classified as heavily joint rock. The slope height is 20 meters and length is 215 meters. The strike and dip angle of slope face is 55 and 78 degrees. The rock type is limestone. The slope is stable. The rock mass has three joint sets (Figure A20), as follows.

Bedding plane has a strike of 291, with 31 degree dip angle. The bedding thickness is 0.5 meters. The joint aperture is 0.5 centimeters and has not infilling material. The JRC is estimated as 4.

Joint set 1 has a strike of 157, with 61 degrees of dip angle. The joint spacing is 0.22 meters. The joint aperture is 3 to 10 centimeters and has not infilling material. The JRC is estimated as 4.

Joint set 2 has a strike of 42, with 40 degrees of dip angle. The joint spacing is 0.55 meters. The joint aperture is 1 centimeters and has not infilling material. The JRC is estimated as 4.

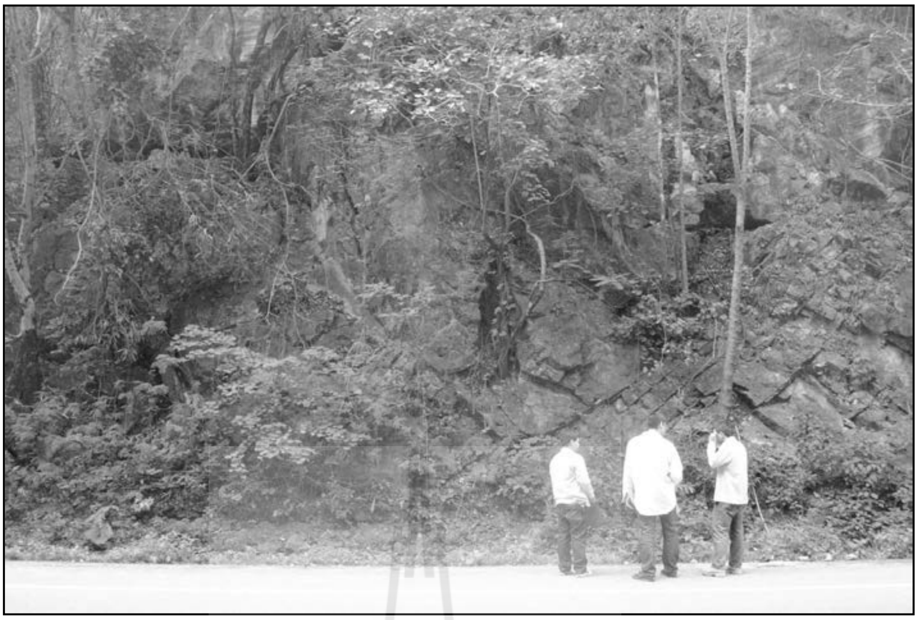
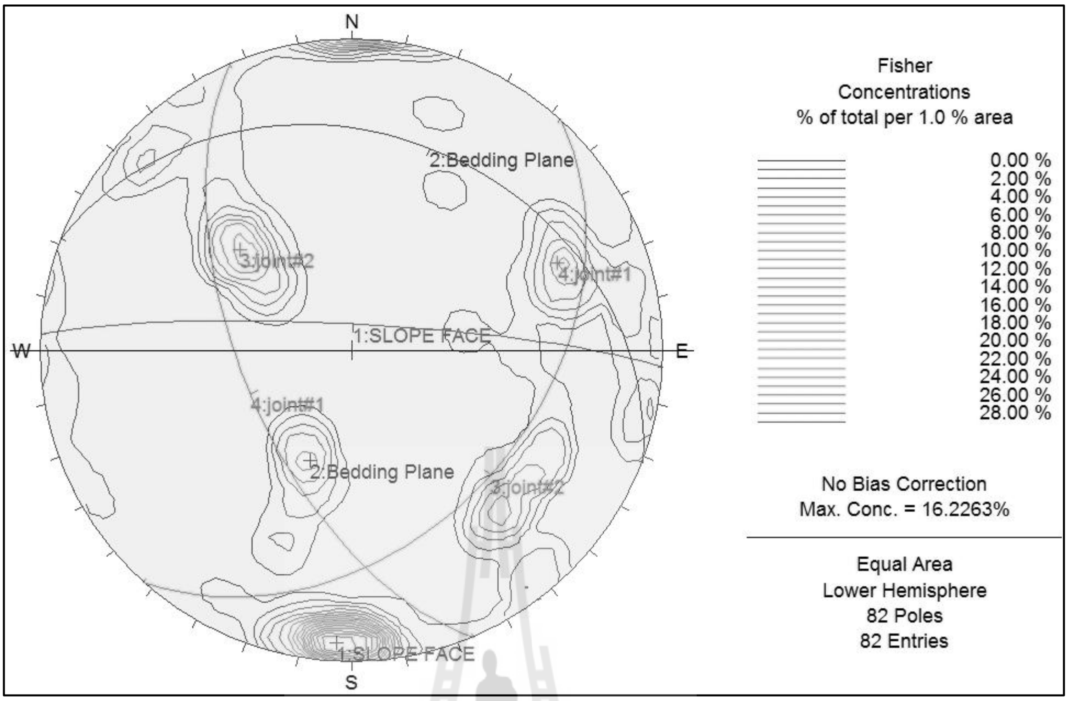


**Figure A19** Slope location at km 27+950 of highway no.12, Lom Sak district, Petchabun province.




| ID | TREND/PLUNGE | STRIKE/DIPR | LABEL |
|---|---|---|---|
| 1 | 183/7 | 273/83 | SLOPE FACE |
| 2 | 201/59 | 291/31 | Bedding Plane |
| 3 | 312/50 | 42/40 | joint#2 |
| 4 | 67/29 | 157/61 | joint#1 |

**Figure A20** Representative plane of slope face of station 10.

**A-2.8 Station 11**

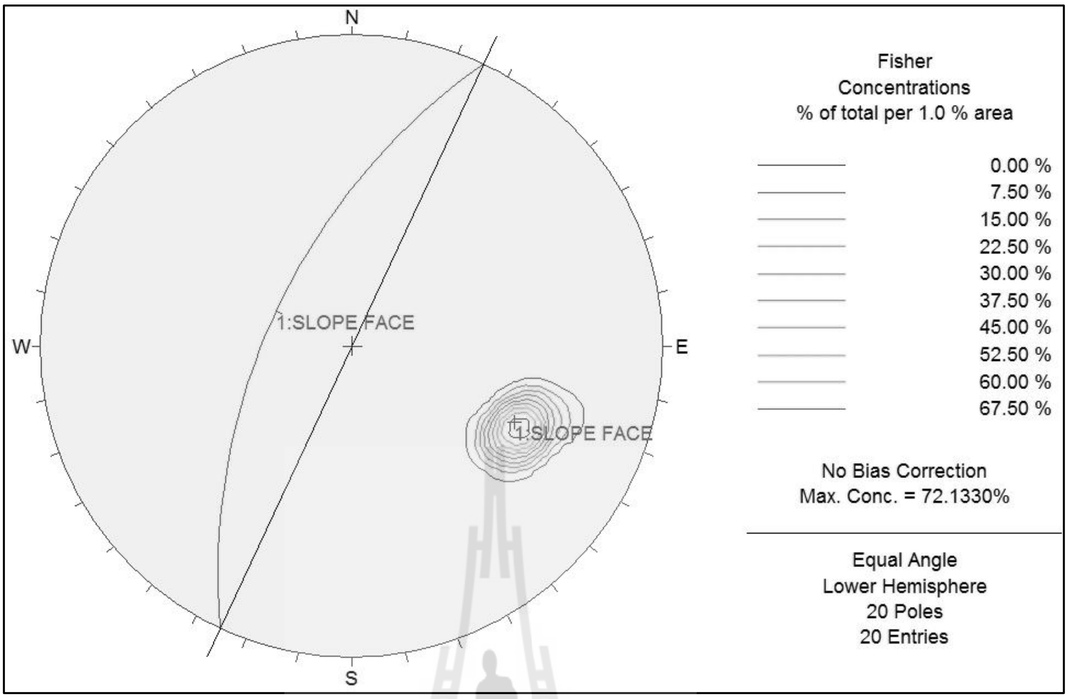
The station 11 at km 28+200 is located on Lonsak-Chumpae highway (Figure A21). The slope location is 47Q 0750788 and UTM 1850988 of GPS system. The slope is classified as highly weathered rock. The slope height is 30 meters and length is 200 meters. The strike and dip angle of slope face is 55 and 78 degrees. The rock type is slaty-shale. The slope is stable. The rock mass has four joint sets (Figure A22), as follows.

Bedding plane has a strike of 168, with 82 degree dip angle. The joint spacing is 0.02 to 0.2 meters. The joint aperture is 0.5 centimeters. The JRC is estimated as 2. The joints are filled with clay.

Joint set 1 has a strike of 27, with 29 degrees of dip angle. The joint spacing is 0.01 to 0.4 meters. The joint aperture is 0.3 to 1 centimeters. The JRC is estimated as 2. The joint are filled with clay.

Joint set 2 has a strike of 255, with 79 degrees of dip angle. The joint spacing is 0.015to 0.4 meters. The joint aperture is 0.1 to 0.5 centimeters. The JRC is estimated as 2. The joint are filled with clay.

**Figure A21** Slope location at km 28+200 of highway no.12. The circular failure was occurred on the top of the slope.




| *ID* | *TREND/PLUNGE* | *STRIKE/DIPR* | *LABEL* |
|---|---|---|---|
| 1 | 115/30 | 205/60 | SLOPE FACE |

**Figure A22** Representative plane of slope face of station 11.

**A-2.9  Station 12**

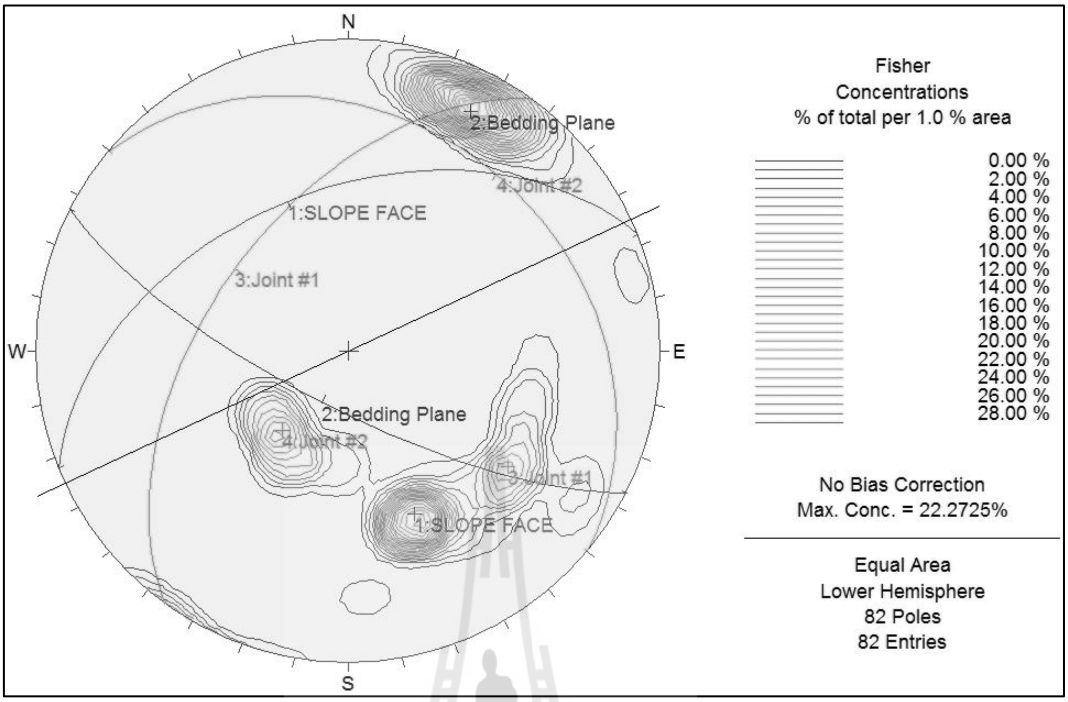
The station 12 at km 32+500 is located on Lonsak-Chumpae highway (Figure A23). The slope location is 47Q 0750788 and UTM 1850988 of GPS system. The slope is classified as bedded rock. The slope height is 50 meters and length is 150 meters. The strike and dip angle of slope face is 55 and 78 degrees. The rock type is slaty-shale. The slope is stable. The rock mass has four joint sets (Figure A24), as follows.

Bedding plane has a strike of 168, with 82 degree dip angle. The joint spacing is 0.02 to 0.2 meters. The joint aperture is 0.5 centimeters. The JRC is estimated as 2. The joints are filled with clay.

Joint set 1 has a strike of 27, with 29 degrees of dip angle. The joint spacing is 0.01 to 0.4 meters. The joint aperture is 0.3 to 1 centimeters. The JRC is estimated as 2. The joint are filled with clay.

Joint set 2 has a strike of 255, with 79 degrees of dip angle. The joint spacing is 0.015to 0.4 meters. The joint aperture is 0.1 to 0.5 centimeters. The JRC is estimated as 2. The joint are filled with clay.

**Figure A23** Slope location at km 32+500 of highway no.12. The circular failure was occurred on the top of the slope.




| *ID* | *TREND/PLUNGE* | *STRIKE/DIPR* | *LABEL* |
|---|---|---|---|
| 1 | 158/43 | 248/47 | SLOPE FACE |
| 2 | 27/15 | 117/75 | Bedding Plane |
| 3 | 126/37 | 216/53 | Joint #1 |
| 4 | 220/63 | 310/27 | Joint #2 |

**Figure A24** Representative plane of slope face of station 12.

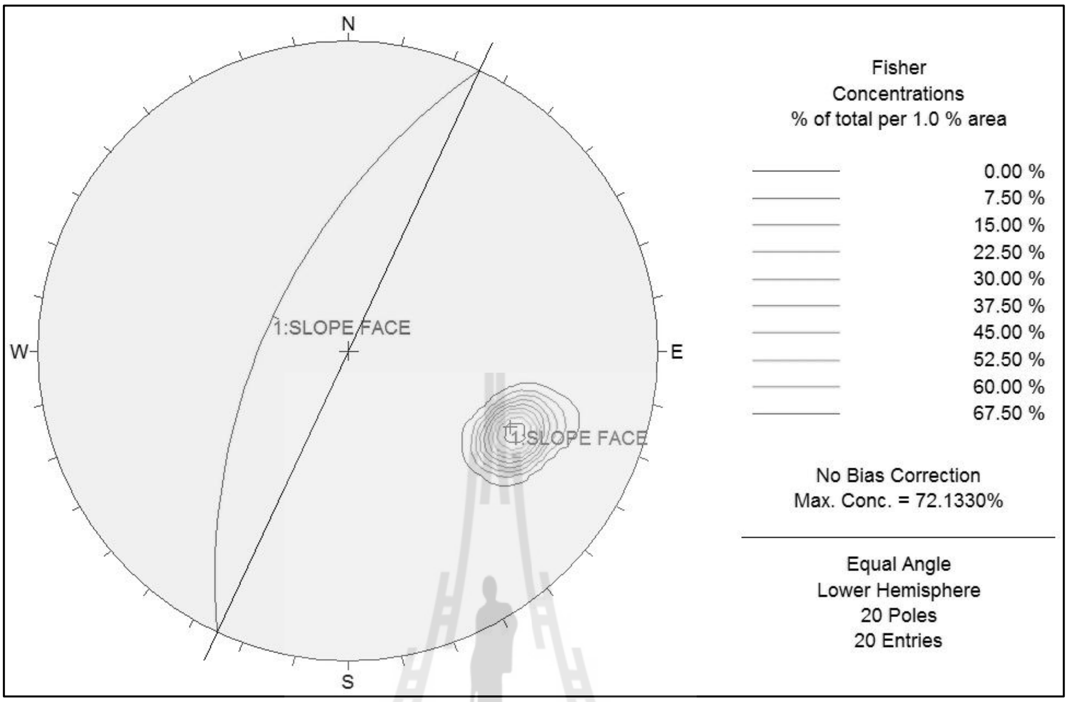
## A-3 Highway number 11 route

The highway no.11 or Laplae - Den Chai is the distance from the middle part to the north of Thailand. It is 320 kilometers long, cutting across Uttaradit and Pae province. The slope failure along the road cut occurred on some location. The slope can classify as soft rock. The mainly failure is circular mode.

### A-3.1 Station 13

The slope no. 13 at km 303+850 is located on Laplae – Den Chai highway (Figure A25). The slope location is 47Q 0619934 and UTM 1964782 of GPS system. The slope is classified as soft rock. The slope height is 50 meters and length is 150 meters. The strike and dip angle of slope face is 250 and 60 degrees. The rock type is shale. The slope is fail in circular mode. The failure caused by the combination of water saturation, ground vibration and the high angle slope face. The slope does not install support. Figure A26 is shown the orientation of the slope face.

**Figure A25** The circular failure occurred on slope no.13. The slope was failed during road construction.



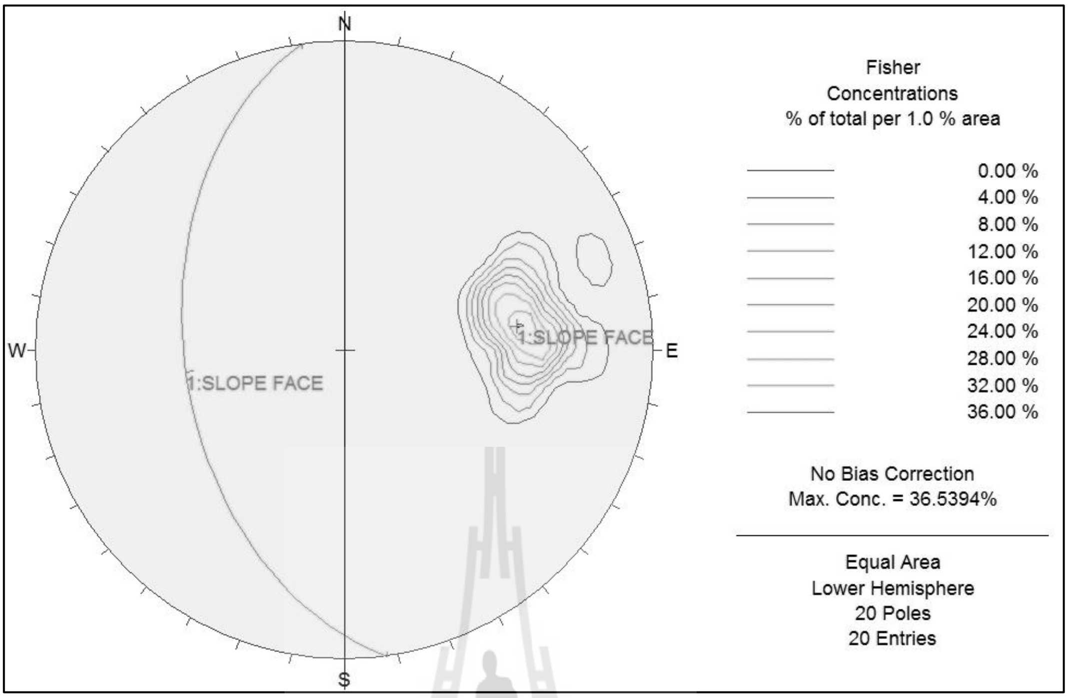

| *ID* | *TREND/PLUNGE* | *STRIKE/DIPR* | *LABEL* |
|---|---|---|---|
| 1 | 115/30 | 205/60 | SLOPE FACE |

**Figure A26** Representative plane of slope face of station 13.

**A-3.2 Station 14**

The slope no. 13 at km 309+800 is located on Laplae – Den Chai highway (Figure A27). The slope location is 47Q 0616465 and UTM 1970400 of GPS system. The slope is classified as soft rock. The slope height is 40 meters and length is 120 meters. The strike and dip angle of slope face is 172 and 47 degrees. The rock type is shale. The slope divided as four benches. The slope is fail in circular mode. The failure caused by the combination of water saturation, ground vibration and the high angle slope face. The slope does not install support. Figure A28 is shown the orientation of the slope face.

**Figure A27** The circular failure occurred on slope no.14. The slope was failed during road construction.



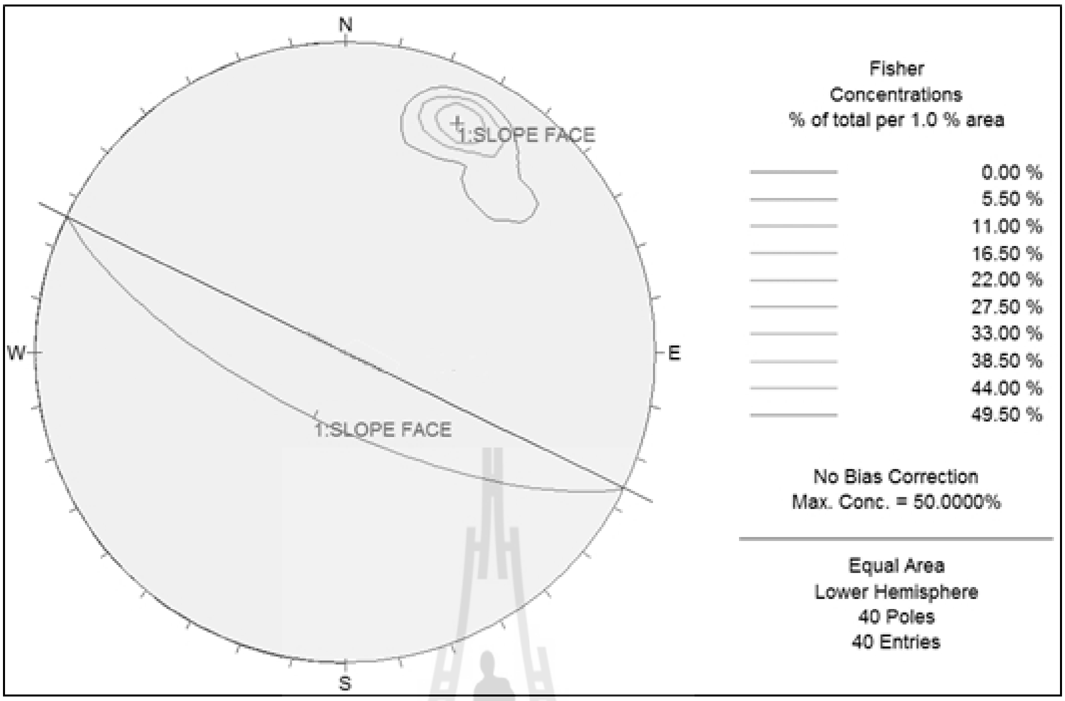

| *ID* | *TREND/PLUNGE* | *STRIKE/DIPR* | *LABEL* |
|---|---|---|---|
| 1 | 82/43 | 172/47 | SLOPE FACE |

**Figure A28** Representative plane of slope face of station 14.

### A-3.3 Station 15

The slope no. 15 at km 315+000 is located on Laplae – Den Chai highway (Figure A29). The slope location is 47Q 0610869 and UTM 1974660 of GPS system. The slope is classified as soft rock. The slope height is 20 meters and length is 150 meters. The strike and dip angle of slope face is 116 and 71 degrees. The rock type is shale. The slope is fail in circular mode. The failure brought down both earthen and shot create. Figure A30 is shown the orientation of the slope face.

**Figure A29** The circular failure occurred on slope no.15.




| *ID* | *TREND/PLUNGE* | *STRIKE/DIPR* | *LABEL* |
|---|---|---|---|
| 1 | 26/19 | 116/71 | SLOPE FACE |

**Figure A30** Representative plane of slope face of station 15.

# APPENDIX B

# NUMERICAL MODELS

# NUMERICAL MODELS

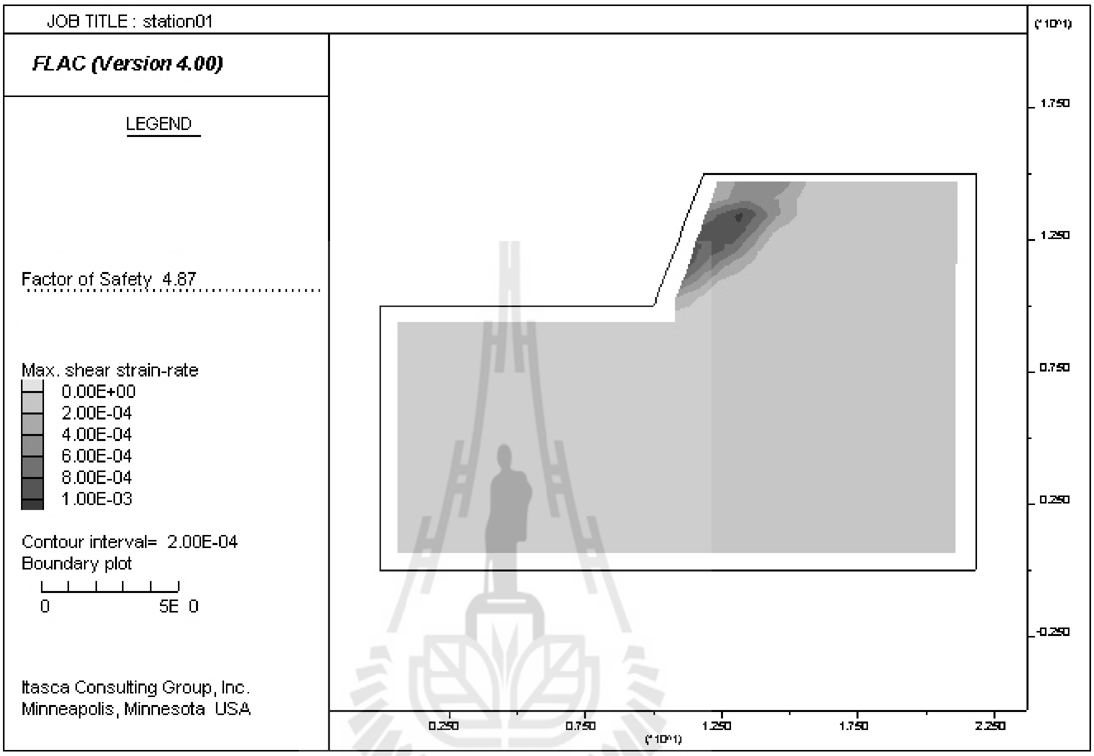



**Figure B1** Stability evaluation of overall slope for station 01 using FLAC4.0 simulation

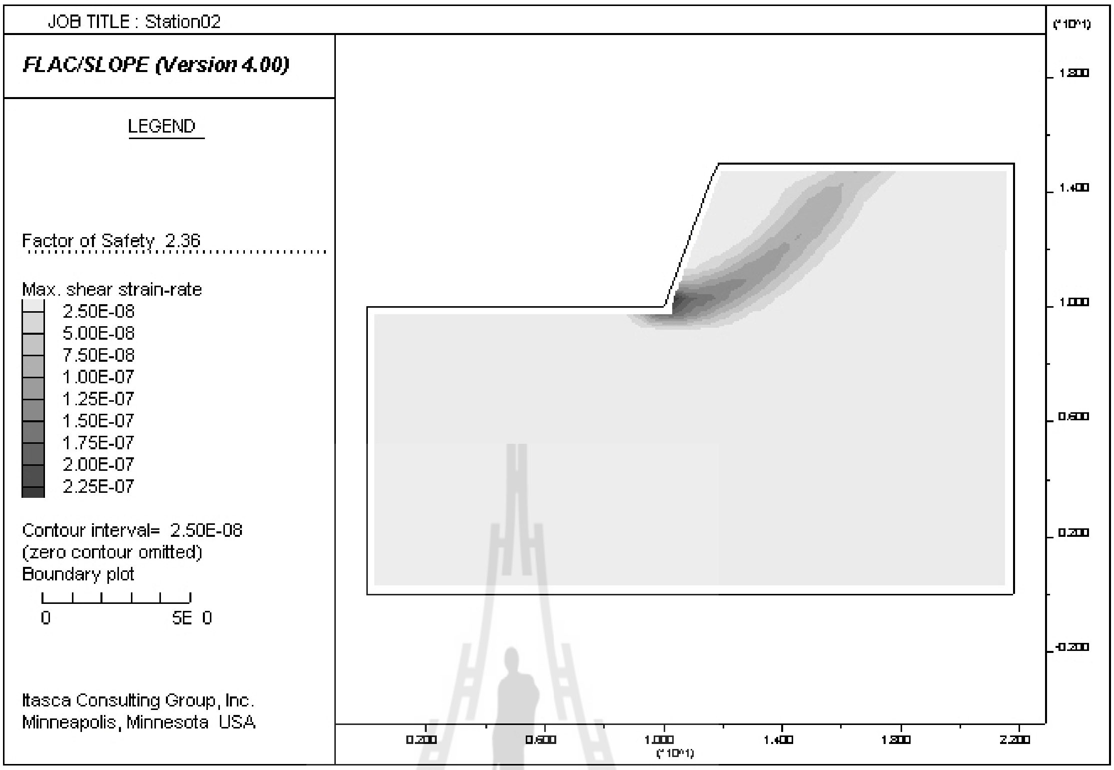



**Figure B2** Stability evaluation of overall slope for station 02 using FLAC4.0 simulation

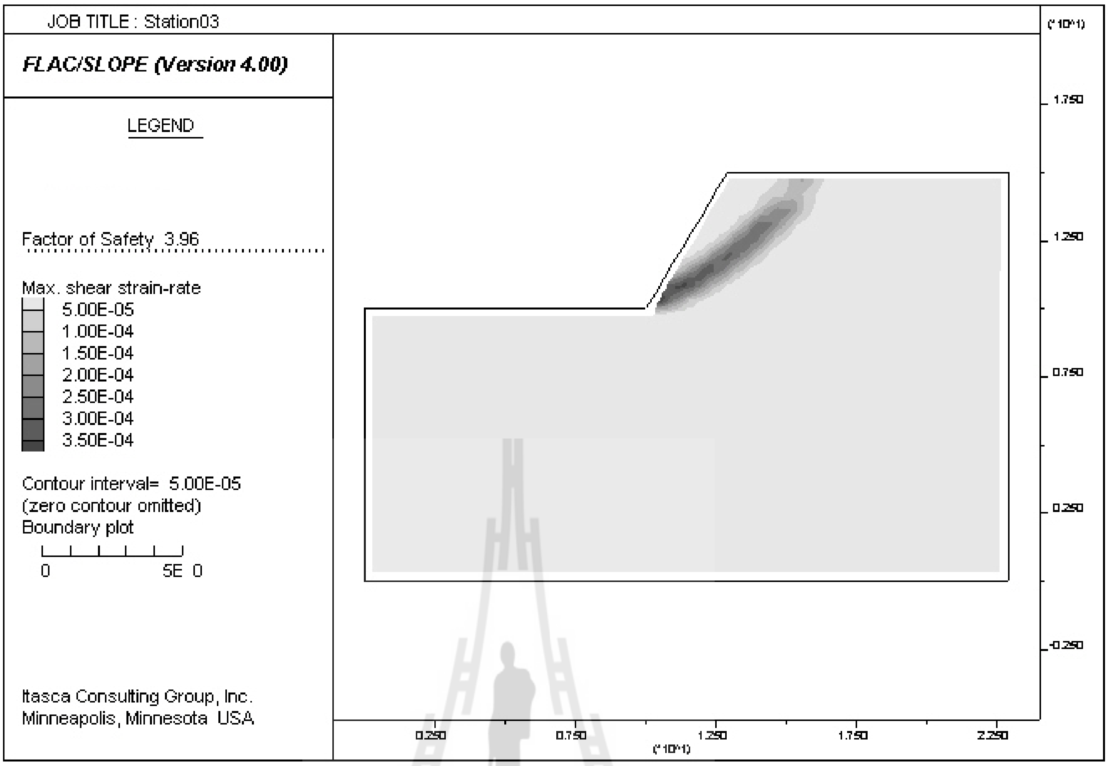



**Figure B3** Stability evaluation of overall slope for station 03 using FLAC4.0 simulation

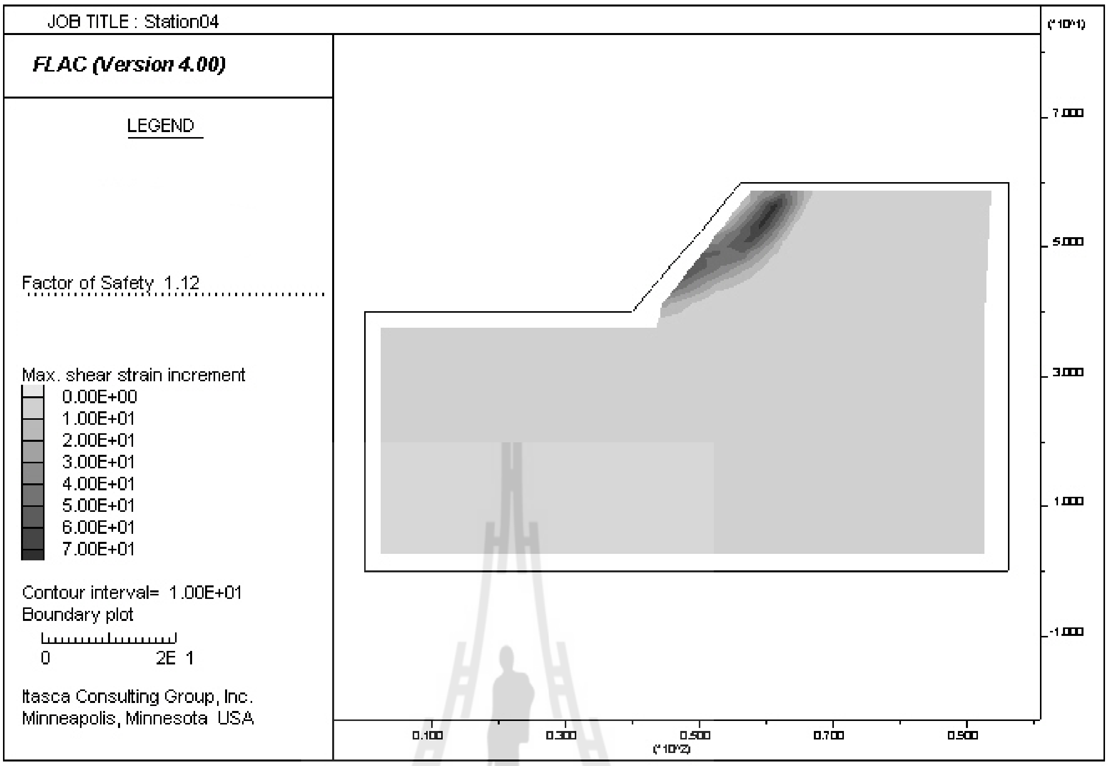



**Figure B4** Stability evaluation of overall slope for station 04 using FLAC4.0 simulation

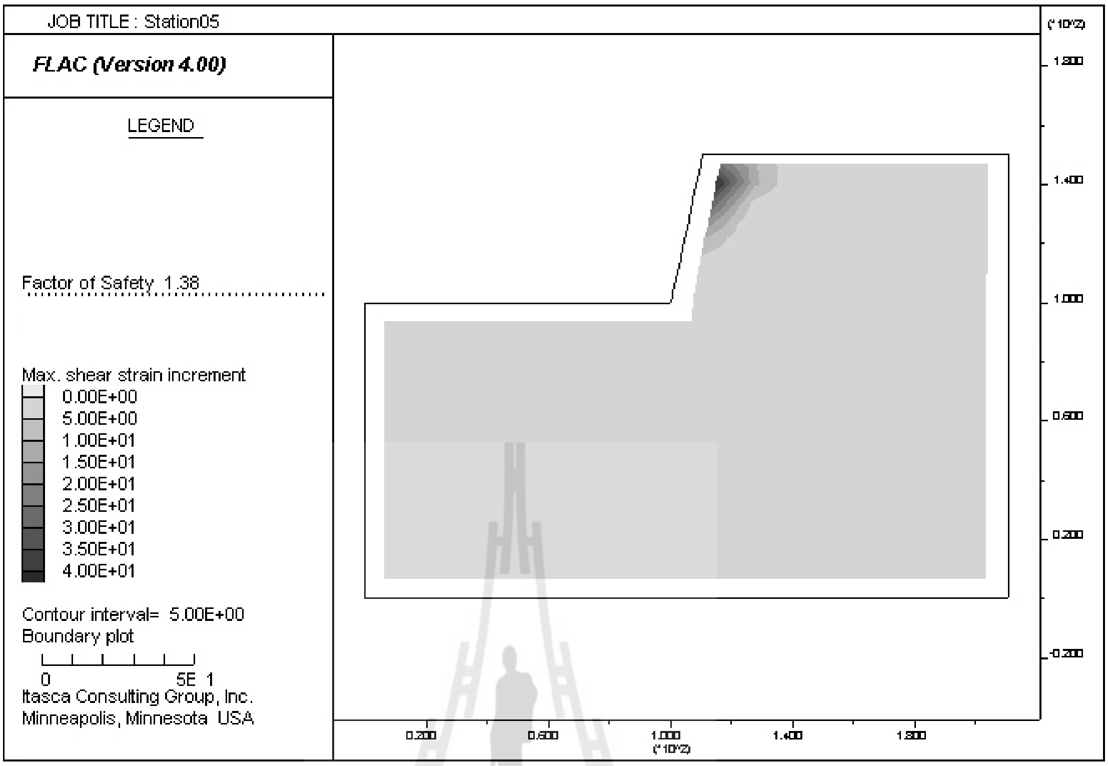



**Figure B5** Stability evaluation of overall slope for station 05 using FLAC4.0 simulation

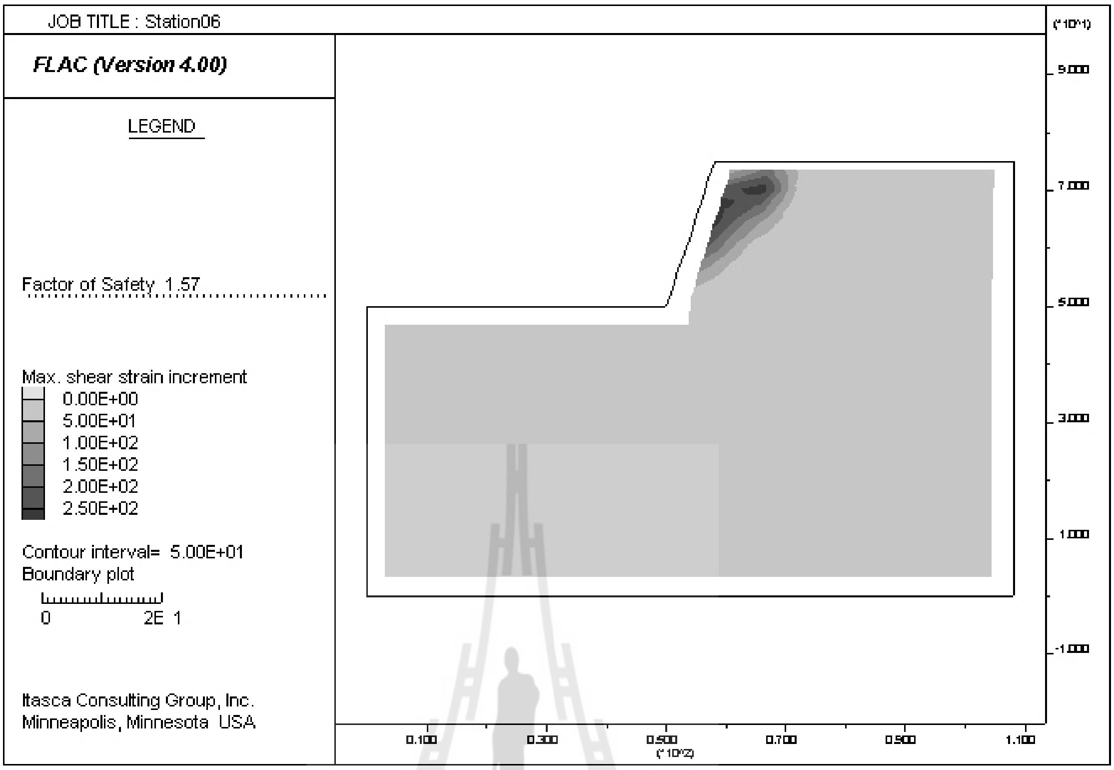



**Figure B6** Stability evaluation of overall slope for station 06 using FLAC4.0 simulation

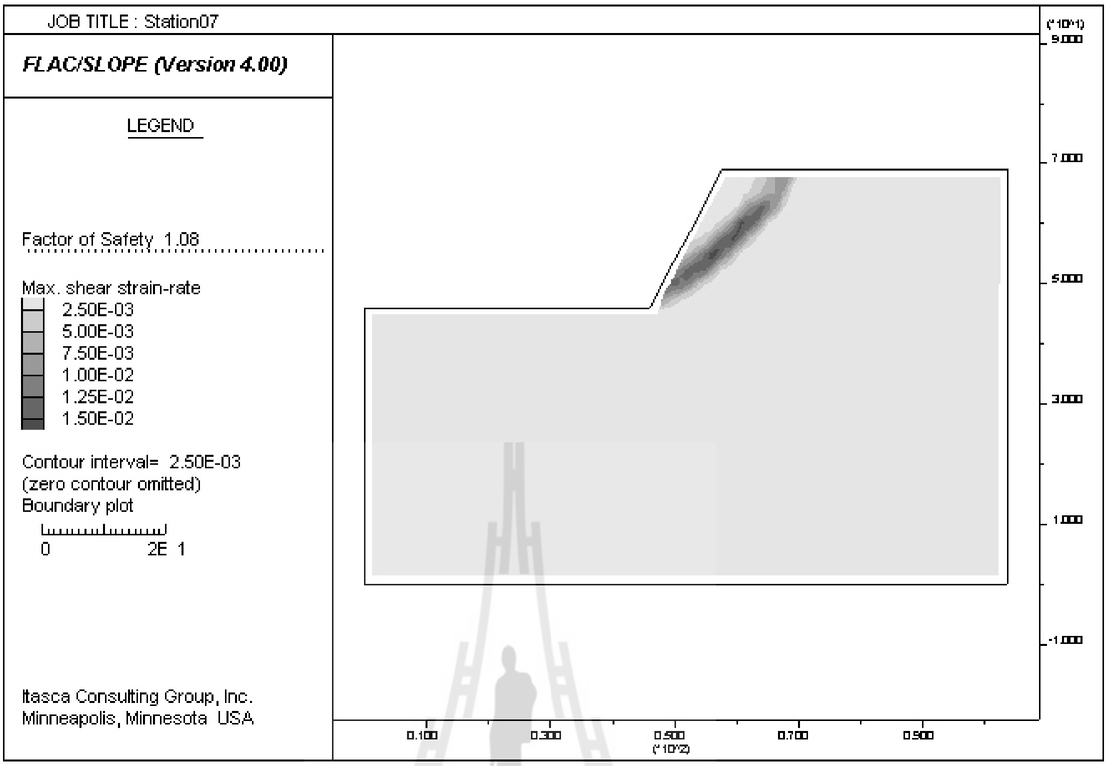



**Figure B7** Stability evaluation of overall slope for station 07 using FLAC4.0 simulation

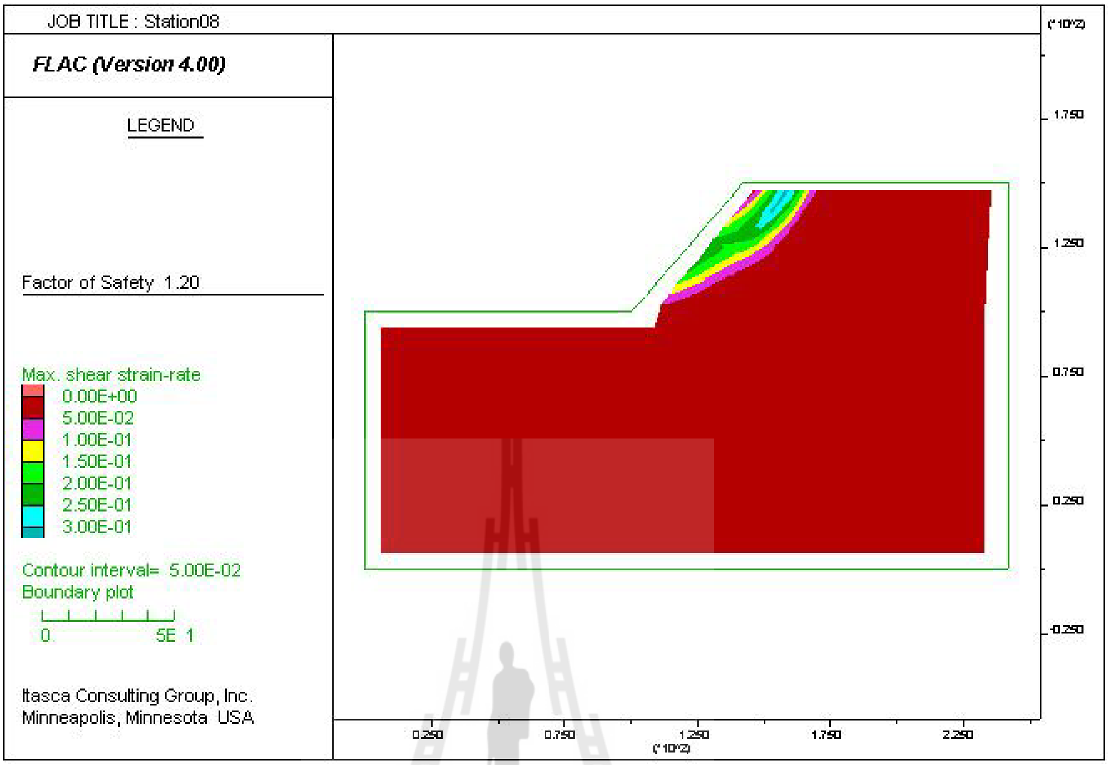



**Figure B8** Stability evaluation of overall slope for station 08 using FLAC4.0 simulation

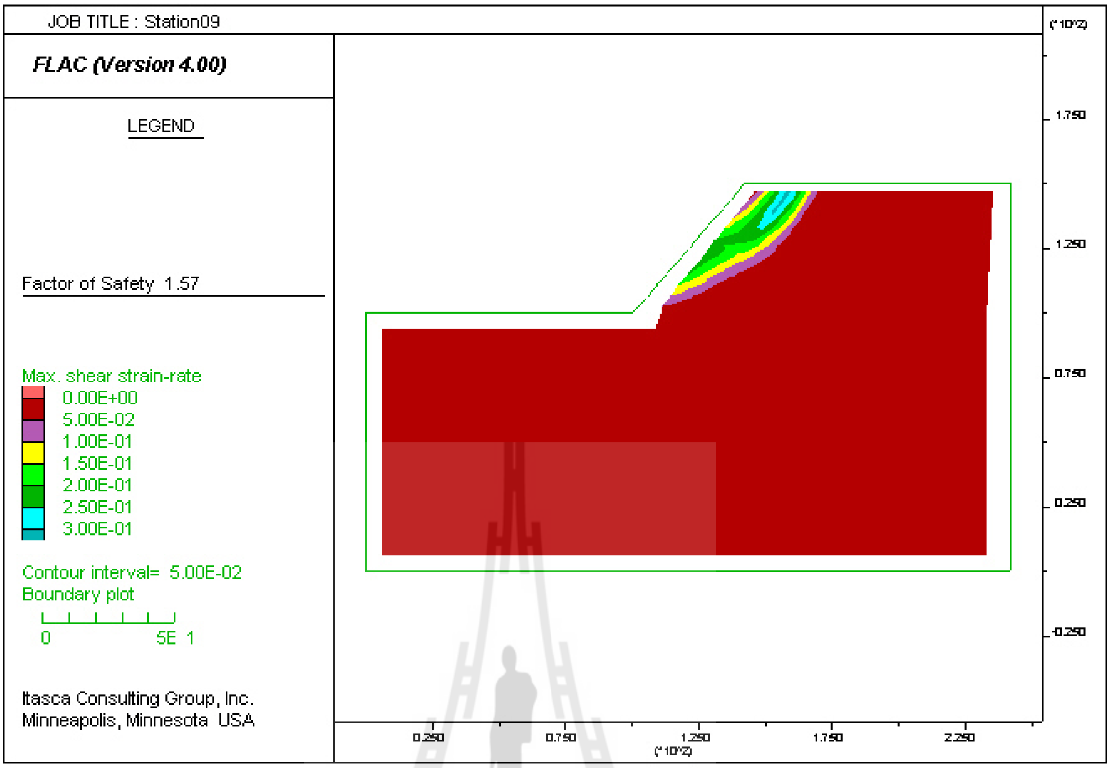



**Figure B9** Stability evaluation of overall slope for station 09 using FLAC4.0 simulation

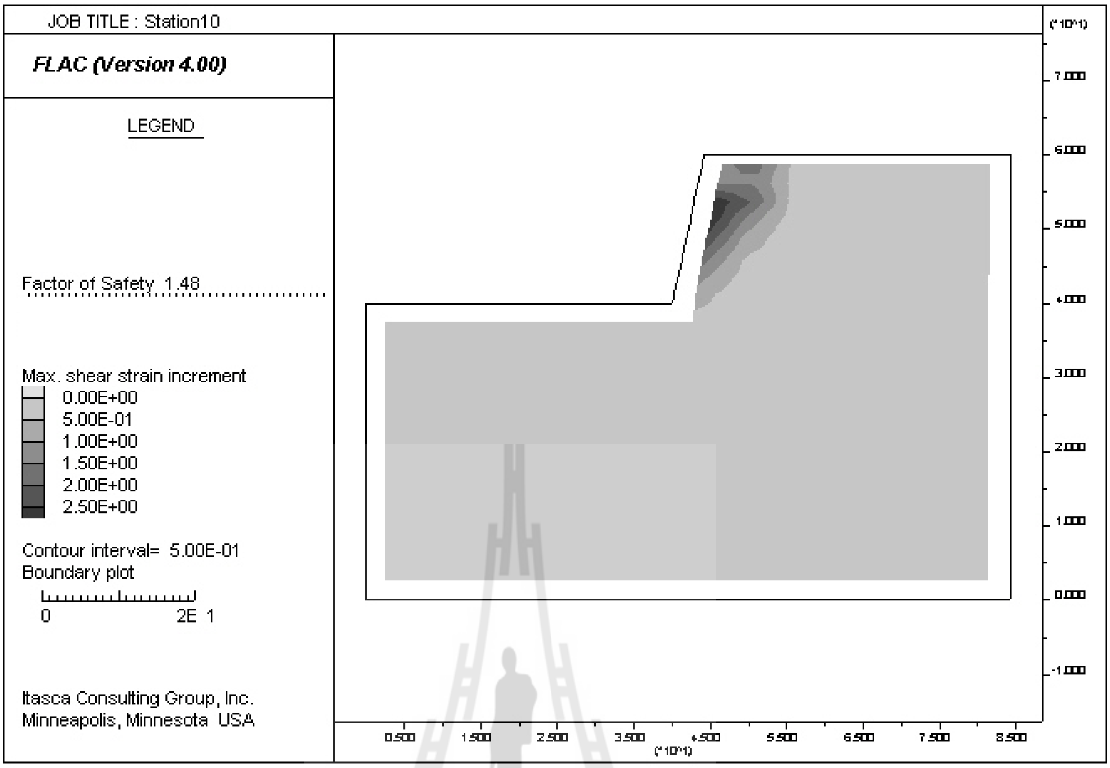



**Figure B10** Stability evaluation of overall slope for station 10 using FLAC4.0 simulation

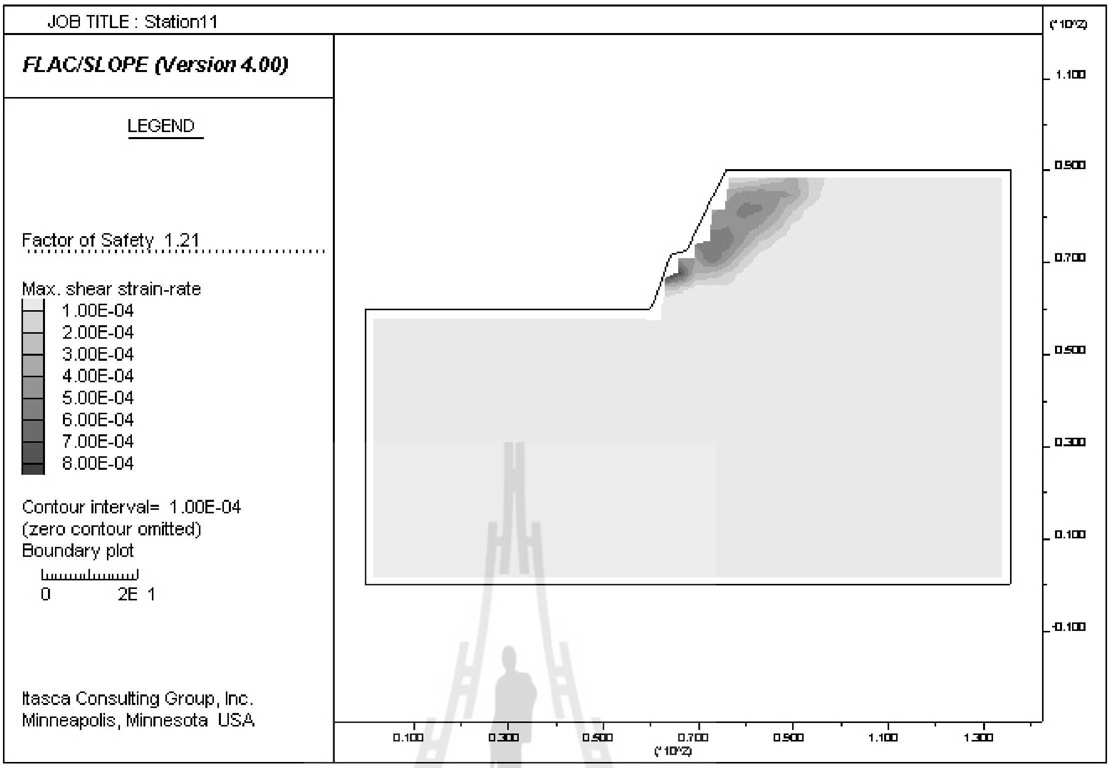



**Figure B11** Stability evaluation of overall slope for station 11 using FLAC4.0 simulation

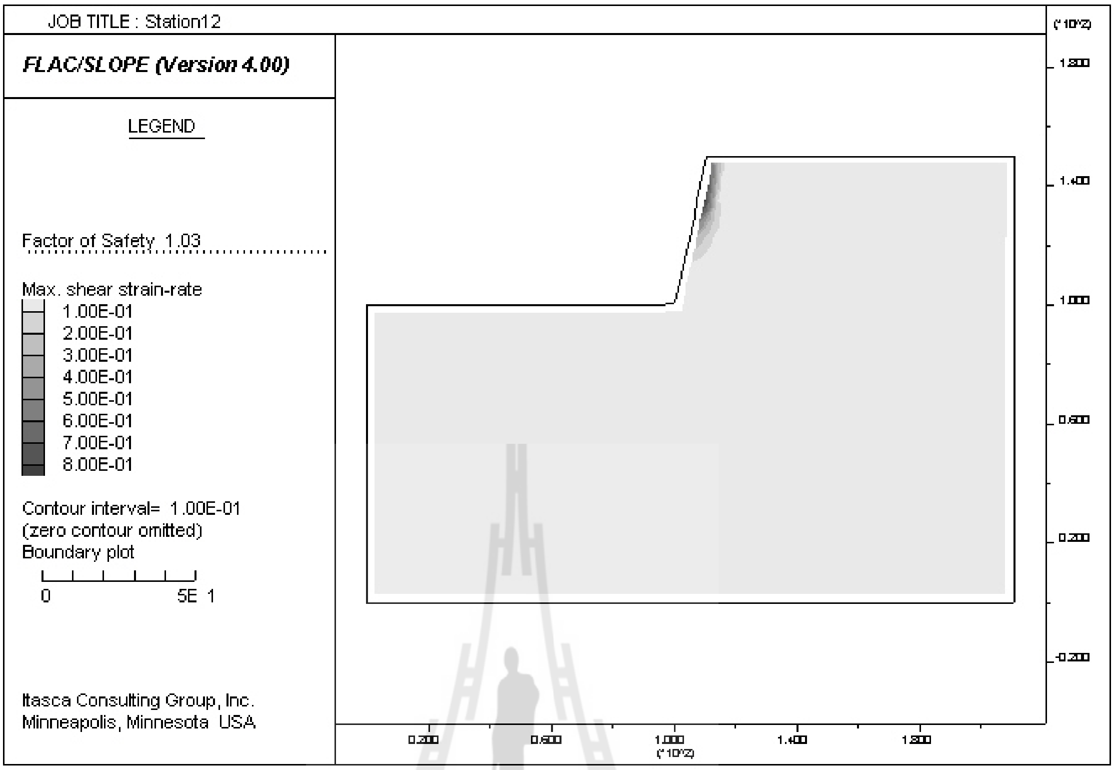



**Figure B12** Stability evaluation of overall slope for station 12 using FLAC4.0 simulation

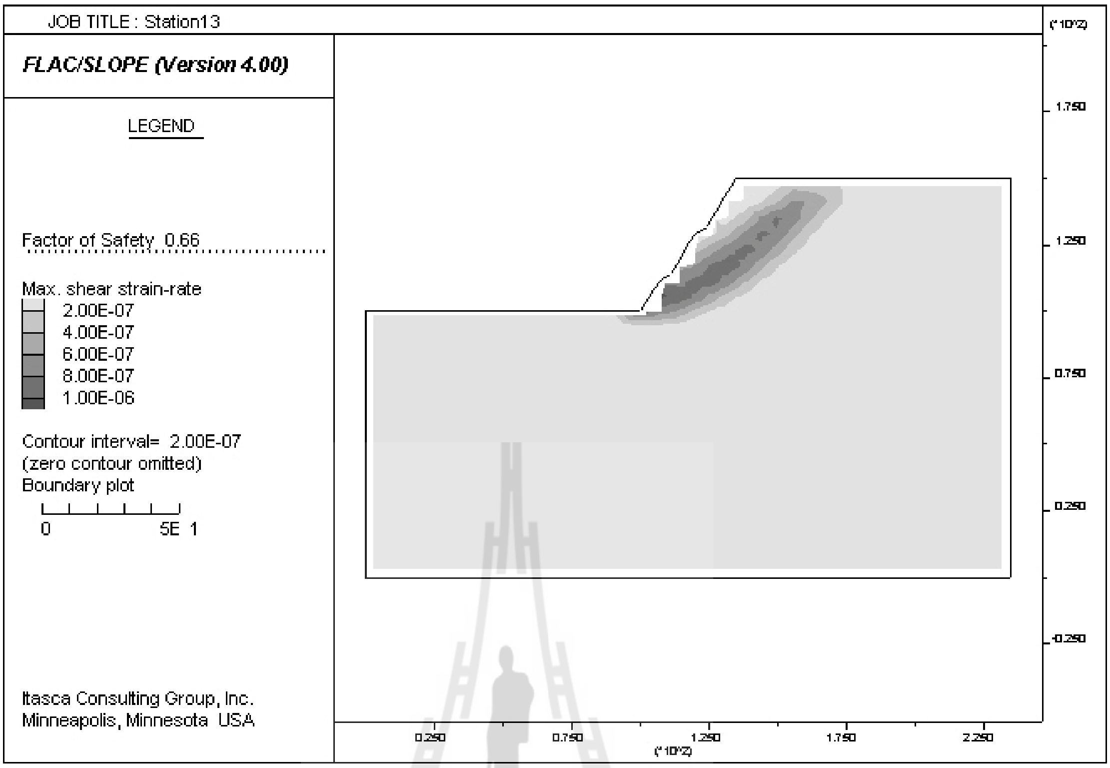



**Figure B13** Stability evaluation of overall slope for station 13 using FLAC4.0 simulation

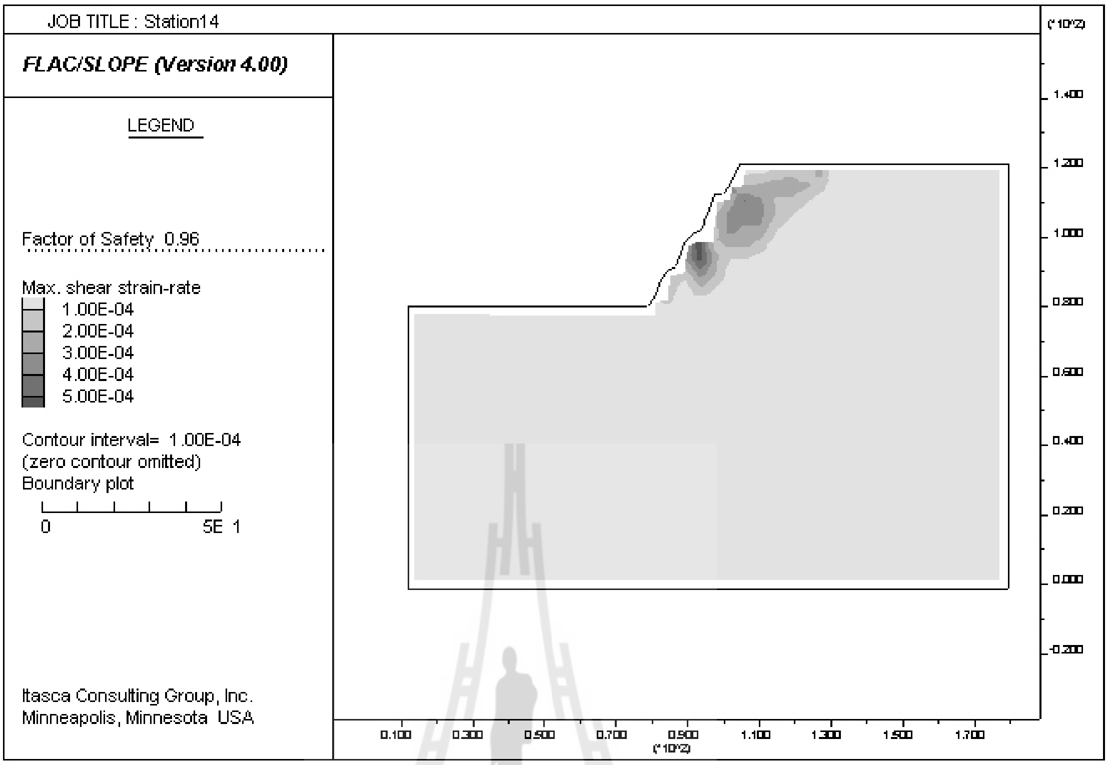



**Figure B14** Stability evaluation of overall slope for station 14 using FLAC4.0 simulation

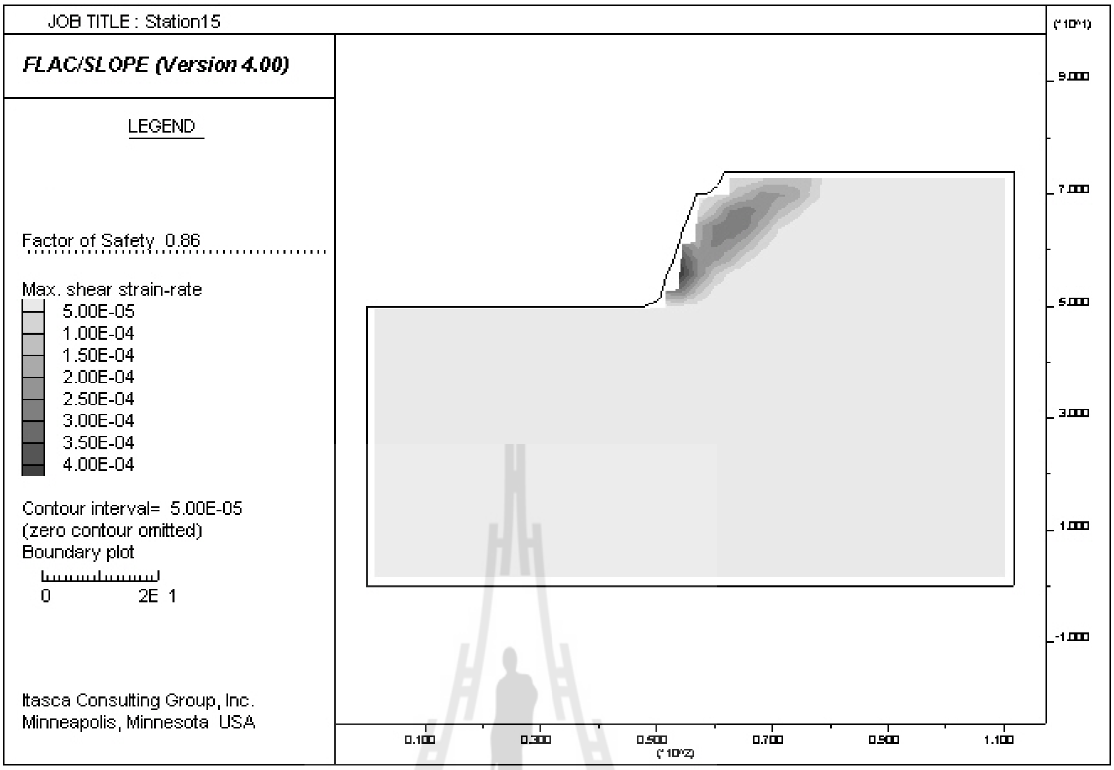



**Figure B15** Stability evaluation of overall slope for station 15 using FLAC4.0 simulation

# Technical Publication

Artkhonghan, K., Tepnarong, P., and Fuenkajorn, K. (2009). **Evaluation of Rock Slope Stability along Highways using GIS and Expert System**. In Proceeding 2nd Thailand Symposium on Rock Mechanics. Chonburi, Thailand. 12-13 March 2009.

# APPENDIX C

# TECHNICAL PUBLICATION

# Evaluation of Rock Slope Stability along Highways using GIS and Expert System

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**ABSTRACT:** The objectives of this research are to determine a potential of slope failure along highway, to locate the potential of instability areas along the road cuts, and to determine the appropriate engineering parameters for predicting further slope failures by using Geo Informatics System (GIS). The analysis focused on circular failure mode. The infinite slope stability analysis was chosen to determine susceptibility index which indicates risk area. The concept of slope stability analysis in terms of probability of failure (PF) was applied for the study. The PF in percent for each mode can then be calculated $PF = \Sigma\{SR_n * GI_n\}$,where $SR_n$ is the rating for each parameter, $GI_n$ is the influencing factor for the corresponding parameter, and n represents type or number of the parameters considered for each slope (varying from 1, 2, 3, 4…..n). Field investigation and computer modeling performed to identify the factor of safety (F.S). The Hoek-Brown criterion and the Mohr-Coulomb criterion are used for estimating the shear strength properties of the rock mass. The GIS method included collecting data in layers such as slope height, slope face angle, rock type, and discontinuity characteristics. The stability of each slope is determined by the expert system, rating each layer and overlaying. A process is shown in potential map. The results from GIS method will be compared with field investigation and developing criteria for analysis in other areas. This criterion is useful for engineering, economics, safe time and safety.

**Keyword:** Rock slope, GIS, Probability of Failure, Expert system

## 1. INTRODUCTION

When slope failure is occur on road cut, it is unfavorable. It is causes a serious damage to the road and the local traffic. Many reports are show about the hazard such as Lomsak-Chumpae highway. The problems of slope failures along the road cuts have repeatedly occurred on some locations. The failures brought down both earthen and installed materials, and obstructed the traffic for several hours. This has posed severe economic impacts on the commercial and tourism of the regions (Thongthiangdee, 2003).

Studying of slope damage triggering factors of their hazards could help effectively in reducing their damages. In general, existing researches on rock slope stability are different in methods, factors used and model types.

Applications of geographic information systems GIS. in mountain areas have been relatively slow in developing. By the late 1980s, the potential of GIS to model slope instabilities was still being discussed in the literature. Stocks and Heywood (1994) accredit this tardiness to characteristically poor baseline data and a general lack of funding. Through the 1990s, however, GIS has been increasingly applied to a wide range of hazards from forest fires to snow avalanches (Walsh et al., 1994). Some research on integrating GIS and deterministic models for slope failure zonation has been conducted. Examples include GIS-based infinite-slope stability models (Kamai, 1991; Terlien, 1996; Pack et al., 1998, 2001), GIS–infinite-slope seepage model (Dietrich et al., 1993; Montgomery and Dietrich, 1994; Montgomery et al., 1998), GIS– probabilistic infinite-slope models (Hammond et al., 1992; Fannin andWilkinson, 1995; Fannin et al., 1996) GIS–infinite-slope probabilistic seismic landslide model (Jibson et al., 1999; Luzi et al., 1998; Khazai and Sitar, 2000), Preliminary rock slope susceptibility using GIS and SMR (Irigaray, 2003), GIS based stability analysis of rock cut slope (Kim et al., 2004)

Interestingly, while various statistical techniques have been tested by different researchers, the techniques have almost exclusively been applied using regular grid cells as the basic analytical unit. Furthermore, on has been directed towards the implications of using regular grid cells. As Carrara et al. (1995) notes, this is somewhat surprising given the importance of the basic analytical unit to any subsequent statistical analysis. In addition, uncertainties surrounding the appropriateness of subdividing the terrain based on an arbitrary, fixed-sized grid must be considered.

Chung et al. (1995) tested the use of 'unique-conditions units' which were produced through multiple overlays involving all the relevant thematic coverage. This approach is based on the logic that each analytical unit will contain homogeneous properties for each of the stability factors being considered, and thus facilitates statistical analysis. In practice, however, this approach is prone to problems associated with the number and size of analytical units generated through multiple overlays. The size of the units in particular may render the units meaningless for statistical analysis, as well as land use management decisions.

Carrara et al. (1991-1995) used 'meaningful terrain units' extracted from a digital elevation model (DEM). The terrain units were constructed from ridge and channel lines, which in effect delineate sub-basins and major slope units within a watershed. Logically, this makes sense from the standpoint that actual slope units are being used in the analysis of slope stability. The approach, however, can be questioned on the basis of an entire slope unit being used to model processes that probably occur only on a small portion of the unit. Nonetheless, the results from the work of Carrara et al. (1991- 1995) encouraging, and particularly noteworthy with respect to the success of discriminant analysis and logistic regression in predicting stable or unstable conditions for the terrain units.

In the recent years, the Geographic Information System (GIS), with its power and versatility for processing spatial data, has attracted significant attention for the assessment of natural disasters. GIS is a system of hardware and software for data capture, input, manipulation, transformation, visualization, combination, query, analysis, modeling and output. GIS provides strong functions both in geostatistical analysis and database processing. In addition, the extension of the analysis to include environmental impact assessment of a slope failure can be easily and effectively performed using GIS. From a survey of recent GIS applications to slope failure hazard zonation, it is found that most research has concentrated on statistical methods in order to determine quantitative relationships between slope failure and influential factors while GIS has been used to perform regional data preparation and processing.

Therefore, the purpose of this study is to apply the simplified rock slope stability analysis, covering geotechnical properties of the basic spatial units, to determine rock slope susceptibility in large area. The indexes obtained by this method are considered more objective and relying on geotechnical concept and theory. Even though the result is not as accurate as site investigation to which FS is practically applied, using this resulting map, more benefit for hazard management e.g. preventing, warning, and mitigation planning in rock slope (road cut) risk area can be expected, comparing to results from the conventional index model.

## 2. FIELD INVESTIFGATION

Field investigation was conducted along highway (Figure 1). The purpose of field investigation is to obtain geological engineering data of the sites. Equipment for the investigation includes global positional system (GPS), geological hammer, geological compass, measuring tape, and geological map with a scale 1:250,000. A route map of Thailand highway with a scale 1:1,000,000 is also used to locate the examined rock slopes. The study criteria follow as much as practical the methods suggested by the International Society of Rock Mechanics (Brown, 1981). The data include slope geometry, joint conditions and orientation, intact rock strength, performance of the existing rock supports (if any), modes of failure, rock conditions, and groundwater conditions. The data obtained from fieldwork were used for kinematics analysis and computer simulation.

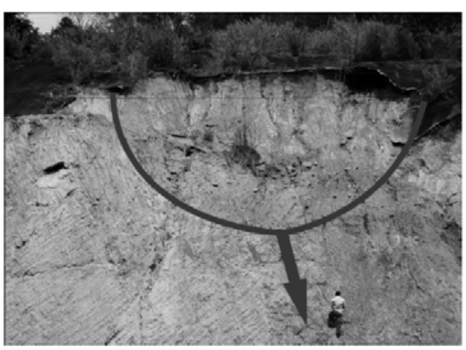

**Figure 1.** A field investigated on highway No. 11. The circular failure was occur after rainfall.

## 3. NUMERICAL MODEL

The numerical computer simulation is to calculate a factor of safety (FS) of rock slope for compare with GIS method. Several values of properties are assumed in the computer simulation, which eventually gives safety factors close to the actual field condition. The FLAC SPLOE was used in the analysis. The result of calculation is showed in Table 1. There are several mode of failure from the result. In this study, the research emphasize on circular failure.

## 4. STABILITY EVALUATION (Fuenkajorn, 2003)

The system classifies each factors considered in the stability evaluation into small ranges or sub-divisions, mainly to convert the input slope characteristics into quantitative form. The classification follows as much as practical the suggested methods by the International Society of Rock Mechanics (ISRM - Brown, 1981). A set of rating is then assigned to these parameters for each failure mode considered. Recognizing that the significance of these parameters can be at different degrees for different conditions of the rock mass, a set of influencing factors is also defined as multiplying factors for the corresponding parameter. The probability of failure P{f} in percent for each mode can then be calculated by

$$P\{f\} = \Sigma\{R_n * I_n\} \qquad (1)$$

where $R_n$ is the rating for each parameter, $I_n$ is the influencing factor for the corresponding parameter, and n represents type or number of the parameters considered for each slope (varying from 1, 2, 3, 4…..n). Tables 2 and 3 list the rates and influencing factors to calculate the probability of the circular failure. In this case, the value n equals to 8.

To correlate the probability of failure to the factor of safety, the system defines that the factor of safety is 1.0 when P{f} equals to

50%. The system recommendations also compare the calculated P{f} against the degrees of safety required for four types of engineering application. For Type A where the slope toe is nearby the residential structures or power plant facilities, P{f} should be less than 10%. Type B is for the slopes along the main highways, railroads, and large bridges, which requires the P{f} less than 30%. Type C is for the slopes along the small roads and reservoirs, which requires the P{f} less than 50%. Type D requires P{f} less than 70% which is defined for the temporary access or small roads in open pit mines.

## 5. GIS METHOD

This section is described an operation of GIS system. The procedure for analysis Rock slope failure is show in figure 2. The parameters of infinite slope stability could be obtained under the domains of geologic units and slope characteristics.

**Table 1.** Result from numerical model.

| Station No. | Unit weight (N/m$^3$) | Friction angle (degree) | Cohesion (Mpa) | F.S. | Remark |
|---|---|---|---|---|---|
| 01 | 22 | 22 | 0.051 | 1.5 | Stable |
| 02 | 22 | 28 | 0.074 | N/A | Rock fall |
| 03 | 22 | 25 | 0.040 | N/A | Rock fall |
| 04 | 22 | 20 | 0.061 | 1.3 | Plane failure |
| 05 | 22 | 26 | 0.038 | 1.3 | Circular failure |
| 06 | 22 | 26 | 0.038 | 1.0 | Circular failure |
| 07 | 22 | 58 | 0.449 | 1.0 | Circular failure |
| 08 | 22 | 24 | 0.045 | 1.2 | Circular failure |
| 09 | 26 | 45 | 0.129 | N/A | Rock fall |

**Table 2.** The influencing factors to calculate the probability of the circular failure.

| Rock grade | Slope height | Slope face angle | Groundwater | Degree of weatering |
|---|---|---|---|---|
| R0 | 2.0 | 2.0 | 3.1 | 0 |
| R1 | 1.7 | 1.8 | 2.2 | 0.2 |
| R2 | 0.1 | 0.1 | 1.2 | 0.4 |
| **Rock grade** | **Vegetation** | **Number of discontinuity** | **Vibration** | **Average discontinuity spacing** |
| R0 | 0.5 | 0 | 2.4 | 0 |
| R1 | 1.1 | 0.4 | 0.5 | 2.1 |
| R2 | 2.0 | 1.2 | 0.1 | 4.9 |

The geologic units in form of GIS vector layer ($GI_n$) were from the geological maps at scale of 1:50,000 (DMR, Thailand). This layer contains attributes of rock properties which consist of rock strength (Brown, 1981). This layer contain rock strength from R0-R2 .The Slope Rating layer ($SR_n$) include slope height later, slope face angle layer, Groundwater later, Degree of weathering layer, Vegetation layer, Number of discontinuity layer, vibration layer and average discontinuity spacing. The probability of susceptibility was following Fuenkajorn 2003. DEM data at scale 1:4000 cover area about 4 km$^2$ used to generate slope height and slope angle layer. The summation of multiply of two GIS vector layers which are $SR_n$ and $GI_n$ then show equation by.

$$PF = \Sigma(SR_n * GI_n) \tag{2}$$

The resulted are show in term of probability of failure (PF) map. The procedure of analysis is shown in Figure 2.

**Table 3.** The rates to calculate the probability of the circular failure.

| **Slope height** | | **Slope face angle** | | **Groundwater** | | **Degree of weathering** | |
|---|---|---|---|---|---|---|---|
| **(m)** | **Rate** | **Degrees** | **Rate** | **(%)** | **Rate** | **Conditions** | **Rate** |
| <7 | 1 | <25 | 0 | 0 | | Fresh | 2 |
| 7-10 | 5 | 25-30 | 1 | 25 | | Slightly | 4 |
| 10-15 | 8 | 30-35 | 2 | 50 | | Moderately | 6 |
| >15 | 10 | 35-40 | 3 | 75 | | Highly | 8 |
| | | 40-45 | 5 | 100 | | Completely | 10 |
| | | 45-50 | 6 | Unknown | *5 or 10 | Unknown | 5 |
| | | 50-55 | 8 | | | | |
| | | 55-60 | 9 | | | | |
| | | 60-65 | 9 | | | | |
| | | 65-70 | 10 | | | | |
| | | >70 | 10 | | | | |
| **Vegetation** | | **Number of discontinuity** | | **Vibration** | | **Average discontinuity spacing** | |
| **Conditions** | **Rate** | **(Sets)** | **Rate** | **Conditions** | **Rate** | **(mm)** | **Rate** |
| No vegetation | 10 | ≤ 2 | 1 | Near Blasting site, earthquake | 10 | < 20 | 10 |
| Only grass | 7 | 3 | 8 | Near main highway | 5 | 20-60 | 7 |
| Grass with small trees | 5 | ≥ 4 | 10 | No vibration | 0 | 60-200 | 5 |
| Full grown trees | 0 | Unknown | 5 | Unknown | 5 | > 200 | 0 |
| Unknown | 5 | | | | | Unknown | 5 |
| ***5 for arid climate, 10 for tropical climate** | | | | | | | |

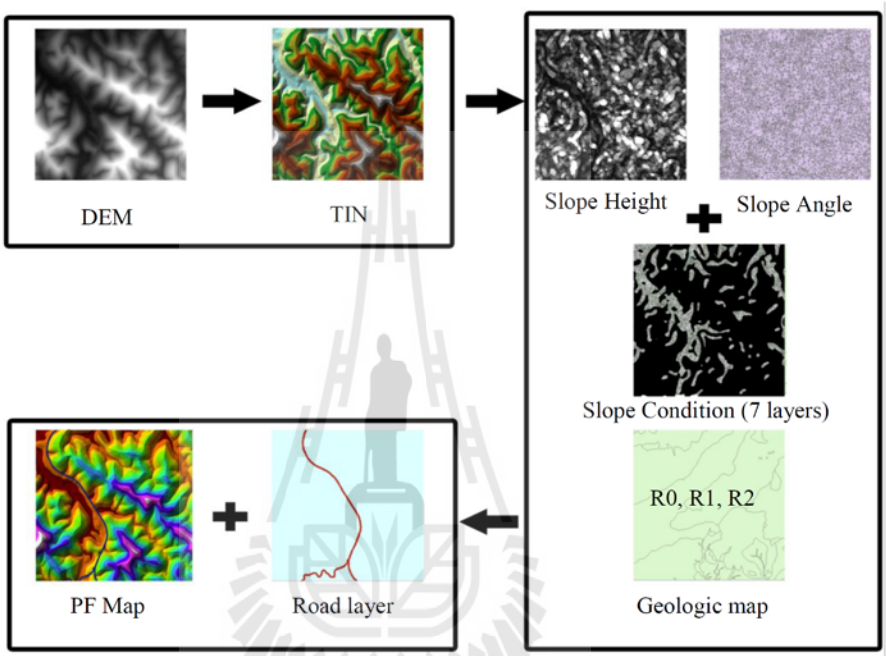


**Figure 2.** The procedure of analysis rock slope Failure Probability (PF).

## 6. RESULT

TIN with 12825 polygon. The initial result of GIS method is trend to Numerical method. At station No.6 (Highway No.12), approximate PF about 60%. It shows the factor of safety of rock slope less than 1.

## 7. CONCLUSIONS AND RECOMMENDATION

The application of infinite slope stability models together with GIS technique can rapidly evaluate rock slope susceptibility in large area. Even though the PF used to classify the rock slope susceptibility were obtained using equation for probability of failure calculation and the input data are not as accurate as data from site investigation, the result of the study is apparently reasonable. The area classified based on PF to be high rock slope susceptibility shows the highest occurrence probability. The probability of the moderate and the low shows considerable consistency.

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