HYDROLOGICAL RESPONSE OF UNSATURATED GRANITIC RESIDUAL SOIL SLOPE DUE TO DIFFERENT RAINFALL AMOUNTS AND SLOPE ANGLE

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by

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LIST OF SYMBOLS

a	Borehole radius
A	Cross-sectional area of the soil sample
α^*	Microscopic capillary length factor
C_c	Coefficient of gradation
cm	Centimeter
cm/s	Centimeter per second
cm^2/s	Centimeter square per second
cm^3	Centimeter cube
C_u	Uniformity coefficient
D	Depth of the wetting front
D_{10}	Diameter corresponding to 10% finer
D_{30}	Diameter corresponding to 30% finer
D_{60}	Diameter corresponding to 60% finer
^{o}	Degree
f	Infiltration capacity
g	Gram
g/cm^3	Gram per centimeter cube
G_s	Specific gravity
H1	First water head height
H2	Second water head height
H_f	Pressure head at the wetting front
H_w	Thickness of the water layer
K	Saturated hydraulic conductivity

K_{f2}	Saturated hydraulic conductivity
kPa	Kilo Pascal
l/min	Liter per minute
m	Meter
min	Minute
mm	Millimeter
mm/h	Millimeter per hour
mm/min	Millimeter per minute
mm/s	Millimeter per second
%	Percent
ϕ_m	Soil matric flux potential
Q	Flow rate of the rainfall water
$\overline{R}$	Steady-state rate of fall of water in reservoir
v	Velocity of the total annual rainfall per hour

LIST OF ABBREVIATIONS

1D	One dimensional
2D	Two dimensional
3D	Three dimensional
ASTM	American Society for Testing and Materials
BS	British Standard
BSI	British Standard Institution
BSCS	British Soil Classification System
CH	High plasticity clay
CL	Low plasticity clay
E	East
GP	Guelph permeameter
GIS	Geographic Information System
Inc.	Incorporated
LL	Liquid Limit
N	North
PI	Plasticity Index
PL	Plastic Limit
SC	Clayey sand with gravel
SW	Well-graded sand
TDR	Time Domain Reflectometry
USM	Universiti Sains Malaysia

TINDAK BALAS HIDROLOGI CERUN TANAH BAKI GRANIT TAK TEPU DISEBABKAN OLEH PERBEZAAN JUMLAH HUJAN DAN SUDUT CERUN.

ABSTRAK

Tujuan kajian ini adalah untuk mengkaji tindak balas hidrologi cerun tanah residu granit tak tepu berdasarkan kepada kesan keamatan hujan dan sudut cerun yang berbeza. Kajian ini melibatkan ciri-ciri tanah residu granit dan eksperimen model cerun fizikal 2D. Pencirian tanah dijalankan ke atas pasir sungai (SW) dan tanah residu granit (SC) yang diperolehi dari Kampus USM Utama, Pulau Pinang menggunakan kaedah ujian tanah di lapangan dan makmal. Eksperimen model cerun fizikal 2D dijalankan bersama sistem simulator hujan, Time Domain Reflectometry (TDR) dan sistem tensiometer-transduser untuk menganalisis kepentingan sifat tanah dari segi tindak balas hidrologi seperti sedutan matrik tanah dan kandungan kelembapan tanah. Jumlah penyerapan air hujan dan air larian di permukaan juga diukur di penghujung eksperimen. Jumlah hujan yang diserap ke dalam tanah dan yang menjadi air larian di permukaan dengan intensiti hujan dan sudut cerun yang berbeza boleh dianggarkan. Dengan menjalankan model cerun fizikal 2D, didapati bahawa peratusan penyerapan air hujan dan kandungan kelembapan tanah mempunyai perbezaan yang sedikit tetapi perbezaan yang besar di antara pasir sungai (SW) dan tanah residu granit (SC) dari segi air larian di permukaan apabila kecerunan tanah meningkat. Dua nilai kadar hujan yang berbeza digunakan dalam kajian ini adalah berdasarkan kepada data dari intensiti hujan yang direkodkan oleh stesen hujan di Air Itam, Pulau Pinang. Data hujan ditukar dengan menggunakan persamaan kadar aliran, Q (butiran terperinci boleh dirujuk di bahagian 3.4.7.1).

Ketika keamatan hujan 9.78×10^{-9}m/s dan 1.66×10^{-9}m/s, nilai minimum air larian di permukaan untuk pasir sungai (SW) direkodkan ialah 15.7% dan 9.2% manakala nilai maksimum masing-masing adalah 28.9% dan 25.9%. Bagi tanah baki granit (SC), nilai minimum air larian di permukaan dicatatkan adalah 30% dan 30.19% manakala nilai maksimum adalah 54% dan 50.06% masing-masing untuk kadar curahan hujan gunaan bagi 9.78×10^{-9}m/s dan 1.66×10^{-9}m/s. Berdasarkan keputusan untuk kedua-dua pasir sungai (SW) dan tanah baki granit (SC), persamaan berkaitan dengan penyerapan air, air larian di permukaan dan kandungan kelembapan tanah dibentuk. Bagi pasir sungai (SW), persamaan penyerapan air hujan, air larian di permukaan dan kandungan kelembapan tanah adalah $y=43.78x^{-0.408}$, $y=16.47x^{0.4389}$ dan $y=37.737x^{-0.712}$ semasa kadar curahan hujan gunaan ialah 9.78×10^{-9}m/s manakala pada 1.66×10^{-9}m/s persamaan tersebut direkodkan adalah seperti $y=45.218x^{-0.316}$, $y=9.9649x^{0.7318}$ dan $y=23.091x^{-0.382}$. Bagi tanah baki granit (SC), semasa kadar curahan hujan gunaan 9.78×10^{-9}m/s persamaan bagi penyerapan air hujan, air larian di permukaan dan kandungan kelembapan tanah adalah $y=42.582x^{-0.493}$, $y=28.254x^{0.4409}$ dan $y=34.945x^{-0.314}$ manakala $y=40.633x^{-0.386}$, $y=29.754x^{0.3589}$ dan $y=35.62x^{-0.384}$ semasa 1.66×10^{-9}m/s kadar curahan hujan gunaan. Dengan mengambil kira jumlah hujan yang menyerap masuk ke dalam tanah dan menjadi air larian di permukaan, kedua-duanya didapati mengalami penurunan dalam penyerapan air hujan dan kandungan kelembapan tanah tetapi meningkat bagi air larian di permukaan apabila kecerunan sudut tanah meningkat. Ini membuktikan bahawa, peningkatan kecerunan sudut tanah juga meningkatkan kandungan air hujan yang menjadi air larian di permukaan daripada diserap ke dalam tanah.

HYDROLOGICAL RESPONSE OF UNSATURATED GRANITIC RESIDUAL SOIL SLOPE DUE TO DIFFERENT RAINFALL AMOUNTS AND SLOPE ANGLE.

ABSTRACT

The aim of this study is to investigate the effect of different applied rainfall rate and slope angle on the hydrological response of unsaturated soil slope. This study involved the granitic residual soil characterization and 2D physical slope model experiments. Soil characterizations included in this study are in-situ and laboratory soil tests which was conducted on the river sand (SW) and granitic residual soil (SC) obtained from the USM Main Campus, Penang Island. The 2D physical slope model experiment is conducted with the rainfall simulator system, Time Domain Reflectometry (TDR) and tensiometer-transducer system to analyze the significance of soil properties in terms of hydrological responses which are soil suction and water content. The amount of rainfall infiltration and surface runoff were also measured by the end of the experiment. The amount of rainfall infiltrated into the soil and became surface runoff with difference applied rainfall rate and slope angles can be estimated. By conducted 2D physical slope model, it was found that the percentage for water infiltration and soil moisture content were slightly different, but substantially different in surface runoff when the soil slope angle increased between river sand (SW) and granitic residual soil (SC). Two difference value of applied rainfall rate used in this study is based on the data from rainfall intensity recorded by the rainfall station in Air Itam, Penang. The rainfall data are converted by using the flow rate, Q equation (details can be referred in section 3.4.7.1). During the applied rainfall rate of 9.78×10^{-9}m/s and 1.66×10^{-9}m/s, the minimum surface runoff for river sand (SW)

recorded are 15.7% and 9.2% whereas the maximum surface runoff are 28.9% and 25.9% respectively. As for granitic residual soil (SC), the minimum surface runoff recorded are 30% and 30.19%, while the maximum surface runoff are 54% and 50.06% of applied rainfall rate of 9.78×10^{-9}m/s and 1.66×10^{-9}m/s respectively. Based on the results of both river sand (SW) and granitic residual soil (SC), the equations related to water infiltration, surface runoff and soil water content are obtained. For river sand (SW), the equations of water infiltration, surface runoff and soil moisture content are recorded as $y = 43.78x^{-0.408}$, $y = 16.47x^{0.4389}$ and $y = 37.737x^{-0.712}$ during the applied rainfall rate of 9.78×10^{-9}m/s while during 1.66×10^{-9}m/s the equations are recorded as $y = 45.218x^{-0.316}$, $y = 9.9649x^{0.7318}$ and $y = 23.091x^{-0.382}$. For granitic residual soil (SC), the equations of water infiltration, surface runoff and soil moisture content during applied rainfall rate of 9.78×10^{-9}m/s are recorded as $y = 42.582x^{-0.493}$, $y = 28.254x^{0.4409}$ and $y = 34.945x^{-0.314}$ while $y = 40.633x^{-0.386}$, $y = 29.754x^{0.3589}$ and $y = 35.62x^{-0.384}$ during 1.66×10^{-9}m/s applied rainfall rate. By measured the amount of the rainfall seeped into the soil and became surface runoff, it was found that both soils decrease water infiltration and soil moisture content but increase surface runoff when slope angle increased. These proved that, as the slope angle increased more rainfall became surface runoff than infiltrated into the soil.

CHAPTER ONE

INTRODUCTION

1.1 Background

The downslope movement of rock debris and soil in response to gravitational stresses or also referred to as mass wasting is the most encountered problems in Geotechnical engineering field (Keller, 2000). These slopes become unstable and cause severe geologic hazards due to the nature of topography, including slope angle, aspect, gradient and curvature, and the weather conditions. Globally, slope failure depends on the geological characteristics, hydrological condition and rainfall distribution (Chau et al., 2004; Dong et al., 2012). Significant numbers of slope failure in Malaysia are reported on man-made and residual soil slopes especially during high intensity rainfall. However, there are three common triggering factors for slope failure with respect to Malaysia which are rainfall intensity, groundwater level change and change of slope loading due to hydrological condition which gives unfavorable impact on the slope stability (Mizal-Azzmi, 2011). Therefore, it is important to consider the geological characteristics, local weather and soil characteristics to properly design the slope (Song et al., 2012).

The occurrence of rainfall-induced slope failure in steep residual soil slopes is a problem encountered in many tropical and subtropical regions. This type of slope failures also occurs in temperate regions of the world when periods of extreme rain and rapid snowmelt take place. One of the most common triggering mechanisms for slope failures is rainfall and the consequent water infiltration (L'Heureux, 2005). Deep-seated rotational and shallow translational failures can often be spotted in slopes after prolonged or heavy rainfall events. Deep-seated rotational failures are assumed directly caused by the water infiltration. The failures will be generated by a rise in the groundwater level and pore-water pressure subsequently lowering the effective stresses in the soil. Usually, this case occurs below the groundwater level. On the other hand, the occurrences of shallow translational failures are mainly triggered in the zone above the groundwater level. These happen once the rain water infiltrating the unsaturated zone of the soil, and then the negative pore-water pressure starts to decrease due to an increase in the water content (L'Heureux, 2005). It is reasonable to neglect the negative pore-water pressure effect when the failure is lying below the phreatic line. However, when deep groundwater level conditions and shallow failure is of concern, negative pore-water pressures should not be ignored (Fredlund & Rahardjo 1993). The magnitude of the negative pore-water pressure is influenced by the depth of the groundwater table. The deeper the groundwater table, the higher the possible negative pore-water pressure. Therefore, the effect of the groundwater table on the negative pore-water pressure becomes particularly significant near the ground surface (Blight, 1980).

The rainfall-infiltration and runoff process (RIRP) is a significant part of the slope hydrologic process. There is an applicable technique to study RIRP by using 2D physical slope model. RIRP is related to many factors, such as rainfall intensity, soil properties and terrain slope. Many researchers have further study related to these aspects. Then, it was found that the presence of soil surface seals or crusts can lead to decreasing of infiltration rates and lower air permeability values (Bissonnais, 1990), increasing surface runoff (Valentin & Bresson, 1992) and thus, accelerate sheet and rill erosion (Ries & Hirt, 2008). Soil crusts are thin layers indicated by greater density, higher shear strength, finer pores, and lower saturated hydraulic conductivity than the underlying soil (Assouline, 2004; Lado et al., 2005). It is obtained from complex and dynamic processes where the soil particles are rearranged and then consolidated into a cohesive superficial structure. The thickness of the soil crust varies from 0.1 to 50 mm (Valentin & Bresson, 1992).

According to (Weyman, 1973), the measurements at various field sites indicate that the saturation may be observed first on the slope either at the bottom of the slope in perched zones at midslope or above (Harr, 1977; Reid et al., 1988), or even simultaneously along the slope (Sidle, 1984). Based on the observations, the saturated zone is typically recedes first on the upper reaches of the slope (Anderson & Burt, 1977; Sidle, 1984). This is the substantial influence of the topography on the location of saturation (Anderson & Burt, 1977; Wilson & Dietrich, 1987; Tanaka et al., 1988). It has been observed that the hydraulic gradient in the saturated zone mainly contains a variety of orientations (Harr, 1977; Tanaka et al., 1988).

This study is carried out to investigate the aspect of slope hydrology works thatinvolve the effect of different applied rainfall rate and slope angle on the response of unsaturated granitic residual soil slope. These are significant before any slope failure prevention or slope protection take place. This study will focus on the changes in soil behavior due to different slope angle and applied rainfall rate. Several parameters that are taken into account are matric suction, water content, applied rainfall rate, infiltration rate and rate of surface runoff.