MODELLING POST-FIRE EROSION ON NATURAL SLOPE CONTAINING NESOSILICATE MINERALS

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Moses asked his Lord:
Who are the most knowledgeable of your servants?
Allah said:
A scholar who is unsatisfied with his knowledge and adds the knowledge of people to his own.
Source: Ṣaḥiḥ Ibn Ḥibban 6352, Grade: Hasan

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In the name of Allah, the Most Gracious and the Most Merciful. “Surely, Allah is with those who are As-Saabiroon (the patient)”. First praise is to Allah, the Almighty, on whom ultimately we depend for sustenance and guidance.

Second, Selawat and Salam always dedicated to our beloved prophet Muhammad SAW, the last prophet and the prophet who had brought us from the darkness to the brightness.

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ABSTRAK

Pasca-kebakaran menyebabkan hakisan dan larian permukaan menjadi semakin meningkat. Kesannya menjadi semakin meningkat apabila melibatkan magnitud intensiti hujan yang tinggi semasa musim hujan yang berpanjangan. Dengan kejadian hujan lebat yang melebihi kapasiti simpanan, kadar hakisan biasanya meningkat dengan ketara disebabkan oleh pemusnahan lapisan tumbuhan, ketersediaan bahan yang mudah hakis dan perubahan dalam sifat fizikal dan hidrologi tanah, menyebabkan peningkatan air larian dan penurunan dalam kekuatan permukaan tanah yang meningkatkan ketertanggalan dan pengangkutan endapan. Dalam kajian ini, pelbagai sifat tanah termasuk graviti tentu, had atterberg, indeks pengembangan dan kandungan bahan organik telah dipelajari. Lengkung ciri tanah-air bagi semua sampel juga ditentukan. Untuk tujuan kajian ini, kandungan lembapan diperolehi untuk sampel tanah yang terbakar dan tidak terbakar dikaji melalui teknik titik embun sejuk cermin. Analisis kestabilan cerun dilakukan dengan menggunakan perisian GeoStudio menggunakan SLOPE / W berdasarkan lengkung ciri tanah-air yang dihasilkan. Parameter kekuatan ricih diperoleh dan digunakan untuk analisis kestabilan dengan perisian SLOPE / W. Keputusan eksperimen menunjukkan bahawa pada suhu 440°C, had cecair, kandungan bahan organik dan lengkung ciri tanah-air berlaku pengurangan dan indeks pengembangan terhapus. Pemanasan tanah pada 800°C dan 1350°C telah menghapuskan had cecair, had plastik, potensi pengembangan dan kandungan organik tanah yang telah diuji. Berdasarkan hasil kajian, FOS berada pada tahap rendah atau kritikal adalah pada tanah terbakar semula jadi dan tanah terbakar 1350 °C berbanding tanah tidak terbakar, terbakar 440°C dan terbakar 800°C. Dari keseluruhan kajian, kajian pemodelan ini mendapati bahawa tanah yang mengandungi mineral kyanit dan mineral kuarza berada pada tahap cerun yang stabil manakala jenis tanah mineral andalusit dan mineral mulit ditunjukkan kestabilan yang kurang stabil. Keputusan membuktikan perlunya mengambil kandungan lembapan untuk menyatakan hakisan pasca-kebakaran apabila memproses analisis kestabilan untuk mencapai cerun yang boleh dipercayai dan selamat.

ABSTRACT

Post-fire increased hillslopes erosion and surface runoff. The effect increased by several magnitude when subjected to high intensity of precipitation during prolonged rainy season. With large rainfall events that exceed the storage capacity, erosion rates usually increase markedly due to destruction of the vegetation layer, the availability of highly erodible material and any changes in soil physical and hydrological properties, leading to an increase in runoff and a decrease in the strength of the soil surface that increases the detachability and transportation of sediment. In this study, various soil properties including specific gravity, atterberg limit, swell index and organic matter content were studied. The soil-water retention curve (SWCC) of all samples were also determined. For the purpose of this study, the moisture content were obtained for unburned and burned soil through chilled-mirror dew point technique test. The slope stability analysis were conducted by using GeoStudio software by SLOPE/W based on SWCC resulted. Parameters of shear strength were obtained and used for stability analysis with SLOPE/W software. Experimental result demonstrated that temperature 440°C, the liquid limit, organic matter content and SWCC were reduced and the swell index was eliminated. Heating the soil at 800°C and 1350°C completely eliminated the liquid limit, plastic limit, swell potential and organic content of soil tested. Based on the findings study, the lowest FOS or critical failure was natural burned sample. Followed by sample of burned 1350°C which also had a low value of FOS compared to natural unburned, burned 440°C and burned 800°C. From overall study, this modelling study examined that soil containing kyanite and quartz minerals are at a stable slope level whereas andalusite and mullite mineral soil types was shown a stability of less stable. Results proved the necessity of taking moisture content into account to express the post-fire erosion when processing stability analyses in order to achieve reliable and safe slope.

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LIST OF SYMBOLS

Fs	Free Swell
Gs	Specific Gravity
M_A	Mass of Crucible and Soil Sample After Ignition
M_C	Mass of Crucible
M_S	Mass of Crucible and Oven Dried Soil Sample
V_0	Volume of Dry Soil
V_1	Soil Volume After Swelling
FOS	Factor of Safety

LIST OF ABBREVIATIONS

ASTM	American Society for Testing Material
BS	British Standard
FS	Free Swell
SWCC	Soil-Water Characteristic Curve
FOS	Factor of Safety

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Global temperature has increased ≈ 0.2°C per decade in the past 30 years, similar to the warming rate predicted in the 1980s in initial global climate model simulations with transient greenhouse gas changes (Hansen et al., 2006). The continued rise in greenhouse gas emissions in the past decade and the delays in a comprehensive global emissions reduction agreement have made achieving this target extremely difficult, arguably impossible, raising the likelihood of global temperature rises 3°C or 4°C within century (New et al., 2011). Furthermore, due to climate change temperatures have been increasingly globally. This climate change is projected to continue and increased by 1.4 – 5.8°C (Haines et al., 2005).

More intense, more frequent, and longer heat-wave are expected in the future due to global warming, which could have dramatic ecological impacts (Wang et al., 2017). This condition of prolonged heat will lead to El Nino occurrence. High temperatures also common during El Nino events, had an independent negative effect on breeding success and might have partly offset the positive effects of high rainfall (Holmgren et al., 2001). The climatic regime determines the vegetation in a region and hence, plays a dominant role in creating fire prone areas. The drier the climate is in a particular region, the more fire prone the site will be. The study area has a dry subtropical climatic regime, making it vulnerable to forest fires (Jaiswal et al., 2002). A study researched by (Rees & Ali, 2012) stated that, the presence of vegetation increased slope stability by about 8%. Plant growth and development on slopes under favourable environmental conditions can also provide long-term mitigation measures for soil protection (Cao, 2006). In other words, in absence of vegetation and factor that Malaysia through changes in monsoon season between August and November, it will lead to direct contact of precipitation on burned or dried slopes and cause to erosion and surface runoff.

Climate change is projected to cause increases in wildfire activity in this region (Hushaw, 2016). Although an entirely natural and essential agent responsible for shaping vegetation dynamics in fire-prone environments, wildfire is also frequently regarded as a major agent of soil erosion and land degradation (Trabaud, 2002). Post-fire intense rainfall events typically increase soil erosion to many times that experienced during pre-burn conditions or that experienced in similar unburned sites (Ferreira et al., 2008). With large rainfall events that exceed the storage capacity of an ash layer if present, erosion rates usually increase markedly due to destruction of the vegetation layer, the availability of highly erodible material and any changes in soil physical and hydrological properties, leading to an increase in runoff and a decrease in the strength of the soil surface that increases the detachability and transportation of sediment (Lloret et al., 2009)

Fire affects both soil chemical properties and nutrient availability. Soil properties most affected by burning are organic matter, pH, cation exchange capacity, nitrogen, sulphur, divalent cations and potassium. When organic matter is destroyed by fire, plant nutrients are released and become highly available for plant growth or loss by erosion (Debano et al., 1979). Many physical, chemical, mineralogical, and biological soil properties can be affected by forest fires. The effects are chiefly a result of burn severity, which consists of peak temperatures and duration of the fire (Certini, 2003). The spatial distribution of soil properties within a soil profile determine to a large extent, the magnitude of change occurring in a particular soil property during a fire. For example, those soil properties located on or near, the soil surface are more likely to be changed by fire because they are directly exposed to surface heating (Debano et al., 1979)

Temperature profiles in the organic horizons and the mineral soil depend on the intensity of the fire, fuel loads, duration of the burning, and antecedent soil moisture. With low-severity soil heating, mineral soil temperatures typically do not exceed 100°C at the surface and 50°C at 5 cm depth. However, where severe soil heating occurs (e.g. underneath slash accumulations, slow-moving fires, etc), temperatures can be nearly

700°C at the soil surface, yet can reach temperatures >250°C at a depth of 10 cm, and exceed 100°C as far as 22 cm belowground surface (Daniel et al., 1999)

The deterministic analysis of slope stability basically involves the calculation of the factor of safety for trial slip surface and the search for a slip surface with the critical for minimum factor of safety. The factor of safety calculation can be based on wide range of methods such as the Bishop's modified method, Morgenstern and Price's, Spencer's and the two edge method dependent on the likely mode of slope failure and the user's option (Nguyen et al., 1985). The risk of slope failures and erosion is enhanced when the vegetation cover is removed. The stability of slopes is governed by load which is the driving force that causes failure and the resistance which is the strength of the soil root system (Morgon et al., 1995). SLOPE/W has been designed and developed to be a general software tool for the stability analysis earth structures. This study aims to determine the effect of fire on the properties of unburned and burned soil and at the same time the effects of erosion on the changes visible through the factor of safety that is computed by using SLOPE/W software.

1.2 Problem Statement

Slope stability is challenging task due to the global warming trend is increasing and expected to continuously which will increase the frequency, duration, and intensity of extreme weather, wildfires and rainfall events which allowed to cause of slope failure or landslide. There is no exception for slope along the highway which has been experiences deep excavation are very vulnerable to slope failure, an engineer need to make sure the design was totally safe for the consumers. Thus the sample from Jalan Gambang, Kuantan were collect to analyse the factor of safety of unburned and burned soil for that slope to define the effect of slope erosion caused by wildfire on the stabilization of the slope.

1.3 Research Objective

The objective of this research were as follows: (i) To determine the effect of fire on the properties of unburned and burned soil (ii) To measure parameter shear strength of the unburned and burned soil for making a simulation model of factor of safety unburned and burned soil for slope at Jalan Gambang, Kuantan using SLOPE/W software (iii) To study the effect of soil erosion on the changes in factor of safety value for unburned and burned soil at Jalan Gambang, Kuantan.

1.4 Scope of Study

The study focuses on the use of SLOPE/W by GeoStudio to analyse the factor of safety for unburned and burned soil on slope of Jalan Gambang, Kuantan. Several laboratory test should be conducted to obtain geotechnical soil properties and soil parameters required to implement the software based on unburned soil and burned soil at 440°C, 800°C and 1350°C. The soil-water retention curve (SWCC) of all sample also determined to obtain the moisture content of each sample. The minimum value of factor of safety will be computed or calculated by the software using data parameters based on the moisture content obtained from laboratory tests. From the result of factor of safety computed by SLOPE/W software, then an analysis should be conduct on the effect of soil erosion unburned and burned soil based on the difference value of factor of safety against moisture content of soil conditions.

1.5 Significance of Research

The understanding towards geotechnical engineers especially in slope stability can help civil engineers and geologist when enters the site. Civil engineers must able to understand and analyse the stability of slope that are affected the wildfire event in order to provide the better construction industry in future without harmful aspects. The factor of safety will shows the stabilization of the slope require an understanding and evaluation of the process that govern the behaviour of slope. Fail to deal with slope behaviour will leads to serious matter. Better understanding of the slope including the type of soil and even the factor can affect the soil strengthen is require to offer the suitable analysis to counter the slope problem.

1.6 Thesis Outline

The thesis are divided into five specific chapters to completing of this research study.

Chapter 2 describes comprehensively on climate change in Malaysia and the effects of fire on physical properties and its affect to slope erosion. In this chapter also contains an analysis of previous studies focused on the effect of fire on the physical properties, shear strength, slope erosion and slope stability for modelling the post-fire erosion on natural slope.

Chapter 3 presents the research methodology that needs to be carried out as to achieve three objectives set out in particular on physical properties, the water content and soil suction relationship, slope measurement for obtaining slope geometry, parameter of soil shear strength and a method for modelling the slope using GeoStudio software by SLOPE/W. It this chapter, it has a detailed description of methodology of each test.

Chapter 4 presents the results for each test conducted on physical and chemical properties, drying suction-water content (SWCC) and parameter of soil shear strength. The slope model by SLOPE/W for burned and unburned also presented in this chapter.

Chapter 5 declare the conclusion of the effect of soil erosion on the changes in factor of safety value for unburned and burned soil at Jalan Gambang, Kuantan. Model of slope for burned and unburned soil by SLOPE/W discussed and compared in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter were discussed the previous research related to burned soil. In particular, the effects of fire on the burned soil and that have an impact to soil erosion has been focused. The method analyses the factor of safety of slope using SLOPE / W also reviewed in this chapter.

2.2 Climate Change

Climate events have received increased attention in the last few years, due to the often large loss of human life and exponentially increasing costs associated with them (Karl et al., 1999). Climate is defined as long-term weather patterns that depict a region while global climate change refers to a change in either the average state of the climate or in its variability, persisting for several decades or longer. Climate change would also affect the patterns of rainfall and other precipitation, with some areas getting more and others less, changing global patterns and occurrences of droughts and floods (Karl et al., 1997). This includes changes in average weather conditions on land, which are changes in average global temperature and changes in how frequently regions experience heat waves, droughts, rising tides, storms etc. (Masih, 2010). Climatologists are confident that over the past century, the global average temperature has increased by about half a degree Celsius. This warming is thought to be at least partly the result of human activity, such as the burning of fossil fuels in electric power plants and automobiles. In the past three decades, globe temperature has increased 0.6°C but in the past century, it has increased to 0.8°C (Hansen et al., 2006). It is clear from the observed record that there has been an increase in the global mean temperature of about 0.6ºC since the start of the 20th century (Easterling, 2000).

From (Tangang et al., 2007) research study, it is found that during the last 42 years from 1961 to 2002, surface temperatures in most regions in Malaysia showed significant warming trends. Malaysia shows warming trend in the annual mean temperature with increasing 0.04°C every year (Quadir et al., 2004). Peninsular Malaysia and Northern Borneo showed warming trends of between 2.7°C-4.0°C/100 years. South-western Borneo showed either lower or insignificant warming rates. Kuching and Bintulu showed comparatively lower rates of between 1.0°C-1.5°C/100 years while Miri was showing no significant warming or cooling trend (Tangang et al., 2007). Moreover, because populations, national economies and the use of technology are all growing, the global average temperature is expected to continue increasing, by an additional 1.0 to 3.5 degrees C by the year 2100 (Karl et al., 1997).

2.3 Forest Fire

There is a strong link between fire and climate and this interest and relationship has be heightened with discussion concerning global warming. It is clear that climate is likely to be a major driver of fire especially catastrophic fire (Cerda et al., 2009). As the global temperature increase with no increasing in rainfall amount will lead to a much drier forest and make fire ignition occur easier (Wotton et al., 1993). The impact of fires on nematode diversity, abundance and biomass was assessed in 20 burnt forests and 20 adjacent control plots across a 3000-km-long north-south transect in European Russia. The transect covered five main forest types (Mediterranean and broadleaved forests, southern, middle, and northern taiga) (Butenko et al., 2017). Forest fires tend to be more severe when temperature is high and air humidity and fuel moisture are low (Nol et al., 2017).

In 2011, wildfires in the southcentral U.S. presented a higher potential and complexity than had been observed in recent history (Stambaugh et al., 2017). Within Southeast Asia and Latin America, out-of-control fires burned more than 20 million hectares in 1997–1998. This is equivalent to half of California and is far from a complete accounting of unintentional burning in the tropics, because burning in many regions has not been well measured. The fire season of 2000 was one of the toughest on record in the United States, with about 3.4 million hectares burned. While in 1997–1998, Indonesia was faced with 8 million hectares of burning. The story is similar across the tropics: 3 million hectares burned in Bolivia, 2.5 million hectares burned throughout Central America, and in Brazil, 5 million hectares burned in a single Amazonian state (Cochrane, 2003). From source of National Interagency Fire Center by period of 2002 – 2015, the area, number, and behaviour of wildfires such as crown fire in conifer and deciduous forests were somewhat unanticipated with areas burned being the highest in Texas (11,018 km2) and Oklahoma (1187 km2) since at least 2002. The phenomenon of forest fires become a new creation in Malaysia but it should be emphasized because of the rising concern problem of forest fires. Nevertheless, the problem of forest fires seems to be increasing and recurring periodically. In terms of the numbers of hectares affected by fire, the figure for 1997 was the worst since 1992 (Setiawan et al., 2004).

The causes of the forest fires can be classified into three main categories (i) natural causes, (ii) intentionally/deliberately caused by man and (iii) unintentionally/accidentally caused by man (Jaiswal et al., 2002). Fire is classified into three criteria according to its severity. The fire is classified as low severity burn if less than two percent of the area is severely burned. The area is classified as moderate severity burned if less than ten percent of the area is severely burned while it is classified as high severity burned if the severely burned area is more than ten percent. Many physical, chemical, mineralogical and biological soil properties can be affected by forest fire. The effects are chiefly a result of burn severity which consist of peak temperatures and duration of the fire. Climate, vegetation, and topography of the burnt area control the resilience of the soil system; some fire-induced changes can even be permanent. Low to moderate severity fires, such as most of those prescribed in forest management, promote renovation of the dominant vegetation through elimination of undesired species and transient increase of pH and available nutrients (Certini, 2005).

2.3.1 Effect of Fire on Soil Properties

Many physical, chemical, mineralogical and biological soil properties can be affected by forest fires. The effects are chiefly a result of burn severity, which consists of peak temperatures and duration of fires. Climate, vegetation, and topography of the brunt area control the resilience of the soil system, some fire-induced changes can even be permanent (Certini, 2005). Fire significantly affects soil properties because organic matter (OM) located on or near, the soil surface is rapidly combusted. The changes in organic matter (OM), in turn affect several chemical, physical and microbiological properties of the underlying soils (Debano, 1990).

Soil properties can experience short-term, long-term, or permanent-fire induced changes, depending chiefly on type of property, severity and frequency of firs, and post-fire climatic conditions (Certini, 2005). Severely burned forest will have 1-8 cm thick reddened layer result from Fe oxide transformation and nearly complete removal of organic matter. The underlying layer was a blackened layer with thickness of 1-15 cm formed as result of charring (Ulery et al., 1991).

Fire has also enhanced the hydrophobicity of the soil, which reduce the ability of soil to soak up water and increase the probability for soil erosion. Severe fires, for example wild fires, cause removal of organic matter, deterioration of both structure and porosity, loss of nutrients, ash entrapment in smoke columns, leaching and erosion, and alteration of both quantity and specific composition of the microbial and soil-dwelling invertebrate communities (Certini, 2005).

Sensitive soil properties are those that are changed at temperatures less than 100°C. Examples of sensitive materials are living microorganisms, plant roots, and seeds. Moderately sensitive soil properties which are sulphur, organic matter and soil properties dependent upon organic matter changed at temperatures between 100 and 400°C. Losses of organic matter can occur at temperatures below 100°C. Volatile constituents in organic matter are lost at temperatures up to 200°C. Destructive distillation destroys about 85% of the soil organic matter at temperatures between 200 and 300°C. Above 300°C, the greater part of the residual organic matter consists of carbonaceous material finally lost upon ignition. Heating the soil to 450°C for 2 hours, or to 500°C for half an hour destroys about 99% of the organic matter. Relatively insensitive soil properties includes clays, calcium, magnesium, potassium and other minerals do not change until temperatures have reached over about 450 °C. The most sensitive textural fraction is clay, which begins changing at soil temperatures of about 400 °C when clay hydration and clay lattice structure begin to collapse. At temperatures of 700 to 800 °C, the complete destruction of internal clay structure can occur.

However, sand and silt are primarily quartz particles that have a melting point of 1,414 °C. Temperature in the forest floor can easily reach 600 °C or higher during burning (Beyers, et al., 2005).

The most intuitive change soils experience during burning is the loss of organic matter includes in Table 2.1.

Table 2.1 Soil properties modifiable by fires

Physical, physico-chemical, and mineralogical properties
Water repellence
Structural stability
Bulk density
pH
Particle-size distribution
Mineralogical assemblage
Colour temperature regime
Chemical Properties
Quality of organic matter
Quality of organic mater
Availability of nutrients
Exchangeable capacity
Base saturation
Biological properties

Source: (Certini, 2005)

In a work by (Abu-Zreig et al., 2001) revealed that temperature had a significant effect on soil physical properties. However, the relative change in these properties was higher when temperature ranged from 100 to 300 °C. Soils were generally not affected by temperatures below 100 °C. At 400 °C, the average liquid limit were decreased by 80%. However, at 400 °C, plastic limits were completely eliminated for all soils tested. The liquid limit decreases very rapidly with the temperature in the interval of 100 and 300 °C, while it decreases very slowly between 300 and 1000 °C. The plastic limit decreases rapidly with the temperature in the interval of 100 and 300 °C. Starting from 400 °C to higher temperatures, the clays show non-plastically behaviour.

2.3.2 Effect of Fire on Slope Erosion

Soil erosion is the removal of soil by wind, water and ice. Soil erosion by water involves the detachment, transportation by flowing water and the subsequent deposition of soil particles. Soil particles are detached by rainfall impact on bare ground and runoff tractive forces (forces per unit area exerted by the flow of water over the soil). Runoff occurs whenever the rainfall intensity is greater than the infiltration rate of the soil (Goh et al., 2006).

Fire changes forest ecosystems causing major effects on geomorphic processes. A comprehensive knowledge of the process and response of the environment is still poorly understood, even in long-term monitored areas like Yellowstone Park in the United States (Christensen et al., 1989). The burning of the vegetational cover generally leads to an increase in the runoff and sediment yield rates (Inbar et al., 1998). In the mediterranean climate type, fire impacts depends on local factors like fire history, ecological conditions and management practicesn (Naveh, 1974). Report studies on hillslopes indicate that fire increases runoff and sediment yiled rates relative to undisturbed forested land (Ahlgren et al., 1960; Laird et al., 1986; Soto et al., 1991). The burning of the vegetational cover is the main factor in increasing erosional processes (White et al., 1979). Other studies report on the change in soil properties as the main factor affecting erosion (Brown, 1972).

In New South Wales, erosion after fire was more substantial compared to erosion following logging in similar areas (Burges et al., 1981). The increase of surface erosion caused by changes in geomorphic processes, can cause the loss high percentage of the soil and affect, in an irreversible way, the complex interaction between soil, hydrology, climate, vegetation and landform development. These kinds of geomorphic changes are irreversible and their magnitude may alter the shaping of landforms depending on the intensity of climatic events and geomorphic processes after fire (Doehring, 1968).

The main reasons for an increase in runoff and erosion following fire are the destruction of the vegetation and little layer (Bohling et al., 1991) and the development of hydrophobic layer (Debano, 1981). The data from the experimental plots in the Carmel area show that in the first year after the fire, there is a marked increase in runoff and sediment yield against non-burnt plots. In the second season there is a sharp decrease in runoff rate and sediment yield of one or two orders of magnitude. The third exceptional rainy season caused an increase in runoff but not in sediment yield, due to the vegetational cover and consolidation of the soil (Inbar et al., 1998). This trend is similar to results from other experimental studies after severe fire: In Southern

California accelerated erosion, about 20 times the normal annual rate of erosion will occur on the slopes during the first year after fire (Doehring, 1968).

2.4 Effect of Shear Strength

Wildfire can accelerate erosion rates because vegetation is an important factor controlling erosion (Wondzell et al., 2003). Two important erosion processes occur following fire when water repellent soils are present—rill formation and raindrop splash. Rill formation occurs when rainfall exceeds infiltration rates and surface runoff occurs. Soil material moved by rill erosion accumulates in channels at the base of steep slopes and remains there until increased stream-flow moves it downstream (Wells, 1987).

A striking feature on freshly burned watersheds during the first postfire rainstorms is an extensive rill network, which is related to water repellency (Wells, 1981). This process occurs uniformly over the landscape so that when the wetting front reaches the water repellent layer, it can neither drain downward nor laterally. As rainfall continues, water fills all available pore space until the wettable soil layer becomes saturated. Because pores cannot drain, pore pressures build up immediately above a water repellent layer. This increased pore pressure reduces intergranular stress among soil particles, and as a result, decreases shear strength in the soil mass and produces a failure zone at the boundary between the wettable and water repellent layers where pore pressures are greatest as shown in Figure 2.1. Pore pressure continues to increase and shear strength decreases until it is exceeded by the shear stress of gravity acting on the soil mass. When this happens, a failure occurs and a portion of the wettable soil begins to slide downslope. If the soil is coarse textured, initial failure causes a re-orientation of the soil particles in the failure zone and causes them to momentarily lose contact with each other. The loss of intergranular contact further reduces shear strength and extends the failure zone downslope as shown Figure 2.2. When most of the soil grains lose contact, a condition develops in which the shearing soil is almost fluid. This fluid condition produces a miniature debris flow in the upper wettable soil layer, which propagates downslope to the bottom of the slope or until it empties into a channel (Wondzell et al., 2003).

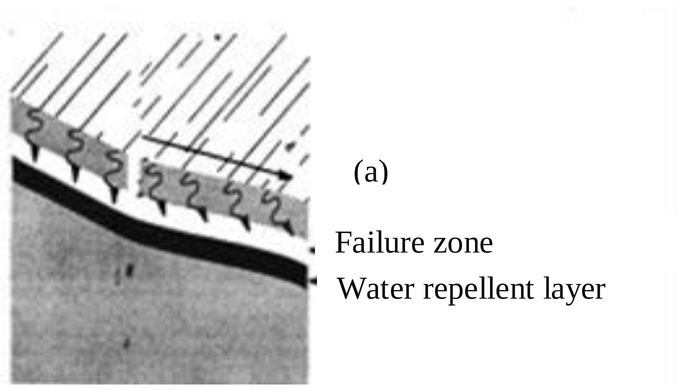


Figure 2.1 (a) Failure zone at the boundary wettable and water repellent layers

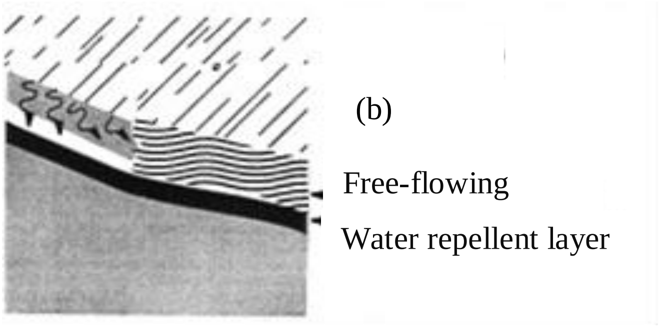


Figure 2.2 (b) Loss of the wettable surface layer, with the flow of water over the water repellent layer

2.4.1 Shear Strength Measurement

The precise purpose of representative soil shear strength of the materials of a slope are essential to significant slope stability analyses. Although it is possible in some circumstances for satisfactory strength measurement to be made in situ, laboratory measurement of strength are by far the most common for fine-grained soils that can be sampled reliably. However, the values of shear strength determined from laboratory tests are dependent upon many factors, particularly the type of soil, quality of the test samples, the size of test samples, and the testing methods.

The triaxial compression (TC) test is one the most common laboratory test used for the determination of shear strength for slope analysis. Depending on test condition, it can be used to determine either the total and or effective strength. Occasionally, if drainage conditions are not critical, the direct shear (DS) test may be selected for its operational simplicity. Due to the thin specimen used, drained conditions can be expected to exist for most materials except for highly plastic clays. The DS test can be completed in about a fifth to a tenth of the time required to run a drained TC test. Therefore, the direct shear strength results are usually reported in terms of effective stress. Furthermore, it is more convenient to subject a sample of clay to large strains and to cycles of strain in the direct shear machine than in the triaxial machine if ultimate strength are required for the analysis.

Several direct simple shear (DSS) testing devices have been developed, but the one described by (Bjerrum et al., 1996) is one of the most commonly used for testing undisturbed samples. The test can be performed under undrained and drained conditions. Although the general state of stress within the sample is in determine, the average normal and shear stresses acting on a horizontal plan can be evaluated with sufficient accuracy for practical applications (Ladd et al., 2001).

For unsaturated soil, special tests are used to determine the shear strengths. These include: (1) modified DS test, (2) undrained (U) test, (3) constant water content (CW) test, (4) controlled suction (CS) test, and (5) dead load test. For most practical applications, the direct shear apparatus modified to monitor suction may be the ideal apparatus in view of its simplicity and short testing time. Similar test can also be run in a triaxial test, but the suction control at the base of the specimen and soil suction monitoring at the top of the specimen cannot be carried out simultaneously as the top must be vented to atmospheric pressure during the test (Abramson et al., 2001).

2.4.1.1 Direct Shear

The direct shear test is one of the oldest and simplest test for determine the shear strength of a sample. Even though the stress circumstances within the sample are unidentified, it can be used to reliably determine the residual shear strength. The direct shear test should be done in accordance with the procedures set forth in ASTM D3080-90 and AASHTO 236-90.

The sample is placed between two porous stones to facilitate drainage and the normal load is applied to the sample by placing weight in a hanger systems, or by a hydraulic piston. The shear force is supplied by the piston drive by an electric motor. The horizontal displacement is measured by horizontal dial and the shear force by a proving ring and load dial. The shear strength can be measured on any predetermined plane in a soil mass by trimming specimens at the correct appropriate orientation. The result of the direct shear test are often plotted as shear stress versus normal stress, from which the effective cohesion and the effective angle can be obtained. Moreover, variations of shear stress and horizontal displacements may sometimes be plotted as well. The shear surface can be formed by cutting a plane through an intact specimen with a fine wire or sometimes by shearing a completely remoulded specimen. Any irregularities of the shear surface would introduce an added resistance, which would not be a measure of the shear strength of the material (Abramson et al., 2001).

2.5 Nesosilicate

In the lattices of silicate minerals SiO4 tetrahedra are linked together in a small number of easily conceptualized ways that are enumerated below (with classical derivations of names in parentheses). Remaining cations fit between the relatively large oxygen atoms of the resultant structures in six or eight fold or higher coordinations. A few silicate minerals have slightly more complex structures that involves the interlocking of SiO4 tetrahedra in combinations if these fundamentals styles. One of the silicate minerals is nesosilicates. The SiO4 of nesosilicates are not linked directly to one another by sharing oxygen atoms but are entirely connected to intervening cations, so that SiO4 tetrahedron is isolated (Hughes, 2013).

The nesosilicates group is extremely heterogeneous, since it includes both olivine and zircon, which are the least resistant and the most resistant silicate materials to weathering (Marini, 2006). Nesosilicates are thus most basic in the sense of containing relatively the most cations either than silica and the basic rocks hence contain greater amounts of nesosilicates and inosilicates than do acid rock (Hughes, 2013).

Table 2.2 Structural classes of rock-forming silicate minerals

Name	Description in terms of SiO4 tetrahedra	Resultant SiO ratio	Major silicate group
Nesosilicates	Isolated tetrahedra	-SiO4	Olivines Garnets

Source: (Hughes, 2013)

2.6 Soil Suction

Engineers are aware of the importance of soil suction in geotechnical applications. In addition, the engineering properties of unsaturated soils are significantly influenced by soil suction. The coefficient of permeability decreases with an increase in soil suction. The shear strength increases with increases in soil suction. An understanding of the flow behaviour through unsaturated soils is required for numerous applications in geotechnical and geoenvironmental areas. The shear strength of a soil is also required for the prediction of the stability of slopes, the bearing capacity of foundations and pressure against earth retaining structures (Fredlund, 1995).

Soil suction can also be referred as the free energy state of the soil water (Mantri et al., 2014) that can be found in all ground that lies above the water table (Hu Pan et al., 2010). In engineering practice, soil suction has two components namely matric suction and osmotic suction. The sum of matric and osmotic suction is defined as total suction of the soil (Krahn et al., 1971). Matric suction is defined as the capillary component of the free energy whereas osmotic suction is defined as the solute component of the free energy (Mantri et al., 2014).

2.6.1 Soil Suction Measurements

There are different method to measure soil suction. There are indirect method which use another medium to determine soil suction and direct method. This paper reports on direct and indirect soil suction measurement methods. Direct suction measurement techniques mainly include axis-transition technique, tensiometer and suction probe. Indirect suction measurement techniques are divided into three categories, namely, measurement techniques of matric suction, osmotic suction and total suction. Indirect matric suction measurement techniques include time domain reflectometry (TDR), electrical conductivity sensors, thermal conductivity sensor (TCS) and in-contact filter paper technique. Indirect osmotic suction measurement techniques chiefly include squeezing technique and saturation extract method. Indirect total suction measurement techniques include psychrometer technique, relative humidity sensor, chilled-mirror hygrometer technique and non-contact filter paper method (Hu Pan et al., 2010).

2.6.2 Soil-Water Characteristic Curve

Soil-water characteristic curve defined as relationship between water content and soil suction (Zapata et al., 2000; Fredlund, 1994; Olsen et al., 2008). Water content can be presented in gravimetric water content, volumetric water content or degree of saturation. The form of water content most often used when soil water suction is initially measured is gravimetric water content. However, when published, the most commonly used form of water content is volumetric water content. The degree of saturation, S, is also used sometimes as a measure of water content for the SWCC (Zapata et al., 2000).

SWCC depend on soil texture, structure, organic matter content and bulk density (Vereecken et al., 1989; Gupta and Larson, 1979). A study conducted by (Pachepsky et al., 2002) suggest that increasing in plasticity, stronger grade for non-plastic soils, and harder dry consistency lead to the increase in SWCC at both -33 kPa and -1500 kPa matric potentials. Wildfire can profoundly impact soil properties by consumption of organic matter (Perez et al., 2004) and alteration of soil structure (Ulery et al., 1993; Duriscoe et al., 1982; Fonseca et al., 2011; Solera et al., 2011; Hubbert et al., 2006), which in turn impacts the SWCC. Changes in soil properties depend on fire severity and frequency of fire (Certini, 2005). According to (Rawls et al., 2003), the effect of changes in organic carbon content on SWCC depends on the proportion of textural components and the amount of organic carbon present in the soil. At low carbon contents, an increase in carbon content leads to an increase in SWCC in coarse soils and to decrease in water retention in fine-textured soils. At high carbon contents, an increase in carbon contents results in an increase in water retention of all textures. A study conducted by (Ebel, 2012) on the impact of wildfire on SWCC in the Colorado Front Range, United States suggest that the primary driver for measured differences in SWCC in burned and unburned soils was organic matter content and not soil-particle size distribution. The study also suggest that high-severity wildfire can homogenize

SWCC across the landscape by erasing SWCC differences resulting from organic matter content, which for this site may be affected by slope aspect.

2.7 Slope Stability Monitoring

Many options are available for monitoring unstable and potentially unstable of slope. The range of method options from inexpensive, short-term solutions to more costly, long-term monitoring programs. Slope stability and landslide monitoring involves selecting certain parameters and observing how they change with time. The two most important parameters are groundwater levels and displacement. Slope displacement can be characterized by depth of failure plane, direction, magnitude, and rate. One or all of these variables may be monitored.

Conventional slope monitoring utilizes a single method or a combination of methods. Piezometers allow the determination of water levels surveying fixed surface monuments. While the method of extensometers, inclinometers, and tiltmeters allow determination of direction and rate of slope movement and depth and areal extent of the failure plane. The extensometers provide an indication of displacement magnitude. In manually operated probe inclinometers are the most common means of long-term monitoring of slopes (Kane et al., 2000).

The electronic instrumentation also available to monitor the stability of the slope. These method includes vibrating wire piezometers, electrolytic bubble inclinometers and tiltmeters, and time domain reflectometry (TDR) for sensing changes in slope conditions. This instrumentation can be monitored by technicians in the field, or remotely by data loggers and telemetry. By combining instrumentation types, a full array of stability parameters can be observed (Kane et al., 2000).

Usually for critical facilities such as dams, quarries, highways and housing development that are adjacent to unstable slope, the monitoring need to create for immediate warning if the movement occurs. Advances in telecommunications and electronic instrumentation now make it possible to economically monitor slope movements remotely. Many types of sensors and data transmission systems are available. The case studies described in this paper are monitoring systems installed in Central and Northern California. These systems used one or more of the following types of electronic sensors such as extensometers, tiltmeters, inclinometers, and TDR.

Telemetry was establish by either cell phone or hard wire phone. Power was provided by rechargeable lead or acid batteries and solar panels (Kane et al., 2000).

2.7.1 Movement in Natural and Artificial (Man Made Slopes)

In all slopes there exists an inherent tendency to degrade to a more stable from (ultimately towards horizontal) and in this context instability is constructed as the tendency to move, and failure as an actual mass movement (Roy, 2001). The main forces that lead to the instability are both gravity and seepage, while there is resistance towards the failure consequential mainly from a combination of slope geometry or shape and the shear strength of the soil or rock mass itself.

Mass movement can we defined as the result of a shear failure along an internal surface or when there are general decreases in effective stresses between particles. Some type of the movement failure have been observed in three (3) classes to be considered:

2.7.1.1 Falls

These are categorized by movement away from existing discontinuities such as joints, fissures, steeply-inclined bedding planes, fault planes, and within which the slope failure assisted or precipitated by the effects of water or ice pressure (Roy, 2001). Figure 2.3 shows the example of falls.

Figure 2.3 Falls

Sources: (Roy, 2001)

2.7.1.2 Slides

In this form of movement, the mas remain basically intact while sliding along a definite failure surface. This form consists of two structural sub-divisions:

(a) Translational slides happen when there is linear movement of rocks blocks along soil layer or surface lying near to the (sloping) surface (Roy, 2001). These movement are normally fairly shallow and parallel to the surface as shown on Figure 2.4.

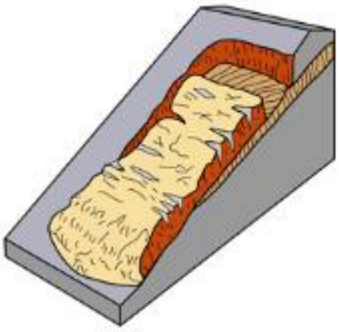


Figure 2.4 Transitional Slide

Soruces: (Roy, 2001)

(b) Rotational slip occur in homogenous soft rocks or cohesive soils. The movement takes place along the curved shear surface in such a way that the slipping mass slumps down near the top of the slope and bulges up near the toe (Roy, 2001). Detail of this mode of movement can be seen in Figure 2.5.

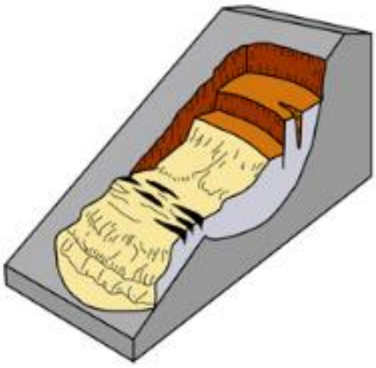


Figure 2.5 Rotational Slide

Sources: (Roy, 2001)

2.7.1.3 Flows

The soil at surface moves partially or wholly as a fluid. The following mass often exists in weak saturated soils when the pore pressure has increased plus decreasing the shear strength of soil (Roy, 2001). The example of this mode is shown in Figure 2.6.

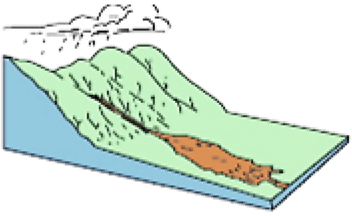


Figure 2.6 Flow

Sources: (Roy, 2001)

2.7.2 Factor of Slope Failure

It is important to understand the agents of instability in slopes. The reason of the deeply understanding towards the factors is because for the purpose of the designing and constructing a new slopes. Significantly, able to anticipate the changes in the properties of the soil within the slope that may occur over time and the various loading and seepage conditions to which the slope will subjected over the course of its life (Abramson et al., 2001). Slope failure are often caused by process that increase that shear stresses or decrease shear strength of soil mass. Processes that most commonly cause a decrease in the shear stresses acting of the slopes are listed in Table 2.3.

Table 2.3 Factors decreasing shear strength in slopes

Factors	**Causes**
Factors inherent in the nature of the material	Composition Structure Secondary or inherent structures Stratification
Change caused by weathering and physiochemical activity	Wetting and drying processes Hydration Removal of cementing agents
Effect of pore pressure	No specific causes
Changes in structure	Stresses release Structural degradation

Source: (W.Abramson et al., 2001)

2.7.3 Method of Slope Modelling

Most textbooks on soil mechanics or geotechnical engineering will include reference to several alternative methods of slope stability analysis. In a survey of equilibrium methods of slope stability analysis. In a survey of equilibrium method methods of stability analysis reported by (Duncan, 1996), the characteristics of a large number of methods were summarized, including the ordinary method of slices (Fellenius, 1936). Bishop's Modified Method (Bishop, 1955), force equilibrium (Lowe et al., 1960), Janbu's generalized procedure of slices (Janbu, 1968), Mongenstern and Price's method and Spencer's method (Spencer, 1967). A difficulty with all the equilibrium method is that they are based on the assumption that the failing soil mass can be divided into slice.

The majority of slope stability analyses performed in practices still use traditional limit equilibrium approaches involving methods of slices that have remained essentially unchanged for decades. Because of traditional method are quite difficulties to understand, the graphical capabilities programs allow better understanding of the mechanism of failure, simplifying the output from reams of paper to manageable graphs and plots of displacement (Griffiths et al., 1999).

There are a number of slope modelling has been applied. Among them are GeoStudio by using SLOPE / W, the finite elements method, and STABLR programs, and GEO5 Slope Stability. The various stated are modelling for analysing the stability of the slope and the details of modelling of slope stability will be discussed in section of 2.7.4 modelling slope stability.

2.7.4 Modelling Slope Stability

The stability of a slope may be measured using either published chart solution or a computer modelling analysis once the slope geometry and subsoil condition have been determined. Most of the computer programs used for slope stability analysis based on the limiting equilibrium approach for a two-dimensional model, although some allow three-dimensional analysis (Abramson et al., 2001).

In analysis of geotechnical problems, the finite element (FE) method has been widely accepted in the research area for many years (Griffiths et al., 1999). The programs are for two-dimensional plane strain analysis of elastic perfectly plastic soils with a Mohr Coulomb failure criterion is assumed. The programs computes the factor of safety (FOS) of the slope by using then non convergence solution, coupled with a sudden increase in nodal displacements as an indicator of failure conditions (Griffiths et al., 1999).

Another modelling method is Slope Stability Analysis Software (STABL) programs. STABL is a computer program for the general solution of slope stability problems by two-dimensional limiting equilibrium methods. It allows also the analysis of reinforced soil slopes with geosynthetics, nailing, and tiebacks using the Bishop, Spencer and Janbu methods. STABL features unique random techniques for generation of potential failure surfaces for subsequent determination of the more critical surfaces and their corresponding factors of safety. One technique generates circular, surfaces of sliding block character and general irregular surfaces of random shape. Specific trial failure surface can also be specified by the user (Salgado, 2017).

Another programs is GEO5 Slope Stability that are solves two dimensional limit equilibrium slope stability on circular (Fellenius/Petterson, Bishop, Spencer, Janbu, Morgenstern-Price) or polygonal (Sarma, Spencer, Janbu, Morgenstern-Price) slip surface. The basic program for stability analysis is Slope Stability. It enables design and analysis of slope stability with circular or polygonal surface and automatic optimization of slip surface. It cooperates with all programs for analysis of Excavation Designs and Retaining Wall Designs. It also enables creation of anchors, georeinforcements, surcharge and earthquake effects modelling. This program, also allow for analysis of MSE Walls reinforced by georeinforcements is MSE Wall, which contains a large database of georeinforcements of different production firms. All stability problems can also be solved by finite element method in the FEM program. The ground water table can be calculated in the FEM – Water Flow program, and then passed into Slope Stability or FEM programs for stability analysis.

2.7.5 Slope Modelling Software

There are several computer programs currently available for slope modelling software to analysing the stability of slopes. These categories may be separated into four distinct categories as follows:

1) STABL Programs the initial program of this group originated at Purdue University in 1975 (Siegel, 1975). Subsequent versions that are a superset of the original are available as PC_STABL, XSTABL, and GEOLSOPE, for example (Abramson et al., 2001).

2) Programs from the University of Texas These programs originated with SSTAB1 and have been subsequently published as SSTAB2, UTEXAS, UTEXAS2, and UTEXAS3 (Abramson et al., 2001).

3) Programs from the University of California, Berkeley STABR, STABGM, SLOPE8R, GEOSOFT (Abramson et al., 2001).

4) Other Programs PC-SLOPE, SLOPE/W, CLARA, GALENA, GSLOPE, TSLOPE (Abramson et al., 2001).

2.7.5.1 SLOPE/W

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

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

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

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

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

As the third objective of this study to study the effect of soil erosion on the changes in factor of safety value for unburned and burned soil at Jalan Gambang, Kuantan, the factor of safety of the slope can be analysed using the SLOPE/W software.

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

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

1. Total height of slope > 15m

2. Global angle of slope > 27°

The Geotechnical Control Office of Hong Kong which experiences similar ropical soil condition as in Malaysia has provided same basic guidelines as shown in Table 2.5 below.

Economic risk	**Risk to Life**		
	Negligible	**Low**	**High**
Negligible	> 1.0	1.2	1.4
Low	1.2	1.2	1.4
High	1.4	1.4	1.4

Source : (Abdullah et al., 2007)

CHAPTER 3

METHODOLOGY

3.1 Introduction

Features of unburned and burned soil investigated through laboratory test. From the laboratory test that are conducted, the physical properties of unburned and burned soil were determined by specific gravity, atterberg limit test, and free swell test. In order to determine the parameter of shear strength of soil, direct shear test is performed to find the shear strength of unburned and burned soil specimen. After getting the important parameters to modelling post fire erosion by SLOPE/W from the result of laboratory test, the parameter is then inserted into the slope w software to determine the factor of safety of unburned and burned soil. In this chapter, all the tests used were discussed to achieve the objectives of this study.

3.2 Site Description

In this study, soil samples were collected from a slope at Jalan Gambang, Kuantan as shown in Figure 3.1. The fire began on October 2016. The slope is located in the Eastern Belt where andalusite deposits can abundantly be found. According to (Hutchison, 1983), andalusite deposits in the area extend approximately 50 km radius from Gambang to Sungai Lembing. The study covered slope on 315 m in length and a portion of the slope (about 131 m) was affected by wildfire. The location of the burned and unburned soils at slope Jalan Gambang, Kuantan shown in Figure 3.2.

Figure 3.1 Map of Gambang showing locality of the burned slope

Figure 3.2 Location of the burned and unburned soils at slope Jalan Gambang, Kuantan

3.3 Selection of Material

The soil specimen for both unburned and burned soil were obtained at the hillside at Jalan Gambang, Kuantan. Then, the soil specimen were brought to the laboratory in sealed bags.

3.4 Specimen Preparation

The soil specimen were crushed and kept in sealed bags. In this study, soil samples were divided into two that was burned and unburned soil. Natural burned soil will be used directly after had been sieve for 0.425 mm while the unburned soil was burned in furnace at different temperature at 440°C, 800°C and 1350°C. Then all specimen were kept in sealed bags before being tested. A certain specimen were added with deionized water to 1.2 times the liquid limit value to prepare slurry specimens. The preparation for the burned soil sample using the furnace is shown in Figure 3.3.

Figure 3.3 Preparation for burned soil sample using furnace

3.5 Properties of Unburned and Burned Soil

Laboratory tests which include specific gravity test, atterberg limits and a free swell test was referred to a different standard as shown in Table 3.1.

Table 3.1 Standard used for the physical properties test

Physical Properties	**Method**
Specific Gravity, Gs	Density both (Small pycnometer) (BS 1377: Part 2: 1990: 8.3)
Liquid Limit, LL	Cone penetrometer method (BS 1377: Part 2: 1990: 4.3)
Shrinkage Limit, SL	Standard Test Method for Shrinkage Factors of Soils by the Wax Method (ASTM D 4943 - 08)
Swell Index, Cs	Free swell test (ASTM D4829)

3.5.1 Specific Gravity Test

This specific gravity test was conducted follows BS 1377: Part 2: 1990: 8.3. This test is performed by inserting about 10 g sample of dried soil sample that passed through the sieve No. 10 (2 mm) to the density bottle. Then, the distilled water was added to filled about half to three fourth of the density bottle. The soil sample was then allowed in the vacuum desiccator for at least one hour to remove the entrapped air. The distilled water was filled until the density full and was then allowed for an hour in room temperature. After that, the soil and water was removed from the bottle. The density bottle was refilled with distilled water only until full and was left for an hour. These step of test were repeated twice on the same soil sample. The specific gravity of the soil solids was can be calculated using the following formula Eq. 3.1.

$$Gs = \frac{(W_2 - W_1)}{((W_4 - W_1) - (W_3 - W_2))} \qquad 3.1$$

Where:

W_1 = Weight of bottle + Stopper

W_2 = Weight of bottle + Stopper + Dry soil

W_3 = Weight of bottle + Stopper + Soil + Water

W_4 = Weight of bottle + Stopper + Water

3.5.2 Liquid Limit Test

This liquid limit test was referred to the BS1337: Part 2: 1990:43. About 250 g oven dried soil passing 0.425 mm were left air dried within about 20 minutes. The distilled water were added to form paste for sample and then transferred to the cylindrical cup of cone penetrometer. The soil paste were pressed against the side of the cup to avoid trapping air and also was pressed into the bottom of the cylindrical cup without creating an air pocket. The penetrometer was adjusted by ensuring the cone point touches or contact with the top of surface of the soil paste. Then the vertical clamp was released to penetrate into the soil paste after 5 seconds under its own weight. The stage of test was repeated for three times of values of penetration in expectation of 13.5 to 27.5 mm. The graph of water content versus cone penetration was plotted to complete this test. Then, about 10 g from the area penetrated by the cone penetration of 20 mm was taken using small spatula for moisture content measurement. The apparatus set-up for the test is shown in Figure 3.4.

Figure 3.4 The apparatus set-up for liquid limit test

3.5.3 Plastic Limit Test

This test was followed the BS1337: Part 2: 1990:53. In this test, the soil paste was rolled, gathering together and kneading under the required pressure for rolling until the tread crumbles can no longer into a 3.2 mm diameter thread. The apparatus set-up for the test is shown in Figure 3.5.

Figure 3.5 Apparatus set up for plastic limit test

3.5.4 Shrinkage Limit Test

This shrinkage limit test is based on ASTM D4943-08 standards test method. At first, the soil sample was added with distilled water until it reaches 1.2 times the liquid limit of soil sample. The empty container was weighed first and grease is applied into the internal of the container and weighed again. Then, the soil sample is transferred into the cylindrical cup of cone penetrometer apparatus, and need to ensure that no air is trapped in the soil sample and the weight was recorded. The soil samples were left dried up until there was no changes occurred in terms of soil weight. Then, the weight of metal cup including soil samples after oven dried were recorded. The dry soil sample was tied with thread and then coated with max. The weight of dry soil with thread and weight of dry soil with thread and wax shall be recorded. And lastly, the graph of void ratio versus water content was plotted to obtain the shrinkage limit value. The shrinkage limit of the soil was taken by the corresponding of the moisture content to void ratio of the soil.

3.5.5 Free Swell Test

In this study, the free swell test was referred to standard of ASTM D4829. This test are started by transferred a 10 ml of soil sample into the cylinder. Then, the distilled water was added up to 50 ml. The soil samples were allowed to air dried until there was no volume changes occurred. Formula of free swell test can be determined by using the Eq. 3.2.

$$FS = \frac{(V_1 - V_0)}{V} \times 100 \qquad 3.2$$

Where:

FS = Free swell, %

V_1 = Soil volume after swelling, cm³

V_0 = Volume of dry soil, 10 cm³

3.5.6 Loss on Ignition

This test was referred to standard of BS 1377: Part 3: 1990:4.3. At first, the soil sample were dried for at least 1 hour in time and cooled in a desiccator for 30 minutes. Then, the sample were transferred into a crucible until half full and weighed. The next step, the soil sample was heated in a furnace with 440°C for three hours, left to cool in a desiccator and weighed again. The step of heating were repeated until there was no further changes in terms of soil weight. The loss of ignition can be determined by using Eq. 3.3.

$$\text{Loss in ignition} = \frac{M_S - M_A}{M_S - M_C} \times 100\% \qquad 3.3$$

Where:

M_S = Mass of crucible and oven dried soil sample

M_A = Mass of crucible and soil sample after ignition

M_S = Mass of crucible

3.6 Soil – Water Characteristic Curve

Soil-water characteristic curve defined as relationship between water content and soil suction. Water content can be presented in gravimetric water content, volumetric water content or degree of saturation. In this study gravimetric water content was used. The soil sample were added with deionized water with increment of 2%. Then the soil sample was kept in sealed bag for at least seven days. Soil suction has two components namely matric suction and osmotic suction. The sum of matric and osmotic suction is defined as total suction of the soil. In this study, total suction is obtained by chilled-mirror dew-point technique using Decagon WP4C PotentiaMeter device.

3.6.1 Chilled-Mirror Dew-Point Technique

The capability of a chilled mirror device for measuring soil water retention curve was investigated on fine grained soils having plasticity indices ranging from about 15 to 80. In decagon's chilled mirror devices, a test specimen is inserted into a sealed chamber that contains a mirror together with means to chill and detect condensation on the mirror. The temperature at which condensation begins determines the water potential in the head space of the sealed chamber. When a test specimen is inserted into the chamber, moisture is transferred between the specimen and the head space until equilibrium is reached. At equilibrium, the water potential in the head chamber equals the water potential in the specimen. In soils, the water potential is usually called suction. The graph of gravimetric water content versus log total suction is plotted.

3.7 Field Density Test – Sand Replacement Method

This test was followed standard of IS 2720-PART-28-1974. This sand replacement method was started with calibration procedures. The mass of sand is weighted in the cone of the pouring cylinder. The pouring cylinder is filled with sand so that the level of the sand in the cylinder is within about 15 mm of the top. Next, the total initial mass, m_1 is weighted, to the nearest 1 g and always use the same initial mass for every calibration. This constant is maintained throughout the tests for which the calibration is used. A volume of sand equivalent to that of the excavated hole in the soil is allowed to run out. After that, the shutter on the pouring cylinder is closed and placed on a metal tray. The shutter on the pouring cylinder is opened and allowed the sand to run out. Tap and vibrate are not allow at this period. Then, the shutter is closed and removed when there is no further movement. The sand on the tray is collected and weighted its m, m_2 to the nearest 1g. The measurement is repeated at least 3 times and the mean value of m_2 is calculated. The bulk density of the sand and the internal volume of the calibrating container are determined.

After the calibration procedure done, a flat area of soil is exposed, approximately 450 mm square to be tested and it trimmed down to a level surface, preferable with the aid of the scraper tool. Some loose extraneous materials have been brushed away. Then, the metal tray is placed on the prepared surface with the hole over the portion of the soil to be test. This hole is used as a pattern to excavated a round hole approximately 150 mm in diameter and the depth is around 100 mm never leave loose material in the hole and distort the immediate surround to the hole. All the excavated soil must collected carefully from the hole and the mass was determined. After that, the pouring cylinder is placed over the excavated hole. The shutter is opened and allowed the sand to run slowly. Tap and vibrate are not allow in this period. The shutter is close when there is no more further movement. The cylinder is removed and its mass is weighted.

The mass of sand, m_a required to fill the calibrating container from the Eq. 3.4.

$$m_a = m_1 - m_3 - m_2 \tag{3.4}$$

Where:

m_1 = Mass of cylinder and sand before pouring into calibrating container

m_2 = Mean of sand in cone

m_3 = Mean of cylinder and sand after pouring into calibrating container

The bulk density of the sand, ρ_a (in Mg/m³, to the nearest 0.01 Mg/m³), from the Eq. 3.5.

$$pa = \frac{m_a}{V} \qquad 3.5$$

Where:

V = Volume of the calibrating container (in mL)

The mass of sand required to fill the excavated hole, m_b from Eq.3.6.

$$m_b = m_1 - m_4 - m_2 \qquad 3.6$$

Where:

m_1 = Mass of cylinder and sand before pouring into hole

m_2 = Mean mass of sand in cone

m_4 = Mean mass of cylinder and sand after pouring into the hole

The dry density was calculated using Eq. 3.7 as follows:

$$pd = \frac{100p}{(100 + w)} \qquad 3.7$$

Where:

w = Moisture content of the soil (in %)

p = Bulk density of soil sample

3.8 Direct Shear Test

This test is refer IS-2720-PART-13-1986 standard test method for direct shear test. This direct shear test was performed to determine the shear strength parameters of unburned and burned soil and the angle of shear resistance. For the purpose of this study, a total of 15 specimen were sheared, where each of the 3 specimen at different water content for unburned soil, burned soil, 440°C, 800°C and 1350 °C. The size of shear box was 60 mm x 60 mm was shown in Figure 3.6.

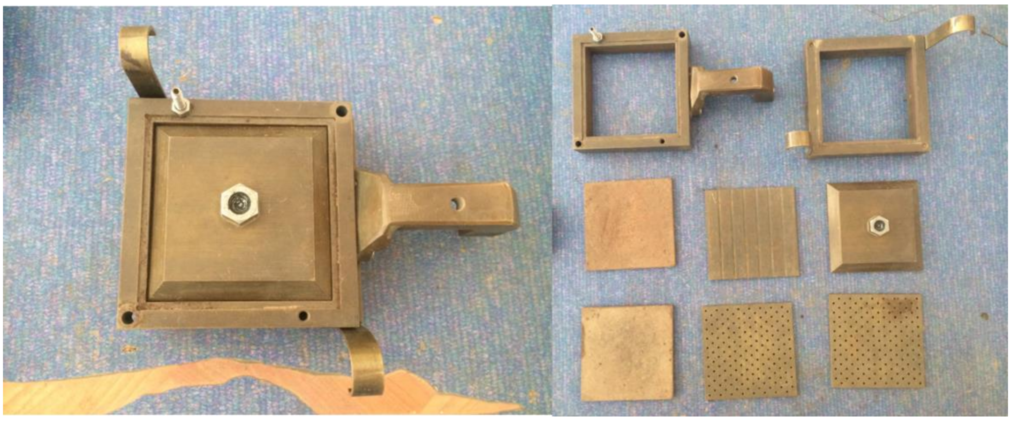


Figure 3.6 Shear box of 60 mm x 60 mm size

The soil sample is placed in a cubic shear box composed of an upper and lower box as shown in Figure 3.7. The limit between the two parts of the box is approximately at the mid height of the sample.

Figure 3.7 The soil sample was placed in cubic shear box

Then, cover it with porous plate and lid. The shear box was placed in the direct shear machine. The jack was tightened, all screws at horizontal and vertical and sensor were ensuring the correct position. This test conducted on three identical soil samples under different vertical compressive stresses at on 5 kg, 10 kg and 15 kg. The apparatus set-up for the test is shown in Figure 3.8.

Figure 3.8 Apparatus set-up for direct shear test

Results of unburned and burned soil are presented in a chart with peak stress on vertical axis and normal stress on the horizontal axis. A linear curve fitting is often made on the test result points. The intercept of this line with the vertical axis gives the cohesion and its slope gives the peak friction angle. The two components are combined in Coulomb's shear strength Eq.3.8.

$$\tau = c + \sigma n \tan ø \qquad 3.8$$

Where τ = shearing resistance of soil at failure

c = apparent cohesion of soil

σ = total normal stress on failure plane

ø = angle of shearing resistance of soil (angle of internal friction)

3.9 Slope Measurement

In order to use SLOPE / W, slope geometry data are required to modelling the slopes. To obtain the factor of safety for slope, slope geometry data such as height and slope angle of the slope should be taken in advance.

To obtain this data, a simple traverse surveying had been conducted using the most accurate instruments for measuring slope which is theodolites. The distance and angle of the survey line are measured to figure out the relative position of the traverse station. The apparatus used for slope measurement are includes theodolites model TOPCON GTS-25O series , adjusted leg-tripod, ranging pole, bull's eye level, measuring tape, staff level, and picket. The theodolites apparatus was shown in Figure 3.9.

Figure 3.9 Theodolite model TOPCON GTS-25O series

The slope is the incline or decline between two points that usual practice call these point "A" and "B" as shown in Figure 3.10. The procedure begins with positioning the eye level or theodolite where can read the level rod at each of the two points.

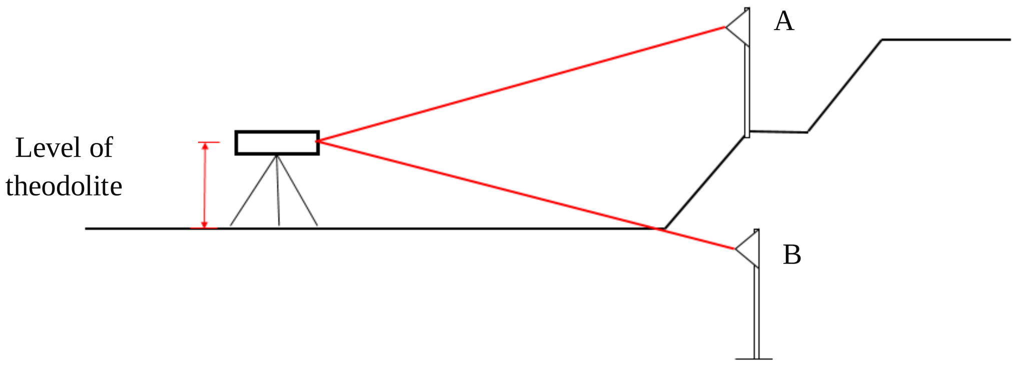


Figure 3.10 Elevation of point A and B

At first, the theodolites was set zero at first point of the slope. The level of theodolites instruments also was measured. Then the elevation of each point was read on the staff level, and subtracts the values to get the height for each point of the slope. This is the difference in elevation between points "A" and "B." The horizontal distance, vertical distance and height of ranging pole for between each point was recorded. The surveying work for slope measurement shown in Figure 3.11.

Figure 3.11 Surveying work for slope measurement

The slope is calculated by the dividing the elevation difference by the horizontal distance or using Pythagorean Theorem rules. Once the measured value were recorded, the slope sketch is drawn using the actual measurable value on the site. Figure 3.12 shows the actual picture of the slope and the slope sketch at hillslope Jalan Gambang, Kuantan.

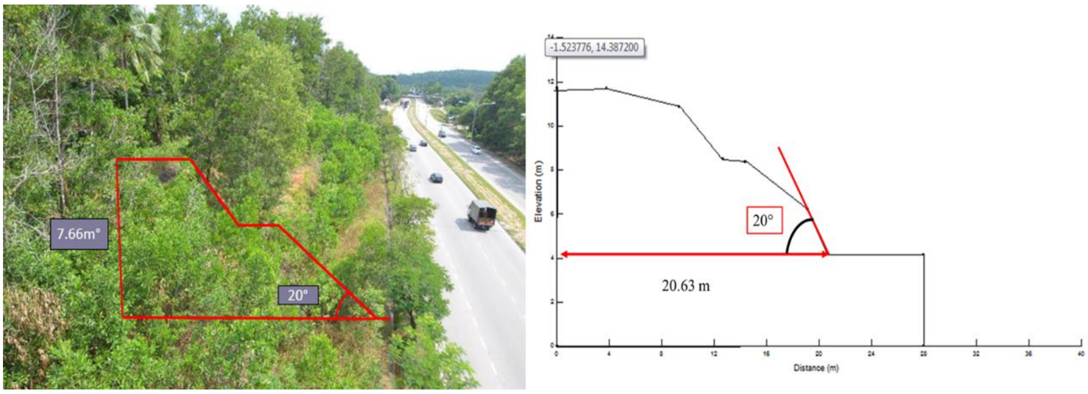


Figure 3.12 The actual picture of the slope and the slope sketch at hillside at Jalan Gambang, Kuantan

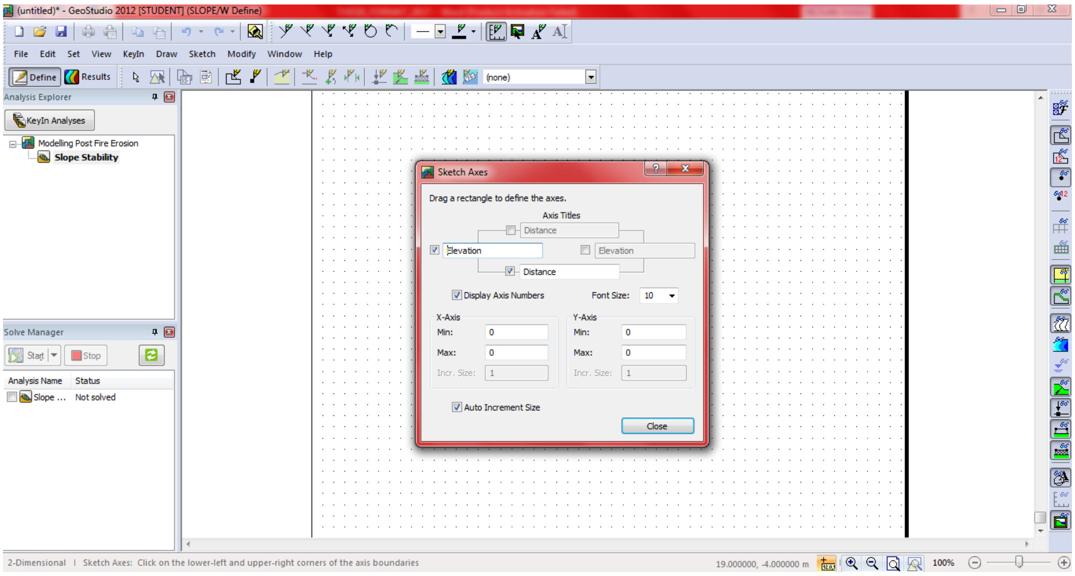
3.10 Slope Analysis using SLOPE/W

Erosion able to change the geometry of a slopes. The effect of erosion may no visible in a short time but the process of erosion has ultimately resulting in major impact on the slope failure. Therefore, the analysis of the erosion becomes important to study because it is closely related to the stability of the slope. The stability of a slope can be examined by analysing the minimum factor of safety and the critical slip surface for the soil profile using SLOPE/W.

Parameter of shear strength and unit weight of the soil were applied as an input parameters for the software GeoSlope SLOPE/W 2012. Bishop method was set for calculation of FOS. The software was used under Student Licence, which available at http://www.geo-slope.com. The height of test hillside slope Jalan Gambang, Kuantan was establish at 7.66 m and using horizontal scale 1: 150 and vertical scale 1:100.

By making modelling in SLOPE / W, the minimum factor of safety can be analysed. In this study there was estimated that no pore water pressure case. Through inserting the parameter of soil characteristic which includes cohesion, c, the angle of friction, φ and unit weight, γ the slope can be analysed.

In order to calculate the factor of safety of slope using SLOPE/W, the following are the procedure to be followed to analyse the minimum factor of safety value by using SLOPE / W. In advance, the axis are set as shown in Figure 3.13., which show the procedure of setting the slope axis and the scale unit of slope.



Sketch Axes

Drag a rectangle to define the axes.

Axis Titles

☐ Distance

☑ Elevation ☐ Elevation

☑ Distance

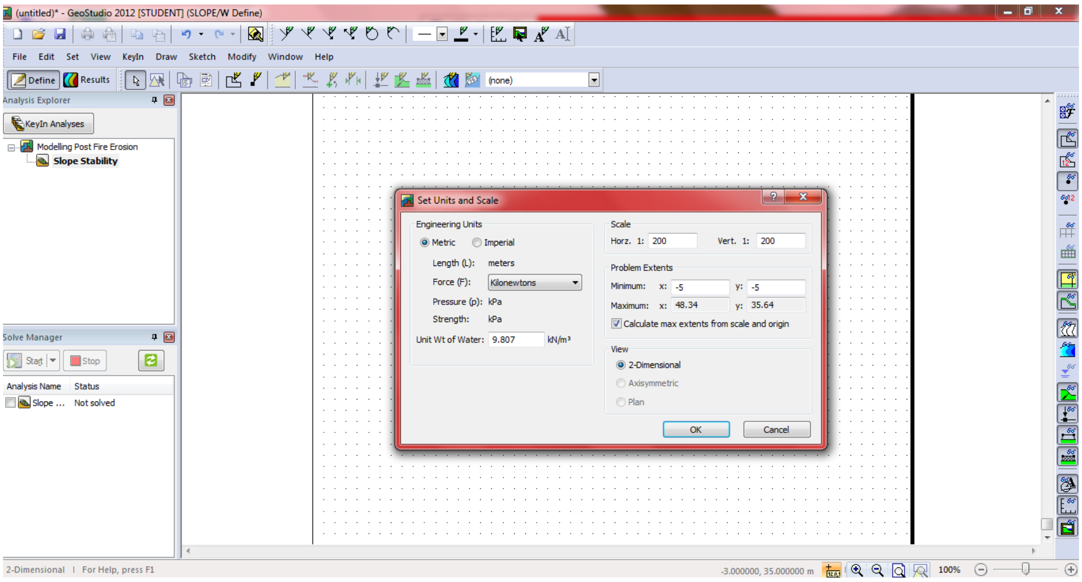
☑ Display Axis Numbers Font Size: 10

X-Axis
Min: 0
Max: 0
Incr. Size: 1

Y-Axis
Min: 0
Max: 0
Incr. Size: 1

☑ Auto Increment Size

Figure 3.13 Setting the axis of the slope



Set Units and Scale

Engineering Units
● Metric ○ Imperial
Length (L): meters
Force (F): Kilonewtons
Pressure (p): kPa
Strength: kPa
Unit Wt of Water: 9.807 kN/m³

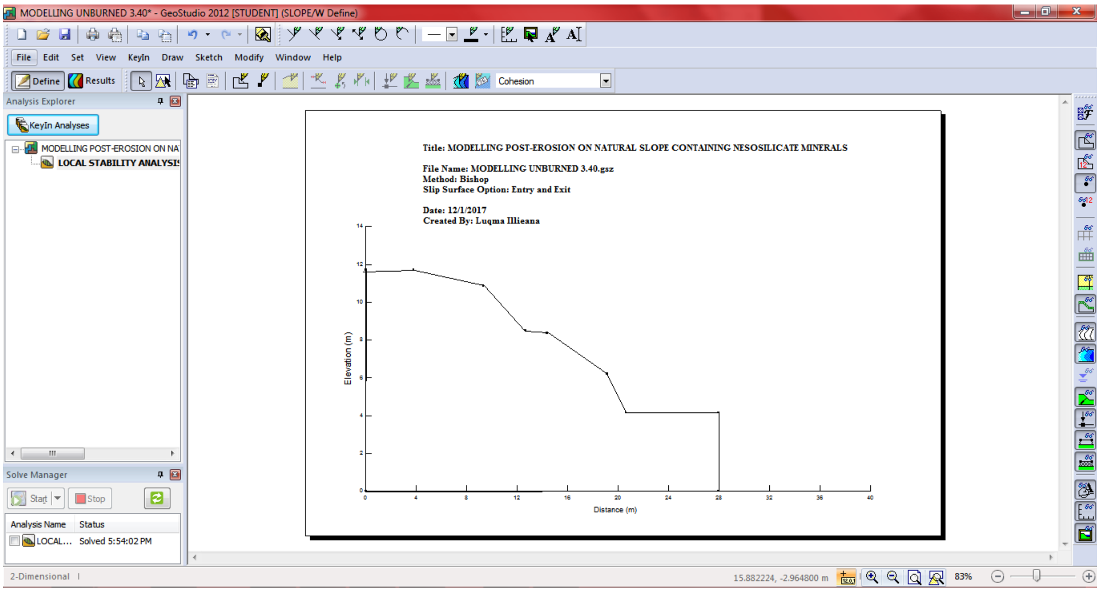
Scale
Horz. 1: 200 Vert. 1: 200

Problem Extents
Minimum: x: -5 y: -5
Maximum: x: 48.34 y: 35.64
☑ Calculate max extents from scale and origin

View
● 2-Dimensional
○ Axisymmetric
○ Plan

Figure 3.14 Setting the unit and scale

The next step was to draw the slope according to data that have been recorded. A pencil from the Sketch menu. The lines are considered objects or slopes that to be analysed. Figure 3.15 shows that the cross section of the slope in 2-dimension as follows:



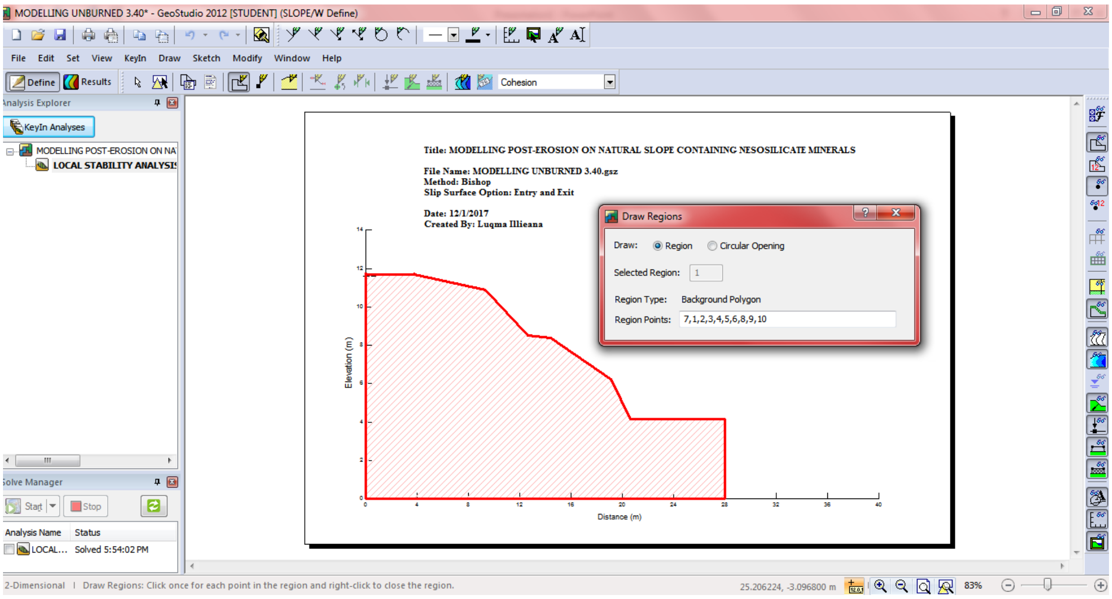
MODELLING UNBURNED 3.40* - GeoStudio 2012 [STUDENT] (SLOPE/W Define)

Title: MODELLING POST-EROSION ON NATURAL SLOPE CONTAINING NESOSILICATE MINERALS

File Name: MODELLING UNBURNED 3.40.gsz
Method: Bishop
Slip Surface Option: Entry and Exit

Date: 12/1/2017
Created By: Luqma Illieana

Figure 3.15 Slope diagram drawn according to site data



MODELLING UNBURNED 3.40* - GeoStudio 2012 [STUDENT] (SLOPE/W Define)

Title: MODELLING POST-EROSION ON NATURAL SLOPE CONTAINING NESOSILICATE MINERALS

File Name: MODELLING UNBURNED 3.40.gsz
Method: Bishop
Slip Surface Option: Entry and Exit

Date: 12/1/2017
Created By: Luqma Illieana

Draw Regions

Draw: ● Region ○ Circular Opening

Selected Region: 1

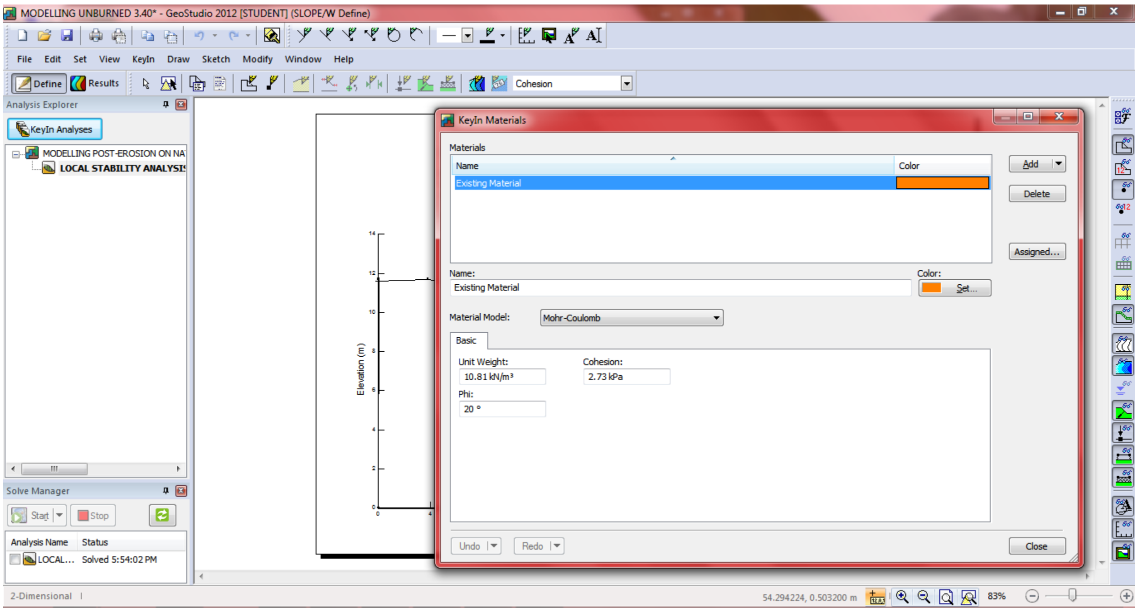
Region Type: Background Polygon

Region Points: 7,1,2,3,4,5,6,8,9,10

Draw Regions: Click once for each point in the region and right-click to close the region.

Figure 3.16 Draw the region of the slope

As the object of the slope has been drawn, the region of the slope can be identified by draw region in draw menu command. After the region is determined, material are first created and the soil properties of the slope must be inserted. The parameter of soil properties consists of the value of the cohesion, c, the angle of friction, φ and unit weight, γ which are needed to analysis slope using SLOPE/W as shown in Figure 3.17.


MODELLING UNBURNED 3.40* - GeoStudio 2012 [STUDENT] (SLOPE/W Define)

KeyIn Materials

Materials

Name	Color
Existing Material	🟧

Name: Existing Material

Color: 🟧

Material Model: Mohr-Coulomb

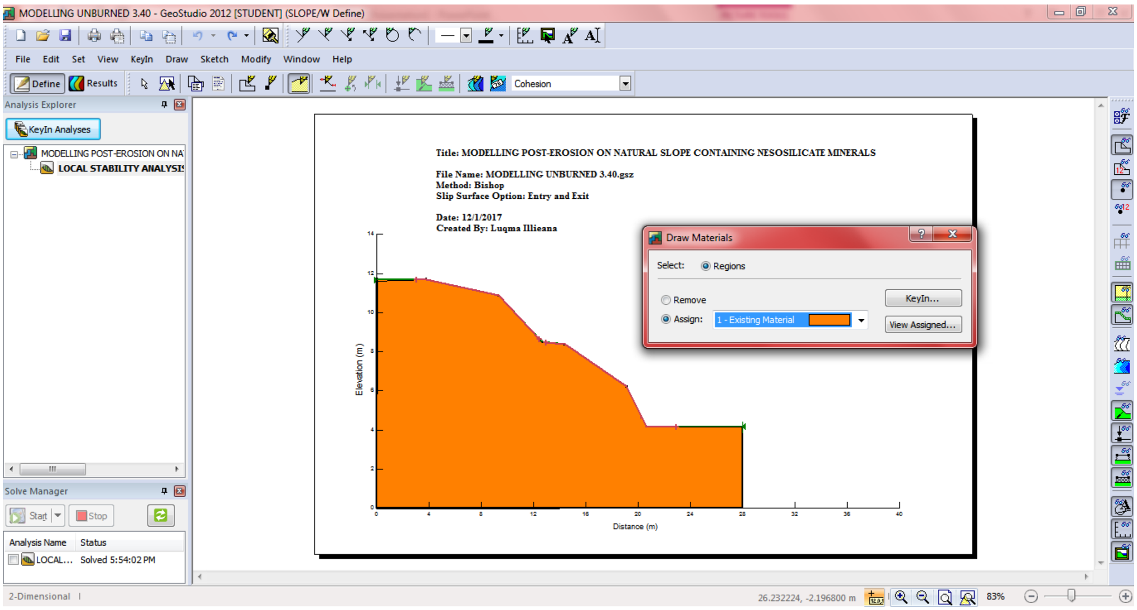
Basic

Unit Weight: 10.81 kN/m³

Cohesion: 2.73 kPa

Phi: 20 °

Figure 3.17 Key in the soil properties of the slope


MODELLING UNBURNED 3.40 - GeoStudio 2012 [STUDENT] (SLOPE/W Define)

Title: MODELLING POST-EROSION ON NATURAL SLOPE CONTAINING NESOSILICATE MINERALS

File Name: MODELLING UNBURNED 3.40.gsz
Method: Bishop
Slip Surface Option: Entry and Exit

Date: 12/1/2017
Created By: Luqma Illieana

Draw Materials

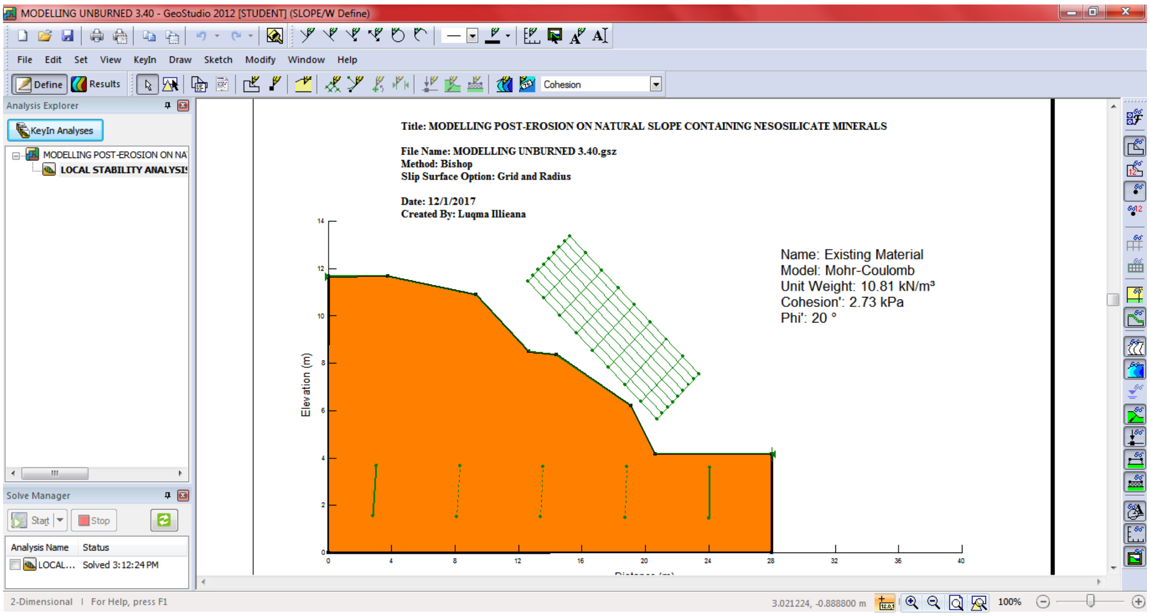
Select: ● Regions

○ Remove

● Assign: 1 - Existing Material 🟧

Figure 3.18 Draw material of the slope

As the data required has been key in the software, then the slope can be analysed. After that, the entry and exit method has to be drawn that indicates the location of the trial slip surface. The trial entry and exit method of the slope has been drawn as Figure 3.19.


MODELLING UNBURNED 3.40 - GeoStudio 2012 [STUDENT] (SLOPE/W Define)

Title: MODELLING POST-EROSION ON NATURAL SLOPE CONTAINING NESOSILICATE MINERALS

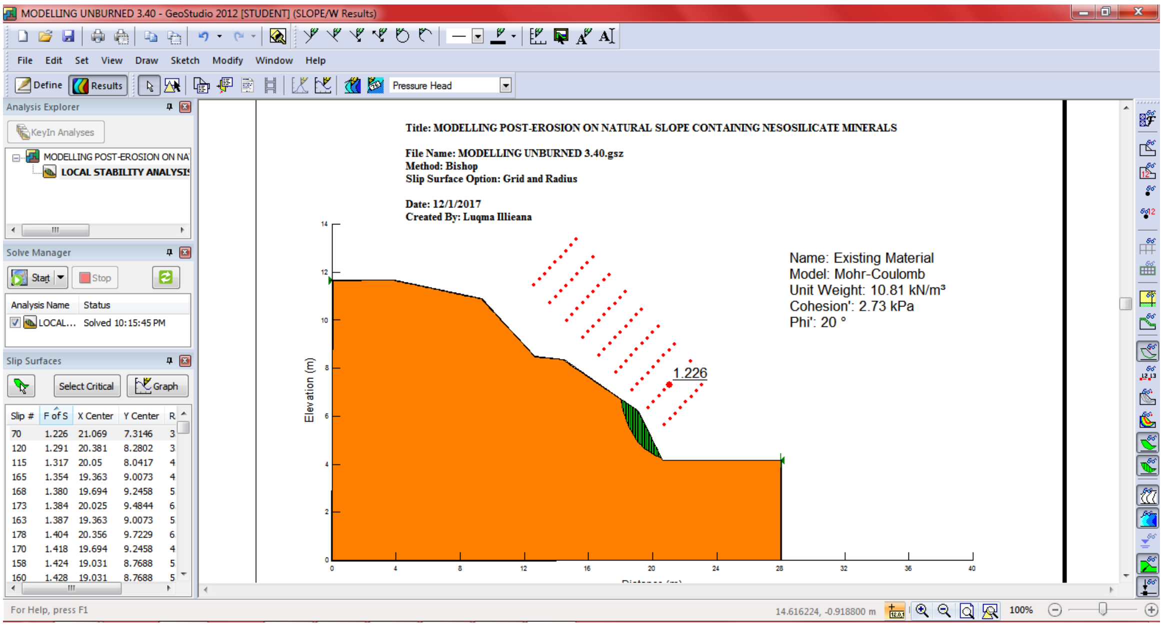
File Name: MODELLING UNBURNED 3.40.gsz
Method: Bishop
Slip Surface Option: Grid and Radius

Date: 12/1/2017
Created By: Luqma Illieana

Name: Existing Material
Model: Mohr-Coulomb
Unit Weight: 10.81 kN/m³
Cohesion': 2.73 kPa
Phi': 20 °

Analysis Name	Status
☐ LOCAL…	Solved 3:12:24 PM

Figure 3.19 Draw the slip surface grid and radius


MODELLING UNBURNED 3.40 - GeoStudio 2012 [STUDENT] (SLOPE/W Results)

Title: MODELLING POST-EROSION ON NATURAL SLOPE CONTAINING NESOSILICATE MINERALS

File Name: MODELLING UNBURNED 3.40.gsz
Method: Bishop
Slip Surface Option: Grid and Radius

Date: 12/1/2017
Created By: Luqma Illieana

Name: Existing Material
Model: Mohr-Coulomb
Unit Weight: 10.81 kN/m³
Cohesion': 2.73 kPa
Phi': 20 °

Analysis Name	Status
☑ LOCAL…	Solved 10:15:45 PM

Slip #	F of S	X Center	Y Center	R
70	1.226	21.069	7.3146	3
120	1.291	20.381	8.2802	3
115	1.317	20.05	8.0417	4
165	1.354	19.363	9.0073	4
168	1.380	19.694	9.2458	5
173	1.384	20.025	9.4844	6
163	1.387	19.363	9.0073	5
178	1.404	20.356	9.7229	6
170	1.418	19.694	9.2458	4
158	1.424	19.031	8.7688	5
160	1.428	19.031	8.7688	5

Figure 3.20 Result of factor of safety using SLOPE/W

As Figure 3.20 above shown that the final result of factor of safety by analysis of SLOPE/W which was shown the indicator for the slope stability whether the slope is safe or not.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Physical and Chemical Properties

In this chapter, all results were discussed to identify the objectives are achieved. The result of soil properties for unburned and burned soil which are specific gravity, atterberg limits, swell potential and organic matter were also identified.

Table 4.1 Effect of temperature on properties of unburned and burned soil at varying temperature

Properties	**Unburned**	**Burned**			
		Natural	**440°C**	**800°C**	**1350°C**
Specific gravity, Gs	2.65	2.58	2.69	2.63	2.60
Liquid Limit (%)	56.40	55	46.40	-	-
Plastic Limit (%)	29.69	37.14	32.10	NP	NP
Shrinkage Limit (%)	32	40	21.40	-	-
Free Swell (%)	5	5	0	0	0
Organic matter content (%)	0.36	0.51	0.20	0.00	0.00

4.1.1 Effect of Temperature on Specific Gravity

Table 4.1 shows effect of temperature specific gravity of unburned and burned soil. The natural burned soil reduced to 2.58 compared to 2.65 for unburned soil. While it shows an increment at 440°C and reduce at 800°C which are 2.69 and 2.63, respectively. However at 1350°C, the specific gravity decrease at 1350°C. It is contrast with research conducted by (Tan et al., 2004) that stated specific gravity reduced rapidly from 100°C to 600°C and does not show significant decrease for interval of 600°C to 1000°C.

4.1.2 Effect of Temperature on Liquid Limit

Liquid limit decrease from 56.40% for unburned soil to 55% after soil burned then reduce steadily at 46.40% at 440°C and finally reached of zero at 800°C and 1350°C. From this result, there are similarities between the studies conducted by (Abu-Zreig, 2001) suggest that the liquid limit decreased with increasing temperature.

4.1.3 Effect of Temperature on Plastic Limit

Plastic limit shows an increment from 29.69% for unburned soil to 37.14% for burned soil. But it continuously reduced from 440°C until it reached non-plastic (NP) state at 800°C and 1350°C. The result contrast with study conducted by (Tan et al., 2004) and (Abu-Zreig, 2001) which suggest that plastic limit reduced as temperature increase until it reached zero at 400°C.

4.1.4 Effect of Temperature on Free Swell

The swell potential does not shows changes 5% for unburned soil and burned soil but it reached zero at 440°C, 800°C and 1350°C.

4.1.5 Effect of Temperature on Organic Content

The organic matter content decreased with increasing temperature and finally reached a zero value at 800°C. In a work by (DeBano, 1990), non-living organic matter begins changing at 200 °C and is completely lost at temperatures of 400 °C. The organic matter for natural burned soil higher compared to unburned soil, which is 0.51% and 0.36% respectively.

4.2 Drying Suction-Water Content (SWCC)

The suction of the unburned and burned soils at various water content are presented in Figure 4.1. Referring to Figure 4.1, the suction-water content SWC of natural burned soil is slightly below that of unburned soil. According to the study by (Alauzis et al., 2004) measured major declines in organic matter content and soil-water retention resulting from wildfire. The suction-water content SWCC of burned soil at 440°C and 800°C is lower compared to natural burned soil, unburned soil, while burned soil at 1350°C has lowest suction-water content SWCC due to non-plastic and zero organic matter content. According to (Ebel, 2012), the primary driver for difference in SWCC in unburned and burned soil is organic matter content.

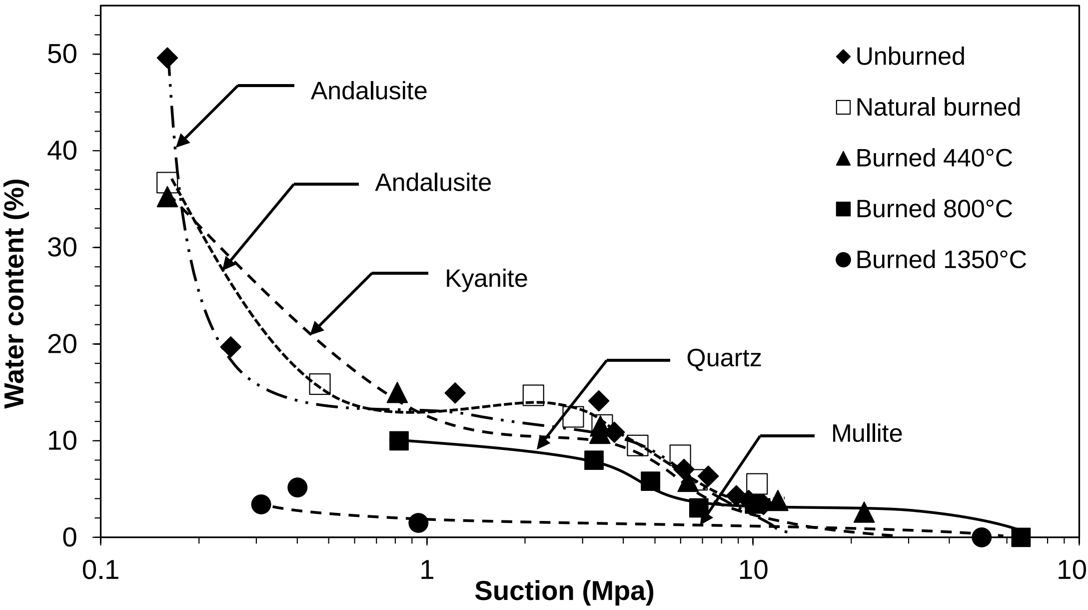


Figure 4.1 Suction-water content SWCCs of the unburned and burned soils studied

Through the result of drying suction water content SWCC, the water content value is used as the as a benchmark measurement to analyse the post fire erosion of the slope using SLOPE/W software. According to the study by (Topp et al., 2002), water in soil acts both as a lubricant and as a binding agent among the soil particulate materials, thereby influencing the structural stability and strength of soil and geologic materials. The result of the drying suction-water content SWCC at varying temperature was shown in Table 4.2.

Table 4.2 Result of drying suction-water content SWCC at varying temperature

Unburned	
Soil Suction (Mpa)	**Water Content (%)**
10.75	3.40
9.70	3.81
8.88	4.29
7.28	6.32
6.14	7.04
3.75	10.86
3.36	14.10
1.22	14.94
0.25	19.70
0.16	49.60

Burned	
Soil Suction (Mpa)	**Water Content (%)**
10.28	5.50
6.73	5.94
5.99	8.48
4.43	9.48
3.45	11.59
2.81	12.45
2.12	14.66
0.47	15.83
0.16	36.69

Burned 440°C	
Soil Suction (Mpa)	**Water Content (%)**
21.92	2.61
11.91	3.82
6.32	5.79
3.39	10.76
3.4	11.52
0.81	14.98
0.16	35.23

Burned 800°C	
Soil Suction (Mpa)	**Water Content (%)**
66.27	0
6.81	3.05
10.09	3.46
4.84	5.81
3.25	7.98
0.82	10

Burned 1350°C	
Soil Suction (Mpa)	**Water Content (%)**
50.16	0
0.94	1.49
0.31	3.42
0.4	5.18

Soil suction plays an important role in determining the soil behaviour within this region. Based on the water retention curves, the result clearly indicate that at low suction where the water content is higher, the ability of the burned soil to absorbed water was limited. From engineering perspective, a decrease in the plasticity characteristics and water retention behaviour would lead to the reduction in the shear strength (Yilmaz, 2011; McCartney et al., 2014).

4.3 Parameter Shear Strength of Unburned and Burned Soil

In order to create the modelling of post fire erosion using SLOPE/W developed by GeoStudio, there are several parameters required to analyse this study for the selected moisture content based on the result of drying suction-water content SWCC which are includes cohesion, c, the angle of friction, φ and unit weight, γ. For the purpose of this study, the sample of the soil were sheared by using direct shear test. From the graph of normal stress (kPa) vs horizontal displacement (mm), the parameter of shear strength which are cohesion, c and the angle of friction, φ were obtained. At the same time, the unit weight of soil γ was determined by field test sand cone replacement method. Table 4.3 shows the parameter shear strength for modelling post-fire erosion using SLOPE/W at varying temperature.

Table 4.3 Shear strength parameter at varying temperature

Unburned				
Soil Suction (Mpa)	**Water Content (%)**	**Cohesion , C (kN/m2)**	**Phi, Φ (deg)**	**Unit Weight, γ (kN/m3)**
7.28	6.32	2.61	20	11.19
6.14	7.04	1.76	25	11.99
3.75	10.86	0	30	11.53
Burned				
Soil Suction (Mpa)	**Water Content (%)**	**Cohesion , C (kN/m2)**	**Phi, Φ (deg)**	**Unit Weight, γ (kN/m3)**
10.28	5.50	0.57	27	9.22
4.43	9.48	0.07	27	9.45
2.81	12.45	0	27	11.27
Burned 440°C				
Soil Suction (Mpa)	**Water Content (%)**	**Cohesion , C (kN/m2)**	**Phi, Φ (deg)**	**Unit Weight, γ (kN/m3)**
3.39	10.76	3.67	22	10.49
3.4	11.52	2.80	23	10.59
0.81	14.98	2.51	26	10.74

Burned 800°C

Soil Suction (Mpa)	Water Content (%)	Cohesion , C (kN/m2)	Phi, Φ (deg)	Unit Weight, γ (kN/m3)
10.09	3.46	3.81	19	10.73
4.84	5.81	3.00	20	10.84
3.25	7.98	2.00	24	10.86

Burned 1350°C

Soil Suction (Mpa)	Water Content (%)	Cohesion , C (kN/m2)	Phi, Φ (deg)	Unit Weight, γ (kN/m3)
0.94	1.49	2.86	19	11.38
0.31	3.42	0.54	26	11.60
0.4	5.18	1.15	25	11.73

Test results are presented in table above. In each direct shear test that has been done, there was clear relation between the shear strength parameters and moisture content. It can be noticed that for the all cases stated for unburned and burned soil at varying temperature, the increase on moisture content caused a decrease in the cohesion, C for soil. At burned 1350°C, the value of cohesion marked drop was observed at 1.49%, where cohesion, C decrease from 2.86 kN/m^2 to 0.54 kN/m^2 but it show an increment at 3.42% moisture content from 0.54 kN/m^2 to 1.15 kN/m^2. According to (Pellet et al., 2014), the friction angle and the cohesion decrease when saturated. Due to increasing water content the shear strength is expected to decrease. The findings of this study was found to be similar to that of (Pellet et al., 2014) where the parameter of cohesion, C decrease with increasing of water content of soil. But when considering the result presented of angle of friction, φ for all cases are in contradiction with expected development as can been seen on table stated.

4.4 Modelling Post Fire Erosion by SLOPE/W

Modelling of post-fire for slope is carried out to determine the stability of the slope at selected moisture content from the suction-water content SWCC result. The modelling was created from software developed by GeoStudio by SLOPE/W. Parameters of shear strength and unit weight of the soil were used as input parameters of the software GeoStudio. Bishop’s method was used for calculation of FOS. The software GeoStudio W/2012 was used under student licence, which is available at http://www.geo-slope.com. The height of hillslope was established at 7.66 metres and 20°. The slope geometry was drawn on SLOPE/W based on the result from simple traverse surveying that had been conducted using the most accurate instruments for measuring slope which is theodolites model TOPCON GTS-25O. Figures 4.2 shows the slope geometry sketches based on surveying on hillslope Jalan Kuantan- Gambang.

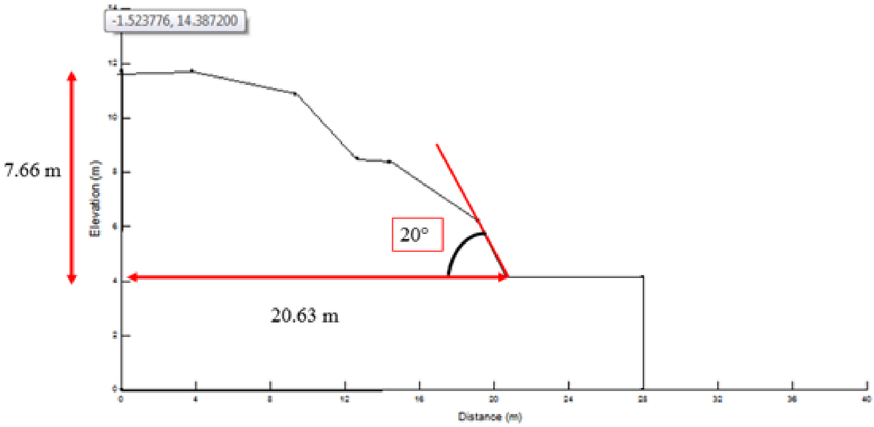
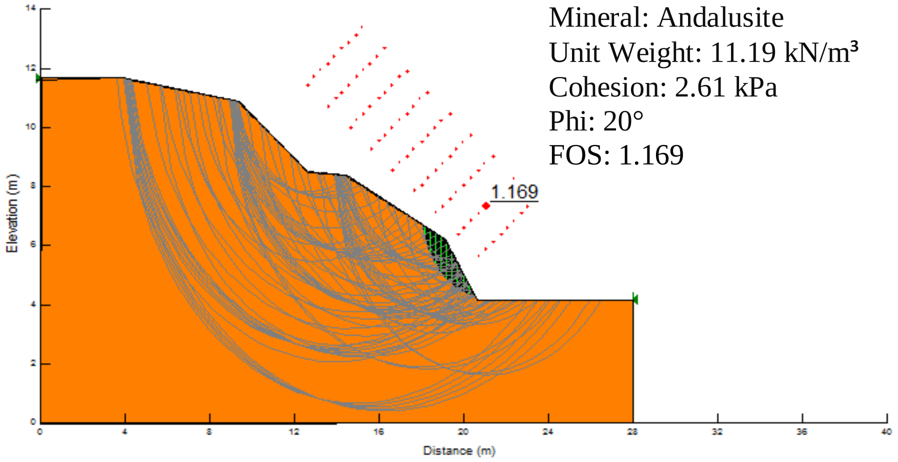


Figure 4.2 Slope geometry for hillside at Jalan Gambang, Kuantan

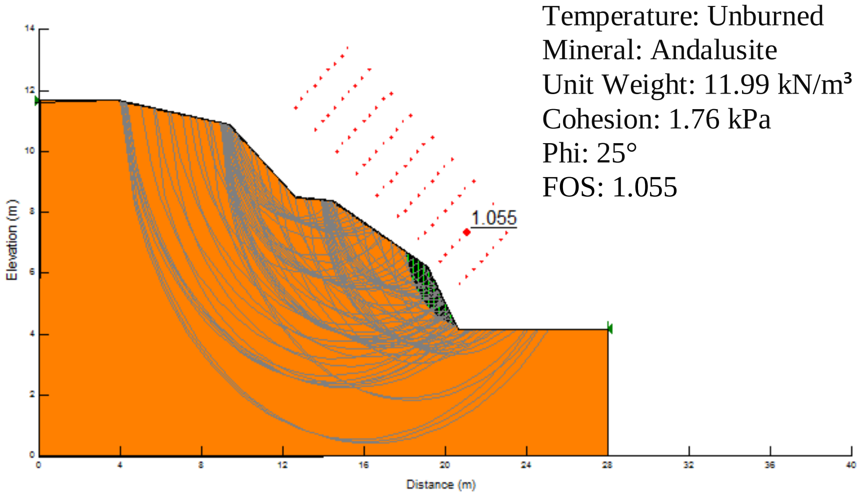
4.4.1 Slope Stability Analysis Result

The result from the stability analyses using SLOPE/W are presented in figure below. While Table 4.12 to Table 4.16 shows values of factor of safety (FOS) for tested hillside slope at Jalan Gambang, Kuantan. The tested hillside is 7.66 metres high and declines in a ratio 1:150 horizontal and 1:100 vertical. Figures below displays stability analysis of the hillside slope with parameters of shear strength gather from direct shear test and sand cone replacement method.



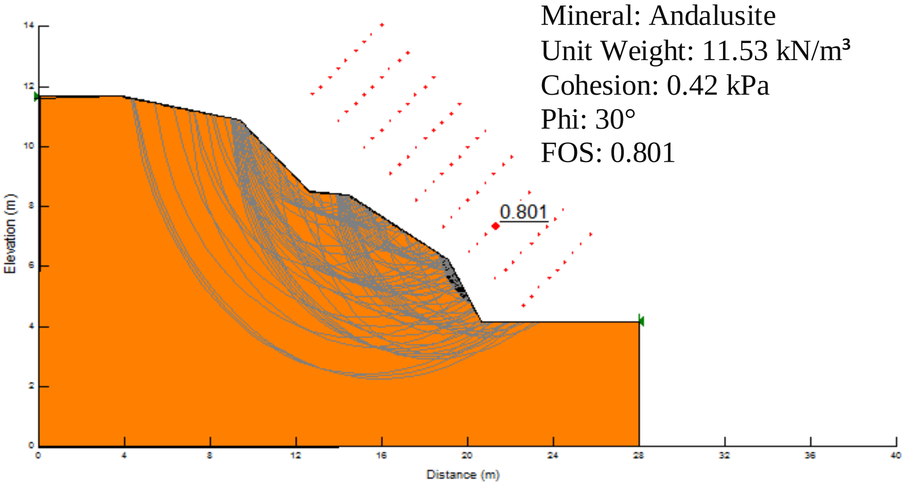
Temperature: Unburned
Mineral: Andalusite
Unit Weight: 11.19 kN/m³
Cohesion: 2.61 kPa
Phi: 20°
FOS: 1.169

Figure 4.3 Modelling unburned slope with moisture content 6.32%



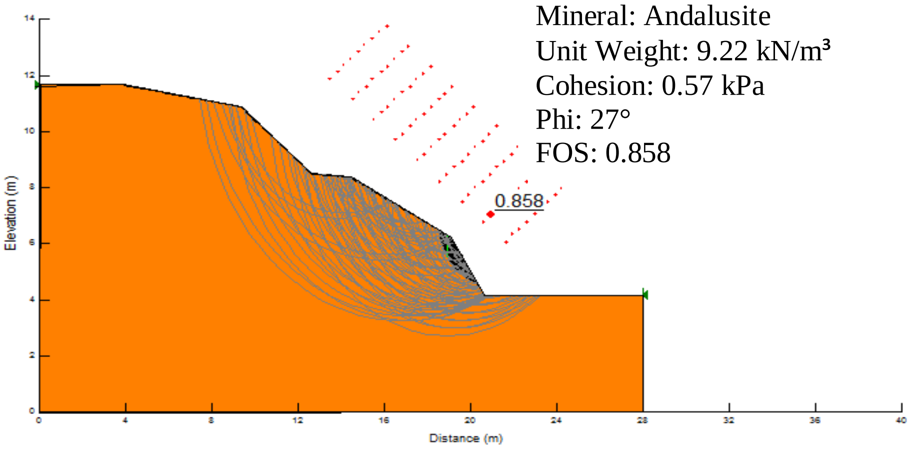
Temperature: Unburned
Mineral: Andalusite
Unit Weight: 11.99 kN/m³
Cohesion: 1.76 kPa
Phi: 25°
FOS: 1.055

Figure 4.4 Modelling unburned slope with moisture content 7.04%



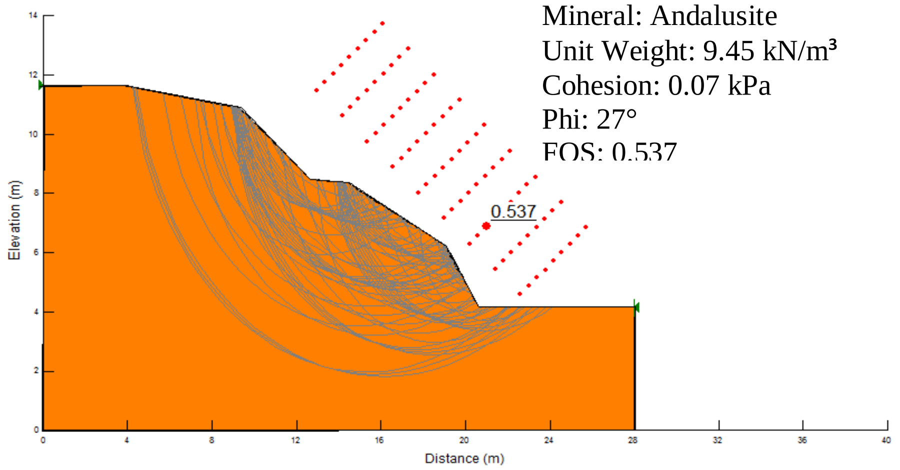
Temperature: Unburned
Mineral: Andalusite
Unit Weight: 11.53 kN/m³
Cohesion: 0.42 kPa
Phi: 30°
FOS: 0.801

Figure 4.5 Modelling unburned slope with moisture content 10.86%



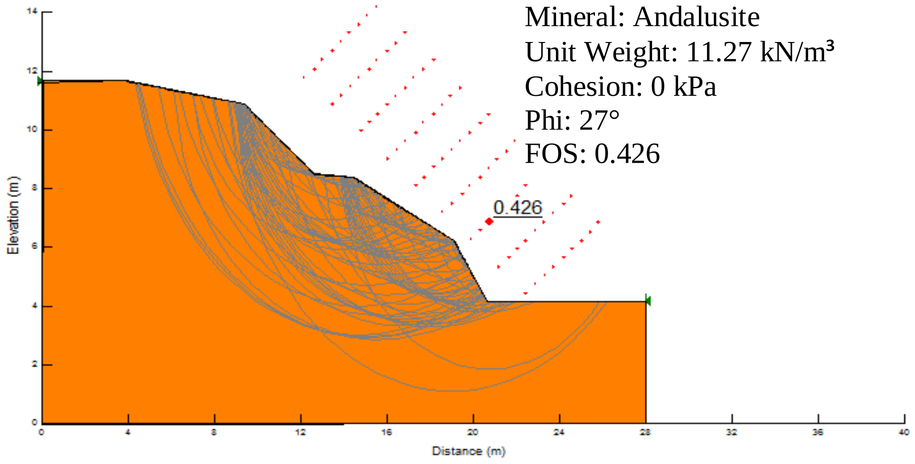
Temperature: Natural burned
Mineral: Andalusite
Unit Weight: 9.22 kN/m³
Cohesion: 0.57 kPa
Phi: 27°
FOS: 0.858

Figure 4.6 Modelling burned slope with moisture content 5.50%



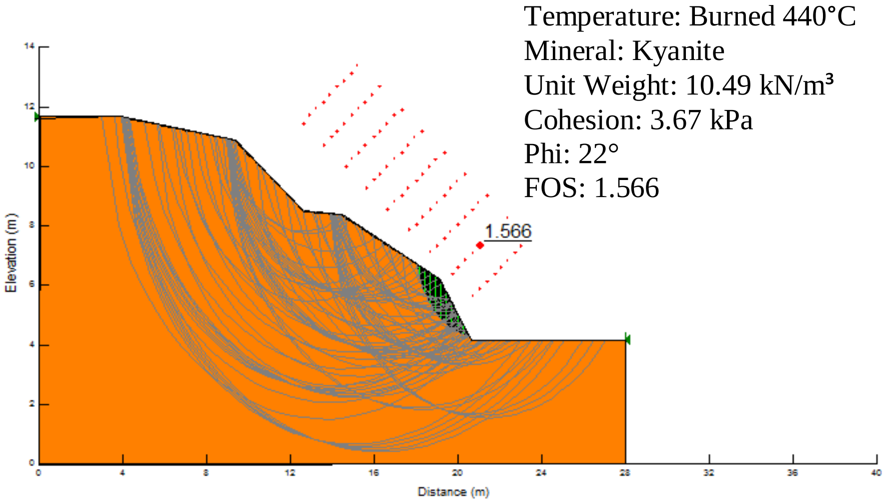
Temperature: Natural burned
Mineral: Andalusite
Unit Weight: 9.45 kN/m³
Cohesion: 0.07 kPa
Phi: 27°
FOS: 0.537

Figure 4.7 Modelling burned slope with moisture content 9.48%



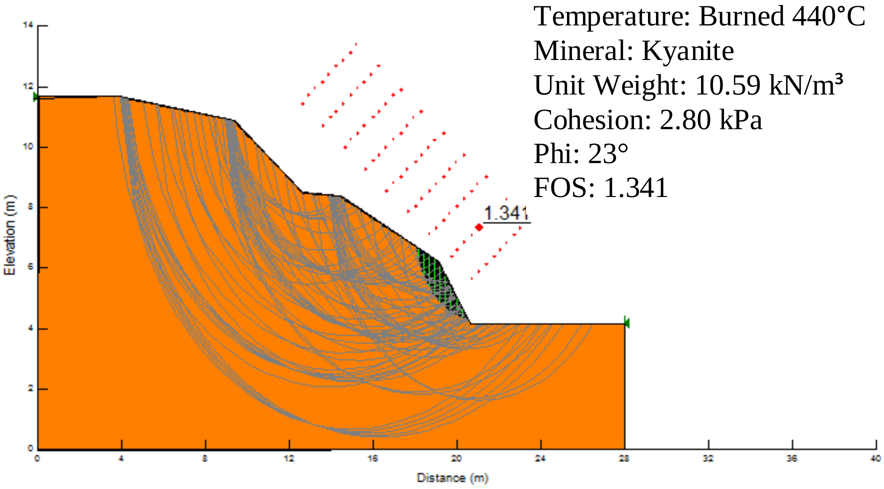
Temperature: Natural burned
Mineral: Andalusite
Unit Weight: 11.27 kN/m³
Cohesion: 0 kPa
Phi: 27°
FOS: 0.426

Figure 4.8 Modelling burned slope with moisture content 12.45%



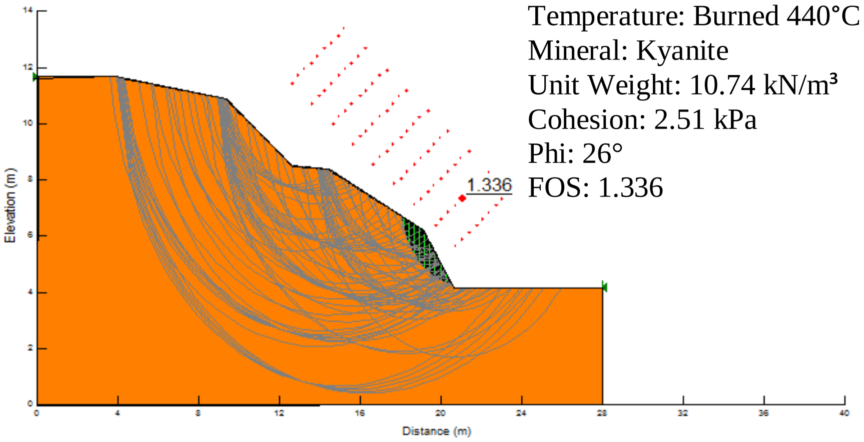
Temperature: Burned 440°C
Mineral: Kyanite
Unit Weight: 10.49 kN/m³
Cohesion: 3.67 kPa
Phi: 22°
FOS: 1.566

Figure 4.9 Modelling burned 440°C slope with moisture content 10.76%



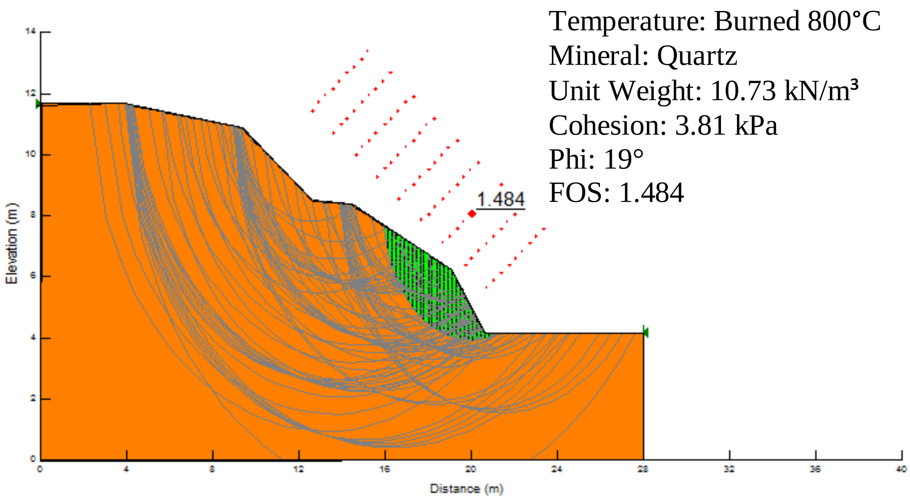
Temperature: Burned 440°C
Mineral: Kyanite
Unit Weight: 10.59 kN/m³
Cohesion: 2.80 kPa
Phi: 23°
FOS: 1.341

Figure 4.10 Modelling burned 440°C slope with moisture content 11.52%



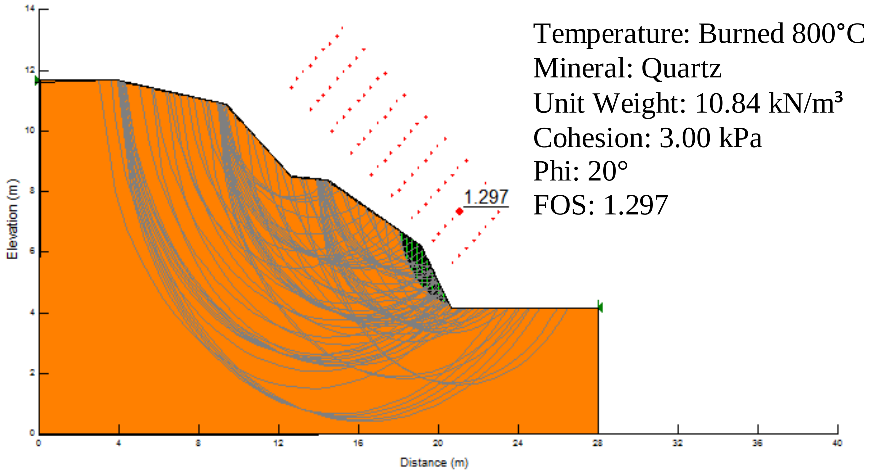
Temperature: Burned 440°C
Mineral: Kyanite
Unit Weight: 10.74 kN/m³
Cohesion: 2.51 kPa
Phi: 26°
FOS: 1.336

Figure 4.11 Modelling burned 440°C slope with moisture content 14.98%



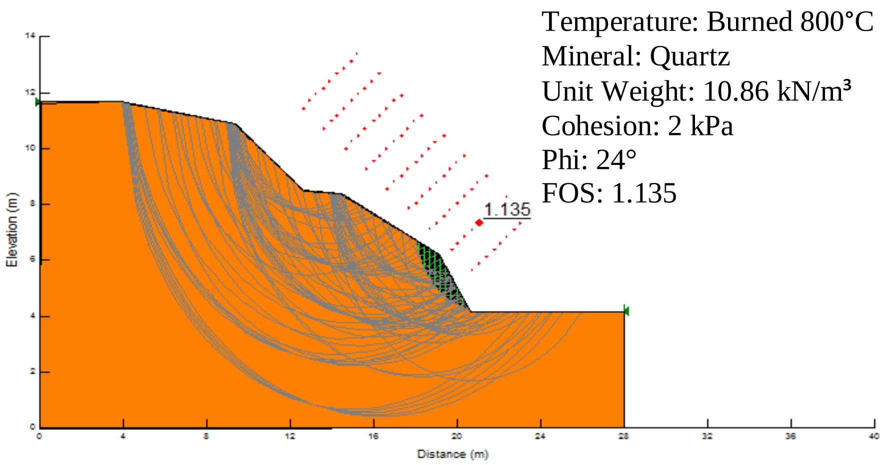
Temperature: Burned 800°C
Mineral: Quartz
Unit Weight: 10.73 kN/m³
Cohesion: 3.81 kPa
Phi: 19°
FOS: 1.484

Figure 4.12 Modelling burned 800°C slope with moisture content 3.46%



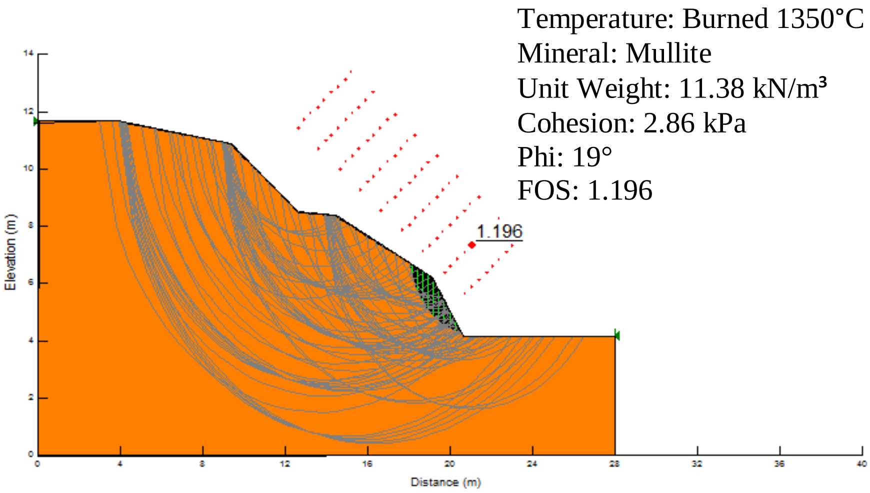
Temperature: Burned 800°C
Mineral: Quartz
Unit Weight: 10.84 kN/m³
Cohesion: 3.00 kPa
Phi: 20°
FOS: 1.297

Figure 4.13 Modelling burned 800°C slope with moisture content 5.81%



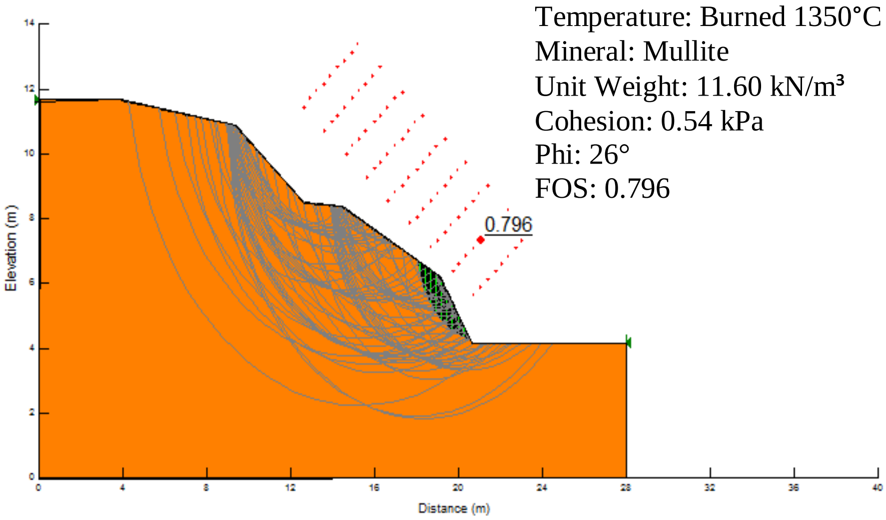
Temperature: Burned 800°C
Mineral: Quartz
Unit Weight: 10.86 kN/m³
Cohesion: 2 kPa
Phi: 24°
FOS: 1.135

Figure 4.14 Modelling burned 800°C slope with moisture content 7.98%



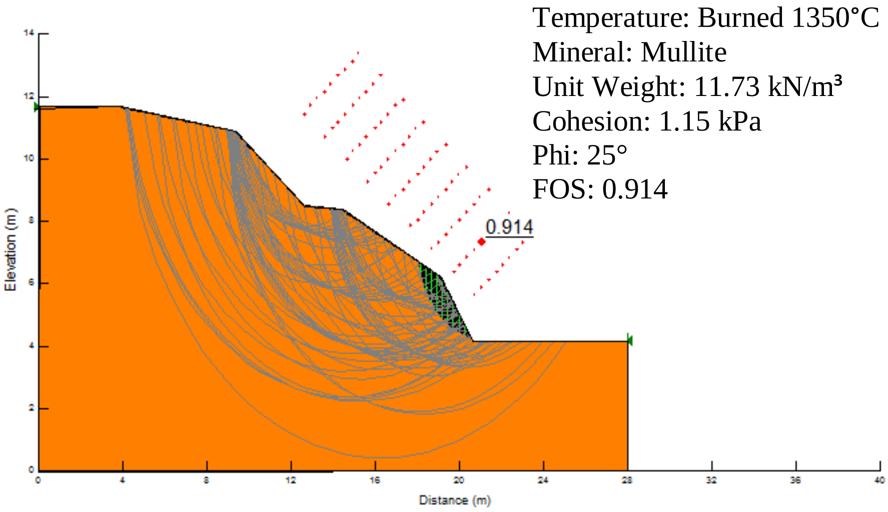
Temperature: Burned 1350°C
Mineral: Mullite
Unit Weight: 11.38 kN/m³
Cohesion: 2.86 kPa
Phi: 19°
FOS: 1.196

Figure 4.15 Modelling burned 1350°C slope with moisture content 1.49%



Temperature: Burned 1350°C
Mineral: Mullite
Unit Weight: 11.60 kN/m³
Cohesion: 0.54 kPa
Phi: 26°
FOS: 0.796

Figure 4.16 Modelling burned 1350°C slope with moisture content 3.42%



Temperature: Burned 1350°C
Mineral: Mullite
Unit Weight: 11.73 kN/m³
Cohesion: 1.15 kPa
Phi: 25°
FOS: 0.914

Figure 4.17 Modelling burned 1350°C slope with moisture content 5.18%

4.4.1.1 Effect of Water Content to Factor of Safety

This table section describes the slope stability analysis results of the different combinations of temperature using SLOPE/W based on selected water content from drying-water suction (SWCC) result.

Table 4.4 Factor of safety (FOS) for each water content of unburned soil

Unburned		
Soil Suction (Mpa)	**Water Content (%)**	**FOS**
7.28	6.32	1.169
6.14	7.04	1.055
3.75	10.86	0.801

For the case of unburned soil in Table 4.4, shows that the factor of safety was continuously reduced when the water content increase. FOS for specimen at 6.32% and 7.04% yielded approximately the same values, reaching 1.169 and 1.055 respectively. Marked drop was observed at 10.86% water content, where FOS reached only 0.801 which indicates critical condition of the tested hillside for unburned. A study conducted by (Vandamme et al., 2013) said that an increase in soil moisture content causes a decrease in its shear strength values.

Table 4.5 Factor of safety (FOS) for each water content of burned soil

Burned		
Soil Suction (Mpa)	**Water Content (%)**	**FOS**
10.28	5.50	0.858
4.43	9.48	0.537
2.81	12.45	0.426

Instead of natural burned sample shown in Table 4.5, the moisture content of all cases are in critical condition where the FOS has declined starting in the water content of 5.5%, 9.48% and 12.45% where FOS decrease from 0.858, 0.537 and 0.426 respectively. This may be due to the value of the cohesion parameter at 0 for 12.45% water content. The friction angle for this sample is the same as 27° for all cases of water content. A study conducted by (Zydroe et al., 2012) suggest that the instability of slope might be attributed to high percentage of sand fraction, which causes lower the value of cohesion, hence lower the values of shear strength. Reason of such drop can also be due to changes in unit weight, which need to be keep constant during all test.

Table 4.6 Factor of safety (FOS) for each water content of burned 440°C

Burned 440°C		
Soil Suction (Mpa)	**Water Content (%)**	**FOS**
3.39	10.76	1.566
3.4	11.52	1.341
0.81	14.98	1.336

However for the case in Table 4.14 for burned 440°C, the model predicted a slightly higher FOS in the early stages for water content 10.76% where the FOS was assigned value 1.566 was passed as described by the Geotechnical Manual for Slopes for the 10-year return period rainfall case Geotechnical Control Office, 1984 which imposed the slope requirement to exceed FOS 1.0 for negligible risk to life. Similarly, the water content of 11.52% and 14.98% showed the same value of FOS at 1.341 but slightly decreased from the original FOS value of 10.76% water content of FOS 1.566. The devaluation of the FOS is also closely related to the parameter of cohesion and phi at 11.52% that give the value of 2.80 kN/m² compared to 2.51 kN/m² in water content 14.98%. Here shows the value of water content rising, the value of cohesion will decrease and thus decrease the shear strength of a soil.

Table 4.7 Factor of safety (FOS) for each water content of burned 800°C

Burned 800°C		
Soil Suction (Mpa)	**Water Content (%)**	**FOS**
10.09	3.46	1.484
4.84	5.81	1.297
3.25	7.98	1.135

FOS most likely shows the same results for burned 800°C which provide the same trending as the water content increases, so the FOS value will decreases.

Table 4.8 Factor of safety (FOS) for each water content of burned 1350°C

Burned 1350°C		
Soil Suction (Mpa)	**Water Content (%)**	**FOS**
0.94	1.49	1.196
0.31	3.42	0.796
0.4	5.18	0.914

In the case of Table 4.8 for burned 1350°C, the trend of FOS is slightly different because in water content 1.49%, FOS value is at 1.196 and decreased in water content 3.42% but refined in water content 5.18% which 0.796 and 0.914 FOS value respectively. This may occur due to the cohesion of 5.18% is slightly greater than on the water content of 3.42%. Here there is no significant difference in phi values for this case.

According to study conducted by (Rees et al., 2012) where indicates that the vegetation and tress on slope induced soil suction and absorb excess water during rainfall. A study by (Rees et al., 2012) noted that, the presence of vegetation increased slope stability by about 8%. From this study, show that after burned the vegetation were absence , and the direct contact of precipitation on burned and dried slopes to an increased in hillslopes erosion and surface runoff. These proven with the result of this study shown that the suction result clearly indicate that at low suction where the water content is higher, the ability of the burned soil to absorbed water was limited. These situation makes it the vegetation difficult to growth and thus slightly affect the shear strength of the soil as well as decreasing the value of the FOS for the slope.

4.4.1.2 Effect of Mineralogical Structure to Factor of Safety

According to (Mohd Tadza et al., 2016), erosion occurred on-site was found to be attributed to reduction in the plasticity characteristic and changes to the mineral structure of the soil. Furthermore, the removal of vegetation as affected by fire reduced the slope surface cover and caused erosion of the slope to occur. The mineral composition were also evaluated using X-ray diffraction analysis which gives the result as shown in Table 4.9.

Table 4.9 Mineralogical properties of unburned and burned soil

Sample	Mineral Properties
Unburned	Andalusite
Natural Burned	Andalusite
Burned 440°C	Kyanite
Burned 800°C	Quartz
Burned 1350°C	Mullite

Source: (Mohd Tadza et al., 2016)

The graph of FOS versus water content at various temperature are presented in Figure 4.18.

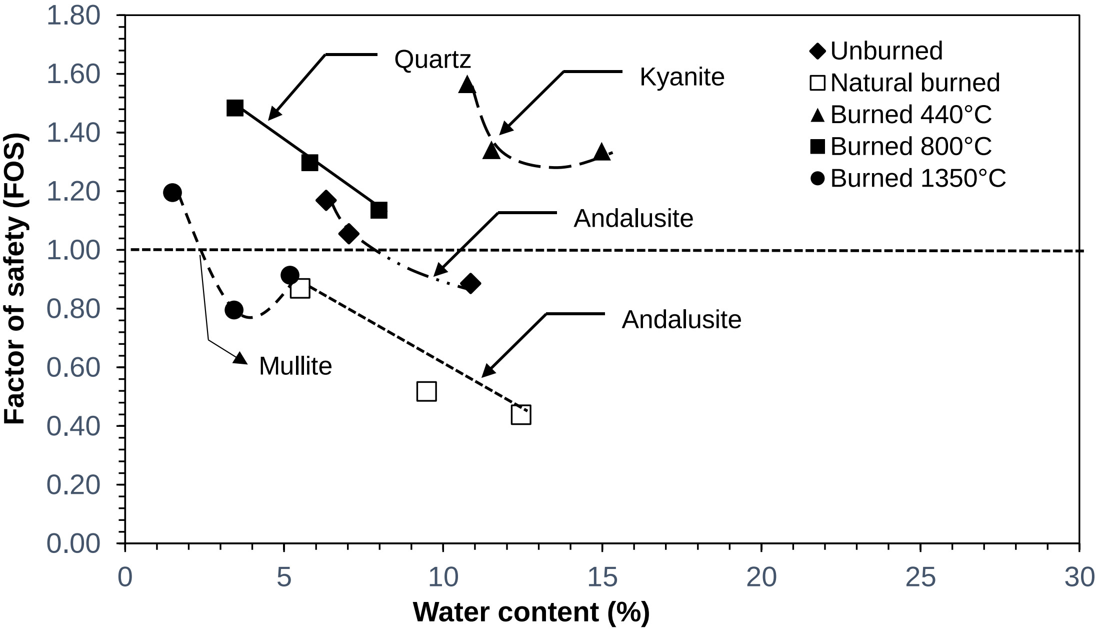


Figure 4.18 Influence of water content for factor of safety (FOS) of the sample

From the results according to temperature, the study found that the lowest FOS or critical failure was natural burned sample. Followed by sample of burned 1350°C which also had a low value of FOS compared to natural burned temperatures, 440°C and 800°C. But at temperature 1350°C, from XRD test results showed that the soil mineral turns to mullite. The findings of this study was found to be similar to (Speyer , 1993) where the temperature exceeding 1100°C kyanite decomposed into mullite. Due to temperature sensitive in nature of nesosilicates, it is expected that the change in the mineralogical composition would occur. Generally, kyanite is stable in low temperature and low pressure environment. Increasing temperature would lead to the transformation of kyanite to other type of minerals.

While noting the FOS for burned 440°C samples had highest value of FOS followed by a temperature of 800°C which the overall point of water content obtained the value exceed 1.0. At this temperature level burned 440°C, the soil minerals are in kyanite categories. For unburned soil mineral, the soil contains andalusite mineral compared to temperature at 800°C that contained totally quartz mineral. Post wildfire revealed that all andalusite minerals in unburned soil sample were converted kyanite minerals. This study shows that soil containing kyanite and quartz minerals are at a stable slope level whereas andalusite and mullite mineral soil types was shown a stability of less stable. The changes in the mineral structure of nesosilicates are expected to occur given that wildfire could have a temperature exceeding 440°C. It is anticipated that, these changes would resulted in increased soil erosion problems during heavy rainfall.

CHAPTER 5

CONCLUSIONS

The objectives of the thesis was to making a simulation model of factor of safety unburned and burned soil for slope at Jalan Gambang, Kuantan using SLOPE/W. The parameter of shear strength of the unburned and burned soil was determined at selected water content from drying soil water characteristic curves (SWCCs) resulted to study the effect of soil erosion on the changes in factor of safety value for unburned and burned soil for slope at Jalan Gambang, Kuantan. The physical and chemical properties of unburned and burned soils was determined following the standard laboratory procedure.

Based on the findings in the thesis, the following conclusion were drawn.

1. This study proved that temperature had significant effect on soil properties which consist of specific gravity, atterberg limits, swell potential, organic matter content and SWCC. However, the changes in these properties were higher when the temperature ranged from 440°C and 800°C.

2. Experimental results demonstrated that shear strength parameters are significantly influenced by moisture conditions and temperature. Test specimen showed variance in values of cohesion and friction angle, hence the value of FOS obtained from stability analyses differed.

3. From the results according to temperature, the study found that the lowest FOS or critical failure was natural burned sample. Followed by sample of burned 1350°C which also had a low value of FOS compared to natural unburned, burned 440°C and burned 800°C. From overall study, this modelling study examined that soil containing kyanite and quartz minerals are at a stable slope level whereas andalusite and mullite mineral soil types was shown a stability of less stable. This study

indicate that the erosion at the toe of the slope is captured from the modelling of post-fire erosion where the critical slip circle most often occurs at there. Thus, the erosion causes a significant change to the stability of the slope and should be included in the modelling of this problem.

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