Empirical approach for estimating wetting path of soil water characteristic curve

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ABSTRACT

The soil-water characteristic curve (SWCC) has been widely used to estimate the strength and hydraulic properties of unsaturated soils. It is characterized by the drying and wetting paths due to hysteresis. It is important to estimate the moisture capacity and characteristics of SWCCs based on the areas of hysteresis in natural and engineering soils. However, the drying path conventionally used to be adopted for applications on unsaturated soils because the measurement of the wetting path is mainly accompanied by the costly and time-consuming processes with system errors during testing. Thus, this study proposes a more practical method for estimating the wetting path through a newly established empirical approach for sandy soils as.

Keywords: Wetting path, Hysteresis, Soil-water characteristic curve, Unsaturated Soils.

1 INTRODUCTION

The soil-water characteristic curve (SWCC) has been widely used to estimate the strength and hydraulic properties of unsaturated soils. In general, it is divided into a drying and a wetting path. The drying path occurs when water is evaporated from the ground surface, and the wetting path happens when water is infiltrated into the soil. When the soil surface is dried from the evaporation, the pore-water pressures decrease tending toward a negative value. Whereas the pore-water pressures increase tending toward a positive value when the soil is wetted by the infiltration. At the same suction value of each path, the volumetric water contents are different due to hysteresis. If it is considered a condition that the water at rainfall is infiltrated to the soil, the application of the wetting path is more reasonable to examine the unsaturated soil behavior. However, the drying path of the SWCC is frequently used to analyze the infiltration condition due to practical reasons such as cost and time of testing.

Based on this reason, it is necessary to develop a method for conveniently estimating the wetting path of the SWCC. Some methods for predicting the wetting path is used the statistical analysis or artificial neural networks (Arya and Paris 1981; Johari et al. 2006). However, most methods have various disadvantages such as the necessity of multiple variables and inconvenience. Also, most of the models predict a scanning curve rather than the wetting path of the SWCC.

In an empirical approach, Pham et al. (2005) proposed a method to estimate the wetting path based on the drying path. It was reported that the suggested parameters used in this method depends on the materials, and the void ratio of the soils affects the estimated wetting path. Thus, based on an empirical approach by Pham et al. (2005), a simple method in this paper was proposed to estimate the wetting path, and discussed.

2 WETTING PATH ESTIMATION MODEL

2.1 Fitting model

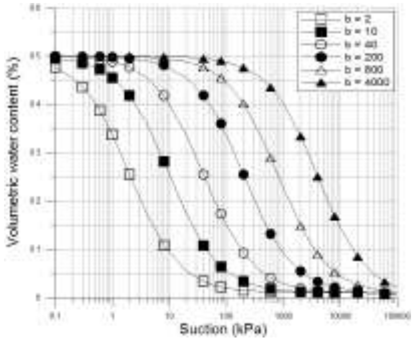
Feng and Fredlund (1999) proposed the fitting model with three variables as shown in Eq. (1). Each variable affects the SWCC, and its effect is shown in Fig. 1. The variable, ‘b’ is related to the air entry value (AEV) and when the variable, ‘b’ decreases, the AEV decreases. The variable, ‘c’ is related to the residual volumetric water content, and if the ‘c’ value decreases, the residual volumetric water content decreases. The slope of the SWCC is related to a variable, ‘d’, and the slope of the SWCC increases as the ‘d’ value increases.

$$\theta(\psi) = \frac{\theta_s b - c\psi^d}{b - \psi^d} \tag{1}$$

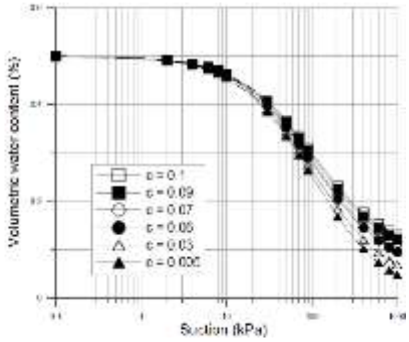
where $\theta(\psi)$= water content for suction; θs= volumetric water content at saturation; ψ= suction; and b, c, d = fitting variables

2.2 Parameters for wetting path estimation

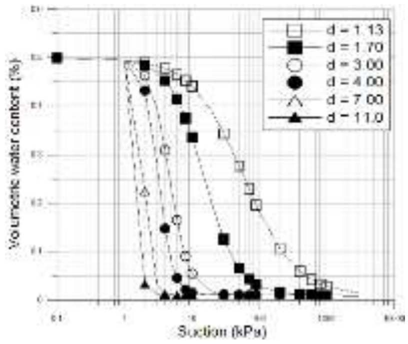
The fitting parameters of the SWCC obtained through experiments and literature for a fitting model of Eq. (1) is shown in Fig. 2~ Fig. 4 (Gallage and Uchimura 2010; Lee et al. 2003; Ministry of Science 2010; Park et al. 2014; Song et al. 2014). The subscript ‘d’ represents



(a) Effect of parameter, ‘b’



(b) Effect of parameter, ‘c’



(c) Effect of parameter, ‘d’

Fig. 1. Effect of fitting parameters on SWCC.

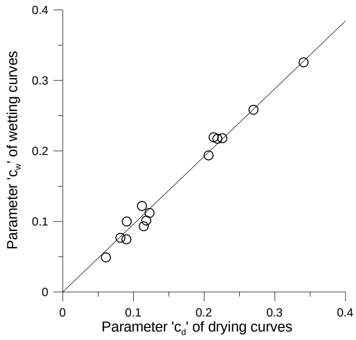
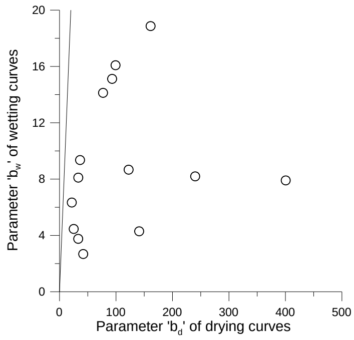
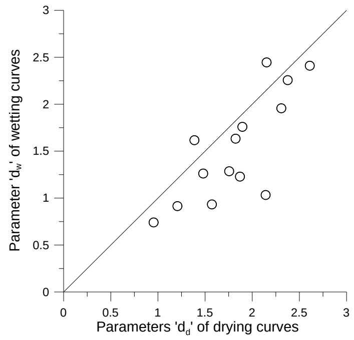


Fig. 2. Comparison of fitting parameters ‘c_d’ and ‘c_w’.



(a) ‘b_d’ versus ‘b_w’



(b) ‘d_d’ versus ‘d_w’

Fig. 3. Comparison of parameters ‘b_d’ vs. ‘b_w’ and ‘d_d’ vs. ‘d_w’.

the drying path, and ‘w’ represents the wetting path. It was found that the difference of fitting variable ‘c’ between the drying and the wetting path ranges from 0.002 to 0.024 as shown in Fig. 2.

The ‘c’ value of the drying and wetting paths could be assumed to be the same value because the difference between the two paths was negligible. The relationship of the variables ‘b’, and ‘d’ between two paths is shown in Fig. 3, when the 'c' values of two paths are the same value. The 'b' values were not correlated, but the ‘d’ values form a linear relationship. The difference in the ‘d’ value was at least from 0.12 to 1.31.

On the other hand, the difference of ‘c’ and ‘d’ values of two paths was insignificant, while the ‘b’ value was sensitive to the soil type. Thus, when the ‘c’ and ‘d’ values of two paths were assumed equal, the ‘b’ value is calculated as shown in Fig. 4. The solid line indicates the value when the ‘b’ value of two paths are the same, and the dotted line means a linear relationship between the ‘b’ value of two paths. From these results, the ‘b’ value of two paths has a relationship as shown in Eq. (2), and it is possible to estimate the wetting path based on the drying path.

$$b_w = 0.1858 b_d + 0.9317 \quad (R^2 = 0.74) \tag{2}$$

The initial volumetric water content of the drying and wetting paths shows a significant difference because air is entrapped in the soil. In general, the initial volumetric water content of the wetting path with entrapped air is 0.85 to 0.95 times compared to that of the drying path and was defined 0.9 times on average (Mualem 1974). Figure 5 shows the initial volumetric water content of two paths of the samples used in this study. In Fig. 5, the dotted line indicates that the ratio of the initial volumetric water content is 0.7, and the solid line is 1.0.

Since the value of the initial volumetric water content between two paths is similar to 0.87, it is not possible to

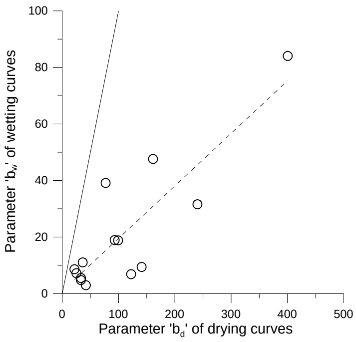


Fig. 4. Relationship of modified parameters ‘b_d’ and ‘b_w’ values.

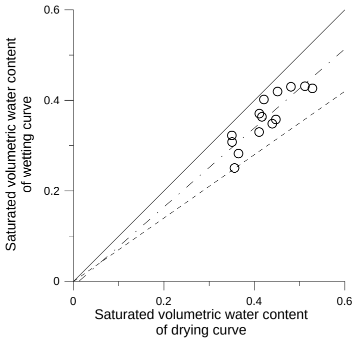


Fig. 5. Saturated volumetric water contents of drying and wetting paths

apply the value of 0.9 to estimate the initial volumetric water content of the wetting path. Thus, the equation (3) was obtained from the relationship between two paths of initial volumetric water content in Fig. 5.

$$\theta_{sw} = 0.873\theta_s - 0.0102 \quad (R^2 = 0.76) \tag{3}$$

3. WETTING PATH ESTIMATION AND COMPARISION

Figure 6 is a comparison between the original SWCC obtained by the pressure plate method and the estimated wetting path based on a proposed method for sandy soils. Since the slopes of the drying and wetting path are assumed to be the same, it was found that the difference between the slopes of the original and the estimated wetting paths is significant. It was observed that the estimated wetting path in this study is similar to the original wetting path. From the result, it can be said that the proposed method in this study can be applied to estimate the wetting path of the SWCC.

4. CONCLUSION

Based on an empirical approach by Pham et al. (2005), a simple method in this paper was proposed to estimate the wetting path. For this, the SWCCs obtained from the literature were used to establish an empirical method for estimating the wetting path of unsaturated soils. The residual volumetric water content and the slope of the drying and wetting paths were similar to each other, but the air entry value was significantly different. Therefore, it was found that the ‘b’ value is an important parameter to estimate the wetting path based on the drying path. It could be observed that the estimated wetting path is similar to the measured result by applying the proposed method. To further examine the proposed method, a more detailed study is requested using both data from field and laboratory tests.

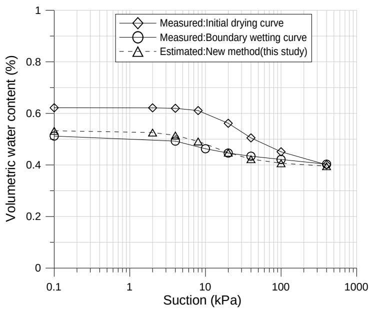


Fig. 6. Comparison of measured and estimated wetting paths

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