Experimental study on characteristics of consolidation of sludge

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Abstract. Sludge dewatering has become an important issue in the sewage treatment industry. The essence of mechanical dewatering is the consolidation and drainage of sludge. Therefore, it is of great significance to study the consolidation characteristics of sludge to improve the dehydration efficiency. Consolidation tests were carried out on the sludge treated with FeCl₃ and Fenton reagent, and the consolidation and permeability characteristics of the treated sludge were studied. The sludge shows ultra-high compressibility. The consolidation coefficient of the untreated sludge is 10⁻⁷~10⁻⁶cm²/s. After adding 15% FeCl₃ (relative to sludge dry weight), the consolidation coefficient of the sludge increased by 5~8 times, and reached 10⁻⁶~10⁻⁵cm²/s after Fenton reaction treatment. The untreated sludge has obvious time deformation characteristics.

1. Introduction
Sewage plant sludge (hereinafter referred to as sludge) is the sediment produced during the sewage treatment process. Its moisture content usually reaches about 80%. Sludge leachate will pollute the water after entering the groundwater layer, so the sludge treatment and disposal problem is urgent to be solved[1-2]. Since the unit volume of sludge contains 80% water, the reduction of sludge after dewatering has become an important part of restricting sludge treatment.

As a result, many scholars are devoted to study some methods including physical and chemical treated methods to treat sludge. Ultrasonic waves, combustion and so on are effective ways to remove the water in sludge and reduce volume of sludge. Zhao et al[3] investigated the pyrolysis combustion process of the sewage sludge and solved the problem of the excess sludge accumulation of the wastewater treatment plant. Shehab[4], studied the effect of ultrasonic waves on sedimentation characteristic of activated sludge and results shows that the ability of dewaterability of sludge decreased with the increasing of ultrasonic contacts time. Mixing sludge with some chemical materials or solution like cement, lime and organic flocculants is also an effective method to treated sludge[5-8]. Lo et al[9] studied cement-treated and cement/sodium silicate-treated sewage sludges by bench processes. Zhang et al[10] investigated the influences of the added cement content, curing period, and initial water content of the sludge on the drying shrinkage properties.

The mechanical dewatering is actually the consolidation and drainage of sludge, so it is extremely important to study the consolidation characteristics of treated sludge. O'Kelly[11] studied the effect of biodegradation on the consolidation characteristics of an anacrobically digested, dewatered municipal sewage sludge, results shows that strongly degraded sludge material was produced after a storage
period of 13 years at ambient temperatures of 5-15 degrees C, with the total volatile solids reducing from initially 70% to 55%. Tan et al[12] used the combinational method from chemical oxidation treatment and secondary mechanical dehydration is a powerful approach to further reduce the moisture content of the sludge, the physicochemical properties of resuspension excess sludge (RES) with the treatment of chemical oxidation were studied, the experimental results indicate that when the protein in supernatant + slime is more mineralized than moved in, the dewaterability of the sample is improved. Lu et al[13] investigated the dewatering of chemically acidified sludge and revealed the respective role of sludge floc structure and sludge extracellular polymeric substances (EPS) in influencing the removal rate of moisture (i.e., dewatering rate) and the removal amount of moisture (i.e., dewatering extent) of acidified sludge.

In this paper, H2O2 and FeCl3 were used as additives to treated sludge, and two conditioning schemes are designed and consolidation experiments are carried out on conditioned sludge, the compressibility and consolidation of conditioned sludge were analyzed deeply by experiment results. The research results can provide some reference for the study of the deformation characteristics of treated sludge.

2. Experimental material and scheme

2.1. Experimental material
In this study, the best conditioning effect was achieved when the pH value was adjusted to 3, w(H2O2) 60mg/g, and w(Fe2+) 40mg/g in the treatment of Fenton (the ratio was relative to the ratio of sludge dry basis). When the pH value of FeCl3 was 3, the optimal addition amount of FeCl3 was 15% of the sludge dry basis. Therefore, the consolidation tests of the sludge under the above two conditioning schemes and pristine sludge were carried out, and F0, F1 and F2 were used to replace them in the following text.

2.2. Experimental scheme
According to the uniaxial consolidation instrument method in the geotechnical test specification, two sets of samples are set for each test to improve accuracy. Loading was carried out according to six levels of 3.125, 6.25, 12.5, 25, 50 and 100kPa. After each stage of loading was applied, the loading was stabilized at 6s, 15s, 1min, 2min15s, 4min, 6min15s, 9min, 12min15s, 16min, 30min15s, 25min, 30min15s, 49min, 64min, 100min, 200min, 23h, 24h, 48h and 72h. When the deformation reading of sludge within 1h is no more than 0.005mm, it is stable.

Table 1. Physical properties index of sludge.

| Sample | Moisture content (%) | Density (g cm⁻³) | Organic matter content (%) | Pore ratio/ε |
|--------|---------------------|----------------|---------------------------|-------------|
| F0     | 446.22              | 1.04           | 58.35                     | 7.63        |
| F1     | 454.91              | 1.12           | 54.32                     | 8.24        |
| F2     | 464.28              | 1.23           | 51.13                     | 8.78        |

3. Results and analysis

3.1. Compression properties of sludge
Figure 1 shows the compression curve of the conditioned sludge. It can be seen that the initial pores of silty clay are relatively small and change slowly and stabilizes quickly. In comparation, the initial pore ratio of sludge was extremely high, reaching about 8, while the initial pore ratio of the sludge conditioned by Fenton is higher. The initial pore ratio of the sludge treated by FeCl3 is about 8.5, and that of the sludge treated by Fenton is close to 10. However, after the load is applied, the pore ratio decreases rapidly and slowly stabilized. After the application of 6.25kPa load, the pore ratio reduces to 4~5, accounting for 55%~63% of the total pore ratio variation, which indicates that the conditioned sludge is more sensitive under low load and has a large deformation range. Under different
conditioning schemes, the compression characteristics of sludge also vary greatly. The pore ratio of F1 changes slowly, but it keeps changing over time. While the pore ratio of F2 decreases rapidly, but it tends to be stable at 50kPa-100kPa.

The results of the consolidation test are organized into the e-lgp curve, as shown in figure 2. The pristine sludge presents a linear state on the e-lgp curve, and there is an obvious logarithmic relationship between e and p. After fitting, the following formula can be obtained:

\[ e = -C_c \times \lg p + e_0 \]  

(1)

where \( e_0 \) is the initial pore ratio, \( C_c \) is the compression exponent, the slope of the straight line on the e-lgp curve. From the above results, it can be seen that there is a big error between the fitted original pore ratio and the actual value.

3.2. Consolidation characteristics of the sludge

The consolidation coefficient reflects the dissipation rate of the pressure between the soil gaps, which is the basis for calculating the deformation rate and the main reason affecting the consolidation time and drainage degree. Based on the time square root method, the consolidation coefficient of sludge was calculated through the indoor consolidation test. The calculation formula of the time square root method is as follows:

\[ C_v = \frac{0.848 h^2}{t_{90}} \]  

(2)

where \( C_v \) is the consolidation coefficient (cm²/s), \( H \) is the maximum drainage distance, which is equal to half (cm) of the average of the original height and final height of the soil under a certain load.

The relationship between the sludge consolidation coefficient and stress is shown in figure 3. It can be seen that the consolidation coefficient of the sludge in the process of consolidation is not constant, and the value is small. The consolidation coefficient of the pristine sludge is 10-7~10-6cm²/s, while the consolidation coefficient of the conditioned sludge is 10-6~10-5cm²/s. There is an obvious increase in comparison, indicating that two conditioning schemes can significantly accelerate the sludge consolidation, thus reduce the completion time of consolidation. With the application of load, the consolidation coefficients of the three kinds of sludge have different variation rules. The consolidation coefficient of F0 decreases slowly with the increase of stress, and finally tends to be stable. The consolidation coefficient of F1 decreases with the increase of stress when the load is 3.125kPa~12.5kPa, and then there is an increasing tendency. Among them, the reduction range of F2 is the largest, which reduces from 1.1×10-5cm²/s to 4.4×10-6cm²/s. After the load is 25kPa, the consolidation coefficient gradually increases, indicating that both FeCl3 and Fenton treatment can significantly accelerate the sludge consolidation, and the conditioned sludge can quickly be stabilized under the consolidation stress.
4. Conclusion
The results of consolidation test show that the sludge exhibits ultra-high compressibility. During the consolidation process, the consolidation coefficient of the sludge does not remain unchanged. The consolidation coefficient of the pristine sludge is 10^{-7}~10^{-6}cm^2/s, after adding 15\% FeCl_3 (relative to dry basis), the consolidation coefficient increases by 5~8 times. While treated by Fenton reaction (pH=3, Fe^{2+}: H_2O_2 = 1:1.5), the consolidation coefficient reaches 10^{-6}~10^{-5}cm^2/s, which is a great improvement compared to the original sludge (10^{-7}~10^{-6}cm^2/s).

The organic content of the samples used in the test sample is at 50\%, its degradation time is long and it has a great influence on the consolidation process. Moreover, the form of moisture inside the sludge is very complex, and it is difficult to discharge the bound water by consolidation stress or the discharge speed is very slow, which lead directly to the long time for completing the sludge consolidation. After conditioned by FeCl_3, FeCl_3 dissolved into the sludge and diffuses to solid-liquid interface and adsorbs to the surface of sludge particles, and the sludge particles adsorbed with conditioner coagulate together with other sludge particles into sludge flocs. With the continuous addition and gradual adsorption of FeCl_3, the sludge flocs become a stronger floc structure, so the consolidation characteristic of the sludge are improved to some extent. After Fenton reaction treatment, the time for sludge consolidation is greatly shortened, the reason is the OH generated by Fenton reaction is extremely oxidizing, which severely damages the original organizational structure of sludge and promotes more bound water to convert into free water. The bound water is quickly discharged when the Fenton reagent was added.

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