Experimental study on treatment of municipal sludge by electro-osmotic method

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***Abstract*—** *The main purpose of the electro-osmosis method in engineering is to reinforce the foundation. The electro-osmosis method has a lot of research on the foundation reinforcement. The most application is the experiment of electro-osmotic combined loading. The experiment on treatment of heavy metals in municipal sludge by electro-osmotic method is still in a blank state. In this paper, the changes of basic physical properties of sludge before and after electro-osmosis and the changes of heavy metals in sludge before and after electro-osmosis were analyzed. The feasibility of electro-osmotic treatment of heavy metals in sludge was verified by comparing the content of heavy metals in the sludge with the standard value of soil environmental quality after electro-osmotic treatment.*

Keywords*— *Electro-osmotic method, Physical properties of sludge, Heavy metal, Experimental research.

I. INTRODUCTION

The field test proves that it is feasible to reinforce the beach land in Bohai Bay by electro-osmotic method (Cheng et al., 2001).In the contrast test of electrode arrangement in electro-osmotic method, 3 kinds of electrodes are arranged with rectangle, plum blossom shape and parallel dislocation. Comparing the experimental results, it is found that the parallel arrangement electrode is reasonable(Tao et al., 2013).In the theoretical and experimental study of reducing the energy consumption of electro-osmotic energy, it is found that the gradual increase of voltage can delay the occurrence of cracks in the process of electro-osmosis and the extent of the crack development. This method effectively reduces the energy loss at the crack during the electro-osmotic process(Pan et al., 2014).In the experimental study of the effect of electro-osmotic reinforcement of soft soil, the effectiveness of electrode inversion has been proved. The concrete calculation method of the parameters of the drainage volume and the electrical permeability coefficient is given through the experimental data. According to the existing engineering examples, the range of empirical values is given for the parameters that can not be determined(Zhuo Chen., 2015).In the experimental study on Influence Factors of electro-osmotic coefficient of soft clay and improvement method, the electro-osmosis heap loading combined air pressure splitting test is carried out aiming at the problem of the poor effect of the electro-osmosis method on the deep soil. The experimental results show that the shear strength of the combined pressure splitting test of electro-osmotic loading is higher than that of the deep soil under the electro-osmotic loading test. This discovery has certain reference significance for some projects which have high requirements for the reinforcement effect of deep soil soil (Hu et al., 2015).An experimental study of the effect of electrode spacing on electro-osmosis under the equal potential gradient using an indoor 1:5 model. The effects of two electrode spacing of 2m x 1m and 1m x 0.5m on the electro-osmotic properties of soft clay under the equal potential gradient were also studied. The results show that keeping the electric potential gradient unchanged and reducing the electrode spacing by half can speed up the electro-osmotic drainage, reduce the soil moisture content, reduce the energy consumption and electrode interface resistance, but also cause the change of pH value and the amount of anode corrosion. It is also found that the smaller the electrode spacing, the lower the potential loss on the electrode and the soil interface, but the loss potential increases the proportion of the supply voltage (Li et al., 2015).

There are few experiments in many literatures on the treatment of heavy metals in municipal sludge by electro-osmotic method. At present, if the basic physical indicators of sludge are improved and the content of heavy metals can be effectively reduced, the basic situation of urban land stress can be alleviated. In this paper, the basic physical properties of the treatment of sludge by electro-osmotic method and the content of heavy metals in sludge are described in this paper.

II. RESEARCH CONTENT METHODS AND BASIC PARAMETERS

2.1 Research Content

Through electro-osmotic real treatment of municipal sludge in laboratory experiments, we measured and calculated the moisture content, density, dry density; void ratio, porosity, saturation, shear strength and heavy metal (copper and zinc) content in the sludge section. Real-time monitoring of the settlement of A, B, C, and recording of current voltage are used to

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calculate the energy consumption, and finally summarize the data.

2.2 Experimental Scheme

1) An organic glass box with 50*30*40 (CM) size used in the experiment. A small hole with a diameter of 1cm at the bottom of the box and a soft rubber hose prepared for electro-osmotic drainage. The bottom of the box has 5cm thick sand in the coarse sand with a catheter to provide drainage layer for drainage.
2) The sludge is taken from the artificial landscape lake in a city in Hebei. The trees are dense around the lake, and there are many sewage and industrial sewage in the lake.
3) Using three iron bar（d=1.5cm）as electro-osmosis anode, using three carbon bar （d=1.5cm） as cathode electro-osmosis. A wide (2cm) draining belt wrapped in a permeable cloth is inserted near each electrode. Insert three groups of electrodes into the device(the two sets of output voltage are 30V, arranged on both sides. Another set of output voltage is 5V, arranged in the middle.)
4) The YBD displacement sensor is used to detect the real time settlement. The results are introduced into the computer for processing.
5) In the process of electro-osmosis, a shear plate is used to test the soil strength once every 4 hours.
6) In the process of electro-osmosis, the current and voltage are measured by the multimeter and the final energy consumption is calculated.
7) The basic properties of the soil are measured once every 4 hours. The content of heavy metals in soil was measured once every 4 hours.

The experimental layout and equipment drawings are as follows

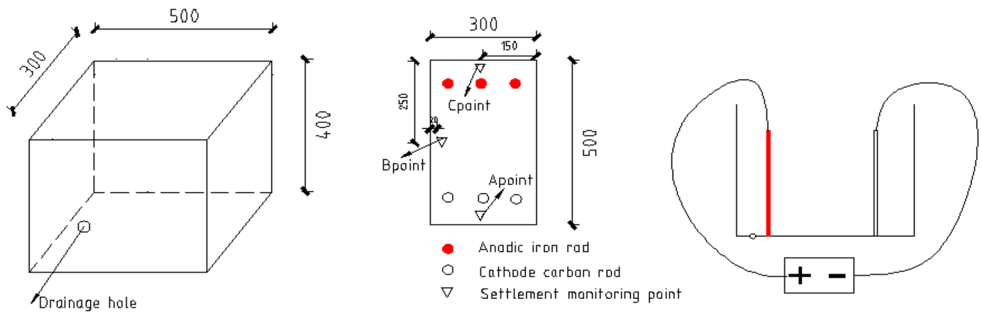

FIGURE 1: EXPERIMENTAL LAYOUT

FIGURE 2: YOUTAI ACQUISITION

FIGURE 3: GUWEI DC POWER SUPPLY

2.3 Basic parameters before electro-osmosis

According to the Standard for test method of geotechnical engineering GB-T50123-1999, the basic mechanical indexes for the determination and calculation of soil include three measured indexes: moisture content; specific gravity of solid particles; density. Six conversion indices: porosity ratio; porosity; saturation; dry density; saturated density; buoyant density. The

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moisture content; density; dry density; porosity ratio; void ratio and saturation of soil are measured and calculated according to the test.

Basic mechanical parameters of soil before electro-osmosis:

TABLE 1
BASIC PARAMETERS OF SOIL BEFORE ELECTRO-OSMOSIS

Density g/cm3	Dry density g/cm3	Specific gravity of solid Gs	Moisture content %	Porosity ratio	Porosity	Saturation %
1.50	1.06	2.7	40.72%	1.54	0.606	71.42%

The plastic limit value of the soil is ω_P =15.19 and the liquid limit is ω_L =33.02。The permeability coefficient of soil is 1.7068×10-6 by the method of variable water head penetration test.

III. EXPERIMENTAL DATA ANALYSIS

3.1 Change of moisture content

In the process of electro-osmosis, water will be discharged, the water content of the soil will be reduced, and the water content varies with time, as shown in Figure 4.The result of curve fitting curve is $w = 0.39651 - 0.00287t$.

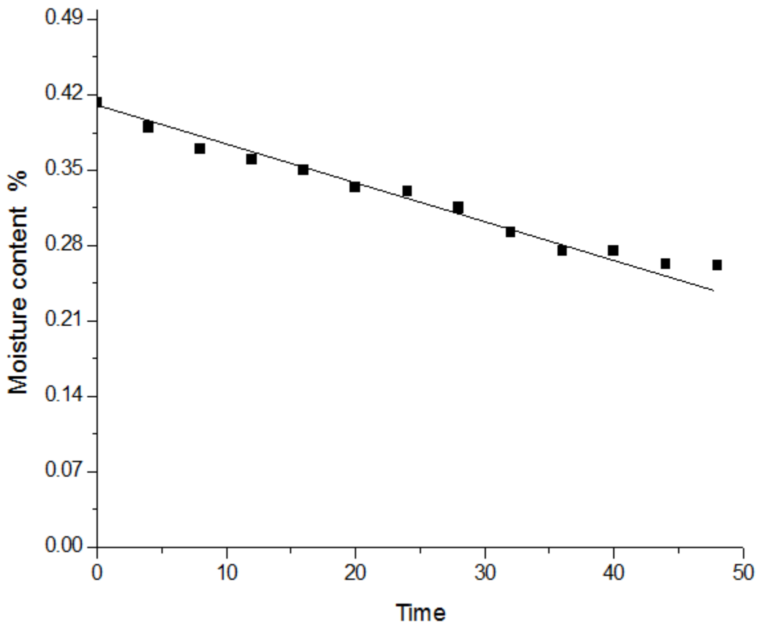

FIGURE 4: WATER FITTING CHANGE FITTING

The original soil moisture content of 40.72%, after the electro-osmosis test, the soil moisture content dropped to 27.76%.At the same time, it can be seen from Figure 4 that the slope of the curve is getting smaller and smaller. This shows that the electro-osmosis experiment at the beginning of the moisture content changes rapidly, the effect of electro-osmosis more obvious. After the test, the soil near the electrode was compared. It was found that the water content of the soil near the anode was 26.68%, and the water content near the cathode was 37.49%.It can be seen that the soil moisture content near the anode is the lowest, lower than the average level, and the water content near the cathode is the highest. In the process of electro-osmosis, the water in the soil is permeated from the anode to the cathode, which leads to the high water content of the cathode.

3.2 Density and dry density

The fitting curves of density and dry density are respectively

$$\rho = 1.50346 + 0.00382t \,,\quad \rho_d = 1.00846 + 0.00471t$$

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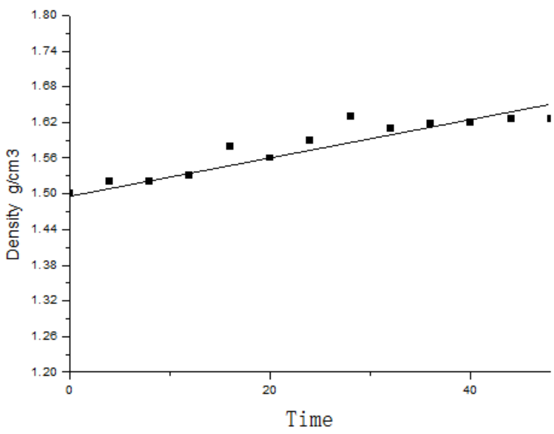

FIGURE 5: DENSITY VARIATION FITTING

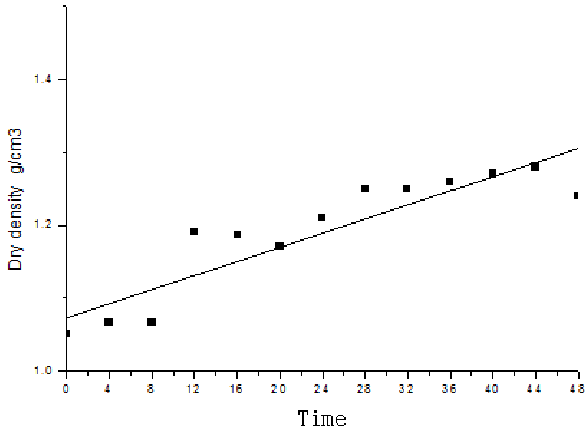

FIGURE 6: DRY DENSITY VARIATION FITTING

The original soil density of 1.50g / cm3 dry density of 1.06g / cm3.After the electro-osmosis test, the density of soil is 1.65g/cm3, the dry density is 1.29g/cm3, and the density increases 0.23g/cm3 for the density of 0.15g/cm3.Due to the consolidation and settlement of soil in the process of electro-osmosis, the porosity in the soil decreases, and the density and dry density of the soil increases.

Analysis of soil sampling near the cathode and anode after the test. The density of soil mass near the anode is 1.69g/cm3 dry density 1.34g/cm3, and the density of soil mass near the cathode is 1.54g/cm3 dry density of 1.12g/cm3.The density and dry density of the anode are greater than that of the cathode, which shows that the anodic electro-osmotic effect is better than that of the cathode.

3.3 Change of porosity ratio and porosity

The consolidation and settlement of soil occurred during the electro-osmosis process. The void in the soil will change to influence the porosity ratio and porosity. The changes in porosity ratio and porosity are fitted as the following

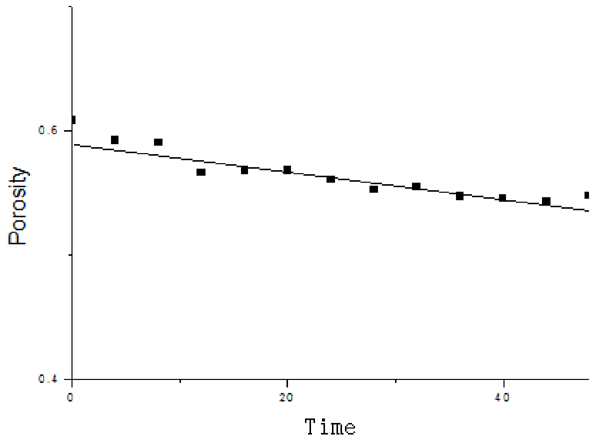

FIGURE 7: FITTING OF POROSITY RATIO VARIATION

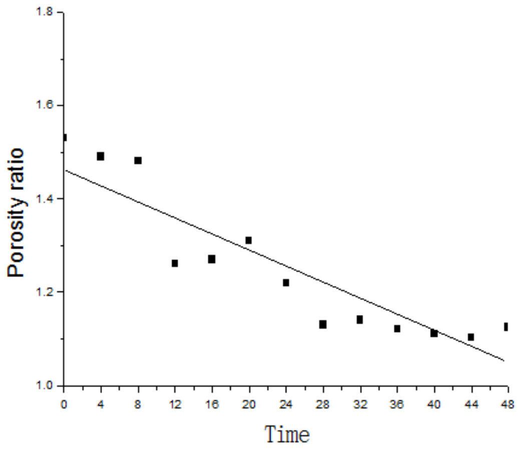

FIGURE 8: POROSITY FITTING CURVE

Analysis of soil sampling near the cathode and anode after the test. The comparison results show that the porosity ratio of the soil near the anode is 1.02, the porosity is 0.505, and the porosity ratio of the soil near the cathode is 1.41 porosity 0.585.The porosity ratio and porosity of the anode and cathode are lower than the porosity ratio and porosity of the original soil. This shows that during the process of electro-osmosis, the consolidation and settlement of soil occur, the porosity of soil decreases. The electro-osmotic effect near the anode is better than that of the cathode.

3.4 Saturation curve

The Moisture content and porosity change during the experiment and the specific gravity of the soil is constant. Calculation of soil saturation based on the basic parameters of the sample. The maximum value of saturation is 75.68%, and the minimum value is 66.37%.

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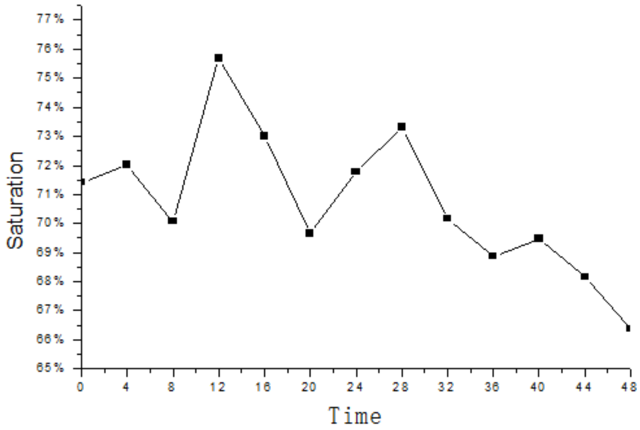

FIGURE 9: SATURATION CURVE

3.5 Change of permeability coefficient

Determination of permeability coefficient by variable head permeability test method.

Determination of permeability coefficient by variable head test method. The permeability coefficient before electro-osmosis was 1.7068 ×10-6 after electro-osmosis, 1.0381×10-6.Data analysis shows that the permeability coefficient of soil becomes smaller after the electro-osmosis experiment is completed.

3.6 The change of shear strength

The strength of the soil will change during the electro-osmosis process. The shear test of the electro-osmotic soil is carried out every eight hours. The shear strength is calculated by formula

$$\tau_f = \frac{2M}{\pi D^2\left(H + \frac{D}{3}\right)}.$$

M - torque (Kn· m)

D - the width of the shear plate(m)

H - the height of the shear plate (m)

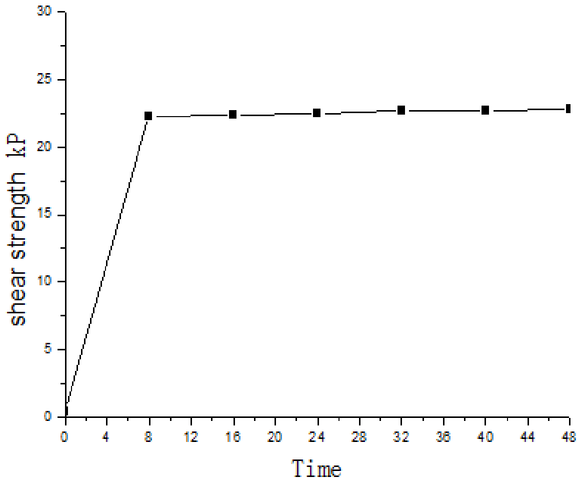

FIGURE 10: SHEAR STRENGTH CHANGE CURVE

It can be found that the shear strength of the original soil is very low, and the shear strength of the soil increases a lot after the electro-osmosis experiment is completed. After 48 hours, the shear strength reached 22.8Kpa.The shear strength increased rapidly in the first eight hours, and the rising speed of shear strength became slower after eight hours. It is found that the shear strength of the anode soil is 26.9Kpa, and the shear strength of the anode soil is greater than that of the cathode soil. The water of the anode permeated the cathode by the electro-osmotic effect, which increased the strength of the anode more.

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3.7 Soil settlement detection

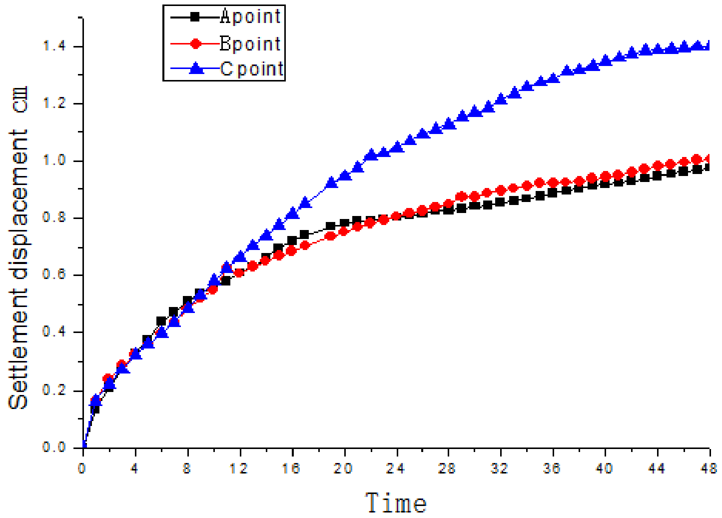

FIGURE 11: REAL-TIME DETECTION OF SETTLEMENT

The final settlement of A point near the cathode is 0.972cm, and the final settlement of B point near the anode is 1.004cm.The settlement of the C point in the middle is 1.399cm.Compared with the settlement of A, B and C, the settlement of C point is relatively large, which may be caused by the disturbance to the C point during the sampling and shear test.

3.8 Measurement of electric energy consumption

TABLE 2
ELECTRO-OSMOSIS ENERGY CONSUMPTION METER

Electro-osmosis energy consumption meter					
Time/h	**Voltage/v**	**Electric current/A**	**Power/W**	**Energy consumption/kw·h**	**Total energy consumption/kw·h**
0	65	0.70	45.50	0.128	2.1294
4	65	0.68	44.20	0.177	
8	65	0.68	44.20	0.177	
12	65	0.66	42.90	0.172	
16	65	0.65	42.25	0.169	
20	65	0.63	40.95	0.164	
24	65	0.62	40.30	0.161	
28	65	0.61	39.65	0.159	
32	65	0.61	39.65	0.159	
36	65	0.60	39.00	0.156	
40	65	0.59	38.35	0.153	
44	65	0.58	37.70	0.151	
48	65	0.58	37.70	0.151	

Energy consumption is 2.1294Kw·h in the process of continuous electro-osmosis per kilowatt hour of 1.025 yuan per kilowatt hour at the peak of current industrial power consumption in 2017.According to the above data, it is estimated that this test will cost 2.19 yuan. The area of this experiment is 0.15m2. The calculated electro-osmosis method takes 14.6 yuan per square meter for sludge treatment. Heavy tamping treatment of sludge foundation requires 30-40 yuan per square meter. It can be seen that the electro-osmosis method can reduce the cost of 2.05-2.74 times.

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3.9 Changes in heavy metals

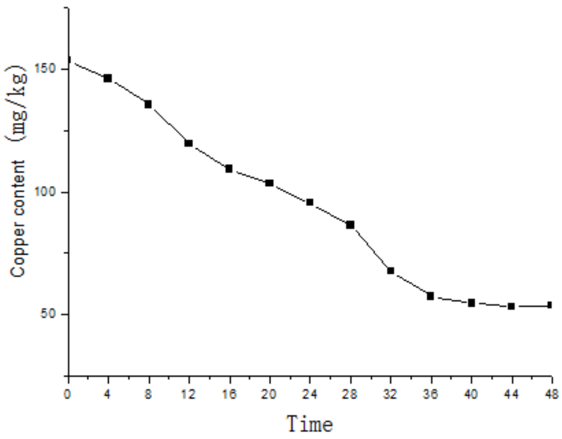

FIGURE 12: CHANGE CURVE OF ZINC CONTENT

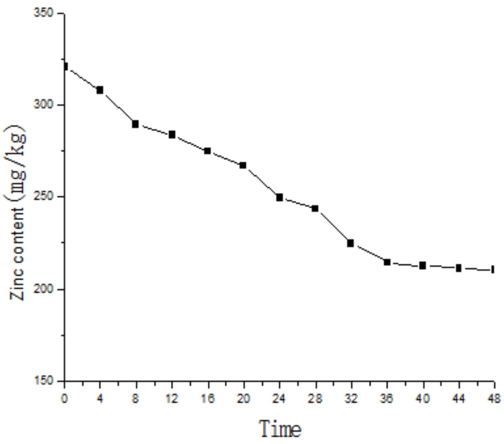

FIGURE 13: CURVE OF COPPER CONTENT CHANGE

Before the electro-osmosis experiment, the content of copper is 153.62mg/kg zinc 320.53mg/kg. After the electro-osmosis experiment, the content of copper is 53.68mg/kg zinc is 210.27mg/kg. According to the standard of soil environmental quality standard (GB15618) for the standard value of soil environmental quality, the content of copper and zinc is basically up to second levels.(the content of two grade copper is <=50mg/kg, the content of two grade zinc is <=200mg/kg).

IV. CONCLUSION

1) After the completion of electro-osmosis, the density increased from 1.50g/cm3 to 1.65g/cm3, and the moisture content decreased from 40.72% to 27.76%, and the shear strength increased from almost zero to the maximum intensity 26.9Kpa.The above changes occur only within 24 hours. From the above data, it is found that the visible electro-osmosis method has a good effect on the treatment of sludge strength.

2) For this two day experiment, from the energy consumption and economic benefits, the treatment of sludge by electro-osmosis method needs 14.6 yuan per square meter, compared with the dynamic consolidation of sludge foundation, the cost is reduced by 2.05-2.74 times.

3) The content of copper in the sludge decreased from 153.62mg/kg to 53.68mg/kg, and the content of zinc decreased from 320.53mg/kg to 210.27mg/kg.The final treatment result is close to the second level standard in the soil environmental quality standard GB15618.

REFERENCES

[1] Qingchen Cheng, Yongjun Sun,et al Application of electro-osmosis technology in consolidation of dredging dams [J]. Northeast Water Conservancy and Hydroelectric Power, 2001, (09): 14-16 + 55.

[2] Yanli Tao,Jian Zhou,Yiwen Li.Electro-osmotic experimental research on three arrangements of electrodes [J] .Building Structure, 2013,43 (S2): 214-218.

[3] Dongqing Pan, Jianzhong Zhang,Chiyu Zhang. Theoretical and Experimental Research on the reduction of electro-osmotic energy consumption [J]. low temperature construction technology, 2014,36 (03): 123-126

[4] Zhuo Chen. Experimental Research on the Effect of Electricity Design to Electro-osmotic Consolidation of Soft Clay[D]., Zhejiang University, 2013.

[5] Pingchuan Hu.Experimental study on the influential factors and improving method of electro-osmotic permeability of soft clay [D]., Zhejiang University, 2015.

[6] Ying Li,Xiaonan Gong.Experimental research on effect of electrode spacing on electro-osmotic dewatering under same voltage gradient [J]. geotechnical mechanics, 2012,33 (01): 89-95.

[7] Jianwei Lu. Experimental Study on Electrochemistry Phenomenon during Electro-osmotic Process [D]. Wuhan University of Technology, 2011.

[8] Yonghua Cao,Zhiyi Gao,Aimin Liu. Characteristics and Development of Electro-osmotic Treatment for Ground Improvement [J]. water transport project, 2008, (04): 92-95+116.

[9] Environmental quality standards for soils[S],GB15618.

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