# ANALYSIS OF METHOD STABILITY OF SLOPE FAILURE USING SLOPE/W AND MANUAL CALCULATION FOR REDESIGNING FAILED SLOPE - A CASE STUDY

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## ABSTRAK

Kegagalan cerun telah menjadi salah satu bencana alam yang selalu berlaku di Malaysia disebabkan banyak factor. Isu tanah runtuh yang bertambah, bencana alam, dan juga keperluan untuk memotong dan menambah cerun untuk pembangunan dan projek pembinaan di Malaysia telah mengembangkan komitmen untuk menambah baik kefahaman tentang prinsip-prinsip mekanik tanah yang menghubungkan ciri-ciri tanah terhadap kestabilan cerun, kaedah analitikal, dan juga kaedah menstabilkan cerun yang sudah gagal untuk mengatasi masalah kestabilan cerun. Kajian ini akan fokus tentang analisis kestabilan cerun dengan menggunakan kaedah Ordinary Method of Slice, dengan menggunakan perisian Slope/W dan juga pengiraan manual. Data dan parameter tanah adalah berdasarkan kajian kes tanah runtuh yang berlaku di Taman Bukit Kuchai, Bandar Kinrara, Selangor Dahrul Ehsan yang telah runtuh. Dengan analisis nilai faktor keselamatan, perbandingan daripada dua kaedah yang digunakan untuk analisis nilai faktor keselamatan boleh dilakukan, faktor berlakunya tanah runtuh boleh dikenalpasti, dan juga kaedah kestabilan cerun yang sesuai boleh diaplikasikan. Daripada kajian analisis yang telah dijalankan, cerun Taman Bukit Kuchai, Bandar Kinrara, Selangor Dahrul Ehsan telah gagal dengan nilai faktor keselamatan 1.060 yang dianggap tidak Selamat dan tidak stabil. Nilai faktor keselamatan yang diperoleh daripada perisian Slope /W dengan kaedah Ordinary Method of Slice adalah 1.060 manakala nilai faktor keselamatan yang diperoleh daripada pengiraan manual dengan kaedah Ordinary Method of Slice adalah 1.1507 dan adalah hampir sama kerana formula yang digunakan adalah sama. Berdasarkan laporan penyiasatan tanah, punca kegagalan cerun adalah mungkin disebabkan daripada hujan lebat yang berterusan dan menyebabkan cengkaman tanah lemah disebabkan oleh ciri-ciri dan parameter tanah itu sendiri. Dengan membandingkan kaedah-kaedah yang boleh diaplikasikan untuk meningkatkan kestabilan cerun ini, kaedah terbaik dengan mengambil kira nilai tertinggi faktor keselamatan adalah pengukuan tanah atau soil nailing. Ia menunjukkan peningkatan tertinggi setelah kaedah kestabilan pengukuan tanah diaplikasikan dengan nilai faktor keselamatan tertinggi iaitu 2.167 dan peningkatan sebanyak 51.08%.

# ABSTRACT

Slope failure have become one of the most natural disasters that commonly happened in Malaysia due to many factors. The rising of the landslide cases, natural disasters, and the demand for engineered cut and fill slopes on development and construction projects in Malaysia also developed the commitment to improve the understanding and principles of soil mechanics that connect soil behavior to slope stability, investigative tools, the analytical methods and stabilization method or remedial measures involved to deal with slope stability issue. This paper will focus more on the slope stability analysis using the Ordinary Method of Slices with approaching using software Slope/W and manual calculation. The data and soil parameters were basically based on a real case study of a failed slope that happened at Taman Bukit Kuchai, Bandar Kinrara, Selangor Dahrul Ehsan which have failed and may cause further failure and effect to the residents around the area in the future. With the analysis and computing of factor of safety, comparison between both methods can be compared, the causes of slope failure can be identified, hence remedial measures can be applied to the failed slope. From the analysis it is found that, the slope at Taman Bukit Kuchai, Bandar Kinrara, Selangor Dahrul Ehsan is considered as failed. With the analysis and computing of factor of safety, the FOS value obtained is 1.060 which is considered as unsafe and unstable. FOS value computed using Ordinary Method of Slice by using Software Slope/W (1.060) and manual calculation (1.1507) is similar to each other. Hence, it shows that both methods have same FOS value due to apply same formula (Fellenius's method) to analyze the slope. Based on soil investigation report, the slope failed may be due to the type of soil which has low strength may cause the potential block slide downward due to its discontinuities parameter, triggered by severe erosion and intense rainfall. Comparing with other remedial measures to stabilize the slope in term of FOS value, the best remedial measures to be selected after considering the highest FOS value of 2.167 is soil nails. It shows that by applying this type of remedial measures, the FOS value have increase by 51.08%.

## TABLE OF CONTENT

## LIST OF TABLES

# LIST OF FIGURES



Figure 2. 1: Plane and wedge failure 9

## LIST OF SYMBOLS

| | |
|---|---|
| c | Cohesion |
| Ø | Angle of friction |
| ψ | Unit weight of the soil |
| gp | Perpendicular component of gravity |
| gt | Tangential component of gravity |
| β | Slice base length |
| N | Base normal |
| W | Slice weight |
| α | Base inclination |

## LIST OF ABBREVIATIONS

| | |
|---|---|
| FOS | Factor of Safety |

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

Slopes exist either by nature or engineered by human beings. Throughout the old days, slope stability problems have been faced when humans or nature has disturbed the delicate balance of natural soil slopes. The rising of the landslide cases, natural disasters, and the demand for engineered cut and fill slopes on development and construction projects in Malaysia also developed the commitment to improve the understanding and principles of soil mechanics that connect soil behaviour to slope stability, investigative tools, the analytical methods and stabilization method or remedial measures involved to deal with slope stability issue.

One of the most horrifying disasters in Malaysian history was the landslide happened on 11 December 1993 in Taman Hillview, Ulu Klang, in Selangor, Malaysia where a total of 48 people perished when one of the three towers collapsed in a landslide, trapping them under mud and rubble and also the highest fatality for a single landslide was recorded on December 26, 1996 where 302 people were killed when debris flow caused by tropical storm Gregg wiped out several villages in Keningau, Sabah (A.Samy, 2011). Not only that, landslide on the NKVE at Bukit Lanjan in 2003, was costliest in repairing, which was estimated to cost RM836 million, consumed time of reconstruction, with traffic being disrupted around the area. Globally the cost runs into billions of Ringgit Malaysia in damage with thousands of deaths and injuries each year had triggered and lead to the development of improved understanding of the soil properties that can occur and change over time. Slope stabilization methods involves specialty construction that must be understood and modelled in realistic ways. An understanding of geology, hydrology, and soil properties is significant to be apply to slope stability principles properly.(J.Michael, 2014). Analyses must be based upon a model that accurately represents site subsurface conditions, ground behaviour and applied loads. Judgements for the acceptable risk or safety factors must be made to assess the results of analyses.

Not only that, the Kenny Hill formation which lithology consists of its residual soils from inter bedding of shale, mudstone, siltstone and sandstone was also commonly found in Kuala Lumpur, Petaling Jaya, Puchong and also Shah Alam. Generally, it was found that the extreme differences in the physical deterioration and durability of sandstone and shale characteristics has resulted to the complex geotechnical problems frequently encountered by civil engineer working in tropically weathered Kenny Hill formation (Mohamed, Rafek, & Komoo, 2007). Based on the geological map Jabatan Mineral and Geosains, the site for this case study was also located in Kenny Hill formation. Figure 1.1 shows the general geology of the site location while Figure 1.2 shows site location of case study.

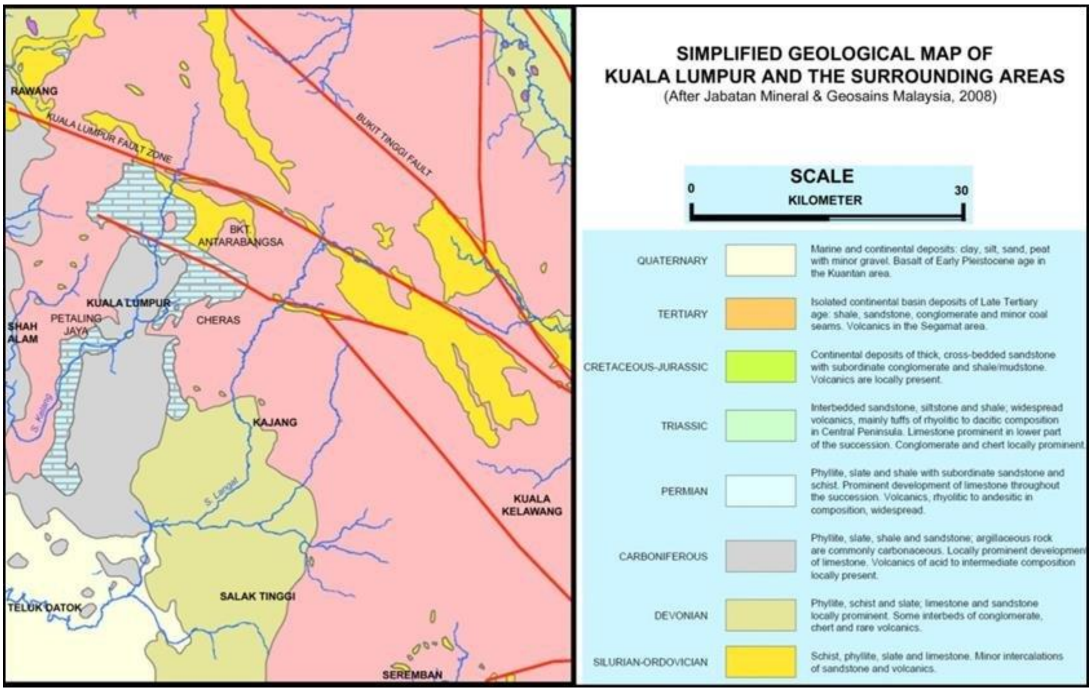



Figure 1. 1: General geology of the site location.


Figure 1. 2: Site location of case study.

The purpose of this study is to analyse the slope failure using GeoStudio 2019 Slope/w software. This study involves the study case of slope failure at Taman Bukit Kuchai, Bandar Kinrara, Selangor Dahrul Ehsan. There was a series of slope failure occurred near the AIR SELANGOR water tank of Taman Bukit Kuchai, Bandar Kinrara with an estimate of size measuring 30m wide with 20m high which resulted a formation of steep slopes between 50 to 70 degrees. The rock slope would have a potential of further failure which may cause the potential block slide downward due to it discontinuities parameter, triggered by severe erosion and intense rainfall in the future. Hence, this study is also to determine and identify the causes of failure, factors of safety of the slope, and to propose the remedial measures for a safe slope.

## 1.2 Objectives of study

For the objectives of the study, a site near Taman Bukit Kuchai, Bandar Kinrara, Selangor Dahrul Ehsan were picked where slope failure occurred. The objectives of this study are to:

i. Identify the main failure or causes for the slope failure at Taman Bukit Kuchai, Bandar Kinrara, Selangor Dahrul Ehsan.
ii. To compute the slope stability by calculating the factor of safety using SLOPE/W software and compare it with the manual calculation by method of slice.
iii. To compare the FOS both of the slope w and slice methods
iv. To propose the most suitable remedial measures, in term of factor of safety using the Slope/W software.

## 1.3 Scope of study

The case study of the slope failure was located at Taman Bukit Kuchai, Bandar Kinrara, Selangor Dahrul Ehsan. There was a series of slope failure occurred near the

AIR SELANGOR water tank of Taman Bukit Kuchai, Bandar Kinrara with an estimate of size measuring 30m wide with 20m high which resulted a formation of steep slopes between 50 to 70 degrees which affected the lots of Jalan 16, Taman Bukit Kuchai, Bandar Kinrara, Selangor Dahrul Ehsan. Due to the slope failure, several rock boulders from uphill slope have been fall onto Jalan 16, Taman Bukit Kuchai, Bandar Kinrara and has caused drain blockage to the roadside drain. The investigation is limited to the collapsed or failure section of slope occurred. The data consists of soil investigation report which is gathered from one related consultant company's project, IKRAM Engineering Services Sdn Bhd. It focused on the use of software slope/W and manual calculation by assistance of Microsoft Excel to analyse the stability and determine the FOS value. The minimum factor of safety will be computed by using the critical parameters from the soil investigation reports data and back analysis results. Figure 1.3 shows the site location of case study at Taman Bukit Kuchai, Bandar Kinrara, Selangor Dahrul Ehsan.


Figure 1. 3: Site Location of case study at Taman Bukit Kuchai, Bandar Kinrara, Selangor Dahrul Ehsan.

## 1.4 Problem statement

The news of landslide or slope failure has been commonly reported in Malaysia not only recently but also many years back then. The need of consistent application and understanding of slope stability analyses for construction and remediation projects in Malaysia and abroad has been a challenging for all the engineers. Proper analysis or design of the slope is needed to overcome the landslide or slope failure before any construction or development, while at the same time, enable the redesign of failed slopes for example, the planning and design of preventive and remedial measures. With the analysis of the slope stabilization, the slope failure can be avoided in the future and avoid the effect to the people surround.

## 1.5 Importance of study

This study is mainly to know and identify the causes of the slope failure that occurred at Taman Bukit Kuchai, Bandar Kinrara, Selangor Dahrul Ehsan by looking and analysing of the data and information of the failed slope gained from the Soil Investigation Report obtained from IKRAM Engineering Services Sdn Bhd. The slope stability also will be analysed by considering their factor of safety value by modelling the slope in the software, including the pore water pressure, and the slip surface, including the properties of the soil such as cohesion c, angle of friction $\emptyset$, and unit weight of the soil, $\psi$. This study also involves the calculation manually by applying the Ordinary Method of Slices to evaluate the FOS value, so that comparison between both methods of manual calculation and computing Software Slope/W can be compared for future research about the methods. Hence, this study can be made as a reference to produce slope stabilization method in term of FOS. Moreover, with the data obtained, a recommendation for the method of stabilization for the slope can be proposed and applied to the slope, and the effect of the method of stabilization can be study, for the safety and assurance of human beings. The study of slope stability is also to solve the slope stability problems at the critical slope in Malaysia so that slope failure would not happen again in the forthcoming.

# CHAPTER 2

# LITERATURE REVIEW

## 2.1 Introduction

In this chapter, a review of the area of study, review and research of the theories and hypothesis, and literature study is crucial to obtain useful information to be apply into the research paper. This chapter will summarize on the literature from other resources on the fundamental and principles of slope stability, slope failure types, the factors that causes slope failure, and the method for slope protection. Besides that, this chapter also will discuss about the factor of safety, Slope/W software, and method of stabilization.

## 2.2 Fundamental and principles of slope stability

Basically, when the slope fails, it is called slope failure or landslide. Failure of soil mass which is placed under a slope is called slide which include the movement and changing of soils either downward or outward that can be influenced by many factors. For the elementary condition for slopes stability, it must be concerned that the shear strength of the soil is essential to be higher than the shear stress needed for equilibrium. Slope stability is basically depending on the interaction among two different types of forces, that are, restraining forces and driving forces. Driving forces promotes movement of downslope in material of soil structure. Resisting forces will inhibit movement of the ground. When shearing forces counteracted resisting forces, the slope is not stable resulting in sliding of soils (Terzaghi & Peck, 2014).

Forces that inhibit the down movement of the slope are classified under the phrase "shear strength and include frictional resistance and cohesion amongst the particles of the slope-forming materials.. There might be a failure of slope and movement of slope-forming materials when the shear stress that act parallel to the slope is larger than the combo of forces that hold the slope-froming materials. (Terzaghi & Peck, 2014). Materials that involves in the slope failure can be either the deposited natural soil, or also fill man-made, or both.

Due to excavation or undercutting the foot of an existing slope, it may induced slides. In some cases, however, when slope begins to fail, they are caused by a gradual disintegration of the soil's structure, starting with hair cracks that divide the soil into angular fragments and can also be caused by increasing pore water pressure in permeable few layers, or by a shock that liquefies the soil below the slope. The conditions for slopes stability often frustate theoretical analysis due to the extraordinary variety of factors and processes that can lead to slides. Various undetected discontinuities in the soil, such as, remnants of old sliding surfaces, thin water-bearing sand seams or hair crack systems, may completely invalidate the calculation results. Every mass of soil under a sloping ground surface or under the sloping sides of an open cut with the influence of gravity, tends to move downward and outward. If the shearing resistance of the soil counteracts this tendency, the slope is stable. Otherwise there will be a slide.

Soils mechanics have a functions which involve in bear with the laboratory exploration and subsurface to create the occurrence and physical properties of the materials in the slope, gaining piezo metric data suitable for quantitative evaluation of pore pressures, establishing reference points and instruments to determine the extent and rate of movement and the geometry of the surface of sliding if a slide is already in progress, and interpreting the data quantitatively in terms of the physical processes involvedStability analyzes may be appropriate in some cases to assess the safety factor a gainst sliding and to investigate the relative benefits of various remedial measures, but s uch analyzes are not justified unless the geological features governing the slide geometr y and the physical properties of the soils are taken into account (Terzaghi & Peck, 2014).

## 2.3 Modes of failure

Slides can occur in almost every conceivable manner, slowly or suddenly and without any apparent provocation,' as stated by Terzaghi and Peck (1967). Usually, these slope failures are because to either a sudden or gradual loss of soil strength or geometric changes. Typical slides that can be expected to occur in soil slopes usually take the form of either (1) plane or wedge failure, (2) translational failure, (3) rotational failure, (4) or these types can be combined.

### 2.3.1 Plane and wedge failure

Wedge failure also acknowledged as block or plane failure and occurs due to external force and discontinuities along the surface failure when there is soil mass movement. This type of failure can usually occur when weak joint or weak soil layers are present, or it can also occur because the slope is made of two different materials. The broken mass moves down the slope as blocks and wedges as shown in figures.

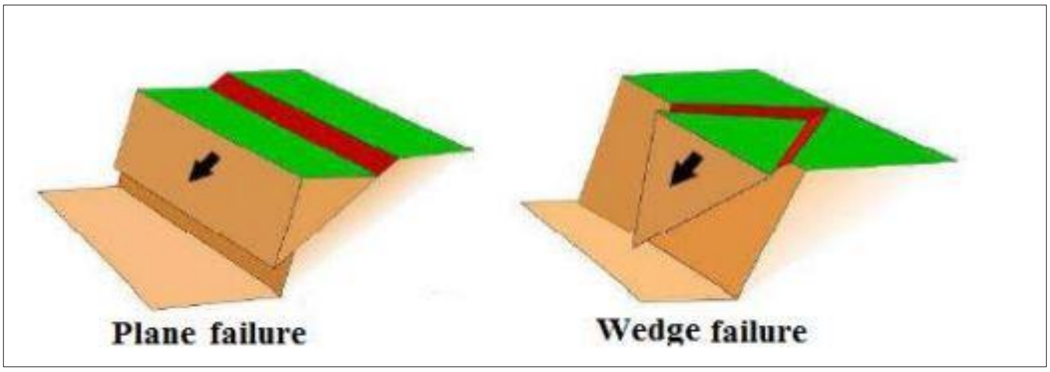



Figure 2. 1: Plane and wedge failure

Source: (Kumar & Tiwari, 2015).

### 2.3.2 Rotational failure

Rotational failure is the sliding of a material along a surface. There are two types of rotation failures, circular and non-circular. In the circular failure, it is assumed that the mechanical properties of the slope are uniform and that the particles in the soil or rock are very small compared to the size of the slope or when the soils are defined as homogenous. The slip surface of a rotational landslide tends to be deep. If the soil conditions are not uniform or non-homogenous soils, slope failure occurs on non-circular shear surfaces. Rotational failure can happen in three different ways such as, slope or face failure, toe failure, and also base failure. Figure 2.2 shows the circular and non-circular failure of slope while Figure 2.3 shows the rotational slope failure.

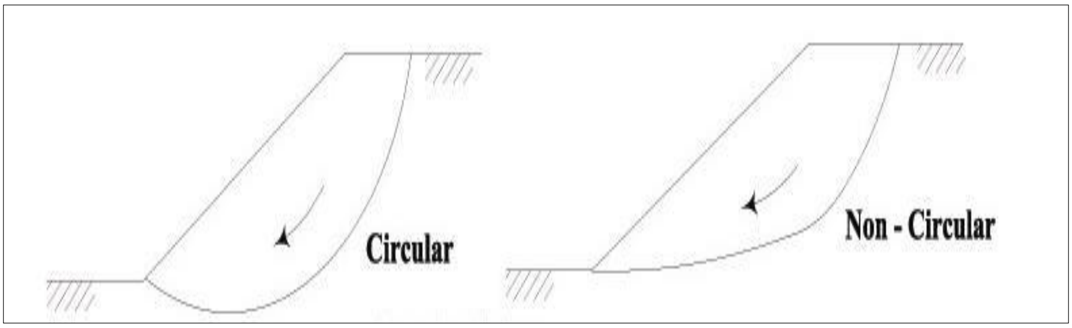



Figure 2. 2: Circular and non-circular failure.

Source: (Kim & Chung, 2014).

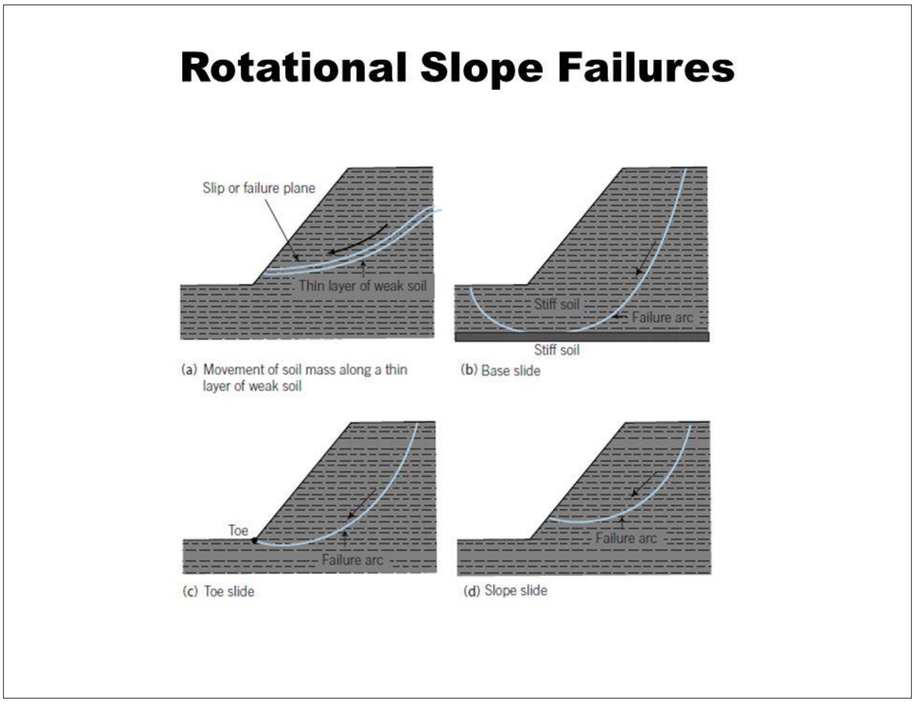



Figure 2. 3: Rotational slope failure.

Source: (Civil Seek, 2019)

### 2.3.3 Translational failure

In the case of infinite slopes, translation failure occurs and here the fault surface is parallel to the surface of the slope. A slope is said to be infinite if there are no definite boundaries on the slope and the soil below the free surface has the same properties up to the same depths along the slope. When there are two discontinuities of soil layer at a certain depth between the upper and below which is hard layer, the weak topsoil will form a parallel slip surface and will cause failure.  A slide-type landslide is a down-slope material movement that occurs along a distinctive weakness surface such as a fault, joint or bedding plane. Figure 2.4 shows the failure of the rotational slope.

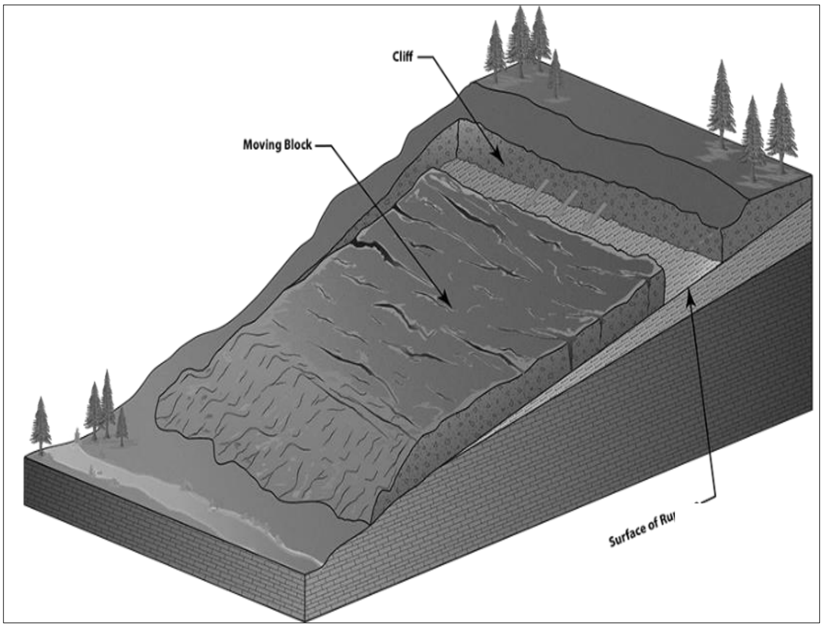



Figure 2. 4: Rotational slope failure

Source: (Survey, 2019)

### 2.3.4 Complex slope movement

A complex slope movement involves combinations of the above, usually occurring during failure with one predominant form as a change from one form to another.In fact, most of the slope failure occurred by combination of two or more type of slope movement (Rotaru, Oajdea, & Răileanu, 2007) . In this case, the slip surface is normally curved on two ends such as the flat on the central portion as in translation failure and rotational slip surface. Whenever there is a hard layer of soil at a considerable depth from the toe, the slip surface becomes flat.

## 2.4 Causes of slope failures

There is few importance to focus the agents that cause the instability in slopes. First, for the purpose of designing and constructing new slopes, where it is important to be able to anticipate changes in the soil's properties within the slope that may occur over time and the different conditions of loading and slope that the slope will be subjected to during its lifetime. Second, for the purpose of repairing the failed slopes. The elements of the situation that lead to its failure can be understood and learned so that in the future can avoid repeating the failure, by learning the steps needed to design, construct and repair slopes so that the slope remains safe and stable. Soil changes over time depend on the soil's permeability, either because of cracks, fissures and lenses of more permeable materials in the soil (J.Michael, 2014). Slope failures are often caused by processes that increase shear stress or decrease soil shear strength. Several different processes can lead to reduced soil shear strength.

### 2.4.1 Water

Water is the most commonly affecting and triggering factor that contributes to the slope failures. Especially in Malaysia, with the climate changes, which annually facing the rainfall events making the disaster of landslide become more severe. In general, the effects of water can manifest in many ways, such as reducing soil suction, increasing pore pressure, lifting the water table, increasing soil unit weight, and weakening anti-shear strength (Ping, Qingquan, Jiachun, & Jianping, 2005). Water is generally few times heavier than air. Soils normally becomes very saturate where water will outflow into pore space and take place of air between the grains of the soil, so that the weight of the soil increases to the slope. Weight equals to force. By general formula of force divided by area stress, increases in soil stress will lead to instability on the slope. Besides, water lower the grain-to-grain contact in soils that resulting in reduction of cohesiveness and the soil’s angle of repose. To summarize up, excessive water in soils at slope is bad because it will destabilize the slope due to the increment of weight that will reduce the cohesion between grains and decreases the friction.

When there is a heavy rainfall, where the water become excessive with inadequate drainage, the water will make the soil becomes saturated where the place of air among the grains and soil are taken, and it enhance the prone to movement. Studies were also carried out to study the stability of the slope when changes in rainfall patterns are taking place around the world. Studies by (Ciabatta et al., 2016) shows that the occurrence of slope failure during the warm-dry season is almost unchanged. However, during the cold-wet season, there is increment of landslide events since there is an increment in rainfall amount and its intensity.

Reported by (Kristo, Rahardjo, & Satyanaga, 2019), Water will infiltrate the soil's pores when it rains, thus increasing the soil water content resulting in increment of groundwater table. This will increase the pressure of pore water and later reduce its effective stress that the shear strength of the soil will decrease to sustain the load. Mentioned by (Chen, Lee, & Law, 2004), if the shear strength accumulates along the critical slip surface and the shear stress can no longer be sustained and supported, the soil will then slide and the slope will fail.

### 2.4.2 Cracking

Slopes failures are often carried out by crack development through the soil near the slope's crest. This mechanism of failure will drive up with many cracks that can usually be caused by many differential factors such as drying and shrinking soil. These cracks develop as a result of the ground surface tension in the soil that exceeds the soil's tensile strength. Surface tension cracks are formed throughout wet and dry cycles in soil slopes. Excessive water outflows through tension cracks during wet seasons and then bleeds into deeper soil layers. Reported by (Reddi, 2003) where the presence of cracks on slopes contribute to an easy pathway for water infiltration into soil making it to have higher moisture content in the deep layers, therefore reduces frictional and cohesive strength. During dry periods, surface tension cracks are formed after a numerous time wet and dry cycles. According to (Bishop, 1967), water that flows into joints and cracks could also initiate gradual failure, resulting in increased pore water pressure and thus weakening the joints. Study by (Wang & Li, 2015) described that cracks reduce slope stability by three effects, which is first, cracks provide a better flow channel that increases soil permeability but then decreases soil strength. Next, cracks that are filled by water utilize an additional driving force on the slope. Finally, cracks are able to form the critical slip surface which has no shear strength.

### 2.4.3 Gravity

Gravity is the main force responsible for the soil's mass movement. The force of gravity acts downwards on a flat surface. Under the force of gravity, it will not move as long as the material remains on the flat surface. If the flat surface material becomes weak or fails, the unsupported mass will move downwards. The gravity force can be resolved on a slope into two components: a component that acts perpendicular to the slope and a component that acts tangentially to the slope. The component of gravity perpendicular, gp, helps to keep the object on the slope. The tangential component of gravity, gt, causes parallel to the slope a shear stress that pulls the object parallel to the slope in the down-slope direction. Figure 2.5 shows the gravity of the slope.

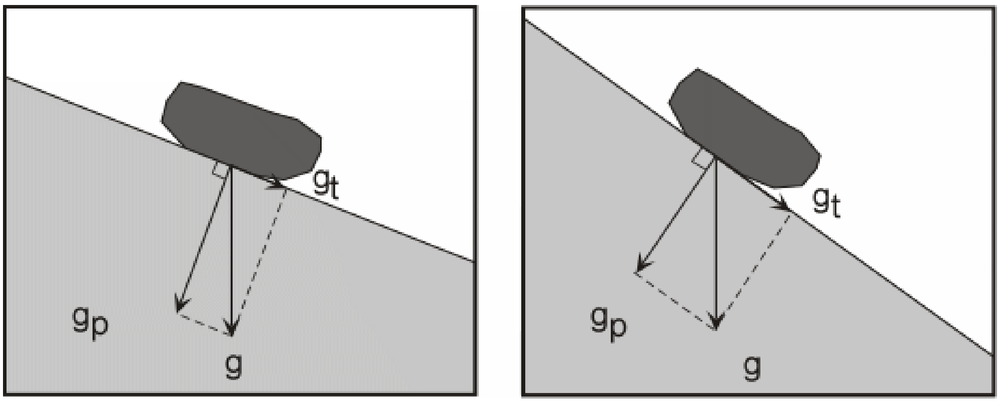



Figure 2. 5: The gravity causes the slope to go down

Source: (A Nelson, 2013).

## 2.5 Slope W

For the analysis, computer programs have been chosen to perform the computations. The computer programs that available are able to work out on many varieties of slope stratigraphy, slope geometry, soil shear strength, external loads, internal soil reinforcement, and pore water pressure conditions. The programs also have the capabilities in searching for the most critical slip surface with lowest factor of safety, and also can compute slip surfaces for both circular and non-circular shapes. It is now possible to deal with complex stratigraphy, highly irregular pore-water pressure conditions, various linear and nonlinear shear strength models, almost any kind of slip surface shape, concentrated loads, and structural reinforcement. The software can analyse problem for a variety of slip surface shape, pore water pressure condition, soil properties, analysis method and loading condition in two dimensional. The computation to get the FOS by Slope/W is easier and faster than the manual calculation.

The FOS can be calculated by modelling the slope in the software, including the pore water pressure, and the slip surface, including the properties of the soil; cohesion C, angle of friction, unit weight of the soil. (Robani, 2009). Geostudio Slope /W is a slope stability analysis software which is used on analysing the slope stability by calculating the factor of safety. Besides the factor of safety, the stability of the slope also can be increased by inserting the remedial measures into the slope by using the software. The software also able to draw or analyse almost any slope stability problem by creating the geometry drew on the screen. A DXF format picture can be imported to assist and then choose an analysis method, specify soil properties and pore water pressures, define reinforcement loads and create the trial slip surfaces (Robani, 2009). Figure 2.6 shows the example of slope stability analysis using the Slope/W software.

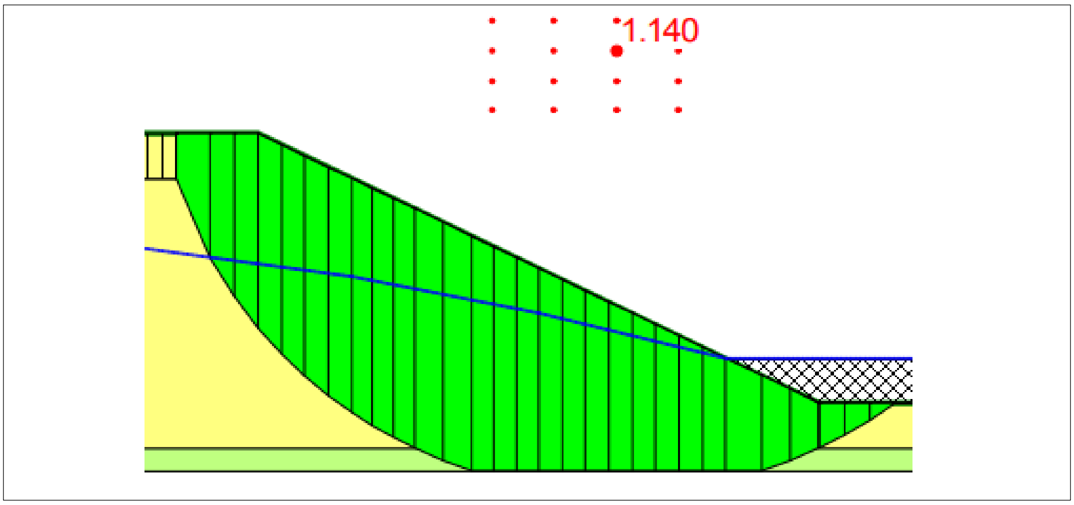



Figure 2. 6: Example of slope stability analysis using the Slope/W software

Source: (GEO-SLOPE International, 2019)

Not only that, the software also can be used to;

1. Analyse the problems with two different bed rock layer
2. Examine and identify the circular and non-circular slip surfaces
3. Compute factors of safety using the properties of the soil; cohesion C, angle of friction, unit weight of the soil gained from Soil Investigation report.
4. Specify the pore water pressure condition with the piezo metric line
5. Compute factors of safety using different methods of slices.

### 2.6 Method of slope analysis

Slope stability analysis using the limit equilibrium method is still very popular because they are simple and contain fewer parameters terrain, static and dynamic loads, hydrogeological conditions, geotechnical engineering parameters, geology and slope parameters (Baba, 2012).

Geo-Studio is a software to identify the slope stability by determine the factory of safety (FOS) by using computer. It is faster to compute using software compared to manual calculation to get the FOS value. In Geo-Studio Software, there are many different method to analyse the slope such as The Ordinary Method of Slices, Bishop's method, Spencer method, Janbu's method, and Morgensten-Price's method. The value of FOS will different from each method but the values are not much differs. Methods of analysis which employ circular slip surfaces include: (Fellenius, 1936) and (Bishop, 1967). Methods of analysis which employ non-circular slip surfaces includes, (Janbu, 1968), Morgenstern and Price (1965); and (Spencer, 1967).

#### 2.6.1 Ordinary Method Of Slice (Fellenius Method)

Ordinary or Fellenius method is the potential sliding mass divided into several slices. The mechanical balance of forces and moments is regarded as the force that acts on each slice. The interactions between slices are ignored and their own role is parallel to each slice's base due to their resulting force. The Ordinary method for a circular slip surface satisfies the moment equilibrium but neglects both normal interslice and shear forces. All forces of interslice are ignored in this method. The weight of the slice is resolved into forces parallel to the base of the slice. The force perpendicular to the base of the slice is the normal base force used to calculate the shear strength available. Parallel to the slice base, the weight component is the gravitational driving force. The safety factor is the total shear strength available along the slip surface divided by the gravitational driving forces summation. The advantage of this method is its simplicity in solving the FOS because an iteration process is not required for the equation. Figure 2.7 shows an analysis of the slope stability of the Ordinary method of slice while Figure 2.8 shows polygon forces acting on the interslice for the Ordinary method of slice.

The FOS is based on moment equilibrium and computed by (Abramson et al., 2001) :

$$FOS = \frac{(\Sigma c'l + (W\cos\alpha)\tan\emptyset'}{\Sigma W \sin\alpha}$$

$$N = W\cos\alpha$$

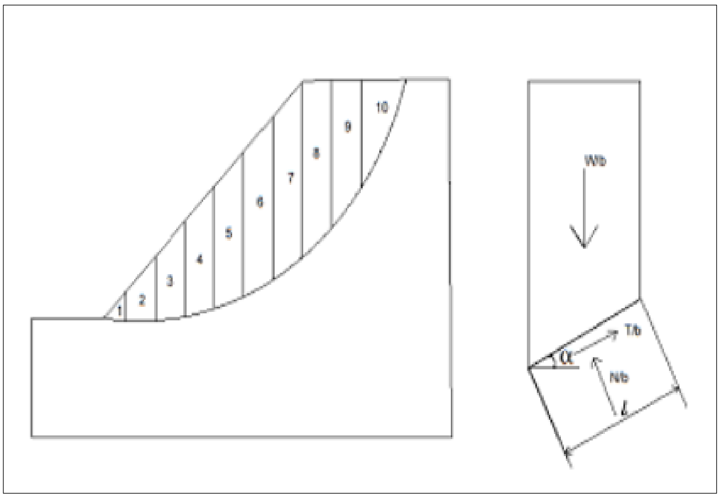



Figure 2. 7: Slope stability analysis of Ordinary method of slice.

Source : (P. Salunkhe, Guruprasd Chvan, N. Bartakke, & Kothavale, 2017)

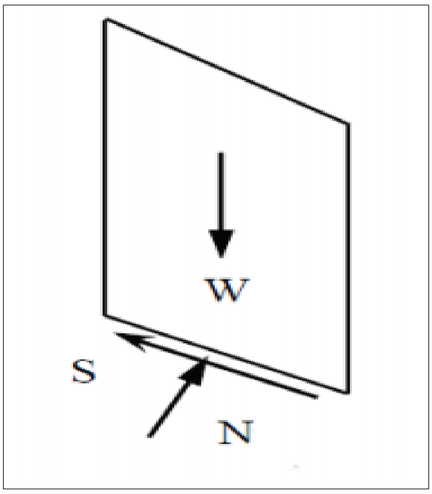



Figure 2. 8: Forces polygon acting on the interslice for Ordinary Method of Slice

Source : (Viswanadham, B.V.S (Department of Civil Engineering, 2018)

Where ;

c = cohesion

β = slice base length

N = base normal (W cos α)

ϕ = friction angle

W = slice weight

α = slice base inclination

### 2.6.2 Bishop Simplified Method

With ordinary method, the method of the Bishop is slightly different. The normal forces of interaction between the slices are assumed to be collinear, but the force of the shear is ignored or zero (Abramson et al., 2001). It also promotes the satisfactory equilibrium of vertical force for effective normal base force (N). Because the method has been shown to produce FOS values which appears at both side, that are close to the valid value, it is necessary to use an iterative calculation to solve the FOS. Figure 2.9 shows forces polygon acting on the interslice for Bishop's method.

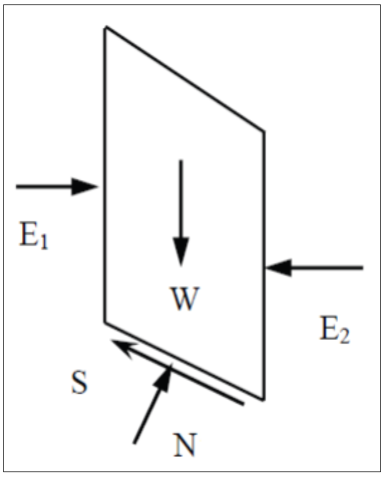



Figure 2. 9: Forces polygon acting on the interslice for Bishop's method.

Source : (Viswanadham, B.V.S (Department of Civil Engineering, 2018)

### 2.6.3 Janbu Simplified Method

The challenge in analyzing non-circular surfaces of failure is that finding a single point where many components of force act is difficult. The moment balance method for circular surfaces is therefore no longer the most suitable. This method uses equations in order to obtain a solution to iterate the method of the same Bishop. The simplified method of Janbu is based on a non-circular composite and the FOS is determined by a horizontal equilibrium of force. This method, therefore, does not satisfy the equilibrium of the moment. The method considers interslice normal forces (E), but as in Bishop's method it neglects the shear forces (T). Figure 2.10 shows forces polygon acting on the interslice for Janbu's simplified method. The base normal force (N) is determined in the same way as in Bishop's method and the FOS is computed by:

$$F = \frac{\sum cl + (N - ul)\tan\varphi)\sec\alpha}{\sum W\tan\alpha + \sum \Delta E}$$

Where,

ΣΔE = E2 − E1 = net interslice normal forces (zero if there is no horizontal force).

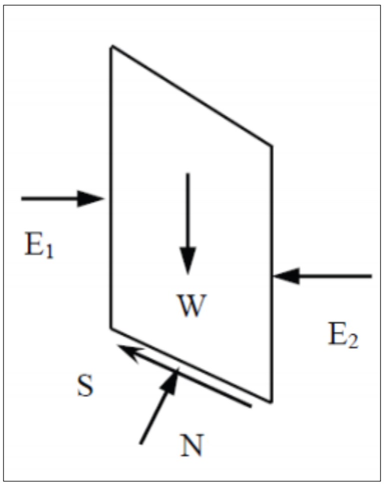



Figure 2. 10: Forces polygon acting on the interslice for Janbu's simplified method

Source : (Viswanadham, B.V.S (Department of Civil Engineering, 2018)

### 2.6.4 Janbu Generalized Method

Janbu's Generalized method (Janbu, 1968) takes into account both interslice forces and assumes a thrust line to determine the interslice forces relationship. As a result, both interslice forces make the FOS a complex function. The normal total base force (N) becomes an interslice shear force (T) function. This is the first method to satisfy the equilibrium of force and moment. It considers both interslice forces where interslice forces were assumed to have a line thrust. Among other methods, this method is advanced in handling complex geometry and surfaces of failure. Figure 2.11 shows polygon forces for the generalized method of Janbu acting on the interslice.

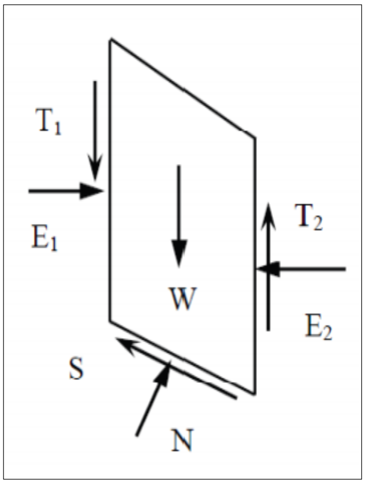



Figure 2. 11: Forces polygon acting on the interslice for Janbu's generalized method

Source : (Viswanadham, B.V.S (Department of Civil Engineering, 2018)

### 2.6.5 Morgenstern Price Method

Morgenstern price required a balance of forces and moments acting on individual blocks to be satisfied. By dividing planes, the blocks are created by dividing the soil above the surface of the slip. It is assumed that each block contributes because of the same forces. The inclination of the interslice force may vary with an arbitrary function (f(x)) that continually varies along the surface of the slip. Figure 2.12 shows the polygon forces acting on the Morgenstern Price method interslice.

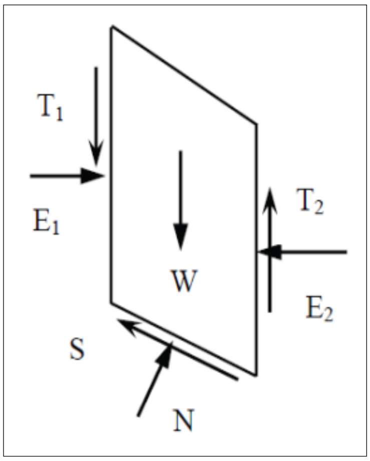



Figure 2. 12: Forces polygon acting on the interslice for Morgenstern Price method

Source : (Viswanadham, B.V.S (Department of Civil Engineering, 2018)

### 2.6.6 Spencer's Method

(Spencer, 1967) developed two factor of safety equations; one with respect to moment equilibrium and another with respect to horizontal force equilibrium. He adopted a constant relationship between the interslice shear and normal forces, and through an iterative procedure altered the interslice shear to normal ratio until the two factors of safety were the same. Finding the shear-normal ratio that makes the two factors of safety equal, means that both moment and force equilibrium are satisfied. In the Spencer method, the function f(x) is a constant where the interslice shear-normal ratio is the same between all slices. Figure 2.13 shows the forces polygon acting on the interslice for Spencer's method.

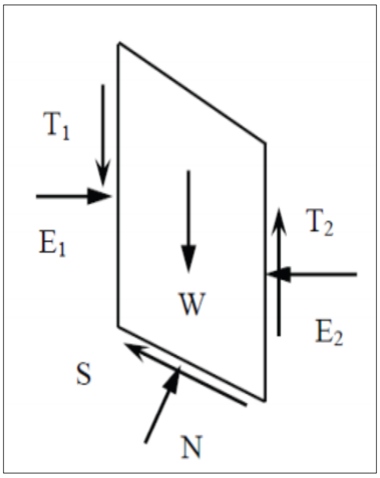



Figure 2. 13: Forces polygon acting on the interslice for Spencer's method.

Source : (Viswanadham, B.V.S (Department of Civil Engineering, 2018)

### 2.6.7 Comparison between different slope stability method

From the literature review, each features or procedures of method of slope stability and their usefulness are summarized as in the Table 2.1.

Table 2. 1: Comparison between different slope stability analysis methods

| Method | Features |
|---|---|
| **Ordinary** | Gives the most conservatives factor of safety value. Simple calculation, with no iteration needed. Applicable to circular failure surfaces only, not always suitable for effective stress analysis. |

| | |
|---|---|
| **Bishop Simplified** | Results are fairly accurate. Calculation required for iterative procedure. Applicable to circular shear surfaces, suitable for both total and effective stress analysis. |
| **Janbu** | Assumption regarding position of line of thrust. Calculation made with inter-slice forces by iterative method. Applicable to slip surfaces of arbitrary shape, suitable for both total and effective stress analysis. |
| **Morgenstern Price** | Acceptability must be checked as in Janbu's method. Satisfies both forces and moment equilibrium and account for inter slice forces. Applicable to failures of arbitrary shape, suitable for both total and effective stress analysis. |

Source: (J.Michael, 2014)

The traditional method of limiting equilibrium remains capable of producing accurate and reliable results. The two have their advantages and disadvantages in choosing which method to use depending on some of the considerations and method that user selects should be based on the complexity of the problem to model. The typical application and limitation and the comment on usage of each slope stability method are summarized in Table 2.2.

Table 2. 1: The typical application and limitation and the comment on usage of each slope stability method.

| 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. |

All limit equilibrium methods are based on certain assumptions for the interslice normal (E) and shear (T) forces, and the basic difference among the methods in how these forces are determined or assumed. In addition to this, the shape of the assumed slip surface and the equilibrium conditions for calculation of the FOS are among theothers. A summary of selected limit equilibrium methods and their assumptions are presented in the Table 2.2. Table 2.2 lists the various procedures discussed in this chapter along with the assumptions that are made, the equilibrium equations that are satisfied, and the unknowns.

Table 2. 2: Procedures discussed in this chapter along with the assumptions that are made, the equilibrium equations that are satisfied, and the unknowns.

| Method | Moment Equilibrium | Force Equilibrium | Shape of slip surface | Interslice Normal (E) | Interslice Shear (T) | Assumption for Interslice Normal and Interslice Shear |
|---|---|---|---|---|---|---|
| **Ordinary or Fellenius** | Yes | No | Circular | No | No | No interslice forces |
| **Bishop's Simplified** | Yes | No | Circular | Yes | No | The side forces are horizontal |
| **Janbu's Simplified** | No | Yes | Any shape | Yes | No | The side forces are horizontal |
| **Janbu generalized method** | Yes (by slice) | Yes | Any shape | Yes | Yes | Location of the interslice normal |

| | | | | | | |
|---|---|---|---|---|---|---|
| | | | | | | force is defined by an assumed line of thrust. |
| **Spencer** | Yes | Yes | Any shape | Yes | Yes | Constant inclination or parallel where Interslice Normal = Interslice Shear |
| **Morgensten-Price** | Yes | Yes | Any shape | Yes | Yes | Direction of the resultant of interslice forces is determined by using a selected function. |

## 2.7 Method of slope stabilization

There are many options for slope stabilization and repair. Method selection is site-specific. The chosen method of stabilization also depends on many factors for example, in term of factor of safety value, cost, and suitability. Managing groundwater and drainage can improve the shear strength in a potential slide area. Surface cover can protect the slope from water and erosion, and roots add stabilizing force to the soil. Excavation and regrading decrease the forces that drive failure. Structural reinforcement features add direct supporting forces to slope material.

Table 2.3 shows the example of stabilization methods and their effect of each applications. As described by (Slope Engineering Branch, 2010), the minimum global factor of safety for treated slopes shall be 1.5.

Table 2. 3: Typical design solutions to mitigate cut slope stability problems.

| Design Solution | Effect on Stability |
|---|---|
| **a. Flatten slope.** | Reduces driving force. |
| **b. Bench slope.** | Reduces driving force. |
| **c. Buttress toe** | Increases resisting force. |
| **d. Lower water table** | Reduces seepage force. |
| **e. Reinforcement (e.g., nails)** | Increases resisting force |

Source : (Yun Zhou PE, 2006)

### 2.7.1 Drainage

Proper water drainage is also one of the important stabilization method. (Abramson et al., 2001). Drainage will reduce the seepage force on the imposed slope, destabilizing hydrostatic and as also the risk of erosion and piping. When there is no direct penetration of water into the soil slope, the cohesion between the particle grains that make up the slope which contributed into resisting moment was not disturbed in while decreasing the probability of liquefaction of the soil. The surface runoff should be carried away from the slope, and avoid the seeping downwards or into the soil of the slope. The temporary preventive ways to be considered after the occurrance of landslide are : (Abramson et al., 2001)

a. Usage of sandbags to reverse the water runoff from coming into the failure area.
b. Cracks on the surface coatings like lean concrete or shotcrete need to be properly sealed to reduce the water infiltration and cause further soil strength failure.
c. The ground surface shall be covered temporary with plastic sheets or canvas to reduce the mass movement of the ground soil during the repairing activity.

### 2.7.2 Geosynthetic

The commonly types of geosynthetics used for soil reinforcement include geotextiles, geogrids and geocells. Geotextiles with high quality polypropylene fibres are continuous sheets of woven, nonwoven, knitted or stitch-bonded fibers or yarns prevents soil movement in erosion control measures. A geotextile acts as a filter when it allows liquid to pass normal to its own plane, while preventing most soil particles from being carried away by the liquid current. (Niroumand et al., 2012). Geogrids have a uniformly distributed array of apertures between their longitudinal and transverse elements to allow direct contact between soil particles on either side of the sheet. Geocells are relatively thick, three-dimensional networks constructed from strips of polymeric sheet. (Ennio & Palmeira, 2006). Geogrids are the ideal option for base reinforcement and pavement optimization, both on weak and stable subgrades. They promote aggregate interlock as well as confinement, increase bearing capacity, and distribute load forces, by creating a stable foundation. Ultimately, geosynthetics improve the roadway structure, reduce maintenance cycles and increase its lifespan.

### 2.7.3 Soil nailing

Soil is reinforced with slender elements such as reinforcing bars which are called as nails. These reinforcing bars are installed into pre-drilled holes and then grouted. The steel as reinforcement will acts as a resistance to shear stresses, tensile stresses, with having strong pull-out resistance and also bending moments imposed by the slope movements. This process creates a reinforced section that is in itself stable and able to retain the ground behind it. Soil nailing technique is used to support new very steep cuts with advantage of strengthening the slope with excessive earth works. 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. (Department of Transportation Administration Federal Highway, 2015).

### 2.7.4 Terracing & benching

The nearer a slope is to its natural angle of repose, the more stable it is. It is for this reason that terracing or benching is a popular way of dealing with steep slopes. This involves making the slope more manageable by dividing it into several smaller and less steep slopes reinforced by retaining walls, friction piles. changing of the slope angle from steep slope to a gentler slope may increase the stabilization of slope and the angle is usually supported by grass bonding together so the soil will hold and bond together. (Cornforth, 2005).

### 2.7.5 Anchor

Prestressed anchors and anchored walls have the advantage that they do not require slope movement before they impose restraining forces. Although anchors can be used without a vertical wall, they do require bearing pads to distribute their loads to the surface of the slope. (J.Michael, 2014). The block layout pattern is typically in rows across the slope or retaining wall. Initially, anchors are installed at the planned centre of each block location. Reaction blocks are either precast or cast-in-place around the anchor heads. Bearing plates are then installed and the anchors are tensioned against the blocks. The finished anchored reaction blocks resist the movement of the retained soil or wall. Tie-back anchors are a common stabilization method for steep excavations. The anchors transfer the load on the wall deeper into the ground behind the wall. From a limit equilibrium perspective, the loads in the anchors are converted to forces acting on the potential sliding mass. The magnitude and application location of these loads must be determined for a stability analysis.

### 2.7.6 Retaining walls

The ability of the retaining wall to perform as a stabilizing mass is a function of how well the retaining will resist the overturning moments, the internal shear forces, bending stresses, and also the sliding forces below its base. The wall also should be deep so that the critical slip surface passes around the wall with adequate factor of safety. Retaining walls are walls that are designed to “retain” or hold in place a substantial amount of soil. The types of retaining wall include cantilever retaining walls, driven piles, drilled shaft walls, and also tie back walls (Abramson et al., 2001).

### 2.7.7 Vegetation

Vegetation on slopes provides protection against erosion and shallow sliding. Roots reinforce or bind the soil and provide cohesion that improves stability against shallow sliding. In addition, plant roots are believed to reduce pore pressures within slopes by intercepting rainfall reducing infiltration and by evapotranspiration (Wu & Mckinnell, 1979). Use of vegetation in combination with mechanical reinforcement such as geogrids is called biotechnical stabilization. (Abramson et al., 2001). Using vegetation for enhancing stability and resilience of hillslopes is increasingly seen as a cost-effective and sustainable alternative to man-made structures. Plant roots in particular stabilize hillslopes by anchoring into deeper soil layers and forming a fiber-reinforced soil composite, resulting in additional shear resistance mechanical cohesion that help counter the destabilizing gravitational forces. Vegetation also removes soil water through evapotranspiration, increasing soil’s cohesive forces against mechanical failure. (Gentile, Elia, & Elia, 2010)

## 2.8 Factor of safety

The factor of safety is very important when performing stability analyses. To make a stability calculation, the position of the potential surface of sliding must be determined and the resistance against sliding along this surface must be computed or estimated. The factor of safety against sliding is equal to the ratio between the sum of the resisting forces and the force exerted on the area of slope. A computational method used to indicate if failure (sliding) occurs is to compare moments that would resist movement to those that tend to cause movement. The maximum shear strength possessed by the soil is used in the calculation of the resisting moment. Failure is indicated when moments causing motion exceed those resisting motion. The factor of safety against sliding or movement is expressed as: soil is greater than the shearing resistance required for equilibrium, failure does not occur.

$$FS = \frac{Moments\ resisting\ sliding}{Moments\ causing\ sliding}$$

A variation to this method for studying slope stability involves determining the shear strength required to have sliding moments and resisting moments balance (equilibrium). The shearing resistance required along the slip surface is compared to the shear strength that can be developed by the soil. The most widely used definition of factor of safety for a slope is the ratio of shear strength of soil to shear stress required for equilibrium. It can be determined from a limit equilibrium analysis using factored strength parameters.

For a slope analysis, a unique factor of safety can be determined using conventional methods based on limit equilibrium methods. Shear strength is often the largest uncertainty in slope stability analysis. A value of F=1.0 indicates that a slope is on the boundary between stability and instability. If all the factors are computed precisely, even a value of 1.01 would be acceptable. However, the computed values of FOS are not precise, due to uncertainty of variables. Therefore, the factor of safety should be larger to be on the safe side (J.Michael, 2014). Another approach of factor of safety of factor of slopes refers to the ratio of resisting moment to overturning moment on circular slip surfaces (J.Michael, 2014).

# CHAPTER 3

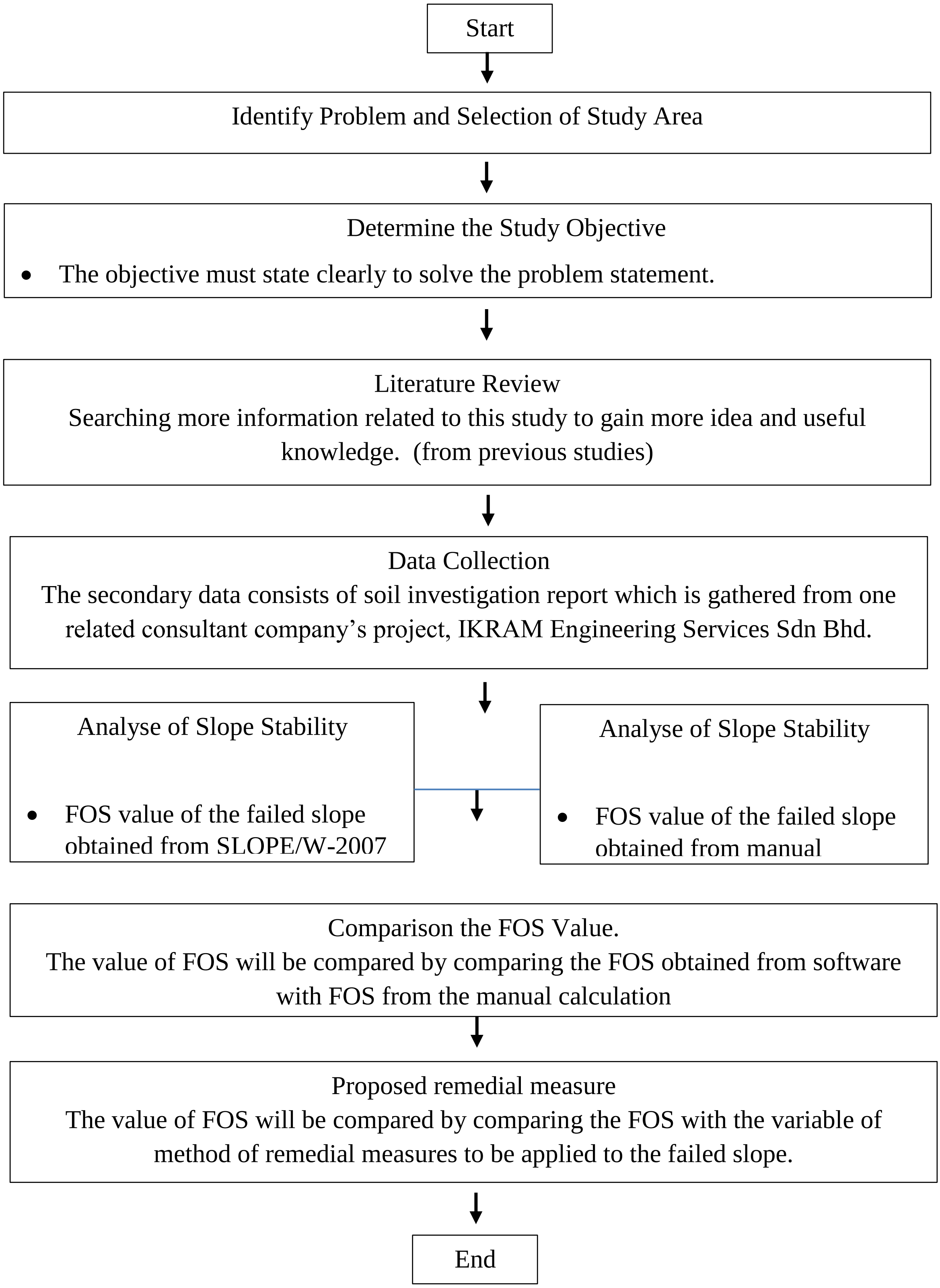
# METHODOLOGY

## 3.1 Introduction

This propose of study for the methodology is to explain the stages or phases involved, and also the method used in this research. The study held with respect to this Final Year Project is an applied, undiscovered, and develops guidelines to manage a specific procedure and develop a new design concept that contribute to the advance of profession. Thence, the study took the form of an existing project aim which using a case study with a real-life issue of slope failure that happened in Malaysia.

At the first phase, the study started with looking into the suitable title of the study or research that are going to be done with the guide of problem statement which explains the problem issue statement, and method used to solve the problem. Hence, the objectives of this study was determined based on the problem statement stated. After the title has been approved by the supervisor, the next phase is to find the materials related to the topic of study for the literature review. Accordingly, the research followed with data collection of the soil investigation report begin with a specific observation and the analysis, which are used to produce theoretical concept and conclusion drawn from the research. The reasons for researcher having preliminary study was to compare the different method to compute the slope stability, comprehend the properties of soil, the causes of the failure on slope geotechnical parameters and slope stability of actual slope works.

The last phase is the analysis of data computed by using the critical parameters from the soil investigation reports data and back analysis results using the softwarechosen. The analysis involves the computation of factor of safety (FOS) of the slope/W software, which was then compared with the manual calculation using Ordinary Method of Slices. Finally, the analysis was then followed by applying the various types of remedial measures to the failed slope, to get the factor of safety, and comparing between them. After being analyze, the most suitable proposal to improve the slope stability will be produced. The flow chart of the methodology is shown in the figure below.




**Flow chart of Research Design**

### 3.2 Title verification and approval

The first step to be done is to get the approval and verification of the title from the supervisor after considering the issue that arise for the research. The finalize title for this study is 'Analysis Of Method Stability Of Slope Failure Using Slope/W And Manual Calculation For Redesigning Failed Slope - A Case Study'. The case study was the slope failure occurred located at Taman Bukit Kuchai, Bandar Kinrara, Selangor Dahrul Ehsan. The problem statement and selection of study area are the first part of study which researcher need to find out the current issue that related to the slope stability and mention in problem statement. Then the site study area must be related to the problem statement like the site study area having the slope stability problems that same with the current issue. Then, the analysis of the slope stability is done using the Slope/W software and also manual calculation, and finally to choose the best remedial measures to improve the stability of slope.

### 3.3 Literature review

The next step is to start with literature review. The literature reviews are subjected to provide an overview of sources that have been explored while researching related to analysis on slope stability and the operation of the Factor of Safety in various method like Fellenius, Bishop, Janbu and Morgenstern Price method. The resources were obtained from the library i-Portal of UMP, Faculty of Civil Engineering and Earth Resources, and other internet websites resources. Downloading the Mendeley Desktop Software also have been done to search the article or journal relevant to this study. Hence, literature reviews are very important in order to gain more knowledge and make the study more professional with evidence and review from official research.

### 3.4 Data collection

This study is mainly to study the slope failure that occurred at Taman Bukit Kuchai, Bandar Kinrara, Selangor Dahrul Ehsan by looking and analysing of the data and information of the failed slope gained from the Soil Investigation Report obtained from IKRAM Engineering Services Sdn Bhd. The slope stability will be analysed using the factor of safety value by modelling the slope in the software and also in Excel for manual calculation, including the pore water pressure, and the slip surface, including the properties of the soil; cohesion C, angle of friction, unit weight of the soil.

### 3.5 Analysis of data

The FOS can be calculated by modelling the slope in the software, including the pore water pressure, and the slip surface, including inserting the properties of the soil; cohesion C, angle of friction, unit weight of the soil. SLOPE/W is formulated in terms of moment and force equilibrium factor of safety equations, and supports a comprehensive list of limit equilibrium methods including Morgenstern-Price, Spencer, Bishop, Janbu, and the Ordinary method. SLOPE/W offers a variety of techniques to search for the critical slip surface. This provides the flexibility to handle various modes of failure such as rotational, translational, composite, and structure-controlled failures. One example of the oldest method of stability is the Ordinary Method of Slice or also known Fellenius Method. With this method, it is possible to calculate the factor of safety using software programming, that is Slope/W Software and also manual calculation with the assistance of Excel due to its simplicity. This research aim to prove that the both approach to obtain the factor of safety using programming of software Slope/W and using manual calculation will yields out relatively the same value factor of safety due to the almost same approach.

A variety of slope stabilization options such as anchors, nails, piles, and geo-synthetics are also available in SLOPE/W. A generalized user-defined reinforcement type can be used to model a wide range of structures, including anchors or nails with plate capacity, end-anchored reinforcement, and pile reinforcement with spatially variable shear resistance. Hence, after the data has been analysed, a proposal of an improved ground stability of the slope can be proposed by applying the remedial measures to the slope in the software. By considering the improvement FOS, the best remedial measures will be chosen.

## 3.6 Slope stability using the Slope/W software procedures

The value for factor of safety is obtained by using software Slope/W at first. Analysis can be done by the following procedures. The analysis was set and determined first. Since the computing of FOS value will use Ordinary Method of Slices, the analyses were defined as in Figure. The axes was sketch base on the slope elevation and their points. The maximum and minimum axes scale is defined as illustrated in Figure 3.1. The unit was defined as in Figure 3.2, and sketched of axes as in Figure 3.3.

### 3.6.1 Setting of the analysis.

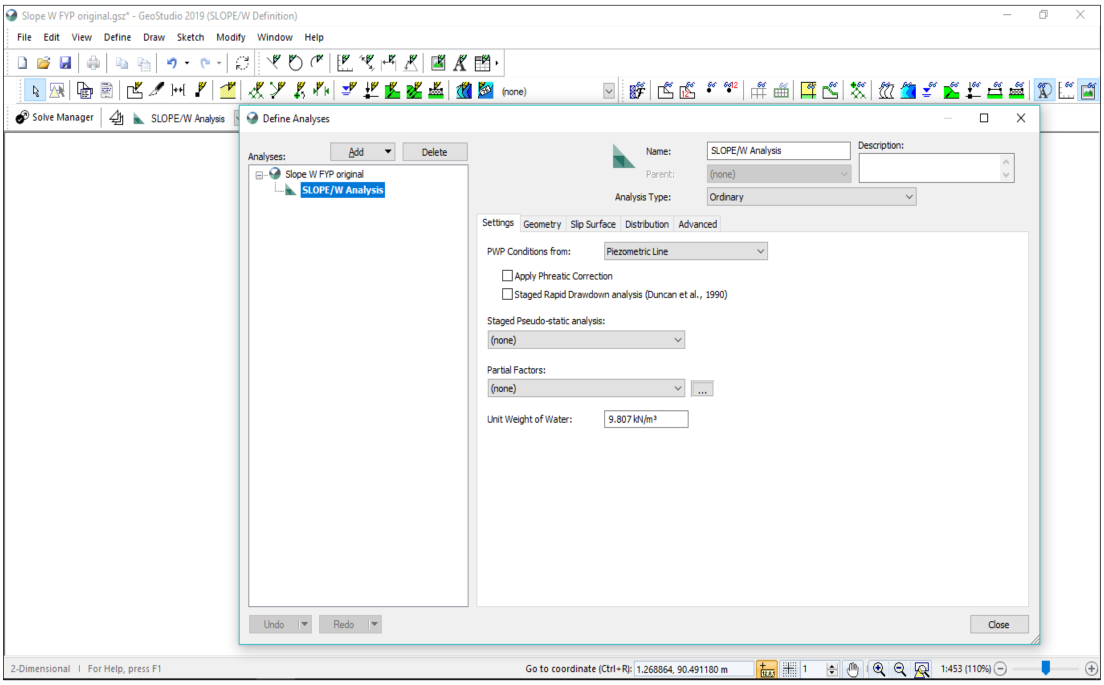



Figure 3. 1: Define the analyses into the software – Ordinary analysis type was chosen.

### 3.6.2 Setting of unit

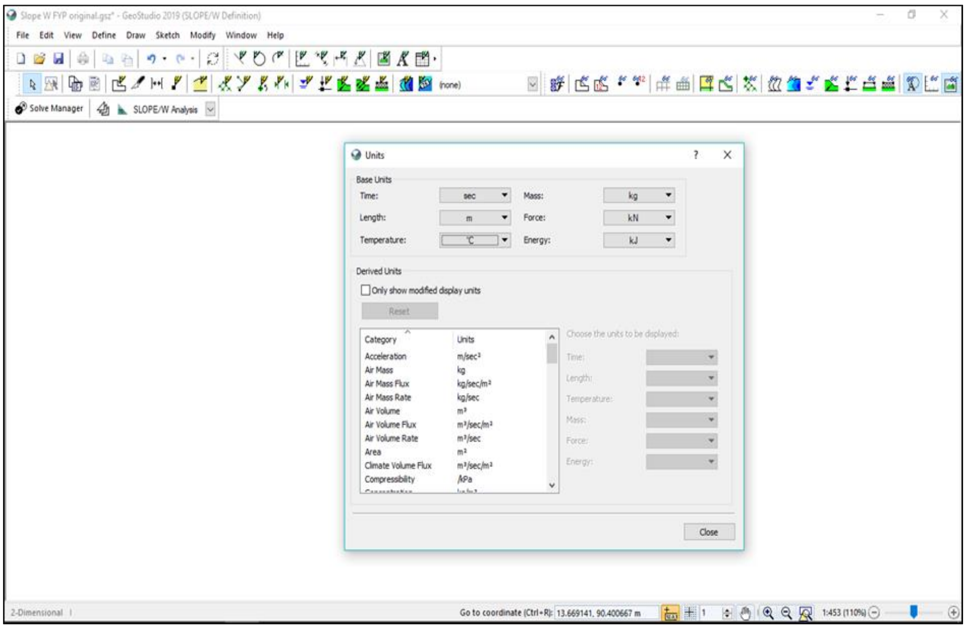



Figure 3. 2: Set units of empirical unit for the analysis.

### 3.6.3 Sketch the axes

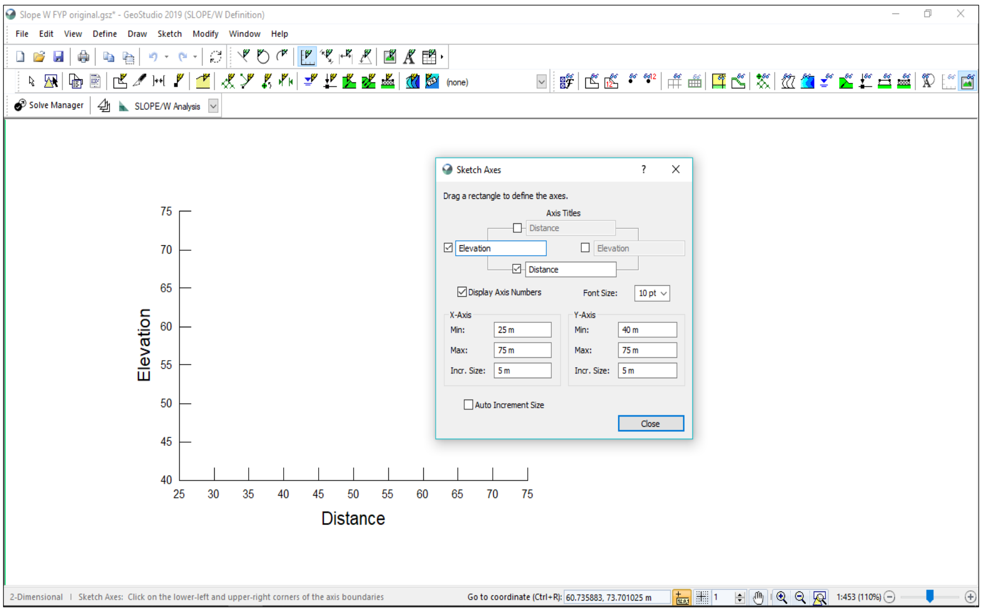



Figure 3. 3: Sketch of the axes and scale.

### 3.6.4 Key-in points by their distance and elevation

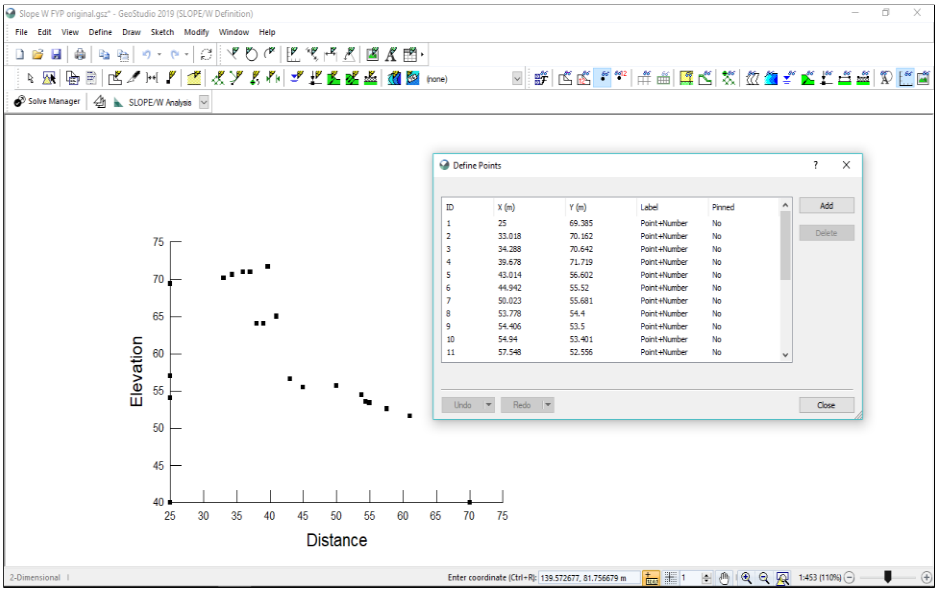



Figure 3. 4: Plotting of points.

### 3.6.5 Drawing of regions

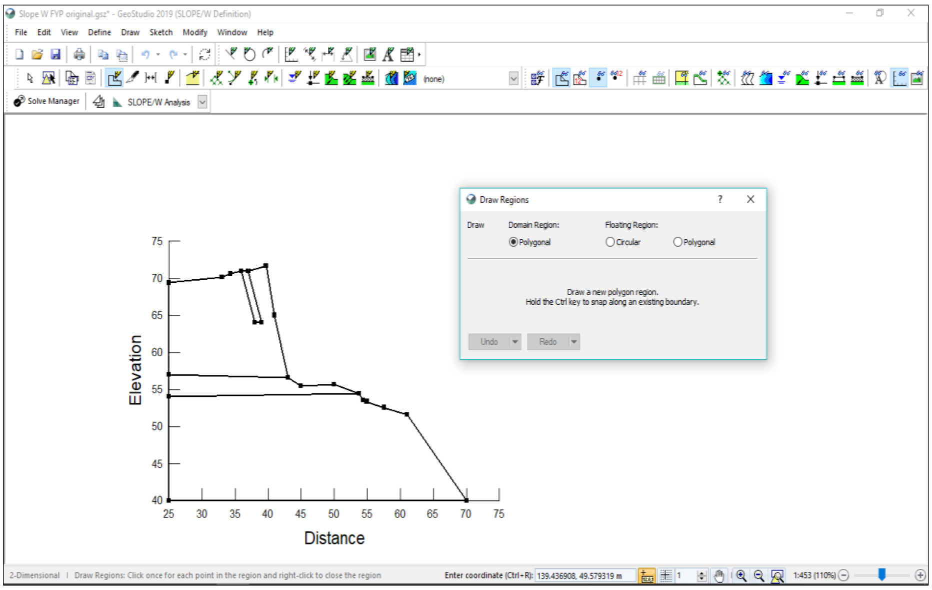



Figure 3. 5: Defining of region of soil.

### 3.6.6 Define each of the region

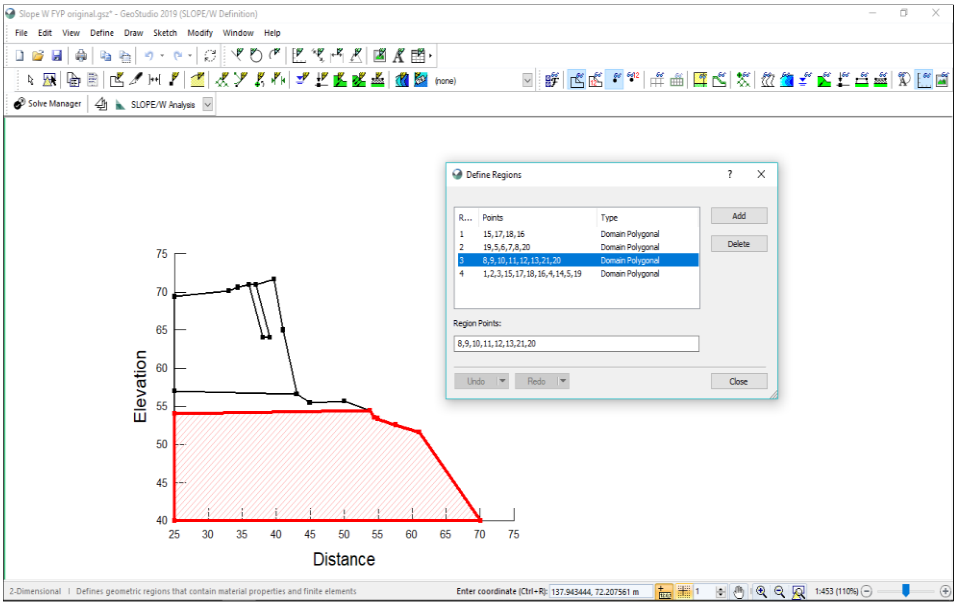



Figure 3. 6: Defining of region of soil.

The points for the slope elevation and distance was then plotted as in Figure 3.4. Each point and elevation of slope can be obtained from the SI report and map of slope. With the of the coordinate y-axis and x-axis information, the slope can be drawn in 2D Dimensional drawing. When the points were inserted, drawing of regions in polygonal is needed as illustrated in Figure 3.5 and Figure 3.6.

### 3.6.7 Key-in the materials of the slope

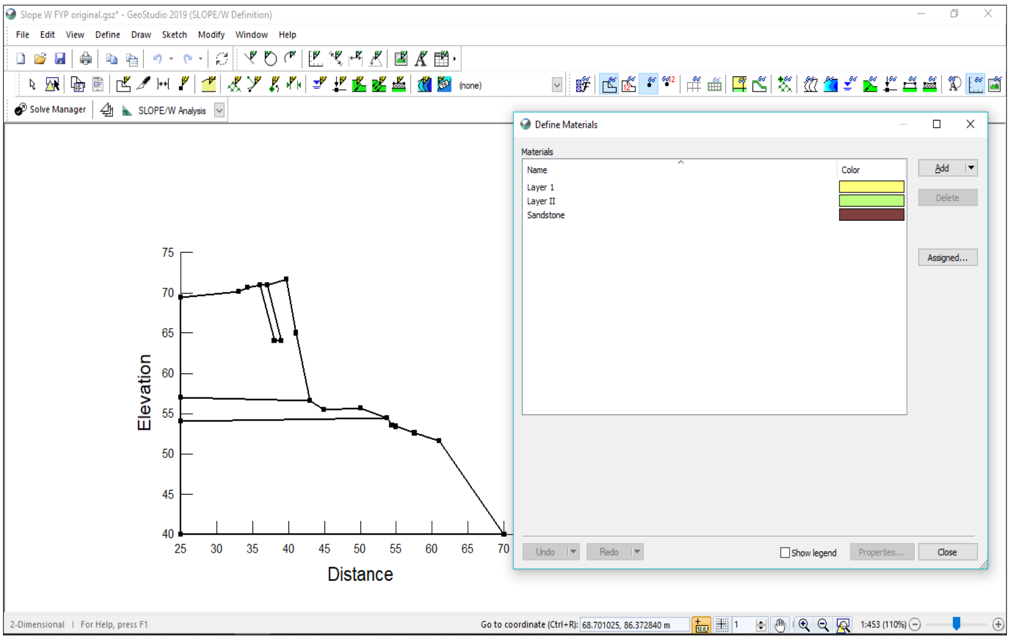



Figure 3. 7: Key in of the soil layer.

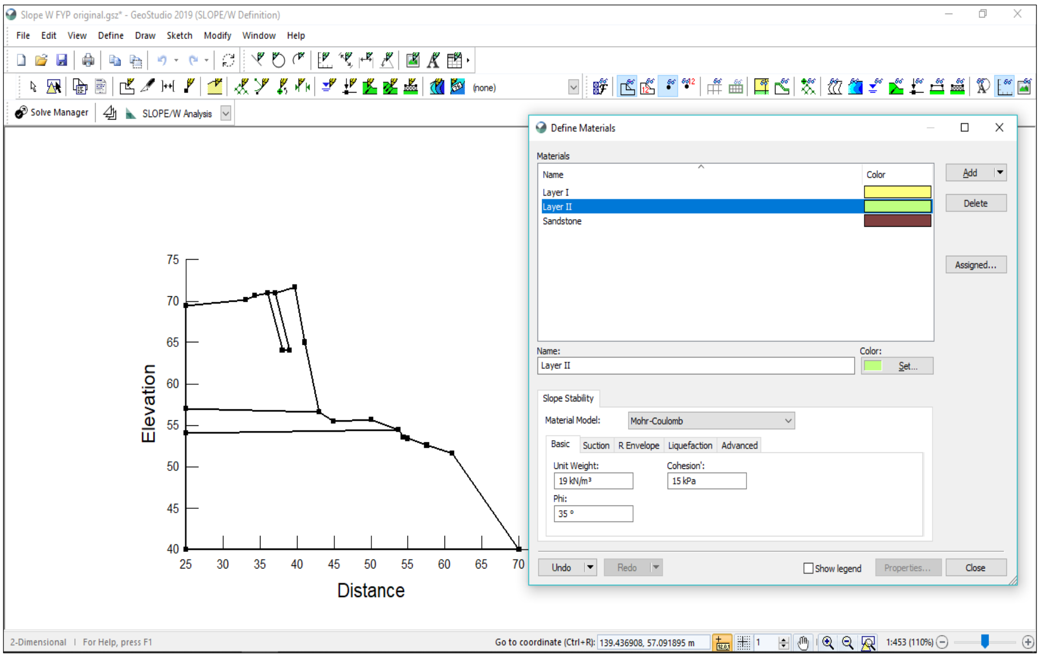



Figure 3. 8: Key in of the soil parameters.

### 3.6.8 Assign the layer of soil to the region drawn

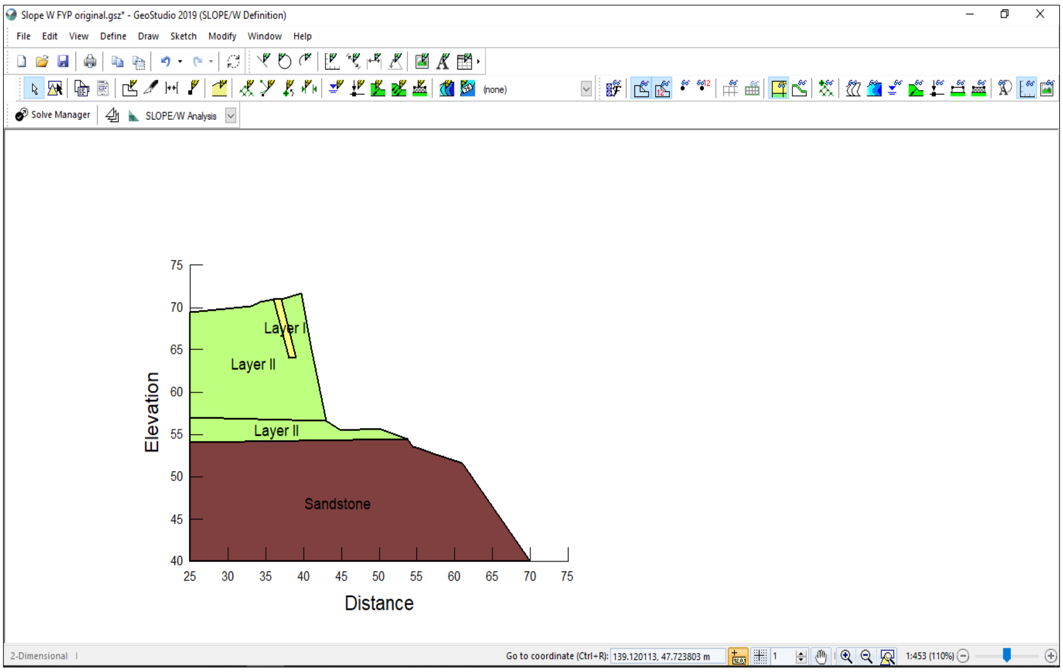



Figure 3. 9: The assigned soil layer.

Insert the layer of the soil with the soil properties of the slope where it consists the data of the value of cohesion, c, the angle of friction, and unit weight of soil which can be obtained from the SI report as illustrated in Figure 3.7 and Figure 3.8. From the SI report, the parameters of the soil have the following information of angle of friction 15kPa, unit weight of 19kN/m2 , and angle of friction of 35°. The region of the soil which is drawn accordingly was then assigned to soil layer to differentiate the soil layer as in Figure 3.9.

### 3.6.9 Draw piezometric line

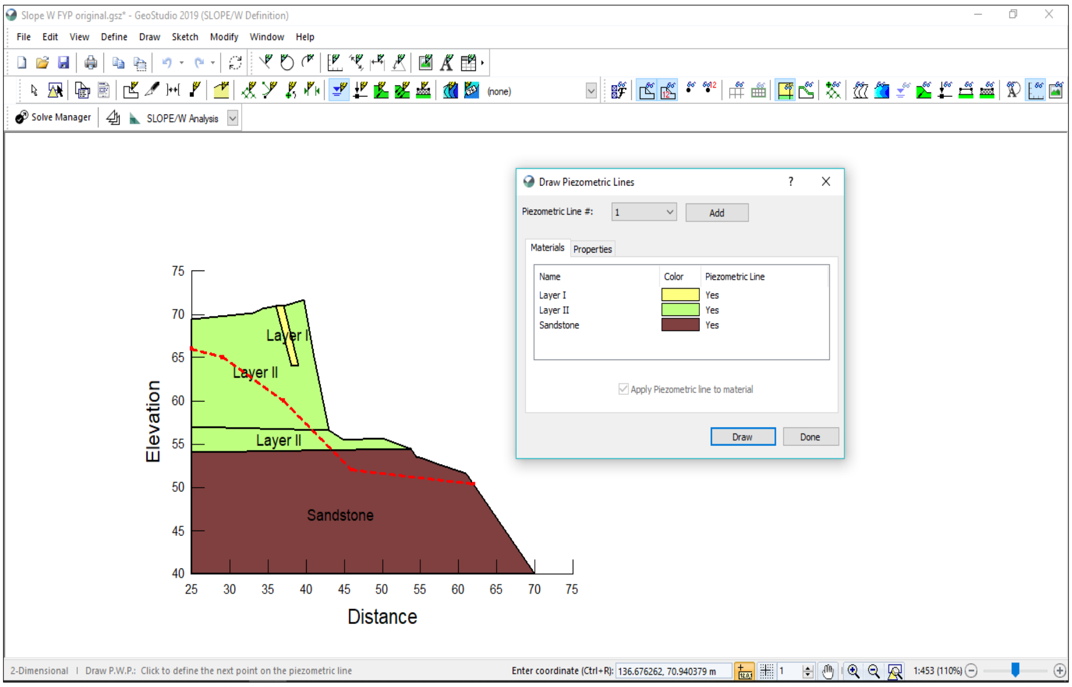



Figure 3. 10: Drawing of piezometric line.

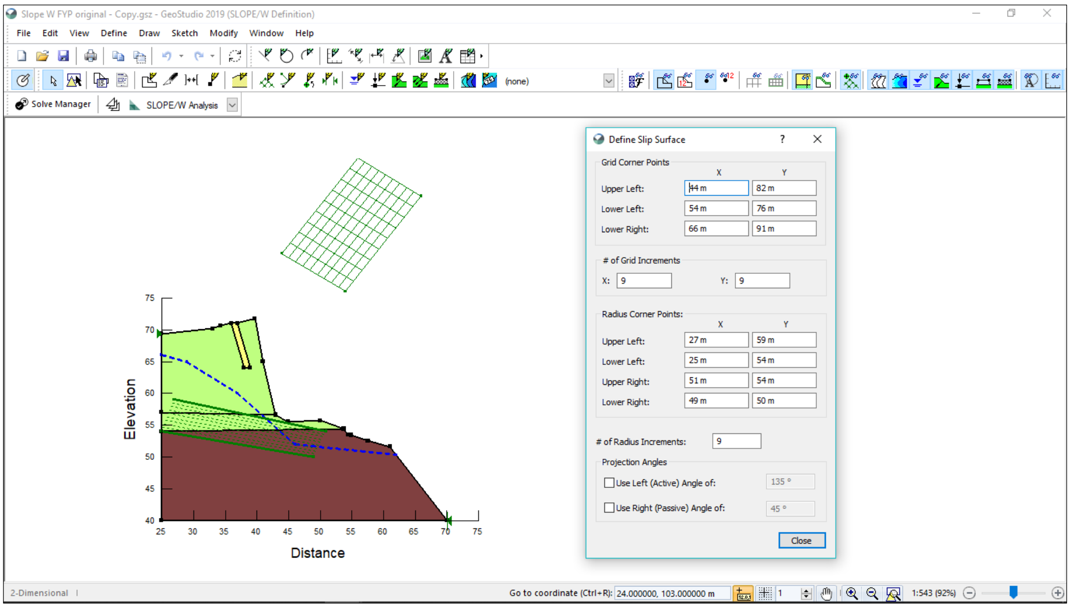



Figure 3. 11: Drawing of radius and grid.

After key in the data of soil properties and the region, the piezometric line is drawn which the data can be determined from the soil investigation report that indicates the depth of the piezometric line from the ground. Figure 3.10 illustrates the step of drawing the piezometric line on the software. 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 3.11 shows the trial slip surface grid and radius of the slope analysis that has been drawn. When all the data required has been inserted in the software, then the slope can be analysed to obtain the FOS value.

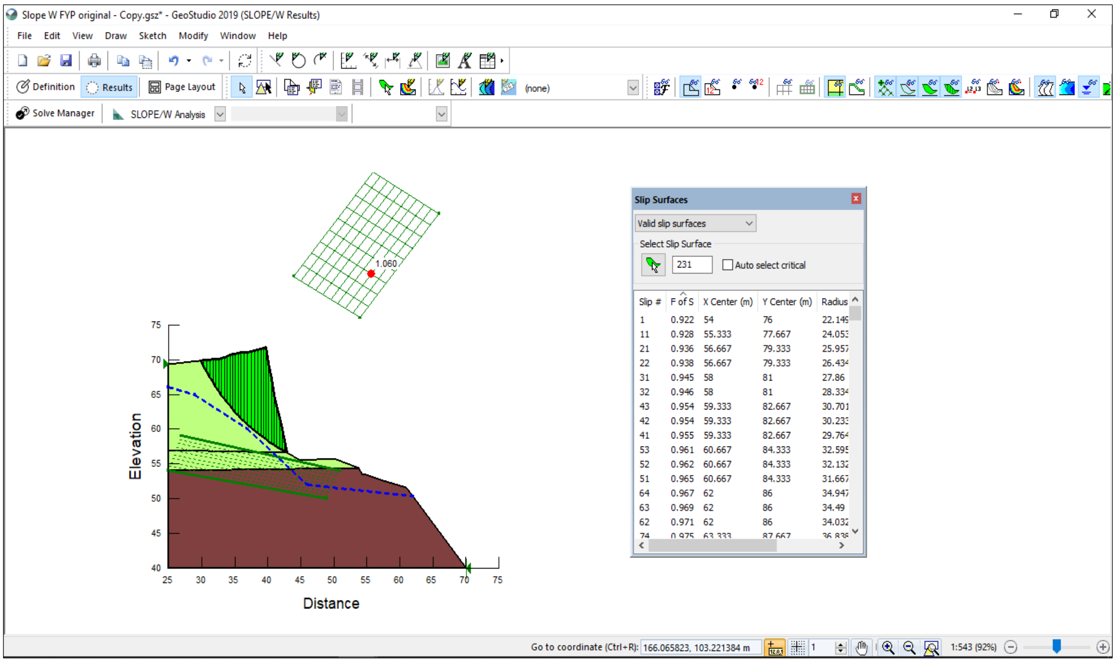



Figure 3. 12: Results for the analysis of FOS value.

The result of the analysis was shown in Figure 3.12. The FOS value obtain from the slope is 1.060 which means that the slope is not stable yet. The software will select the most critical value, or the lowest value of FOS.

### 3.7 Manual calculation using Spreadsheet Excel of Ordinary Method of Slices

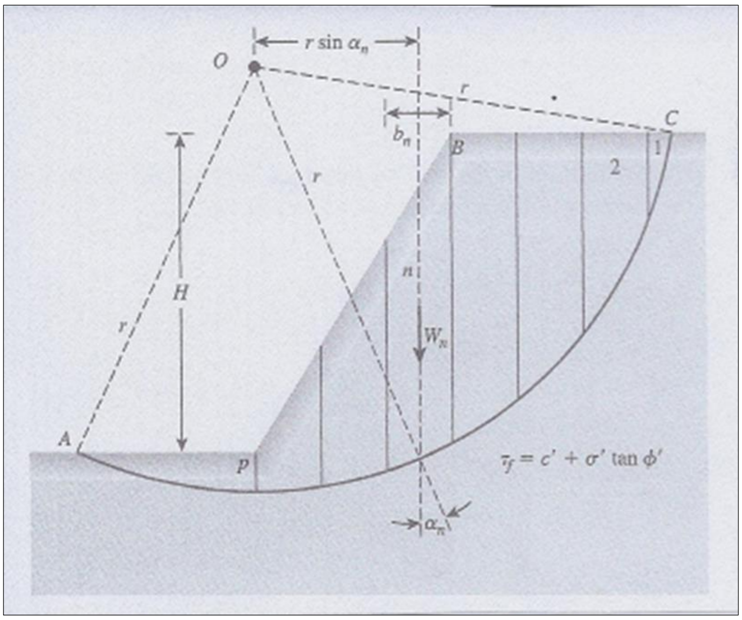



Figure 3. 13: Example of hand calculation of Ordinary Method of Slices

Source: (Das, 2006)

Manual calculation can be done and as illustrated in Figure 3.13. Inserting of the value or data from the manual calculation can be inserted into the table or excel as illustrated in Figure 3.14. The procedures for the calculation of Factor of Safety value using Ordinary Method of Slices was done as below:

1. The cross section of the slope embankment was drawn based on the elevation and the distance of the slope.
2. Selecting the circular failure of the surface slope by choosing as the same in the Slope/W software.
3. The circular mass was divided above the circular failure surface accordingly into 10 vertical slices.
4. Vertical line drawn from the center of gravity of the slice.

5. Lines which are called rays are then drawn from the center of the circle to the centroid point on the circular arc.

6. The α angles are then measured from the vertical to each ray.

7. From the area and width of the slope, the weight (WT) of each slice was determined from the graph paper. Where W= γt × Average Slice Height × Slice Width

8. Compute frictional resisting force for each slice depending on location of ground water table.

9. Compute cohesive resisting force for each slice.

10. T is the component of total weight of the slice, WT, acting tangent to the slice base.

11. Sum resisting forces and driving forces for all slices and compute factor of safety.

Layer I

| c (kPa) | $\phi'$ (°) | $\phi b$ (°) | $\gamma$ (kN/m3) | $\psi$ (kPa) |
|---|---|---|---|---|
| | | | | |

Layer II

| c (kPa) | $\phi'$ (°) | $\phi b$ (°) | $\gamma$ (kN/m3) | $\psi$ (kPa) |
|---|---|---|---|---|
| | | | | |

| Slice No | h (cm) | b (m) | W (kN) | $\alpha$ (°) | sin $\alpha$ | Wsin $\alpha$ (kN) | l (m) | $\psi$ (kPa) | tan $\phi'$ | tan $\phi b$ | c'l (kN) | Wcos $\alpha$ (m) | Wcos $\alpha$ tan $\phi'$ (kN) | $\psi$ltan $\phi b$ (kN) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | | | | | | | | | | | | | | |
| 2 | | | | | | | | | | | | | | |
| 3 | | | | | | | | | | | | | | |
| 4 | | | | | | | | | | | | | | |
| 5 | | | | | | | | | | | | | | |
| 6 | | | | | | | | | | | | | | |
| 7 | | | | | | | | | | | | | | |
| 8 | | | | | | | | | | | | | | |
| 9 | | | | | | | | | | | | | | |
| 10 | | | | | | | | | | | | | | |
| Total | | | | | | | | | | | | | | |

$$FOS = \frac{\Sigma W\cos\alpha\tan\phi' + \Sigma\psi l\tan\phi b + \Sigma c'l}{\Sigma W\sin\alpha}$$

Figure 3. 14: Table to insert the value obtained from manual calculation.

Legend:

WT = Total weight of Slice (soil + water)

l = Base length of the slice

c = Cohesion at base of slice

φ = angle of internal friction along base slice

u = pore water pressure at base of slice

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 Analysis of slope failure

In this chapter, results from the analysis of data from both using Software Slope/W and manual calculation will be discussed in detail. Analysis of data is done by applying the soil parameters obtained from the site investigation report and also data that was used to plot into the software. By having the data and soil parameters, analysis of data using manual calculation and software can be done to obtain the factor of safety (FOS) value. Through the FOS value, the determination of slope whether it is fails or not can be done.

The data from the soil investigation report shows that the site at Taman Bukit Kuchai, Bandar Kinrara has failed and can cause dangerous to the residents surround in the future. From the results, there will be two analysis, where the analysis is about comparing FOS of both the manual calculation and software slope/w obtained from the real case failed slope.

## 4.2 Possible causes of slope failure

Water can be considered as the main factor that contributes to the slope failure in Taman Bukit Kuchai, Bandar Kinrara slope. The triggering factor to the slope failure may be due to the weather in Malaysia which receives rain all the year. The slope failure may be caused by continuous heavy rain, and prolong rainfall. Water will permeate through soil which will make the soil has high water content and heavier. The soil will become saturated and decrease the cohesiveness where the water will take place between the soil voids, hence reduce the soil strength. This will make the soil become unstable and fail. Water that flows through the slope also gives changes in the fluid pressure on the slope, which will increase the probability of downslope mass movement. Proper water drainage needs to be applied to make sure the water flow on the slope. No proper surface drainage systems will cause the surface water to channelled freely and causes intense weathering. 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 there is any crack or damage found.

From the elevation and distance of the slope, to get the slope structure, the slope is also considered as toppling failure which may cause the potential block slide downward due to its discontinuities parameter, triggered by severe erosion and intense rainfall. Moreover, the steep slope is also more than 60% causing the process of weathering, soil accumulation, erosion which makes the slope have no strength to hold its soil parameter and cause the slope failure at last. 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 clayey soil. As we can see in Table 4.1, the soil consists of 54.75% of clay, 42.75% of sand and 2.5% of gravel. So, the type of soil can be classified as sandy 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 water also increases the surface of water volume. The existence of water in soil will disturb the correlation between soil particles and hence reduce the shear strength of soil. The soil properties data can be summarized in the Table 4.1 below.

Table 4. 1: Summary of the data for the soil of the slope.

| **Depth (m)** | **Clay (%)** | **Sand (%)** | **Gravel (%)** |
|---|---|---|---|
| **1.5 – 1.95** | 60 | 26 | 14 |
| **4.5 – 4.95** | 74 | 26 | 0 |
| **6.0 – 6.45** | 30 | 70 | 0 |
| **7.5 – 7.95** | 76 | 24 | 0 |
| **9.0 – 9.45** | 59 | 41 | 0 |
| **10.5 – 10.95** | 63 | 37 | 0 |
| **12.0 – 12.3** | 40 | 57 | 3 |
| **13.5 – 13.7** | 36 | 61 | 3 |
| **Average** | 54.75 | 42.75 | 2.5 |

### 4.3 Analysis of FOS value from both method

Analysis was done to get the factor of safety value. The first approach is by using Software Slope/W and the second approach is by using manual calculation with the assisting of Excel. Both approaches used Method of Ordinary or Method of Slice (Fellenius Method).

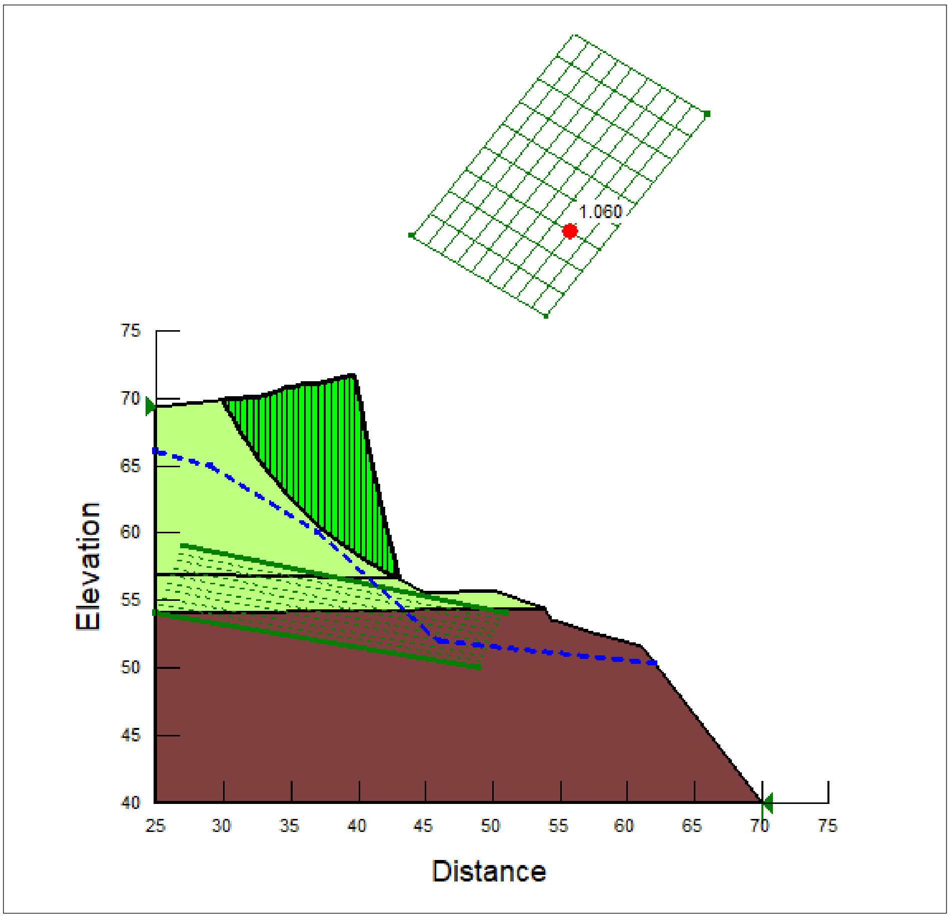



Figure 4. 1: FOS value of the failed slope using Software Slope/W.

| c (kPa) | ϕ' (°) | ϕb (°) | γ (kN/m3) | ψ (kPa) | | c (kPa) | ϕ' (°) | ϕb (°) | γ (kN/m3) | ψ (kPa) |
|---|---|---|---|---|---|---|---|---|---|---|
| 15 | 35 | 0 | 19 | 0 | | 10 | 35 | 20 | 18 | 0 |

| Slice No | h (cm) | b (m) | W (kN) | α (°) | sin α | Wsin α (kN) (4) | l (m) | ψ (kPa) | tan ϕ' | tan ϕb | c'l (kN) (1) | Wcos α (m) | Wcos α tan ϕ' (kN) (2) | ψl tan ϕb (kN) (3) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 2.125 | 0.750 | 30.281 | -80.0 | 0.994 | 30.096 | 4.500 | 0 | 0.474 | 0.000 | 67.500 | -3.343 | -1.584 | 0.000 |
| 2 | 5.625 | 1.000 | 106.875 | -70.0 | -0.774 | -82.710 | 2.250 | 0 | 0.474 | 0.000 | 33.750 | 67.686 | 32.071 | 0.000 |
| 3 | 7.250 | 1.000 | 137.750 | -60.0 | 0.305 | 41.988 | 1.750 | 0 | 0.474 | 0.000 | 26.250 | -131.195 | -62.162 | 0.000 |
| 4 | 9.500 | 1.000 | 180.500 | -55.0 | 1.000 | 180.456 | 1.500 | 0 | 0.474 | 0.000 | 22.500 | 3.994 | 1.892 | 0.000 |
| 5 | 10.875 | 1.000 | 206.625 | -50.0 | 0.262 | 54.213 | 1.500 | 0 | 0.474 | 0.000 | 22.500 | 199.386 | 94.472 | 0.000 |
| 6 | 12.000 | 1.000 | 228.000 | -40.0 | -0.745 | -169.886 | 1.250 | 0 | 0.474 | 0.000 | 18.750 | -152.062 | -72.049 | 0.000 |
| 7 | 12.125 | 1.000 | 230.375 | -40.0 | -0.745 | -171.655 | 1.250 | 0 | 0.474 | 0.000 | 18.750 | -153.646 | -72.800 | 0.000 |
| 8 | 10.250 | 1.000 | 194.750 | -30.0 | 0.988 | 192.419 | 1.000 | 0 | 0.474 | 0.000 | 15.000 | 30.040 | 14.234 | 0.000 |
| 9 | 7.250 | 1.000 | 137.750 | -30.0 | 0.988 | 136.101 | 1.000 | 0 | 0.474 | 0.000 | 15.000 | 21.248 | 10.068 | 0.000 |
| 10 | 6.000 | 1.000 | 114.000 | -25.0 | 0.132 | 15.088 | 1.500 | 0 | 0.474 | 0.000 | 22.500 | 112.997 | 53.540 | 0.000 |
| **Total** | | | | | | **226.111** | | | | | **262.500** | | **-2.319** | **0.000** |

$$FOS = \frac{\Sigma W\cos\alpha\tan\phi' + \Sigma\psi l\tan\phi b + \Sigma c'l}{\Sigma W\sin\alpha}$$

FOS = 1.1506814

Figure 4. 2: FOS value of failed slope using manual calculation.

$$FOS = \frac{\Sigma W\cos\alpha\tan\phi' + \Sigma\psi l\tan\phi b + \Sigma c'l}{\Sigma W\sin\alpha}$$

$$FOS = \frac{-2.319 + 262.5}{226.111}$$

$$FOS = 1.1506814$$

Figure 4. 3: FOS value of failed slope using manual calculation.

Figure 4.1 and Figure 4.2 shows the results obtained showing the value of factor of safety using Slope/W software while Figure 4.3 shows the results obtained showing the value of factor of safety using manual calculation. From the software, the value of FOS obtained is 1.060 whereas from the manual calculation using Method of Ordinary the value of FOS is 1.1506814. The value of the FOS is classified as acceptable because it is greater than 1, but it is not safe and fails because it is less than 1.5. Table 4.2 shows the results or the value of FOS obtained from both methods.

Table 4. 2: The results obtained from both methods.

| **Slope/W software using Ordinary Method** | **Manual Calculation using Ordinary Method** | **Percentage difference (%)** |
|---|---|---|
| 1.060 | 1.1507 | 7.88% |

From the results above, the obtained factor of safety value from this method is very close to the values obtained from those traditional limit equilibrium methods. It can be concluded that the value of both methods are roughly not the same value, but the value are relatively almost the same. The percentage difference for both methods are also very small that is 7.88%. Calculation of FOS by using conventional method, that is the method of slices and using Software Slope/W will having small different due to the method adopted and are very similar approach. The FOS values obtained using finite element method compare very well with that obtained from limit equilibrium methods. In using software, the FOS for critical slip surface is automatically obtained. In case of limit equilibrium methods, several slip surfaces should be analysed to find the critical slip surface. Thus, there will be a small difference in both approaches.

## 4.4 Analysis of slope by applying remedial measures

When the slope has failed, remedial measures should be taken and applied to the failed slope to make sure the slope will not cause any more damages and can cause life. There are several methods of remedial measures that can be applied to the failed slope. Analysis is done by applying the remedial measures, to identify which remedial measures will gives out the best effect to the slope considering their stability and best factor of safety value.

### 4.4.1 Application of anchor to the slope

Ground anchors also known as tiebacks are designed to prevent landslides by resisting the slope forces that cause deformation. The working mechanism of slope-stabilizing anchors involves transmitting the tensile load generated in anchors into the ground through the shear resistance mobilized at their interfaces. The load is usually developed by the anchorage of the tendon within the soil mass and tensioning at the surface against a bearing plate. 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. Hence, the anchor will act as the reinforced mass that will retain the ground mass against the active pressure, sliding and also the overturning.

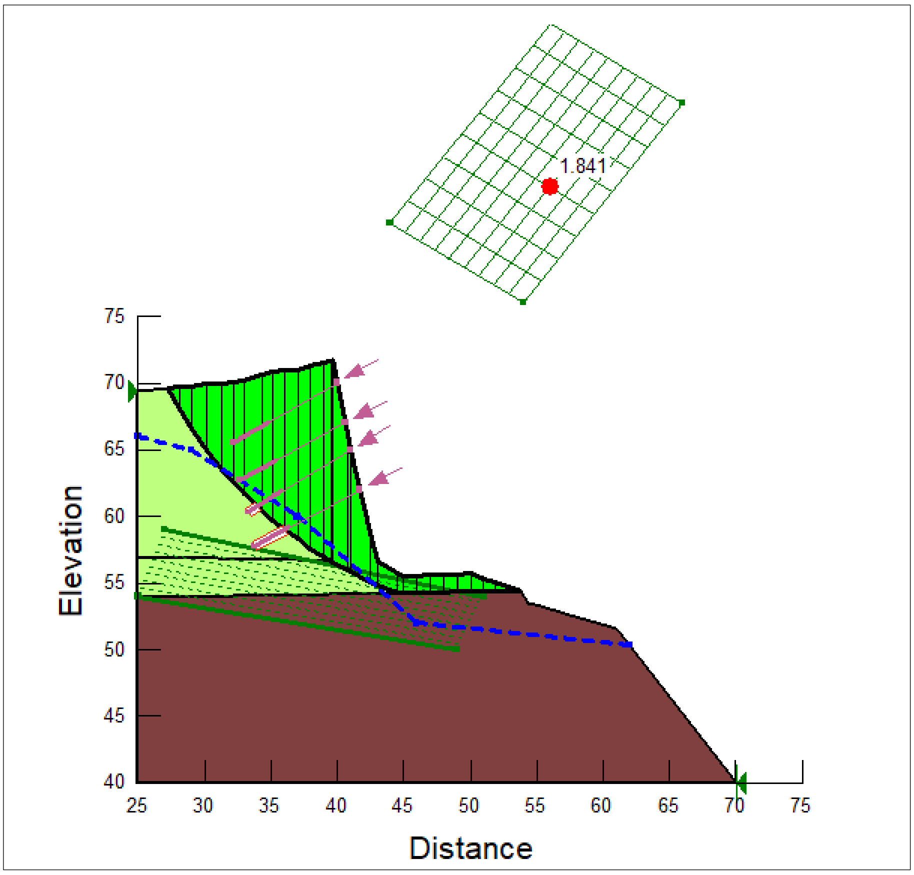



Figure 4. 4: Analysis of failed slope using anchor.

Figure 4.4 shows the FOS value obtained after applying anchors to the failed slope. It can be seen that the FOS after the application become higher than the original failed slope. The summary of the value of FOS can be illustrated as in the Table 4.3 below.

Table 4. 3: The summary of the value of FOS before and after application of anchors.

| **Method of analysis** | **Factor of safety before applying anchors** | **Factor of safety after applying anchors** | **Increment percentage %** |
|---|---|---|---|
| **Method of Ordinary** | 1.060 | 1.841 | 42.4% |

### 4.4.2 Application of geotextile to the slope

The geotextile will reduce the pore water pressure within the slopes during the rainy season, thereby increased the shear strength. The geotextile also acts as a filter which prevents the migration of soil or sometimes called the internal erosion within the slope. A geotextile acts as a filter when it allows liquid to pass normal to its own plane while preventing most soil particles from being carried away by the liquid current. It acts as a tensile member when it provides tensile modulus and strength to a soil with which it is interacting through interface shear strength, for instance the interlocking, friction, cohesion and adhesion.(Selezen, 2016) Figure 4.5 illustrated the FOS value obtained from application of geotextile to the slope.

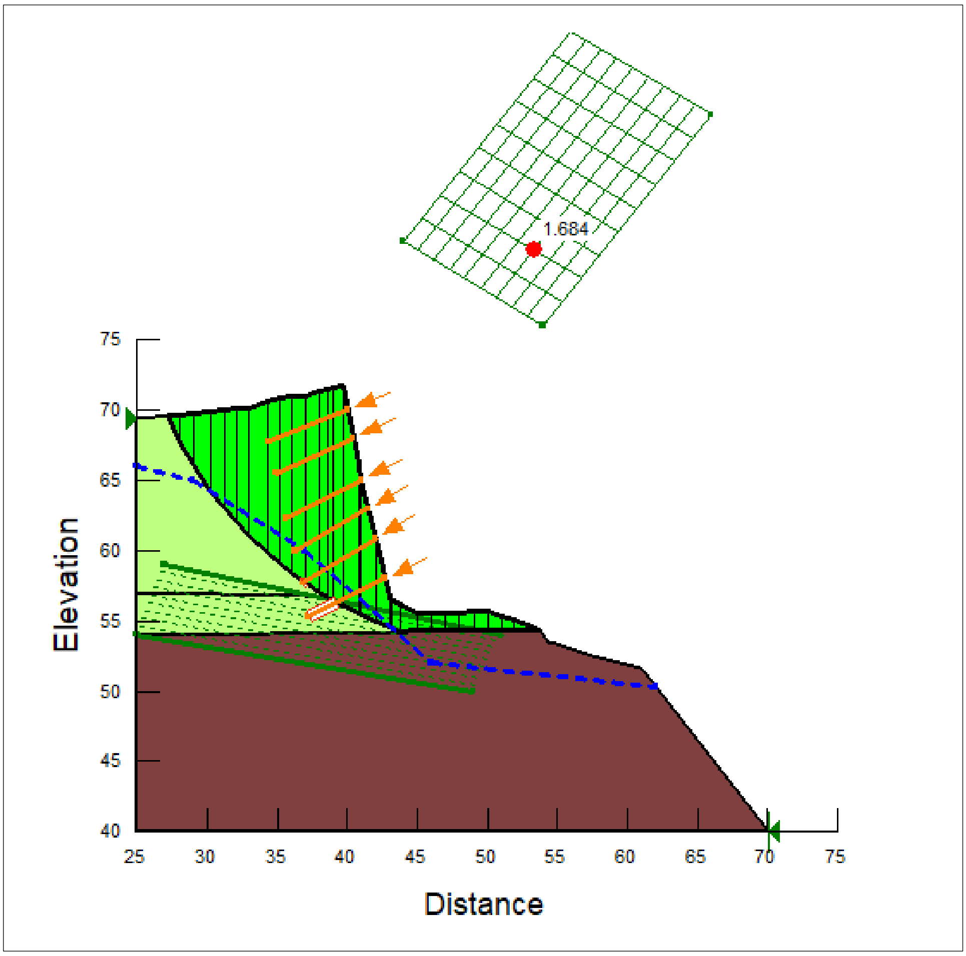



Figure 4. 5**:** Analysis of failed slope using geotextile.

The summary of the value of FOS can be illustrated as in the Table 4.4 below.

Table 4. 4**:** The summary of the value of FOS before and after application of geotextile.

| **Method of analysis** | **Factor of safety before applying geotextile** | **Factor of safety after applying geotextile** | **Increment percentage %** |
|---|---|---|---|
| **Method of Ordinary** | 1.060 | 1.684 | 37.5% |

Applying geotextile to the slope can increase the factor of safety value by 37.5%. The value of the FOS after applying geotextile is 1.684. The slope is considered as safe when the FOS value is more than 1.5.

### 4.4.3 Application of soil nails to the slope

Soil nails increase the shearing resistance of soil by acting in tension. The slope is reinforced by the insertion of relatively slender elements that is steel reinforcing bars and the load was transferred to the ground and was subjected to tensile stress. Figure shows the FOS value after the application of soil nails to the failed slope. The FOS value increased by 51.08% from 1.060 to 2.167. The slope is considered as safe because the value become more than 1.5. Figure 4.6 illustrated the FOS value obtained from application of soil nails to the slope. The summary of the value of FOS before and after application of soil nails are summarized in Table 4.5.

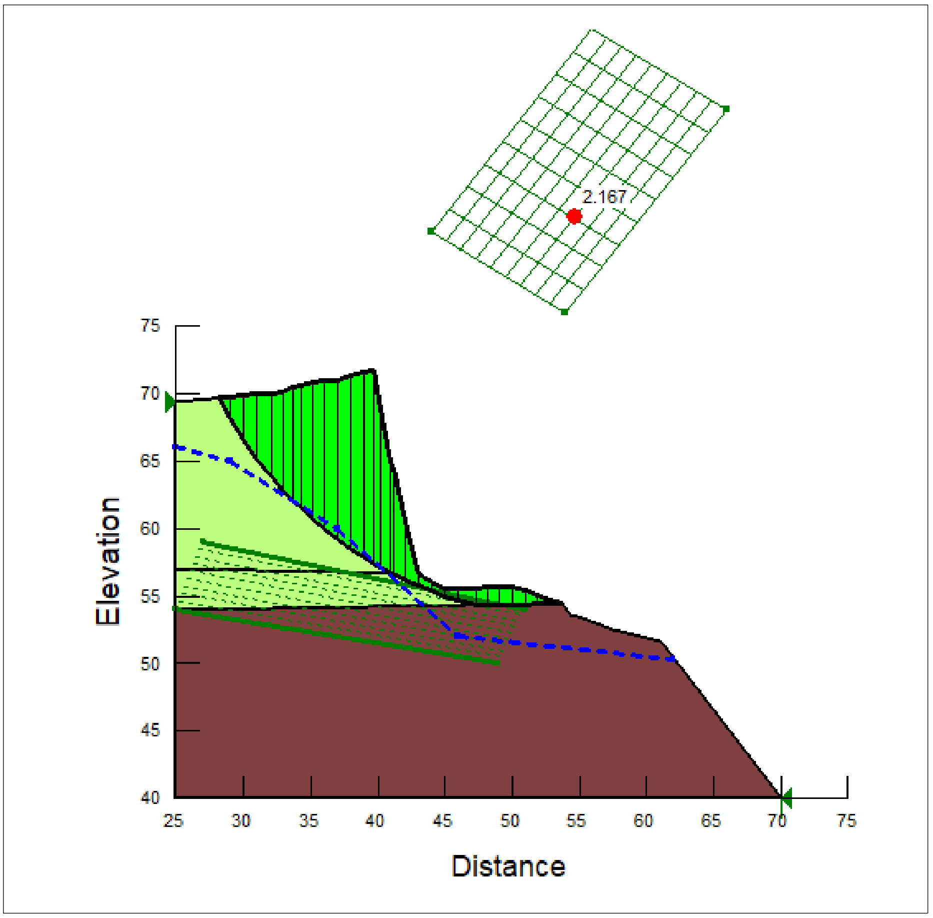



Figure 4. 6: Analysis of failed slope using soil nails.

Table 4. 5: The summary of the value of FOS before and after application of soil nails.

| **Method of analysis** | **Factor of safety before applying soil nails** | **Factor of safety after applying soil nails** | **Increment percentage %** |
|---|---|---|---|
| **Method of Ordinary** | 1.060 | 2.167 | 51.08% |

### 4.4.4 Application of benching 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 4.7 visualizes the analysis of the slope stability after applying the benching method. As we can see from Table 4.6, after the slope is cut off to make it less steep, the values of FOS are increases but not much. This may be due to the soil properties and soil parameters which make the slope is still in less strength even after application of remedial measure by benching method. The value of the FOS is less than 1.5, and it is considered as unsafe.

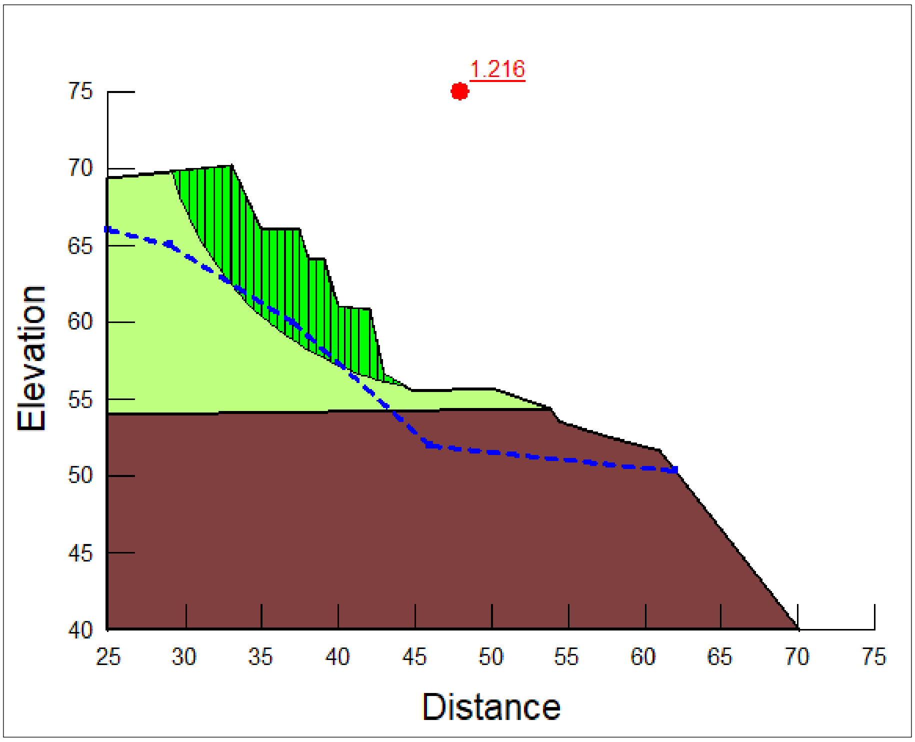



**Figure 4. 7:** Analysis of failed slope using benching.

Table 4. 6**:** The summary of the value of FOS before and after application of benching.

| Method of analysis | Factor of safety before benching method | Factor of safety after benching method | Increment percentage % |
|---|---|---|---|
| **Method of Ordinary** | 1.060 | 1.216 | 12.83% |

## 4.5 Analysis of remedial measures in term of factor of safety

One of the important factors that need to be consider in selecting the best remedial measures to be applied or redesign of the failed slope is by looking into the factor of safety value. The highest value of factor of safety yields the best choice and best stability to the slope. This can increase the strength of the slope, and at the same time preventing the similar case of slope failure to occur in the future. For all the method of the remedial measures, the value of FOS increases, and are better than the previous value of FOS. The increment percentage, FOS value before and after the application of remedial measures was summarized in Table 4.7.

Table 4. 7: The summary of the value of FOS before and after application of remedial measures to the slope.

| Method of remedial measures | Factor of safety before application of remedial measures | Factor of safety after application of remedial measures | Increment percentage % |
|---|---|---|---|
| **Anchor** | 1.060 | 1.841 | 42.42% |
| **Geotextile** | 1.060 | 1.684 | 37.05% |
| **Soil Nails** | 1.060 | 2.167 | 51.08% |
| **Benching** | 1.060 | 1.216 | 12.83% |

Based on the table, the FOS value for all remedial measures shows increments. The highest percentage increment is by applying soil nails which compute 51.08%, followed by anchors that is 42.42%, geotextile at 37.05% increment and the lowest one is benching with 12.83%.

From the analysis done, the best and effective method will be applying the soil nails to the failed slope. This is because when the method is applied to the slope, it stabilise the existing steep slope by increasing the normal force on shear plane and hence increase the shear resistance along slip plane in friction soil. It also reduces the driving force along slip plane both in friction and cohesive soil. Soil nails develops their reinforcing action through soil-nail interaction due to the ground deformation which results in development of tensile forces in soil nail. The major part of resistances comes from development of axial force which is basically a tension force. The length of soil nails 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.

For the lowest increment that is the benching method, even though there is cutting of slope, making the slope more manageable by dividing it into several smaller and less steep slopes to make the slope structure become nearer to its natural angle of repose, the FOS value yielded was not satisfied. This may because of the slope soil properties and the groundwater itself. The strength of the slope is too low, hence there is the needing in applying reinforcement into the soil to make the slope more stable, more vulnerable to mass movement of the soil and resistance to driving forces.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATIONS

## 5.1 Conclusion

Based on the analysis that done, it can be concluded that:

1) The slope at Taman Bukit Kuchai, Bandar Kinrara, Selangor Dahrul Ehsan is considered as failed. With the analysis and computing of factor of safety, the FOS value obtained is 1.060 which is considered as unsafe and unstable.

2) The slope is sandy clay. The type of soil which has low strength may cause the potential block slide downward due to its discontinuities parameter, triggered by severe erosion and intense rainfall.

3) FOS value can be obtained by modelling the slope in the software SLOPE/W, including the pore water pressure, and the slip surface, including the properties of the soil; cohesion C, angle of friction, unit weight of the soil and manual calculation using Ordinary Method of Slice is possible because of the simplicity.

4) FOS value computed using Ordinary Method of Slice by using Software Slope/W (1.060) and manual calculation (1.1507) is similar to each other. Hence, it shows that both methods have same FOS value due to apply same formula (Fellenius's method) to analyse the slope.

5) Remedial measures such as application of anchors, soil nails, geotextile, and benching can be computed using Slope/W for their FOS value.

6) FOS value after applying remedial measures to the failed slope for soil nails is 2.167, 1.841 for anchors, 1.684 for geotextile, and 1.216 for benching.

7) FOS value for all remedial measures shows increments. The highest percentage increment is by applying soil nails which compute 51.08%, followed by anchors that is 42.4%, geotextile at 37.05% increment and the lowest one is benching with 12.83%.

8) The best remedial measures to be selected after considering the highest FOS value is soil nails.

## 5.2 Recommendations

With the chance to study the case study to compute and analyses the data, there are some weaknesses identified. Proper action needs to be taken for the purpose of study in the future.

1) 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 analysed to determine the cause of the slope failure.

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

3) The computing of FOS with different and more numerous remedial measures should be done so that the method and their effect are numerous to be used as comparison and selected.

4) More data from the soil investigation will be useful for the researchers in the future. The number of boreholes should be more, so that analysing of the soil properties and their depth can be determined easily and more accurate.

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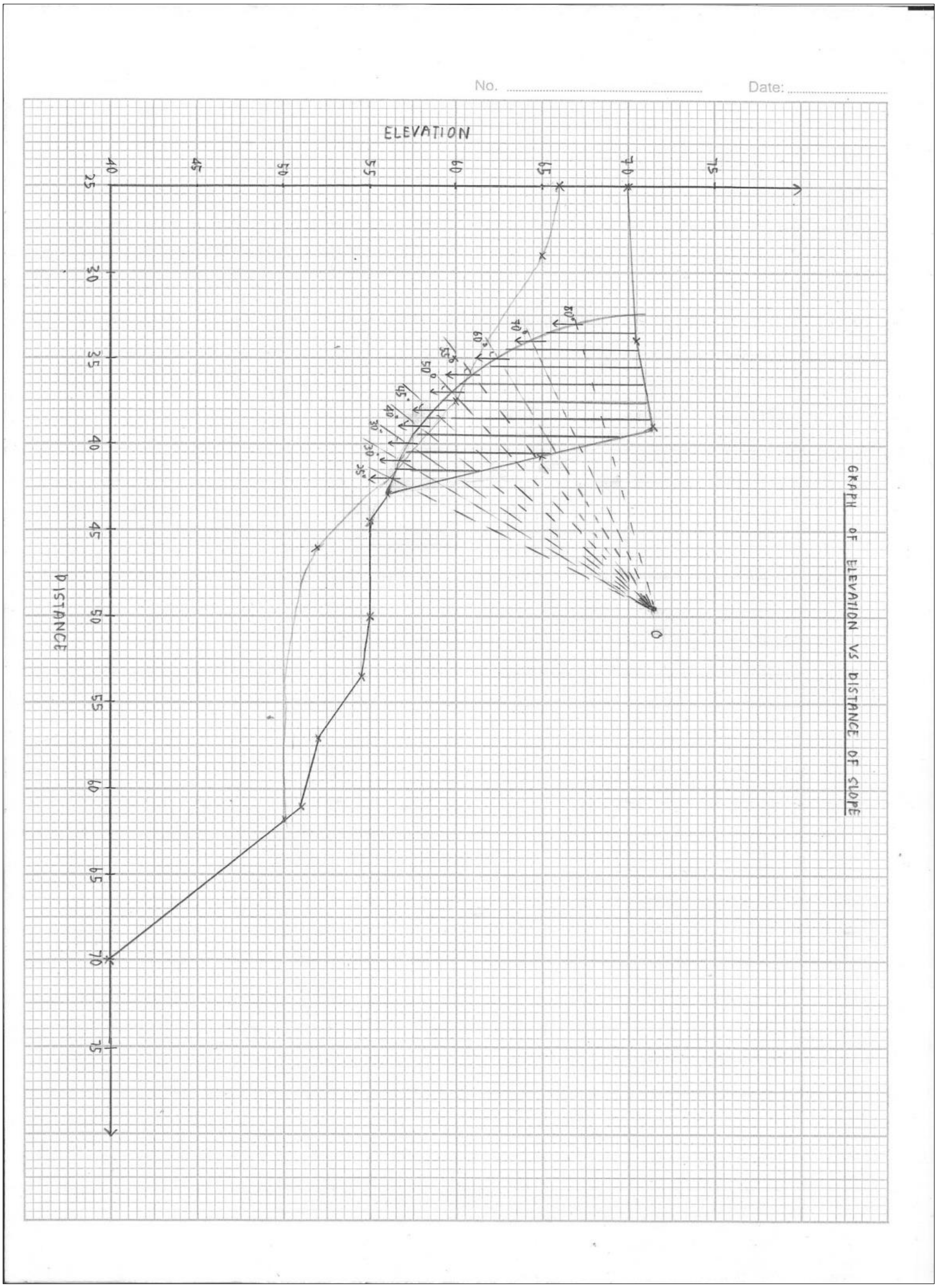
# APPENDIX A

## GRAPH FOR MANUAL CALCULATION USING ORDINARY METHOD OF SLICES


No.
Date:
ELEVATION
DISTANCE
GRAPH OF ELEVATION VS DISTANCE OF SLOPE
40
45
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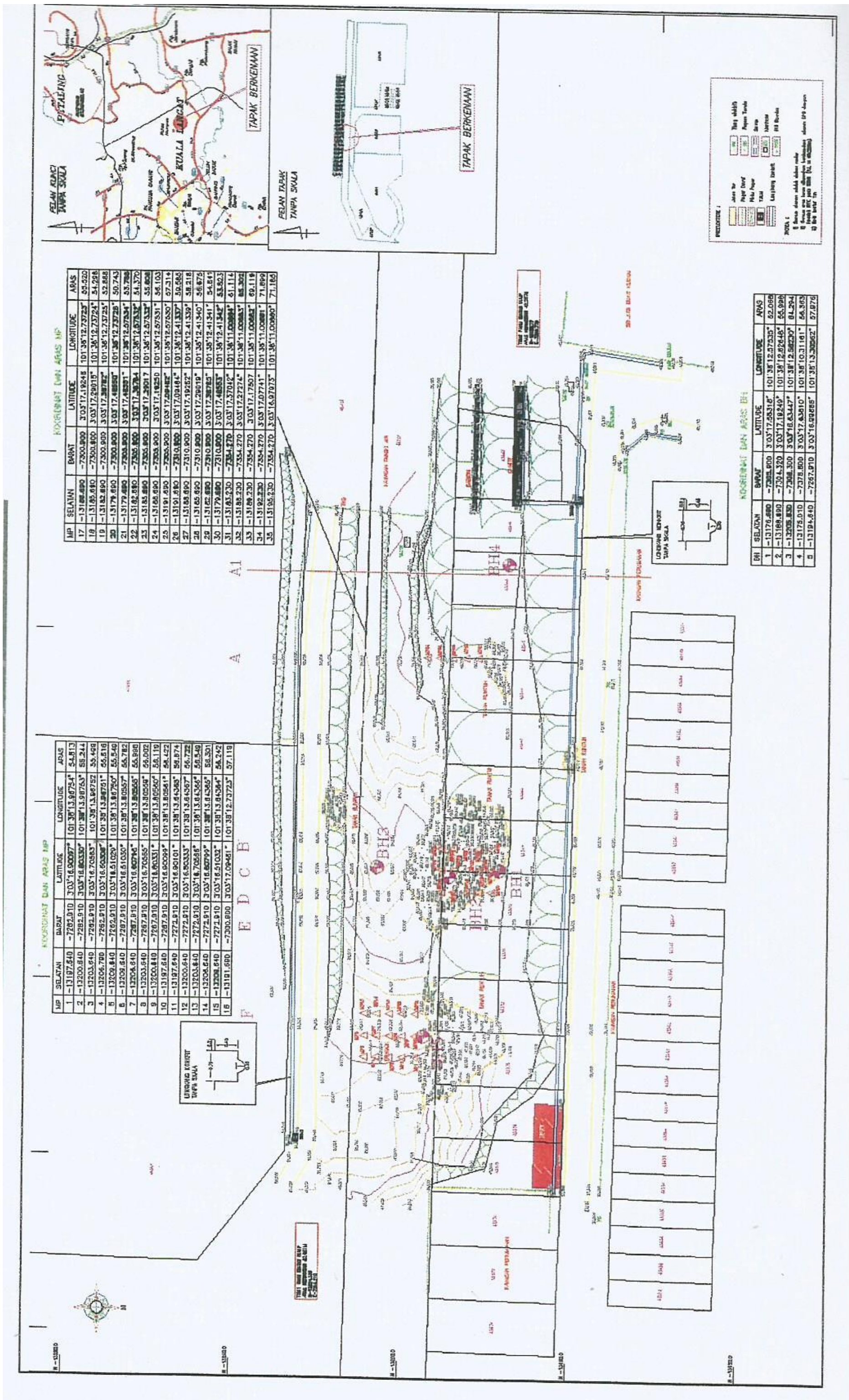
## APPENDIX B

## MAP AND LOCATION OF BOREHOLE


PELAN KUNCI
TANPA SKALA
PETALING
KUALA LANGAT
TAPAK BERKEMAN
PELAN TAPAK
TANPA SKALA
TAPAK BERKEMAN
KOORDINAT DAN ARAS MP
KOORDINAT DAN ARAS BH
A1
A
F E D C B
BH1
BH2
BH3
BH4

## APPENDIX C

## SOIL INVESTIGATION DATA OF BOREHOLE

| IKRAM GEOTECHNICAL LABORATORY | PROJECT : KAJIAN RUNTUHAN CERUN BERHAMPIRAN KOLAM AIR SYABAS BANDAR KINRARA, TAMAN BUKIT KUCHAI, KINRARA, SELANGOR | |
|---|---|---|
| Summary Of Laboratory Test Results - BS 1377 : 1990 | | Your Ref : IC/16/B20(011) Jld.1 |
| | | Our. Ref : ICGL/B/14 |
| | | Job No : 18/16 |
| | | Report No : T/36/2016 |
| | | Date : 3.5.2016 |

| BH | Sample | Depth | MS 2038 | M/C | Bulk | Dry | SG | 1-D Consol Test | | | UCT Test | Permeability Test | CU Test | | Soil Chemical Test / Water Chemical Test | | | | | | Atterberg Limit | | | | Sieve & Hydrometer Analysis | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | Density | Density | | Pc | Cc | Initial | c | K | c ' | φ ' | OM | $SO_3$ | $SSO_3$ | ph | Cl | SCI | LL | PL | PI | LS | CLAY | SILT | SAND | GRAVEL |
| No | No | (m) | | % | Mg/m³ | Mg/m³ | | kN/m² | | Void | kN/m² | | kN/m² | Degree | % | % | % | | % | % | % | % | % | % | % | % | % | % |
| BH/4 | S1D2 | 1.5 - 1.95 | MS | 24 | 1.74 | | | | | | | | | | | | | | | | N.E.S | N.E.S | | | 24 | 36 | 26 | 14 |
| BH/4 | S2D3 | 3 - 3.45 | CI | 22 | 1.86 | | | | | | | | | | | | | | | | 38 | 24 | 14 | | 9 | 65 | 26 | 0 |
| BH/4 | MZ1 | 4.5 - 5.5 | SCL | 14 | 1.80 | | 2.63 | | | | | 5.52x10-9 (m/s) | 13 | 33 | | <0.1 | | | | | 19 | 12 | 7 | | 5 | 25 | 70 | 0 |
| BH/4 | S3D4 | 6 - 6.36 | CI | 22 | 1.71 | | | | | | | | | | | | | | | | 39 | 25 | 14 | | 16 | 60 | 24 | 0 |
| BH/4 | S4D5 | 7.5 - 7.875 | MS | 15 | | | | | | | | | | | | | | | | | N.A | N.A | | | 5 | 54 | 41 | 0 |
| BH/4 | S5D6 | 9 - 9.435 | CL/CIS | 18 | 1.71 | | | | | | | | | | | | | | | | 35 | 20 | 15 | | 5 | 58 | 37 | 0 |
| BH/4 | S6D7 | 10.5 - 10.915 | CL/CIS | 15 | | | | | | | | | | | | | | | | | 35 | 20 | 15 | | 2 | 38 | 57 | 3 |
| BH/4 | S7D8 | 12 - 12.295 | CLS | 14 | 1.70 | | | | | | | | | | | | | | | | 28 | 20 | 8 | | 2 | 34 | 61 | 3 |

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

| Laporan Disediakan Oleh | Disahkan Oleh |
|---|---|
| [signature] | [signature] |

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# MASTER TESTING SERVICES SDN. BHD.

## PARTICLE SIZE DISTRIBUTION

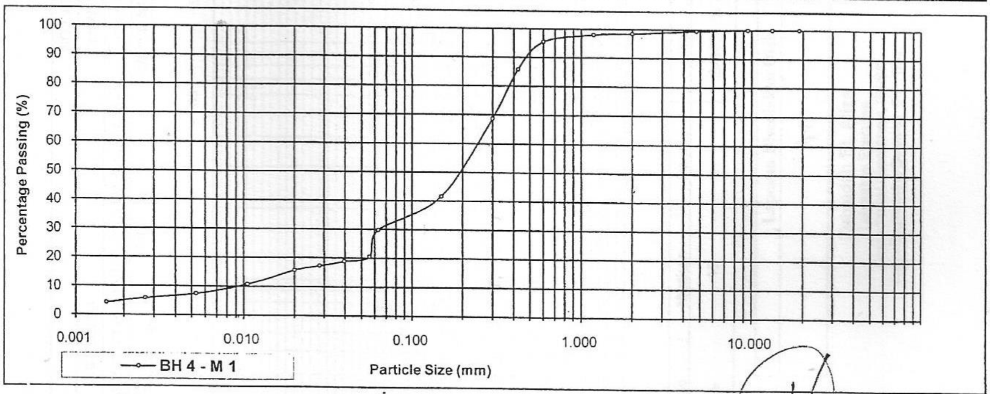
ISO 9001:2008
Cert No.: 2377

Project: Runtuhan Cerun Berhampiran Kolam Air Syabas Bandar Kinrara
Location : Taman Bukit Kuchai Selangor Darul Ehsan
Job No.: MTS/J115/16

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Wt.of Dry Soil, : | 50 | gm | Depth : 0.00 m | Dry Wt.of Soil, : | | gm | Depth : |
| Specific Gravity : | 2.60 | (Assumed) | Date : 26/04/2016 | Specific Gravity : | | (Assumed) | Date : |
| **BH No.:** | **BH 4** | | **Sample: M 1** | **BH No.:** | | | **Sample:** |

| B.S.Sieve No. (mm) | | Wt of Soil Retained | % Retained | % Passing | Wt of Soil Retained | % Retained | % Passing |
|---|---|---|---|---|---|---|---|
| 3/4" | 20.0 | | | 100.00 | | | |
| 1/2" | 14.0 | | | 100.00 | | | |
| 3/8" | 10.0 | | | 100.00 | | | |
| 3/16" | 5.0 | 0.24 | 0.48 | 99.52 | | | |
| #8 | 2.0 | 0.54 | 1.08 | 98.44 | | | |
| #14 | 1.18 | 0.25 | 0.50 | 97.94 | | | |
| #25 | 600 um | 1.26 | 2.52 | 95.42 | | | |
| #36 | 425 um | 4.85 | 9.70 | 85.72 | | | |
| #52 | 300 um | 8.54 | 17.08 | 68.64 | | | |
| #100 | 150 um | 13.52 | 27.04 | 41.60 | | | |
| #200 | 63 um | 5.88 | 11.76 | 29.84 | | | |
| | Pan | 14.92 | 29.84 | 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 | 1.0070 | 7.5 | 182.50 | 6.3 | 0.0558 | 20.47 | | | | | | |
| 2 | 1.0065 | 7.0 | 184.50 | 5.8 | 0.0396 | 18.85 | | | | | | |
| 4 | 1.0060 | 6.5 | 186.50 | 5.3 | 0.0282 | 17.23 | | | | | | |
| 8 | 1.0055 | 6.0 | 188.50 | 4.8 | 0.0200 | 15.60 | | | | | | |
| 30 | 1.0040 | 4.5 | 194.50 | 3.3 | 0.0105 | 10.73 | | | | | | |
| 120 | 1.0030 | 3.5 | 198.50 | 2.3 | 0.0053 | 7.47 | | | | | | |
| 480 | 1.0025 | 3.0 | 200.50 | 1.8 | 0.0027 | 5.85 | | | | | | |
| 1440 | 1.0020 | 2.5 | 202.50 | 1.3 | 0.0015 | 4.23 | | | | | | |
| Dispersant Correction:4 | | | CLAY % | SILT % | SAND % | GRAVEL % | | | | | | |
| Water Temperature: 25°C | | | 4.9 | 25.0 | 68.6 | 1.6 | | | | | | |




MASTER TESTING SERVICES SDN. BHD.
Director

**IKRAM GEOTECHNICAL LABORATORY**

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

**PROJECT : KAJIAN RUNTUHAN CERUN BERHAMPIRAN KOLAM AIR SYABAS**
**BANDAR KINRARA, TAMAN BUKIT KUCHAI, KINRARA, SELANGOR**

| | |
|---|---|
| Your Ref : | IC/16/B20(011) Jld.1 |
| Our. Ref : | ICGL/B/14 |
| Job No : | 18/16 |
| Report No : | T/36/2016 |
| Date : | 3.5.2016 |

| BH No | Sample No | Depth (m) | MS 2038 | M/C % | Bulk Density Mg/m³ | Dry Density Mg/m³ | SG | 1-D Consol Test Pc kN/m² | 1-D Consol Test Cc | 1-D Consol Test Initial Void | UCT Test c kN/m² | Permeability Test k | CU Test c' kN/m² | CU Test ø' Degree | Soil Chemical Test OM % | $SO_3$ % | $SSO_3$ % | Water Chemical Test ph | Cl % | SCI % | Atterberg Limit LL % | PL % | PI % | LS % | Sieve & Hydrometer Analysis CLAY % | SILT % | SAND % | GRAVEL % |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| BH/3 | S1D2 | 1.5 - 1.95 | C | 30 | 1.83 | | | | | | | | | | | | | | | | N.E.S | N.E.S | | | 50 | 21 | 29 | 0 |
| BH/3 | S2D3 | 3 - 3.45 | CHS | 25 | 1.90 | | | | | | | | | | | | | | | | 53 | 25 | 28 | | 39 | 18 | 42 | 1 |
| BH/3 | S3D4 | 6 - 6.45 | C | 32 | 1.78 | | | | | | | | | | | | | | | | N.E.S | N.E.S | | | 49 | 47 | 4 | 0 |
| BH/3 | S4D5 | 7.5 - 7.95 | MH | 34 | | | | | | | | | | | | | | | | | 62 | 33 | 29 | | 41 | 51 | 8 | 0 |
| BH/3 | S5D6 | 9 - 9.35 | M | 21 | 1.70 | | | | | | | | | | | | | | | | N.E.S | N.E.S | | | 37 | 53 | 10 | 0 |
| BH/3 | S6D7 | 10.5 - 10.95 | MH | 22 | | | | | | | | | | | | | | | | | 55 | 30 | 25 | | 38 | 48 | 13 | 1 |
| BH/3 | S7D8 | 12 - 12.45 | MH | 45 | 1.70 | | | | | | | | | | | | | | | | 64 | 34 | 30 | | 52 | 42 | 6 | 0 |
| BH/3 | S8D9 | 13.5 - 13.95 | MH | 35 | | | | | | | | | | | | | | | | | 69 | 35 | 34 | | 58 | 41 | 1 | 0 |
| BH/3 | S9D10 | 15 - 15.235 | MS | 12 | 1.69 | | | | | | | | | | | | | | | | N.E.S | N.E.S | | | 20 | 38 | 42 | 0 |
| BH/3 | S10D11 | 16.5 - 16.675 | M | 22 | | | | | | | | | | | | | | | | | N.E.S | N.E.S | | | 38 | 58 | 4 | 0 |
| BH/3 | S11D12 | 18 - 18.185 | M | 24 | | | | | | | | | | | | | | | | | N.E.S | N.E.S | | | 40 | 56 | 4 | 0 |
| BH/3 | S12D13 | 19.5 - 19.815 | MH | 22 | 1.71 | | | | | | | | | | | | | | | | 57 | 32 | 25 | | 37 | 59 | 4 | 0 |
| BH/3 | S13D14 | 21 - 21.21 | CI | 20 | | | | | | | | | | | | | | | | | 45 | 25 | 20 | | 26 | 41 | 28 | 5 |
| BH/3 | MZ1 | 4.5 - 5.5 | CI | 39 | 1.86 | | 2.61 | | | | | 4.95 X 10-8(m/s) | 5 | 26 | | <0.1 | | | | | 39 | 24 | 15 | | 57 | 32 | 11 | 0 |
| BH3 | MZ2 | 12.5 - 13.5 | CH | 28 | 1.85 | | 2.58 | | | | | 9.83E-08(cm/sec) | 7 | 26 | | 0.02 | | | | | 66 | 30 | 36 | | 38 | 55 | 7 | 0 |

NOTE : N.E.S = NOT ENOUGH SAMPLE

N.A = NOT APPLICABLE

N.D = NOT DETECTED

| Laporan Disediakan Oleh | Disahkan Oleh |
|---|---|
| (signature) | (signature) |

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# MASTER TESTING SERVICES SDN. BHD.

## PARTICLE SIZE DISTRIBUTION

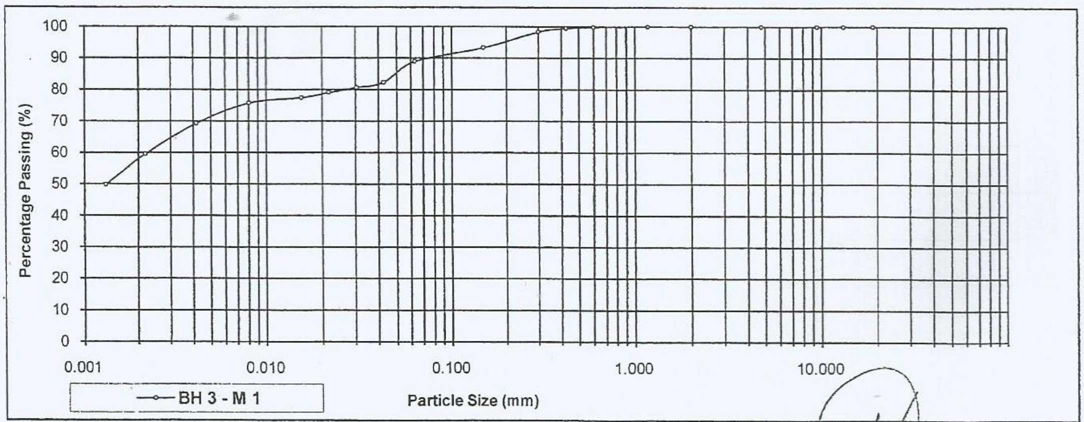
ISO 9001:2008 Cert No.: 2377

Project: Runtuhan Cerun Berhampiran Kolam Air Syabas Bandar Kinrara
Location : Taman Bukit Kuchai Selangor Darul Ehsan
Job No.: MTS/J115/16

| | | | | | |
|---|---|---|---|---|---|
| Wt.of Dry Soil, : 50 gm | Depth : 0.00 m | Dry Wt.of Soil, : | gm | Depth : | |
| Specific Gravity : 2.60 (Assumed) | Date : 26/04/2016 | Specific Gravity : | (Assumed) | Date : | |
| BH No.: **BH 3** | **Sample: M 1** | BH No.: | | Sample: | |

| B.S.Sieve No. (mm) | | Wt of Soil Retained | % Retained | % Passing | Wt of Soil Retained | % Retained | % Passing |
|---|---|---|---|---|---|---|---|
| 3/4" | 20.0 | | | 100.00 | | | |
| 1/2" | 14.0 | | | 100.00 | | | |
| 3/8" | 10.0 | | | 100.00 | | | |
| 3/16" | 5.0 | | | 100.00 | | | |
| #8 | 2.0 | | | 100.00 | | | |
| #14 | 1.18 | 0.03 | 0.06 | 99.94 | | | |
| #25 | 600 µm | 0.06 | 0.12 | 99.82 | | | |
| #36 | 425 µm | 0.22 | 0.44 | 99.38 | | | |
| #52 | 300 µm | 0.56 | 1.12 | 98.26 | | | |
| #100 | 150 µm | 2.49 | 4.98 | 93.28 | | | |
| #200 | 63 µm | 2.21 | 4.42 | 88.86 | | | |
| | Pan | 44.43 | 88.86 | 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 | 1.0260 | 26.5 | 106.50 | 25.3 | 0.0426 | 82.23 | | | | | | |
| 2 | 1.0255 | 26.0 | 108.50 | 24.8 | 0.0304 | 80.60 | | | | | | |
| 4 | 1.0250 | 25.5 | 110.50 | 24.3 | 0.0217 | 78.97 | | | | | | |
| 8 | 1.0245 | 25.0 | 112.50 | 23.8 | 0.0155 | 77.35 | | | | | | |
| 30 | 1.0240 | 24.5 | 114.50 | 23.3 | 0.0081 | 75.73 | | | | | | |
| 120 | 1.0220 | 22.5 | 122.50 | 21.3 | 0.0042 | 69.23 | | | | | | |
| 480 | 1.0190 | 19.5 | 134.50 | 18.3 | 0.0022 | 59.47 | | | | | | |
| 1440 | 1.0160 | 16.5 | 146.50 | 15.3 | 0.0013 | 49.73 | | | | | | |
| Dispersant Correction:4 | | | CLAY % | SILT % | SAND % | GRAVEL % | | | | | | |
| Water Temperature: 25°C | | | 57.4 | 31.5 | 11.1 | 0.0 | | | | | | |




MASTER TESTING SERVICES SDN. BHD.
Director