The Soil-Water Characteristic Curve of Unsaturated Tropical Residual Soil

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Abstract. This study was conducted to determine the SWCC of unsaturated tropical residual soil in Kuala Lumpur, Malaysia. Undisturbed soil samples at five locations of high-risk slopes area were taken at a depth of 0.5 m using block sampler. In the determination of the SWCC, the pressure plate extractor with the capacity of 1500 kN/m² has been used. The index properties of the soil such as natural moisture content, Atterberg limits, specific gravity, and soil classification are performed according to BS 1377: Part 2: 1990. The results of index properties show that the natural moisture content of the soil is between 36% to 46%, the plasticity index is between 10% - 26%, the specific gravity is between 2.51 - 2.61 and the soils is classified as silty organic clay of low plasticity. The SWCC data from the pressure plate extractor have been fitted with the Fredlund and Xing equation. The results show that the air entry value and residual matric suction for residual soils are in the range of 17 kN/m² to 24 kN/m² and 145 kN/m² to 225 kN/m² respectively. From the fitting curve, it is found that the average value of the Fredlund and Xing parameters such as a, n and m are in the range of 0.24-0.299, 1.7-4.8 and 0.142-0.440 respectively.

Keywords: Unsaturated soil, soil water characteristic curve.

1. Introduction

More than 70% of the land area in Malaysia covered by residual soil [1]. The properties of residual soil have been investigated by many researchers regarding saturated condition [2,3]. However, research work on unsaturated properties of residual soil in Malaysia is still lacking. Recently some investigations have been performed after very serious slope stability problems occurred [4]. The landslides often occur, especially during the rainy season, resulting in property damage, sometimes causing injury and fatality.

The high intensity of rainfalls infiltrates into the soil led to loss of the soil suction and hence reduce the additional shear strength that exists in unsaturated soils. Most of the designer, prefer to use
saturated parameters in their design of the slope by assuming that the slope is in saturated condition due to their simplicity. But, this is not true in real situations where most of the slopes are in partially saturated. In designing the slope, they have to consider the effect of the soil suction which is the important properties of unsaturated soils. One of the basic parameters of unsaturated soil is the SWCC. From the SWCC, the unsaturated shear strength and unsaturated permeability can be estimated. This study has been conducted to determine the SWCC of unsaturated soil at high risk slope area. Then, the laboratory data were fitted according to Fredlund and Xing function [5].

1.1 Soil-Water Characteristics Curves (SWCC)

SWCC is the relationship between the moisture content and suction which is the key in the implementation of unsaturated soil mechanics in engineering practices [6]. Initially the SWCC was used in estimating the in situ soil suction by measuring its natural moisture content. Then, the SWCC has been used as an indirect method to predict the unsaturated soil properties such as unsaturated permeability, shear strength and volume change which are expensive and time consuming to measure in the laboratories [6]. The typical SWCC for drying curve is shown in Fig.1. The SWCC consist of air entry value –AEV (\(a\)) and residual matric suction (\(r\)) where the AEV is the suction that air start to enter the voids in the soil and the residual matric suction is the suction that water start to exist in discontinuous phase.

![Typical SWCC - drying curve](image)

There are many mathematical equations have been proposed to describe the SWCC but the best SWCC model is Fredlund and Xing equation [5]. Therefore in this study, the SWCC data were fitted with the Fredlund and Xing equation.

2. Laboratory testing

Residual soil samples used in this study were derived from five locations of the high risk slope area in Kuala Lumpur, according to the map issued by the JKR National Slope Master Plan, (2009-2023). The exact locations of the soil samples were Kuala Lumpur tower, Bukit Damansara, Bukit Dinding, Desa Putra and Bukit Kiara. All the undisturbed soil samples were taken at a depth of 0.5 m using block sampler.
The index properties of the samples such as particle size distribution and Atterberg limits were performed according to BS 1377 at the Geotechnical Laboratory, Faculty of Civil and Environmental Engineering, UTHM. Three specimens for each location were prepared for the determination of SWCC using pressure plate extractor with the capacity of 1500 kN/m² according to ASTM D6836-02 (2008).

3. Results and discussion

Table 1 shows the results of the index properties of the soil samples from five locations in Kuala Lumpur. The samples were categorized as from low to high plasticity. The specific gravity are in the range of 2.51 – 2.62. The highest percentage of clay are from Kiara, which is in line with the highest value of the liquid limit.

| Parameters       | Pantai Dalam | Kiara | KL Tower | Bukit Dinding | Desa Putra |
|------------------|--------------|-------|----------|---------------|------------|
| Liquid Limit     | 27           | 60    | 50.2     | 53.4          | 40         |
| Plastic Limit    | 17           | 39    | 31       | 27            | 26         |
| Plasticity Index| 10           | 21    | 19       | 26            | 14         |
| Specific Gravity | 2.62         | 2.60  | 2.51     | 2.61          | 2.61       |
| Gravel (%)       | 18           | 4     | 13       | 10            | 9          |
| Sand (%)         | 46           | 47    | 45       | 47            | 36         |
| Silt (%)         | 26           | 21    | 24       | 26            | 42         |
| Clay (%)         | 10           | 28    | 18       | 17            | 13         |

The results of the SWCC from Pantai Dalam, Kiara, KL Tower, Bukit Dinding and Desa Putra are presented in Fig. 1, Fig.2, Fig.3, Fig. 4 and Fig.5 respectively. The average of measured SWCCs were fitted with the Fredlund and Xing function [5] as in Equation (1) by assuming that $C(\psi)$ is equal to 1 as recommended by Leong and Rahardjo [8].

$$\theta_w = \frac{\theta_s}{\left\{ \ln\left( e + \left( \frac{\psi}{a} \right)^n \right) \right\}^m}$$

where $\theta_w$ = volumetric water content; $\theta_s$ = saturated volumetric water content; $\psi$ = soil suction (kN/m²); a, b and c are constants.
Figure 1. The SWCC of Pantai Dalam soils.

Figure 2. The SWCC of Kiara soils.

Figure 3. The SWCC of KL Tower soils.
Table 2 shows the properties of SWCC based on the average value. The air start to enter the soil sample when the pressure are in the range of 17 kN/m² to 24 kN/m² and the residual matric suction are in the range of 145 kN/m² to 225 kN/m². In terms of volumetric water content, the saturated and residual values are in the range of 0.296-0.497 and 0.165-0.363 respectively. The results show good agreement in term of volumetric water content with Indrawan et al. [9] Where the samples were obtained from the Singapore residual soil.
Table 2. SWCC properties.

| Location       | Air entry value, $\psi_a$ (kN/m²) | Residual matric suction, $\psi_r$ (kN/m²) | Saturated volumetric water content, $\theta_s$ | Residual volumetric water content, $\theta_r$ |
|----------------|----------------------------------|------------------------------------------|-----------------------------------------------|-----------------------------------------------|
| Pantai Dalam   | 19.5                             | 145                                      | 0.329                                         | 0.213                                         |
| Kiara          | 17.0                             | 190                                      | 0.473                                         | 0.363                                         |
| KL Tower       | 18.0                             | 193                                      | 0.497                                         | 0.275                                         |
| Bukit Dinding  | 17.0                             | 225                                      | 0.296                                         | 0.165                                         |
| Desa Putra     | 24.0                             | 170                                      | 0.470                                         | 0.340                                         |
| Indrawan et al [5] | 4.687                        | 14.88                                    | 0.432                                         | 0.232                                         |

Table 3 shows the value of fitting parameters ($a$, $n$ and $m$). The $a$ value is in the range of 0.24 – 0.299, lower than the Singapore residual soil [9]. The $n$ value is quite similar with result from Indrawan et al [9] but has significant difference can be seen for $m$ value.

Table 3. Summaries of fitting parameters.

| Location       | Fredlund and Xing fitting parameters |
|----------------|--------------------------------------|
|                | $a$ | $n$ | $m$                |
| Pantai Dalam   | 0.260 | 2.6 | 0.260             |
| Kiara          | 0.240 | 2.0 | 0.176             |
| KL Tower       | 0.255 | 2.0 | 0.340             |
| Bukit Dinding  | 0.299 | 1.7 | 0.440             |
| Desa Putra     | 0.290 | 4.8 | 0.142             |
| Indrawan et al [9] | 0.321                    | 2.468                          | 0.937                                    |

4. Conclusion
In the present study, the soil water characteristic curve for five residual soils were investigated. The experimental data obtained from pressure plate extractor were best fitted with the Fredlund and Xing (1994) equation [3] and the fitting parameters were then collected. The main conclusions that can be drawn from this study are.

1) The air entry value and residual matric suction for residual soils are in the range of 17 kN/m² to 24 kN/m² and 145 kN/m² to 225 kN/m² respectively.

2) The fitting parameters such as $a$, $m$ and $n$ are in the range of 0.24 – 0.299, 1.7 – 4.8 and 0.142 – 0.440 respectively.

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