Rainfall-Induced Hydraulic Properties for Unsaturated Soil in Klang Valley

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Abstract. Klang Valley area is one of the most landslide-prone areas in Malaysia, especially at Hulu Kelang, Kuala Lumpur. The area has been frequently hit by landslide since 1990s. Soil instability is agreed by researchers occurred due to high precipitation and long duration of rainfall which cause property damage and leading to injury and fatality. Slope failure is also triggered by the antecedent rainfall leads to infiltration of rainwater into soil. Therefore, study of rainwater infiltration is vital to relates soil – water interaction and soil behaviour for varies of rainfall intensities and duration for unsaturated soil. The objective of this paper is to determine and compare soil water characteristic curve (SWCC) which is one of the soil hydraulic parameters for Klang Valley area. Samples were collected to determine the soil hydraulic properties at Hulu Kelang area, Universiti Kebangsaan Malaysia (UKM) and Universiti Pertahanan Nasional Malaysia (UPNM) campuses. SWCC was obtained by pressure plate extractor apparatus experiment and the analysis was performed using Van Genuchten equation. Result of parameters obtained shows significant differences of soil at Hulu Kelang area compared to soils at UKM and UPNM campuses. This research is relevant to supports national slope master plan 2009-2023.

1. Introduction

Landslides occur due to decreasing of soil shear strength that leads to instability of the slope. The slope instability is dependent on the cohesion movement of the soil particles and with internal friction of the soil, geometry of the soil, slope angle and hydraulic behaviour of the soil, triggered by the rainfall infiltration. Previous research had shown perched water table development, increment level of groundwater table, existence of surface erosion and the denser in soil unit weight are depending on the soil moisture content from the rainfall process [1]. The factor of safety is the influential of soil slope stability analysis especially in geotechnical structure as well as in slope engineering design. The factor of safety is defined as the ratio of the shear strength to the shear stress. The unstable slope gives the safety factor output of less than 1. The factor of safety also represents the ratio of resisting forces to driving forces. The slope failure would be quick sliding when the resistance safety factor is below the allowable safety factor [2]. The volumetric water content of the slope increasing extremely followed with the decreasing of the safety factor during the raining season.
It is observed that the soil structure changed due to the precipitation of rainfall infiltration. The rainwater infiltrates into the soil structure through the voids of the particles. The major geotechnical problems to the structure are influenced by the presence of water. The history of the landslides zone is occurred from the rainwater, leaking pipe from the drainage and the presence of water through the void of soil particles. In consequence, water can cause a disaster to the slope instability, hence it induced the hydraulic properties of the soil matric suction. As the result, the slope stability formed a negative impact since water can pass through porous space and fracture in soil.

The rainfall intensity reduces the factor of safety marginally [3]. It was introduced that water in the soil categorized into water of gravity, water of capillary and water of hygroscopic [4]. The freely movement of water due to the force of gravity through the soil is known as water gravity. Water of capillary exists when the water moves due to the potential of capillary. Meanwhile, the adhesion force is required to hold very tightly the films formed by water of hygroscopic around the soil particles surface. The rainfall influenced the variation of the soil behaviour accommodate with the higher the rainfall intensity, the lower of effective cohesion and internal degree of friction, the lower or even disappearance of matrix suction, and the appearance and higher of pore water pressure [5].

The rainfall infiltration sustained by gravity and capillary action from the soil particles that able to collect the intensity of rainwater and creates groundwater table. The rainwater infiltrate into the ground while the capillary action promotes the capillary potential and capillary conductivity between the void of the soil particles. The relationship between the capillary potential with condition for water transmitted and stored when the soil in the unsaturated state was measured by E. Buckingham [6]. The increment of the pore air pressure together with the decrement of matric suction occurred due to the advancing wetting front during the process of rainwater infiltration to the soil slope of unsaturated zone. This phenomenon leads to decline of slope stability [7].

The presence of water in the soil particles is the major problems for geotechnical structure. Pores with variation geometry, sizes, and connectivity in the porous system of soil are reflected from the results of the soil hydraulic properties [8]. The weathering process of the soil triggered the movement of soil particles. Climate in Malaysia is equatorial throughout the year with hot, humid, and rainy. Soil slope becomes less stable when the matric suction decreases while the unit weight of soil increases due to the rainfall infiltration. From the previous observation, it is found that hydraulic conductivity of soil is the main role in rainfall-induced failures of the slopes. Moreover, it was stated that residual soil slopes have experienced a very long and severe weathering process consequently these slopes are potentially susceptible to instability [9].

1.1. History of Affected Area

In the area of Hulu Kelang, rainwater is the major factor influence the slope stability. The factor of safety decreases when the rainfall intensity increases. The annual rainfall can achieve as high as 4500 mm. The intense chemical weathering and formation of thick residual soil profiles influenced by the high temperatures combined with the annual rainfall. It was found that landslides are the deadliest catastrophic other than flood [10]. The landslides often happened during monsoon seasons each year.

Hulu Kelang region is one of the most prominent landslides tragedies in Malaysia. The historical of the avalanche zone demonstrates that various slope failures have happened to ensure the safety for the residents. The major landslides knocked in 1993 where the building of Highland Tower apartment was collapsed. There are 48 people killed during the tragedy. In 1999, many people were trapped in their homes when a landslide occurred near the Athenaeum Tower condominium and reoccurring until 2000. In another year, the instability slope is found in Taman ZooView, Ulu Klang which happened twice in October and November of 2001. The Taman Hill View is another location occurrence with landslides in November 2002. Later, in 2003, the Oakleaf Park Condominiums was having a major landslide on November and followed by the Jalan Bukit Mulia in five days after. In 2008, a landslide buried 14 bungalows in Taman Bukit Mewah. In 2017, the landslide in the Riverdale Park Apartments caused shock to the residents although there were no casualties or structural damages. In 2018, the backyard of Bukit Antarabangsa Mosque damaged due to the landslides. Therefore, mentioned
tragedies provides evidence to investigate the location of Bukit Antarabangsa as one of location prominently with major landslides.

This paper is to investigate the correlation of the soil basic properties and its hydraulic properties which is SWCC in which indicates the soil behaviour towards soil stability of each location. The results from this study are intended to provide future basic risk management plan.

2. Methodology

2.1. Location of study

This research study was conducted by using three previous papers about unsaturated soil. Previous researchers have studied the hydraulic conductivity impacts to the soil where the slope failure affected by the rainfall based on current condition for every year of rainfall event. The slope stability may change every year from the rainwater infiltration. The pore water pressure distribution in unsaturated zone is influenced strongly by the saturated or unsaturated permeability. Thus, this study is focused on the comparison of previous papers of the same method used which is soil water characteristic curve (SWCC) but at different locations which are the area with landslides tragedy (Hulu Kelang), the area of rainforest reserved (UKM) and the area of the development (UPNM).

It was discovered that 24 locations from Hulu Kelang soil slope region [11]. The major landslides of Highland Tower have been observed that it caused by the leakage of pipe under the ground [12]. However, the further question is whether the main problems of pipe leakage are the main cause of all the landslides in Hulu Kelang region. This question has previously never been addressed because the investigation from the causes of the landslide’s disaster is still in observation. From previous researchers, landslides in Malaysia are triggered by earthquakes, rainfall, and volcanic activities, changes of groundwater and slope profile or combinations of all these factors. Therefore, further investigation is needed to find out the factors of the landslides in Hulu Kelang region.

The investigation of the effect rainfall infiltration into unsaturated soil using column located at Universiti Kebangsaan Malaysia (UKM) has been done by A. Ibrahim et al. [13]. The UKM main campus in Bangi is an area covered with the permanent reserved forest. The area is officially known as Bangi Forest Reserve (BFR) and act as a catchment area. The forest acts as a big sponge that soaking the rainwater while the infiltration process also occurred at the roots of the trees water seep into the ground. The slope of this rainforest reserved is considered stable.

R.M Ammer [14] studied the hydraulic properties parameter at Sungai Besi Camp Area. This paper is chosen because the area of Sungai Besi Camp especially in Universiti Pertahanan Nasional Malaysia (UPNM) is in progress with the development. Thus, one of the locations in Sungai Besi Camp area had been investigated and the hydraulic properties of the soil have stated in the results of this paper.

2.2. Instrumentation

All data were obtained through undisturbed samples that have been saturated. Samples were placed in pressure plate extractor machine and varies of pressures were applied to the samples. Each sample was weighted before increment of subsequent pressure applied to the sample. Then, results are interpreted using graph of suction versus volumetric water content. To obtain the parameters, the results measured through laboratory works were fitted using Van Genuchten [1] equation. It is suggested by M. Mukhlisin et al. [15] that this equation is widely used model and the equation is expressed by:

\[
Se=\left[\frac{1}{1+(ah)^n}\right]^m \quad (m=\frac{1}{1-n})
\]

(1)

where, \( Se \) is the effective water content, \( h \) is the suction head, \( a \) and \( n \) are the fitting shape parameters of SWCC [16].

3. Results
3.1. Basic properties of soil

It is noted that the soil consists of particle of minerals, organic matter, water molecules and air void where the combination of all these can determine the basic properties. Those properties of soil which are used in the identification and classification of soil are known as Index Properties. The variety Index Properties of soil are water content, in-situ density, specific gravity, particle size and consistency. The texture of the soil and the structure of the soil together with the types of soil also determined the soil properties. The basic properties of soil were obtained from the laboratory by testing the soil for moisture content, porosity, bulk density, and soil classification.

Based on the previous studies by T.H Guan [11], A. Ibrahim et al. [13] and R.M Ammer [14], soil of Hulu Kelang area is classified as very clayey sand while reserved forest soil in UKM is classified as poorly graded gravel with sand. Soil of UPNM development area is classified as silt and clayey sand. These three distinctive groups of soil will give better representation on hydraulic properties of every soil respectively.

3.2. Hydraulic properties of soil

Hydraulic properties of soil are defined as the behaviour of the soil. It can be measured by using soil water characteristic curve (SWCC). Hydraulic conductivity defined the movement of water in the soil that passes through the interconnected void spaces and to show the type of the soil which is silt, sand, or loam. According to A. R. Dexter [8] the pores with variation geometry, sizes and connectivity in the porous system of soil are reflected from the results of the soil hydraulic properties. The soil hydraulic properties reflect the movement of water for saturated and unsaturated soil condition through the void of soil particles. The pore size distribution reveals the hydraulic properties of soil due to the present of watercourse at the porosity of soil which relates with the definition of hydraulic conductivity, $K$ [17].

Figure 1 show graphical presentation of SWCC plot derived from data of soil of every location. Table 1 shows the parameter obtained from the graphical data of SWCC of every soil.

The type of soil can affect the values of volumetric residual water content, $\theta_r$ and pore-size distribution, $n$ obtained from SWCC function which are shown by higher values of $\theta_r$ and $n$ of clayey
Hulu Kelang and UPNM soil compared to gravelly sand of UKM soil. Results also prove that Hulu Kelang has the highest value of saturated water content, \( \theta_s \) compared to the soil at UKM and UPNM. It shows that the highest water interaction, the highest soil porosity, the higher the density of soil to become saturated promoting the soil slope failure in Hulu Kelang.

| Parameter                                      | Hulu Kelang | UKM     | UPNM    |
|------------------------------------------------|-------------|---------|---------|
| Volumetric saturated water content, \( \theta_s \) | 0.5227      | 0.3919  | 0.4434  |
| Volumetric residual water content, \( \theta_r \) | 0.1727      | 0.14636 | 0.3395  |
| Inverse to air entry suction, \( \alpha \)       | 229.88      | 12.471  | 1.6712  |
| Pore-size distribution, \( n \)                  | 1.2918      | 1.0886  | 3.7839  |
| \( R^2 \)                                        | 0.9932      | 0.9994  | 0.9824  |

### 4. Conclusion

The soil water characteristic curve (SWCC) is the best method to investigate the hydraulic properties for unsaturated soil because it is closely related with the matric suction and the volumetric water content of soil. The results from the hydraulic parameter of SWCC is calculated using Van Genuchten [1] equation formula and the graphs are constructed with the output of best fit curve representing the volumetric water content verse matric suction. It shows that the unsaturated soil is partially saturated because the reading of SWCC for unsaturated soil shows there is existence of water content in the soil particles. In contrast, the soil moisture contents can be decreasing with high temperature and formed an unsaturated soil. Therefore, it can be concluded that the movement of water infiltration in the soil changing from dry soil to wet soil and returned to dry soil may influence the movement of soil particles before leading to landslides phenomenon.

Further studies are needed in determining the behaviour of the landslides slope especially for the unsaturated soil because the unsaturated soil usually can turn into saturated soil during rainfall and the weathering process for the soil to return unsaturated is existed. Thus, the authorities must check overall area to ensure the safety for the residents. Besides, the landslides can be overcome by preparing the chemical agents so the slope can be reinforced. On the other hand, further studies can be continued by modifying the geometry of the slope. The installation of retaining walls, piles, grouting rock joints and fissures together with the rerouting surface and underwater drainage also can reduce the disaster of landslides.

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