IMPROVING SOIL PROPERTIES TO PREVENT SURFICIAL SLOPE FAILURE

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To my beloved parents

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ABSTRACT

Many hill slope areas in Malaysia are vulnerable to soil erosion and shallow slope failures due to intense and frequent rainfall events. Rainfall induced slope failure can be attributed to: seepage force and seepage erosion, the loss of shear strength of the soil, and formation of tension cracks. Lime was used to improve soil properties and resistance against failure. When mixed with in-situ soil, the lime can reduce the potential for swelling and shrinkage; therefore inhibit the formation of cracks at the surface. Lime can also reduce the soil's dispersibility, therefore reduce the erosion potential. Soil mixed with lime has lower permeability, therefore enhance of capillary barrier effect and limit the rainfall infiltration into the soil. This study focuses on the improvement of soil properties to prevent surficial slope failure. Laboratory tests have been performed on soil and soil mix with deferent percentage of lime to evaluate properties of blended soil. The results show that the optimum lime content to be used in the mix design is 7%. A two dimensional finite element model of the slope was used to evaluate the performance of the optimum lime – soil mix as capillary barrier. The analysis revealed that the optimum thickness of slope cover system as capillary barrier is 30cm.

ABSTRAK

Kebanyakan cerun bukit di Malaysia mudah terdedah kepada hakisan tanah dan kegagalan cerun di sebabkan oleh hujan yang terlalu kerap. Kegagalan cerun akibat hujan boleh menyumbang kepada daya resipan dan hakisan resipan, kehilangan kekuatan ricihan tanah dan pembentukan keretakan tegangan. Dalam kajian ini, Kapur digunakan untuk memperbaiki ciri-ciri tanah dan ketahanan terhadap kegagalan tanah. Apabila bercampur dengan tanah in-situ, Kapur berupaya mengurangkan potensi tanah daripada membengkak dan mengecut: yang mana berfungsi menghalang pembentukan rekahan pada permukaan tanah. Kapur juga berupaya mengurangkan kebolehselerakan tanah, yang seterusnya menurunkan potensi hakisan. Tanah yang bercampur dengan Kapur mempunyai kebolehtelapan yang rendah, oleh itu meningkatkan kesan perintang kapilari dan had resapan air hujan ke dalam tanah. Kajian ini tertumpu kepada pembaikan ciri-ciri tanah untuk mencegah kegagalan cerun. Ujian makmal telah dijalankan terhadap tanah dan campuran tanah dengan peratusan Kapur yang berbeza untuk menilai ciri-ciri tanah campuran. Keputusan mendapati dengan menggunakan 7% kandungan Kapur, rekabentuk campuran tanah yang optimum dapat dicapai. Satu model cerun dengan dua unsure dimensi finit digunakan untuk menilai pencapaian Kapur yang optimum – campuran tanah sebagai perintang kapilari. Kajian telah menunjukkan bahawa ketebalan optimum untuk sistem penutup cerun dalam perintang kapilari ialah 30cm pada sudut tegak.

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k	-	Coefficient of Permeability
$Ca\ (OH)_2$	-	Calcium Hydroxide
MgO	-	Magnesium Oxide
$CaCo_3$	-	Calcium Ions
Ca^{2+}	-	Calcium Ions
CSH	-	Calcium Silicate Hydrates
CAH	-	Calcium Aluminates' Hydrates
Al^{3+}	-	Aluminum Ions
Si^{4+}	-	Silicate Ions
$CASH$	-	Calcium Aluminates Silicate Hydrate
LFC	-	Lime Fixation Capacity
ICL	-	Initial Consumption of Lime
$SWCC$	-	Soil Water Characteristic Curve
L_L	-	Liquid Limit
P_L	-	Plastic Limit
S_L	-	Shrinkage Limit
PI	-	Plasticity Index
h_1	-	Hydraulic Head at Beginning
h_2	-	Hydraulic Head at End
q_u	-	Confined Compressive Strength

φ	-	Friction Angle of Soil
c	-	Cohesion of Soil
UCT	-	Unconfined Compressive Test
Q	-	Flow Boundary
q	-	Unit Flux
OMC	-	Optimum Moisture Content
MDD	-	Maximum Dry Density

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CHAPTER 1

INTRODUCTION

1.1 Background

Slope failure is one of the oldest geotechnical problems. Even though it is less catastrophic as compared with other geotechnical hazards such as earthquake, the occurrence of landslide and slope failure is more frequent. Slope failures are costly to repair and can damage highway infrastructure such as guardrails, shoulders, pavement surfaces, drainage facilities, utility poles and slope landscaping. They can also create dangerous road conditions when debris flows onto highway. It is also a major problem during the construction of surface facilities.

One of the most significant components for slope failure occurrence is rainfall or rainstorm. Rainfall infiltration increases the moisture content of the soil hence raising the unit weight of soil and increasing the driving force. On the other hand, infiltration of rain water into soil alters the structure of the soil and thus reduces or eliminates frictional and cohesive strength (Reddi, 2003). It also have an effect on reducing the negative pore water pressure in unsaturated zone and increasing the positive pore water pressure that induced the seepage force in the saturated zone; thus decreasing the shear strength of the soil (Rahardjo *et.al.*, 2000).

Rainfall induced slope failure are most common in tropical region where the climatic condition is governed by wet and dry periods. Shrinkage or creep of the soil during dry periods after prolonged wet-and-dry cycles lead to the development of

tension cracks on the surface of a sloping land. During wet seasons, large amount of water infiltrated through the tension cracks and further seeped into the soil layers. The presence of tension crack also initiates a seepage pattern different from those predicted based on the original slope geometry and soil properties and this could certainly lead to slope failure (Gofar *et al.*, 2006).

In summary, the rainfall induced slope failure can be attributed to: (1) seepage force and seepage erosion, (2) the loss of shear strength of the soil, and (3) the formation of tension cracks. Which mechanisms will be dominant depend primarily on the rainfall pattern, soil properties and the relative shape of unsaturated characteristics curve of the soil (Collins and Znidarcic, 2004).

Soil properties estimate some of characteristics and features that affect soil behavior. The most essential soil properties affecting the response of soil to rainfall infiltration are the unsaturated shear strength, soil water characteristic curve and permeability function of soil (Gofar and Lee, 2008). The importance of permeability in the suction distribution was pointed out by Pradel and Raad (2003). Permeability refers to the ability of soil to transmit water or air through its pores and maximum permeability is reached when the soil becomes saturated. Soil with low permeability is preferred to limit the infiltration of rain water into the soil. However, the development of tension crack in such soil could increase the infiltration significantly. The presence of tension crack has been the reason for many slope failure presented in case studies for example by Gofar *et al.* (2006).

Apart from conventional methods of stabilization and bioengineering method to reduce erosion at slope surface, one of the possible mechanisms to improve the slope stability against rainfall induced slope failure problem is to utilize the capillary barrier effect where material with low permeability is placed on top of the natural soil. The additives such as lime can be mixed with in situ soil and decrease the permeability of the soil. Lime is a good additive to control the shrink swell behavior of soil (Kassim, 1998), thus preventing the formation of tension crack at the surface.

The effect of capillary barrier on controlling the rainfall infiltration has been studied by several researchers (e.g. Ross, 1990; Parent and Cabral, 2005) for the purpose of the design of as soil covers for landfill and mining waste. The possibility of utilizing the capillary barrier effect on slope was studied through physical model and numerical analysis by Yang *et al.* (2002) and Tami *et al.* (2004). The effect of capillary barrier reaches optimum when the upper layer is designed at a specific thickness and the difference in the permeability of surface layer and the bottom layer is about 3 to 5 orders of magnitude (Rahardjo *et al*, 2006). Despite of the research done on the potential application of capillary barrier on slope, no optimum design has been presented for the mitigation failure in natural as well as cut slope.

1.2 Problem statement

Rainfall induced slope failure can be attributed to, among other factors, the loss of shear strength of the soil due to reduction of matrix suction in unsaturated soil and the formation of tension cracks on the slope surface. One method to improve the slope stability against rainfall induced failure problem is to utilize the capillary barrier effect where material with low permeability is placed on top of the natural soil. The reduction in permeability can be expected by mixing natural soil with lime. Besides reducing the permeability, the lime is known as a good additive to control the swell shrink characteristics of soil, thus preventing the formation of tension crack.

This project will evaluate the effect of improving soil properties with the optimum percentage of lime in terms of permeability and shrinkage characteristics of soil. Furthermore, optimization of capillary barrier effect in terms of permeability disparity and thickness will be evaluated through numerical analysis.

1.3 Objectives of study

The aim of this study is to find the optimum percentage of lime to be used to obtain the most eligible soil cover to enhance the capillary barrier effect. To achieve this aim, the following objectives are proposed:

1. To investigate the effect of lime on the swelling characteristics of the soil and reducing the possibility of the development of crack at the surface, hence reducing the possibility of the occurence of surficial slope failure.
2. To enhance the capillary barrier effect by contrasting the hydraulic conductivity of the surface soil improved by lime and the original soil, thus improving the slope stability against surficial failure.

1.4 Scope of study

Soil sample for this study is collected at a location within UTM campus (across the road from Kolej 12) which frequently suffered from rainfall induced failure despite of past effort to stabilize the toe of the slope using gabions. The lime obtained from *Lime Treat*; Johor was used for the preparation of all test specimens. This study is limited to the following scope of work in order to meet the specific objectives:

1. Collect the existing data and information related to the study area, that is the soil properties and lime characteristics.
2. Perform laboratory test to obtain the effect of lime on soil and to find the optimum mix.
3. Evaluate the capillary barrier effect by numerical model using Seep/W from GeoStudio.