Experimental Analysis on Soil-Water Characteristic Curve of CH_3COO^- Contaminated Clay

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ABSTRACT

Based on the soil-water characteristic curve (SWCC) of CH_3COO^- contaminated clay determined by test, SWCC parameters and equations, as well as SWCC factors and its application of forecasting on permeability and shear strength of the CH_3COO^- contaminated clay are confirmed.

Comparative study on CH_3COO^- contaminated clay and non-contaminating clay are carried out, and the fitting parameters are gotten. It is found that Van Genuchten model and Fredlund-Xing model are suitable for CH_3COO^- contaminated clay. Then, such factors as concentration, initial moisture content and initial dry density influence on the soil-water characteristic curve of the CH_3COO^- contaminated clay are explored. Specially, the SWCC of CH_3COO^- contaminated clay is used to predict the permeability coefficient and shear strength of the CH_3COO^- contaminated clay in this article. The researches show as follows: with the increase of concentration of CH_3COO^-, value of air-entry suction and residual water content are reducing gradually; meanwhile, saturation moisture content is increasing, and the SWCC curve slope is rising, which indicate that water-holding capacity is declining with CH_3COO^- concentration increase. When the initial water content is equal to plastic limit, such parameters as saturation moisture content, value of air-entry suction and residual water content reach to maximum, at the same time, the soil-water characteristic curve becomes flat, which represents the maximum water-holding capacity. With the increase of initial dry density, the value of air-entry suction and residual water content are increasing, and saturation moisture content is declining. Additionally, with increasing matric suction, the permeability coefficient of the CH_3COO^- contaminated clay declines and the shear strength increases, but the changing rate becomes slower and slower.

Keywords: CH_3COO^- contaminated clay; Soil-water characteristic curve; Fitting; Engineering geological properties prediction

INTRODUCTION

The soil contaminated by leachate is a common type of contaminated soil in the nature. CH_3COO^-, a common composition in the organic acid, influences the physical-mechanical properties of soil greatly. For example, the compression coefficient and deformation value of the foundation soil increasing obviously due to contamination will induce the buildings to crack. The determination of Soil-water characteristic curve is a premise of the study on physical-mechanical properties of soils. Thus, it is important to research contaminated soil and its soil-water characteristic curve (SWCC).

The researches on contaminated unsaturated soils are performed widely at home and abroad. A migration model on heavy metal in unsaturated soil was established (Chen W *et al*., 2010). The component and physical property of clay before and after the contamination of hydrochloric acid and sodium hydrate were analyzed (Zhang X.L. 2007). Bo researched the physical-mechanical properties and structure as well as corrosion mechanism of hydrochloric acid contaminated red clay (Bo T.Z. 2012), and Cao researched the influence of concentration of sulphuric acid and corrosion time on the physical-mechanical properties of clay (Cao H.R. 2012). Additionally, some researchers focused on salt contaminated soils, for example, physical-mechanical properties of clay change with the concentration of salt solution (Niu X.L. 2009). In the aspects of soil-water characteristic curve of unsaturated soil, the relationship between void ratio and soil-water characteristic curve of unsaturated soil, as well as the prediction of soil-water characteristic curve through any initial void ratio was involved (Chen G.F. *et al*., 2008.Cai G.Q. *et al*.,2010).

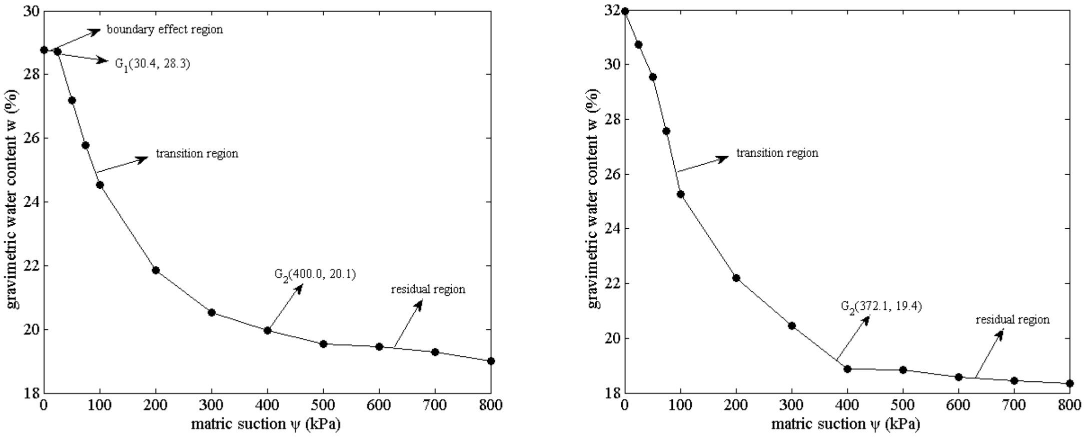
However, the leachate contaminated clay, especially CH_3COO^- contaminated clay, is scarcely touched upon. Based on theory of the unsaturated soil mechanics, the author investigates the soil-water characteristic curve of CH_3COO^- contaminated clay, and its influence factors, and then the parameters and equations of CH_3COO^- contaminated clay are confirmed.

THE SOIL-WATER CHARACTERISTIC CURVE OF CH_3COO^- CONTAMINATED CLAY

The SWCC feature of CH_3COO^- contaminated clay

The CH_3COO^- contaminated clay sample was prepared through soaking in 10% of acetic acid solution. According to the test data, soil-water characteristic curve of CH_3COO^- contaminated clay is obtained.

As is illustrated in Figure 1, the SWCC of CH_3COO^- contaminated clay shows the same tendency with that of uncontaminated clay. With increasing matric suction, the water content is declining, specially, the water loss rate declines obviously in high matric suction stage. Furthermore, the SWCC of uncontaminated clay can be divided into three sections named as boundary effect region, transition region and residual region by two inflection points G_1 and G_2. Similarly, the SWCC of CH_3COO^- contaminated clay can be divided into two sections named as transition region and residual region by one inflection point G_2 without boundary effect region. The same feature is presented in CH_3COO^- contaminated clay and non-contaminated clay in the transition region and residual region.



(a) SWCC of uncontaminated clay

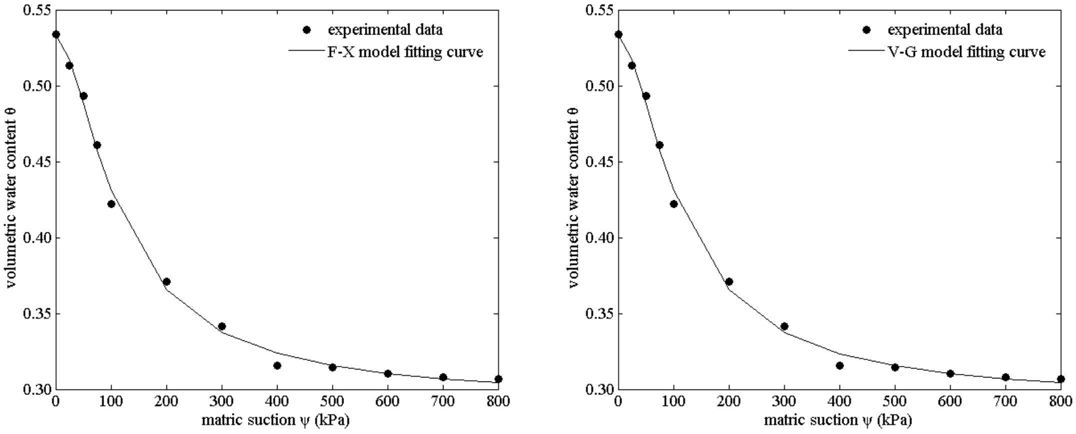
(b) SWCC of 10% of CH_3COO^- contaminated clay

Figure 1 SWCC of uncontaminated and 10% of CH3COO- contaminated clay

Meanwhile, the saturation moisture content of CH_3COO^- contaminated clay is greater than that of uncontaminated clay; however, the residual moisture content shows a contrary trend. Additionally, the gradient of soil-water characteristic curve of CH_3COO^- contaminated clay is larger than that of uncontaminated clay, which indicates the moisture holding capacity of the clay declines due to CH_3COO^- contamination.

The SWCC model of CH_3COO^- contaminated clay

Among the soil-water characteristic curve models, Van Genuchten model and Fredlund-Xing model are frequently used with characteristic of considering more factors and higher representative (Guo *et al.*, 2013).



(a) V-G model fitting

(b) F-X model fitting

Figure 2 The fitting curves of 10% CH_3COO^- contaminated clay

In this paper, the scatter diagram on soil-water characteristic curve of CH_3COO^- contaminated clay is drawn from experimental data, then, Van Genuchten model (V-G model) and Fredlund-Xing model (F-X model) are used for fitting, as showed in Figure 2.

The soil-water characteristic curve model equations are demonstrated as follows:

$$\theta_w = 0.279 + \frac{0.255}{\left[1+\left(0.23\varphi\right)^{1.72}\right]^{0.88}} \tag{1}$$

$$\theta_w = 0.281 + \frac{0.253}{\left\{\ln\left[e+\left(0.13\varphi\right)\right]^{1.66}\right\}^{1.97}} \tag{2}$$

THE EFFECT FACTORS ON SWCC OF CH_3COO^- CONTAMINATED CLAY

The effect of acetic acid concentration on SWCC of CH3COO- contaminated clay

The CH_3COO^- contaminated clay samples with four concentrations: 1%, 4%, 7% and 10% of acetic acid were prepared. The SWCCs of the clay samples are tested as shown in Figure 3 with the corresponding relation between volumetric water content and matric suction displayed in Table 1.

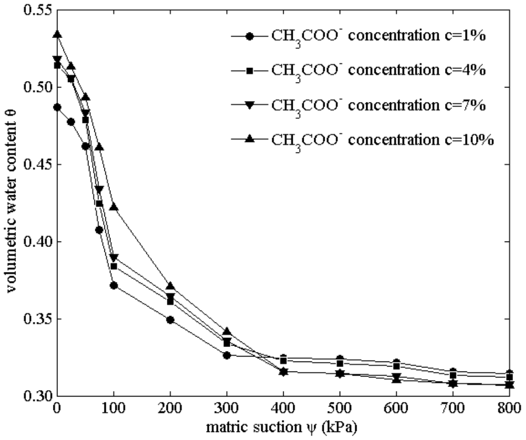


Figure 3 The SWCC of contaminated clay with different acetic acid concentrations

With increasing acetic acid concentration, the saturation moisture content of CH_3COO^- contaminated clay is rising. In the stage of lower matric suction (0-350kPa), the corresponding moisture content is increasing gradually with the acetic acid concentration rising as to the same matric suction, on the other hand, the SWCCs in the stage of higher matric suction (>350kPa) show a contrary trend.

Suffered from acetic acid pollution, the clay mineral compositions change significantly. For instance, mental salts are dissolved. High valence ions such as Al, Si and Fe, as well as Na, Mg, K, Ca and other elements content reduce significantly. With the increase of acetic acid concentration, the dissolution increases obviously, while the adsorption capacity of soil particles to water and water holding capacity gradually decreases. Meanwhile, with the increase of acetic acid concentration, the clay porosity and pore size increase, thus inducing the decrease of value of air entry, water holding capacity and residual water content.

Table 1 The volumetric water content and matric suction of contaminated clay with different concentrations

matric suction (kPa)	contaminated clay with 1% acetic acid	contaminated clay with 4% acetic acid	contaminated clay with 7% acetic acid	contaminated clay with 10% acetic acid
0	0.4865	0.5141	0.5182	0.5337
25	0.4775	0.5050	0.5053	0.5135
50	0.4614	0.4783	0.4830	0.4932
75	0.4072	0.4245	0.4338	0.4607
100	0.3716	0.3837	0.3900	0.4218
200	0.3492	0.3607	0.3644	0.3710
300	0.3261	0.3340	0.3355	0.3414
400	0.3246	0.3224	0.3153	0.3154
500	0.3236	0.3211	0.3145	0.3145
600	0.3214	0.3191	0.3128	0.3105
700	0.3154	0.3135	0.3077	0.3078
800	0.3146	0.3123	0.3075	0.3065

The effect of initial water content on SWCC of CH_3COO^- contaminated clay

The CH_3COO^- contaminated clay samples with three initial water contents: 15%, 21% and 27% were prepared. The SWCCs of the clay samples are tested as shown in Figure 4 with the corresponding relation between volumetric water content and matric suction displayed in Table 2.

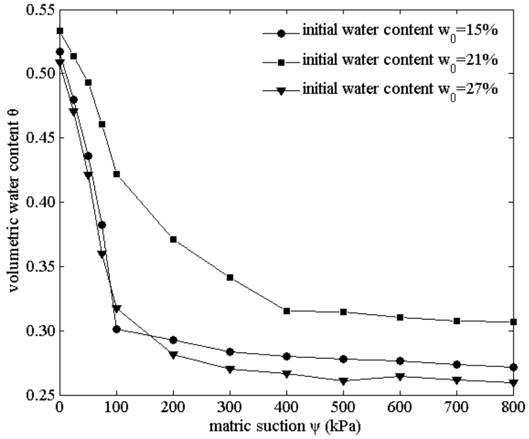


Figure 4 The SWCC of contaminated clay with different initial water contents

Table 2 The matric suction and volumetric water content under different initial water content of CH_3COO^- contaminated clay

matric suction kPa	w_0=15%	w_0=21%	w_0=27%
0	0.5172	0.5337	0.5086
25	0.4796	0.5135	0.4703
50	0.4357	0.4932	0.4215
75	0.3825	0.4607	0.3597
100	0.3013	0.4218	0.3173
200	0.2928	0.3710	0.2812
300	0.2837	0.3414	0.2701
400	0.2801	0.3154	0.2668
500	0.2778	0.3145	0.2610
600	0.2765	0.3105	0.2648
700	0.2733	0.3078	0.2617
800	0.2714	0.3065	0.2598

When the initial water content is equal to plastic limit 21%, such parameters as saturation moisture content, value of air-entry suction and residual water content reach the maxima, at the same time, the soil-water characteristic curve becomes flat, which represents the maximum water-holding capacity.

The initial water content has important effect on clay pore structure. When initial water content is small, the clay possesses lower value of air entry and the water holding capacity. When the water content increases to plastic limit, the clay possesses optimal pore arrangement, inducing the water holding capacity, saturated moisture content and residual water content reached the maxima. When the water content increases continually, the adsorption ability of clay particles decrease, causing the water holding capacity, saturated moisture content and residual water content declines as well.

The effect of initial dry density on SWCC of CH_3COO^- contaminated clay

CH_3COO^- contaminated clay samples with three initial dry densities: 1.64g/cm^3, 1.72g/cm^3 and 1.78g/cm^3 were prepared. The SWCCs of the clay samples are tested as shown in Figure 5 with the corresponding relation between volumetric water content and matric suction displayed in Table 3.

With the increase of the initial dry density, the CH_3COO^- contaminated remolded clay has the smaller saturation moisture content, but the bigger value of air-entry suction and residual water content. The curve slope increasing represents the water holding capacity rising.

The influence of initial dry density on SWCC of CH_3COO^- contaminated clay is realized by changing clay pore structure. With increasing initial dry density, the clay pore space decline gradually, thus decreasing the water storage space and saturated water content of the clay. With the increase of dry density and the decrease of pore space, the specific surface area of clay particles increases, enhancing the adsorption to water, water holding capacity, air entry value and residual water content greatly under the same matric suction.

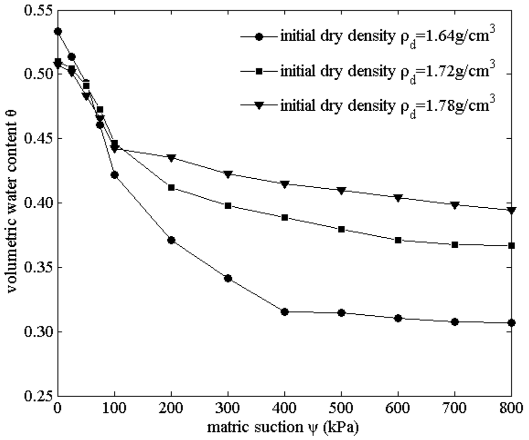


Figure 5 The SWCC of CH_3COO^- contaminated clay with different initial dry densities

Table 3 Matric suction and volumetric water content under different initial dry density

matric suction kPa	ρ_d=1.64g/cm^3	ρ_d=1.72g/cm^3	ρ_d=1.78g/cm^3
0	0.5337	0.5102	0.5075
25	0.5135	0.5043	0.5018
50	0.4932	0.4911	0.4832
75	0.4607	0.4725	0.4653
100	0.4218	0.4468	0.4424
200	0.371	0.4117	0.4356
300	0.3414	0.3981	0.4223
400	0.3154	0.3885	0.4148
500	0.3145	0.3793	0.4096
600	0.3105	0.3713	0.4045
700	0.3078	0.3674	0.3989
800	0.3065	0.3668	0.3944

Additionally, with the matric suction increasing, the permeability coefficient of the CH_3COO^- contaminated clay declines and the shear strength increases, but the changing rate becomes slower and slower.

FORECASTING ON PERMEABILITY COEFFICIENT AND SHEAR STRENGTH OF THE CH_3COO^- CONTAMINATED CLAY

In this paper, SWCC was used to predict the permeability coefficient and shear strength of the CH_3COO^- contaminated clay. Jackson equation and Vanapalli equation are used to predict the permeability coefficient and shear strength of the CH_3COO^- contaminated clay as to the same permeability coefficient and shear strength of the CH_3COO^- contaminated clay sample. The relevant forecasting equations show as follows:

$$k = 6.38\times10^{-13}\times\left(2.76\times10^{15}\right)^{\theta} \tag{3}$$

$$k = e^{-8.8-0.04\varphi+6.16\times10^{-5}\psi^{2}} \tag{4}$$

$$\tau = 4.3\times10^{5} - 3.3\times10^{-5}e^{25\theta} - 4.3\times10^{5}e^{7.69\times10^{-6}\theta} \tag{5}$$

$$\tau = 5.4\times10^{5} - 19e^{-0.02\psi} - 5.4\times10^{5}e^{1.43\times10^{-6}\theta} \tag{6}$$

The above equations can be used to forecast the permeability coefficient and shear strength of the CH_3COO^- contaminated clay.

CONCLUSIONS

Based on the experiment of the CH_3COO^- contaminated clay, the soil-water characteristic curve (SWCC) of CH_3COO^- contaminated clay and their SWCC parameters as well as equations are obtained, meanwhile, SWCC factors and its application of forecasting on permeability and shear strength of the CH_3COO^- contaminated clay are confirmed.

(1) It is found that Van Genuchten model and Fredlund & Xing model are suitable for CH_3COO^- contaminated clay.

(2) Such factors as concentration, initial moisture content and initial dry density influence on the soil-water characteristic curve of the CH_3COO^- contaminated clay are explored, meanwhile, their influence mechanism are touched upon.

With the increase of concentration of CH_3COO^-, value of air-entry suction and residual water content are reducing gradually; meanwhile, saturation moisture content is increasing, and the SWCC curve slope is rising, which indicate that water-holding capacity is declining with CH_3COO^- concentration increase. When the initial water content is equal to plastic limit, such parameters as saturation moisture content, value of air-entry suction and residual water content reach the maxima, at the same time, the soil-water characteristic curve becomes flat, which represents the maximum water-holding capacity. With the increase of initial dry density, the value of air-entry suction and residual water content are increasing, and saturation moisture content is declining. The shape of the water content curve is more sensitive to the initial dry density value than the concentration of acetic acid.

(3) The SWCC of CH_3COO^- contaminated clay is used to predict the permeability coefficient and shear strength of the CH_3COO^- contaminated clay, and the related forecasting equation are obtained.

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NOMENCLATURE

k	permeability coefficient
w	gravimetric water content
θ	volumetric water content
ρ_d	initial dry density
τ	shear strength

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