Effects of dry density on soil water characteristic curve of clay

[a]Hu Mengling, [b]Yao Hailin, [c]Ren Jianxi

[a]School of Architecture and Civil Engineering, Xi'an University of Science and Technology, Xi'an, China

[b]Institute of Rock and Soil Mechanics, Chinese Academy of Sciences, Wuhan, China

[c]School of Architecture and Civil Engineering, Xi'an University of Science and Technology, Xi'an, China

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ABSTRACT: The soil water characteristic curve is a important parameter that expresses the unsaturated characteristic of water holding and moisture migration. With filter paper method, the matric suctions of soil samples in six water contents and three dry densities are measured, and the soil water characteristic curves in different dry densities are obtained. Then the soil water characteristic curves are fitted with VG model. The effects of dry density on soil water characteristic curve and the parameters of VG model are discussed. The results show that for the clay in different dry densities the parameter - the residual mass water content in VG model of soil water characteristic curve is a constant. The parameter a is linearly correlation with the reciprocal of air entry value. The dry density has great influence on soil water characteristic curve, so the influence must be considered in the analysis of moisture migration with hydro-mechanical coupling.

INTRODUCTION

The embankment filling is a typical unsaturated soil. It's engineering properties are significantly influenced by the variation of moisture condition. When filled, the water content of filling is controlled in the range of optimal moisture content ±2% (The Ministry of Communications of the People's Republic of China. 2006). In this case, the soil has high strength and great stability. As the embankment is in the natural environment, its moisture content are influenced with the moisture migration cased by the rainfall infiltration and the variation of groundwater level. When the water content of soil increases, the matric suction reduces, the shear strength decreases, and the ability of resisting the deformation weakens which results in wetting deformation. That is one of the primary reasons that in many areas the embankments were spoiled by water and the slopes slid. Accordingly, it is quite necessary to analysis the law of moisture migration from the perspective of unsaturated soil. The soil water characteristic curve is a key parameter of soil property in the research of moisture migration of unsaturated soil. The curve includes the information that concerning the pore size distribution and the characteristic of water holding of soil. The soil water characteristic curve plays an important role in unsaturated soil mechanics by which the related parameters such as the permeability coefficient and shear strength of unsaturated soil can be obtained. In view its importance role, many researchers have been devoted to this aspect. The current researches show that the soil water characteristic curve is influenced by the dense condition, stress condition and temperature etc (Vanapalli, S.K. et al. 1998 & Miller, C.J. et al. 2002 & Zhou J. 2005 & Wang T.H. et al. 2008 & Liu F.Y. et al. 2011 & Zhang X.D. et al. 2010). In which, the influence of dense condition is most significant. And the stress condition takes effect through its impact on dense condition. So, the soil water characteristic curve considered the influence of dry density is a necessary parameter in the research of moisture migration with hydro-mechanical coupling. Therefore, study on the influence of dry density on soil water characteristic curve is meaningful for carrying on the research of the law of moisture migration of sbugrade with hydro-mechanical coupling.

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THE SOIL WATER CHARACTERISTIC CURVE TEST WITH FILTER PAPER METHOD

Taken the clay in Xiaohongshan, Wuhan, China as experimental soil. The depth of soil is about 3～5m. Its basic physical property indexes are shown in table 1. The soil is a low liquid limit clay.

Table 1. The basic physical property indexes of the clay in Xiaohongshan

physical property in-	unit	value
natural water content	%	21.8
natural wet density	g/cm^3	1.69
specific gravity	/	2.762
liquid limit	%	44.41
plastic limit	%	21.11
plasticity index	/	23.30

The test uses “shuangquan” NO.203 filter paper made in Hangzhou Xinhua paper mill to test the matric suctions of soil samples in different water contents. It tests the matric suctions of soil samples in six water contents(0.14, 0.16, 0.18, 0.20, 0.22 and 0.24 respectively) and three dry densities(1.70, 1.75 and 1.80g/cm^3 respectively) to analysis the influence of dry density on soil water characteristic curve.

The soil water characteristic curves of soil in three dry densities are obtained with the experiment data. As the soil water characteristic curve is a important parameter that expresses the unsaturated characteristic of water holding and moisture migration, in recent years a large number of scholars made deep researches on it, and more and more mathematical models were adopted to express the soil water characteristic curve. So far the widely used models are Brooks-Corey model (Brooks, R.H. et al. 1964), Van Genuchten model (Genuchten M.T.V. 1980), Fredlund-Xing model (Fredlund D.G. et al. 1994), fractal model (Xu Yongfu et al. 2002) and logarithmic equation model (Qi Guoqing et al. 2004) etc. A large number of researches showed that Van Genuchten model had universal applicability in the range of quite wide water potential or water content for most soil, and was the most commonly used model for soil water characteristic curve. So, the relationship of volumetric moisture content and matric suction in three dry densities, those are 1.70g/cm^3, 1.75g/cm^3 and 1.80g/cm^3, are fitted with Van Genuchten model, that is

$$q = q_r + \frac{q_s - q_r}{\left[1 + (aj)^n\right]^{(1-1/n)}} \quad (1)$$

In which, q_r is residual volumetric moisture content, q_s is saturated volumetric moisture content, a, n are fitting parameters.

The fitting curves are shown in fig. 1. The figure shows that the data points agree well with the fitting curves in these three dry densities.

Fig. 1 shows the fitting curves of soil water characteristic curves in 1.70g/cm^3, 1.75g/cm^3 and 1.80g/cm^3. As depicted in the figure, it can be seem that the dry density have great influence on soil water characteristic curve. The larger the dry density, the smaller the saturated water content, the larger the air entry value, the greater the desorption rate when

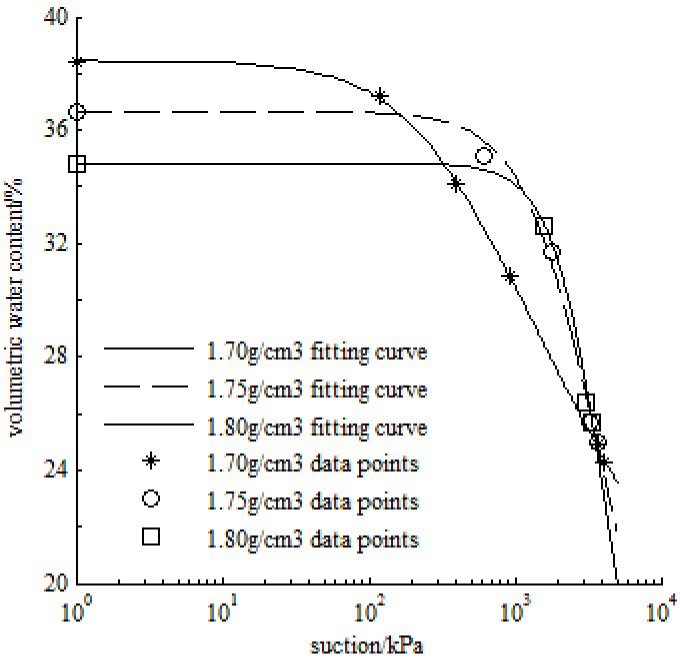

Figure 1. The fitting curves of soil water characteristic curves in three dry densities

matric suction go beyond the air entry value, and the stronger the characteristic of water holding. The reason can be attributed to that the larger the dry density, the more the soil particles in soil per unit volume, the less the pore in soil, the smaller the pore
ratio, then the smaller the saturated volumetric water content. The larger the dry density, the smaller the pore ratio. The most likely porosity reduction method is diminish the large pore in soil. The smaller the maximal pore in soil, the larger the air entry value, that is the matric suction when the air begin to enter into the soil. Besides, when the pore ratio decreases, the average pore size reduces, the characteristic of water holding boosts up, then the desorption rate slows down.

INFLUENCE OF DRY DENSITY ON THE PARAMETERS OF VG MODEL

Table 2. The fitting parameters of SWCCs in three dry densities

parametesrs	dry density/ g/cm^3		
	1.70	1.75	1.80
a	0.3845	0.3665	0.3483
a	0.0576	0.0593	0.0610
a	2.768e-3	3.981e-4	2.838e-4
n	1.2282	1.7925	2.4503

Table 2 shows the fitting results of VG model for soil water characteristic curve in three dry densities. It can be seem that the dry density have a great impact on the parameters of VG model of soil water characteristic curve. The effects will be described below one by one.

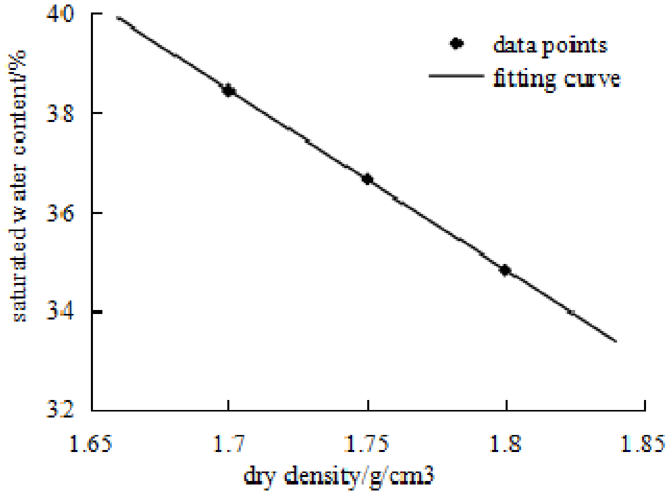

Figure 2. The variation of saturated volumetric water content with dry density

There is the following relationship between the saturated volumetric water content and dry density,

$$q_s = \frac{G_s r_w - r_d}{G_s r_w} = 1 - \frac{r_d}{G_s r_w} \qquad (2)$$

From equation (2), it can be seem that the saturated volumetric water content decreases linearly with dry density. Fig. 2 verifies the relationship between saturated volumetric water content and dry density.

The residual water content refers to the critical water content when the increase of soil suction do not result in significant change in water content. It means that the the desorption rate in desaturation zone is much larger than that in the zone of residual saturation, and the sorption of soil on water in the zone of residual saturation is much larger than that in desaturation zone. So, it can be assumed that under matric suction the discharged water in soil is the free water in desaturation zone and is bound water in the zone of residual saturation which is tightly adsorbed on the surface of soil particles(Sillers W S et al. 2001). Therefore, the volume of bound water in unit volume is directly proportional to the surface area of soil particles. When the soil is a homogeneous medium, the surface area of soil particles is proportional to the quality of soil particles. Then the following equation can be obtained

$$\frac{m_{\text{w-res}} r_w}{m_s} = w_{res} = const \qquad (3)$$

In which, $m_{\text{w-res}}$ is the quality of residual water in soil per unit volume, m_s is the quality of soil particles in unit volume, w_{res} is residual mass water content.

Based on the relationship between volumetric water content and mass water content, the following equation can be obtained

$$q_{res} = w_{res} . r_d \qquad (4)$$

In which, q_{res} is residual volumetric water content.

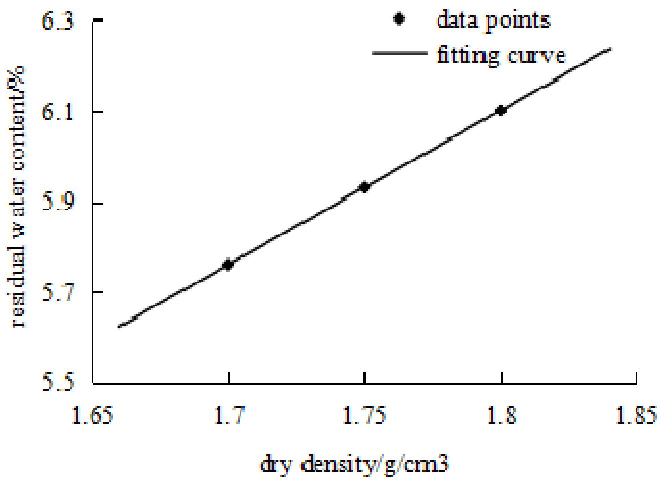

Figure 3. The variation of residual volumetric water content with dry density

From equation (4), it can be seem that the residual volumetric water content have a linear correlation with dry density. Fitted the experimental data in table 2 with equation (4), the following results can be received

$$q_{res} = 0.03389 r_d \tag{5}$$

The fitting results is shown in fig. 3. It can be seem that the experimental data are agree well with the fitting curve. It proves the analysis of residual water content above and the relationship between residual volumetric water content and dry density.

In VG model, the parameter a is related to the air entry value y_a. The air entry value refers to the matric suction of the intersection between the asymptote of capilliary saturation zone and the asymptote of desaturation zone (Fredlund D.G. et al. 1994). From the values of a in table 2, it can be seem that the value a in dry density=1.70g/cm3 is much greater than those in dry density=1.75g/cm3 and dry density=1.80g/cm3. Based on the drawing method, the air entry values of these three soil water characteristic curves are 168.13kPa, 1134.66kPa and 1787.07kPa respectively. It indicates that the more the dry density, the more the air entry value. By the means of data analysis, the linear correlation coefficient of parameter a and the reciprocal of air entry value is 0.99, which reveals the sound linear relation between them. By data fitting, the relationship between the parameter a and the air entry value is obtained, that is

$$a = \frac{0.4635}{y_a} \tag{6}$$

The fitting curve is shown in fig. 4.

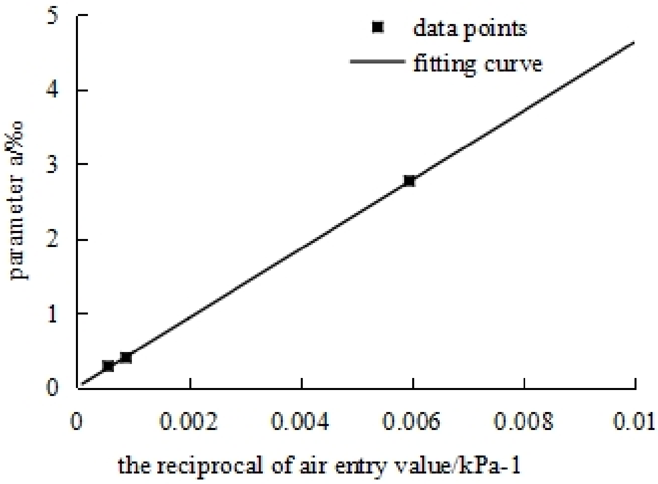

Figure 4. The variation of parameter a with air entry value

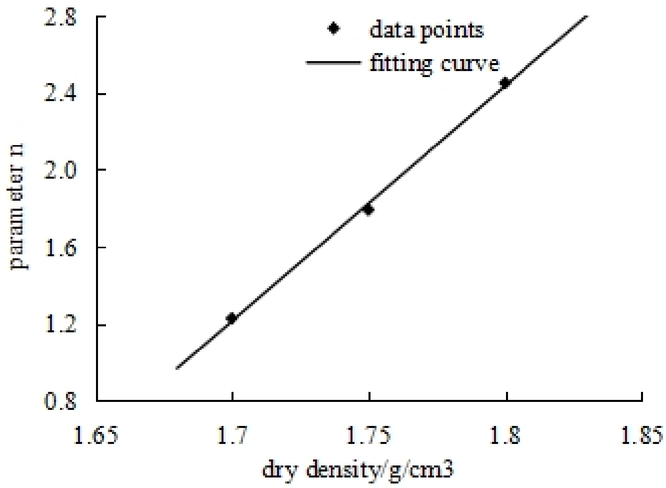

Figure 5. The variation of parameter n with dry density

Fig. 5 shows the variation of parameter n with dry density. In VG model, the parameter n is related to the slope of desaturation zone in soil water characteristic curve. Fig. 5 indicates that the parameter n increases with dry density and there are satisfied linear relation between them. With data fitting, the relationship of parameter n and dry density is received, that is

$$n = 12.2217 \times r_d - 19.5642 \qquad (7)$$

CONCLUSION

(1)The dry density has great influence on soil water characteristic curve. The more the dry density, the smaller the saturation water content, the bigger the air entry value, the large the desorption rate in desaturation zone, the stronger the characteristic of water holding of soil.

(2)The parameter-residual mass water content in VG model of soil water characteristic is a constant, which refers to the water content when the soil particles only adsorb bound water after missing free water under matric suction.

(3)The parameter a in VG model is linear correlation with the reciprocal of air entry value.

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