# ANALYSIS OF SLOPE FAILURE AT KM 43.2 ROUTE C130 KUALA WAU-KERTAU ROAD USING SLOPE/W

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# ANALYSIS OF SLOPE FAILURE AT KM 43.2 ROUTE C130 KUALA WAU-KERTAU ROAD USING SLOPE/W

**MUHAMMAD HAFIZ BIN ISHAK**

A report submitted in partial fulfillment of the
requirements for the award of the degree of achieving
Bachelor of Civil Engineering

**Faculty of Civil & Earth Resources**
**Universiti Malaysia Pahang**

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I declare that this project report entitled "*Analysis of Slope Failure at Km 43.2 Route C130 Kuala Wau-Kertau Road in Maran Using Slope/W* "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.

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*A special thanks to my beloved……*

*Father, Ishak bin Samsuddin,*

*Mother, Yatimah binti Sulaiman,*

*My siblings Hafidah, Faizah, Syafiq, Saufi, Syairah, Faris,*

*And to all my other family members,*

*And to all of my friends…*

*Thank you for all the supports that have been given to me.*

## ACKNOWLEDGMENT

Alhamdulillah, in the name of Allah I am grateful that I can finish this Final Year Project successfully and I wish to express my greatest appreciation to my supervisor ENGR. Muzamir bin Hasan, for his comments, critics, encouragements, advices and guidance towards this Final Year Project. His continuous passion and desire to guide me throughout the year in this Final Year project are highly appreciated and honored.

A special thanks to FKASA laboratory officers and staffs for their consistent guidance and help, in order to make all the tests become successfully done. I would also like to express my gratitude and appreciation to my fellow (BAA 06-09) friends for their consistent supports and useful information regarding this Final Year Project.

I wish to thank to all my friends for their supports, advices and helps to me in order to finish this Final Year Project. Lastly, a special thanks to all my family members, for their encouragement and support which had given me strength to finish up the Final Year Project successfully.

# ABSTRACT

Slope stability issues become one of the main problems in construction industry due to nature of the topography and the weather conditions in Malaysia. Improper slope analysis design might cause slope failure which has been acknowledged as one of the most frequent disaster that can lead to great loss of properties and life. To overcome this problem, analysis of slope failure must be carried out to determine the slope stability. This slope failure study has contributed to local engineering studies regarding the slope failure that occurred at Kuala Wau-Kertau road which located in Maran. This study analyses the slope stability and proposes the method of ground improvement to be applied on the slope in term of factor of safety (FOS) and cost. Data from the soil investigation report of the slope is used to analyze the stability of the slope using GeoStudio 2007 Slope/w. From the results, the FOS of the slope before the failure by using Morgenstern-Price Method is 1.710 which can be considered as stable due to the FOS value is more than 1. According to FOS value, the failure is not due to improper design at the preliminary stages of constructing the road but may be due to other factors. By comparing the analysis of remedial measures to the slope, the best method remedial measure to be applied on the slope in term of FOS value and cost is by using anchors. The FOS value of the slope after applying anchors on the slope increased to 2.370. The overall estimated cost of applying this method on the slope is about RM 500,000. The results that have been determined from this study can be made as reference for engineers in order to improve the slope stability of Kuala Wau-Kertau road or any other slope in the future.

# ABSTRAK

Isu kestabilan cerun telah menjadi salah satu daripada masalah utama yang dihadapi dalam industri pembinaan kesan daripada bentuk muka bumi dan keadaan cuaca di Malaysia. Analisis cerun yang tidak betul boleh mengakibatkan tanah runtuh yang telah dikenalpasti sebagai salah satu daripada bencana yang dan merugikan harta benda serta meragut nyawa. Analisis cerun yang betul amat penting bagi mengetahui kestabilan sesuatu cerun. Projek ini boleh membantu dalam menganalisis kejadian tanah runtuh yang telah berlaku di Jalan Kuala Wau-Kertau di Maran. Projek ini mengkaji kestabilan cerun dan mencadangkan kaedah-kaedah yang boleh diaplikasikan kepada cerun dengan mengambilkira faktor keselamatan dan kos. Data yang diambil daripada laporan penyiasatan tanah digunakan dalam menganalisa cerun dengan menggunakan perisian GeoStudio 2007 Slope/w. Berdasarkan keputusan kajian, faktor keselamatan bagi cerun ini sebelum ia runtuh menggunakan kaedah Morgenstern-Price ialah 1.710 dan ia boleh dianggap selamat kerana faktor keselamatan lebih dari 1. Berdasarkan dari nilai faktor keselamatan, kegagalan cerun ini bukan disebabkan oleh kesilapan semasa proses merekabentuk cerun tetapi mungkin disebabkan oleh faktor-faktor lain. Dengan membandingkan analisa tentang kaedah-kaedah yang boleh diaplikasikan untuk meningkatkan kestabilan cerun ini, kaedah yang terbaik setelah mengambilkira faktor keselamatan dan kos ialah dengan menggunakan sauh tanah. Faktor keselamatan telah meningkat kepada 2.370 setelah menggunakan kaedah ini. Anggaran keseluruhan kos bagi mengaplikasikan kaedah ini ialah RM 500,000. Keputusan daripada kajian ini boleh dijadikan sebagai rujukan bagi meningkatkan kestabilan cerun di Jalan Kuala Wau-Kertau serta cerun-cerun lain pada masa hadapan.

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## LIST OF SYMBOLS

| | | |
|---|---|---|
| $\Theta$' | - | Effective Stress Angle of Friction |
| *PL* | - | Plastic Limit |
| *PI* | - | Plasticity Index |
| *LL* | - | Liquid Limit |
| $c_u$ | - | Shear Strength |
| $\gamma$ | - | Unit Weight |
| $e_o$ | - | Pore Water Pressure |
| $\boldsymbol{\tau}_m$ | - | Shear Strength |
| $\boldsymbol{\tau}_f$ | - | Shear Stress |
| c | - | Cohesion |
| $\varphi$ | - | Angle of Friction |

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# CHAPTER 1

# INTRODUCTION

## 1.1 General

Malaysian citizens are increasing rapidly year by year. By year 2005, the population of Malaysian people is reaching 24 million people and the number will continue to increase. As the population growth, we will need more land which mean that more civil engineering project will be carried out in mountainous regions. In order to undergo the mountainous region project, the most important thing that must be taking care of is the slope stability.

Slope stability issue becomes one of the main problems in construction industry due to nature of the topography and the weather conditions in Malaysia. Slope failure has been acknowledged as one of the most frequent natural disaster that can lead to great loss in property and life.

In Malaysia, the collapse of Block 1 of Highland Towers in 1993, slope failure at Taman Hillview in November 2002 and the tragic landslide at Bukit Lanjan in 2003 had prompted our government and public to concern about the stability of slope and the risk involve in such circumstance. The most recent tragedy of slope failure in Bukit Antarabangsa, Kuala Lumpur which killed 5 people is one of the disasters that caused by slope failure. This disaster is because the drainage system in slope development is in the form of horizontal drains in which rain water flows out into the monsoon drains, rivers or streams. The results, no water is retained in the soil and resulting the slope failure. Hence, the analysis of slope stability is very important in order to protect the slopes from fail and minimize the likelihood of slope failure.

There are several techniques to analyze slope stability in order to prevent slope stability, for example, using method of slices. The method of slices is one of a technique that has been widely used to analyze the slope stability in two dimensions. The sliding mass above the failure surface is separated into a number of slices. The forces acting on each slice are obtained by considering the mechanical equilibrium for the slices.

The purpose of this study is to analyze the slope failure using GeoStudio 2007 Slope/w software. This study involves the study case of slope failure at Kuala Wau-Kertau road in Maran, Pahang. The study will analyze one of the slope failures which are occur along the road which may not safe for the road user if the slope continued to fail. Besides, this study will produce slope stability analysis for the slope using Slope/w.

Slope/w is one of geotechnical software that can be use in analyzing slope stability. The slope stability analysis will identify the most probable failure from consideration of the shape of the slope. In other words, it will show whether the slope of the Kuala Wau-Kertau road is suitable or not based on its design. And if the slope is not suitable, this study will also produce a proposal on how to improve slope stability along Kuala Wau-Kertau slope using Slope/w. The software will analyze data in order to get slope stability by inserting the data from the slope to the software. The data of the slope, which used in analyzing the slope stability using Slope/w, was obtained from IKRAM Engineering Services Sdn. Bhd. (IKRAM).

## 1.2 Problem Statement

Slope stability issues become one of the main problem in construction industry due to nature of topography and the weather condition in Malaysia. Improper slope analysis design might cause slope failure which has been acknowledge as one of the most frequent disaster that can lead to great loss of properties and life. To overcome the disaster from occur, the slope needs to be analyzed to determine the best solution of stabilization method that can be applied to the slope. There are many types of slope stabilization method that can be applied to the slope. The factor that must be taking care of in selecting the right method is by considering the effect of the method towards the stability of the slope and the cost of applying the method. The best method of slope stabilization must give a great value of factor of safety (FOS) which indicates the stability of the slope with a low cost.

## 1.3 Objective of Study

The analysis on slope failure in Kuala Wau-Kertau slope using Slope/w has three specific objectives which are:

1. To produce slope stability analysis for Kuala Wau-Kertau slope using Slope/w.
2. To produce a proposal to improve ground stability for Kuala Wau-Kertau slope.
3. To determine the best method of slope stability on Kuala Wau-Kertau slope in term of factor of safety and cost.

## 1.4 Scope of Study

The study is focus on Kuala Wau-Kertau road. It is located at the mountainous region in Maran, Pahang. Figure 1.1 and Figure 1.2 illustrate the maps of Maran and Kuala Wau-Kertau road respectively. Along the road, there are numerous number of slope failure that happened which may not safe for the road user if the slope continued to fail. According to the soil investigation report which collected from IKRAM, the slope which analyze by this study has fail. The failure has damages a part of the road and disturbing the traffic of Kuala Wau-Kertau road. This study will analyze the slope failure and produce a proposal of method that can be applied in order to avoid the slope from fail in the future. The analysis of the slope failure will be made using GeoStudio 2007 Slope/w which a software to analyze the slope stability. By using the software, the slope stability will be analyzed and the FOS of the slope will be determined.


**Figure 1.1: Peninsular Malaysia Map (www.maps.google.com)**


**Figure 1.2: Maran Map (www.maps.google.com)**

## 1.5 Importance of Study

The importance of the study is to analyze the slope failure of the slopes at Kuala Wau-Kertau road. A proposal of the method to stabilize the slope also will be produced in order to prevent the slope failure from happened again in the future. The analysis and the method of slope stabilization from this study can be applied to the slope in order to ensure the safety of pedestrian and the road user. Besides, this study also will analyze the effect of slope stabilization method to the slope and the cost of applying the method to the slope. This study can be made as a reference to produce slope stabilization method in term of FOS and cost in the future. As we know, slope stability issues become one of the main problems in construction industry that has been acknowledged as one of the most frequent natural disaster that can lead to great loss in property and life. So, the study of slope stability in Kuala Wau-Kertau road would be one of the best solutions in order to avoid the slope failure from happened again in the future.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

According to McCarthy (2007), the stability of sloped land areas and the potential for failure, or landslide, is a concern where movement of existing or planned slope would have an effect on the safety of people and properties or the usability and the value of the area. So, it is very important for the engineer to analyse the slope stability before the construction project being carried out in order to make sure that the slope is safe and did not risk human life.

Felix (2003) stated that, the stability of slope depends on its capability to sustain load act or change in environmental condition, which may affect the geomaterials mechanically or chemically. The first sign of instability is usually a tension crack in the ground behind the crest of the slope, sometimes accompanied by slumping of the soil in front of the crack. The rate of failure is very slow but continuous for days until finally fail.

The understanding of the slope failure or slope instability has not come immediately, but the idea has been advanced from time to time. Some of the idea has been accepted and passed into body of knowledge, other which may represent the concept too far from the time, have been rejected.

Limit equilibrium theory has been widely used in slope stability analysis for years. Equilibrium method of slope stability analysis all involved assumptions because the numbers of equilibrium equations available is smaller than the number of unknown involved (Felix, 2003).

For the past years, engineer used the manually calculated method in order to analyze the slope stability. More time, energy, and commitment needed to design a slope using the conventional method of slope stability analysis. As time passes, they have created advanced method to simplify the calculation and at the same time, to get more accurate result. An increased computational power enabled engineer to obtain a right answer for a problem in a short time. This will allow them to concentrate more on other important thing that need to do in order to analyzing the slope stability for example in selecting appropriate model for the slope.

Due to the complexities of the laboratory testing, which require costly laboratory equipment, expert test techniques and long test time, it is unpractical to rely solely on laboratory testing. Additionally, the difficulties in undisturbed soil sampling also greatly limit applications of laboratory testing. Back analysis has been widely accepted for landslide control works because it avoids many problems associated with laboratory tests (Felix, 2003).

## 2.2 Classification of slope failure

Movement of sloped soil can be classified into numerous categories, depending on the type of movement relative to the adjacent or underlying earth (McCarthy, 2007). The slope movement is divided into six categories which are; falls, topples, slides, lateral spreads, flows, and complex (Kehew, 2006).

Each type of slope movement has different effect to the slope. However, in most of the slope movement cases, there is more than one type of slope movement. Thus, the slope movements are includes into complex movement category which indicates that the slope movement has more than one type of movement involved.

Moreover, the type of slope movements is also classified based on the type of material of the slope. Different type of material has different name to indicate the slope movement. According to Kehew (2006), slope material is divided into:

1. Bedrock.
2. Soil composed of predominantly coarse particle (debris).
3. Soil composed of predominantly fine clasts.

.

There are many classification systems created before in order to differentiate the type of slope failure. For example, Felix (2003) founded that a major source of difficulty with these schemes is limited terminology which can be used to describe different types of mass movement; this gives a superficial degree of similarity to the various classification systems, but a descriptive term is one scheme may represent something completely different in another. Furthermore, mass movements come in such enormous range of size, shape and types that even if there was only one classification system, it would be often be difficult to decide precisely how to classify a particular mass movement.

The classification of the slope failure might be different depends on the researcher. For example, Varnes classification system takes in account types of movement and types of material which different type of slope movement has a different name as the material change is showed in Table 2.1.

**Table 2.1: Varnes Classification system (Felix, 2003).**

<table>
<tr><th colspan="3" rowspan="3">Type of movement</th><th colspan="3">Type of material</th></tr>
<tr><th rowspan="2">Bedrock</th><th colspan="2">Engineering soil</th></tr>
<tr><th>Predominantly coarse</th><th>Predominantly fine</th></tr>
<tr><td colspan="3">Falls</td><td>Rock fall</td><td>Debris fall</td><td>Earth fall</td></tr>
<tr><td colspan="3">Topples</td><td>Rock topple</td><td>Debris topple</td><td>Earth topple</td></tr>
<tr><td rowspan="3">Slides</td><td>Rotational</td><td rowspan="2">Few units</td><td>Rock slump</td><td>Debris slump</td><td>Earth slump</td></tr>
<tr><td rowspan="2">Translation</td><td>Rock block slide</td><td>Debris block slide</td><td>Earth block slide</td></tr>
<tr><td>Many units</td><td>Rock slide</td><td>Debris slide</td><td>Earth slide</td></tr>
<tr><td colspan="3">Lateral spreads</td><td>Rock spread</td><td>Debris spread</td><td>Earth spread</td></tr>
<tr><td colspan="3">Flows</td><td>Rock flow (deep creep)</td><td>Debris flow (soil creep)</td><td>Earth flow (soil creep</td></tr>
<tr><td colspan="3">Complex</td><td colspan="3">Combination of two or more principle types of movement</td></tr>
</table>

Felix, (2003) also gave a classified system with the definition with classifies slope failure forms in terms of the velocity of movement which is illustrated in Table 2.2.

**Table 2.2: Hunt classification of slope failure (Felix, 2003)**

| Type | Form | Definition |
|---|---|---|
| Falls | Free fall | Sudden dislodgement of single or multiple blocks of soil or rock which fall in free descent. |
| | Topples | Overturning of a rock block about a pivot point located below its center of gravity. |
| Slides | Rotational or slump | Relatively slow movement of an essential coherent block(or blocks) of soil, rock, or soil-rock mixture along some well-defined ach-shaped failure surface. |
| | Planar or translational | Slow to rapid movement of an essential coherent block(or blocks) of soil or rock along some well-defined planar failure surface. |
| | Subclasses<br>• Block glide<br>• Wedges<br>• Lateral spreading<br>• Debris slide | <br>• A single block moving along a planar surface.<br>• Block or blocks moving along intersecting planar surface.<br>• A number of intact block moving as separate units with differing displacement.<br>• Soil-rock mixture moving along a planar rock surface. |
| Avalanches | Rock or debris | Rapid to very rapid movement of an incoherent mass of rock or soil-rock debris wherein the original structure of the formation is no longer discernible, occurring along an ill-defined surface. |
| Flows | Debris, sand, silt, mud, soil | Soil or rock-soil debris moving as a viscous fluid or slurry, usually terminating at distances far beyond the failure zone: resulting from excessive pore pressure. (subclassed according to material type). |
| Creep | | Slow, imperceptible down slope movement of soil or soil-rock mixtures. |
| Solifuction | | Shallow portions of the regolith moving down slope at moderate to slow rates in Artic to sub-Artic climates during period of thaw over a surface usually consisting of frozen ground. |
| Complex | | Involves combinations of the above, usually occurring as a change from one form to another during failure with one form predominant. |

Besides that, Felix (2003) also classified slope failure in term of the velocity of movement as been illustrated in Figure 2.1.

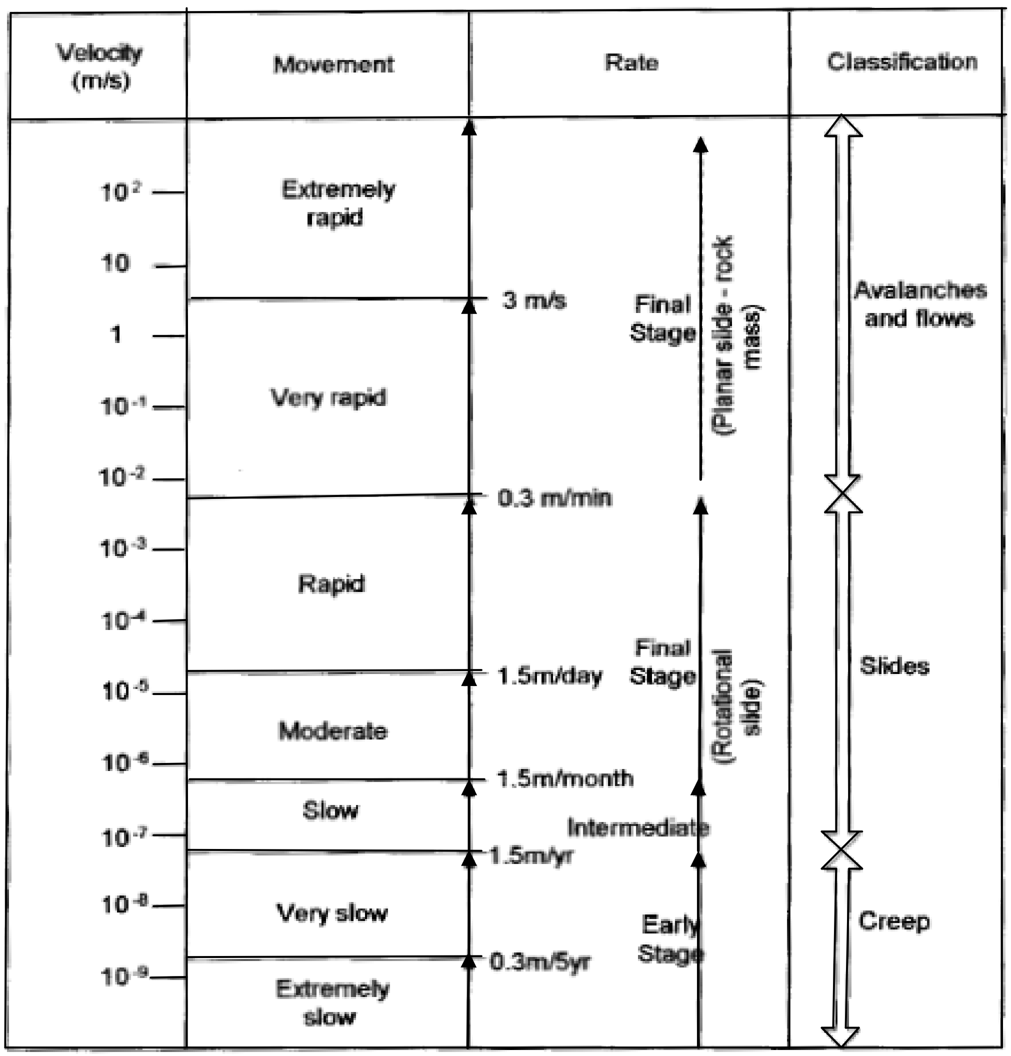


**Figure 2.1: Velocity movement for slope failure forms (Felix, 2003)**

## 2.3 Type of slope failure

Based from the slope failure classification made by the previous researchers, the most common type of failure that frequently happened are falls, topples, slides, lateral spreads, and flows. These are the definition and the figure of each type of the slope failure.

### 2.3.1 Falls

When a mass of rock, debris, or soil separates from a steeply sloping surface and rapidly moves down slope by free fall, bounding or rolling, the movement is termed as fall. These phenomena range from massive bodies of rock on mountain peaks set in motion by earthquake to small block of soil that fall down a river bank when lateral erosion by the stream under cult the bank to the point where the overhanging section collapse (Kehew, 2006). Figure 2.2 shows the fall slopes which an unstable rock on the slope is falling down.

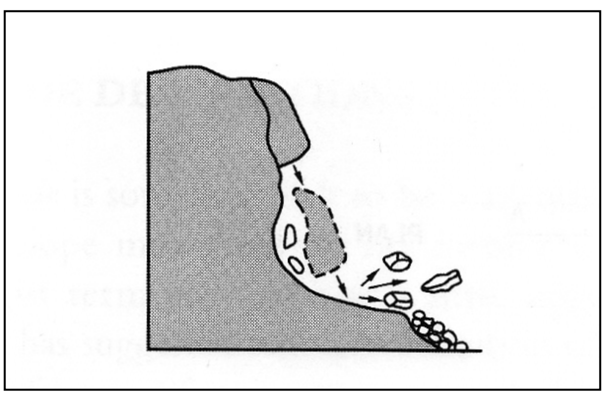

**Figure 2.2: Falls (McCarthy, 2007)**

### 2.3.2 Topples

A topples is a rotational movement that occurs as a block of material pivots forward about a fixed point near the base of the block. Topples develop in rock or cohesive-soil slopes divides into blocks by vertical fractures or joints oriented parallel to the slope face. Horizontal discontinuities, such as bedding may affect the process if differential erosion allows a more resistant column of overlying rock to be undermined (Kehew, 2006). Figure 2.3 illustrates the diagram of topples.

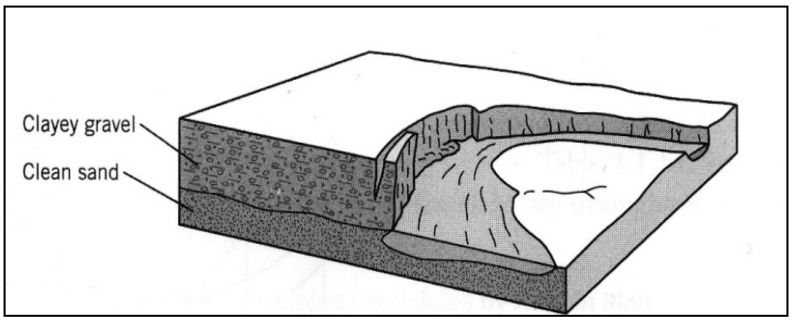


**Figure 2.3: Topples (McCarthy, 2007)**

### 2.3.3 Slides

Slides refer to the occurrence where the moving mass is rather well defined and separated from the underlying and adjacent earth by plane, or a zone comprising a number of adjacent planes, which slippage results. The slippage plane or zone represents the continuous surface where the maximum shear strength of the earth material has been reached, with the result that large displacement occurs (McCarthy, 2007).

A translational slide is associated with slope of layered material where the mechanism of slippage occurs along a weak zone or plane that possesses a downward dip (McCarthy, 2007). This type of slide is usually relatively shallow (typically 0.5-2m deep), with the failure surface being more or less parallel to the ground surface (Felix, 2003). As we can see in Figure 2.4, translational slide is frequently seen on the sides of newly formed cut slopes, where the failure of the topsoil cover has occurred. Typically, after failure the slipped material accumulates as a soft heap at the toe of the slope.

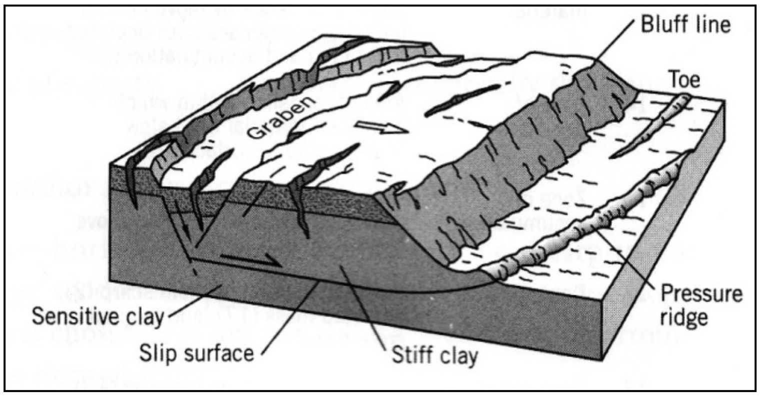


**Figure 2.4: Translational slide (McCarthy, 2007)**

Rotational slide is associated with the natural slope and constructed embankments of the homogenous materials possessing the cohesion; the failure surface is curved, with the failed mass characteristically slumped in the toe area of the original slope. There is failure plane at which the soil which slide along the failure plane as is illustrates in Figure 2.5. The rotation that occurs about an imaginary axis in space, one that is aligned parallel to the slope (McCarthy, 2007).

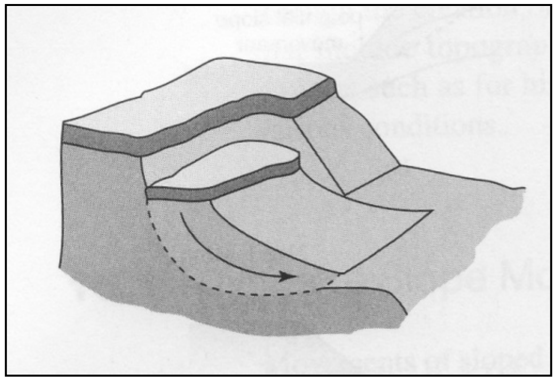

**Figure 2.5: Rotational slide (Kehew, 2006)**

### 2.3.4 Lateral Spreads

The slow-to-rapid lateral extensional movements of rock or soil masses are known as lateral spread. Liquefaction and flowage of a weak soil layer within a slope is a cause of most lateral spread in the debris and earth categories of the slope-movement classification. The stronger material above the failure is rafted along without intense deformation; although it may be broken into blocks that can be subside or rotate as the spread progresses (Kehew, 2006). Figure 2.6 shows the lateral spread movement of soil.

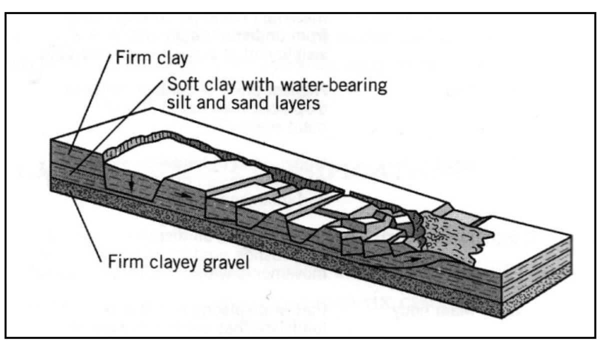


**Figure 2.6: Lateral spread (McCarthy, 2007)**

### 2.3.5 Flows

Flow is a complex physical phenomenon which may exhibit viscous or plastic behavior, as well as variation and combination of both. Velocities of flows span the entire velocity class scale and densities are also highly variable, reaching 80% by weight. High-density flows are able to transport boulders that are many meters in diameter, creating the potential for great destructiveness. The overriding criterion in distinguish flows from slides is that flow must involved continuous internal deformation of the moving material.

When a flow travels at velocities at the slow end of velocity scale, the process is called creep, creep may occur in rock or surficial debris. In rock, creep like flow can be a very slow, steady process, persisting over long period of time. Alternatively, slow creep may accelerate to the point where a dramatic failure results (Kehew, 2006). Figure 2.7 visualizes the flow of soil.

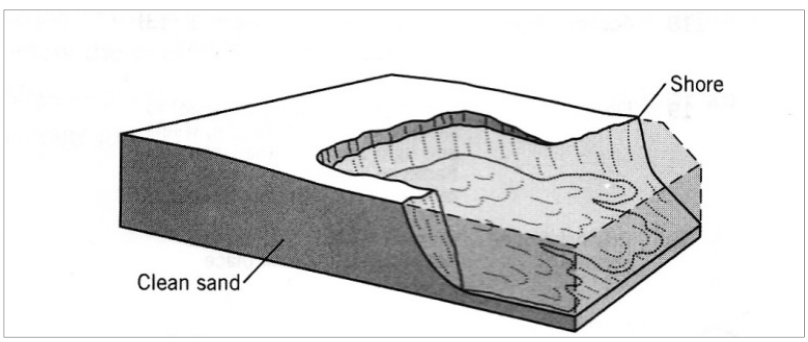


**Figure 2.7: Flow (McCarthy, 2007)**

### 2.3.6 Complex slope movement

A complex slope movement involves combinations of the above, usually occurring as a change from one form to another during failure with one form predominant. In fact, most of the slope failure occurred by combination of two or more type of slope movement (Felix, 2003).

## 2.4 Factor that influence slope stability

There are many types of factor that may contribute to slope failure. The factor that will be discussed in this subtopic can be considered as the main factor which can cause slope failure. The factors that influence the slope stability are (Nelson, 2009):

1. The factors are the act of gravity.
2. The role of water.
3. The troublesome earth material.
4. Weak materials.
5. Structure and triggering events.

### 2.4.1 Gravity

One of the factors is the act of gravity. Gravity is the force that acts everywhere on the Earth's surface, pulling everything in a direction toward the center of the Earth. On a flat surface the force of gravity acts downward. As long as the material remains on the flat surface, it will not move under the force of gravity. In Figure 2.8, the force of gravity can be resolved into two components which are; the component acting perpendicular to the slope and the component acting tangential to the slope.

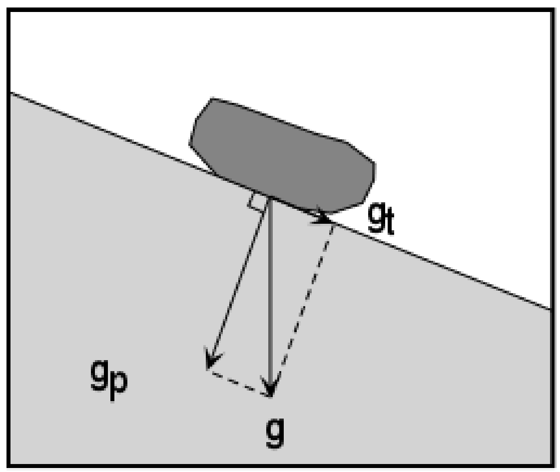


**Figure 2.8: Gravity (Nelson, 2009)**

The perpendicular component of gravity, $g_p$, helps to hold the object in place on the slope. The tangential component of gravity, $g_t$, causes a shear stress parallel to the slope that pulls the object in the down-slope direction parallel to the slope. On a steeper slope, the shear stress or tangential component of gravity, $g_{t,}$ increases, and the perpendicular component of gravity, $g_p$, decreases. The forces resisting movement down the slope are grouped under the term shear strength which includes frictional resistance and cohesion among the particles that make up the object. When the sheer stress becomes greater than the combination of forces holding the object on the slope, the object will move down-slope (Nelson, 2009).

Alternatively, if the object consists of a collection of materials like soil, clay, sand, etc., if the shear stress becomes greater than the cohesion forces holding the particles together, the particles will separate and move or flow down-slope. Thus, down-slope movement is favored by steeper slope angles which increase the shear stress, and anything that reduces the shear strength, such as lowering the cohesion among the particles or lowering the frictional resistance. This is often expressed as the factor of safety, $F_s$, the ratio of shear strength to shear stress. If the FOS becomes less than 1.0, slope failure is expected (Nelson, 2009).

$$\text{FOS} = \frac{\text{Shear Strenght}}{\text{Shear Stress}} \tag{2.1}$$

### 2.4.2 The role of water

Water becomes important factor that influence the slope stability due to several reasons as water from rainfall or snow melt adds weight to the slope. Water can be considered as the main factor that contributes to the slope failure in Malaysia. It is due to the weather in Malaysia which receives rain all the year. In fact, most of the slope failure that happened in Malaysia is results from water due to the heavy rain.

Water can seep into the soil or rock and replace the air in the pore space or fractures. Since water is heavier than air, this increases the weight of the soil. Weight is force, and force is stress divided by area, so the stress increases and this can lead to slope instability. Water has the ability to change the angle of repose which is the slope angle which is the stable angle for the slope (Nelson, 2009).

Water can be adsorbed or aborted by minerals in the soil. Adsorption causes the electronically polar water molecule to attach itself to the surface of the minerals. Absorption causes the minerals to take the water molecules into their structure (Nelson, 2009).

By adding water to soil, the weight of the soil or rock is increased. Furthermore, if adsorption occurs then the surface frictional contact between mineral grains could be lost resulting in a loss of cohesion, thus reducing the strength of the soil. In general, wet clays have lower strength than dry clays, and thus adsorption of water leads to reduced strength of clay-rich soils.

Liquefaction occurs when loose sediment becomes oversaturated with water and individual grains loose grain to grain contact with one another as water gets between them. It can also occur gradually by slow infiltration of water into loose sediments and soils. The amount of water necessary to transform the sediment or soil from a solid mass into a liquid mass varies with the type of material. Clay bearing sediments in general require more water because water is first absorbed onto the clay minerals, making them even more solid-like, then further water is needed to lift the individual grains away from each other (Nelson, 2009).

Groundwater exists nearly everywhere beneath the surface of the earth. It is water that fills the pore spaces between grains in rock or soil or fills fractures in the rock. The water table is the surface that separates the saturated zone below, wherein all pore space is filled with water from the unsaturated zone above. Changes in the level of the water table occur due changes in rainfall. The water table tends to rise during wet seasons when more water infiltrates into the system, and falls during dry seasons when less water infiltrates (Nelson, 2009).

Another aspect of water that affects slope stability is fluid pressure. As soil and rock get buried deeper in the earth, the grains can rearrange themselves to form a more compact structure, but the pore water is constrained to occupy the same space. This can increase the fluid pressure to a point where the water ends up supporting the weight of the overlying rock mass. When this occurs, friction is reduced, and thus the shear strength holding the material on the slope is also reduced, resulting in slope failure (Nelson, 2009).

### 2.4.3 Earth material problem

Earth material problems also can be defined as the properties of the soil that made the slope which may consider as the factor that influenced the slope stability. For example the expansive and the hydrocompacting of soil.

Such clay minerals expand when they become wet as water enters the crystal structure and increases the volume of the mineral. When such clays dry out, the loss of water causes the volume to decrease and the clays to shrink or compact. This process is referred to as hydrocompaction. Another material that shows similar swelling and compaction as a result of addition or removal of water is peat soil. Peat soil is organic-rich material accumulated in the bottoms of swamps as decaying vegetable matter (Nelson, 2009).

In some soils the clay minerals are arranged in random fashion, with much pore space between the individual grains. This is often referred to as a "house of cards" structure. Often the grains are held in this position by salts (such as gypsum, calcite, or halite) precipitated in the pore space that "glue" the particles together. Compaction of the soil or shaking of the soil can thus cause a rapid change in the structure of the material (Nelson, 2009).

The clay minerals will then line up with one another and the open space will be reduced. But this may cause a loss in shear strength of the soil and result in slippage down slope or liquefaction. This is referred to as remolding. Clays that are subject to remolding are called quick clays. Some clays, called thixotropic clays when the soil specimen is kept in an undisturbed state (without any changes of moisture content) after being remolded, it will continue to gain strength with time (Das, 1994). Thus, small earthquakes or vibrations caused by humans or the wind can suddenly cause a loss of strength in such materials.

### 2.4.4 Weak material and structure

Bedding planes are basically planar layers of rocks upon which original deposition occurred. Since they are planar and since they may have a dip down-slope, they can form surfaces upon which sliding occurs, particularly if water can enter along the bedding plane to reduce cohesion (Nelson, 2009).

Some rocks are stronger than others. In particular, clay minerals generally tend to have low shear strength. If a weak rock or soil occurs between stronger rocks or soils, the weak layer will be the most likely place for failure to occur, especially if the layer dips in a down-slope direction as in the illustration above. Similarly, loose unconsolidated sand has no cohesive strength. A layer of such sand then becomes a weak layer in the slope (Nelson, 2009).

Joints are regularly spaced fractures or cracks in rocks that show no offset across the fracture (fractures that show an offset are called faults). Joints form as a result of expansion due to cooling, or relief of pressure as overlying rocks are removed by erosion. Joints form free space in rock by which water, animals, or plants can enter to reduce the cohesion of the rock. If the joints are parallel to the slope they may become a sliding surface. Combined with joints running perpendicular to the slope, the joint pattern results in fractures along which blocks can become loosened to slide down-slope (Nelson, 2009).

### 2.4.5 Triggering events

Triggering events are the natural occasion which can occur any time which might affect the stability of slope. It is the phenomenon that initiates the slope failure for example shock, change in hydrologic characteristic and volcanic eruption.

A sudden shock, such as an earthquake may trigger slope instability. Minor shocks like heavy trucks rambling down the road, trees blowing in the wind, or human made explosions can also trigger mass-wasting events (Nelson, 2009).

Heavy rains can saturate regolith reducing grain to grain contact and reducing the angle of repose, thus triggering a mass-wasting event. Heavy rains can also saturate rock and increase its weight. Changes in the groundwater system can increase or decrease fluid pressure in rock and also triggers mass-wasting events (Nelson, 2009).

Volcanic Eruptions will produce shocks like explosions and earthquakes. They can also cause snow to melt or empty crater lakes, rapidly releasing large amounts of water that can be mixed with regolith to reduce grain to grain contact and result in debris flows, mudflows, and landslides (Nelson, 2009).

## 2.5 Method of slope protection

Slope protection is done on the slope in order to prevent slope surface erosion due to surface runoff and to reduce infiltration which main reason of slope failure. Proper slope protection not only can protect the slope from fail, but also it can enhance slope appearance with pleasing and aesthetic environment. Purpose of slope protection is to protect the slope and hence reduce the probability of slope failure (Neoh, 2009).

There are many types of slope protection for example turfing, hydroseeding, guniting, gabion mattress, stone pitched slope and many more. Different types of method have different effect towards the slope stability. The selection of the method that can be applied to the slope is by considering many factors for example the cost of applying the methods, the availability of the product and many more. Table 2.3 shows the factor that can effect slope protection and suitable method of slope protection.

**Table 2.3: Method of slope protection (Neoh, 2009)**

| Method / condition | Close turfing | Hydro seeding | Hydro seeding with biomat | Vetiver grass | HDPE geocell | Gabion mattress | Stone pitching | gunite | RC skin wall |
|---|---|---|---|---|---|---|---|---|---|
| **soil type** | | | | | | | | | |
| Silty/sandy clay | vs | vs | vs | vs | vs | vs | s | s | s |
| Sandy silt | s | d | s | s | vs | s | s | s | s |
| Silty sand | s | x | d | d | vs | vs | s | s | s |
| Fractured/rocky | x | x | d | x | s | s | s | s | s |
| Very stiff/hard | d | d | s | d | s | s | s | s | s |
| Acidic | d | x | x | d | s | d | s | s | s |
| **slope geometry** | | | | | | | | | |
| Gentle slope, B<35 ° | vs | vs | vs | vs | vs | vs | s | s | s |
| Medium slope | d | s | s | s | d | d | s | s | s |
| Steep slope, B>42° | x | d | s | d | x | x | s | s | s |
| Down slope length, L>10m | s | s | s | s | s | s | s | s | s |
| **miscellaneous** | | | | | | | | | |
| Aesthetic | s | s | s | d | d | d | s | s | s |
| Green requirement | s | s | s | s | x | x | x | x | x |
| High water table | s | s | s | s | s | s | d | x | x |
| Poor slope surface drainage | d | d | d | s | s | s | s | s | s |
| Shady area | d | d | d | x | s | s | s | s | s |
| Unit cost (RM/m$^2$) | < 8 | < 3 | < 5 | < 5 | < 50 | <70 | < 70 | < 90 | <100 |

| Legend | | |
|---|---|---|
| Vs | = | very suitable |
| S | = | suitable |
| D | = | doubtful |
| X | = | not suitable |

## 2.6 Method of slope stabilization

Slope stabilization method includes mechanical stabilized slope/ wall or reinforced concrete wall or geosynthetic reinforced wall/ slope. For cut slopes, common slope stabilization methods that usually used are soil nailing, reinforced concrete (RC) anchorage wall and etc.

### 2.6.1 Soil nailing

Soil nailing is one of the most widely used methods of slope stabilization since 1980 to reinforce and stabilize the new cut slope enhance slope stability of existing or natural slope with low factor of safety.

The basic design concept of soil nailing is to reinforce and strengthen the slopes in-situ by installing grouted steel bars or driven pipes, called nails into progressively excavated slope/ wall by the top down process. This process can create a reinforced mass that is internally stable and able to retain the ground mass against active pressure, sliding, bearing an overturning force (Neoh, 2009).

Estimation of pull-out resistance of soil nail is the most important part in the soil nail design. In practice, the pull-out resistance is mainly based on bond strength or adhesion at the interface of nail-soil by empirical formula or some assumed or correlated values based on site investigation result and then verified by pull-out tests during the construction stages. The soil nail should be long enough and extended a minimum distance beyond the back of the critical slip surface to achieve the minimum targeted factor of safety.

Generally, Morgenstern & Price or Janbu stability analysis method is preferred well than Bishop Modified Method because it is less sensitive to the assumed location of applied load in soil nail (Neoh, 2009).

### 2.6.2 Horizontal Drains

Horizontal drain is the effective method to reduce the undesirable effect of groundwater on slope stability. Presence of groundwater reduces the stability of slope through reduction of shear resistance of the soil, decrease in cohesion, subsurface erosion, lateral pressure in fractures and joints, and excess water pressure (Neoh, 2009).

The effectiveness of horizontal drain is depends on the spacing, diameter of the drain and on the location relative to the critical slip zone or zones of pervious, water bearing material, which usually located near grade 0.75 weathering profile or the interface of the soil and bedrock (Neoh, 2009).

### 2.6.3 Geosynthetic reinforced slope

Geosynthetic products in form of geotextile, geogrid, geocell, and many more in compacted fill soil structures can prevent excessive localized shear deformation of localized weakness due to rain or soil property variation or seepage that may trigger shear failure (Neoh, 2009).

Reinforced slope using geotextile or geogrid or other method should be adopted as such reinforced slope is very flexible to undertake deformation in order to avoid failure due to localized weakness as the result of subsoil variation. Geotextile and geogrid will transfer excessive shear stress in soil in localized weak soil mass into tension within the geotextile or geogrid. The will reduce the slope movement in order to prevent slope failure. By using geotextile and geogrid, it is possible to construct steeper slope to save space/ land or increase factor of safety to more than 1.4 (Neoh, 2009).

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### 2.6.4 RC anchored wall

RC anchored wall is applicable for existing very steep eroded/failed slope where site constraint is the main problem. It consists of the RC vertical wall panel held by soil nails or anchors which are also used to stabilized the slopes. The lateral load of RC wall is reduced by the inclusion of geotextile reinforced fill (sand). Adequate subsoil drainage including horizontal drains, free drainage backfill materials and weep holes are included to prevent the risk of building-up pore water pressure If the safety factor becomes less than 1.0, slope failure is expected (Neoh, 2009).

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The advantages of this method are it is easy to construct which only light and portable machines are necessary with small and light staging for working platform. The inclusion of reinforced geotextile can reduce lateral load hence lateral deflection of wall is negligible. The construction of RC anchored wall is fast and neat which almost no earthwork needed.

### 2.6.5 Bored pile wall

This method is normally applicable for creeping slope with poor soil in mountainous regions where heavy machines can be deployed. Larger diameter bored piles of 1m to 1.5m socketed in stable soil or the bedrock with or without tie-back anchors. In order to satisfy the requirement to keep the road open at all time, expensive temporary staging to support the heavy boring rig and crane are necessary. This method rarely adopted for residential development project (Neoh, 2009).

## 2.7 Slope stability analysis

Stability analyses are usually carried out in order to evaluate the safe and functional design of a slope. The analysis method chosen depends on both site surroundings and the prospective mode of failure, with careful consideration being given to the varying strengths, weaknesses and limitations inherent in the method being used in the analysis.

The evaluation of the slope stability is one class of problems that is dominated by uncertainties. Geological anomalies, material properties, environment conditions and analytical models are all factors contributing to uncertainty. Conventional slope design practices do not account for these uncertainties, thus compromising the adequacy of predictions. On the other hand, reliability slope stability analysis offers a proficient framework for logical systematic incorporation of uncertainty, thus providing a more rational basis for design (Ng, 2005).

The following section will highlight the shortcomings of conventional methods used in practice for stability analysis and introduce the available probabilistic analysis and its application on the slope stability. It is understood that there is uncertainty in any type of analysis. Conventional slope stability analysis has relied on a factor of safety approach to account for uncertainties. This approach does not necessarily yield sound economic designs. Nor does it explicitly give a finite indication of the safety of the design (Ng, 2005).

Probabilistic slope analysis, on the other hand, explicitly accounts for uncertainty. The output of the probabilistic analysis, in terms of failure probability or reliability index, is a measure of the reliability of the design. Probabilistic analysis provide greater insight into design reliability, thus, enhancing the engineering judgment and improving the decision making process. So, the clarity, simplicity and cost/time effectiveness are essential elements in order to effectively convey and communicate a probabilistic methodology to practicing engineers (Ng, 2005).

## 2.8 Conventional Slope Stability Analysis

Slope stability analysis is usually done using limit equilibrium methods. Most limit equilibrium method assumes the validity of Coulomb's failure criterion along an assumed failure surface. A free body of the slope is considered to act upon by known and unknown forces. Shear stress induced on the assumed failure surface by the body and external forces is compared with the available shear strength of the material (Ng, 2005). Table 2.4 shows partial listing of procedures for analyzing slope stability using method of slices.

**Table 2.4: Partial listing of procedures for analyzing slope stability using method of slices (McCarthy, 2007)**

| **Procedure** | **Typical application and limitation** | **Comment on usage** |
|---|---|---|
| Basic method | Circular failure surface in isotropic clay slopes. | Nonrigorous method; hand-calculator solution practical. |
| Fellenius method of slices | Circular failure surface, all soil types. | Nonrigorous method; hand-calculator solution practical. |
| Bishop method of slices | Circular failure surface, all soil types. | Rigorous method; computer program best for solution. |
| Simplified bishop method | Circular failure surface, all soil types. | Semirigorous method; hand-calculator solution practical but computer solution preferable. |
| Morganstern-price method of slices | Circular and noncircular failure surface, all soil types. | Rigorous method; computer required for solution. |
| Spencer method of slices | Circular and noncircular failure surface, all soil types. | Rigorous method; computer required for solution. |
| Janbu method of slices | Circular and noncircular failure surface, all soil types. | Widely used for noncircular failure surface; computer best for rigorous method but chart aids make hand-calculator solutions practical. |

Felix (2003) concluded that simple sliding models fall into the category of limit equilibrium method. In the method of slices, soil mass above the slip surface is divided into wedges or slices. This method is not an exact method because there are more unknown than the equilibrium method. This will require many assumptions made concerning the interslice force. Table 2.5 presents the summary and the assumption for various methods. Some characteristic of the commonly used method of slices are given in Table 2.6.

**Table 2.5: Summary and the assumption for various methods (Felix, 2003)**

| **Types of method of slices** | **Assumption concerning interslice forces** | **References** |
|---|---|---|
| Ordinary method of slices | Resultant of the interslice forces is parallel to the average inclination of the slice. | Fellenius (1936) |
| Bishop simplified method | Resultant of the interslice forces is horizontal (no interslice shear force). | Bishop (1955) |
| Janbu simplified method | Resultant of the interslice forces is horizontal (a correction factor is used to account for interslice shear forces). | Janbu (1968) |
| Janbu generalized method | Location of the interslice normal force is defined by an assumed line of thrust. | Janbu (1957) |
| Spencer method | Resultant of the interslice forces is of constant slope throughout the sliding mass. | Spencer (1967, 1968)) |
| Morgenstern-Price method | Direction of the resultant of interslice forces is determined by using a selected function. | Morgenstern and Price (1965) |

Some of the commonly used methods of slices are given in Table 2.6 including the characteristic of each of the method.

**Table 2.6: Characteristic of the commonly used method of slices (Felix, 2003)**

| Method | Characteristics |
|---|---|
| Slope Stability Charts | 1. Accurate enough for many purposes.<br>2. Faster than detailed computer analyses. |
| Ordinary Method of Slices | 1. Only for circular slip surface.<br>2. Satisfies moment equilibrium.<br>3. Does not satisfy horizontal or vertical forces equilibrium. |
| Bishop's Modified Method | 1. Only for circular slip surface.<br>2. Satisfies moment equilibrium.<br>3. Satisfies vertical forces equilibrium.<br>4. Does not satisfy horizontal force equilibrium. |
| Force Equilibrium Method | 1. Any shape of slip surfaces.<br>2. Satisfies all conditions of equilibrium.<br>3. Permits side force locations to be varied.<br>4. More frequent numerical problems than some other methods. |
| Janbu's Generalized Procedure of Slices | 1. Any shapes of slip surface.<br>2. Satisfies all conditions of equilibrium.<br>3. Permits side forces location to be varied.<br>4. More frequent numerical problems than some other methods. |
| Morgernstern and Price's Method | 1. Any shape of slip surface.<br>2. Satisfies all condition of equilibrium.<br>3. Permits side force orientation to be varied. |
| Spencer's Method | 1. Any shape of slip surfaces.<br>2. Satisfies all conditions of equilibrium.<br>3. Side forces are assumed to be parallel. |

The method of slices depicted in Figure 2.9, which is a rotational failure analysis, is most commonly used in limit equilibrium solutions. The soil mass (ABCD) above a trial failure surface (AC) is divided into slices by vertical planes. Each slice is taken as having a straight-line base. For any slice, the inclination of the base to the horizontal line is $\alpha_i$ and the height (measured at the centerline) is $h_i$.

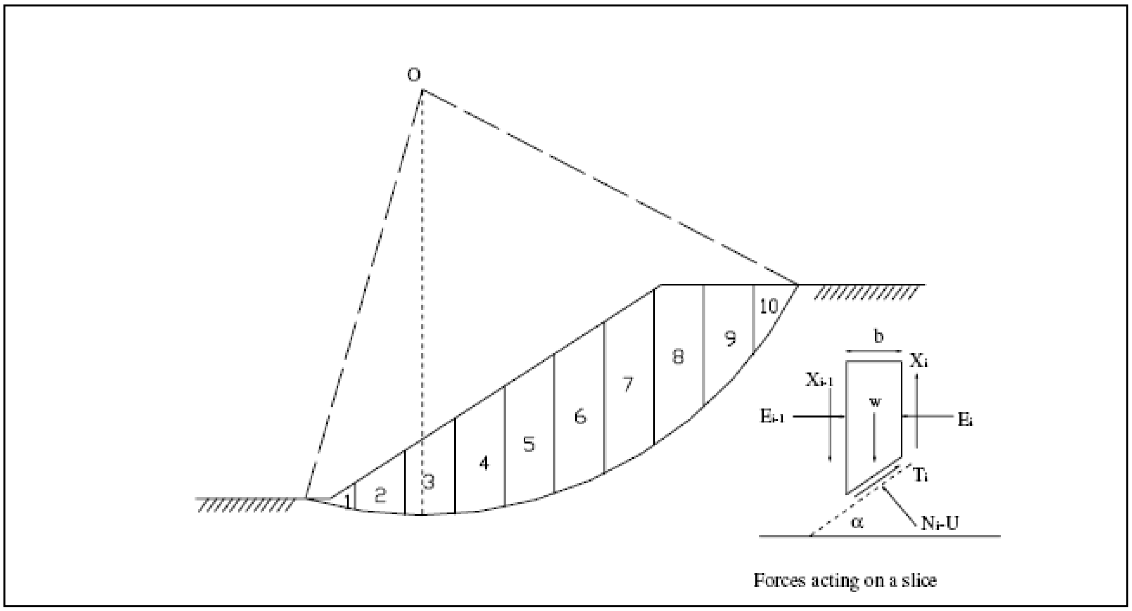


**Figure 2.9: Method of slices (Ng, 2005)**

As shown in Figure 2.9, the forces acting on slice 9 are (Ng, 2005):

1. The total weight of slices, $W = \gamma b h_i$
2. The total normal force on the base: the effective normal force $N' = \sigma' l_i$ and the boundary water force, $U = e_o\ l_i$ where $e_o$ is the pore water pressure at the center of the base and $l$ is the length of the base.
3. The shear force on the base, $T = \boldsymbol{\tau}_m l_i$
4. The total normal forces on the side, $X_i$ and $X_{i-1}$
5. Any external forces working on the slope must be included in the analysis.

The factor of safety of each slice is assumed to be the same, involving mutual support between the slices. The forces acting between the slices are denoted by E and X.

There are many unknown forces involved in the equilibrium for a slice. If pore water pressure and the inter-slice forces E and X are assumed equal to zero, the factor of safety can be evaluated based only on the weight of slices which can be resolved into two component T and N.

In circular failure plane, the overall factor of safety can be evaluated by determining the sliding and the resistance moment about point O. The factor of safety is defined as the ratio of the available shear strength, $\boldsymbol{\tau}_m$.

$$FOS = \frac{\boldsymbol{\tau}_f}{\boldsymbol{\tau}_m} \tag{2.2}$$

The component T which is parallel to the base of the slice tends to cause sliding. Taking moment about O, the sum of the moments of the shear forces T on the failure arc AC must equal to the moment due to the weight of the soil mass ABCD.

$$\sum TR = \sum W\, R \sin \alpha \tag{2.3}$$

Resistance to these sliding forces is provided by the cohesion and internal friction of the soil. The cohesion force is equal to the product of the cohesion of the soil and the length of the slices curved (La). The friction force is the normal components of the weight (N) multiplied by the friction coefficient which is equal to tan φ. For analysis in terms of effective stress the general factor of safety is given as:

$$FOS = \frac{\sum c'_i L_i + \sum N' \tan \varphi}{\sum W \sin \alpha} \tag{2.4}$$

Or if the c is constant, then

$$\text{FOS} = \frac{\sum (c' L_a + N' \tan \varphi')}{\sum W \sin \alpha} \qquad (2.5)$$

## 2.9 Slope/w

GeoStudio 200 Slope/w is slope stability analysis software which can be used in analyzing the slope stability by calculating the factor of safety. Beside factor of safety, the stability of the slope can be increased by inserting the remedial measures into the slope by using the software. The software can be used to analyze both simple and complex problem for a variety of slip surface shape, pore water pressure condition, soil properties, analysis method and loading condition (Krahn, 2004).

Using the limit equilibrium method, Slope/w can model heterogeneous soil types, complex stratigraphic and slip surface geometry and variable pore water pressure conditions using a large selection of soil models (Krahn, 2004).

Slope stability analyses can be performed using deterministic or probabilistic input parameter. Stresses computed by a finite element stress analysis can be used in addition to limit equilibrium computation for the most of complete slope stability analysis available (Krahn, 2004).

Slope/w can be used to analyze almost every slope stability problem by calculating the factor of safety. The factor of safety can be calculated by modeling the slope in the software, including the pore water pressure and the slip surface, inserting the soil properties of the slope which includes the cohesion, c, the angle of friction, φ and also the unit weight of the soil, γ the slope can be analyze.

The CAD-like technology in Slope/w is able to create the geometry by drawing it into the software. A DXF format picture can even imported to assist, then choose the analysis method, specify the soil properties and pore water pressure, define reinforcement load and make the trial slip surface (Krahn, 2004).

As the second objective of this study which is to produce a proposal to improve the ground stability of slope in Kuala Wau-Kertau road, the suitable remedial measures will be choose to apply to the slope. The effect of each remedial measure to the factor of safety of the slope also can be analyzed using the Slope/w software. Figure 2.10 illustrates an example of slope stability analysis using Slope/w.

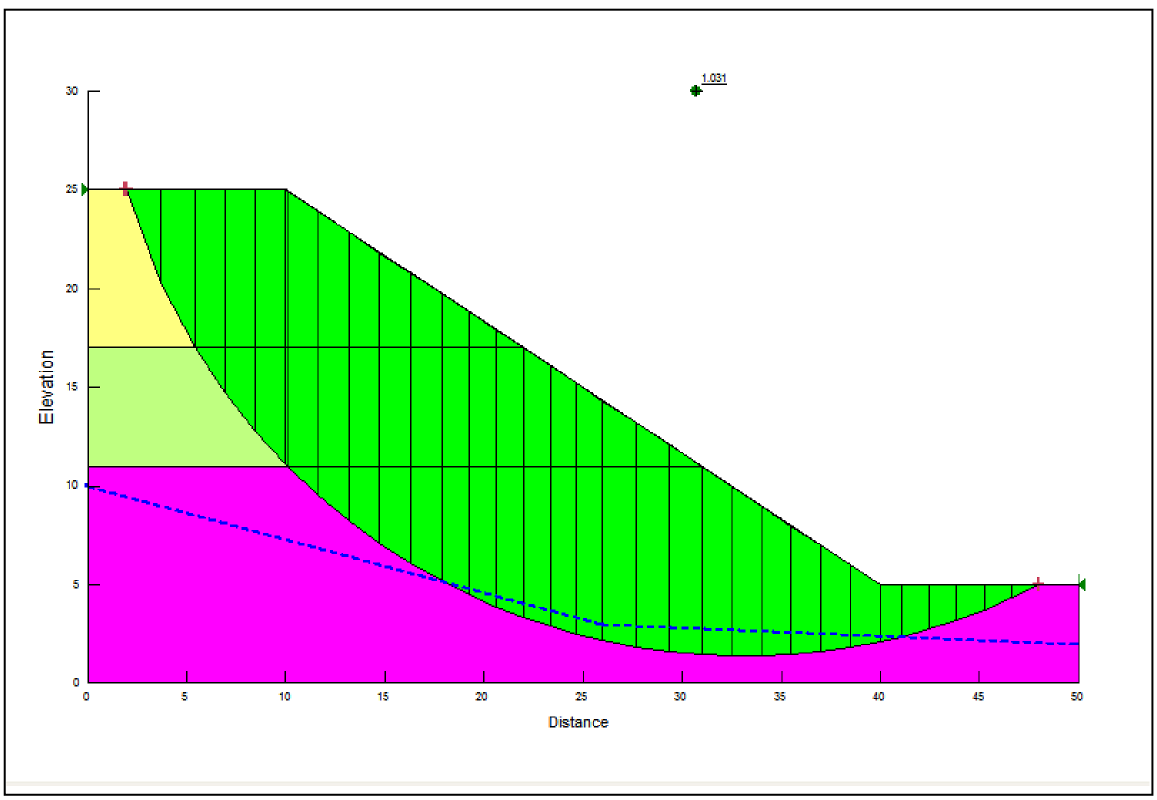


**Figure 2.10: Example of Slope/w analysis**

## 2.10 Factor of safety

Factor of safety (FOS) is the ratio of the shear strength possessed by the soil to the soil shear strength required for equilibrium (McCarthy, 2007). In reality, the satisfactory FOS is dependent on the combination of economic risk and risk to life deemed acceptable. Although no specific guidelines on acceptable FOS for slope design, generally the value of FOS >1 is can be define as safe while if FOS < 1, the slope is not safe.

As for slope in Malaysia, the simplified classification of risk to landslide for hill area development is been referred to the recommendation by the Institution of Engineers, Malaysia (IEM). The recommendations of failed slope are classified are as follow:

1. Total height of slope > 15m
2. Global angle of slope > 27°

The Geotechnical Control office of Hong Kong which experiences similar tropical soil condition as in Malaysia has provided same basic guidelines as shown in Table 2.7 below.

**Table 2.7: Modified recommended FOS for new slopes (Amizatulhani, 2007)**

| Economic risk | Risk to life | | |
|---|---|---|---|
| | Negligible | Low | High |
| Negligible | > 1.0 | 1.2 | 1.4 |
| Low | 1.2 | 1.2 | 1.4 |
| High | 1.4 | 1.4 | 1.4 |

# CHAPTER 3

# METHODOLOGY

## 3.1 Introduction

This propose methodology consist of three phases that will give further explanation on the method use in this study. The methodology used the guideline of the study to achieve the proposed objective.

At the first phase, the title is been chosen and then the problem statements is determined. Then, the objectives are decided relating to the problem statements stated. When the proposed title of study has been accepted, then only the study can be proceeded to search for information related for the literature review. After that, at the second phase, the study will be proceeding to the collection of data of the case study
For the third phase, the data collected will be analyzed using Slope/w software. The analysis includes determining the factor of safety of the slope. After being analyze, new proposal on how to improve the slope will be produced. The flow chart of the methodology is shown in the Figure 3.1.

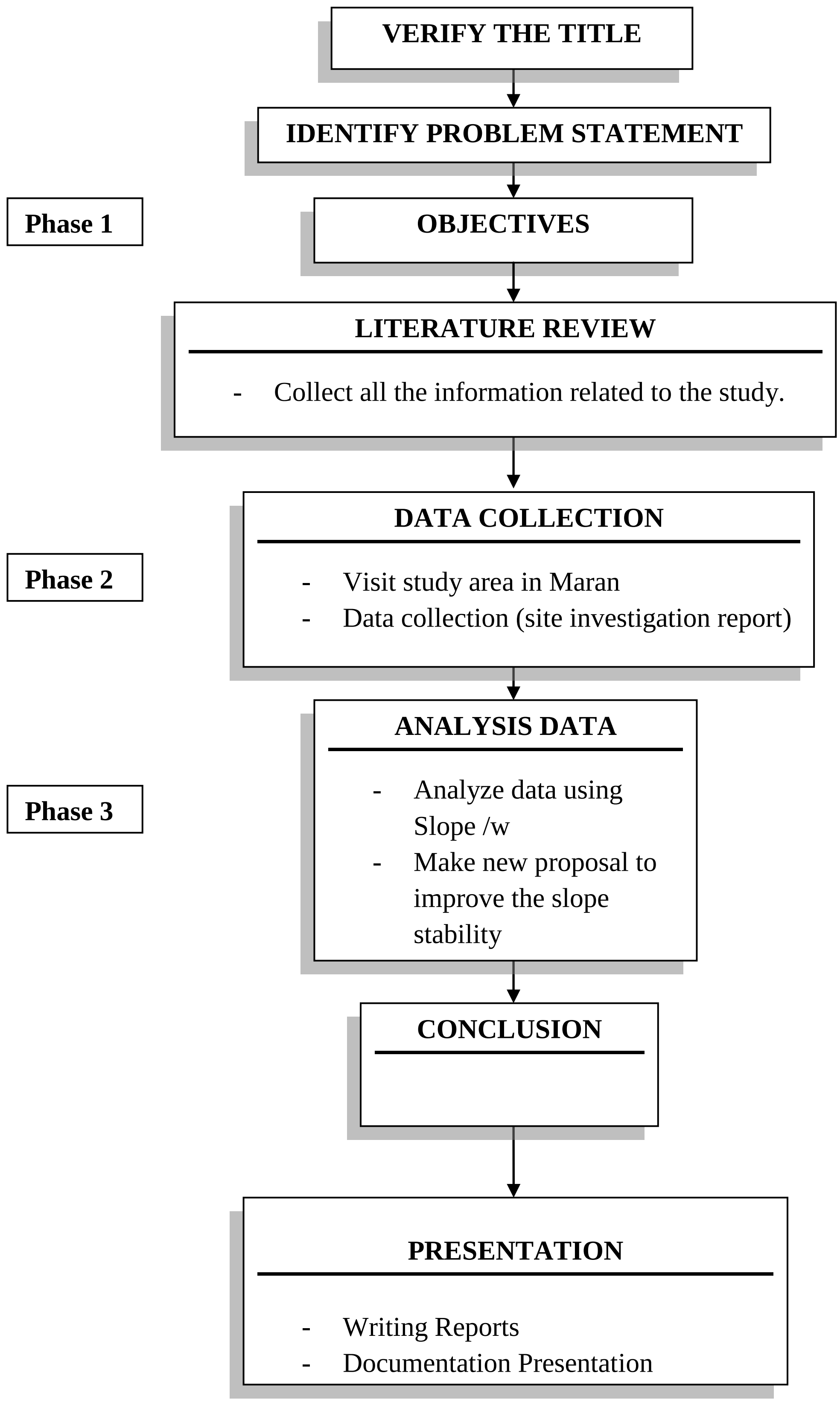


**Figure 3.1: Flow Chart Methodology**

## 3.2 Title verification

This is the first step that has been taken before this study been selected. The title of the study which is the analysis of slope failure at km 43.2 route C130 Kuala Wau-Kertau road in Maran using Slope/w was chosen after discussing with the supervisor before the problems statements were identified. After the problems statements have been decided, then only the objectives of the study to produce slope stability analysis for Kuala Wau-Kertau road slope using Slope/w and to produce a proposal to improve ground stability for the slope were decided.

## 3.3 Literature review

The next step is collecting data for the literature review. The literature review is the process to collect all the information that is related to the study, such as the site investigation report, soil properties and all related material with the study.

This literature review is also conducted by reading books to get the information and also analyze the previous studies done that related to the chosen topics. By this way, the references can be made and at the same time it can increase my knowledge about the topic of the study. The related references taken during this stage include the journals, reference books, internet, previous studies, reports and many more.

## 3.4 Data collection

At this phase, data of Kuala Wau-Kertau road slope is collected from the IKRAM. The case study area is specified which the slope is along the Kuala Wau-Kertau road. The data is consisting of the site investigation report of the slope including the topographic map of the slope area which is necessary in order to draw the slope in the software. The data also must consist of cohesion, c, the angle of friction, φ and the unit weight of the soil, γ.

## 3.5 Data analysis

After the data has been collected, the slope stability can be analyze using Slope/w. Slope stability analyses can be performed using deterministic or probabilistic input parameter. Stresses computed by a finite element stress analysis can be used in addition to limit equilibrium computation for the most of complete slope stability analysis available.

Slope/w can be used to analyze almost every slope stability problem by calculating the factor of safety. The factor of safety (FOS) can be calculated by modeling the slope in the software, including the pore water pressure and the slip surface, inserting the soil properties of the slope which includes the cohesion, c, the angle of friction, φ and also the unit weight of the soil, γ the slope can be analyze.

After the data has been analyzed, a proposal of an improved ground stability of the slope is carried out as the second objective of this study which is to produce a proposal to improve the ground stability of slope in Kuala Wau-Kertau road, the suitable remedial measures will be to apply to the slope in the software. The effect of each remedial measure to the FOS of the slope also can be analyzed using the Slope/w software. The best of remedial measure is been choose considering the effect to the slope stability and the total cost of the method.

## 3.6 Slope analysis using Slope/w

The stability of a slope can be determined by calculating the value of FOS using Slope/w. The software can analyze both simple and complex problem for a variety of slip surface shape, pore water pressure condition, soil properties, analysis method and loading condition in 2-dimentional.

Slope/w can be used to analyze almost every slope stability problem by calculating the factor of safety. The factor of safety can be calculated by modeling the slope in the software, including the pore water pressure and the slip surface, inserting the soil properties of the slope which includes the cohesion, c, the angle of friction, φ and also the unit weight of the soil, γ the slope can be analyze.

In order to determine the FOS of slope using Slope/w, there are some procedures that need to be done. The axis of the slope needs to be set first. Figure 3.2 and Figure 3.3 show the procedure of setting the axis of the slope and the scale unit of the slope.

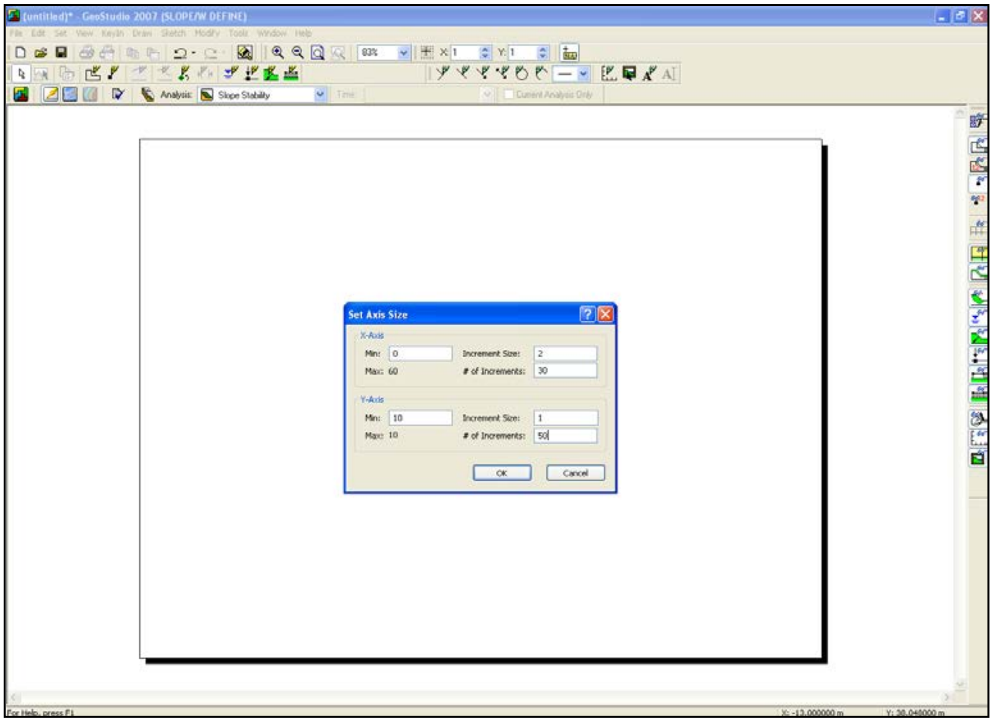


**Figure 3.2: Setting the axis of the slope**

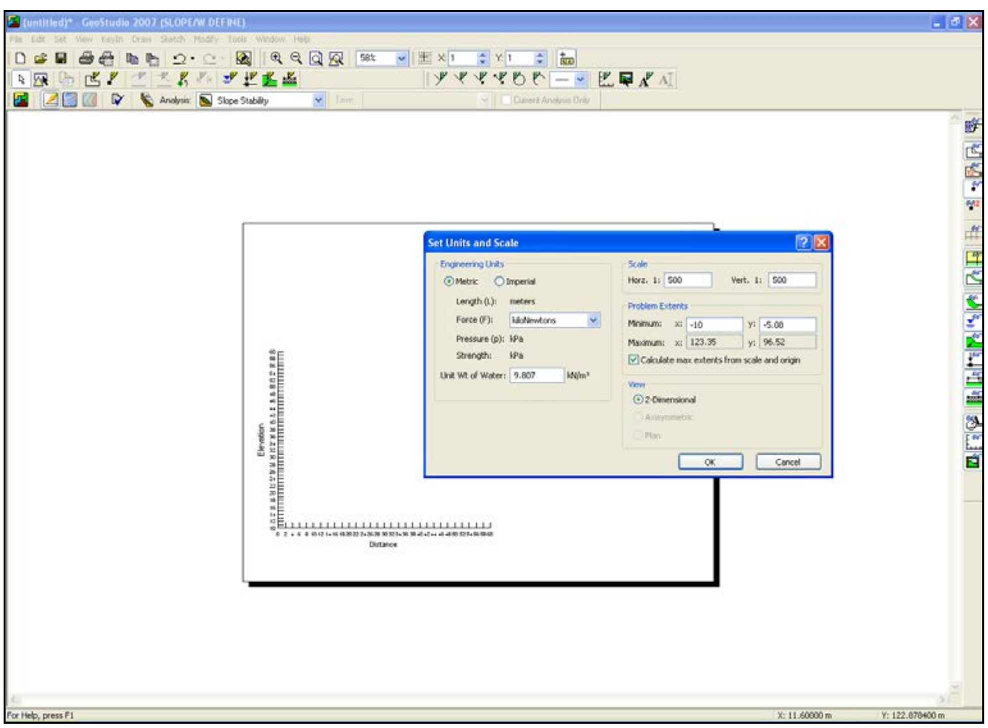


**Figure 3.3: Setting the unit and scale**

The point of the slope need be inserting into the software before the region can be draw. The point of the slope can be draw using the data from the soil investigation (SI) report. The elevation of each point can be determined from the map which needs to be drawn in 2-dimentional drawing using coordinate of x-axis and y-axis. Figure 3.4 illustrates the procedure of inserting the point of the slope.

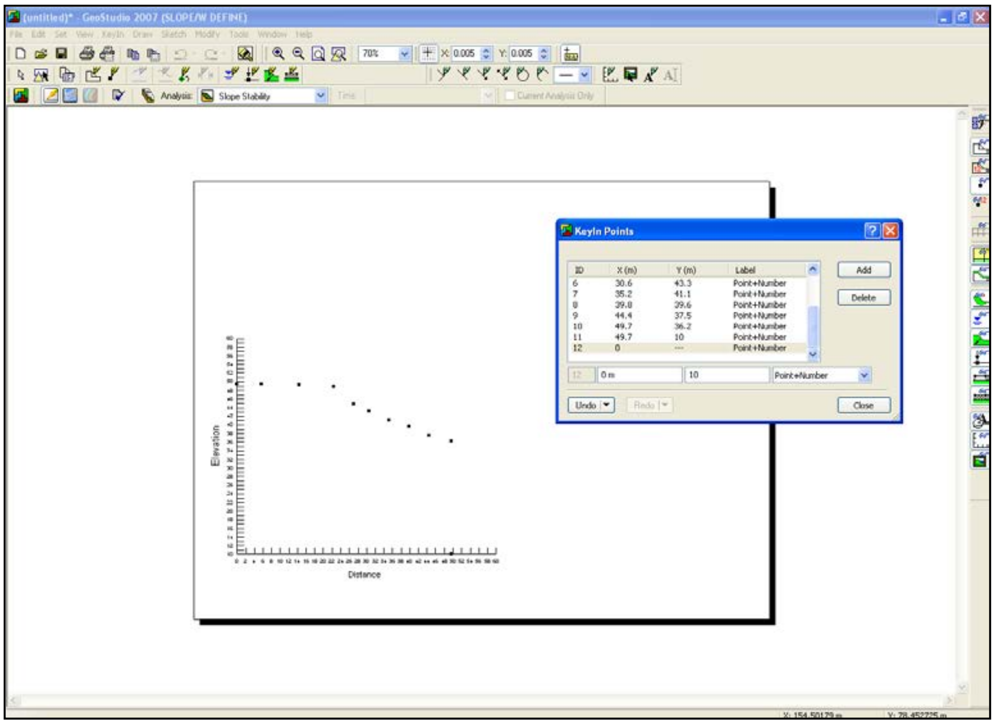


**Figure 3.4: Key in the points of the slope**

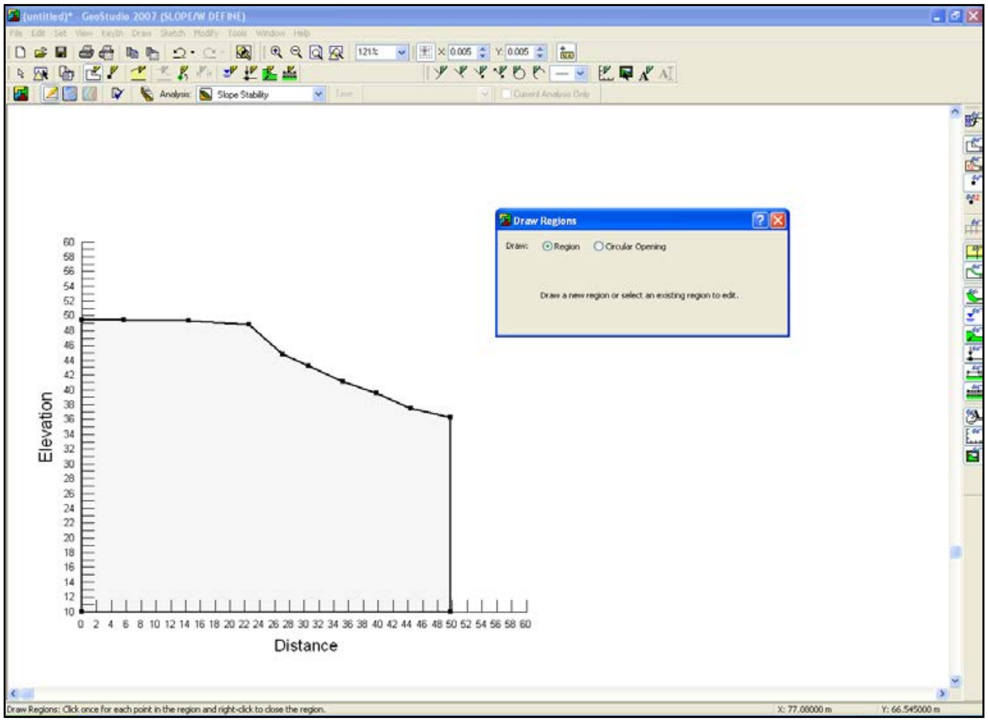


**Figure 3.5: Draw the region of the slope**

As the points inserted, the region of the slope can be determined. The drawing now illustrates the cross section of the slope in 2-dimention as shown in Figure 3.5.
After the region is determined, the soil properties which consist of the soil properties of the slope must be inserted. The data must consist of the value of the cohesion, c, the angle of friction, φ and also the unit weight of the soil, γ which are needed in the analysis using Slope/w as shown in Figure 3.6. The data of the soil properties can be obtained from the SI report.

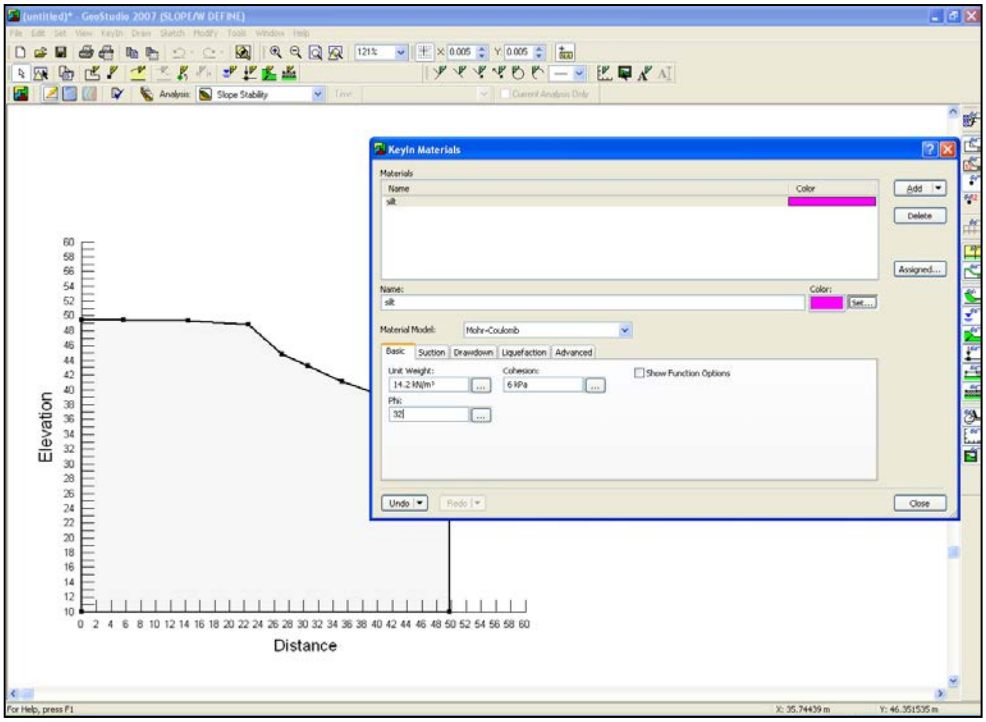


**Figure 3.6: Key in the soil properties of the slope**

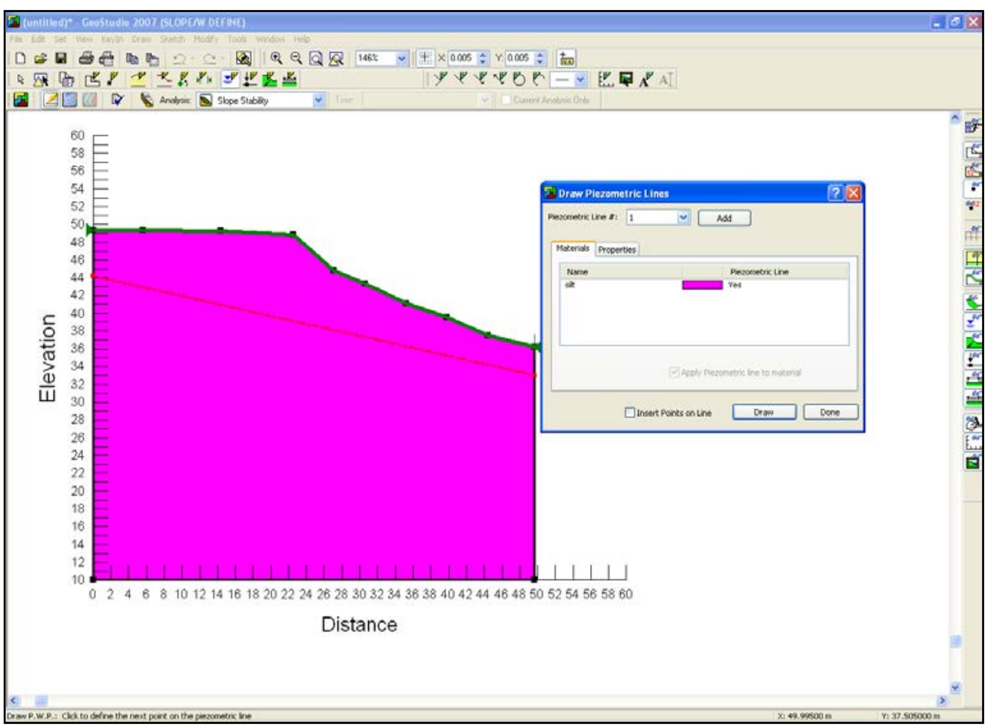


**Figure 3.7: Draw the piezometric line**

After key in the data of soil properties and the region, the piezometric line is drawn on the drawing which the depth of the piezometric line from the ground can be determined from the soil investigation report. Figure 3.7 illustrates the step of drawing the piezometric line on the software.

As all the data required has been inserted in the software, then the slope can be analyzed. The slip surface grid and radius of the imaginary failure plane has to be drawn. The slip surface grid indicates the trial point of the radius of failure plane while the slip surface radius indicates the trial radius of the failure plane. Figure 3.8 shows the trial slip surface grid and radius of the slope analysis that has been drawn.

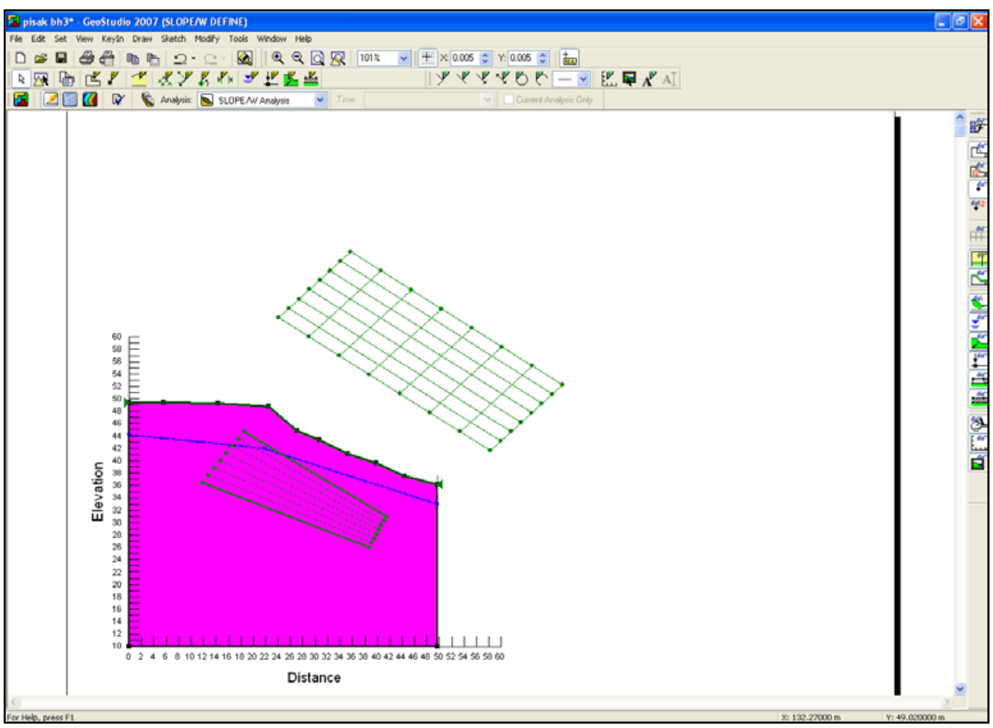


**Figure 3.8: Draw the slip surface grid and radius**

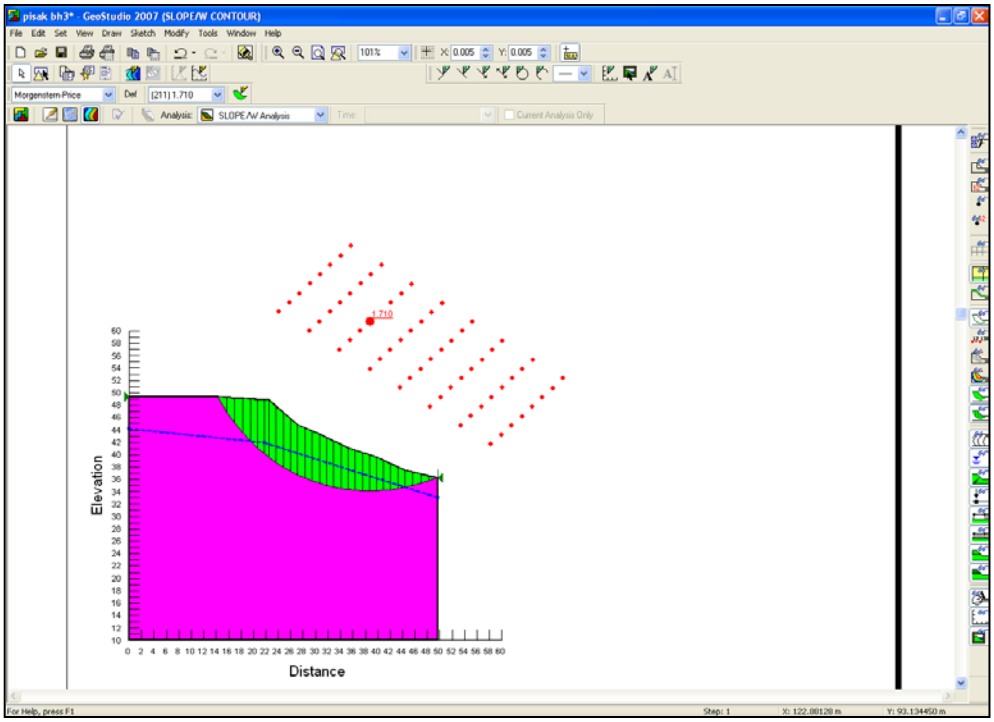


**Figure 3.9: The final result of slope analysis using Slope/w**

The final result of the analysis of slope using Slope/w as illustrated in Figure 3.9 shows the value of factor of safety (FOS) which can be the indicator for the slope stability whether the slope is safe or not. Beside the software also can analyze the slope stability after applying some remedial measures that will increase the value of FOS and hence improve the slope stability.

## 3.7 Conclusion

After the data of soil investigation is obtained, the slope stability is analyzed by using Slope/w to calculate the factor of safety of the slope. The analysis is carried out in order to achieve the first objective which is to produce slope stability analysis for Kuala Wau-Kertau road slope using Slope/w.

From the analysis, some remedial measures will be applied to the slope and the analysis of each method in term of FOS is determined. The best method of remedial measure in term of cost and effectiveness for the slope is choose in order to achieve the third objective which is to determine the best method of slope stability on Kuala Wau-Kertau slope in term of FOS and cost.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Analysis of Slope Failure

This chapter will give the detail of the data and results of the study. From the data, the analysis of the result is carried out. The analysis of slope stability is done by Slope/w using such parameters of soil after the slope is plotted in the software. The factor of safety (FOS) of the slope which is determined by the software indicates whether the slope is stable or not.

The data from the soil investigation report shows that the Kuala Wau-Kertau slope has failed. In this chapter, the analysis of the slope before and after failure is carried out. Figure 4.1 illustrates the analysis of the slope before failure using the software and Table 4.1 shows the FOS of the slope of each method of analysis used.

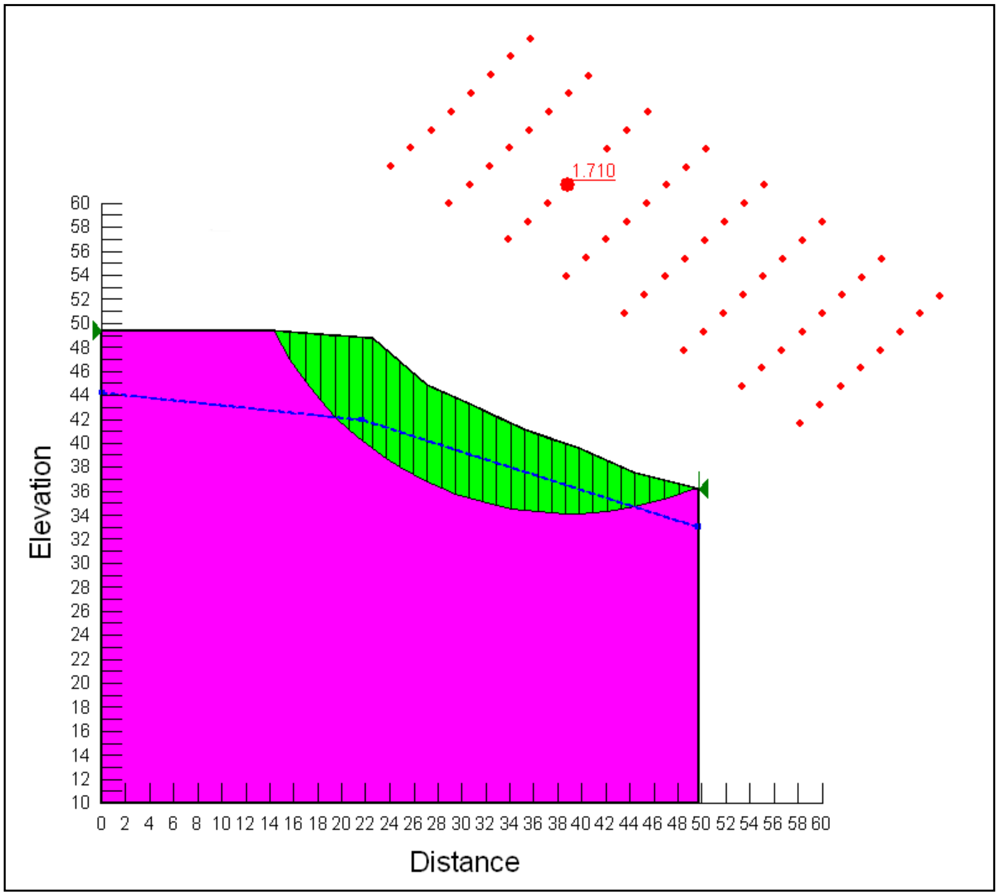


**Figure 4.1: Analysis of slope before failure**

**Table 4.1: FOS of each method of analysis before failure**

| Method of analysis | Factor of safety (FOS) |
|---|---|
| Ordinary | 1.495 |
| Bishop | 1.704 |
| Janbu | 1.538 |
| Morgenstern-Price | 1.710 |

From Table 4.1, we can see that the values of FOS from the slope before fail are within 1.538 to 1.710. All of the values of FOS determined can be classified as acceptable because the values are more than 1. Even though the value of FOS is acceptable, but the slope is still fail. The failure of the slope was not caused by inappropriate design since the acceptable values of FOS determined. The failure might be because of some other factor.

Figure 4.2 visualizes the analysis of slope after the failure and Table 4.2 shows the value of FOS of each method. From Table 4.2, we can see that the values of FOS of the slope after fail are within 1.668 to 2.101. From Figure 4.2, the type of slope failure can be classified as rotational slide which the slope seems like to fail along the failure plane. This type of failure happened due to the movement of soil which separated from the underlying and adjacent earth by plane comprising a number of adjacent planes, which failure results. The failure plane represents the continuous surface where the maximum shear strength of the earth material has been reached, with the result that large displacement occurs.

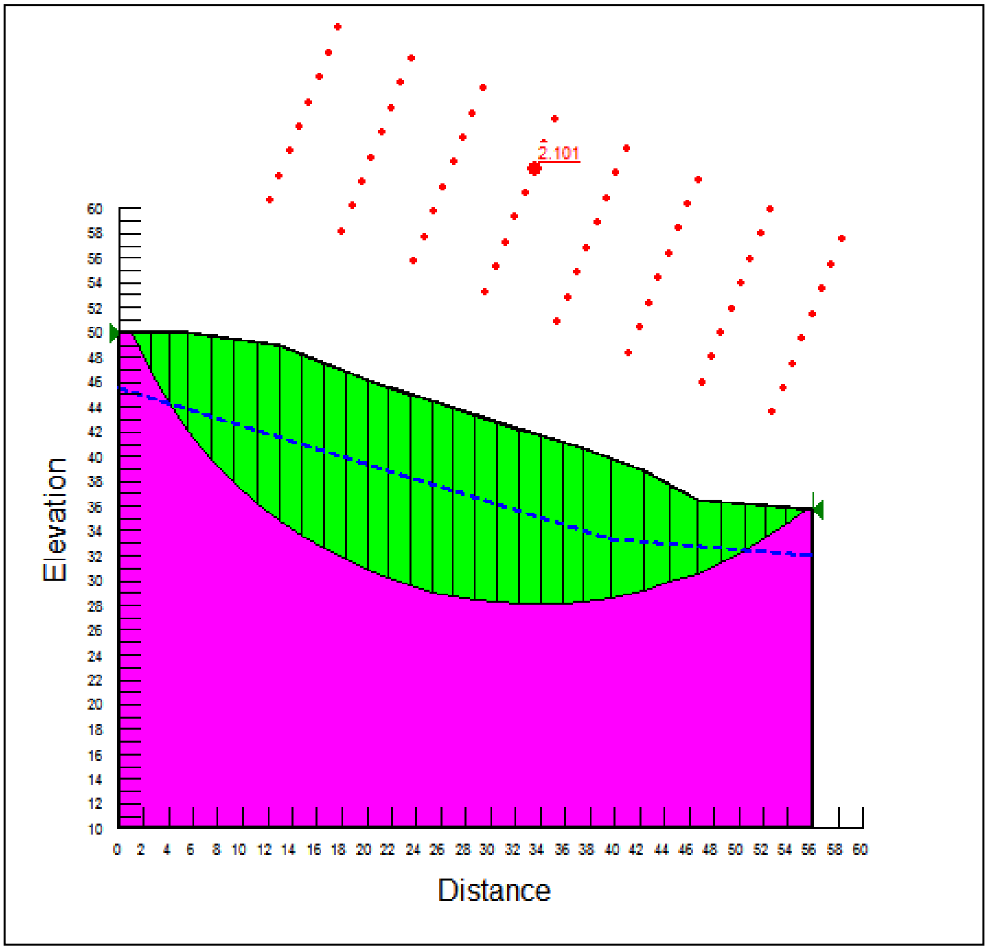


**Figure 4.2: Analysis of slope after failure**

**Table 4.2: FOS of Each Method of Analysis after Failure**

| Method of analysis | Factor of safety (FOS) |
|---|---|
| Ordinary | 1.668 |
| Bishop | 2.092 |
| Janbu | 1.808 |
| Morgenstern-Price | 2.101 |

Table 4.3 shows the comparison of FOS value before and after failure for each method of analysis. Most of the FOS from the slope after fail is increase compared to the FOS of slope before fail. The increment of FOS values is because of the slope is tend to be more stable after the failure.

**Table 4.3: The Comparison of FOS Values before and after Failure**

| **Method of analysis** | **Factor of safety (FOS) before failure** | **Factor of safety (FOS) after failure** |
|---|---|---|
| Ordinary | 1.495 | 1.668 |
| Bishop | 1.704 | 2.092 |
| Janbu | 1.538 | 1.808 |
| Morgenstern-Price | 1.710 | 2.101 |

From Table 4.3, the values of FOS before failure can be classified as acceptable because the values are more than 1. Even though the value of FOS is acceptable, but the slope is still fail. The failure of the slope was not caused by inappropriate design since the acceptable values of FOS determined. The failure might be because of some other factor such as the act of water, the type of soil and inappropriate drainage design.

Water can be considered as the main factor that contributes to the slope failure in Kuala Wau-Kertau slope. It is due to the weather in Malaysia which receives rain all the year. The slope failure may be caused by continuous heavy rain, especially in rainy season. Water will permeated through soil which will make the soil has high water content. The soil will become saturated and decrease the cohesiveness which will make it loose and easy to move to other places. This will make the slope become unstable and fail. Water need to be properly drained to avoid it from being permeated through the soil and hence make the soil loose and unstable. Proper water drainage needs to be applied to make sure the water flow on the slope and not through the slope. The water drainage also needs to be properly maintenance regularly to avoid it from clogging. Besides, the water drainage must also properly maintain by repair if any crack or damage.

The other factor that might be the factor of the slope failure is the type of soil of the slope. Data from the soil investigation report show that the type of soil of the slope is clay. As we can see in Table 4.4, the soil consists of 77.4% of clay, 15.1% of sand and 7.5% of gravel. So the type of soil can be classified as clay. Clay has a low permeability toward water which once water has infiltrate into the soil, it will remain in the soil for a long period of time. The existence of water in soil will disturb the correlation between soil particles and hence reduce the shear strength of soil.

**Table 4.4: Soil Classification of the Slope**

| Depth (m) | Clay (%) | Sand (%) | Gravel (%) |
|---|---|---|---|
| 1.5 – 1.95 | 87 | 11 | 2 |
| 4.5 – 4.95 | 89 | 9 | 2 |
| 6.0 – 6.45 | 80 | 15 | 5 |
| 7.5 – 7.95 | 72 | 12 | 16 |
| 9.0 – 9.45 | 41 | 43 | 16 |
| 10.5 – 10.95 | 49 | 31 | 20 |
| 12.0 – 12.3 | 82 | 8 | 10 |
| 13.5 – 13.7 | 95 | 5 | 0 |
| 15.0 – 15.2 | 84 | 12 | 4 |
| 16.5 – 16.6 | 95 | 5 | 0 |
| **Average** | **77.4** | **15.1** | **7.5** |

The lack of maintenance work on the slope can be considered as the factor of the slope failure. Proper maintenance works should be conduct to ensure the slope is in good condition. Routine inspections are compulsory to be made on the slope to establish the need for the maintenance work. The most important type of maintenance work that needs to be applied on the slope is to inspect the drainage channels and clear any blockage that can cause the channel from clogging. Any crack or damage on the drainage channel also needs to be repair to prevent it from disturbing the flow of water. This can prevent water from infiltrated into soil and hence reduce the strength of the soil. According to Mohd (2007), the type of routine maintenance works that need to be made on the slope are:

1. Clear accumulated debris from drainage channels and slope surface.
2. Repair cracked or damaged drainage channels or pavements.
3. Repair or replace cracked or damaged slope surfacing.
4. Unblock horizontal drain and outlet drain pipe.
5. Repair missing or deteriorated pointing in brick walls.
6. Remove any vegetation which can cause severe cracking of the slope surface cover and drainage channels.
7. Replant bare slope surface area with vegetation.
8. Remove loose rock debris and undesirable vegetation from rock slope.

## 4.2 Analysis of Remedial Measures

There are several remedial measures that can be applied to the slope in order to improve the stability of a slope. The factors that need to consider in choosing the type of remedial measure to be applied on the slope are the effect of the remedial measure toward the stability of the slope and the cost of the method applied.

### 4.2.1 Application of anchors to the slope

A few anchors are applied to the slope using Slope/w in order to improve the shear strength between the soil along the failure plane. By adding the anchors, the soil will be anchored and hence reduce the possibility of failure along the failure plane. The anchors applied will create a reinforced mass that is internally stable and able to retain the ground mass against active pressure, sliding, bearing an overturning force. Figure 4.3 shows the analysis of the slope and the FOS when anchors are applied to the slope.

Table 4.4 shows the comparison of FOS value before and after applying anchors to the slope. The result shows that the values of FOS are greatly increase after applying anchors although only 3 anchors are applied to the slope.

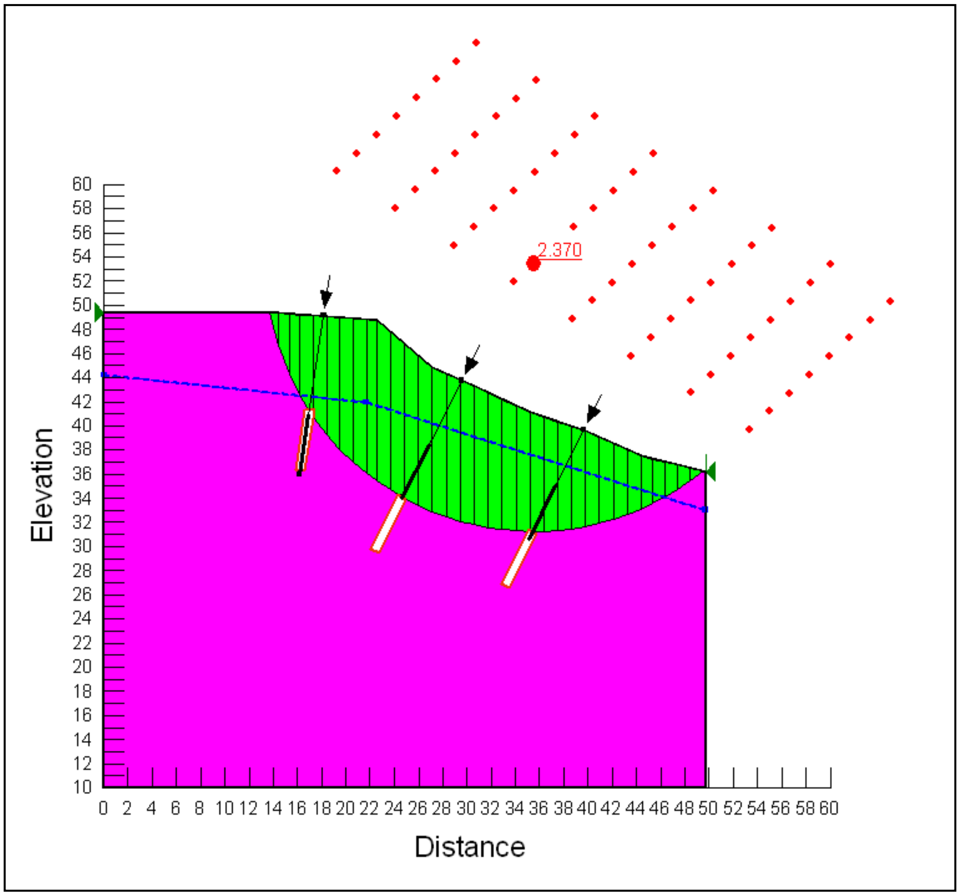


**Figure 4.3: Analysis of slope stability using anchors**

**Table 4.5: The comparison of FOS value before and after applying anchors**

| **Method of analysis** | **Factor of safety before applying anchors** | **Factor of safety after applying anchors** |
|---|---|---|
| Ordinary | 1.495 | 1.815 |
| Bishop | 1.704 | 2.366 |
| Janbu | 1.538 | 1.896 |
| Morgenstern-Price | 1.710 | 2.370 |

### 4.2.2 Application of benching method to the slope

The existing slope will be redesign to become more stable by applying this type of method. Some of the soil from the slope will be cut off to make the slope more stable and hence improve the stability of the slope. Figure 4.4 visualizes the analysis of the slope stability after applying the benching method. As we can see from Table 4.5, after the slope is cut off to make it less steep, the values of FOS are increases.

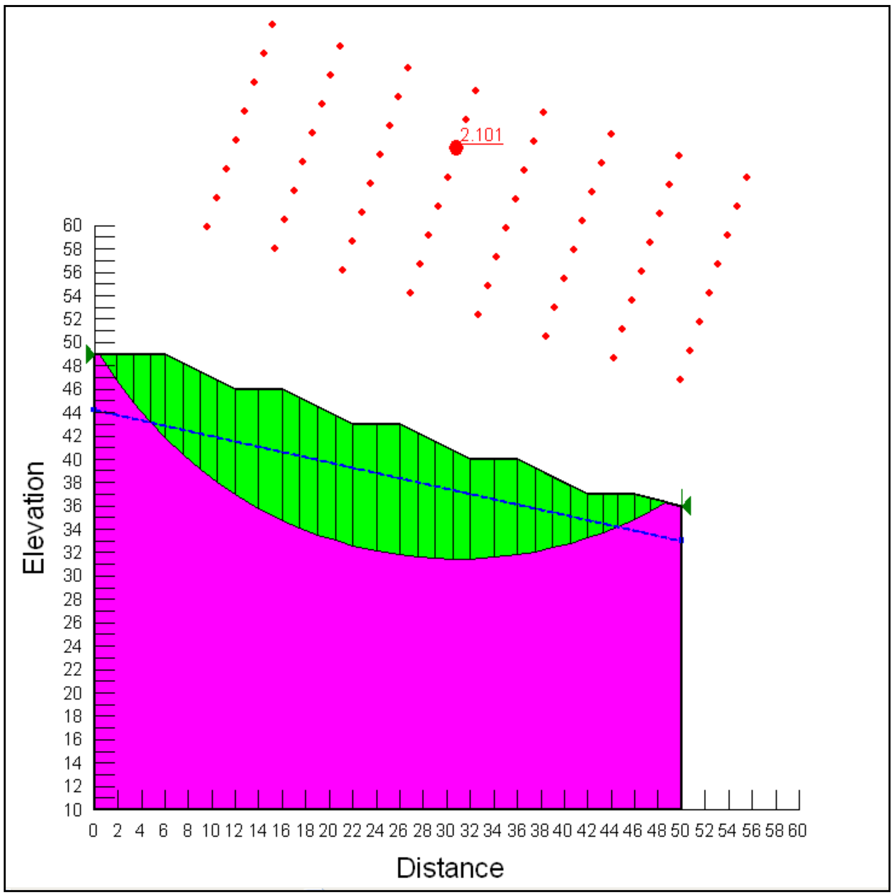


**Figure 4.4: Analysis of slope stability using benching method**

**Table 4.6: The comparison of FOS value before and after applying benching method**

| Method of analysis | Factor of safety before applying benching | Factor of safety after applying benching |
|---|---|---|
| Ordinary | 1.495 | 1.768 |
| Bishop | 1.704 | 2.094 |
| Janbu | 1.538 | 1.873 |
| Morgenstern-Price | 1.710 | 2.101 |

### 4.2.3 Application of soil nails to the slope

Soil nails is one of the most widely method that has been used in slope stabilization. The basic design concept of soil nailing is to reinforce and strengthen the slopes in-situ by installing grouted steel bars or driven pipes, called nails into progressively excavated slope by the top down process. This process can create a reinforced mass that is internally stable and able to retain the ground mass against active pressure, sliding, bearing an overturning force. The soil nail should be long enough and extended a minimum distance beyond the back of the failure plane to achieve the minimum targeted factor of safety.

In order to use this method of slope protection, reinforce concrete wall needs to be build on the slope to avoid water from permeated through the soil and hence make the soil loose and unstable. If there is no reinforce concrete, water might permeated between the soil nails and soil to the failure plane and resulting the slope fail along the failure plane.

Figure 4.5 illustrates the application of soil nails to the slope. As we can see the soil nails are long enough beyond the back of failure plane to act as anchors to hold the failure plane. Table 4.6 shows that the values of FOS of the slope are increase after applying soil nails.

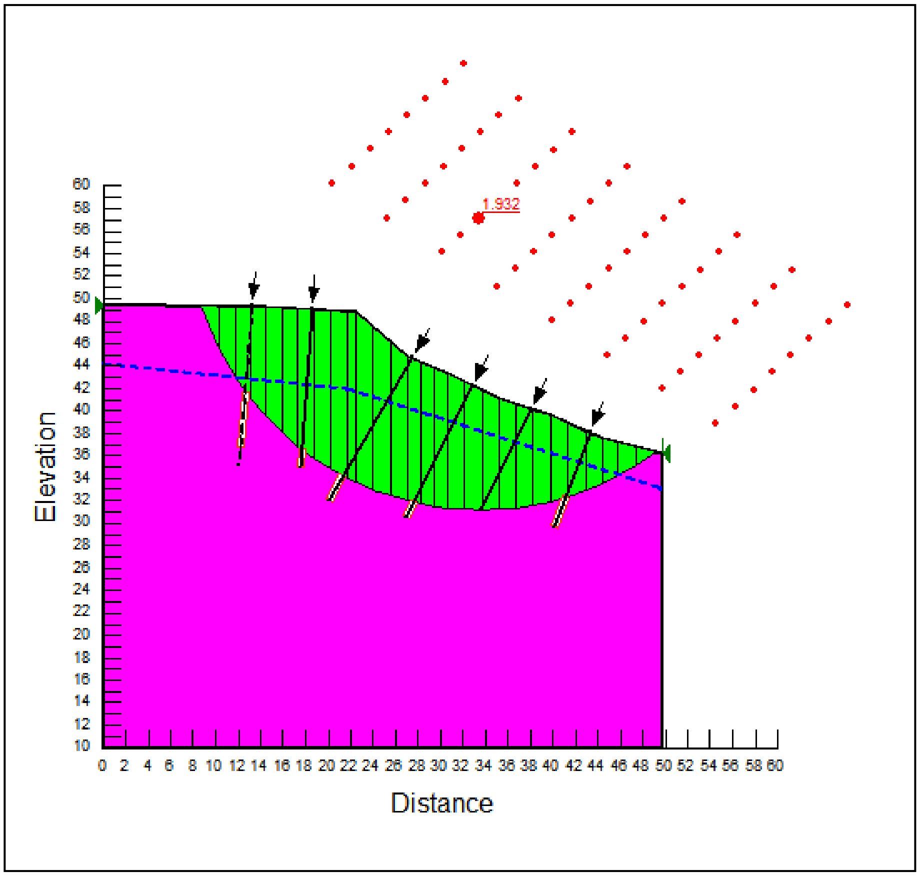


**Figure 4.5: Analysis of slope stability using soil nails**

**Table 4.7: The comparison of FOS value before and after applying soil nails**

| Method of analysis | Factor of safety before applying soil nails | Factor of safety after applying soil nails |
|---|---|---|
| Ordinary | 1.495 | 1.495 |
| Bishop | 1.704 | 1.919 |
| Janbu | 1.538 | 1.621 |
| Morgenstern-Price | 1.710 | 1.932 |

### 4.3 Analysis of Remedial Measures In Term Of Factor Of Safety

The most important criteria that must be taking care of in selecting the method of remedial measures to apply on the slope are from the value of FOS. After applying some method of remedial measures on the slope, the value of FOS of each method are better than before applying the remedial measure.

**Table 4.8: The percentage of increment of FOS value**

| **Method of analysis** | **% of increment for anchors** | **% of increment for benching** | **% of increment for soil nails** |
|---|---|---|---|
| Ordinary | 21.4 | 18.3 | - |
| Bishop | 38.8 | 22.9 | 12.6 |
| Janbu | 23.3 | 21.8 | 5.4 |
| Morgenstern-Price | 38.6 | 22.9 | 13.0 |
| **Average %** | **30.5** | **21.5** | **7.8** |

Table 4.8 shows the percentage increment of FOS value of each method applied on the slope. As we can see the highest percentage increment of FOS value is by applying anchors method on the slope which is by 30.5%. The percentage increment of FOS value for benching is 21.5% and the lowest percentage increment of FOS value is by applying soil nails on the slope.

From the result, the most effective method of slope protection in term of FOS is by applying anchors on the slope. This is because the anchors applied will create a reinforced mass that is internally stable and able to retain the ground mass against active pressure, sliding, bearing an overturning force than any other method. Besides, the shape of anchor which bigger at the base will grasp the soil particle and hence improve the shear strength of the soil. The length of anchor which is long enough to retain the soil particle from sliding at the failure plane also will improve the FOS and hence improve the slope stability.

Benching method will improve the FOS of the slope because the slope is cut to become less steep. By applying this method, the slope is stabilized externally and not considering the internal part of the slope. It means that the slope is cut just to reduce the possibility of the slope failure at the surface of the slope. This method will not prevent the slope from sliding and fail along the failure plane.

The lowest increment of FOS value after applying soil nails to the slope might be due to insufficient length of the soil nails which not extended a minimum distance beyond the back of the failure plane to achieve the minimum targeted factor of safety. The installation of the soil nails should grip the soil particle of the slope and hence improve the stability. However if the length of the soil nail is not long enough to reach the failure plane, this method is ineffective.

## 4.4 Analysis of Remedial Measures in Term of Cost

One of the factors that need to consider in selecting the remedial measures that can be applied to the slope is by considering the cost of each method. The best method of slope stability must give a better result on FOS and also a better price. The total estimated cost of each method is determined by multiplying the area of slope or volume of soil with the cost per unit. The overall area of slope is determined from the soil investigation report collected from IKRAM. The overall volume of soil that needs to cut by applying benching method is determined by the alteration of slope design using the Slope/w software. The overall area of slope is about 1600m$^2$ and overall volume of soil the need to cut is about 9000m$^3$. Khaksar (2008) gives the cost per unit of each method as shows in Table 4.9.

**Table 4.9: The Estimated Cost of Remedial Measures**

| **Method** | **Anchors** | **Benching** | **Soil nails** |
|---|---|---|---|
| Cost per unit | RM 102/unit/m$^2$ | RM 42/m$^3$ | RM 102/unit/m$^2$ |
| Total estimated cost | RM 500,000 | RM 400,000 | RM 980,000 |

From the result, the total estimated cost of applying soil nails on the slope is the most expensive which is RM 980,000. This is due to the high technology machinery that is needed to install the soil nails on the slope. Besides, the number of soil nail that needed to install is the factor that makes this method costly. Compared to anchors method, the number of anchors that needed to install to improve the slope stability is less. The total estimated cost of applying benching method is the cheapest because simple work and low cost machinery that is needed.

# CHAPTER 5

# CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

Based on the testing that has been done, it can be concluded that:

1. The value of factor of safety (FOS) using Morgenstern-Price Method for the slope before failure is 1.710. Although the result can be classified as acceptable which is more than 1, but the slope still fail. The failure is not caused by improper design of the slope but might due to other factor such as the act of water, the type of soil of the slope and lack of maintenance work.

2. The value of FOS after the slope fail by using Morgenstern-Price Method is 2.101. The increment of FOS value after the failure is due to the slope is tended to be more stable than before the failure.

3. The type of the slope failure can be classified as rotational slide which the slope seems like to fail along the failure plane. This type of failure happened due to the movement of soil which separated from the underlying and adjacent earth by plane comprising a number of adjacent planes, which failure results.

4. By applying anchors to the slope, the value of FOS for Morgenstern-Price Method is 2.370. The great increment of FOS value is due to the shape of anchor which bigger at the base will grasp the soil particle and hence improve the shear strength of the soil. Besides, the length of anchor which is long enough to retain the soil particle from sliding at the failure plane also will improve the FOS and hence improve the slope stability.

5. The increment of FOS value by applying the slope with benching method is 2.101 for Morgenstern-Price Method. The increment is due to the slope is stabilized externally which is by cutting the slope to become less steep.

6. By applying soil nails to the slope, the value of FOS for Morgenstern-Price Method is 1.932. The increment of FOS value is due to the soil nails will create a reinforced mass that is internally stable and able to retain the ground mass against active pressure, sliding, bearing an overturning force.

7. The best method of remedial measures that should be apply to the slope after considering the effect of FOS and the cost of the method applied is by using anchors. The selection of this method is due to the greatly increment of FOS value which is by 38.6% for Morgenstern-Price Method, 23.3% for Janbu Method, 38.8% for Bishop Method, and 21.4% for Ordinary Method. The total estimated cost to apply this method also is low which is about RM 500,000.

## 5.2 Recommendations

By the chances in increasing the knowledge and experiences during the analysis of this project is been carried out, many weaknesses are identified. After all the weaknesses has analyzed, the solutions that can be recommended to overcome those weaknesses for further study in the future are:

1. The study should analyze the slope that is more critical which the possibility of the slope failure is high and has more effect towards public safety. This will increase the implementation of the study towards the public safety. The examples of the critical slope in Malaysia are in Bukit Antarabangsa and the slopes along Karak Highway.

2. The soil investigation report of the slope should have more data which will helps in analyzing the slope stability. The number of bore hole that is done during the soil investigation should be numerous to simplify the process of analyzing the slope. Besides, more numbers of bore hole will helps the student in determining the type of soil at different depth.

3. In order to simplify the process of comparing the best method of remedial measures used to improve the slope stability, the number of remedial measures should be numerous. The student will be able to choose the best method of remedial measures in term of the effect towards the slope stability and cost of the applying the method.

4. By analyzing the combination of two or more remedial measures, the best FOS will be determined especially for the critical slope area. The result will be better which considering all the methods combined. The cost of

combining the methods might be higher. Hence in order to reduce the costs of applying both methods, combine the method which is low cost of installation but has a great effect towards slope stability for example by combining benching and anchors method.

5. There are many factors that affect the slope stability that needs to be considered for further study. For example the depth of water table, the height of the slope, the angle of the slope, the type of soil, the water drainage and many more. These factor needs to be analyzed to determine the cause of the slope failure.

6. To improve the result of the analysis for further study in the future, the analysis should be done by using other software that would gives better result. Different type of software may have different factor of consideration in determining the slope stability.

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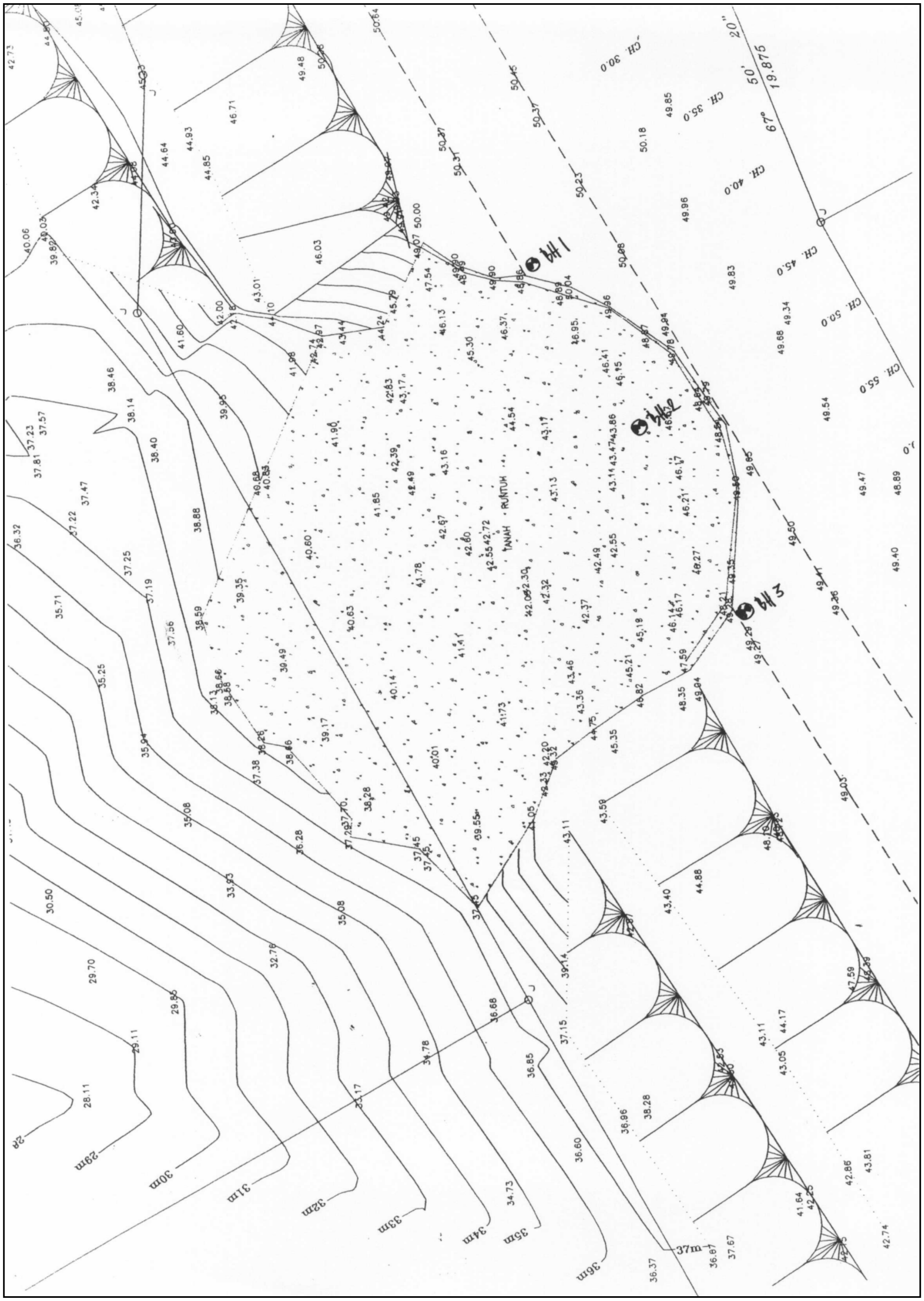
# APPENDIX A

# MAP OF KUALA WAU-KERTAU SLOPE


TANAH RUNTUH
BH1
BH2
BH3
CH. 30.0
CH. 35.0
CH. 40.0
CH. 45.0
CH. 50.0
CH. 55.0
67° 50' 20"
19.875
28m
29m
30m
31m
32m
33m
34m
35m
36m
37m

# APPENDIX B

# DATA OF SOIL PROPERTIES AND SOIL TYPES

**IKRAM CENTRAL GEOTECHNICAL LABORATORY**

**Summary Of Laboratory Test Results - BS 1377 : 1990**

**PROJECT : CERUN RUNTUH DI JALAN KUALA WAU - KERTAU, MARAN, PAHANG.**

| | | |
|---|---|---|
| Your Ref | : | IC/09/C55(046)Jld.1 |
| Our. Ref | : | ICGL/C/11 |
| Job No | : | 37/09 |
| Report No | : | T/86/2009 |
| Date | : | 18.5.2009 |

| BH No | Sample No | Depth (m) | B.S.C.S | M/C % | Bulk Density $Mg/m^3$ | SG | 1-D Consol Test Pc $kN/m^2$ | Cc | Initial Void | UCT Test c $kN/m^2$ | UU Test c $kN/m^2$ | UU Test $\phi$ Degree | CU Test c' $kN/m^2$ | CU Test $\phi'$ Degree | Soil Chemical Test / Water Chemical Test OM % | $SO_3$ % | $SSO_3$ % | ph | Cl % | SCl % | Atterberg Limit LL % | PL % | PI % | LS % | Sieve & Hydrometer Analysis CLAY % | SILT % | SAND % | GRAVEL % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BH/3 | S1D2 | 1.5 - 1.95 | CH | 26 | | 2.63 | | | | | | | | | | | | | | | 55 | 28 | 27 | | 28 | 59 | 11 | 2 |
| BH/3 | S2D3 | 4.5 - 4.95 | C | 27 | | 2.68 | | | | | | | | | | | | | | | N.E.S | N.E.S | 39 | 18 | 45 | 44 | 9 | 2 |
| BH/3 | S3D4 | 6 - 6.45 | MV | 34 | | 2.73 | | | | | | | | | | | | | | | 73 | 45 | 28 | | 26 | 54 | 15 | 5 |
| BH/3 | S4D5 | 7.5 - 7.95 | MV | 33 | | 2.75 | | | | | | | | | | | | | | | 72 | 42 | 30 | | 23 | 49 | 12 | 16 |
| BH/3 | S5D6 | 9 - 9.45 | MS | 18 | | 2.73 | | | | | | | | | | | | | | | N.A | N.A | 12 | 5 | 13 | 28 | 43 | 16 |
| BH/3 | S6D7 | 10.5 - 10.95 | CS | 25 | | 2.61 | | | | | | | | | | | | | | | N.E.S | N.E.S | 26 | 12 | 28 | 21 | 31 | 20 |
| BH/3 | S7D8 | 12 - 12.315 | CI/CH | 14 | | 2.68 | | | | | | | | | | | | | | | 50 | 25 | 25 | | 23 | 59 | 8 | 10 |
| BH/3 | S8D9 | 13.5 - 13.685 | M | 8 | | 2.61 | | | | | | | | | | | | | | | N.E.S | N.E.S | 29 | 14 | 21 | 74 | 5 | 0 |
| BH/3 | S9D10 | 15 - 15.135 | M | 9 | | 2.68 | | | | | | | | | | | | | | | N.E.S | N.E.S | 27 | 13 | 19 | 65 | 12 | 4 |
| BH/3 | S10D11 | 16.5 - 16.64 | M | 10 | | 2.59 | | | | | | | | | | | | | | | N.E.S | N.E.S | 29 | 14 | 19 | 76 | 5 | 0 |
| BH/3 | UD1 | 3 - 3.7 | CI | 37 | | 2.622 | | | | | | | 6 | 32 | | | | | | | 49 | 23 | 26 | | 24 | 43 | 5 | 28 |

NOTE : N.E.S = NOT ENOUGH SAMPLE N.A = NOT APPLICABLE N.D = NOT DETECTED

**IKRAM CENTRAL GEOTECHNICAL LABORATORY**

**Summary Of Laboratory Test Results - BS 1377 : 1990**

**PROJECT : CERUN RUNTUH DI JALAN KUALA WAU - KERTAU, MARAN, PAHANG.**

| | | |
|---|---|---|
| Your Ref | : | IC/09/C55(046)Jld.1 |
| Our. Ref | : | ICGL/C/11 |
| Job No | : | 37/09 |
| Report No | : | T/86/2009 |
| Date | : | 18.5.2009 |

| BH | Sample | Depth | B.S.C.S | M/C | Bulk Density | SG | 1-D Consol Test | | | UCT Test | UU Test | | CU Test | | Soil Chemical Test / Water Chemical Test | | | | | | Atterberg Limit | | | | Sieve & Hydrometer Analysis | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | Pc | | Initial | c | c | φ | c' | φ' | OM | $SO_3$ | $SSO_3$ | ph | Cl | SCl | LL | PL | PI | LS | CLAY | SILT | SAND | GRAVEL |
| No | No | (m) | | % | $Mg/m^3$ | | $kN/m^2$ | Cc | Void | $kN/m^2$ | $kN/m^2$ | Degree | $kN/m^2$ | Degree | % | % | % | | % | % | % | % | % | % | % | % | % | % |
| BH/1 | S1D2 | 1.5 - 1.95 | MH | 34 | | 2.70 | | | | | | | | | | | | | | | 67 | 36 | 31 | | 36 | 38 | 19 | 7 |
| BH/1 | S2D3 | 3 - 3.45 | MH/MV | 33 | | 2.67 | | | | | | | | | | | | | | | 70 | 37 | 33 | | 32 | 43 | 16 | 9 |
| BH/1 | S3D4 | 6 - 6.45 | MV | 32 | | 2.72 | | | | | | | | | | | | | | | 71 | 40 | 31 | | 30 | 46 | 17 | 7 |
| BH/1 | S4D5 | 7.5 - 7.95 | M | 30 | | 2.64 | | | | | | | | | | | | | | | N.E.S | N.E.S | 43 | 20 | 27 | 41 | 24 | 8 |
| BH/1 | S5D6 | 9 - 9.385 | MS | 11 | | 2.69 | | | | | | | | | | | | | | | N.A | N.A | 15 | 7 | 1 | 34 | 64 | 1 |
| BH/1 | S6D7 | 10.5 - 10.95 | MS | 11 | | 2.66 | | | | | | | | | | | | | | | N.E.S | N.E.S | 32 | 15 | 13 | 31 | 39 | 17 |
| BH/1 | S7D8 | 12 - 12.28 | M | 11 | | 2.71 | | | | | | | | | | | | | | | N.E.S | N.E.S | 26 | 12 | 20 | 73 | 4 | 3 |
| BH/1 | S8D9 | 13.5 - 13.685 | MS | 10 | | 2.71 | | | | | | | | | | | | | | | N.A | N.A | 16 | 8 | 6 | 38 | 43 | 13 |
| BH/1 | UD1 | 4.5 - 5.2 | CH | 22 | | 2.613 | | | | | | | 9 | 30 | | | | | | | 62 | 25 | 37 | | 45 | 51 | 4 | 0 |

NOTE : N.E.S = NOT ENOUGH SAMPLE N.A = NOT APPLICABLE N.D = NOT DETECTED

Project Cerun Runtuh Di Jalan Kuala Wau-Kertau Maran, Pahang — Cert No [illegible]
Location
Job No MTS/J188/09

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Wt of Dry Soil | 50 | gm | Depth | 3 00-3 70 m | Dry Wt of Soil | gm | Depth | | m |
| Specific Gravity | 2 60 | (Assumed) | Date | 16/04/09 | Specific Gravity | (Assumed) | Date | | |
| **BH No.:** | **BH 3** | | **Sample:** | **UD1** | **BH No.:** | | **Sample:** | | |

| S Sieve No | (mm) | Wt of Soil Retained | % Retained | % Passing | Wt of Soil Retained | % Retained | % Passing |
|---|---|---|---|---|---|---|---|
| 3/4" | 19 0 | | | 100 00 | | | |
| 1/2" | 13 2 | | | 100 00 | | | |
| 3/8" | 9 5 | 9 64 | 19 28 | 80 72 | | | |
| 3/16" | 4 75 | 3 76 | 7 52 | 73 20 | | | |
| #8 | 2 00 | 0 76 | 1 52 | 71 68 | | | |
| #14 | 1 18 | 0 30 | 0 60 | 71 08 | | | |
| #25 | 0 60 | 0 40 | 0 80 | 70 28 | | | |
| #36 | 0 425 | 0 20 | 0 40 | 69 88 | | | |
| #52 | 0 300 | 0 22 | 0 44 | 69 44 | | | |
| #100 | 0 150 | 0 57 | 1 14 | 68 30 | | | |
| #200 | 0 063 | 0 88 | 1 76 | 66 54 | | | |
| | Pan | 33 27 | 66 54 | 0 00 | | | |
| | TOTAL | 50 00 | 100 00 | | | | |

| Elapsed Time t (min) | Hydrometer Reading Rh' | True Reading Rh | Effective Depth Hr (mm) | Corrected Reading Rd | Particle Diameter D (mm) | % Finer | Hydrometer Reading Rh' | True Reading Rh | Effective Depth Hr (mm) | Corrected Reading Rd | Particle Diameter D (mm) | % Finer |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 0190 | 19 5 | 134 50 | 18 3 | 0 0479 | 59 47 | | | | | | |
| 2 | 1 0180 | 18 5 | 138 50 | 17 3 | 0 0343 | 56 23 | | | | | | |
| 4 | 1 0175 | 18 0 | 140 50 | 16 8 | 0 0245 | 54 60 | | | | | | |
| 8 | 1 0160 | 16 5 | 146 50 | 15 3 | 0 0177 | 49 73 | | | | | | |
| 30 | 1 0140 | 14 5 | 154 50 | 13 3 | 0 0094 | 43 23 | | | | | | |
| 120 | 1 0120 | 12 5 | 162 50 | 11 3 | 0 0048 | 36 73 | | | | | | |
| 480 | 1 0090 | 9 5 | 174 50 | 8 3 | 0 0025 | 26 97 | | | | | | |
| 1440 | 1 0070 | 7 5 | 182 50 | 6 3 | 0 0015 | 20 47 | | | | | | |
| Dispersant Correction 4 | | | CLAY % | SILT % | SAND % | GRAVEL % | Dispersant Correction 4 | | CLAY % | SILT % | SAND % | GRAVEL % |
| Water Temperature 25 C | | | 23 9 | 42 7 | 5 1 | 28 3 | Water Temperature 25 C | | | | | |

Project Cerun Runtuh Di Jalan Kuala Wau-Kertau. Maran. Pahang Cert No. 2377
Location
Job No MTS/J188/09

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Wt of Dry Soil | 50 | gm | Depth : | 4 50-5 20 m | Dry Wt of Soil | | gm | Depth | m |
| Specific Gravity | 2 60 | (Assumed) | Date | 16/04/09 | Specific Gravity | | (Assumed) | Date | |
| **BH No.:** | **BH 1** | | **Sample:** | **UD1** | **BH No.:** | | | **Sample:** | |

| S.Sieve No | (mm) | Wt of Soil Retained | % Retained | % Passing | Wt of Soil Retained | % Retained | % Passing |
|---|---|---|---|---|---|---|---|
| 3/4" | 19.0 | | | 100 00 | | | |
| 1/2" | 13.2 | | | 100.00 | | | |
| 3/8" | 9.5 | | | 100.00 | | | |
| 3/16" | 4 75 | 0 90 | | 100.00 | | | |
| #8 | 2 00 | 0.96 | | 100.00 | | | |
| #14 | 1 18 | 0.35 | 0 70 | 99 30 | | | |
| #25 | 0 60 | 0.15 | 0.30 | 99.00 | | | |
| #36 | 0.425 | 0.31 | 0.62 | 98 38 | | | |
| #52 | 0.300 | 0.25 | 0 50 | 97 88 | | | |
| #100 | 0 150 | 0.51 | 1.02 | 96.86 | | | |
| #200 | 0.063 | 0.50 | 1.00 | 95.86 | | | |
| | Pan | 46.07 | 92.14 | 3.72 | | | |
| | TOTAL | 50.00 | 96.28 | | | | |

| Elapsed Time t (min) | Hydrometer Reading Rh' | True Reading Rh | Effective Depth Hr (mm) | Corrected Reading Rd | Particle Diameter D (mm) | % Finer | Hydrometer Reading Rh' | True Reading Rh | Effective Depth Hr (mm) | Corrected Reading Rd | Particle Diameter D (mm) | % Finer |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 0280 | 28 5 | 98 50 | 27 3 | 0.0410 | 88 73 | | | | | | |
| 2 | 1 0235 | 24 0 | 116 50 | 22 8 | 0 0315 | 74 10 | | | | | | |
| 4 | 1 0230 | 23 5 | 118 50 | 22 3 | 0 0225 | 72 47 | | | | | | |
| 8 | 1.0220 | 22.5 | 122 50 | 21.3 | 0 0162 | 69 23 | | | | | | |
| 30 | 1 0210 | 21 5 | 126 50 | 20 3 | 0 0085 | 65 97 | | | | | | |
| 120 | 1 0195 | 20 0 | 132 50 | 18 8 | 0.0043 | 61 10 | | | | | | |
| 480 | 1.0150 | 15 5 | 150 50 | 14 3 | 0.0023 | 46 47 | | | | | | |
| 1440 | 1.0140 | 14.5 | 154.50 | 13 3 | 0 0014 | 43 23 | | | | | | |

| | CLAY % | SILT % | SAND % | GRAVEL % | | CLAY % | SILT % | SAND % | GRAVEL % |
|---|---|---|---|---|---|---|---|---|---|
| Dispersant Correction 4 | | | | | Dispersant Correction 4 | | | | |
| Water Temperature: 25 C | 45 4 | 50 4 | 4 1 | 0.0 | Water Temperature: 25 C | | | | |