APPLICATION OF THERMAL IMAGING FOR PREDICTION SOIL SATURATION FOR SLOPE MONITORING

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ABSTRACT

Landslide can cause human injury, loss of life and economical problem. One of the factors is due to the heavy rain. Hence, to overcome this problem, this study investigates a new method to detect spots of high water saturation which is integrated with a thermal camera system to provide early detection of landslide. This study examines the usage of thermal camera on slopes at hillside at Jalan Gambang for prediction of soil saturation of the soil. The thermal camera is selected because it provides accurate predict where landslide going to occur. Various soil properties were studied, including specific gravity, Atterberg limits, swell index and organic matter content. The soil-water characteristic curve (SWCC) of soil sample were also determined. Experimental results demonstrated that the results obtained are able to determine the point of soil that starts to saturate and from the thermal imaging, the image of the saturated soil will be in blue colour with range of water content stated for each image. From the observation, this technique is quite accurate but still has their weakness and error.

ABSTRAK

Tanah runtuh boleh menyebabkan kecederaan manusia, kehilangan nyawa dan masalah ekonomi. Salah satu faktor adalah disebabkan oleh hujan lebat. Oleh itu, untuk mengatasi masalah ini, kajian ini satu kaedah baru untuk mengesan tempat ketepuan air yang tinggi yang disepadukan dengan sistem kamera haba untuk menyediakan pengesanan awal tanah runtuh. Kajian ini mengkaji penggunaan kamera haba ke atas cerun di lereng bukit di Jalan Gambang untuk ramalan ketepuan tanah tanah. Kamera haba dipilih kerana ia menyediakan ramalan yang tepat di mana tanah runtuh akan berlaku. Pelbagai sifat-sifat tanah telah dikaji, termasuk graviti tentu, had Atterberg, indeks membengkak dan kandungan bahan organik. Lengkung ciri tanah-air (SWCC) daripada sampel tanah juga ditentukan. Keputusan eksperimen menunjukkan bahawa keputusan yang diperolehi dapat menentukan titik permulaan tanah untuk menjadi tepu dan dari pengimejan haba, imej tanah yang tepu akan berada dalam warna biru dengan pelbagai kandungan air dinyatakan untuk setiap imej. Dari pemerhatian, teknik ini agak tepat tetapi masih mempunyai kelemahan dan kesilapannya.

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LIST OF SYMBOLS

Gs	Specific Gravity
m_s	Mass of dry soil
Sr	Degree of Saturation
w	Water content
V	Volume
V_d	Volume of dry soil
ρ_w	Density of water

LIST OF ABBREVIATIONS

AEV	Air Entry Value
ASTM	American Society for Testing and Materials
BS	British Standard
CEC	Cation Exchange Capacity
EGME	Ethylene Glycol Monoethyl Ether
JPEG	Joint Photographic Experts Group
LL	Liquid Limit
MPa	Mega Pascal
PL	Plastic Limit
SL	Shrinkage Limit
SSA	Saturated Surface Area
XRD	X – Ray Diffraction

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Due to rapid development since 1980s, strategic and suitable low-lying areas for development have become limited in Malaysia. As result, development of highland or hilly terrain has increased, especially in areas due to high population of citizens (Suhaimi, 2006).

From 1993 to 2004, six major landslide were reported which cause nearly 100 fatalities. There were also landslide phenomenon that cause great significant disruption but with no fatalities recorded (Hussein, 2006):

- May 1999: Anthenaeum Condominium, Ulu Klang
- 2003: Rock slope failure at Bukit Lanjan on New Klang Valley Expressway

In Malaysia, the wet tropical climatic conditions constantly expose slope materials to weathering activities (Tan, 1995). Massive landslide in Malaysia are mainly attributed to frequent and prolonged rainfall, which is mostly related with monsoon rainfalls. Of all many places in Malaysia, Hulu Kelang area has received most publicity. It is located at the toe of the Titiwangsa mountain range. Total of 28 historical landslide event have been reported in Hulu Kelang area from 1990 to 2011 (Farisham, 2007).

According to Akmal (2006), there are several factors that lead to slope failure. Mostly in Malaysia, slope failure occurred due to the weather event. For an example, rainfall which is the major contributor to landslide. As addition, our country receives annual rainfall about 2000 to 3000 mm per year. The existence of excess of water through rainfall will penetrate into the soil and thus the soil become active. Other than decreasing the overall strength of slope, the excess water penetration and existing groundwater will increase the water pressure in the soil and seepage flow. Seepage reduces the stability of slope by making it easier to slide. Increase of moisture content in the soil will reduces the shear strength of the slope and thus decrease slope safety.

A new approach and method to detect spots of high water saturation will be developed which then to be integrated with a thermal camera system to provide an early detection of landslide. The proposed technique is to predict the area of landslide going to occur accurately using thermal camera. Thermal camera can be used to detect high water saturation spots which are key component that contributes to landslide activity (Chang, 2013). Thermal camera is able to identify spot of intense saturation, a red flag of a landslide, before any actual damage is done (Mollaee, 2013). Such spots of high water saturation are prime candidates for landslide activity when certain other criteria are met (Mehta, 2007).

1.2 PROBLEM STATEMENT

Slope fails due to too much presence of water that cause the soil to be fully saturated. Once the slope fully saturated, it tends to fail and this phenomenon called landslide. On the other hand, existing methods for slope monitoring are time consuming.

1.3 OBJECTIVES

The objectives of the study are:

I. To determine the shrinkage behaviour of unprotected natural slope material

II. To investigate the correlation between thermal imaging with variation in water content and degree of saturation

III. To evaluate the applicability of thermal imaging for slope monitoring

1.4 SCOPE OF STUDY

The soil is collected at slope of Jalan Kuantan – Gambang. It has been conducted through laboratory testing which its results are only applicable for soil at that area only.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents about several case studies of slope stability, types of slope failure, causes of slope failure and ways of monitoring slope failure.

2.2 SLOPE STABILITY

Slope stability is the potential of soil covered slope to withstand pressure and prevent the soil movement so collapsed can be avoided (Nelson, 2013). Most instability of slopes cases as sliding mass of soil, the sliding body in straight or curved sliding surface. Due to the stresses on top of the soil and the lower soil strength, especially in case of fine – grained soil, opening of cracks will occurs, which due to direction of motion, scarp on the surface will be revealed and this can lead to landslide (Bacic, 2014).

Slope failures are defined as sudden movement of slope materials under influence of gravity. Slope material consists of consolidated and unconsolidated materials such as soil, rock, artificial filling or a combination of the above (Nicholas, 1995).

Maintaining slope stability is important to support the safe and functional design of soil slopes. Parametric analyses allow one to assess the physical and geometrical problem parameter influence on the slope stability (Giani, 1988). He also stated that a rock and soil slope stability analysis allows one to evaluate:

1. The optimal staged excavation or construction time sequence determination.
2. The role, which design parameters such as slope angle and excavation or embankment height, play in the work stability.
3. Consolidation works such as retaining wall, drainage systems or rock – bolting, which can stabilize slope.

Factor of safety (FS) is equal to the ratio of resisting forces to driving forces. This can be refer to the equation below:

FS = Resisting Forces / Driving Forces

If FS > 1, it is classified as safe

If FS < 1, it is classified as not safe

A safety factor of ~ 1.25 or higher is acceptable for slope stability. A factor safety of ~10 is often used in building design to accommodate slight variances in materials and construction practises (Hughes, 2003).

2.3 TYPE OF SLOPE FAILURE

2.3.1 FALLS

In falls, a mass of any size is detached from slope along a surface on which there is no or little shear displacement takes place and mostly by free fall, leaping, bounding or rolling. The movement are very rapid to extremely rapid (Varnes, 1978).

According to Rapp (1960), newly detached material be called primary and those involving earlier transported loose debris be called secondary.

At Valtellina, Italy, the rock block fall movement been measured by velocities of more than 28 m/s on artificially induced rock blocks falls (>100 km/h) (Azzoni, 1991).

2.3.2 TOPPLES

Topples is a kind of movement consists of the forward rotation of a unit, or units about some pivot point, below or low in the unit, under the action of gravity and forces exerted whether by units or by water in cracks. It is tilting without collapse (Freitas and Watters, 1973).

2.3.3 SLIDES

In this type of movement, the mass remain basically intact while sliding along a definite failure surface (Roy, 2001). Slides consists of two structural sub – divisions:

a) Translational slides. Involves shear failure an almost planar surfaces in a down slope section (Hutchinson, 1988). The movement of translational slides is commonly controlled structurally by surfaces of weakness such as joints, bedding planes and variations in shear strength between layers or by contact between firm bedrock (Eckel, 1958).

b) Rotational slides. Common phenomenon involve sliding surface with a spoon shape or a convex cylindrical shape. Rotational slides mainly occur in slopes made up of relatively homogenous clay and shale deposits. It also occurs at slope of granular material or closely joint rock which pore water pressure is high (Giani, 1992).

Several incidents in Malaysia that related to slides are on January 1999 which occurred Squatters settlement, Sandakan Town, Sabah which has killed 22 people due to debris flow and failure of upstream natural dam during heavy rain triggered “snowball effect” debris avalanche (Suhaimi, 2006).

2.3.4 LATERAL SPREADS

Movement of lateral spreads is a lateral extension created by shear of tensile fracture generation and often determines when slope is formed by a stiff formation lying on soft formation (Giani, 1992).

Two type may distinguished:

a) Movement distributions results in overall extension but without a recognized or well – defined controlling basal shear force or zone plastic flow. The mechanics of movement are not well known (Varnes, 1958).

b) Movements may involve fracturing and extension of coherent material, owing to liquefaction or plastic flow of subjacent material. Coherent upper may subside, translate, rotate or disintegrate (Varnes, 1949).

2.3.5 FLOWS

In unconsolidated materials, it generally takes the form of fairly obvious flows, whether fast or slow, wet or dry. In bedrock, the most difficult movements to be categorized are in extremely slow and disturbed among many closely spaced, noninterconnected fractures or within the rock mass results in folding, bending or bulging (Varnes, 1978).

One of the incident that have been reported about flows is on November 2002 at Hillview, Ulu Kelang which has killed 8 people due to debris flow. Sliding or flowing of debris soil of abandoned projects during heavy rain (Suhaimi, 2006).

2.4 CAUSES OF SLOPE FAILURE

2.4.1 RAINFALL

One of the main factor that cause slope failure is rainfall and storm water activity (Farisham, 2007). Statistics indicated that the major triggering factor of slope failures is due to rainfall. Prolong of and high intensity of rainfall especially during monsoon periods every year allows rainwater penetrate with ease into slope and causes saturation at shallow depth in the field during the service life of slope (Niroumand, 2012).

Water may cause unstable conditions in slopes as it affects the changes in geometry of slope. Forces resulting from seepage of water through a slope have significant effect on stability of slope and this usually encountered in highway cut slopes and side hill fills (Havens, 1975).

Presence of water in soil will replace the air in pore space and it has ability to change angle of repose. Angle of repose for dry soil lies between 30 - 45º. As the soil becomes wet, angle of repose will be slightly higher because surface tension between water and soil grains tends to hold the grains in place. When too much presence of water, angle of repose reduced to very small values and the soil tends to move like fluid. This is due to the water gets between the grains and eliminates the frictional contact between grains (Nelson, 2013). The effect of water on soil particle is shown as Figure 2.1.

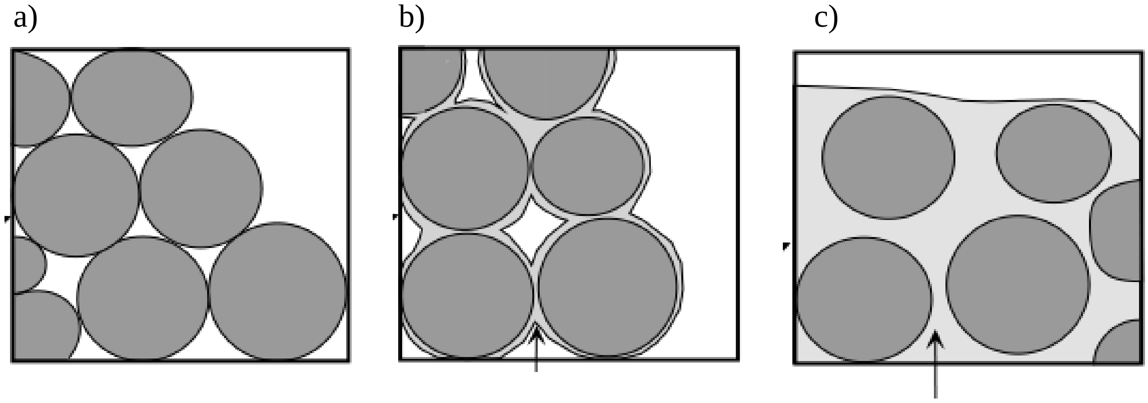

Figure 2.1: Effect of water on soil particle a) Grain to grain frictional contact, b) water holds the grain together, c) water eliminates all grain to grain contact

Based on the Figure 2.1, a) the soil particles are contact too each other as no presence of water and it is in stable condition. At b) the soil slightly become wet as presence of water occurred and water take over by holds the soil grains in place and c) when the soil becomes saturated with water, the soil tends to flow like a liquid as the water already eliminates grain to grain frictional contact .

2.4.2 EROSION

In agriculture, soil erosion refers to the wearing a way of a field's topsoil by the natural physical forces of water and wind or through forces associated with farming activities such as tillage (Ritter, 2012).

Some of the rainwater runs off the slope and cause surface erosion if the protection surface of the slope is inadequate (Anuar, 2012). According to Pimentel (1995), erosion results from energy transmitted from rainfall and even wind. Erosion is intensified on sloping land, where more than half of the soil contained in the splashes is carried downhill due to rainfall effect.

Erosion may lead to decline in soil quality. In fact, soil erosion can be manifestation of soil degradation because it involves physical movement of soil whether in a vertical and/or horizontal direction and it also degrades soil quality (Lal, 2001).

2.4.3 LOSS OF STRENGTH

Slip surfaces from previous landslides or tectonic behaviour make it easy to understand and predict slope's behaviour. The shearing strength along slip surface is very low due to prior movement has caused slide resistance to peak and gradually reduce the residual values (Abramsom, 2002).

Shear strength of soil is the internal resistance per unit area that the soil can offer to resist failure and sliding plane inside it. Knowledge of shear strength is required for solution of problems regarding slope stability (Ghafooripour, 2012).

According to Terzaghi (1936), shear strength is an important parameter for slope stability analysis as the factor of safety of slope is defined by the ratio of the resistance force to the mobilized force.

2.4.4 VEGETATION

Landslide frequency can increase after trees are removed from slopes (Croft and Adams, 1950). Vegetation can modify slope stability by adding slope surcharge from the weight of trees and levering and wedging soil by roots (Gray, 1970).

Several reports have been made stated that vegetation at slopes tends to reduce the stability of the soils (Greenway, 1987). The roots will increase permeability, infiltration and thus increase the pore water pressure of the soil. Not only that, vegetation increased the surcharge weight and loads on slope (Rickson, 2005).

The frequency of slope failure tends to increase when tress are cut down and their roots decay. This gradual decay of interconnected root systems was one of the cause of increased slope failure (Abe, 1997).

2.4.5 HUMAN ERRORS

Morgenstern (1995) stated that the catastrophic failure of Kwun Lung Lau landslide in Hong Kong is due to the input of human uncertainty. Mostly accidents or structural failures are not due to the loads variation or resistance but actually it is an outcome of human errors (Ellingwood, 1977).

According to Gue and Wong (2008), design errors like abusing the perspective method, construction errors pinpointing over excavation or wrong side excavation and maintenance errors like clogged drainage system. These are the major errors pragmatic by Malaysian construction industry that lead to rapid boost of slope failures take place in different regions of Malaysia.

Other than that, Subsurface Investigation and laboratory tests were not carried out to obtain representative soil parameters, subsoil and groundwater profiles for design and analysis of slopes (Gue & Tan, 2006).

2.4.6 EXTERNAL LOADING

Slope failure often aggravated by development activities such as construction of buildings, telecommunication towers and transportation systems. All of these activities are able to increase load and artificial vibrations on the surface of the slopes which results in slope instability in the areas (Knapen et al. 2006; Schuster & Highland 2007).

2.5 SLOPE MONITORING

2.5.1 INCLINOMETER

A slope inclinometer is a device for monitoring the onset and continuation of deformation normal to the axis of the borehole casing by passing a probe along the casing (Dunnicliff 1988). Thus, an inclinometer monitors deformation normal to the axis of the casing which provides a profile of subsurface horizontal deformation. The depth at which shear movement is detected by the slope inclinometer is the depth of the failure surface (Stark, 2007). As a landslide moves, the vertical casing moves in the direction of landsliding. The difference between the zero and subsequent readings is used to determine the change in the shape and position of the initially vertical casing (Terzaghi, 1967). As a landslide moves, the vertical casing moves in the direction of landsliding. Comparison of the verticality of the casing with time and width of the slide provides an insight to the magnitude, rate, direction, depth, and type of the landslide movement.

Unfortunately, many inclinometer projects fail to achieve the intended aim because of lack of appreciation of the many factors that need to be correctly implemented during installation, monitoring, and data reduction (Mikkelsen, 1986).

2.5.2 TOTAL STATION

Total station consists of a device to measure horizontal and vertical angles, along with capability to measure distance with help of Electromagnetic Distance Measurement (EDM) system (Affeni, 2013). This allows the surveyor to measure 3D coordinates of points remotely, typically targeted by the placement of reflective prisms. It also permits recording of the data in a digital format to be later downloaded or transmitted to a central processing site (Wylie, 2004). The main considerations for effective monitoring have to do with correct design, legal compliance, monitoring requirements and systems design that provide for both geotechnical and survey monitoring instrumentation (Cawood, 2006). Steps in slope monitoring using total station start with staffing and budget, in addition to systems design and implementation (Stacey, 2006). One advantage of using total stations to monitor surface deformation is that the measurements can provide 3D position solutions of the point of interest (Mah, 2004).

2.5.3 LASER IMAGE SCANNING SYSTEM

3-D laser scanning has recently become popular in the mining industry because of its high precision and speed, which surpasses that of the traditional single-point measurement method (Hack, 2004). This technique captures the integrated, comprehensive, consecutive and associated panoramic coordinate data with high precision. It also describes factually the frame and configuration of the object. Therefore, the resulting estimates are closer to actual conditions. The rescale range analysis method and a 3-D laser image scanning system are used to obtain slope data (Conforti, 2005). From this, the characteristic slope displacement may be analyzed. A 3-D laser scanning system is capable to predict slope failure with better accuracy (Crosetto, 2008).

The displacement monitoring equipment used in this study is a long-range terrestrial laser scan (TLS) which principle is based on the time-of-flight distance measurements using an infrared laser (Slob, 2004). This technology is very interesting for monitoring slope displacements because it provides a rapid collection of field topographical data with a high density of points (Rosser, 2007).

2.6 SOIL SATURATION

Saturation is soil water content when all pores been filled with water. Water content for soil saturation is same to the percent of porosity. Movements of water enter the soil is called infiltration. This is possible as soil is not solid matter instead it is a porous medium made of solid granular and voids that may be filled with water or air (Tarboton, 2003).

According to James Hartsig, 2016, he stated that water will move in and out of pores between soils if they are connected with each other and the water will moving both laterally and vertically. Movement of water also depends on the permeability of soils.

Soil permeability is the property of the soil to transmit water and air. It is known that sandy soil percolate water rapidly and clays are slightly impermeable (Baver, 1965). Table 2.1 shows the average of water permeability for different types of soil.

Table 2.1: Average permeability for different soil texture (cm/hr)

Sand	5.0
Sandy loam	2.5
Loam	1.3
Clay loam	0.8
Silty clay	0.25
Clay	0.05

From Table 2.1, clay has the lowest permeability which only 0.05 cm/hr while sand has the highest permeability which is 5.0 cm/hr. it shows that water can easily pass through sand as its size particle is larger compare to sandy loam, loam, clay loam, silty clay and clay.

2.7 THERMAL CAMERA

A new approach and method to detect spots of high water saturation will be developed which then to be integrated with a thermal camera system to provide an early detection of landslide. The proposed technique is to predict the area of landslide going to occur accurately using thermal camera. Thermal camera can be used to detect high water saturation spots which are key component that contributes to landslide activity (Chang, 2013). Thermal camera is able to identify spot of intense saturation, a red flag of a landslide, before any actual damage is done (Mollaee, 2013). Such spots of high water saturation are prime candidates for landslide activity when certain other criteria are met (Mehta, 2007).

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter presents the experimental testing on the soil. The soil is collected at slope Jalan Gambang as shown in Figure 3.1. The soil sampling is sieved passing 425 μm. Method to obtain physical and chemical properties, mineralogical properties and volume measurement of the soil are been focused in this chapter.

a) b) c)

Figure 3.1: Soil sample a) location, b) slope failure and c) location from satellite

Figure 3.1 shows the area of the soil sample location and failure of slope. The geographical location of the soil sample is approximately 3º43’12.1”N 103º08’36.5”E which is equal to latitude of 3.720025 and longitude of 103.143478.

3.2 PHYSICAL PROPERTIES

Specific gravity, particle size distribution, initial water content, liquid limit and plastic limit been referred to BS 1377: Part 2: 1990 and loss on ignition test is referred to BS 1377: Part 3: 1990.

3.2.1 SHRINKAGE LIMIT

Shrinkage limit is determined by following methods described in ASTM D4943-08 (2010). Soil specimens were prepared at 1.2 times their respective liquid limit values. Then, the specimens were placed into the greased shrinkage dish. Mass measurements were conducted frequently until no further reductions were noted. Specimens were then be removed for water content determination and volume measurement using wax method. The shrinkage limits of soil were calculated by using Eq. (3.4).

$$SL\ (\%) = \frac{[(V - V_d)]\rho_w}{m_s} \text{ x } 100 \tag{3.1}$$

Where:

SL = Shrinkage limit

V = Volume of wet specimen

V_d = Volume of dry soil

ρ_w = Density of water

m_s = Mass of dry soil

3.2.2 SPECIFIC SURFACE AREA

Specific surface area of soil is the total surface area contained in a unit mass of soil. Soil with higher specific surface area have higher water holding capacity, higher absorption contaminants and swell potential is higher too. Several methods available to determine specific surface area of soils whether in dry or wet conditions. The most commonly method used is adsorption of ethylene glycol monoethyl ether (EGME). The process is by saturating prepared soil sampler, equilibrating them in vacuum over a $CaCl_2$ EGME solvate and weight to find the point when equilibrium is reached. Specific surface then determined from the mass of retained EGME, comparing it with the amount of pure montmorillonite clay, which assume its surface area is 810 m^2/g (Tadza, 2011). The measurement usually takes 2 days to complete.

Soil is usually in hydrated state and surface area measurements also should be apply in hydrated state. Water is the ideal to be used as probe to determine specific surface area. Recent work however, using modern methods to determine specific surface area by measure the energy state of water is one of the simplest method.

3.3 CHEMICAL PROPERTIES

3.3.1 CATION EXCHANGE CAPACITY

Cation exchange capacity (CEC) or base exchange capacity is the ability of soil to retain certain amount of positively charged ions in exchangeable fashion on negatively charge surface (Bache, 1976). For any given soil, due to the environment and minerology conditions, the CEC is neither a fixed nor a single value and it is usually expressed in unit of positive charge (miliequivalent) per weight of dry soil (Van Olphen, 1977).

General methods used of measuring CEC are by ammonium acetate method (Chapman, 1965) and barium chloride compulsive exchange method (Hendershot and Duquette, 1986) by saturating the soil with NH_4^+ and Ba^{2+} at pH 7 (Grim, 1968).

For this project, method use is ammonium acetate method. The procedures are 5 g of soil was mixed with ammonium acetate solution in a 50 ml centrifuge tube and ammonium hydroxide was used to increase pH value to 7. Then, pH and conductivity meter was used as an indicator that the pH is at constant level of 7. Then, the sample was placed in centrifuge and subjected to a rotation of 115 rpm for 15 minutes. The soil solid fractions then was filtered using filter paper with the assist of a vacuum pump for accelerate the extraction process. Next 30 ml of 1 M ammonium acetate solution were poured four times, by letting the portion filtered completely before pouring the next to rinse the soil sample. Lastly, the liquid extracted from the test was collected and then be analysed using Inductively Coupled Plasma Optical Emission Spectrometry (ICP – OES) for various fractional of cations (Na, K, Ca^{2+}, Mg^{2+} and Al^{3+}) and the total of the cation complex were determined.

3.4 MINERALOGICAL PROPERTIES

3.4.1 X – RAY DIFFRACTION

5 g of soil is been tested using Desktop X – ray Diffractometer. The Diffractometer used is RIGAKU Miniflex II.

3.5 VOLUME MEASUREMENT

3.5.1 CHILLED MIRROR

300g of soil that has been sieved passing 425 μm is added with water with every increment of 2% of water content. Once water is added, the soil will be place in tin container and its mass is recorded. Approximately 5 g of soil is taken out from the tin container and be place in plastic container to be tested using chilled mirror apparatus as shown in Figure 3.2.

Figure 3.2: Chill mirror apparatus

Figure 3.2 shows the apparatus use for chilled mirror testing. Its model is WP4C. Before running the test of the sample in the apparatus, the soil must be in temperature of -19^{o}C to – 11^{o}C. Once the temperature has stabilize in the temperature range, turn the knob to “read” and wait for the machine to “beep” before collect the data. Repeat all steps until degree of saturation become 100% and graph will be plotted.

3.6 THERMAL IMAGING

Thermal camera used for this study is FLIR A655sc and a laptop installed with Matlab Programming R2013a. The camera is placed nearest to the slope which the maximum distance for the image captured is 50m. The position of the camera is not static as it is searched for higher risk spots in the study area. After recording the video of slope, that video was converted into image of JPEG (Joint Photographic Experts Group) image format by using Matlab coding.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

This chapter discuss about the results from conducted experiments. Final results from physical properties, correlation of thermal imaging and water content and relation of water suction to degree of saturation.

4.2 RESULTS

4.2.1 SOIL PHYSICAL PROPERTIES

The physical properties of soil are tabulated as shown in Table 4.1.

Table 4.1: Physical properties of soil

Physical properties	**Results**
Specific gravity, Gs	2.65
Liquid limit, LL	36%
Plastic limit, PL	25.53%
Shrinkage limit, SL	23%
Swell index, C_s	0
Organic matter content	4.09%

From Table 4.1, the Specific Gravity of the soil is 2.65 as the redundant mineral found in the soil is Quartz which is approximately 54%. Liquid limit, plastic limit and shrinkage limit are 36%, 25.53% and 23% respectively. The swell index is 0 as the soil does not expand when it is immersed in the water and its organic matter content found in the soil is 4.09%.

4.2.2 SUCTION – WATER CONTENT

The suction – water content curve obtained from the experiment of chilled mirror is presented in Figure 4.1.

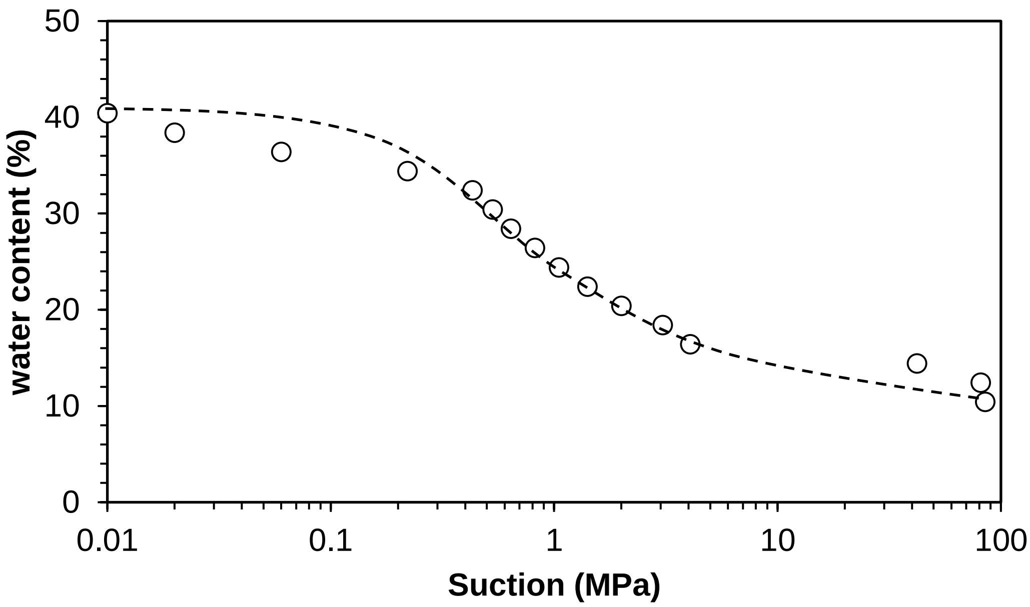

Figure 4.1: Suction – water content

Based on the experimental data from chilled mirror test, suction – water content curve can be drawn as in Figure 4.1. From the Figure 4.1, as the water content decrease, the suction value of water by the soil will also decrease. Excessive water is flow out from the soil and thus suction of water by the soil will decrease.

4.2.3 THERMAL IMAGING

Figure 4.2 shows the water content in the soil after been captured using the thermal imaging camera.

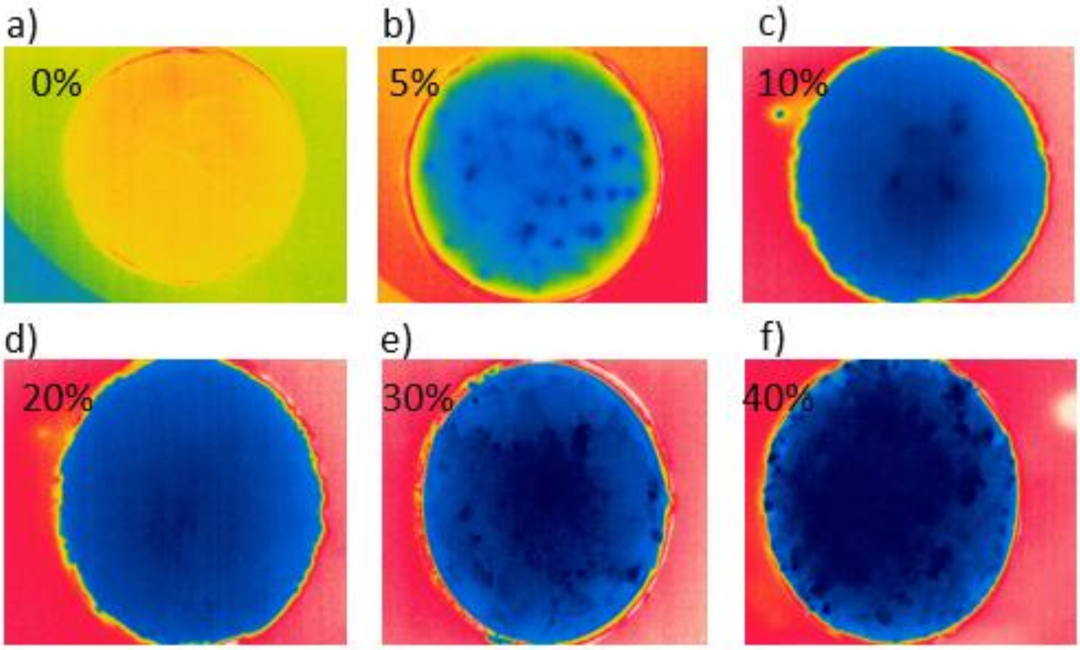

Figure 4.2: Thermal of the soil with a) 0%, b) 5%, c) 10%, d) 20%, e) 30% and f) 40% of water content

Based on the Figure 4.2, it shows that when there 0% water content, which means the soil is dry, the picture of the soil will be yellow or orange. When 5% water content present in the soil, light blue colour will appear and every increasing of water content to 10%, 20%, 30%, and 40%, the blue colour slightly change to dark blue. Darker blue shows that the soil is already fully saturated.

4.2.4 SHRINKAGE CURVE

Figure 4.3 shows the shrinkage curve of the soil. The measurements of shrinkage limit in this study depend upon the accurate measurement of the volume of the soil specimen as it dries out by air drying. Volume will decrease as the water content of the soil is decreasing. No further volume decrease indicates that the shrinkage limit is expressed.

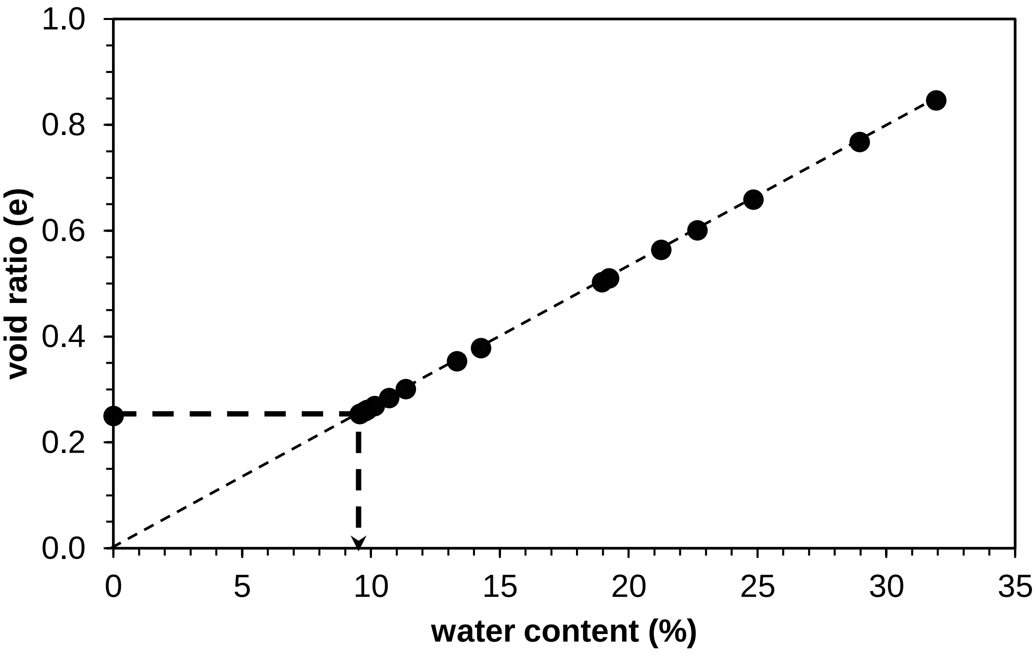

Figure 4.3: Shrinkage curve

Based on Figure 4.3, it indicates that the shrinkage limit occurs at void ratio of 0.25 which the water content is around 9%. At that point, the soil mass is already constant as it is already loss excessive of water. The solid particles of the soil are in close contact and the water content in the soil is sufficient to fill the voids between them. Further, reduction of water content cannot bring the particles together (Head, 2006).

4.2.5 SUCTION – DEGREE OF SATURATION

Figure 4.4 shows the Suction – degree of saturation curve which is obtained to determine the relation of degree of saturation and suction of water by the soil. Air entry value (AEV) is also been determined from this graph.

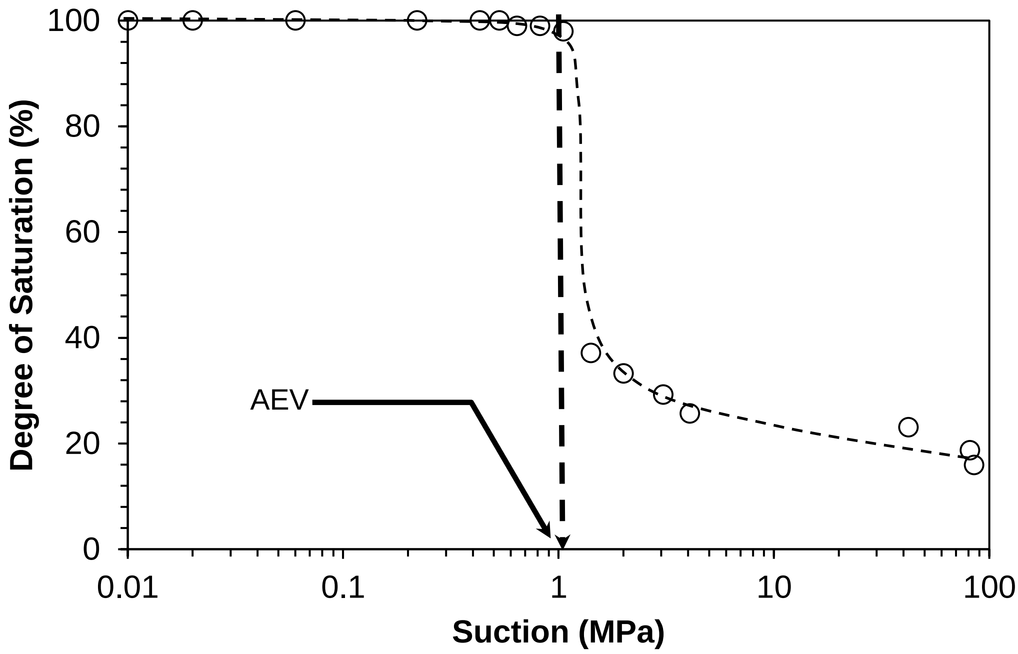

Figure 4.4: Suction – degree of saturation

From Figure 4.4, the higher that degree of saturation, the lower the suction of water by the soil. As the point where degree of saturation starts to drop, air entry value occurs. From the graph, air entry occurs when suction of water is around 1.05 MPa. Due to air entry value, the soil will turns from saturated to unsaturated as presence of void is increasing. From the table of properties, the Shrinkage limit is 25% and by referring to this graph, air entry value occurs when the water content is around 25% and the degree of saturation is 99%.

CHAPTER 5

CONCLUSION

The conclusion based on the finding of this research are as follows:

1. The shrinkage curve enabled the determination of the unprotected natural soil where the shrinkage limit will occurred when water content in the soil is at 9%.

2. Thermal imaging will detect the soil with different of colours to indicate the soil is saturated or not. It will shows colour of yellow or orange to indicate that the soil is in dry condition and blue if presence of water detected in the soil. The darker the blue colour shows that the higher the water content and degree of saturation of the soil.

3. From the experiment that have been conducted, water content and degree of saturation have been determined. As to compare to the thermal imaging picture, at 30% of water content, the slope has already become saturated. Apart from it, this thermal imaging can only predicting the soil which it begin to become saturated. It cannot determine the exact value of the water content which is the critical point of the soil starts to become saturated.

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