COMPARISON OF FACTOR OF SAFETY USING DIFFERENT METHOD OF ANALYSIS FOR SLOPE STABILITY

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COMPARISON OF FACTOR OF SAFETY USING DIFFERENT METHOD OF ANALYSIS FOR SLOPE STABILITY

AHMAD AMIRUL BIN MOHD ZAKI

Project report submitted in partial fulfilment of the requirements for award of the degree of B. Eng (Hons) Civil Engineering

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JULY 2015

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I hereby declare that I have checked this project report and in my opinion, this project "COMPARISON OF FACTOR OF SAFETY USING DIFFERENT METHOD OF ANALYSIS FOR SLOPE STABILITY" is adequate in terms of scope and quality for the award of the degree of B. Eng (Hons) Civil Engineering.

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Date : 3 JULY 2015

STUDENT'S DECLARATION

I declare that this project report entitled "COMPARISON OF FACTOR OF SAFETY USING DIFFERENT METHOD OF ANALYSIS FOR SLOPE STABILITY" is the result of my own research except as cited in the references. The project report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ………………………………………...
Name : AHMAD AMIRUL BIN MOHD ZAKI
Date : 3 JULY 2015

This project report I dedicated to the most sincere,

To my loved parents:

Mohd Zaki bin Husin
Rahani bt Abd Rahman
Nur Shafina bt Mohd Zaki
Nur Ain Munirah bt Mohd Zaki
Ahmad Hafifi bin Mohd Zaki
Nur Shahira bt Mohd Zaki
Ahmad Khalid bin Mohd Zaki
Ahmad Hanafi bin Mohd Zaki

To my lovely person:
Siti Baqis binti Rosly

And all my friends

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Praise be to ALLAH, the Lord of Universe

Alhamdulillah and thanks to the Almighty for with His permission to complete my Bachelor of Civil Engineering. First and foremost, I would like to express my appreciation to my Final Year Project supervisor, Ir Azhani Zukri for giving me the opportunity to do this project under her supervision. I am very proud to be your student. Thank you for your generosity and countless effort to help at all time.

I also would like to give lot of thanks to all my family members for their support, love and prayer for me in completing this project report. My fellow friends, for all the help, information and encourage me through difficult time in through this project and complete my project studies.

With all the guidance, this report are manages to be completed successfully. Thank you for all.

ABSTRACT

Slope failure in our country is an issue that needs to be taken seriously as it involves public safety. Therefore there are various efforts being carried out, particularly in the treatment of critical slope, redesign the slope that has failed and also analyze the factor of safety of the slope. This study was conducted to determine the safety factor of the slope at KM259.95 the North-South Expressway which is cut slope that built for infrastructure development, using computer software, Geo-studio 2007 (SLOPE / W) and the conventional method; infinite slope method in sand. Based on site investigation report, the slope has sandy soil profile. The first layer is silt with properties γ= 18.25kN/m^3, c' = 0kN/m, ϕ' = 39^o, sand with properties γ= 16.19kN/m^3, c' = 0kN/m^2 ϕ' = 39^o and granite (impermeable) .To carry out this analysis, three cross-sections have been developed to obtain the factor of safety. Using all the parameters, the factor of safety has been obtained for the three cross sections. Using conventional method, the factor of safety (FOS) for cross section A, cross section B and cross section C is 1.036, 1.000 and 1.036 respectively. While for the FOS for cross section A using SLOPE/W for Morgenstern Price, Janbu's, Ordinary and Bishop are 1.156, 1.091, 1.090 and 1.135 respectively. For the cross section B, the FOS for Morgenstern Price, Janbu's, Ordinary and Bishop are 1.509, 1.283, 1.303 and 1.392 respectively. And for cross section C, the FOS for Morgenstern Price, Janbu's, Ordinary and Bishop are 1.284, 1.250, 1.251 and 1.300 respectively. After obtaining the factor of safety for the slope, the coefficient for each type of analysis has been evaluated. For all cross section, the coefficient for Morgenstern Price analysis is 0.789, Janbu's method with 0.853, Ordinary method with 0.848 and Bishop Method with 0.809. The percentage difference between the factor of safety for SLOPE/W and conventional has also analyzed where Morgenstern Price method has the highest difference of 0.211% and the lowest percentage of different between both methods is Janbu's method with 0.147%. For the Ordinary and the Bishop method, the percentage difference is 0.152% and 0.191%.As a conclusion, factor of safety for cut slope of research is critical and requires immediate treatment with appropriate improvements. From percentage difference, both methods still suitable to be used as a way to get the optimum safety factor of slope.

ABSTRAK

Kegagalan cerun di negara kita merupakan satu isu yang perlu diberi perhatian serius kerana ia melibatkan keselamatan awam. Oleh itu terdapat pelbagai usaha sedang dijalankan, terutamanya dalam merawat cerun kritikal, merekabentuk semula cerun yang gagal dan juga menganalisis faktor keselamatan cerun. Kajian ini dijalankan untuk menentukan faktor keselamatan cerun di KM259.95 Lebuhraya Utara-Selatan yang merupakan cerun potong yang dibina untuk pembangunan infrastruktur, dengan menggunakan perisian komputer, Geo-Studio 2007 (SLOPE/W) dan kaedah konvensional; kaedah cerun tak terhingga dalam pasir. Berdasarkan laporan penyiasatan tapak, cerun mempunyai profil tanah berpasir. Lapisan pertama adalah kelodak dengan ciri γ = 18.25kN / m3, c '= 0kN / m, φ' = 39^{o}, pasir dengan ciri γ= 16.19kN / m^{3}, c '= 0kN / m^{2}, φ' = 39^{o} dan granit (tidak telap) .Untuk menjalankan analisis ini, tiga keratan rentas telah dibangunkan untuk mendapatkan faktor keselamatan. Menggunakan semua parameter, faktor keselamatan telah diperolehi bagi tiga keratan rentas. Mengunakan kaedah conventional, faktor keselamatan (FOS) untuk keratan rentas A, keratan rentas B dan keratan rentas C adalah masing-masing 1.036, 1.000 dan 1.036. Manakala bagi FOS untuk keratan rentas A menggunakan SLOPE / W untuk Morgenstern Price, Janbu, Ordinary dan Bishop adalah 1,156, 1,091, 1,090 dan 1,135. Untuk keratan rentas B, FOS untuk Morgenstern Price, Janbu, Ordinary dan Bishop adalah 1,509, 1,283, 1,303 dan 1,392. Dan bagi keratan rentas C, FOS untuk Morgenstern Price, Janbu, Biasa dan Bishop adalah 1,284, 1,250, 1,251 dan 1,300 masing-masing. Selepas mendapatkan faktor keselamatan bagi cerun, pekali bagi setiap jenis analisis telah dianalis. Untuk kesemua keratan rentas, pekali untuk analisis Morgenstern Price adalah 0.789, kaedah Janbu dengan 0.853, kaedah Ordinary dengan 0.848 dan Kaedah Bishop dengan 0.809. Perbezaan peratusan antara faktor keselamatan untuk SLOPE / W dan konvensional juga telah dianalisis di mana kaedah Morgenstern Price mempunyai perbezaan yang paling tinggi 0.211% dan peratusan terendah yang berbeza antara kedua-dua kaedah adalah kaedah Janbu dengan 0.147%. Bagi kaedah Ordinary dan kaedah Bishop, perbezaan peratusan adalah 0.152% dan 0.191%. Kesimpulannya, faktor keselamatan bagi cerun potong yang dikaji adalah kritikal dan memerlukan rawatan segera dengan penambahbaikan yang sesuai. Dari perbezaan peratusan, kedua-dua kaedah masih sesuai untuk digunakan sebagai satu cara untuk mendapatkan faktor keselamatan cerun yang optimum.

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α = inclination of slip surface

β = inclination angle of slope

c' = effective cohesion of soil

E = Young Modulus

$\phi' =$ effective friction angle of the soil

L = length of slices

N = normal forces

S = shear strength

τ = Undrained shear strength

ν= Poisson ratio

W = weight of slice

γ= unit weight of soil

γ_{sat} = saturated unit weight

CHAPTER 1

INTRODUCTION

1.1 Background

Soil erosion is one phenomenon that has to be given attention in this country as has sparked a wide range of issues and problems in this country. Soil erosion occurs on cut slopes usually caused by natural factors and the consequences of human activities. Natural factors is difficult to predict and difficult to avoid regulations, but control measures and improvements should be done from time to time to prevent the occurrence of landslides. To solve the problem, slope stability analysis is performed to obtain a factor of safety of slope with conventional methods and software. As we know, the conventional method is still practicable to serve as a reference. For analysis using computer software, the factor of safety can still be idealized by multiplying by the coefficient to obtain the optimum value that can be derived from a comparison of the factor of safety between the conventional method and computer software, Geo-Studio 2007 (SLOPE/W).

1.2 Problem statement

Since the recent 20 years, more frequent landslides occur mainly slope in the path of the highway, a residential and industrial area which has resulted in deaths and huge property losses. Results of the investigations carried out by the authorities, main factors landslides is rainfall in Malaysia uncertainty and indirectly increase the rate of surface runoff in a critical slope. In addition, slope failures also occur when there is increased pressure and shear strength of the soil decreases. To reduce the risk of landslides, various attempts have been made include reviewing the characteristics of the soil, slope improvements, re-slope design, and many more. One way to identify problems is analyzed in terms of the factor of safety of the slope has the potential to fail.

To identify these problems, analyzing the stability of slopes at KM259.95 the North-South Expressway was carried out using the conventional method (infinite slopes method in sand) and computer software; Geo-Studio 2007 (SLOPE/W).

1.3 Objective

This study will be conducted to established following objective:

i. To analyzing the factor of safety of slopes (cut slope) using conventional methods and computer software; Geo-Studio 2007 (SLOPE/W).
ii. To making a comparison of factor of safety from conventional methods and computer Geo-studio 2007 software (SLOPE/W) analysis.
iii. To determine the coefficient of factor of safety from analysis using conventional methods and computer software, Geo-Studio 2007 (SLOPE/W).

1.4 Scope of study

The scope of this study was to determine the stability of cut slopes at KM259.95 the North-South Expressway using conventional methods (infinite slopes method in sand) and Geo-Studio 2007 software (SLOPE/W). Analysis of data using computer software was use three type of simplified soil profile which analyzed data obtained from the site investigation report. To seek solutions to these problems, the analysis and comparison of the slope made between the conventional method and Geo-Studio 2007 software (SLOPE/W).

CHAPTER 2

LITERATURE REVIEWS

2.1 Introduction

General Director of Lembaga Lebuhraya Malaysia (LLM); Datuk Ir Mohamad Razali Othman has issued a statement that, there are 179 slopes in the North-South Expressway, which was found to be at risk of landslides. The situation has sparked concern in many quarters but with more frequent monitoring was carried out. According to him, the factors that contribute to this problem are increases of agricultural activity around the slope which could affect the stability of the slope (Utusan Malaysia, 17.12.2008). The risk of slope failure resulting from natural conditions is hard to predict, but it can be overcome by constantly monitoring and maintenance. For the reason that comes from human activities, it is important for us to know the stability of the slope prior to any activity carried out in order to avoid untoward incidents occurs.

As we know, scientifically landslides occurring due to soil erosion. Soil erosion can be define as a process of destruction and creation of terrain in other areas due to the action of water flowing from the rain that hit the earth until the formation of the water flowing over the surface of the earth, including the flow of the river. This situation can be seen more clearly, especially on the cut slope that has a high gradient. There are two classifications of erosion that occurs naturally and the effects of human activities. However, change the natural terrain difficult to avoid, but it can be solved with the methods of controlling the slope. While the causes of soil erosion from human activities such as agriculture, logging and mining also cause slope failure may be at the expense of lives and loss of property (Pagar Museh, 2013).

2.2 Type of slope

Analysis of slope stability factor to take into account various factors related to topography, geography and characteristics of the soil on the slopes involved. Any information also depends on the type of slope to be analyzed. In general, there are two types of slope that is classified as an infinite slope and finite slope. Besides that, slope has also been classified into two types, namely natural slopes and man-made slopes (Murthy, 2003).

2.2.1 Infinite slope

For too long slope failure that considered a surface parallel to the surface of the earth as the original slope, infinite slope stability analysis is made according to the balance of forces acting on the slices “abcd” in Figure 2.1. While for the equations to obtain the factor of safety is show as Equation 2.1:

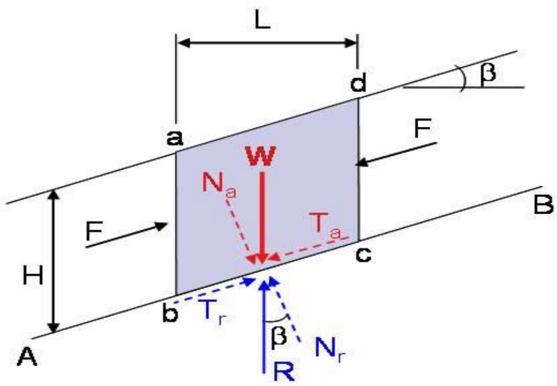

Figure 2.1: Analysis of infinite slope

Source: Winniyarti, 2010

FOS= $$\frac{c}{\gamma H\cos^2\beta\tan\beta}+\frac{\tan\emptyset}{\tan\beta}$$ (Equation 2.1)

where

FOS = factor of safety

c' = effective cohesion of soil (kN/ m^2)

γ = unit weight of soil (kN/m^3)

W = weight slice (= $\gamma \times$ slices area $(\frac{kN}{m})$

α = inclination of slip surface (degree)

ϕ' = effective friction angle of the soil

β = inclination angle of slope

In the case of ground water level is below the plane of failure (dry slope), and ground friction only (c' = 0), the equation as shown in Equation 2.2 can be used to determine the safety factor slope:

FOS = (tan ϕ)/ (tan β) (Equation 2.2)

2.2.2 Finite slope

When the value of H_{cr} approaches the height of the slopes, the slopes generally may be considered finite. For simplicity, when analyzing the stability of a finite slope is a homogeneous soil, some assumption need to be made about the general shape of the surface of potential failure. Culmann (1875) suggest that slope failure usually occur on curved failure surface. Other than that, after extensive investigation of slope failure in the 1920s, a Swedish geotechnical commission recommended that actual surface sliding may be to be circularly cylindrical. After that assumption has been made, most conventional stability analysis of slopes is considered as arc of a circle as shown in Figure 2.2.

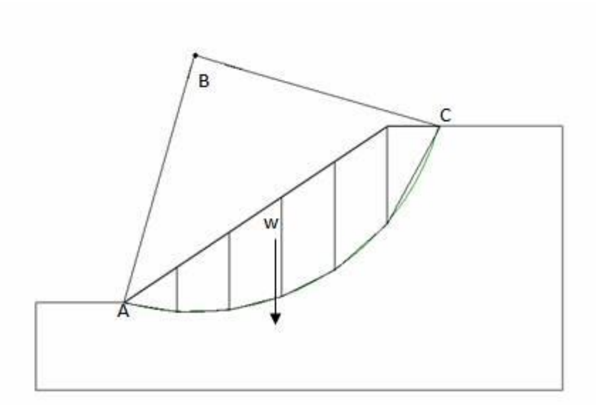

Figure 2.2: Circular slip surface

Source: Indian Institute of Technology

2.2.3 Natural slopes

Natural slopes are usually formed in the hilly areas where the formation processes take a long time without disturbance process. Slope formation is also influenced by the movement of the earth's core and earthquakes. The slopes of this type are also strong and stable as long as no human activities such as logging and mining that disturb the stability of the slope (Shah Jahan bin Abdullah, 2012).

2.2.4 Man-made slopes

Man-made slope is when humans leveling the land for construction, they cut slope or embankment to provide ground level to facilitate construction. This is a man-made slopes and stability should be monitored sari time to time to prevent landslides (Dr. Ibrahim Komoo, 2013). Man-made slopes can be classified into two categories as follows:

i. Cut slopes
ii. Fill slopes

2.2.4.1 Cut slopes

Cut slopes categorized as man-made slopes seek to make way for the construction of roads or other infrastructure. This slope construction process involves changing geometry in terms of angle and height. There are guidelines and conditions that must be met in order to build the slope of this kind in Malaysia. All slopes are not treated will be designed with a minimum width of the berm height of 2m and 6m maximum berm with a safety factor greater than 1.3. Stabilization measures may include soil nailing the slope surface protection, permanent soil anchors, retaining walls or any other related methods. Global minimum factor of safety for slope treated was 1.5. (Public Works Department, 2010). Each guideline is intended that the construction is done in the slope of this type are not exposed to the risk of landslides and various other risks such as property damage and casualties.

2.2.4.2 Fill slopes

Fill slope is also one of the man-made slopes with the reclamation of land from other areas. This situation can usually be seen in the area of highway construction. Each slope construction process must adhere to standards set by authorities. All untreated fill slopes should be designed with 2m berm width and 6m berm height with a minimum factor of safety of 1.3. The stabilization measures may include geo-grid or geo-textiles reinforcement, reinforced concrete retaining structure, reinforced fill structure, or replacing the fills with elevated structures. While for the slopes that have been treated, a minimum safety factor of 1.5(Mohd Riza Aizad Bin Shauri, 2012).

2.3 Type of slopes failure

Slope failure can be defined as mass wasting, is the down slope movement of rock debris and soil in response to gravitational stresses. Slope failure can be classified by source and form of the ruins of the movement in the soil. Potential slope failures are usually caused by increased pressure or shear strength of the soil decreases. Usually, a pressure increase will come from increasing the load or vibration element near the slope. Besides that, the increase in pore water pressure can also reduce the shear strength of the soil and indirectly slope will risk to a landslide. There are several types of failures are identified through the study of causes and forms of ground movement. Types of slope failure are:

i. Topples
ii. Flowage
iii. Sliding
iv. Lateral spread
v. Complex

For example slope failure that occurred in our country is on 2004, Malaysia has experienced the latest in a series of landslide when a large rock slope collapse and fail to New Klang Valley Expressway (NKVE) at Bukit Lanjan. The landslides were outstanding, as show in Figure 2.3, closed the highway for several months, prompting a huge cost, though no reports of public who were killed in the incident. (Dave Petley, 7 November 2012).

Figure 2.3: New Klang Valley Expressway (NKVE) landslides at Bukit Lanjan (2004)

Source: American Geophysical Union, 2012

2.3.1 Topple

Topples is the forward rotation out of the slope of mass of soil or rock about a point or axis below the centre of gravity of the displaced mass. Toppling is sometimes driven by gravity exerted by material upslope of the displaced mass and sometimes by water or ice in cracks in the mass (Varnes, 1996). Among the causes of this type of slope failure is of vibration of human activity such as quarrying, cutting slopes that are not in accordance with prescribed standards, excavation, or stream erosion. The Figure 2.4 shows the overview of topple landslide.

Figure 2.4: Topple

Source: Idaho Geological Survey, 2008

2.3.2 Flowage

Flow can be defined as the unconsolidated materials where the material is in the liquid state. Therefore, the water content in the soil is the main mechanism for this process. There are several categories of this type of slope failure as follows:

i. Debris Flow
ii. Mudflow

2.3.2.1 Debris flow

A debris flow is a form of rapid mass movement in which a combination of loose soil, rock, organic matter, air, and water mobilize as slurry that flows down slope. Debris flows are commonly caused by intense surface-water flow, due to heavy precipitation or rapid snowmelt that erodes and mobilizes loose soil or rock on steep slopes. Debris flows also commonly mobilize from other types of landslides that occur on steep slopes, are nearly saturated, and consist of a large proportion of silt- and sand-sized material. Fires that denude slopes of vegetation intensify the susceptibility of slopes to debris flows. The overview of this type landslide can be seen in the Figure 2.5.

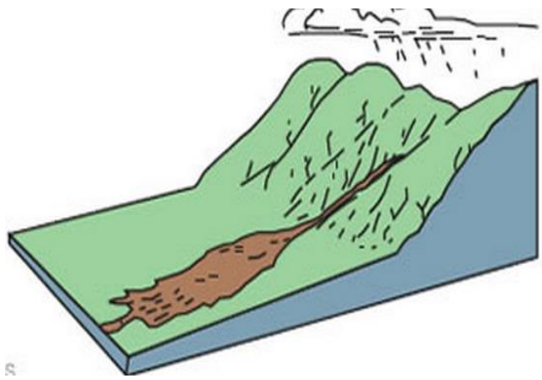

Figure 2.5: Debris flow

Source: Idaho Geological Survey, 2008

2.3.2.2 Mudflow

A mudflow is an earth flow consisting of material that is wet enough to flow rapidly and that contains at least 50 percent sand, silt, and clay-sized particles. Sometimes, for example in newspaper reports, mudflows and debris flows are commonly referred to as "mudslides”. As show in Figure 2.6, mudflow is a kind of slope failures that occur frequently in our country that has a relatively high rainfall.

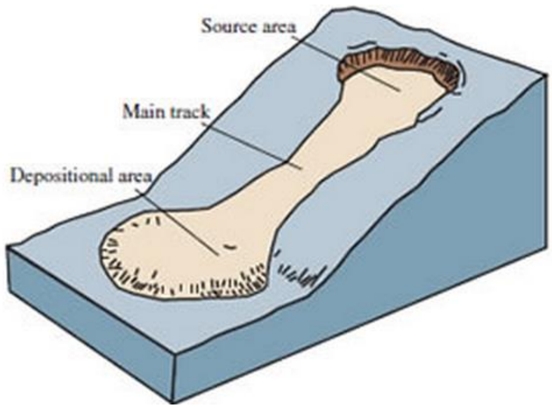

Figure 2.6: Mudflow

Source: Idaho Geological Survey, 2008

2.3.3 Slides

Sliding can be defined as uniform movements in a smooth surface and it is continuous (Dictionary). From the scope of slope failure, it was classified into several types:

i. Translational slide
ii. Rotational slide

2.3.3.1 Translational slide

Landslides are mass translational slide downwards and outwards at the top surface of the inclined plane. Slip plane is influenced by stratum stronger base than the upper layer. This difference leads to a lack of adhesion forces between the layers of the structure. Landslides of this type involve a greater failure. This is because the fault plane, which extends for some distance and it is difficult for expected failures. The overview of translational slide is shown in Figure 2.7.

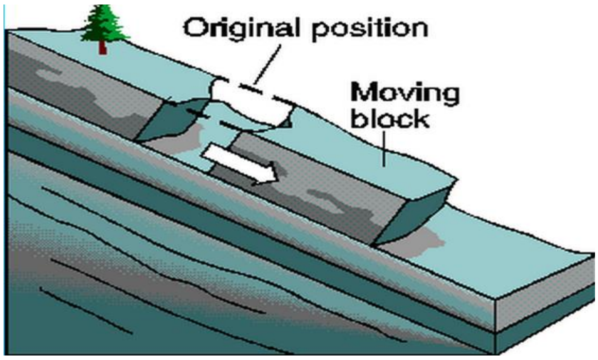

Figure 2.7: Translational slide

Source: Idaho Geological Survey, 2008

2.3.3.2 Rotational slide

Rotational slide or also known as slump, is described is the sliding of a material along a curved surface. The cause for this slide is due to erosion at the base of the slope. The masses technically slide outwards and downwards or more concave-upward failure surfaces that gives a backward tilt to the slipping mass. The failure mass then sinks at the rear and heaves at the toe of the slope. The overview of the rotational flow can be seen in Figure 2.8.

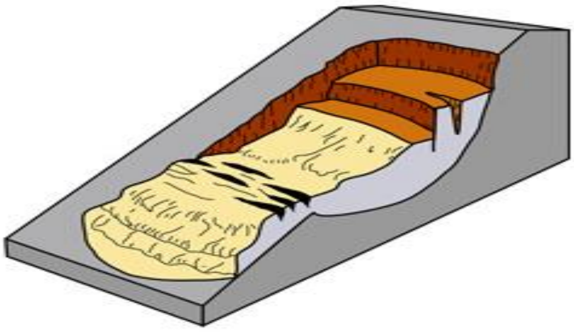

Figure 2.8: Rotational slide

Source: Idaho Geological Survey, 2008

2.3.4 Lateral spread

This type of failure usually occurs at a very gentle slope or wavy. The main mode of movement is lateral extension accompanied by shear or tensile fractures. Failure is usually caused by the rapid movement of soil, such as that experienced during the earthquake. When coherent material, either bedrock or soil, rests on materials that liquefy, the upper units may undergo fracturing and extension and then subside, translate, rotate, disintegrate, or liquefy and flow. Lateral spreading in fine-grained materials on shallow slopes is usually progressive. The failure starts suddenly in a small area and spreads rapidly. Combination of two or more of the above types is known as a complex landslide. (Geology.com, 2005-2014). The overview of the lateral spread can be seen in Figure 2.9.

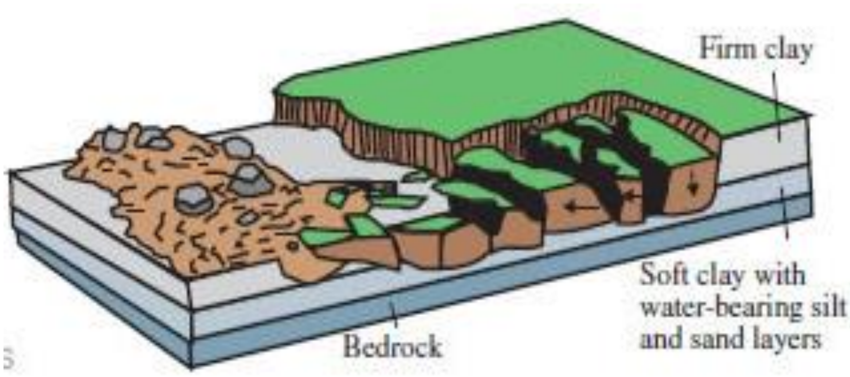

Figure 2.9: Lateral spread

Source: Idaho Geological Survey, 2008

2.4 Factors of slopes failure

Slope stability is an issue that must be emphasized that before any activity carried out mainly in the hilly terrain. This is because there are numerous other major sources can lead to instability of the slope, if underestimated. Among other causes which can lead to slope instability is natural factors and human activities factors. An opinion about the factors affecting landslide in Malaysia is, heavy rain for a long period of time. Second, changes in the material properties of the earth through geomorphologic processes. Third, the discontinuity rocks planes. The erosion of soil by the action of rainwater which is lead to surface runoff. (Ibrahim, 1985 to 1986). These factors are the main causes of slope failure in Malaysia.

2.4.1 Natural factors / physical factors.

There are various causes of slope failure, whether natural or the effects of human activities. Natural sources such as the action of water, geological factors and drainage systems will lead to slope failure. While in terms of human activity as well, can be said to have a major impact on slope failures such as logging, mining, and more. There are several natural factors that cause the landslide, such as:

i. Type of slopes
ii. Plants
iii. Rain

2.4.1.1 Types of slope

Dahal (2008) and Avanzi (2004) categorize the gradient slope into 4 groups: 30^o to 35^o, 35^o to 40^o, 40^o to 45^o and more than 45°; generally from the results of the analysis indicated that the gradient of the slope is between 40 to 45° has a high frequency of landslides. Slope geometry also include gradient, slope height, slope and width of each number is also found on the slopes of the slope. Indirectly, every aspect of this slope geometry will affect the stability of the slope. In conclusion, a steep slope conditions is very easy slope to slope failure occurrence such as landslides.

2.4.1.2 Plants

As we know, the plants grown on the slope has its own reason; either in terms of slope stability or aesthetics. Generally, plants that are on the slopes also affect landslide process. In this case, the plants on the slope of a top layer of earth that is able to control erosion on slope surfaces to further strengthen the structure of the soil on slope surface. In addition, the plant on the slope also acts by binding soil particles by creating an attachment structure between plant roots and soil particles. Therefore, the plant roots will act with growing deep into the soil to act as anchors to hold the slope of the sliding surface and also it will absorb the momentum of the falling rain from falling directly into the ground. This situation will be able to control the quantity and surface water flow because the stream is absorbed by plants found on the slopes and the effects of erosion on sloping surfaces can be reduced. Examples of the types of cover crops are often grown on sloping surfaces are Vetiveria Zizanioides and Axonopus Compressus. Figure 2.10 shows how the Vertiveriazizanioides are planted on slopes to maintain slope stability.

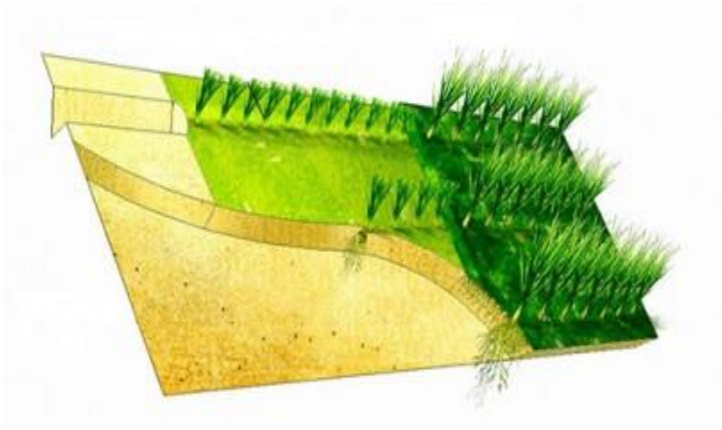

Figure 2.10: Vetiveria Zizanioides

Source: Agrowing Culture, 2012

2.4.1.3 Rain

Heavy annual rainfall (over 2000 mm), especially in the humid tropics as in Malaysia encourage a mass movement or slope failure. The effect of water on the surface of the slope can cause pore water conditions on the slopes. Water that seeps into the pores of this land will weaken the strength of the soil on the slopes either artificial or natural slopes. Indirectly, soil at slopes become saturated soil and lost the cohesive property. These situation will cause the soil to become loose and easy to move. In addition, changes in ground water level are one of the causes of the instability of the slope. The increase in the slope of the ground water level is able to increase the pore water pressure and reduce stress on the slope of the land that is saturated with water.

2.4.2 Factor of human activity

The main cause of slope failure is usually caused by human activities carried out in the vicinity of a slope. Human activities are carried out without control; pose a risk to slope failure. Between human activities is the cause of the landslide is:

i. Quarry
ii. Logging activities
iii. Development

2.4.2.1 Quarry

Normally quarry activities involving the use of explosives and excavation of land. Soil structure slopes become loose. Vibration caused by the use of explosives causing soil and rock slopes are easily broken and collapsed**.**

2.4.2.2 Logging activities

Plant roots serves to hold and grip the soil on the slopes. The absence of vegetation causes soil on the slopes unstable and easily collapsed. So logging and deforestation may speed up the process of slope failure especially in the slope of the precipice.

2.4.2.3 Development

Development activities such as construction of roads, infrastructure in the slope will cause deforestation of the area of origin. Deforestation will reveal the surface of the earth to the activity that caused the weathering of soil in the area to become loose and unstable. Soil loose and unstable easy to fall in the occurrence of vibration, rain and so on. Similarly, the construction of buildings on the slopes such as the construction of hotels, residences and so will involve the work of excavating and clearing of natural vegetation in that area. The exposed surface of the earth and loose soil will accelerate the process of slope failure. (Zuhairi, 2007)

2.5 Site investigation

Before the commencement of construction work, site investigation is preliminary work that must be done before any work is commenced design and civil engineering. However, site investigations usually depend on the overall size and type of structure in a project. In fact, in certain circumstances the work of small civil engineering also requires investigation site. For the construction of the slope, site investigation is to:

i. Provide a suitable slope design, complete, economical and safe.
ii. Determine soil texture, thickness and area of the side of a layer of soil and bedrock level.
iii. Determine the most appropriate alternative in the choice of site for the project to be implemented.
iv. To obtain a representative sample of soil (and rocks) for the purpose of identification and classification, used in laboratory tests to determine the appropriate soil parameters.
v. Identify groundwater conditions.

Results of site investigations are very important for the next process in terms of design, cost and alternative construction project. There are some details that need to be considered during the planning process are:

i. Information regarding the condition of ground water, including cedar and level exchange according to the season, soil water pressure, etc.
ii. Information involving the design; such as shear strength of soils, soil compaction, and others.
iii. Explanation of the effects of the changes that may occur either naturally or as a result of construction.

2.6 Factor of Safety (FOS)

Usually, slope stability is evaluated in terms of Factor of Safety (FOS). Analysis of stability of slopes in terms of FOS is important to define the stability of a slope. (Agrahara Krishnamoorthy, 2007). In other words, FOS is the ratio of the available shear strength required for achieving equilibrium state as shown in the Equation 2.3.

$$\text{FOS} = \frac{\text{resisting force}}{\text{driving force}} = \frac{\text{shear strength}}{\text{shear stress}} \qquad \text{(Equation 2.3)}$$

FOS is not a measure of stability at a point; it is a number that represents averaging. In addition, factor of safety cannot be measured in the field. Modeling a slope is a difficult task since the FOS is model-dependent. Generally, a stable slope can be verified when the FOS value is significantly greater than 1.0. However, there are in Malaysia standards set by the Public Works Department (PWD). As a reference, the FOS as the Table 2.1 is a general standard for slope stability. In most cases of design slope, the typical minimum FOS is about 1.5 for long-term loading conditions and 1.5 for temporary slope or end-of-construction conditions in permanent slopes (Kramer, 1996).

Table 2.1: Guidelines for Limit Equilibrium of a slope

Factor of safety	**Detail of slopes**
< 1.0	Unsafe (fail)
1.0 – 1.25	Questionable safety
1.25 – 1.4	Satisfactory for routine cuts and fills
> 1.4	Satisfactory for dams

2.7 Method of analysis

To fulfill objectives of the study, the conventional method and software has been used. For the conventional method, Microsoft Excel was used for analysis. While for the computer software, the SLOPE / W were used.

2.7.1 Computer software, Geo-Studio 2007 (SLOPE/W)

SLOPE / W are one of the software components in a product complete geotechnical and it's called Geo-Studio and the cover of the software can be seen in the Figure 2.11. One of the features of this software is able to analyze various types of analysis, larger and more complex problems. The main role of this software is to get the safety factor of the slope. This software is also able to solve complex problems in terms of surface, soil characteristics, and load conditions. With its comprehensive features, SLOPE/W can be used to analyze almost any slope stability problems that would be encountered in civil engineering especially in geotechnical engineering and construction. To complete this study, the student's versions were used. Although there are some restrictions in its use, especially in terms of analyzing the load imposed on the slopes. However, the situation does not interfere with the ongoing research.

Figure 2.11: Computer software; GeoStudio

Source: Civil Engineers PK, 2015

Computer software, SLOPE / W has the ability to analyze a problem to get the slope safety factor using various methods, namely:

i. Ordinary Method, 1927.
ii. Simplified Bishop Method, 1955.
iii. Janbu's method, 1956.
iv. Morgenstern and Prices method, 1965.

v. Spencer’s method, 1967.

The method commonly used is the ordinary method of slices. This method used trial and error to get the minimum safety factor of a slope.

2.7.1.1 Ordinary Method of Slices (Fellenius, 1927)

This method is a procedure of slices that neglects the forces on sides of slices as show in Figure 2.12. Fellenius methods also assume a circular slip surface and sums moment about the center of the circle; the method only satisfies moment equilibrium. Other than that, this method also convenient for hand calculation because this method permits the factor of safety to be calculated directly. All of the others procedure of slices described subsequently required an iterative, trial and error solution for the factor of safety. This method also less accurate than other procedure of slices. The accuracy is less for effective stress analysis and decreases as the pore water pressure become larger. (J. Michael Duncan and Stephen G.Wright). Accuracy of this method can be improved by using Equation 2.4.

$$F = \Sigma \frac{(c'L + (W\cos\alpha - uL)\tan\varphi')}{\Sigma W \sin\alpha} \qquad \text{(Equation 2.4)}$$

where

Fs = factor of safety

c’ = effective cohesion of soil (kN/m^2)

L = length of slices (m)

W = weight slice (= $\gamma \times$ slices area ($\frac{kN}{m}$)

$\alpha =$ inclination of slip surface (degree)

$\emptyset' =$ effective friction angle of the soil

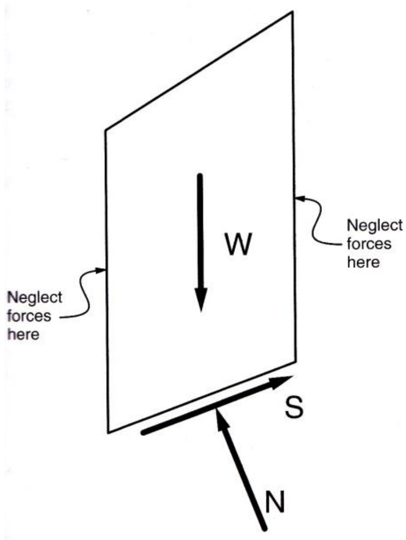

Figure 2.12: Slices with forces considered in Ordinary Method of Slices

Source: Wikipedia, 2015

2.7.1.2 Simplified Bishop Method

In the Simplified Bishop procedure the forces on the sides of the slices are assumed to be horizontal (no shear stresses between slices). The overview of this assumption can be seen in Figure 2.13. Forces are summed in the vertical direction to satisfy equilibrium in this direction and to obtain an expression for the normal stress on the base of each slice. The equilibrium equation can be expressed for forces in the vertical direction as show in Equation 2.5. (J. Michael Duncan and Stephen G.Wright).

$$N \cos \alpha + S \sin \alpha - W = 0 \qquad \text{(Equation 2.5)}$$

where

N = normal forces

$\alpha =$ inclination of slip surface (degree)

S = shear strength

W =weight slice (= $\gamma \times$ slices area ($\frac{kN}{m}$)

Other than that, this method also gives relatively accurate value for the factor of safety. Bishop (1955) showed that the procedure give improved result over the Ordinary Method Of slices especially when analysis are being performed using effective stresses and pore-water pressure are relatively high.

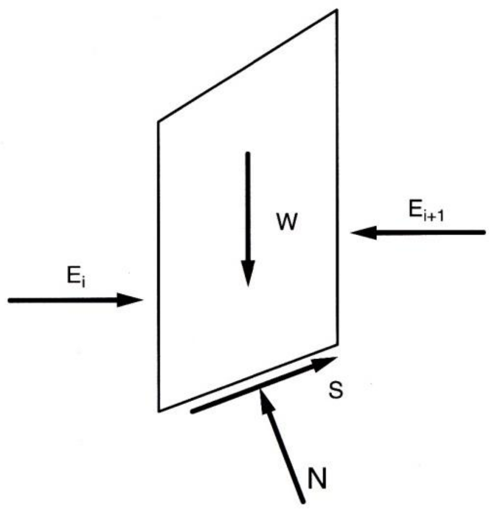

Figure 2.13: Slices with forces for the Simplified Bishop method

Source: Wikipedia, 2015

2.8 Slope stability

Slope stability is one of the issues that exist in civil engineering. Other than that, the stability of the slope has also given attention by some of the parties to the case as serious landslides caused by various factors and consequently had to sacrifice human lives and damage to property. Therefore, measures critical slope and slopes stabilization efforts undertaken by the authorities by way of compaction, reducing the load on the slope, increasing shear stress on the slopes and build water drainage systems on the slopes. Bio-engineering methods (bioengineering) and plants cover can also be done to control the stability of a slope.

Stability of slopes can be improved by compaction method. This method is usually done in reclaimed slope to increase stability. This method is usually done using vibrator machinery. By performing compaction, air voids in the soil can be compressed into a strong and solid condition. Indirectly, reduce the ratio of the voids in the ground. For road construction, the compaction is mandatory element for increasing the strength of the soil and sub-grade. Compaction method was also influenced by several factors such as the characteristics of the soil, the water content and the type of vibrator. (Muhamad Fadzly bin Muhamad Mohtar, 2011).

Besides from that, slope stability can also be enhanced through the construction of retaining walls, gabion walls (Figure 2.14), soil nailing (Figure 2.15), rock buttress (Figure 2.16), Geocell and hydrosedding (Figure 2.17) and also spray concrete on sloping surfaces. This method can be seen especially in the construction of highways to ensure the slope is stable and safe for public use.

To resolve issues of surface runoff, drainage on slopes is also an effective method to control the stability of the slope. Effective drainage system is able to reduce the rate of surface runoff.

As a conclusion, slope analysis also plays a role in determining the appropriate methods for controlling and improving the slopes in Malaysia. That’s methods are the best alternative for reducing the risk of slope failure indirectly endanger the safety of the public.

Figure 2.14: Gabion wall

Source: International Erosion Control Association, 2015

Figure 2.15: Soil nailing at slope

Source: Civil Kedar, 2013

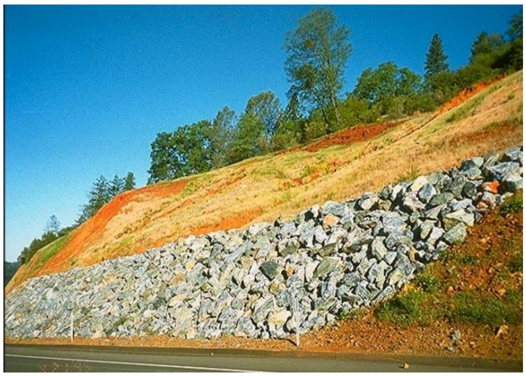

Figure 2.16: Rock buttress

Source: Bereau of Land Management, 2015

Figure2.17 : Geocell and hydrosedding

Source: ASP Enterprises, 2015

2.9 Previous studies on slope stability

There are several references to studies that have been conducted by several individuals who have become references in achieving the objectives of my research in the field of slope stability. A study conducted by them has become a benchmark and reference for me throughout my sessions. There are two studies which became my reference, which is:

i. Comparison Analysis of factor of safety for Slope Stability at Kolam Air Damai Perdana, Selangor, 2011.
ii. The Effect of Seismic Loading On Slope Stability Using Limit Equilibrium Method at Ibu Pejabat Jabatan Bomba dan Penyelamat Malaysia di Mukim Tebrau (Johor), 2012.
iii. Slope stability analysis and road safety evaluation at Piteå river- in Sikfors (Sweden), 2012.

2.9.1 Comparison Analysis of Factor of Safety for Slope Stability at Kolam Air Damai Perdana, Selangor, 2011.

Based on a study conducted by Muhamad Fadzly Bin Muhamad Mohtar at Kolam Air Panas Damai Perdana, the soil profiles were analyzed in the slope obtained from standard penetration test performed by contractors appointed by the consultant. Results of tests performed, the type of soil profiles identified in the slope is kind of soft sandy clay to solid dark gray. The cohesion(c) value for this type of soil is 52 KN/m^2, effective friction angle of soil, 'Ø' are 3 degrees and the unit weight of the soil of 17.65 KN/m^2. From the analysis also found that, there are no water tables in the soil at a depth of up to 12 meters from the ground.

After the analysis of method SLOPE / W is done, the factor of safety include the minimum factor of safety using Ordinary slices method, Bishop method, Janbu and Morgenstern and Price obtained. Table 2.2 shows the slope safety factor using Slice method (conventional) and SLOPE / W.

Table 2.2: Factor of safety using Slice Method (conventional) and SLOPE / W.

Slope	Conventional	Morgenstern Prices	Ordinary	Bishop	Janbu
Slope A-A1	2.1	2.5	2.5	2.5	2.6
Slope B-B1	1.7	1.9	1.9	1.9	1.9
Slope C-C1	1.8	2.5	2.4	2.4	2.4
Slope D-D1	1.6	2.0	1.9	1.9	2.0
Slope E- E1	1.6	1.9	1.8	1.8	1.8

From the results of the analysis found that all of the analysis conducted is located in a safe condition for the original slope of 1.25 to 1.4. Using the results of the safety factor SLOPE/W will provide a factor of safety for reading the four methods used in software SLOPE/W which means Morgenstern Price, Bishop Method, Ordinary Slices method and Janbu method.

Other than that, from the results obtained, the reading of the factor of safety using the Slope/W higher than conventional methods. A higher value makes the slope of the analyzed safer, but this would involve high costs in construction. Therefore, the ratio between the readings safety factor using both methods are obtained. Ratio of the readings obtained from five slopes using SLOPE/W and conventional, the average reading for a safety factor of slope divided by five readings slope-slope safety factor analyzed.

The average ratio of comparative safety factor value will be obtained. The average ratio value will be used as the coefficients of the analysis method SLOPE/W. For example, for the slope of the A-A1, the ratio of the average readings for analysis using the SLOPE/W method for Morgenstern Price methods is 0.83, this value will be used as a coefficient to the actual reading and an analysis of the proceedings of the more optimum safety factor will be obtained. This step is repeated on all slopes are analyzed. From Table 2.3, the factor of safety for the SLOPE/W method still on the safe condition. This suggests the use of an analysis SLOPE/W method still can optimize again. The effects of this analysis, construction cost can be saved.

Table 2.3: Result of Slope Factor of Safety Analysis using SLOPE/W method.

Cerun	Morgensten Price	Pekali	FOS	Ordinary	Pekali	FOS	Bishop	Pekali	FOS	Janbu	Pekali	FOS
Cerun A-A1	2.50	0.83	2.08	2.49	0.86	2.14	2.50	0.85	2.13	2.57	0.84	2.16
Cerun B-B1	1.90	0.83	1.58	1.88	0.86	1.62	1.89	0.85	1.61	1.89	0.84	1.59
Cerun C-C1	2.50	0.83	2.08	2.39	0.86	2.06	2.41	0.85	2.05	2.42	0.84	2.03
Cerun D-D1	2.00	0.83	1.66	1.91	0.86	1.64	1.92	0.85	1.63	2.00	0.84	1.68
Cerun E-E1	1.90	0.83	1.58	1.76	0.86	1.52	1.76	0.85	1.50	1.79	0.84	1.50

From the results of analysis conducted safety factor, there is a difference in the slope safety factor; the difference in value of the safety factor is different if using SLOPE / W. Proceedings of the minimum value of the difference of methods SLOPE/W is the Ordinary slices method, which is simply the difference of 0.14%. For the Bishop method, the safety factor is the difference of 0.15%. For Janbu’s and Morgenstern Price methods, the percentage difference of only 0.16 and 0.17%. The table 2.4 has shown the difference factor of safety between Slices method and SLOPE/W method.

Table 2.4: Difference of Factor of Safety (FOS) between Slices method and SLOPE/W method

Slope	Ordinary slices method	Morgenstern Prices	% difference	Ordinary	% difference	Bishop	% difference	Janbu	% difference
Slope A- A1	2.1	2.5	0.2	2.5	0.2	2.5	0.2	2.6	0.2
Slope B-B1	1.7	1.9	0.1	1.9	0.1	1.9	0.1	1.9	0.1
Slope C-C1	1.8	2.5	0.3	2.4	0.2	2.4	0.2	2.4	0.2
Slope D-D1	1.6	2.0	0.2	1.9	0.2	1.9	0.2	2.0	0.2
Slope E-E1	1.6	1.9	0.1	1.8	0.1	1.8	0.1	1.8	0.1
Total			0.8		0.7		0.7		0.8
Average			0.17		0.14		0.15		0.16

From the information in Table 2.4, the analysis of slope stability safety factor for soil profiles of the type of clay is between 0.14% until 0.17%. Analysis of SLOPE/W for the Ordinary method has the fewest differences between other methods. Therefore, the use of analysis using conventional methods and Slope / W is practically used. Use analyzed using SLOPE/W can facilitate the analysis of the safety factor of the slope and slope analysis makes work faster. However, this method can be performed revision using conventional methods as reference.

2.9.2 The Effect of Seismic Loading on Slope Stability Using Limit Equilibrium Method at Ibu Pejabat Jabatan Bomba dan Penyelamat Malaysia at Mukim Tebrau (Johor), 2012.

Based on the study that conducted by Mohd Riza Aizad bin Shauri at Ibu Pejabat Jabatan Bomba dan Penyelamat Malaysia at Mukim Tebrau (Johor), software was used to obtain the pseudo-static coefficient and the coefficient was used as a parameter for Slope/W software analysis. The results from NERA analysis indicates that the peak ground acceleration (PGA) value for 500year return period is 0.090g while PGA value for 2500year return period is 0.093g.

Based on the results from NERA analysis, it can be said that the PGA values for both 500 and 2500 years return period are considered relevant since the PGA value in Johor Bahru is higher than 0.025g for 500year return period and 0.035g for 2500year return period.

However, according to the Modified Mercalli Intensity (MMI) Scale, the PGA values for both seismic conditions represent very strong earthquakes. These conditions are not logical for Peninsular Malaysia because according to Adnan et al. (2005), Peninsular Malaysia is located in the stable Sunda Shelf with low to medium seismic activity level which means Peninsular Malaysia is not susceptible to that level of intense of earthquake shaking.

The slope was model by referring the slope profile from the slope profile from the site investigation report. The input parameters for the slope model are as tabulated in Table 2.5.

Table 2.5: Input parameters for slope analysis

Soil layer	Unit weight, γ (kN/m^3)	Saturated unit weight, γ_{sat}(kN/m^3)	Angle of internal friction, ϕ' (^{o})	Soil cohesion, c' (kPa)
1 (Hard clay)	19	19	33	20
2 (Soft clay)	19	19	33	15

For the comparison of Factor of Safety (FOS) between Limit Equilibrium (LE) methods, since the flow of FOS for all three seismic conditions is the same, the comparisons of methods of analysis were discussed generally. Table 2.6 shows the results of FOS for all three seismic conditions.

Table 2.6: The FOS obtained from SLOPE/W analysis

METHOD	FACTOR OF SAFETY		
	α_1=0.000g (no seismic effect)	α_2=0.090g (500year return period)	α_3=0.093g (2500year return period)
Ordinary Method (OM)	1.750	1.478	1.468
Bishop's simplified Method(BSM)	2.041	1.668	1.658
Janbu's Simplified Method (JSM)	1.786	1.485	1.475
Morgenstern Prices(M-PM)	2.043	1.676	1.666
Spencer Method (SM)	2.044	1.678	1.668

Based on the result from Table 2.6, it can be said that Spencer Method has the highest value of FOS in all three seismic conditions. This may due to its principle of assuming a constant inter-slice force function and the equation of static that satisfies both moment and force equilibrium.

Morgenstern-Price Method has the second highest value of FOS. The FOS values however are slightly lesser than SM since this method uses arbitrary function to determine the direction of the resultant inter-slice forces. Followed by Bishop Simplified Method, the assumption used for this method is that the resultant inter-slice forces are horizontal.

Next is Janbu Simplified method. Even though the principles for this method are similar to BSM, the equation of static does not satisfy the moment equilibrium. However, Ordinary Method has the lowest value of FOS for all three seismic conditions. This is most likely because this method neglects both normal and shear inter-slice forces.

In a nutshell, the slope stability analysis using all five methods in this study were satisfied since the FOS values exceeds the minimum requirement of FOS required by the Guidelines of Slope Design by Slope Engineering branch, Public Work Department (PWD) Malaysia which is 1.3.

2.9.3 Slope stability analysis and road safety evaluation at Piteå river- in Sikfors (Sweden) (2012).

Based on a study conducted by Md. Zillur Rahman at Piteå river, Sikfors, Sweden the stability of natural slopes ware analyzed for drained and undrained conditions by using Limit Equilibrium Methods (LEM) slope stability software SLOPE/W. Results from slope stability analysis are presented in Table 2.7 which is shows the factors of safety calculated by SLOPE/W utilizing the Morgenstern-Price methods, Ordinary method, Modified Bishop Method and Janbu method.

Table 2.7: The factors of safety calculated by SLOPE/W

Method	Section							
	B1		B2		C1		C2	
	Drained	Undrained	Drained	Undrained	Drained	Undrained	Drained	Undrained
Morgenstern Prices	1.830	1.814	1.355	1.146	1.312	0.994	0.879	0.747
Ordinary	1.782	1.814	1.187	1.146	1.306	0.853	0.897	0.745
Modified Bishop	1.840	1.814	1.361	1.146	1.314	0.996	0.886	0.751
Janbu	1.783	1.818	1.250	1.148	1.309	0.840	0.899	0.746

A distinction should be made between drained and undrained strength of cohesive materials. As cohesive materials or clays generally possess less permeability compared to sand, thus, the movement of water is restricted whenever there is change in volume. So, for clay, it takes years to dissipate the excess pore water pressure before the effective equilibrium is reached. Shortly, drained condition refers to the condition where drainage is allowed, while undrained condition refers to the condition where drainage is restricted.

Besides, the drained and undrained condition of cohesive soils, it should be noted that there is a decline in strength of cohesive soils from its peak strength to its residual strength due to restructuring. The existence of trivial failure surface is a large problem in stability analysis of natural slopes and we try to avoid these types of failure. That's why we sometimes cut some portions of the slope or use high strength soil parameters in exposed part, i.e. cohesion, c´ = 100 kPa, and friction angle, $\phi' = 45^{o}$.

In Slope/W analysis we consider critical slip surface failure. If the critical failure is trivial, then we consider the secondary failure.

Landslides on the slope in the area Sikfors Stora occurred very potently and the soil has progressed into the river. In this area we selected two section B and section C between the road 374 and the Piteå River for analysis. Soil properties were evaluated from by CPT sound test result presented in Table 2.8 and Table 2.9. The ground water table found in this area is approximately situated 6 meter below the ground surface at the crest in the spring season. In the autumn season we found that the groundwater levels the same as the river level.

Table 2.8: Geotechnical parameters of section B1/B2 for the different layers

Soil layer	**γ_{sat} (kN/m3)**	**γ_{unsat} (kN/m3)**	**Friction angle, ϕ, (º)**	**Undrained shear strength, τ**	**Cohesion, c' (kPa)**	**Young Modulus E (MPa)**	**Poisson ratio, *v***
saSi	17	11.11	34	-	10.0	3.00	0.33
Si	17	11.11	38	-	10.0	2.00	0.33

Table 2.9: Geotechnical parameters of section C1/C2 for the different layers

Soil layer	**γ_{sat} (kN/m3)**	**γ_{unsat} (kN/m3)**	**Friction angle, ϕ, (º)**	**Undrained shear strength, τ**	**Cohesion, c' (kPa)**	**Young Modulus E (MPa)**	**Poisson ratio, *v***
saSi	18	12.70	33	-	10.0	15.90	0.33
Si	15	7.94	28	-	10.0	19.20	0.33
MSa	18	12.70	34	-	-	19.40	0.33
Cl	15	7.94	28	15-80	1.5 -8	2.00	0.33
saSi	18	12.70	35	-	10	39.25	0.33

In section B1, it is a low ground water table in the slope and a low water in the river. In section B2 the pore pressures are high because of a high ground water table in the slope while the water level is low in the river. Most likely the worst case scenario occurs when the river water level is increased rapidly, and then quickly drops while the water table in the embankment is retained on an extremely high level so that the low effective stresses might lead to failure.

Figure 2.18 and Figure 2.19 shows the sensitivity analysis in section B1 under drained condition. In Table 2.10 content different analysis result.

In section C1 and C2, we find factor of safety below the allowable limit due to the trivial failure. The results of these calculations show that the slope is stable and meet with Swedish road administration guide line TK Geo 11.

Table 2.10: Factor of safety for Sikfor Stora

Section name	Slope/W		Plaxis 2D		Tyrens analysis		TK Geo Allowable	
	D*	UD*	D*	UD*	UD*	C*	UD*	C*
B1	1.830	1.814	2.080	1.870	-	1.720	1.500	1.300
B2	1.355	1.146	1.500	0.880	-	1.300	1.500	1.300
C1	1.312	0.994	1.230	1.148	-	1.100	1.500	1.300
C2	0.879	0.747	1.220	0.600	-	0.620	1.500	1.300

*D = Drained, *UN = Undrained and *C = Combined Analysis

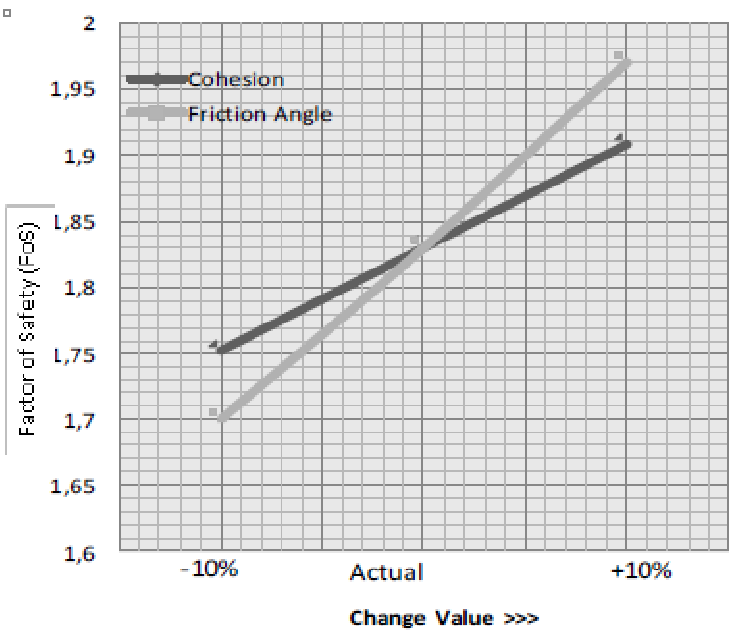

Figure 2.18: Section B1 sensitivity analysis for friction angle and cohesion in drained condition

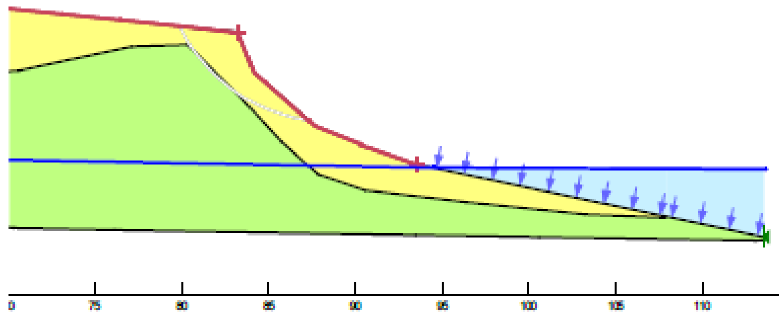

Figure 2.19: Safety map in drained condition at section B1

In section B1/B2, we found that the soil is cohesive (i.e. Silt and sandy Silt). The cohesion of a clay soil changes significantly depending on the presence of water. In dry conditions clay soils can break up into lumps. If the soil is very dry and the lumps are small then a clay soil can behave (at least locally) very much like a frictional soil. In Figure 2.14 show that, with friction angle, ϕ and cohesion, c change constantly where the safety factor change linearly.

In section C1, it is a low groundwater table in the slope and a low water level in the river and in section C2; it is a high groundwater table in the slope and a low water in the river. In the same way as in section B1/B2 is the most likely worst case scenario simulated for section C1/C2. In section C2 the pore pressures are high because of the high groundwater table in the slope. Most likely the worst case scenario occurs when the river water level is increased rapidly, and then quickly drops while the water in the embankment is retained on an extremely high level so that the low effective stresses might lead to failure. The slope is not smooth. At the bottom portions of the slope, the inclination is quite low (36^0) and at the top of the slope, the inclination are quite high (65^0). In this section we found different type of soil layer, i.e., sand, silt and medium sand.

The worst case scenario has been simulated in the calculation cases section C2 and the results show that the slope computationally under these conditions is stable. The silt layer is the most important factor to occur the failure of the slope. From Figure 2.20 we can find out the different slip surface. The more favorable condition after drainage, when the groundwater table in the slope is on the same level as the water level in the river, has been simulated in the calculation case of section C. Here the drained calculations are more important. The results of these calculations show that the slope is stable and meet with Swedish road administration guide line TK Geo 11.

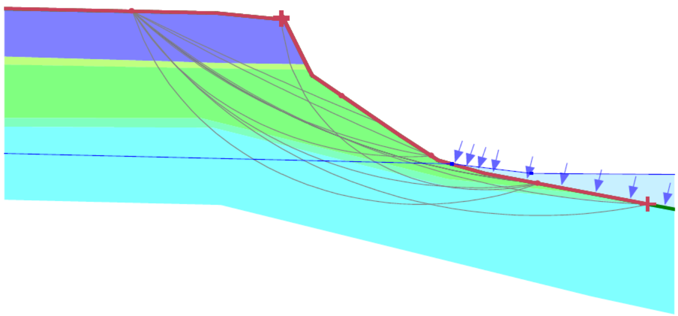

Figure 2.20: Multiple slip surfaces in drained condition at section C1

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter explains the methodology that has been done to achieve the objectives listed. The methodology for this study was divided into several phases to facilitate more effective investigation. The first phase of this study was to obtain information about site investigation study area. The next phase will describe a method to obtain a factor of safety of three cross slope was analyzed using conventional methods and using the computer software Geo-Studio (SLOPE / W) version of the student. After the factor of safety of both methods obtained, comparison of both methods will be conducted and the results obtained. Work flow chart shown in the Figure 3.1.

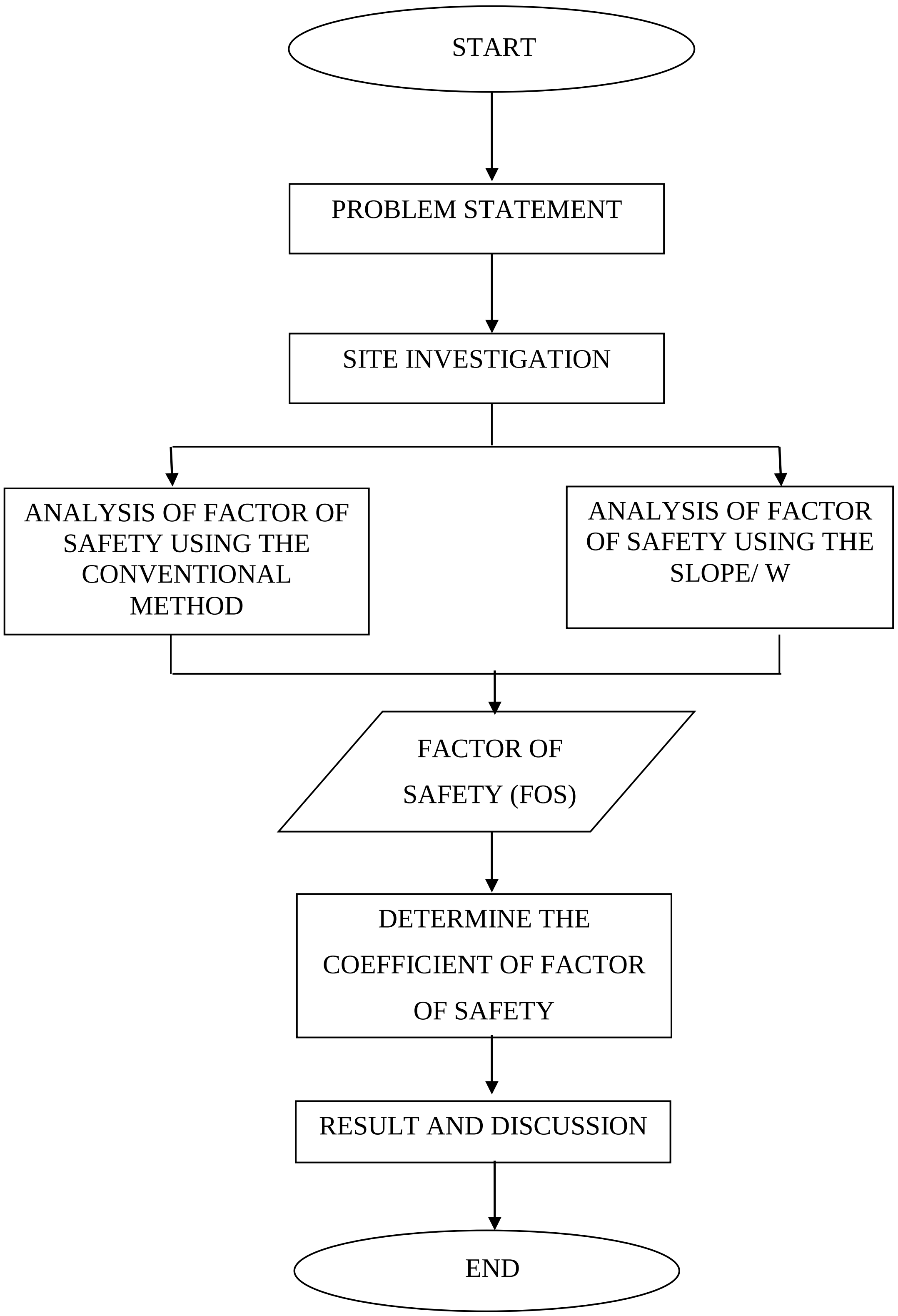

Figure 3.1: Research Methodology.

3.2 Research methodology

Research methodology is divided into four phases. Each phase is divided to achieve the objectives of this study. The first phase is the collection of data for the study area. This process involves the results of tests in the laboratory and also of the cross-section of land in the study area. The second phase is the factor of safety analysis using conventional methods and also computer software, Geo-studio (SLOPE/W). While, the third phase is the comparison between the factor of safety analysis method. And the fourth phase, analysis and discussion. Each phase is described in more detail below:

3.2.1 Phase I: Data collection of area study.

In this phase methodology, site investigation report has been reviewed in order to get information required in the analysis process. All necessary information is obtained from laboratory tests and also the slope of the soil profile. From the results of Standard Penetration Test conducted, the cohesion of the soil 'c' kN / m^2, the effective angle of friction 'ϕ' ', the unit weight of saturated soil' γ 'kN / m, height of water table' Z_w 'meter and surface slope angle earth 'α' degrees was obtained. The data obtained will be used to calculate the factor of safety for slope studied using conventional methods and SLOPE / W.

3.2.2 Phase II: Safety Factor Analysis

This phase describes how the two methods of analysis for the factor of safety for slope studied. There are two methods that run the conventional methods and also computer software. All data required for this analysis was obtained from Phase I.

3.2.2.1 Conventional method

General calculation for infinite slope methods in sand was used to obtaining the safety factor. The calculation for factor of safety analysis of the slopes will be performed on three cross-section of slope failure. Computer software 'Microsoft Office - Excel' has been used to simplify the calculations done while reducing the risk of error during calculation process if done manually. Microsoft Office software can also save time.

3.2.2.2 Computer software method; Geo-studio (SLOPE/W)

Software SLOPE/W 2007 student version used to obtain the slope safety factor studied. Three cross-sectional slopes have been analyzed. The information used to analyze slope are composed of soil cohesion value 'c', the unit weight of saturated soil 'γ' and effective friction angle 'φ' obtained from the investigation site using borehole 'borehole log'. Although there are some restrictions on its use, particularly in terms of the burden imposed on the slopes. However, the situation does not interfere with the investigation.

3.2.3 Phase III: comparison factor of safety method of analysis

Comparison between the conventional method and SLOPE/W will be made after analysis of the factor of safety using both methods performed on the three cross slopes identified. After that, the average value for the conventional method will be divided by the average reading method SLOPE / W. The results of the division of the average value of both of these methods will produce a coefficient value that will be used as the multiplier for the method SLOPE/W value. The value of the difference between analysis using conventional methods and SLOPE /W will be performed to determine the difference of the two methods of slope stability analysis.

3.2.4 Phase IV : Analysis and Discussion

For the final phase, the results of the comparison between the two methods will be discussed. Coefficients obtained from the comparison will be used to get optimum factor of safety value which is can save costs. In this phase, the proposed optimum method of construction or improvement of slope, resulting from differences between the methods used for analysis. In addition, the advantages and disadvantages of both methods will be discussed in this phase.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

Construction, improvement works and slope control at KM259.95 the North-South Expressway is one of the methods needs to be done to avoid undesirable events occur such as landslides. To implement and promote the improvement of planning, all aspects have been considered, such as the cause, soil and slope conditions before the slope improvements carried out.

4.2 Soil profile

The information needed to perform the analysis of this study was obtained from a site investigation report. Reports indicate soil in the slope of the cross section consisting of a granite, sand and silt. For silt layer that potential to contribute to the slope failure has description as sandy silt and reddish brown in color. While the explanation of sand, the reddish very silt gravelly sand**.** Table 4.1 shows the parameters of the soil on the slopes of the study and Figure 4.1 shows the cross section for the soil profile of the slope that contains silt, sand and granite.

Table 4.1: Soil properties

Soil Property	**Silt**	**Sand**
Unit weight of soil (γ) , kN/m^3	18.25	16.19
Cohesion (c') , kN/m^2	0	0
Angle of internal friction (ϕ ')	39^o	39^o

SLOPE SURFACE

SILT

- γ= 18.25 kN/m^3, c'=0 kN/m^2, ϕ '= 39^o

SAND

- γ= 18.25 kN/m^3, c'=0 kN/m^2, ϕ '= 39^o

GRANITE

- Impenetrable layer

Figure 4.1: Simplified soil profile

4.3 Mechanism of failure

From the research that has been conducted at KM259.95 the North-South Expressway based on soil cross section and soil parameters, the slope has the potential to fail in term of flowage especially during the rainy season. In other words, debris flow which is combination of loose soil, rock, organic matter, air, and water mobilize as slurry that flows down. Debris flows also commonly mobilize from other types of landslides that occur on steep slopes, are nearly saturated, and consist of a large proportion of silt and sand-sized material. Fires that denuded slopes of vegetation intensify the susceptibility of slopes to debris flows.

Other than that, presence of granite in the slope which is at the lower layers of silt and sand has also led to the occurrence of slope failure because granite has a very significant difference parameter compared silt and sand. This situation better appreciated if the rainy season, and the presence of water causing the top layer of the surface slope becomes saturated and water cannot penetrate into granite layer.

4.4 Safety factor analysis for slope

The result of the factor of safety calculation using the conventional method and SLOPE / W, all the factor of safety is in critical condition, around 1.000, particularly using conventional methods. Table 4.2 shows the FOS of slopes for both methods of analysis used.

Table 4.2: Factor of safety for conventional method and SLOPE/W

Factor of safety (FOS)	Conventional method	SLOPE /W			
		Morgenstern Price	Janbu	Ordinary	Bishop
Cross section A (BH1, BH2 & BH3)	1.036	1.156	1.091	1.090	1.135
Cross section B (BH2 & BH3)	1.000	1.509	1.283	1.303	1.392
Cross section C (BH1 & BH3)	1.036	1.284	1.250	1.251	1.300

Based on the FOS in Table 4.2, it shows that the entire FOS is questionable in terms of safety whose value is 1.00 to 1.25. Only several values of FOS from SLOPE / W indicate that in safe FOS for slope construction. Based on the value obtained in Table 4.2 and Figure 4.2, the FOS of the SLOPE / W is higher than the conventional method. High FOS value, theoretically would lead to high construction costs, stabilization and maintenance.

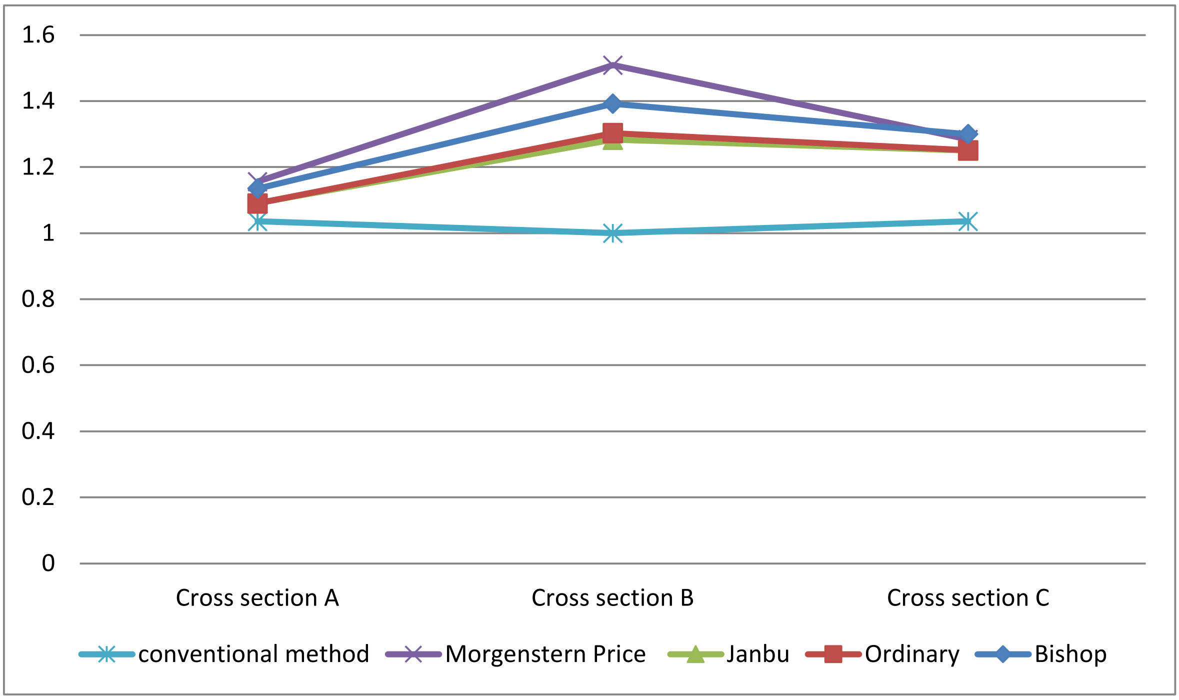

Figure 4.2: Graph of FOS Analysis Method using Conventional and SLOPE / W

4.5 Comparison of analysis

Analysis using different methods necessarily has different results even have some similarities. These differences can be used as benchmarks to determine whether the use of different methods appropriate to compare or not. Regarding to that, a comparison of the FOS using the conventional method and SLOPE / W for the slopes at KM 259.95 the North-South Expressway has been carried out to ensure the safety for the construction of the slope. Table 4.3 shows a comparison between the conventional method (infinite slope method in sand) and SLOPE / W which is the percentage difference was obtained.

To obtain the percentage difference, the FOS of analysis SLOPE / W was minus by the FOS from conventional method. Then, divide by the FOS from SLOPE / W. This method is adapted to all FOS of SLOPE / W. The result can be seen in Table 4.3.

Table 4.3: Comparison Analysis between conventional method and SLOPE W

Factor of safety (FOS)	Conventional method	Morgenstern Price	% difference	Janbu	% difference	Ordinary	% difference	Bishop	% difference
Cross section A (BH1, BH2 & BH3)	1.036	1.156	0.104	1.091	0.050	1.090	0.050	1.135	0.087
Cross section B (BH2 & BH3)	1.000	1.509	0.337	1.283	0.221	1.303	0.234	1.392	0.282
Cross section C (BH1 & BH3)	1.036	1.284	0.193	1.250	0.171	1.251	0.172	1.300	0.203
Total			0.634		00.442		0.456		00.572
Average			0.211		0.147		0.152		0.191

From the Table 4.3, the analytical method for the minimum difference is Janbu method with a difference of 0.147%. While, Ordinary method with the percentage difference is 0.152 %. For Bishop and Morgenstern Price method, percentage difference is 0.191% and 0.211%.

4.6 Coefficient for slope stability

Therefore, to minimize the factor of safety of slope, the ratio between the readings FOS using conventional methods and SLOPE / W are obtained. The reading obtained from the ratio of the three cross-sections using the SLOPE / W and conventional will total up and, divided by three which means for three cross section for the average reading of coefficient for each FOS.

As an example for calculating the coefficients for Morgenstern Price, the FOS from conventional will be divided by FOS from SLOPE/W. This calculation will used for all other cross section. After that, all value from that calculation will total up before divided by three. Therefore, all cross section have the same coefficient that will multiply by FOS from SLOPE/W. For example, the FOS for cross section B; FOS for Morgenstern Price is 1.509 before multiplied by coefficient. After multiplied by coefficient, the values of FOS are reduced to 1.191. The situation is the same for all the FOS and it can be seen in Table 4.4 and Figure 4.3.

Table 4.4: The result of the factor of safety using SLOPE/W software

Cross section	Morgenstern Price (BEFORE)	coefficient	Morgenstern Price (AFTER)	Janbu (BEFORE)	coefficient	Janbu (AFTER)	Ordinary (BEFORE)	coefficient	Ordinary (AFTER)	Bishop (BEFORE)	coefficient	Bishop (AFTER)
Cross section A (BH1, BH2 & BH3)	1.156	0.789	0.912	1.091	0.853	0.908	1.090	0.848	0.924	1.135	0.809	0.918
Cross section B (BH2 & BH3)	1.509	0.789	1.191	1.283	0.853	1.094	1.303	0.848	1.105	1.392	0.809	1.126
Cross section C (BH1 & BH3)	1.284	0.789	1.013	1.250	0.853	1.066	1.251	0.848	1.061	1.300	0.809	1.052

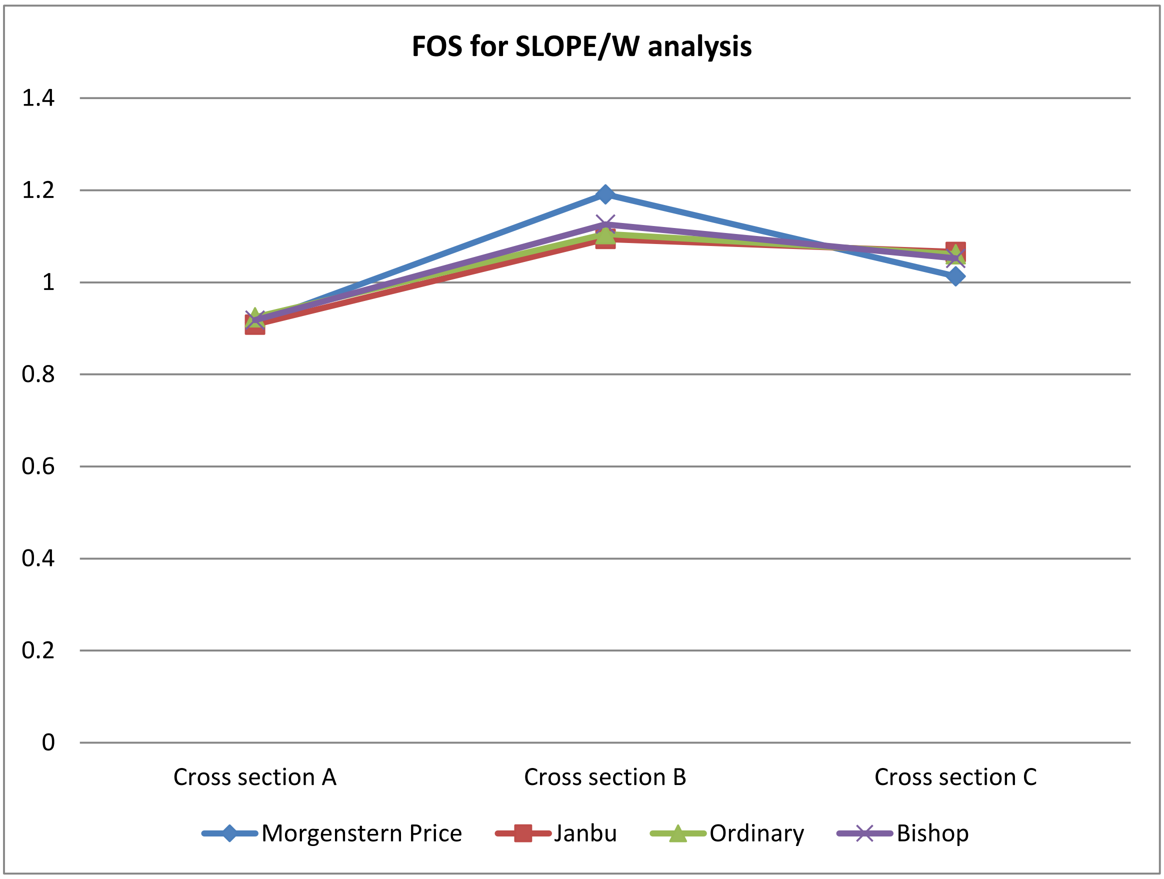

Figure 4.3: Graph of the safety factor using SLOPE/W software (After)

To make it convenient comparison between before and after the safety factor multiplied by coefficient, Figure 4.4 shows the factor of safety for SLOPE/W analysis methods.

Overall, the slope of the study is one of the critical slopes at KM259.95 the North-South Expressway, which has a factor of safety about 1.000. This situation will be something unexpected to everyone, especially when the slope of this study is exposed to various factors that lead to slope failure mechanisms such as the rainy season and deforestation on the hillsides. Based on the analysis carried out using conventional methods and SLOPE / W, safety factor of slope for both methods is in a questionable level of safety which was around 1.000 to 1.250. These situations are not safe and should be solved by methods of treatment the slope or slope stabilization because a standard by Public Work Department (PWD) for the untreated cut slope must greater than 1.3 and for the treated cut slope must be greater than 1.5.

While for the factor of safety of the SLOPE / W after multiplied by the coefficient also in unsafe condition, in other words, a slope failure will occur. This situation can be seen in Figure 4.3 and Figure 4.4, which is, in cross-section A, for all kinds of analysis, has resulted in the factor of safety less than 1.000. Therefore, improvements must be made with the slope of the most effective methods to prevent landslides in the future.

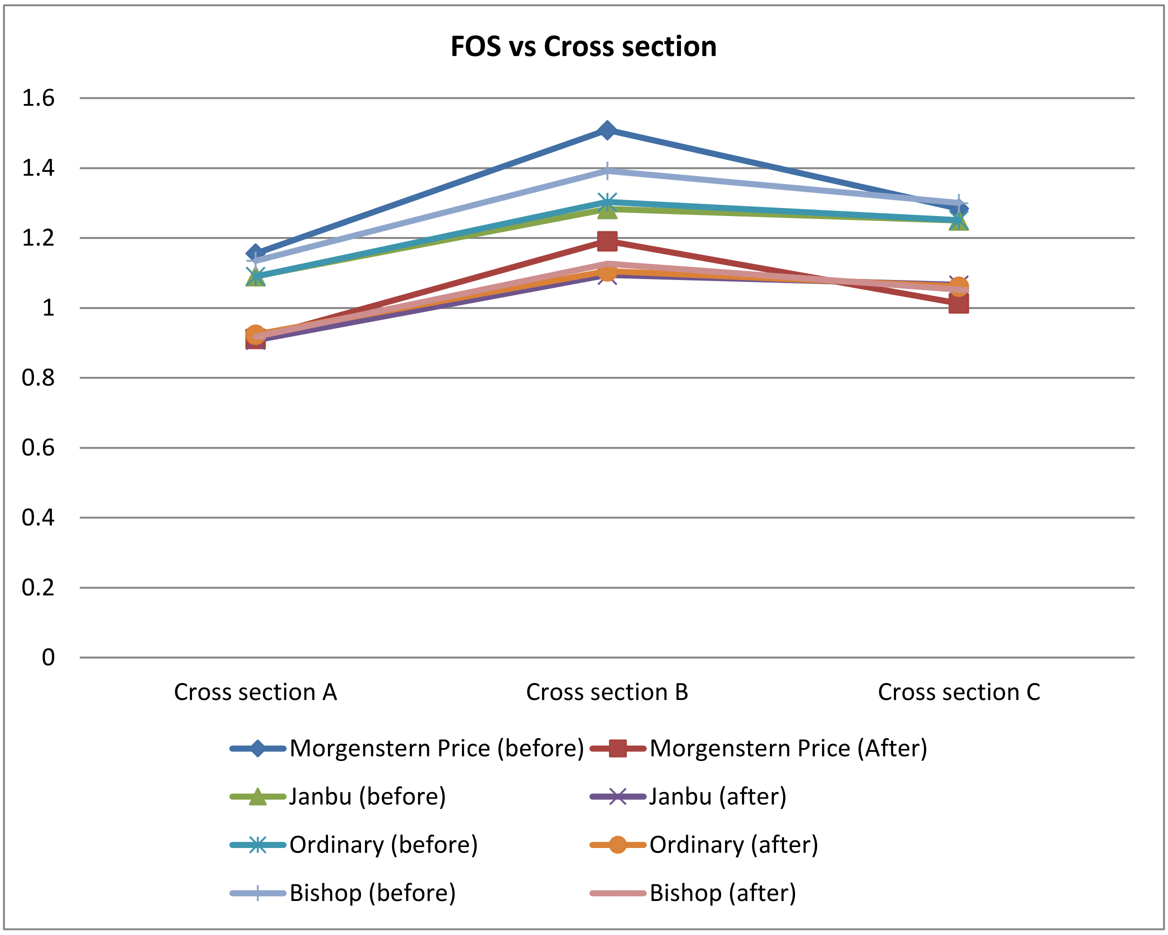

Figure 4.4: Reading pattern of safety factor for SLOPE/W

4.7 Discussions

Overall, the conventional method and SLOPE W is very suitable for analyzing the stability of slopes in addition to the work of analyzing the slope be faster and more effective. Conventional methods still need to be used as a guide to measure and analyze a slope. While SLOPE/W are very suitable to use when there are complex problem in term of analyzing of factor of safety. This software also easily to learn especially for those wish to enter the field of civil engineering especially related to the slope. However, SLOPE/W for student version, there are some limited usage in term of analyzing the load imposed on the slopes. However, the situation does not interfere with the ongoing research. For the conventional method, these methods are easily exposed to an error during calculation.

For the methods that can be used to treat the research slopes are drained by using a rock buttress. This method is often used in Malaysia and it does not require high maintenance costs. The use of 'geocell' and 'hydrosedding' can also be used to overcome the failure of the slope by slope surface layer protects and strengthens the bonds between soil particles at the surface of the slope.

CHAPTER 5

CONCLUSION

5.1 Conclusions

As a conclusion, cut slope at KM259.95 the North-South Expressway are in critical condition because factor of safety is in the range which is quite worrying especially the factor of safety that obtained from conventional methods. Other than that, the factor of safety of the two methods are also in questionable safety with FOS 1.000 to 1.250 This situation is very dangerous to the public especially the slope is on the route of the Expressway . In addition, the FOS of research slope also did not fulfill the standards that fixed by the Jabatan Kerja Raya (JKR) which is untreated slope must exceed 1.3 and treated slope must exceed 1.5.

From this research, the FOS for cross section A, cross section B and cross section C using conventional method (infinite slope method in sand) are 1.036, 1.000 and 1.036 respectively. While for the FOS for cross section A using SLOPE/W for Morgenstern Price, Janbu, Ordinary and Bishop are 1.156, 1.091, 1.090 and 1.135 respectively. For the cross section B, the FOS for Morgenstern Price, Janbu, Ordinary and Bishop are 1.509, 1.283, 1.303 and 1.392 respectively. And for cross section C, the FOS for Morgenstern Price, Janbu, Ordinary and Bishop are 1.284, 1.250, 1.251 and 1.300 respectively. Overall, the FOS from SLOPE/W is higher than FOS from conventional method.

For the comparison of FOS between conventional method and SLOPE/W, Percentage difference for Morgenstern Price, Janbu, Ordinary and Bishop is 0.211%, 0.147%, 0.512 % and 0.191% respectively.

For the coefficient of FOS for SLOPE/W, for Morgenstern Price, Janbu, Ordinary and Bishop is 0.789, 0.853, 0.848 and 0.809 respectively.

Generally, the FOS for cut slope of research is critical and requires immediate treatment with appropriate improvements in order to make sure public safety are guaranteed and both method still suitable to be used as a way to get the optimum safety factor of slope.

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