Experimntal study on sludge solidification in a landfill site in Shenzhen

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Abstract. As urban land use is relatively tight, the rational use of sludge landfills has become a problem that must be solved. Because the sludge has the characteristics of high water content, poor permeability, strong flocculation, high combined water content, and high organic matter content, the traditional vacuum preloading method, stacking preloading method and other curing methods are too inefficient and cannot meet engineering requirements. In this paper, an indoor electroosmosis drainage consolidation test was designed for sludge in a sludge landfill area in Shenzhen. The test results show that the reasonable drainage method, stacking method and shortening the electrode spacing increase the strength of solidified sludge by 1.1 times, 1.6 times and 2.8 times. The water content is reduced by 19.8%, 25.5% and 55.6%. The drainage rate is linear with the current.

1. Introduction

Sludge is a mud-like substance formed after sewage treatment. It has the properties of perishability, odor, fine particles, small density, high moisture content and is not easy to dehydrate. It is a hydrophilic substance with a gel structure [1]. The sludge contains a lot of organic matter, microorganisms, pathogens, heavy metals, etc. If it is not professionally and properly treated, it will cause irreparable damage to the surrounding soil and groundwater. With the rapid development of China's economy, the sludge output has increased rapidly, and the area of sludge landfills has increased accordingly. The sludge landfill formed after landfill disposal cannot be directly applied to the building foundation.

In 1939, L. Casagrande [2] applied electro-osmosis for the first time in railway excavation engineering. Since then, the electroosmotic method has been gradually applied in practical projects. Esrig and Shang [3-4] successively proposed 1D electroosmotic consolidation theory and two-dimensional electroosmotic consolidation theory. It is concluded that the seepage is caused by the superposition of electroosmotic gradient and hydraulic gradient. Wan and Mitchell [5] proposed that electro-osmosis can accelerate the dissipation of the excess pore pressure generated by the heap load, and the conversion electrode can make the soil solidification more uniform. Wang and Zhou [6] studied the effect of electrode conversion method on electroosmotic consolidation drainage.
et al. [7] analyzed the electroosmosis effect by using a new type of composite electrode material. The test results show that the new type of composite electrode material can improve the reinforcement effect and save the electrode cost. Wang et al. [8] and Li et al. [9] studied the relationship between the effect of electroosmosis and the current density and voltage, and determined the optimal current density and voltage when electroosmosis treatment of soil. Zhang [10] used electroosmotic chemical treatment to treat marine soft soil, which showed the benefits of electroosmotic chemical treatment to improve marine soft soil and defined the effective time for consolidation.

However, in the current research process of electroosmosis, the research on the influencing factors mainly focuses on: soil water content, salt content, electric field strength, energization method, electrode layout, electrode material, additives, stacking or vacuum pressure, etc. Aspect, less research on drainage methods. In this paper, the sludge landfill sludge is taken as the object, the indoor electroosmosis drainage consolidation test is designed, and finally the comprehensive evaluation of the strength, moisture content and electroosmosis rate, electroosmosis efficiency, and economy of the solidified sludge The electroosmosis test plan for each group.

2. Design of test plan

2.1 Physical and mechanical properties of sludge landfill

The original sludge in this article comes from a sludge landfill in Baoan District, Shenzhen, covering an area of about 4.2 square kilometers. The PH value of the water sample in the sludge analysis of sludge is between 6-8. The average natural water content of the sludge is 105.4%, the average specific gravity is 2.59, the average natural density is 1.61g/cm³, the average permeability coefficient is 2.65×10⁻⁷cm/s, and the organic matter content is 23.8%.

The average content of powder particles (fine particles ≤0.075mm) in the soil of the sludge landfill area is about 40%, and the content of fine particles is relatively high. The scanning result of sludge by electron microscope is shown in Fig. 1. The sludge structure is mainly a flocculent structure, and the water in the pores mainly exists in the form of bound water. The content of main heavy metal elements: cadmium Cd atomic weight content 0.158, chromium Cr atomic weight content 0.014, copper Cu atomic weight content 0.026, lead Pb atomic weight content 0.64, mercury Hg atomic weight content 0.402.

2.2 Experimental design of electro-osmotic drainage consolidation

Four sets of parallel experiments are designed in this experiment. The electroosmotic gradient takes a constant and is set to 1.5V/cm. Explore the effects of drainage, stacking, and electrode layout on the consolidation effect. Considering the layout and size of the electrodes and the drainage body during soft foundation treatment, the model test is designed according to the ratio of 1:5. As shown in Fig 1, the main test device consists of experimental model box, DC power supply, multimeter, measuring cylinder, magnetic support, displacement sensor and other devices. The model box is made of glass plate, and the size of the model box is 50cm×25 cm×40 cm.

In this test, the electrodes E1, E2, and E3 are all arranged in a rectangular shape, and the electrode spacing is 40cm×20cm. The E4 electrodes are arranged in a square shape and the electrode spacing is 20cm×20cm. The diameter of the steel bar is 1cm and the length is 40 cm. When there is no drainage board, a sand drain with a diameter of 2cm is set around the electrode. The sand bag is made of geotextile. The electrode is placed at the central axis of the sand drain. A 2mm drainage board is provided in the sand drain.

When adding drainage boards, the arrangement of sand drain around the electrodes remains the same, and two drainage boards with a width of 20mm are arranged in the middle of the Cathode and anode.
Table 1. Arrangement of electroosmosis test

| Test serial number | Drainage method   | Stack(kPa) | Electrode spacing(cm) |
|--------------------|-------------------|------------|-----------------------|
| E1                 | No drainage board | 0          | 40                    |
| E2                 | Drainage board×2  | 0          | 40                    |
| E3                 | Drainage board×2  | 5          | 40                    |
| E4                 | No drainage board | 5          | 20                    |

3. Analysis of test results

3.1 Moisture content and strength

Figs. 2 and 3 are cloud diagrams on the z = const plane. The statistical values on the x = const plane are shown in Table 2. It can be seen that the moisture content changes little on the x = const plane, and the coefficient of variation does not exceed 0.23.

The increase in soil strength is positively correlated with the decrease in water content, that is, the more the water content decreases, the greater the increase in soil strength, and it reaches the maximum at the Cathode and anode and the minimum at the middle of the poles. In experiments E1 ~ E3, except for the vicinity of the middle of the model box, the moisture content of most soils decreased from about 105% before the treatment to within 70% after the treatment, with a decrease of more than 33%. The unconfined compressive strength increased from 20kPa to more than 50kPa before the test.
Table 2. Statistical value of water content on x = const plane

| x / cm | 5   | 15  | 25   | 35   | 45   |
|--------|-----|-----|------|------|------|
| w /%   | 62.2| 79.91| 106.48| 100.27| 59.95|
| δ      | 0.04| 0.18| 0.05 | 0.08 | 0.23 |

Note: w is Mean moisture content, δ is coefficient of variation.

From Figs.4 and 5, the soil strength in the middle of E2 and E3 was improved 1.1 times and 1.6 times compared with E1, respectively. This shows that the method of adding a drainage plate in the middle of the model box in the E2 test and increasing the stacking load in the E3 test have obvious effects on improving the soil strength and reducing the soil moisture content.

Among them, E3 has a more obvious effect than E2. In the strength test, the unconfined compressive strength of E3 is increased by 25.6% compared with E2. The moisture content and intensity of the Cathode and anode in E2 and E3 are similar, but the moisture content of E3 in the middle is lower and the intensity is higher. This shows that the drainage plate and stacking have a certain effect on the increase of the strength of the soil in the middle of the cathode and the anode, and the decrease of the water content. After adding an electrode in the middle of the model box in the E4 test, the strength of the soil in the middle was significantly increased to 2.8 times that of E1, and the water content decreased significantly to less than 50% of E1. This shows that the method of adding electrodes in the E4 test is more effective than the E2 and E3 in improving the solidification effect of the central soil.

3.2 Displacement

The amount of drainage directly affects the moisture content of the solidified soil and thus the solidification effect, and the drainage rate can directly reflect the rate of electroosmosis. Through the analysis of drainage rate and drainage volume, the effect and efficiency of drainage method, stacking, and electrode spacing on sludge solidification can be directly obtained. Figs.6 and 7 are graphs showing the relationship between drainage mode, stacking load, electrode spacing and drainage rate and displacement.
The drainage rate of test E1, E2 and E3 all fluctuated within a range within the first 20 hours, while the drainage rate of test E4 stabilized within a range within the first 15 hours. The drainage rate in the first 20 hours of test E1 is 40 ~ 100ml/h, the drainage rate in the first 20 hours of test E2 is 45 ~ 120ml/h, the drainage rate in the first 20 hours of test E3 is 100 ~ 140ml/h, and the drainage rate in the first 15 hours of test E4 is 280 ~ 206ml/h. It can be seen that the drainage rates of experiments E1, E2, E3, and E4 are gradually increasing, which shows that the drainage plate, stacking, and shortening the electrode spacing play a positive role in accelerating drainage during the electroosmosis. It can be seen from Fig. 8 that the drainage rate of E4 is greatly increased compared to E1, E2, and E3, so shortening the electrode spacing is the most effective method to increase the drainage rate.

After 20 hours of electroosmosis, the drainage rate of test E1, E2 and E3 decreased sharply in the range of 20-25h, and gradually stabilized after 25h, and the drainage rate gradually decreased to zero. In the test E4, the drainage rate showed a downward trend after 15 hours of electroosmosis. The drainage rate dropped sharply within the range of 15-20h, and gradually stabilized after 20h, and the drainage rate gradually decreased to 0. This shows that experiment E4 shortening the electrode spacing can effectively and faster electroosmosis process and shorten the total electroosmosis time.

Since the rate of electroosmotic drainage shows a process of stabilizing first, then rapidly decreasing and finally steadily decreasing, the curve corresponding to the total drainage volume first increases linearly, then slowly, and finally gradually stabilizes. Judging from the cumulative displacement, E4 > E3 > E2 > E1, the total displacement of the test increased in turn, and it can be seen that the drainage plate, load, and shortening the electrode spacing can increase the electroosmotic drainage, and shortening the electrode spacing has the best effect.

### 3.3 Drainage rate and current

Fig.9. show the fitted straight lines of the relationship between the drainage rate and the current in each group. It can be seen from the eq.(1) that under the action of different drainage methods, loads, and electrode arrangements, there is an approximately linear relationship between the drainage rate and the current:

\[ V = AJ + B \]  

A and B are coefficients and corresponding fitting degree of each group are shown in Fig.8.
4. Conclusion
In the process of electroosmosis, the drainage plate, load, and shortening the electrode spacing can effectively improve the electroosmotic drainage rate and displacement, and shortening the electrode spacing has the most obvious effect on it.

When the voltage is constant, the drainage rate is linearly related to the current. The drainage method has little effect on electroosmotic migration. Stacking and shortening the electrode spacing have a positive effect on electroosmotic migration, which can effectively improve the electroosmotic efficiency.

References
[1] Cao Yonghua, Run Pengwang, Yang Changmin. Experimental study on sludge solidification[J]. Journal of Tianjin University, 2006, 39 (2): 199-203.
[2] Casagrande L. Electroosmosis in soils[J]. Geotechnique, 1948, 1(3):159-177.
[3] Esrig M I. Pore pressure, consolidation and electrokinetics [J]. Journal of the SMFD, American Society of Civil Engineers, 1968, 94(4):899-921.
[4] Shang J Q. Electroosmosis-enhanced preloading consolidation via vertical drains [J]. Canadian Geotechnical Journal, 1998, 35(3):491-499.
[5] WAN T Y, MITCHELL J K. Electro-osmotic consolidation of soils[J]. Journal of the Geotechnical Engineering Division, 1976, 102(5): 473–491.
[6] Wang Xiequn, Zhu Weili. Experimental study on the reinforcement of lacustrine soft clay by electroosmotic drainage method [J]. Journal of Wuhan University of Technology, 2007, 34 (2): 95-99.
[7] Zhang Lei, Wang Ningwei, Jing Liping, Fang Chen, Dong Rui. Comparative experiment of electrode materials in electroosmotic drainage consolidation[J]. Rock and Soil Mechanics, 2019,40(09): 3493- 3501+3514.
[8] Wang Junbo, Liu Shihong, Xu Wei, etc. Laboratory test of electro-osmotic treatment of Dalian Dajiawan ultra-soft soil [J]. Water Transport Engineering, 2010, 437 (1): 15-19.
[9] Li Ying, Gong Xiaonan, Zhang Xuechan. Experimental study on the effect of voltage on one-dimensional electroosmotic drainage [J]. Rock and Soil Mechanics, 2011, 32 (3): 769-714.
[10] Lei Zhang, Li-ping Jing. Electro-Osmosis Chemical Treatment of High-Salinity Soft Marine[J]. The Open Civil Engineering Journal, 2017,11,109-120