Slope Stability Analysis in Residual Soils

by

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Civil Engineering Programme
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Approved by,

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(Ms. Niraku Rosmawati Bt Ahmad)

UNIVERSITI TEKNOLOGI PETRONAS
BANDAR SERI ISKANDAR, PERAK
January 2022

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein has not been undertaken or done by unspecified sources or persons.

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ZAKIAH BINTI ZAINAL ARIFFIN

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ABSTRACT

Slope failure is a widespread geological event brought on by a range of factors including geography, weather, and human activity. The risks associated with this are high, and not only would slope failure result in financial losses for developers, but it would also jeopardise the safety of persons living in the surrounding area. As a result, engineers must take necessary measures and steps to prevent injury to persons and property as a result of a wide variety of ground vibrations. Malaysia is prone to landslides due to the abundance of hills and mountains with Weathered Granite Grade IV to V soils. The goal of this research is to investigate the effect of slope gradient, water table, and soil properties on residual soil slope stability in order to resolve this difficult problem. This study investigates the critical combination factors which trigger mechanisms of slope failure in residual soil using Slope/W with varying the variables of the geometry of slopes, pore water pressure. The initial step in this study's procedure is to determine the slope geometry and the range of soil parameters. The slope stability analysis is then performed using SLOPE/W, utilizing the Bishop technique, using the information gathered. To understand the results, control and parametric analysis are performed, and the data is then concluded and documented. The use of geotechnical software as a result of this methodology allows for more in-depth research and comprehension of physical characteristics and the effects of gradient, water table, and various soil parameters. We can observe that the higher the gradient and the height, the less stable the slope is. From the analysis conducted, we also can observe that the soil parameters play a vital role in resisting slope failure. The effect of varying the variable of the factor influence to the slope stability could be understood and studied through this project. The horizontal berm provided in this research helps to increases the factor safety of the slope. The findings of this project could be used for future preliminary designing of the slope in residual soil as the software analysis presented the factor of

safety of the slope. As a result, a comprehensive analysis of the geotechnical properties of residual soils is essential for a safe and cost-effective construction design.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND STUDY

Residual soil is soil that formed from the process of decomposition and weathering of the rocks and particularly remains at the origin location (in situ) without any movement. Granite residual soil, sedimentary residual soil, and meta-sedimentary residual soil are the three main forms of soil found in tropical areas. The residual soils are composite soils with varying quantities of sand, silt, and clay depending on the geological background of the soil. The two most frequent types of residual soil in Malaysia are granite and sedimentary residual soils. As mentioned by Saffari et al., 2019, Salih, 2018 and Tan et al., 2008, tropical countries like Malaysia usually develop extensive physical and chemical in situ weathering due to geological, topography factors and receive a lot of rainfall throughout the year. The features of these residual soils differ from those of transported soils since the residual soils have high permeability and heterogeneity. Since the process of forming residual soils is complicated, it is typically defined as different weathering grades that play an essential role in slope stability analysis, as they are able to determine potential slope failure and soil material behaviour.

Slope stability problems have passed off since the dawn of time, either because of natural occurrences including landslides or due to human beings converting the natural structure and stability of natural soil slopes. Landslides are the most dangerous natural disaster, causing enormous loss of life and injury to people and property, as well as damage to infrastructure, agricultural areas, and housing. Malaysia is vulnerable to landslides because of its geographical conditions of excessive lands and mountains, especially in the Peninsular area, in which the maximum of the soil is residual soil.

Landslides are caused by a variety of factors, including the physical properties of the underlying material, intense weather, a lack of vegetation cover, excessive water, and poor drainage. Based on some research conducted, in other regions, geological and morphological are the causes of landslides as shown in Figure 1.1. However, as shown in Figures 1.2 and Figure 1.3, errors during the design or building phase, as well as non-maintenance of slopes, are the main causes of slope failures in Malaysia. According to studies of retroactive landslides in Malaysia, human errors, which typically involve design/construction inaccuracies and inadequate slope maintenance, are the causes that primarily trigger the landslide (Kazmi et al., 2016). Inadequacy in design, according to Gue and Tan (2001), is usually the result of a lack of comprehension of ground conditions and geotechnical concerns. In addition to that, they found that building failures were responsible for 8% of all landslides, with technique, materials, and/or a lack of supervision all influencing. A combination of design and construction flaws caused approximately 20% of the landslides studied. Slope failures caused by geological features account for 6% of landslides in residual soil slopes, the same as landslides caused by a lack of maintenance.

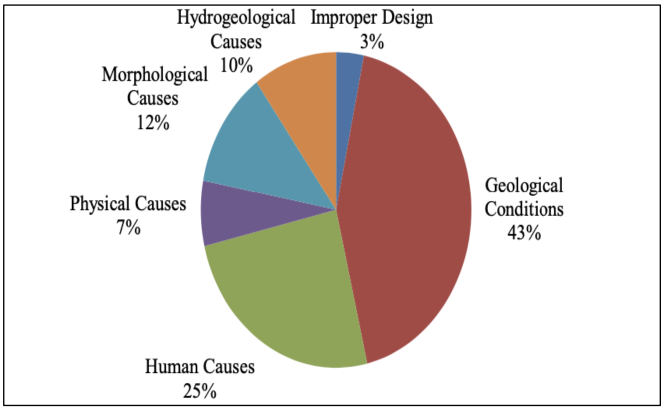

FIGURE 1.1:Contributing factors of landslides for countries other than Malaysia

(Kazmi et al., 2016)

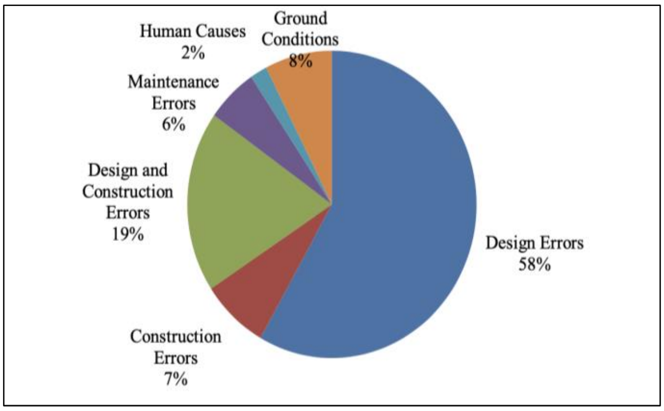

FIGURE 1.2:Contributing factors of Malaysia landslides

(Kazmi et al., 2016)

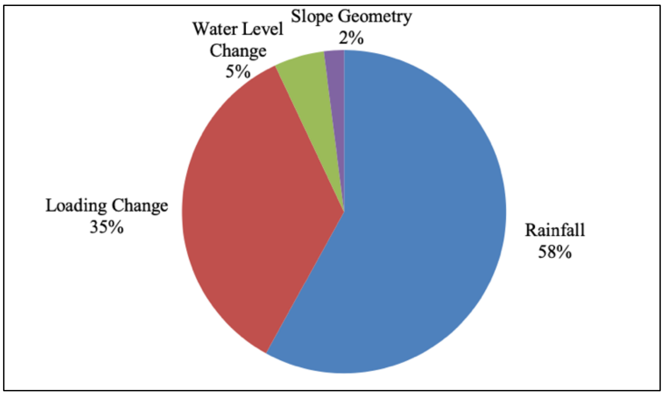

FIGURE 1.3:Contributing factors of Malaysia landslides

(Kazmi et al., 2016)

In terms of triggering factors, rainfall plays a big role in Malaysia, representing 58% of the total and acting as a primary triggering factor due to the country's annual precipitation of 2550 mm. In addition, the loading change on the slope contributes 35% due to disturbances in hillside developments such as retaining walls and highways which affect the stability of a slope. The strength of the soil and the angle of the slope varies depending on the conditions and locations also contribute to huge factors to slope instability.

Slope Stability appraisals have evolved in the geotechnical calling due to late headways in soil and rock mechanics. However, deciding on a slope stability investigation approach isn't always a smooth task, and time must be spent accumulating area data and failure observations to completely recognize the failure process, which will determine the slope stability method to utilise in the study. Engineers could simply analyse slope stability employing computer systems using the appropriate software programme based on the purpose of the analysis once the slope form and soil properties have been specified. To appropriately utilize slope stability speculations, an extra noteworthy comprehension of geography, soil attributes, and hydrology is required. Incline stability problems are settled utilizing the enhancements on Morgenstern and Price's procedure, the Janbu approach, Bishop technique, Spencer's approach, customary approach for cuts and different breaking point stability strategies. These methods are generally performed using either the limit equilibrium or the finite element method to figure out the slope ability failure mechanisms and calculate safety factors for a given geotechnical condition.

1.2 PROBLEM STATEMENT

According to Rahman et al., 2018, residual soil, weathered from granites that underlie predominantly around the hills and mountains area, sedimentary and meta-sedimentary formation rocks, covers more than 75% of the surface in Malaysia. The remaining percentages are made up of alluvium and clay found on rivers and beaches, while granite rock, the most acidic igneous deposit, makes up roughly half of the ground surface in Peninsular Malaysia. Most of Malaysia's slopes have been subjected to various types of weathering, ranging from Weathered granite grade IV to VI. Particle size distribution, specific gravity, plastic index, soil-water characteristic curve, and shear strength are all factors that affect slope angles, stability, and construction ability of the soil, since some soils may require different soil stabilisation procedures.

As we are in the twenty-first century, technological advancements have resulted in significant advancements in society. Any structure or megaproject built is intended to rest on the earth's surface. Future accommodations must not only be pleasant but also offer a stunning view to live a better life. A substantial number of residences, condominiums, and recreational areas have been developed on the hillside as a result of this phenomenon. Due to the tremendous development and restrained land space, some sites including mountains and slopes are excavated for future development such as retaining walls and roadways. Apart from that, the construction on this type of soil cannot be avoided, since, as mentioned earlier, 3/4 of the land area in Malaysia is covered by residual soils but appropriate design and sufficient information of the soils are important in the preliminary task.

According to Gue & Tan, (2006), 20% of annual slope failures in Malaysia occur due to a combination of design and construction errors as opposed to geological conditions. Meanwhile, 6% was recorded as a lack of maintenance for landslides in residual soil slopes. The structures constructed on the slopes area are the main source of concern since they might be triggered by slope instability which is caused by infiltration, lack of vegetation and maintenance as well as an inadequate shear strength of the soil on the excavated slope. Throughout this project, the author aim is to analyse the stability of slope in residual at the different conditions and to study the critical combination triggering mechanisms of slope failure.

1.3 OBJECTIVES

Based on the background research presented above, few objectives have been listed to outline the direction of this research project:

i. To access the effect of slope gradient on slope stability of residual soil.

ii. To access the effect water table to the slope stability of residual soil.

iii. To access the effect of soil parameters on the slope stability of residual soil.

1.4 SCOPE OF STUDY

This paper emphases the properties of residual soil distributed widely in Malaysia at different conditions that contribute to the critical combination triggering mechanisms of slope failure. In this project, parametric studies of the stability of residual soil slopes are conducted using the stability analysis software SLOPE/W which will be further discussed in Chapter 3. The simulations conducted using advanced software such as SLOPE/W by GeoStudio are vital before designing the structures that land on the area of the slope. Slope stability is assessed in practical engineering to determine whether the soil slope section design is sustainable. If the slope is too steep, it will sink quickly; if it is too moderate, the quantity of earthwork needed will double (Ishak et al., 2017) (Jamalludin, D., 2014). In these analyses, the variables that were investigated to determine the influence on the factor safety of the slope are as below:

i. Geometry of slopes

ii. Pore water pressure

iii. Soil parameters

CHAPTER 2

LITERATURE REVIEW

2.1 RESIDUAL SOILS IN MALAYSIA

According to the satellite information gathered by the geography of Malaysia, Malaysia lies north of the equator in central Southeast Asia which experiences a wet type of tropical climate. Generally, the average temperature is around 25-27° C with little seasonal change. However, it might vary by up to 5 degrees Celsius from the norm since it receives a lot of rainfall throughout the year. One of the geological factors in the production of residual soils in the tropical climate. Considering that granites underpin many of the area's hills and mountains, it's widely agreed that granitic residual soil and sedimentary soil contribute more than 75% of Peninsular Malaysia's soils (Taha et al., 2014; Jamalludin et al., 2014; Rahman et al., 2018; Saffari et al., 2019). Based on Jamalludin et al., (2014), the distribution of the three major types of soils consisting of sedimentary rocks, granitic rocks, and alluvium soils that are widely distributed in Peninsular Malaysia is shown in Figure 2.1.

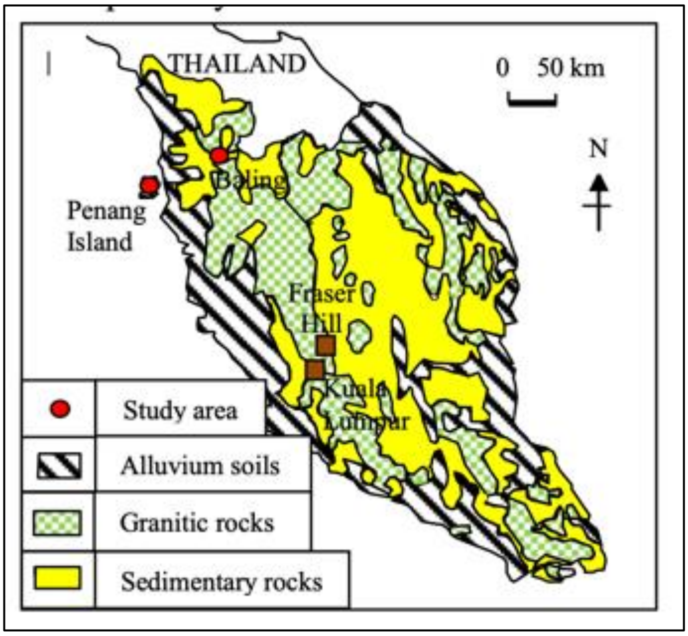

FIGURE 2.1 Geology map of Malaysia
(Jamalludin et al., 2017)

Due to high temperatures with high intensity of the rainfall then infiltrating to the subsoil, chemical weathering is responsible for the majority of Peninsular Malaysia's residual soils. The geomorphic conditions reflect the pattern and thickness of the weathering profile, simulating the lithology and structure of the rock mass. The figure below shows that there are six grades of residual soil. Omar et. al (2018), in his review paper, shared the same view with Saffari et. al (2019) and concluded that most of the slope in Malaysia has different grades of weathering from grade IV to V and they affect the slope angles, as well as the soil's stability and construction ability. Figure 2.2 shows the typical weathering profile of residual soil in which the top layer of the profile consists of soils that are formed from the weathering of rocks and the grade of weathering is known as grade V. The weathering profile is decreasing with depth until the fresh rock is found, described as grade I. Further descriptions of the characteristics of weathering grades is explained in Table 2.1. According to Chen et. al (2020), the weathering profile is essential for slope stability analysis because it usually controls the potential failure surface and the mode of failure, the groundwater hydrology, and therefore the critical pore pressure distribution in the slope and the erosion characteristics of the materials.

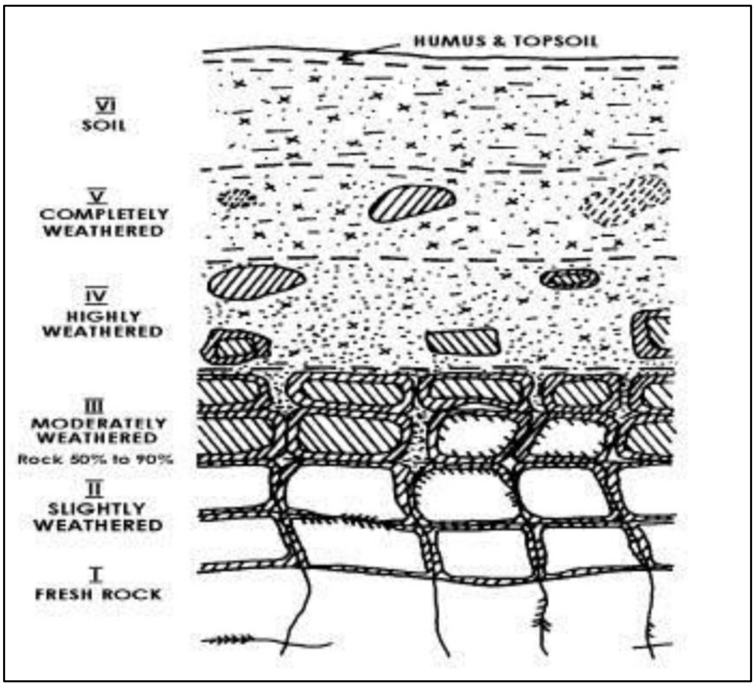

FIGURE 2.2 Typical weathering profile of residual soil

(Little,1986)

TABLE 1.1 Material grade classification (Geo,1988)

Descriptive Term	Grade	General Characteristics
Residual Soils	VI	- Original rock texture completely destroyed. - Can be crumbled by hand and finger pressure.
Completely Decomposed	V	- Rock wholly decomposed but rock texture preserved. - No rebound from N Schmidt hammer. - Can be crumbled by hand and finger. - Easily indented by point of geological pick. - Slakes when immersed in water. - Completely discoloured compared with fresh rock.
Highly Decomposed	IV	- Rock weakened and can be broken by hand into pieces. - Positive N Schmidt rebound value up to 25. - Makes dull sound when struck by hammer. - Geological pick cannot be pushed into surface. - Does not slake readily in water. - Hand penetrometer strength index greater than 250kPa. - Individual grains may be plucked from surface. - Completely discoloured compared with fresh rock.
Moderately Decomposed	III	- Usually cannot be broken by hand but easily broken by geological hammer. - N Schmidt rebound value 25 to 45. - Makes dull or slight ringing sound when struck by hammer. - Rock material not friable. - Completely stained throughout.
Slightly Decomposed	II	- Not broken easily by geological hammer. - N Schmidt rebound value greater than 45. - Makes ringing sound when struck by hammer. - Strength approaches that of fresh rock. - Fresh rock colours generally retained but stained near joint surfaces.
Fresh Rock	I	- No visible signs of weathering not discoloured. - Not broken easily by geological hammer. - Makes ringing sound when struck by hammer.

2.2 TYPES OF RESIDUAL SOILS

As Malaysia experiences humid temperature and heavy rainfalls, the formation of tropical residual soils are intense with a predominance of chemical weathering of rocks. Rock properties, climate, terrain, hydrology, and vegetation are all the factors that influence weathering (biology). As stated by Tan B.K. (2005), chemical weathering involves the breakdown of minerals within the rock by a range of chemical processes like oxidation, hydrolysis, hydration, carbonation, and others. This process produces new minerals that eventually become a part of the soil components like clay minerals and iron oxides with different behaviour in terms of their physical and chemical behaviours and also the soil composition.

Based on the past research, granitic soils are predominantly in Peninsular Malaysia since granites underlie many of the hills and mountains. As a result, granitic soils are commonly found and employed in construction, particularly in hilly terrains like highway and dam construction. Granite is an intrusive stone that forms when cooling magma that's rich in quartz, feldspar and mica. Granite dirt in Malaysia is sandy as sand-sized quartz and partially weathered feldspar as extracted from the granite before gradually weathering into fine-grained clay minerals over time. The numerous difference (nearly doubled) between the expansion coefficients of quartz and feldspar causes granite surfaces to crack easily within the process of expansion and contraction. Due to granite itself resistance to weathering, hence the ultimate soil will contain both sand-sized quartz, feldspar and clay. This may change over time, geographical movement and climate change as the residual clay that forms from granite becomes more clayey (Niu. X, 2020).

2.3 SLOPE STABILITY

Slope stability problems have existed from the beginning of time, either as a result of natural phenomena involving landslides or as a result of humans disrupting the natural structure and balance of natural soil slopes. According to Kazmi et al., (2016) landslides in residual soils are frequently happened at the hilly caused by slope instability, distressed slopes, and cut slopes as occurred in Hong Kong. It is recorded that hundreds of landslides occur each year as a result of ancient slope failures due to the cut and fill process of slopes. As stated in his research that in Hong Kong, they were cutting the slopes at a range between 40° to 70° degree angle and fill it back at 30° to 35°. This is due to a lack of geotechnical control, as a result of which the majority of the slopes have severely deteriorated and are vulnerable to failure. As mentioned previously, slope stability is influenced by a variety of elements, including the soil shear strength, slope geometry, pore pressures and soil properties. Description of the factors will be described in sections 2.3.1 to 2.3.4 below.

2.3.1 Effect of rainfall

Malaysia's climate is characterized by consistent temperature and pressure, excessive humidity, and common rainfall. Rahardjo. H, (2016) reported that the rainfall-induced slope failures are massive in tropical climate zones, which are separated into seasons, the wetter Northeast Monsoon and the drier Southwest Monsoon. According to statistics from Malaysia's Meteorology Department, the wetter Northeast Monsoon season runs from December to May, and the drier Southwest Monsoon season runs from June to November. The wettest months are usually December and January, with June being the driest.

During rainfall infiltration, the shallow soil of the landslide mass quickly reaches saturation and increases surface runoff, which erodes the slope, and the seepage subject is changed throughout rainfall infiltration, increasing the moisture content material of the landslide mass. Different types of soils perform differently in terms of rainfall penetration under rainy conditions, the hydraulic and mechanical behaviour of the soil changes as the slope inclination changes. Infiltration of water into the soil during rain causes a discount in suction, which ends in a very decrease in soil strength, resulting in slope failure. According to Zhang et al. (2014), the movement of rainfall-triggered landslides is significantly linked to the moisture content of the soil mass. Bulk density moisture content material is a physical index that displays soil-water properties.

As rainwater runs off the slope, it causes surface erosion and most of the water infiltrates into the subsoil thus increasing the soil permeability and somehow causing the perched water table to form at a less permeable border indicated by the weathering profile (Yean Chin, T, 2001). Chen, R et. al, (2012) and Salih. A, (2018) claimed that the mechanical failure of residual soil slope is due to the high intensity of rainfall. This is because continuous periods of rainfall allowed water to easily percolate into the soil, increasing pore water pressure and lowering soil shear strength. Shear strength of the soil is affected by the moisture content, pore pressure, disturbance of structure, groundwater table, stress history, time, and environmental conditions. This condition of the effect of rainfall on the high permeable slope has been illustrated in Figure 2.3.1.

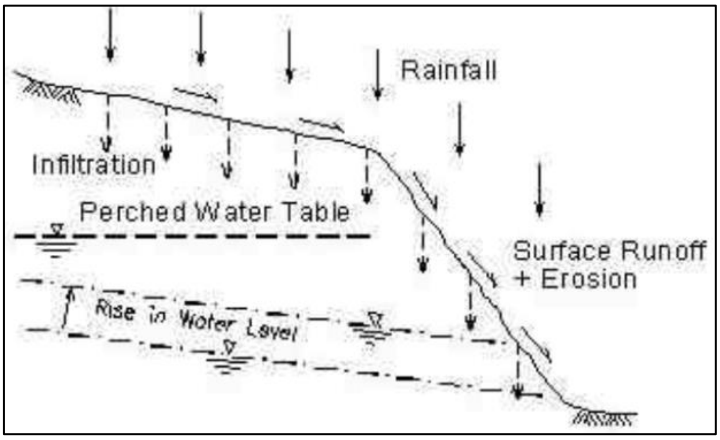

FIGURE 2.3.1 Effects of rainfall on high permeable slope

(Kassim, 2012)

2.3.2 Effect of slope geometry

According to Wesley.L (2011), the slope failures in residual soils happen when slopes are steep because the inclination is beyond 60° with 10 m high. The steeper the slope, the higher the shear stress component of gravity, but the lower the perpendicular component of gravity. The perpendicular component of gravity sustains the soil on the slope, whereas the tangential component creates shear stress parallel to the slope, dragging the soils down the hill and causing landslides.

Shear and normal strength in shear surfaces are influenced by slope, which is the original stability factor. A steep slope reveals how high the shear stress is and how low the slope's security factor is since tangential stress increases within the colluvium in residual or consolidated soil covers, axial tension lowers (shearing strength increases in steep slopes) and stability deteriorates. Thus, with the increase of the slope, the block-creation potential of the material increases, and this leads to the increase in the weight of rock blocks. As a result, slope affects the magnitude of shear and normal stress on shear surfaces furthermore because of the distribution of stress within masses (Çellek. S, 2020).

The gravitational strength component ensures the shear of the slope, regardless of how steep the slope is and thus the thing that's that massive decides how influential that strength is in ensuring the movement of the item. As a result, slope steepness could also be thought to be a risk factor associated with the foremost important soil factor, which affects slope stability (Kornejady et al., 2017). The stress distribution within the slope is directly influenced by the slope angle. Different slope angles impact not only the magnitudes of residual stress on existing or potential shear surfaces, but also the renewal and process of deformation (Zhu et al., 2017).

2.3.3 Shear strength of the soil

The barrier to prevent sliding friction between particles and particle cohesiveness is derived from two essential parts of soil shear strength. Moisture content, pore pressure, structural disturbance, groundwater level variations, stress history, time, and environmental conditions are the factors affecting the shear strength (Salih. A, 2018). However, determining residual soil shear strength is difficult due to the variable composition of the soil and the difficulty in obtaining undisturbed high-quality samples, which influences the soil's shear strength. The disruption in the stability of the soil results in a lower value of shear strength due to the collapse of soil structure and increases the value of effective friction angle (ϕ). As stated by Salih. A (2018), when the effective shear strength, parameters such as cohesion (c) and the friction angle (ϕ) are determined, saturation of the specimen is required. This is related to the fact that specimen saturation might enhance soil moisture content and saturation level and reduce the value of cohesion (c) of the soil. Based on the previous research done, Table 2.2 shows some of the soil properties of residual soil in Malaysia collected from research papers by the author.

TABLE 2.2 Soil properties of residual based on the location.

NO	Location	Friction angle $\emptyset$ (°)	Unit weight $(\mathbf{kN/m^3})$	Cohesion c (kPa)	References
1	Kuantan, Pahang	32- 35	19.4- 22.2	8-9	Stability analysis and improvement evaluation on residual soil slope: building cracked and slope failure
2	Malaysia	30-35	16-18	0-15	Parametric study of residual soil slope stability.
3	Kota Samarahan, Sarawak	10.94 -17.14	-	8.83 - 18.64	Engineering Properties of residual soils
5	Kuala Lumpur	26-35	17-20	2-15	Slope stability analysis at hilly areas of Kuala Lumpur, Malaysia
6	Malaysia	17- 40	13-23	7- 77	Characterization the geotechnical properties of a Malaysian granitic residual soli grade V
7	Northern Malaysia	35.6	12.2- 20.4	30.2	Characteristics of soil taken from slope failures in sedimentary and granitic residual soils
8	Kuantan-Dungun	32-35	19.4-22.2	8-9	Stability analysis and improvement evaluation on residual soil slope
9	Perak	21	16.5	0	Slope Stability Analysis of Granitic Residual Soil Using SLOPE/W, Resistivity and Seismic (Weathered Granite IV to V)

2.3.4 Particle shape of soils

The shape of debris found in a soil mass is similarly vital because the particle size distribution as it has a significant impact on the physical properties of a given soil. The particle shape commonly may be divided into three major classes includes bulky, flakey and needle-shaped. Particle shape description may be categorised as qualitative or quantitative. Qualitative describes in terms of words the shape of the particle such as elongated, spherical, flaky, etc while quantitative relates the measured dimensions. In the engineering field, the quantitative description of the particle is more essential because of the reproducibility. Bulky particles are formed typically by the mechanical weathering of rock and minerals. Geologists use such phrases as angular, subangular, subrounded, and rounded to explain the shapes of bulky particles. Small sand particles placed near their origin are usually very angular. Sand particles carried through wind and water for an extended distance may be subangular to rounded in shape. The shape of granular debris in a soil mass has a tremendous influence on the physical properties of the soil, including maximum and minimum void ratio, shear strength, compressibility, etc. There are two mechanisms used in order to classify the particle shape of the soils which are the arrangement of particles and the inter-particle contact. Some of the typical values of soil friction angle for different soil types based on the arrangement of the particle are shown in Table 2.6.

As part of the soil characteristics, the arrangement of the debris can be classified into three types: loose, medium, and dense. Cho et. al., (2006) and Rodiguez. J (2013) concludes that minimum and maximum void ratios growth when sphericity and roundness decrease. Generally, loose, porous soils and those rich in natural matter have decreased the bulk density. Since the overall pore area of sands is less than that of silt or clay soils, they have a comparatively high bulk density. In comparison to sandy soils, finer-textured soils with an adequate structure such as silt and clay loams have more pore space and lower bulk density. Loose soil will settle in volume on shearing, and may not develop any peak strength. In this case, the shear strength will grow progressively until the residual shear strength is revealed, as soon as the soil has ceased contracting in volume. A dense soil may contract slightly earlier than the granular interlock preventing further contraction as the granular interlock is depending on the shape of the grains and their initial packing arrangement. Particle arrangement and interlocking are probably the elements that control the void ratio; the bridge effect allows a void to remain among the debris, while interlocking allows the debris to form arches, preventing rotation and allowing it to stay in a more stable configuration.

TABLE 2.3.4 Typical values of angle of friction for different soil types based on the arrangement of the particle.

NO	**Soil type**	**Porosity**	**Friction angle, (ϕ)**
1	Rounded grains	Loose	27-30
		Medium	30-35
		Dense	35-38
2	Angular grains	Loose	30-35
		Medium	35-40
		Dense	40-45
3	Gravel with some sand		34-48
4	Silts		26-35

2.4 FACTOR OF SAFETY (FOS)

Slope stability analysis is the most fundamental goal is to estimate a safety factor for a probable collapse, such as a landslide. The factor of safety is a fundamental design criterion for slope stability research (FOS). In order to build sensible slopes and account for uncertainty, it is necessary to understand the role of the factor of safety (FOS). Meanwhile, determining the factor of safety is necessary to determine whether the condition of a specific application is long-term or short-term, as well as to determine the accuracy of soil parameters and analytical models, as well as to understand the effects of each design on a specific slope project. Although finite element and finite difference methods are equally effective for determining slope stability, traditional limit equilibrium-based approaches are still widely employed in practice. The Shear Strength Reduction methodology is one of the most frequent approaches for computing the FOS utilising finite difference and finite element analysis. In general, if FOS is greater or equal to 1, it can be said that the slope is in a stable condition. However, if FOS is less than 1, it is usually regarded as unstable.

The finite element method or the limit equilibrium method are commonly used to analyse slope stability. Bishop's Simplified Method, Spencer's Method, and Morgenstern and Price Method are the most commonly used methods in the limit equilibrium framework. The critical slip surface, which is obtained by a random search technique, has the lowest factor of slope safety. In this research, the simplified Bishop method has been used as the approach employs the method of slices. In contrast to typical slice methods, Bishop's method considers normal contact forces between nearby slices to be collinear, resulting in a zero interslice shear force. Imperial College's Alan W. Bishop was the one who came up with the idea. The problem is statically ambiguous due to the limits imposed by normal pressures between slices. As a result, to solve for the factor of safety, iterative processes must be used. According to research, the approach provides a factor of safety statistics that are within a few percent of the proper values and this method is most accurate rather than the others.

In Malaysia, there are several government departments involved in reducing landslide hazard and their consequences, namely the Department of Mineral and Geosciences (DMG), Center of Remote Sensing (MACRES) and the Public Works

Department (PWD). Based on the PWD's recommendations, the FOS for unreinforced slope and embankment on soft ground and also for reinforced slope are 1.2 and 1.5 respectively. Table 2.4 below shows the comparison of FOS requirements based on different references used for the different countries based on the condition highlighted for the slope.

TABLE 2.4 Comparison of FOS requirements based on different references.

References	FOS Requirements
BS 6031	1.3-1.4 for first time slide 1.2 for slide with pre-existing slip surface
JKR Road Works	1.2 for unreinforced slope & embankment on soft ground 1.5 for reinforced slope
Hong Kong Ge-oguide	1.0-1.4 for new slopes depending on risk categories. 1.0-1.2 for existing slope depending on risk categories
NAVFAC DM7.1	1.5 for permanent loading condition 1.15-1.2 for transient load
British National Coal Board 1970	1.5/1.35 (peak/residual strength used) for risky slope 1.25/1.15 (peak/residual strength used) for non-risky slope
Canada, Mines Branch 1972	1.5/1.3 (peak/residual strength used) for risky slope 1.3/1.2 (peak/residual strength used) for non-risky slope

2.4.1 Guidelines for Slope Design

As part of the authority requirement, JKR has been required by the Malaysian government to participate in slope mitigation, research and development, risk management, safety, and planning since 2004. Landslides occurred 42 % of the time in mountainous terrain areas between 1966 and 2003, and more than 90 % of the time in developed sectors such as infrastructure, residential and commercial. As a consequence, JKR has been entrusted to work on slope design and construction, particularly in steep terrain. In the guidelines, JKR also mentioned that slope stability analysis are including establishing design criteria and performing calculations that will be required for all cut, fill especially for natural slopes. In line with that, JKR emphasised the need of cut slopes in residual soils and thoroughly degraded rock. All untreated slopes with a factor of safety greater than 1.3 must have a minimum of 2 m berm width and a maximum of 6 m berm height. When the design is poor, stabilisation solutions can be considered.

CHAPTER 3

METHODOLOGY

3.1 FLOW CHART

Figure 3. 1 below shows the project flow chart. SLOPE/W software using Bishop simpified method was used to carry out the slope stability analyses through parametric studies by varying the slope geometry, water table level and soil properties. The residual soil properties were selected based on the data collected which was presented in the literature review chapter. The ordinary method of slices or Bishop's simplified method can be used for undrained and effective stressed analyses. However, Bishop's method more accurate than the ordinary method of slices and when incorporated into computer programs, it results yield satisfactory in most cases. The Bishop simplified technique solved the vertical forced equilibrium for each slice and the overall moment equilibrium equations around the trial circular surface's centre pointed (Khan & Wang , 2021). This research aims to analyse the critical combination triggering mechanisms of slope failure in residual soil at different conditions.

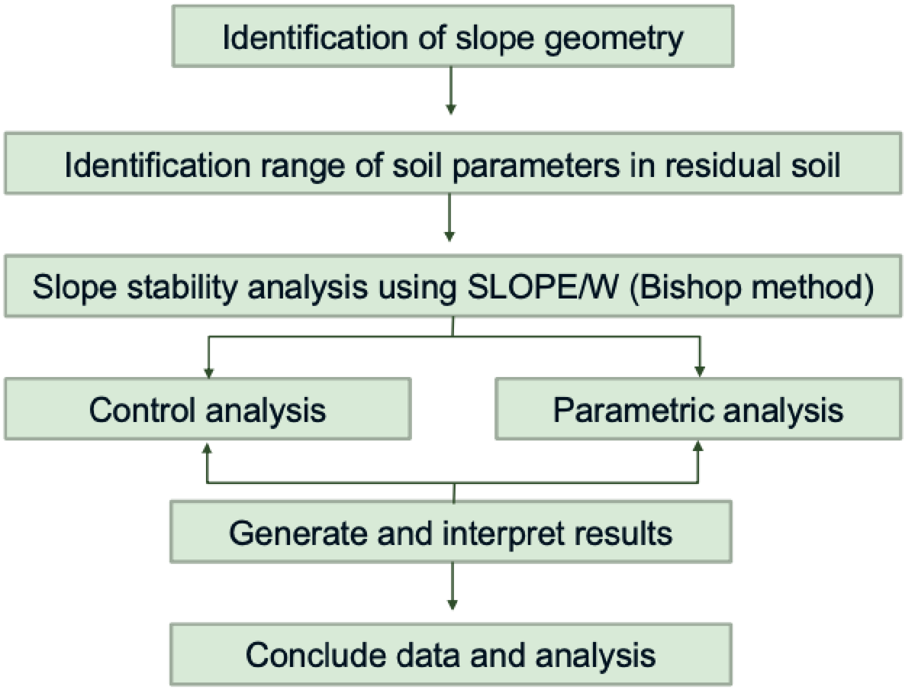

FIGURE 3.2:Project flow chart

3.2 IDENTIFICATION OF SLOPE GEOMETRY

The project aims to study the effect of slope gradient of the residual soil based on the factor of safety and the slope heights of 3 m, 6 m and 10 m corresponding to Set 1, 2 and 3 respectively were selected for the analyses. For set 1, the slope height of 3 m was made constant for every analysis which was divided into three analyses namely 1(a), 1(b), 1(c) and 1(d). However, the slope angles of the slope were varied from 30°, 45°, 60° and 80° and the range of soil parameters have also been varied into three ranges which is low, medium and high indicating the types of weathering. Table 3.2.1 below illustrated the parameters for set 1 analysis conducted by constant the height of slope to 3 m with variations of the soil parameters based on the classification of the residual soil weathering as mentioned above in Chapter 2.1.

Then, these analyses have been repeated for 6 m and 10 m height of the slope with constant slope angle and variations of the height of the slope and also the water table in order to study the effect of the water table on the factor safety of the residual soil slope. The groundwater table was set to 1 m and 2 m below the ground surface. The minimum allowable FOS for this research is taken as 1.0. The analyses were labelled according to the condition of with and without water table shown in Tables 3.2.2, 3.2.3 and 3.2.4.

TABLE 3.2.2: Parameters used for Set 1

Set	Range	Height of the slope	Unit weight (kN/m^3)	Cohesion (c)	Friction angle (Ø)	Slope angle			
						30°	45°	60°	80°
1	Low	3m	12	0	15	/	/	/	/
	Medium		18	8	27	/	/	/	/
	High		25	15	40	/	/	/	/

TABLE 3.2.2: Parameters used for Set 2

Set	Range	Unit weight (kN/m^3)	Cohesion (c)	Friction angle (Ø)	Height of the slope	Slope angle	Water table (m)		
							0	1	2
2	Low	12	0	15	3m	30°	/	/	/
	Medium	18	8	27			/	/	/
	High	25	15	40			/	/	/

TABLE 3.2.3: Parameters used for Set 3

Set	Range	Unit weight (kN/m^3)	Cohesion (c)	Friction angle (∅)	Height of the slope	Slope angle	Water table (m)		
							0	1	2
3	Low	12	0	15	6m	30°	/	/	/
	Medium	18	8	27			/	/	/
	High	25	15	40			/	/	/

TABLE 3.2.4: Parameters used for Set 4

Set	Range	Unit weight (kN/m^3)	Cohesion (c)	Friction angle (∅)	Height of the slope	Slope angle	Water table (m)		
							0	1	2
4	Low	12	0	15	10m	30°	/	/	/
	Medium	18	8	27			/	/	/
	High	25	15	40			/	/	/

3.3 IDENTIFICATION OF THE RANGE OF SOIL PARAMETERS

Table 3.3 is the summary of the selection range of the soil parameters used in the analysis based on the soil parameters data obtained from literature review tabulated in Table 2.1. The range of the soil parameters have been divided into low, medium and high range with most of the soil made of Weathered Granite Grade VI. Prior to conducting the parametric analysis, the slope analysis without the existing water table has been set up for the control analysis in line to evaluate the effect of critical combination soil parameters, pore water pressure and slope gradient of the residual soil in Malaysia to the factor of safety.

3.4 BERM ANALYSIS

Slope stability analysis includes of establishing design criteria required for all cut, fill and natural slopes to reduce the failure of the slope especially for residual soils. From the analyses conducted previously to study the effect of slope geometry based on the slope angle, the height of the residual slope and the soil properties, the effect of berm design on the slope with two slope angles of 30° and 45° marked as Set 5 were also carried out as shown in Table 3.4 below. In these analyses, the berm of 2 m width and 3 m height of berm was considered. For Set 5, the slope height used was 3 m for every range of analysis. The slope angles used were 30° and 45° and also the range of soil parameters were ranging from low, medium and high indicating the types of weathering.

TABLE 3.4: Parameters used for Set 5

Set	Range	Height of the slope	Unit weight (kN/m^3)	Cohesion (c)	Friction angle (Ø)	Width of berm	Slope angle	
							30°	45°
5	Low	3m	12	0	15	2m	/	/
	Medium		18	8	27		/	/
	High		25	15	40		/	/

3.5 SUMMARY OF TESTING PROGRAM

Table 3.5 shows three sets of the analyses performed in these studies to analyse the stability of the remaining slopes under different conditions. The controlled analysis consists of the slope geometry, the height of the slope, the unit weight of the residual soil as well as the friction angle and cohesion of the soil. As mentoned earlier, the height of the slopes varied from 3 to 10 m. These variables were fixed to compare the results of the effect of water table, and berm on the slope. In summary, there were 36 slope analyses were performed by the parametric grouping. Set 1 represents the low range of soil parameters, followed by medium and high range as tabulated in sets 2 and 3, respectively. The gradients of slope vary from the lowest as 30° to the highest which was set to 80°. The minimum allowable FOS for this research is taken as 1.0. The analyses were labelled according to the condition of with water table, without water table and after berm was added. From the parametric analysis, the objective of this project would be achieved in order to study the critical combination triggering mechanisms of slope failure.

TABLE 3.5 Control analysis and parametric analysis for the testing programme.

Range	Analysis	Slope angle (°)	Slope height (m)	Unit weight	Cohesion (*c*)	Friction angle (Ø)	Water Table (WT)		Adding berms
							No WT	Existing WT	
Low	P1	30	3	12	0	15	/	/	/
	P2	45					/	/	/
	P3	60					/	/	/
	P4	80					/	/	/
Medium	P5	30		18	8	27	/	/	/
	P6	45					/	/	/
	P7	60					/	/	/
	P8	80					/	/	/
High	P9	30		25	15	40	/	/	/
	P10	45					/	/	/
	P11	60					/	/	/
	P12	80					/	/	/
Low	P13	30	6	12	0	15	/	/	/
	P14	45					/	/	/
	P15	60					/	/	/
	P16	80					/	/	/
Medium	P17	30		18	8	27	/	/	/
	P18	45					/	/	/
	P19	60					/	/	/
	P20	80					/	/	/
High	P21	30		25	15	40	/	/	/
	P22	45					/	/	/
	P23	60					/	/	/
	P24	80					/	/	/
Low	P25	30	10	12	0	15	/	/	/
	P26	45					/	/	/
	P27	60					/	/	/
	P28	80					/	/	/
Medium	P29	30		18	8	27	/	/	/
	P30	45					/	/	/
	P31	60					/	/	/
	P32	80					/	/	/
High	P33	30		25	15	40	/	/	/
	P34	45					/	/	/
	P35	60					/	/	/
	P36	80					/	/	/

CHAPTER 4

RESULTS AND DISCUSSION

As outlined in the methodology for this research, the factor of safety (FOS) of the residual slope was analysed to study the factors that contributed to the slope failure. Figures 4.1.1 to 4.2.9 show the summary and graph of FOS of the parametric analyses carried out in this project. The detailed explanation of the effects of slope geometry, slope gradient, soil parameters and water table are described in Section 4.1 to 4.3 in this chapter.

4.1 SLOPE GEOMETRY

Table 4.1 and Figures 4.1.1 to 4.1.3 illustrated the factor safety gathered from the parameters for set 1 analysis conducted without water table by constant the height of slope to 3m, 6m and 10m but varied the soil parameters based on the classification of the residual soil weathering as mentioned above in Chapter 2.1.

TABLE 4.1 Parameters used for Set 1

Set 1	Range	Height	Unit weight (kN/m^3)	Cohesion (c)	Friction angle (Ø)	FOS with slope angle			
						30°	45°	60°	80°
a	Low	3m	12	0	15	0.466	0.280	0.269	0.117
	Medium		18	8	27	2.395	1.836	1.435	1.055
	High		25	15	40	3.595	2.725	2.132	1.546
b	Low	6m	12	0	15	0.448	0.269	0.159	0.114
	Medium		18	8	27	1.743	1.307	1.001	0.694
	High		25	15	40	2.679	1.979	1.504	1.028
c	Low	10m	12	0	15	0.448	0.269	0.158	0.111
	Medium		18	8	27	1.522	1.108	0.842	0.569
	High		25	15	40	2.370	1.700	1.275	0.854

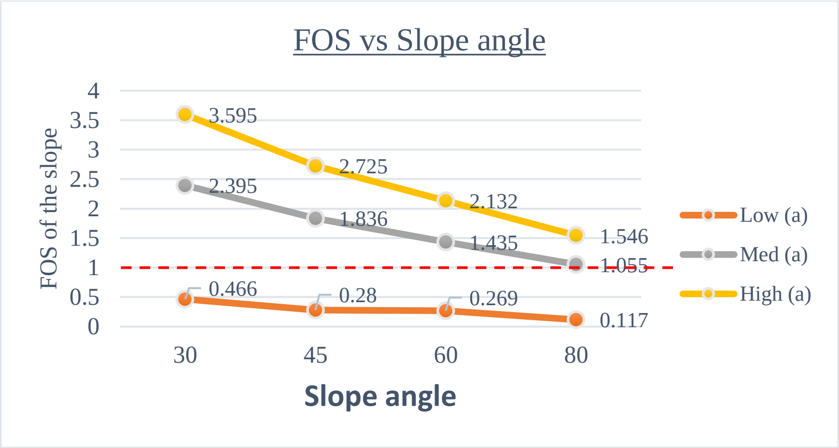

FIGURE 4.1.3 Factor of safety vs the slope angle for set 1 (a)

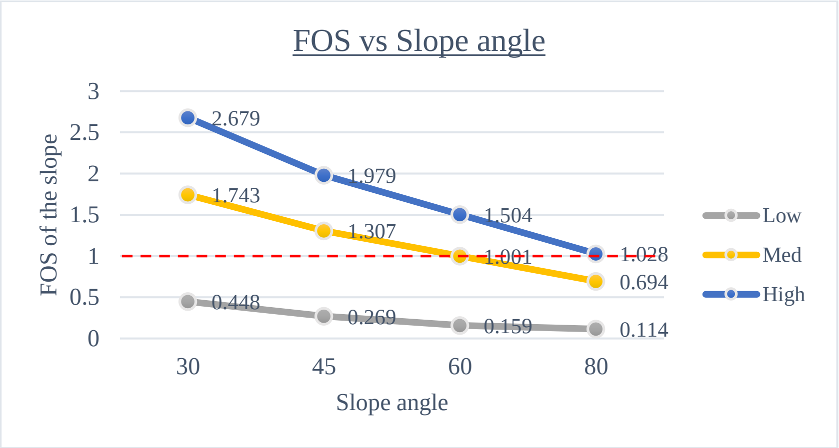

FIGURE 4.1.2 Factor of safety vs the slope angle for set 1 (b)

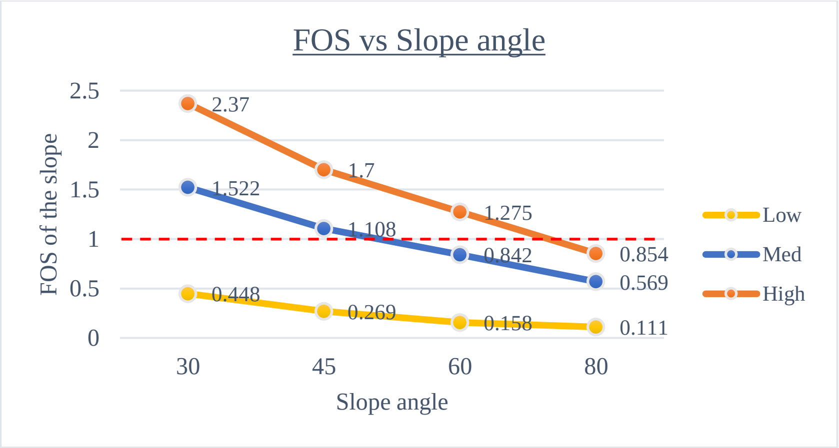

FIGURE 4.1.3 Factor of safety vs the slope angle for set 1 (c)

From Figures 4.1.1 to 4.1.3, the effect of slope geometry can be seen in the reduction of FOS as the gradient of the slope increases. The minimum allowable FOS which is 1.0 is indicated as a red dotted line as the limit of safe factor safety of residual slope. From the figures, all the slopes in the three sets of analyses failed at a condition of low soil parameters despite of slope gradients and the heights of the slopes. This is due to the soil properties for the low range are having low cohesion, friction angle that contributes to the decrease in the shear strength of the soil which lowered the factor safety of the slope. In these three sets of analyses, slope with gradient of 30° is the gentle slope among the others and it can be seen that the slope failure still occurred at this gradient when the soil parameters are at the lowest range. For the parametric studies of this residual soil slope, typically for a 3 m height slope of residual depicted in Figure 4.1.1, the slope at the medium and high range of the soil properties were stable. For a 6 m and 10 m slope heights having medium range of soil parameters, the slope failed at slope gradient 80° and 60°, respectively and may be considered as the critical combination of parameters for these slopes.

4.2 FACTOR OF SAFETY SLOPE WITH VARYING WATER TABLE

The groundwater table is another component that impacts slope stability. According to an analysis of the stability safety factor utilising various slope models, the major effect of the water table on soil slope stability follows a set of rules. Generally, the safety factor decreases as the water table rises. The presence of groundwater diminishes the earth's shear strength because water fills the pores and fractures beneath the water table, generating pressure that tends to cancel out part of the friction and cohesive forces. The factor of safety analysis was tested depending on the slope angle and the height of the slope. The groundwater table was set to 1m and 2 m below the ground surface.

4.2.1 Slope Angle

The analyses were labelled according to the condition of with and without water table which are shown in Figures 4.2.1 to 4.2.3. Set 2 analyses were conducted to study the effect of water table in the slope failure behaviour. The height of the slope is kept constant at 3 m. However, the slope angle and the soil parameters were varied based on the classification of the residual soil weathering. From the analyses, it can be seen that, the lowest FOS was obtained in set 2 (a) which was having the lowest range of soil parameters compared to set 2 (b) and (c). This indicating that, the soil parameters influencing the failure in the slope stability analyses. The trend of value of FOS is reducing as the gradient increases, again indicating the influence of gradient to the slope stability. For set 2 (b), the critical combination of parameters occurred at slope gradient of 80 °. For set 2 (c), all the FOS passed the minimum FOS.

TABLE 4.2.1 Parameters used for Set 2

Set 2	Range	Height	Unit weight (kN/m^3)	Cohesion (c)	Friction angle (∅)	FOS with slope angle			
						30°	45°	60°	80°
a	Low	3m	12	0	15	0.466	0.280	0.269	0.117
b	Medium		18	8	27	2.395	1.836	1.435	1.055
c	High		25	15	40	3.595	2.725	2.132	1.546

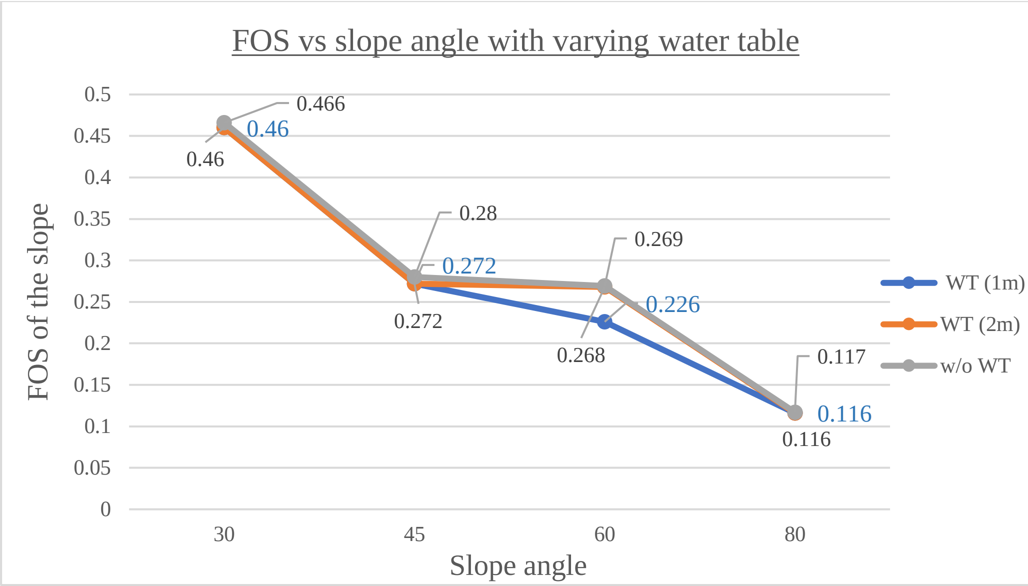

FIGURE 4.2.4 Factor of safety vs the slope angle for set 2 (a)

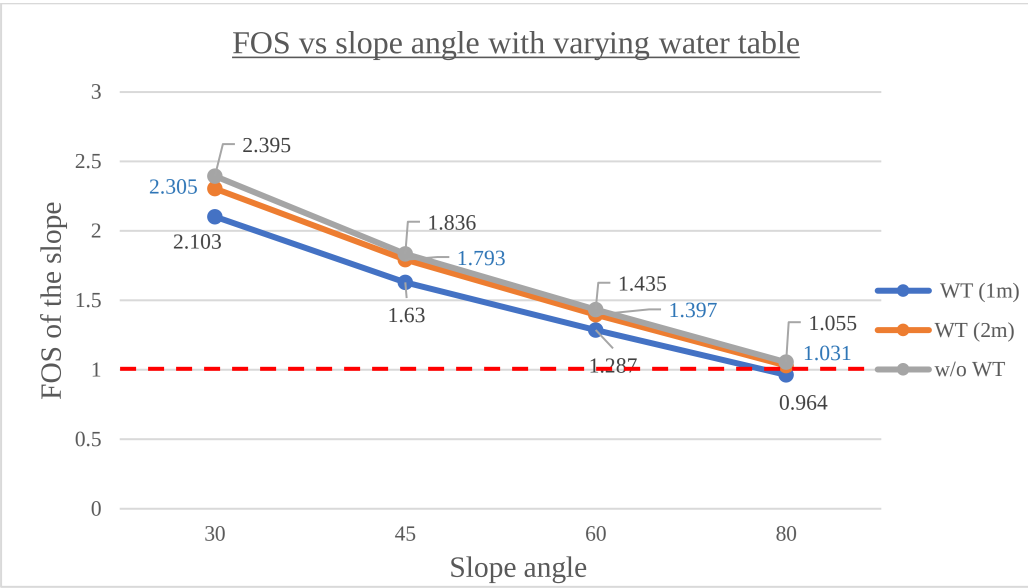

FIGURE 4.2.2 Factor of safety vs the slope angle for set 2 (b)

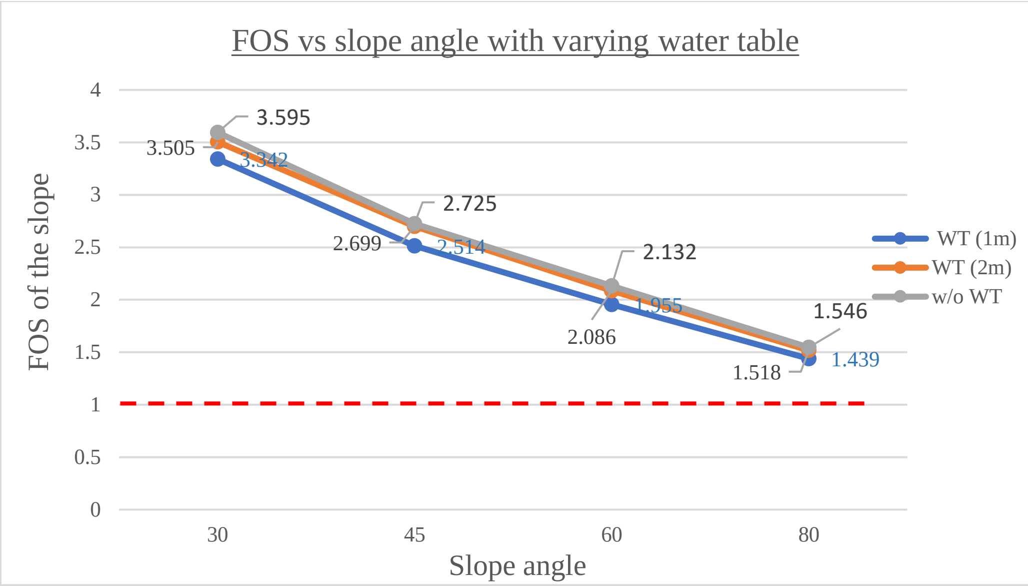

FIGURE 4.2.3 Factor of safety vs the slope angle for set 2 (c)

4.2.2 Height of the Slope

In these analyses, the set 3 analyses were similar to that described in 4.2.1 section, however the slope angle of 30° was kept constant, and the analyses were further carried out for the height of slope of 6 m and 10 m.

TABLE 4.2.2 Parameters used for Set 3

Set 3	Range	Unit weight (kN/m^3)	Cohesion (c)	Friction angle (Ø)	Slope height	Slope angle	Water table (m)		
							0	1	2
a	Low	12	0	15	3m	30°	0.466	0.460	0.460
	Medium	18	8	27			2.395	2.103	2.305
	High	25	15	40			3.595	3.342	3.505
b	Low	12	0	15	6m	30°	0.448	0.278	0.378
	Medium	18	8	27			1.743	1.313	1.448
	High	25	15	40			2.679	2.204	2.370
c	Low	12	0	15	10m	30°	0.448	0.203	0.278
	Medium	18	8	27			1.522	1.025	1.126
	High	25	15	40			2.370	1.807	2.060

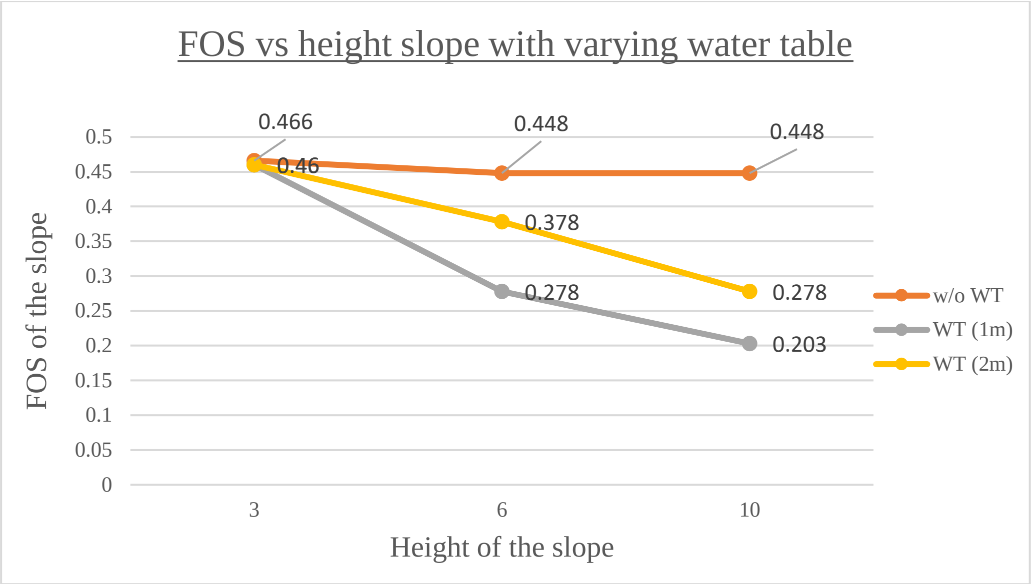

FIGURE 4.2.4 Factor of safety vs the slope angle for set 3 with lowest soil parameters

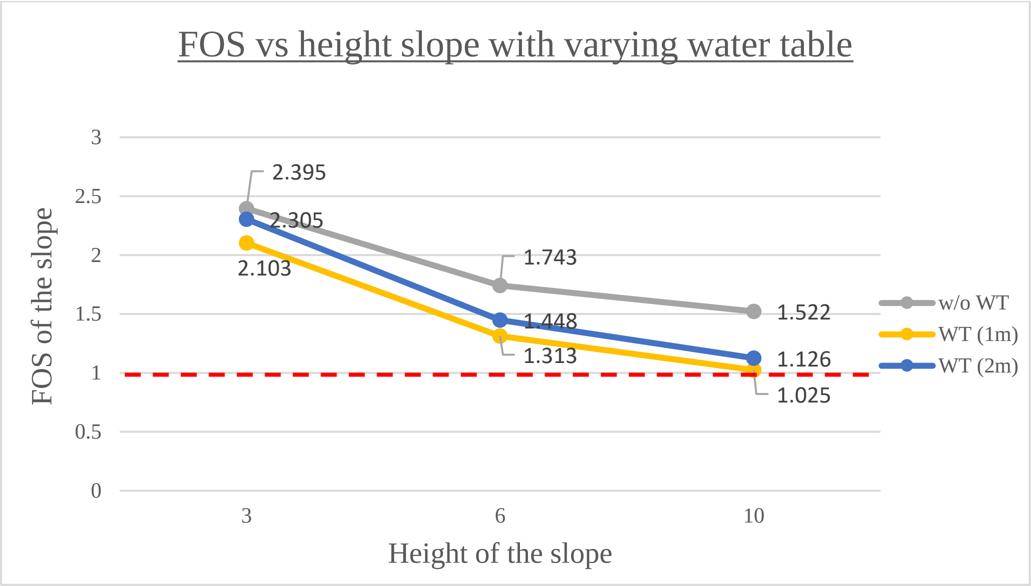

FIGURE 4.2.5 Factor of safety vs the slope angle for set 3 with medium soil parameters

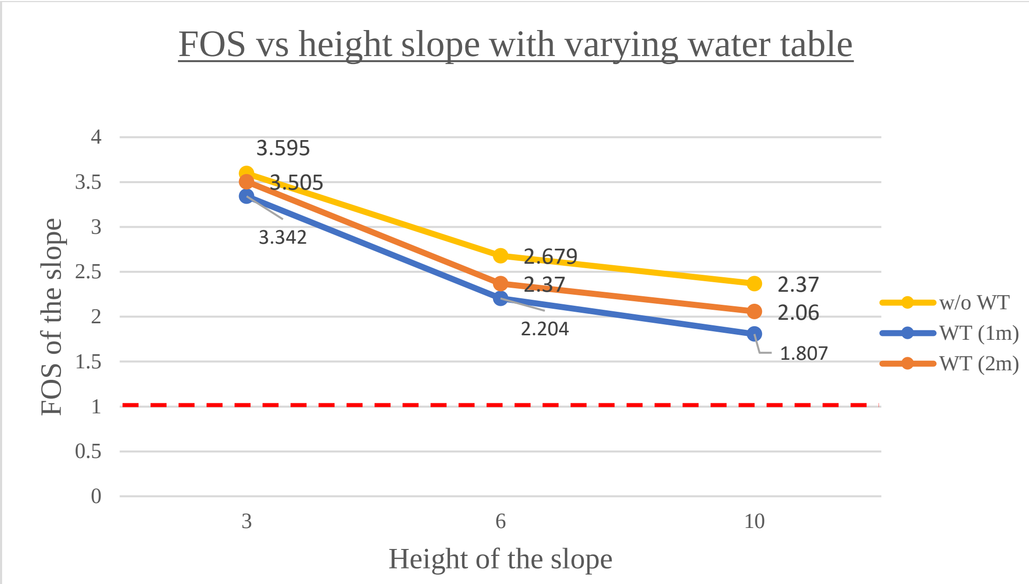

FIGURE 4.2.6 Factor of safety vs the slope angle for set 3 with highest soil parameters

In general, the factor of safety decreases linearly as the water table increases as shown in Figures 4.2.4 to 4.2.6. This is due to the existing water table, causing pressure that tends to cancel out some of the friction and cohesive forces and also reduces the shear strength of the soil. The results also showed that the critical combination of parameters that contributed to the failure of FOS was found when the soil parameters were in the lowest range despite of the heights of the slopes which is shown in Figure 4.2.4.

4.3 BERM ANALYSIS

The effect of berm on the slope at two slope angles of 30° and 45° were also studied and the results are shown in Table 4.3 below. For set 4, the slope height is kept constant at 3 m and the width of the berm is kept at 2 m for every range of analysis. In this analysis, the water table is not considered. Set 4 (a) analysis indicated the slope before adding the berm while (b) were the slope after the berm was added as shown in Figures 4.2.7 to 4.2.9.

TABLE 4.3 Parameters used for Set 4

Set 4	Range	Slope height	Unit weight (kN /m^3)	Cohesion (c)	Friction angle (Ø)	Width of berm	Slope angle	
							30°	45°
Without Berm	Low	3m	12	0	15	2m	0.466	0.280
	Medium		18	8	27		2.395	1.836
	High		25	15	40		3.595	2.725
Added Berm	Low	3m	12	0	15	2m	0.605	0.413
	Medium		18	8	27		2.672	2.062
	High		25	15	40		4.039	3.077
Without Berm	Low	6m	12	0	15	2m	0.448	0.269
	Medium		18	8	27		1.743	1.307
	High		25	15	40		2.679	1.979
Added Berm	Low	6m	12	0	15	2m	0.566	0.335
	Medium		18	8	27		1.954	1.387
	High		25	15	40		3.005	2.109
Without Berm	Low	10m	12	0	15	2m	0.448	0.269
	Medium		18	8	27		1.522	1.108
	High		25	15	40		2.370	1.700
Added Berm	Low	10m	12	0	15	2m	0.525	0.329
	Medium		18	8	27		1.666	1.177
	High		25	15	40		2.580	1.813

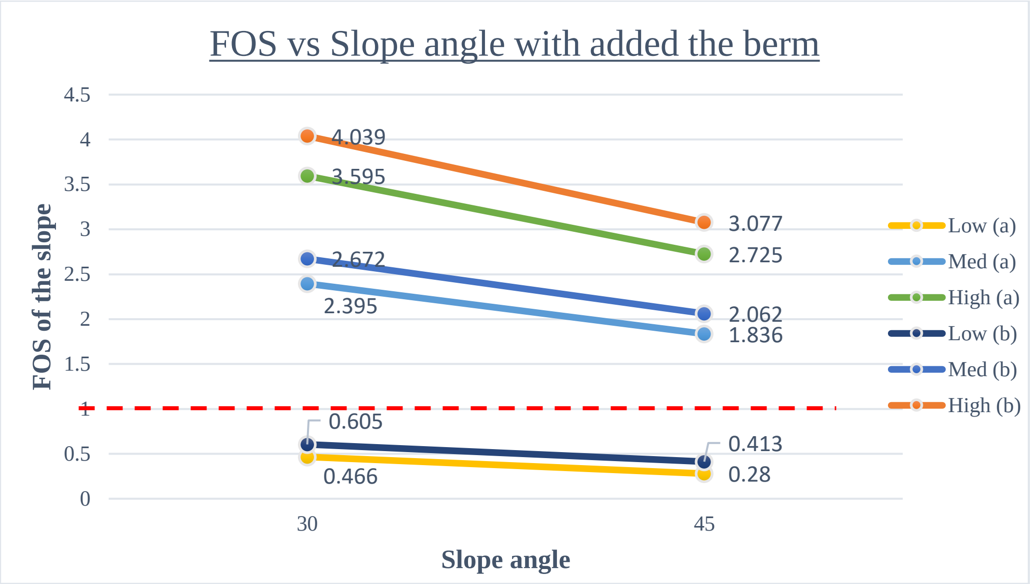

FIGURE 4.2.7 Factor of safety vs the slope angle for 3m slope height

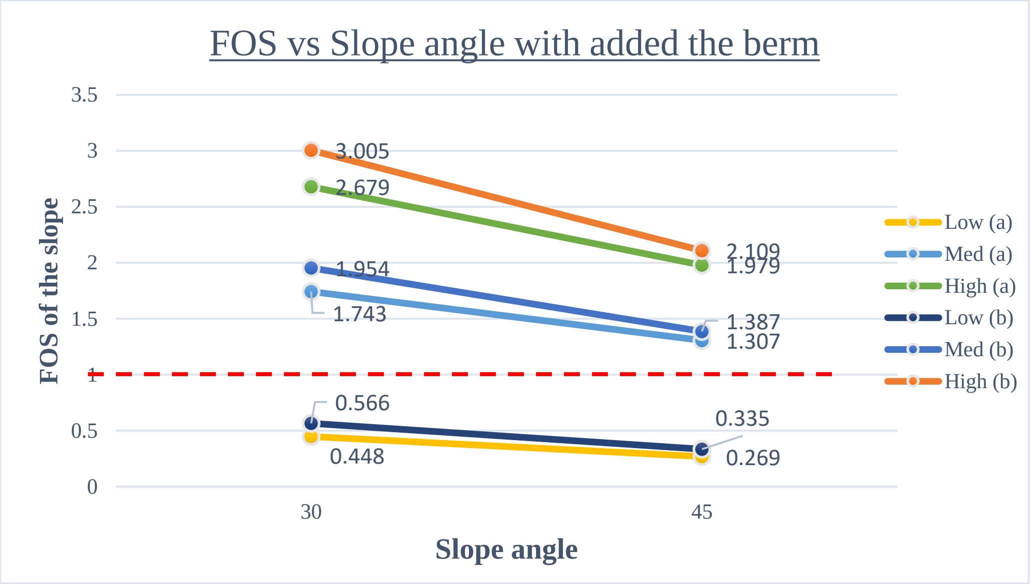

FIGURE 4.2.8 Factor of safety vs the slope angle for 6m slope height

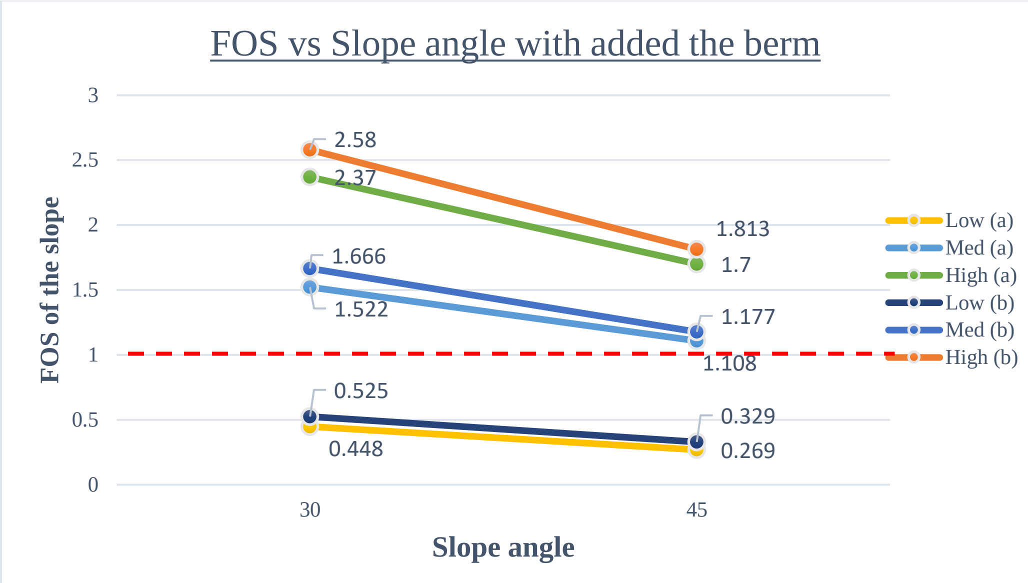

FIGURE 4.2.9 Factor of safety vs the slope angle for 10 m slope height

The analysis conducted for Set 4 as shown in Figures 4.2.7 to 4.2.9 between the original slopes were compared to the slope with berm as the slope stabilisation technique. In general, it can be seen that by adding the berm, the FOS increases. However, for the slope of 3 m height, despite of adding the berm, the FOS yielded failure. This is shown that the soil properties influenced the factor safety of the slope as it decreases the shear strength of the slope itself as shown by the low range in the figure.

CHAPTER 5

CONCLUSION

In conclusion, the parametric studies shown that in general, the slope angle, the height of the slope, water table existing are the factors that influenced the residual slope stability. It is difficult to order the importance of the factors to one another. However, from the analyses carried out, albeit the slope heights and the slope gradients, the soil parameters seemed to influence the slope failure in this study. Despite of all these essential factors contributing to the slope failure in residual soils, the slope failed when it is having the critical combination of these factors which was discussed in Chapter 4. The stability of a slope is an important consideration in the development and construction of infrastructure, residential and commercial round that area. The use of a berm is proven as one of the techniques that may be employed to improve the slope's performance depending on the slope angle and must fulfil the requirement highlighted by JKR regarding the slope design. Slope stability investigation utilizing geotechnical software allows an in-depth understanding of the physical characteristics of the subsurface factors which influence slope stability. In general, this analysis is used to evaluate the safe design of man-made or natural slopes, as well as to investigate potential failure mechanisms of the slope based on the slope sensitivity for various triggering mechanisms. The effect of varying the variable of the factor influence to the slope stability could be understood and studied through this project. The findings of this project could be used for future preliminary designing of the slope in residual soil as the software analysis presented the factor of safety of the slope. As a result, for a safe and cost-effective building design, a comprehensive assessment of the geotechnical characteristics of residual soils is essential.

CHAPTER 6

RECOMMENDATION

In light of the early discoveries, it is suggested that different attributes, like more vulnerable soil properties and different slope geometry, be considered as contextual analyses and comparisons of failure mechanisms later on. Since there are different vulnerabilities for geotechnical hardships, FOS is not the only data required as an indicator to evaluate the slope stability. Accordingly, the FOS results ought to be twofold checked and contrasted with the slope stability risk and unwavering quality analysis. An essential comprehension of slope stability, just as the plan approach and technique, would help the creator in a future review. Due to the ease of building approach, the FHWA 1998 and FHWA 2003-IF-03-017 guides are suggested for Malaysian slopes practices. Moreover, the FHWA suggests the "slip surface" strategy, which might be handily executed in genuine circumstances utilising a slope stability analysis program.

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