Study on Matric Suction of Silty Clay Modified by INDUSTRIAL Wastes

Dongxue Li [1], Haibin Wei [2,*], Jiangkun Jia [3], Yangpeng Zhang [2] and Qiuqi He [2]
[1] *Jilin Provincial Transport Scientific Research Institute,Changchun 130000, China;*
[2] *School of Transportation, Jilin University, Changchun 130000, China;*
[3] *China Railway 16th Bureau Group Luqiao Engineering Construction Co.Ltd., Beijing,101500,China.*
Email:weihb@jlu.edu.cn

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Abstract: Northeast China is located in the seasonally frozen area. Under the influence of low temperature, the roads are prone to serious problems. Modification of subgrade soil with industrial waste can effectively prevent road problems. In this study, fly ash and rubber crumbs were selected to be mixed with silty clay as roadway subgrade to prepare modified soil specimens with different dry densities. Matric suctions of the modified soil specimens were measured and compared to those of the unmodified soil specimens. Soil water characteristic curves for both modified and unmodified soil specimens were investigated and stability under low temperature was studied. The test results show that the matric suction changes with the density, but the change of the modified soil is smaller than that of the unmodified soil. The stability of the modified soil is better especially at low temperatures.

1 INTRODUCTION

Northeast China is in the seasonally frozen area. There is freezing and thawing of soil water in winter and spring. The freeze-thaw cycle will make soil moisture migrate and bring some disasters to engineering. Subgrade soil modified by industrial waste slag can effectively prevent road problems. The amount of fly ash and waste rubber is very large. By 2010, the discharge of fly ash in China had reached 200 million tons (Jiang, 2011). In 2016, there are almost 300 million tire wastes in China, with a weight of more than 10 million tons, and the tire wastes produced every year are growing at a rate of 8- 10 percent (Xiao, 2017). These two kinds of industrial waste used to modify silty clay can not only realize the reuse of industrial waste but also be used as subgrade filler.

Most of the subgrade soil is unsaturated soil. The matric suction can well characterize the state of water in the soil, and it also reveals the strength of the force between water and soil particles. At present, the research on matric suction is mainly focused on the method of measurement, influencing factors, and applications. ZHU Yan-bo et al. studied the effect of different water contents, different dry densities and grading curves on the SWCC of the siltized intercalation of red-bed soft rock (Zhu et al., 2013). LI Shun-qun et al. discussed the error in the measurement of the matric suction in the axis translation technique (LI, et al., 2016). JU Chang-wei et al. summarized and introduced the measurement methods of matric suction (JU and LI, 2016). Many scholars also use soil and water characteristic curves to predict shear strength and permeability coefficient (Pujiastuti et al., 2018; Li et al., 2013).

From the point of view of current research, the studies of matric suction after freeze-thaw cycles are still few, so this paper studies the matric suction of modified soil and unmodified soil in the normal state and after the freeze-thaw cycles.

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2 MATERIALS AND EXPERIMENTAL METHODS

2.1 Basic Physical Indices of Experimental Materials

The experimental silty clay is taken from the homogeneous soil layer at the bottom of the foundation pit of a large construction site in Changchun City. Fly ash is taken from the Second Heating power plant in Changchun. According to the classification standard of American test materials Association, F type fly ash is adopted in this study. Its composition and ignition loss are shown in Table 1.

Table 1: Composition and loss on ignition of fly ash.

SiO_2+Al_2O_3 +Fe_2O_3 (%)	CaO (%)	SO_3 (%)	Mg+Ti+K oxides (%)	Loss on ignition (%)
88.64	0.92	0.24	6.01	4.19

The rubber crumbs are obtained from rubber tires scraps ground at normal temperature. This method has the advantage of simplicity, low cost and high conversion rate. The size of rubber crumbs used in the experiment is between 1-2mm and the apparent density of rubber crumbs is 1.19g/cm3.

According to the dry weight ratio of 65.3 : 32.7 : 2 (Li, 2012), soil, fly ash and rubber crumbs were mixed. The physical parameters of modified soil are shown in Table 2:

Table 2: The physical parameters of the modified soil.

	Liquid limit	Plastic limit	Index of plasticity	Optimum water content	Maximum dry density
Modified soil	38.33 %	24.88 %	13.45 %	15.38%	1.73g/cm^3
Unmodified soil	34.00 %	22.40 %	11.60 %	12.10%	1.92g/cm^3

2.2 Experimental Principle

Operation of the filter paper method is simple, and it has the advantage of a low price and good accuracy (Bulut, 2001). The filter paper method is based on the hypothesis that suction in filter paper and soil are balanced through the movement of moisture. When the dry filter paper is put in the soil sample and directly in contact with it, water flows from the soil into the filter paper and reaches the balance. Then the water content of filter paper at equilibrium is measured. The water content in the filter paper is related to the suction, through the calibration curve of the filter paper (Fredlund and Rahardjo 1993). When the filter paper is directly in contact with the soil sample, the equilibrium moisture content of the filter paper is representative of the matric suction of the soil. In this paper, the filter paper method is used to measure the matric suction, and filter paper Whatman No.42 model is selected. The calibration curve formulas of this type of filter paper are as follows (ASTM International, 2010):

$$\lg S = 5.327 - 0.0779 w_f (w_f \le 47\%) \quad (1)$$

$$\lg S = 2.412 - 0.0135 w_f (w_f > 47\%) \quad (2)$$

2.3 Experiment Scheme

Test soil specimens with dry densities of 1.73g/cm^3, 1.64g/cm^3 and 1.61g/cm^3 were prepared. According to the optimum water content, five different mass moisture contents were chosen: 11.38%, 13.38%, 15.38%, 17.38%, 19.38% for soil samples to determine the matric suction. In freeze-thaw cycle test, the freezing temperature is -15^{o}C during the freezing process (Bing, 1992), the thawing temperature is room temperature during the thawing process, about 10^{o}C.

Freeze-thaw cycle consists in freezing for 24 hours followed by melting for 24 hours. The samples with mass moisture contents of 11.38%, 15.38%, and 19.38% experienced 1, 3, 5, 7, 9 freeze-thaw cycles. During the freeze-thaw cycle, soil samples were coated with preservative film to prevent moisture loss. Matric suctions were measured on the original and modified soils after each freeze-thaw cycle.

3 EXPERIMENTAL RESULTS AND ANALYSIS

3.1 The Results of Matric Suctions

The relationship between the matric suction and the water content is reflected by SWCC. For modified soil and unmodified soil, the influence of the different water contents and dry densities were considered. The results of the test are shown in Table 3.

Table 3: The matric suction of the modified soil and the silty clay.

Soil	Water content	Dry density(g/cm³)		
		1.73	1.64	1.61
Modified soil	11.38%	4022.44	3452.23	3309.94
	13.38%	2438.33	1932.47	1554.73
	15.38%	1368.77	1109.92	906.19
	17.38%	902.23	832.60	668.56
	19.38%	458.20	425.23	301.97
Silty clay	11.38%	6448.63	3812.77	2278.34
	13.38%	3760.99	2191.10	1334.99
	15.38%	2589.54	1509.49	726.17
	17.38%	1111.60	771.83	356.34
	19.38%	229.41	156.32	76.02

Water content is set to Y-axis, logarithmic of the matric suction is set to X-axis. The curves are shown in Figures 1 and 2.

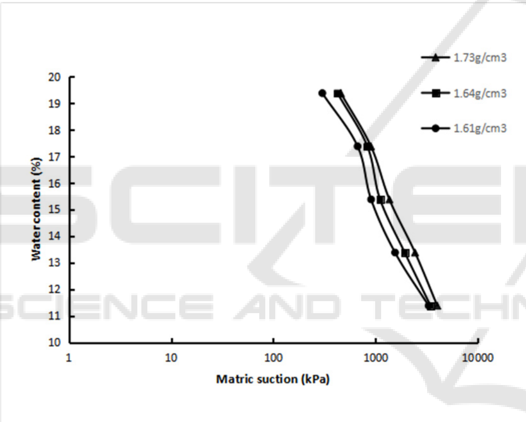

Figure 1: The soil water characteristic curves of modified soil.

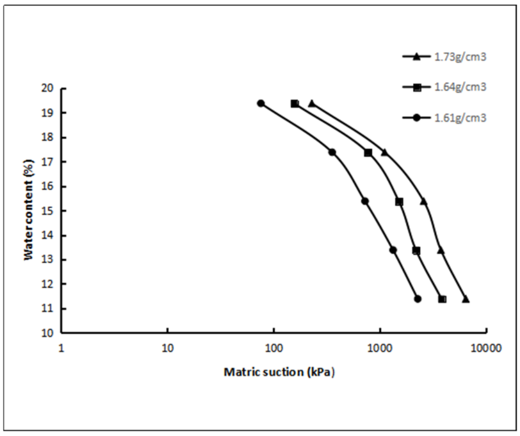

Figure 2: The soil water characteristic curves of silty clay.

Figure1 and Figure 2 show that, for the two kinds of soils, the matric suction increases with dry density. When the density becomes large, the soil changes from loose condition to compact condition. The arrangement of soil particles becomes denser, the contact between particles increases as the space between particles becomes smaller. It causes water content to decrease and matric suction to increase. The increase of dry density makes the void ratio decrease, it is difficult for air to enter the soil, and drainage becomes difficult. The difference between the two kinds of soils is the changes of the matric suctions: in the original soil, changes are much larger than in the modified soil at different dry densities. It may be related to the structure of the pores.

3.2 Experimental Results of Freeze-Thaw Cycle

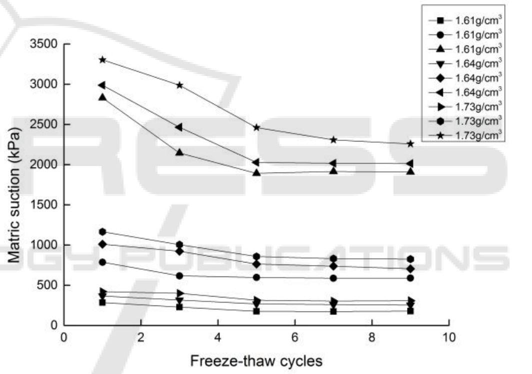

Figure 3: The matric suction of the modified soil after freeze-thaw cycles.

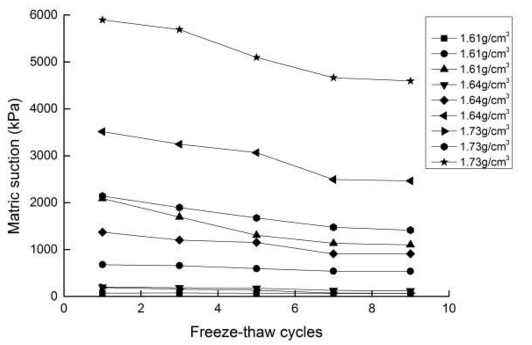

Figure 4: The matric suction of the silty clay after freeze-thaw cycles.

To study the influence of freeze-thaw cycle times on the two kinds of soils matric suction, the relationship between freeze-thaw cycle times and matric suction is shown in the Figures 3 and 4.

It can be seen from Figures 3 and 4, that the matric suction of the two kinds of soils decreases first and then tends to be stable as freeze-thaw cycle time increases. For the modified soil, the matric suction remains stable after 5 freeze-thaw cycles. As for the unmodified silty clay, the matric suction tends to be stable after 7 freeze-thaw cycles. The effect of dry density on the matric suctions is still obvious after freeze-thaw cycles. The matric suction of soils at high dry density is higher than that of soils at low dry density. The reason for this phenomenon lies in adsorption and capillary effects in soils. During the freezing and thawing processes, the space between soil particles become greater, Van der Waals' forces and electrostatic forces in the space between soil particles decrease. So, the adsorption and capillary effect is weakened. After several freeze-thaw cycles, the equilibrium between the particles is reached, the matric suction reaches a stable state too.

4 CONCLUSIONS

For two kinds of soils, the matric suction consistently decreases with the increase in water content. The matric suction increases with the increase in dry density.

It can be concluded from the SWCC that change in the matric suction of the modified soil is smaller than that of the unmodified soil when the density is changing.

The matric suction of the two kinds of soils decreases with the increase in freeze-thaw cycles time. The modified soil stabilizes after the fifth time freeze-thaw cycle, and the silty clay stabilizes after the seventh time freeze-thaw cycle. The modified soil tends to be stable quicker than the silty clay after freeze-thaw cycles.

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