Effect of organic content on compression properties of municipal sewage sludge

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Abstract: Urban sewage sludge is rich in a large amount of organic matter, which has a significant impact on the compression characteristics of sludge, and ultimately affects the landfill disposal and resource utilization of sludge. Quartz sand was mixed into the sewage sludge to prepare sludge samples with an organic content of 8%, 16% and 26% (raw sludge) respectively, and then a standard consolidation test was carried out to explore the influence of the organic content on the compression properties of the sludge and mechanism of action. The results show that the compressibility of urban sludge increases with the increase of organic content. The compression coefficient and index of sewage sludge both increase exponentially with the increase of organic content. The ln(1+e)~lgp curve of urban sludge has a significant “inflection point” and a certain consolidation yield stress. With the increase of organic content, the consolidation yield stress decays exponentially. Organic matter in the sludge has a flocculent structure and a large specific surface area. It is easily adsorbed on the surface of the clay particles, hindering the cementation of the clay particles and reducing the permeability of the sludge. At the same time, organic matter has water-retaining property, hinders the consolidation and drainage of sludge, and ultimately affects the compression properties of sludge.

1. Introduction
With the advancement of the country's urbanization, the amount of sewage treatment has increased significantly, and a large amount of sewage sludge will be produced. If it is not handled properly, it will seriously harm the social environment. Urban sewage sludge is the product of sewage dehydration and contains a large amount of organic matter, heavy metals and other harmful substances [1]. Data from the E20 Research Institute shows that the current output of urban wet sewage sludge in the country has reached 60 million tons (based on a moisture content of 80%) [2]. Common sludge disposal methods mainly include landfill and solidification. After the sewage plant sludge is dehydrated, the water content is still high, its physical and mechanical properties are extremely poor, and it is easy to cause engineering accidents and secondary pollution when landfilled [3,4]. The sewage sludge is rich in a large amount of organic matter, which has a greater impact on the physical and mechanical properties of the sludge, and ultimately affects the landfill disposal and resource utilization of the sludge. In this paper, sewage sludge samples with organic content of 8%, 16% and 26% (raw mud) were prepared by mixing quartz sand in the sludge, and then a standard consolidation test was carried out to explore the effect of organic content on the compression properties of urban sludge.
and clarify its mechanism of action. It can provide certain theoretical guidance and technical support for sludge landfill disposal and resource utilization.

2. Test equipment and methods

The quartz sand used in the experiment was taken from the quartz sand tailing pit of a glass factory in Fengyang County of Anhui Province, and the sewage sludge sample was taken from the dewatered sludge of a sewage treatment plant in Fengyang County. After sampling, water content, specific gravity, liquid plastic limit, particle analysis, and standard consolidation test were conducted. The test method refers to the "Geotechnical Test Method Standard" (GB/T50123-2019) [5]. The organic matter content test is conducted in accordance with the "Highway Geotechnical Test Regulations" (JTG 3430—2020) [6]. The moisture content test adopts the drying method, the temperature is controlled at 65°C, and the initial moisture content of the sludge is determined to be 296%. The organic matter content of the sewage sludge was measured by the loss-on-ignition method, with a control temperature of 950°C and burning for 0.5 h. The measured organic matter content of the sludge was 26%. The particle size curve of sludge and quartz sand is tested with a laser particle size analyzer, and six slices of sodium phosphate and ultrasonic are used for double dispersion, and data collection is performed after the shading rate meets the requirements. The basic physical indicators of the sludge obtained by the test are shown in Table 1, and the particle size curves of the sludge and quartz sand are shown in Figures 1 and 2 respectively. Mix appropriate amount of quartz sand into the sludge, prepare sludge samples with the organic content of 8%, 16% and 26% (raw mud) respectively, and then make three groups of consolidated samples (two parallel tests in each group), the sample size is 61.8mm in diameter and 20mm in height. After curing for 7 days under standard curing conditions (humidity 90% and temperature 20°C), a standard consolidation test is carried out. The standard consolidation test was carried out using the VG single-lever consolidation instrument, and the test method was carried out in accordance with the "Standard for Geotechnical Test Methods" (GB/T50123—2019) [5]. The applied pressure is 25kPa, 50kPa, 100kPa, 200kPa, 300kPa, 400kPa, 800kPa, 1600kPa, and the sample height change within 24h after each level of pressure is applied is the stability standard.

Table 1 Physical indicators of sewage sludge

| water content (%) | liquid limit (%) | plastic limit (%) | plasticity index (%) | organic content (%) | specific gravity |
|------------------|------------------|-------------------|----------------------|--------------------|-----------------|
| 268              | 178              | 74                | 104                  | 26                 | 2.3             |

Figure 1. Grain size curve of sludge (raw sludge)

Figure 2. Grain size curve of quartz sand
3. Analysis and discussion of test results

Standard consolidation tests were carried out on sludge samples with organic content of 8%, 16% and 25% (raw sludge) respectively, and e–p curve of the sludge can be obtained as shown in Figure 3. It can be seen from Figure 3 that the e–p curve of sludge with high organic matter content is located above the low organic matter content. The higher the organic matter content, the steeper the e–p curve, indicating that as the organic matter content increases, the compressibility of the sludge gradually increases. When the consolidation pressure is between 0 and 500 kPa, the e–p curve is steeper, and the void ratio changes greatly. When the consolidation pressure exceeds 500 kPa, the void ratio changes gradually with the consolidation pressure. It can be seen that the consolidation pressure is between 0 and 500 kPa, and the organic content has a significant impact on the compressibility of sludge, mainly due to the discharge of free water and the compression of the organic flocculent structure. When the consolidation pressure exceeds 500 kPa, the As the consolidation pressure continues to increase, the large amount of organic matter in the sludge makes the particle-bound water film thinner and the cohesive force increases. The organic matter flocculent structure tends to compress and stabilize, and the influence of organic matter content gradually decreases.

![Figure 3. e-p curves of different organic contents](image1)
![Figure 4. Relation between compressibility and organic content](image2)

According to the e–p curve, the compression coefficient of sludge in the range of 100kPa–200kPa can be obtained. The compression coefficient of sludge with an organic content of 8% is 0.297MPa⁻¹, which is between 0.1MPa⁻¹ and 0.5MPa⁻¹, which is moderately compressible soil. The compressibility coefficients of sludge with 16% and 26% organic matter content are 0.526MPa⁻¹ and 1.556MPa⁻¹, respectively, both greater than 0.5MPa⁻¹, which are highly compressible soils. The relationship between compressibility and organic matter content is shown in Figure 4. The compression coefficient of urban sludge increases exponentially with the increase of organic content.
The e-lgp curve of the sludge can be obtained by using the e-p curve as shown in Figure 5. The compression index of the sludge can be obtained through the e-lgp curve. The compression index reflects the overall compressibility of the sludge. When the organic matter content is 8%, the compression index of sludge is 0.073, less than 0.2, which is a low compressibility soil. While the sludges with an organic content of 16% and 26% have compression indexes of 0.205 and 0.38, between 0.2 and 0.4, which are medium compressibility soils. The relationship curve between the compression index and the organic content is shown in Figure 6. It can be seen that the compression index increases exponentially with the increase of the organic content. This paper uses the double logarithmic coordinate method, proposed by Butterfield [7], to determine the consolidation yield stress of sludge. The ln(1+e)~lgp double logarithmic compression curve of sludge can be obtained through the e-p curve as shown in Figure 7.

It can be seen from Figure 7 that the double logarithmic compression curve of the sludge has an obvious "inflection point", indicating that the urban sewage sludge with different organic content has a certain consolidation yield stress. The pressure is the consolidated yield stress of the sludge at the "inflection point" of the ln(1+e)~lgp curve. When the organic content is 26%, the sludge consolidation yield stress is 190kPa. When the organic content is 16%, the sludge consolidation yield pressure is 300kPa. When the organic content is 8%, the sludge consolidation yield pressure is 550kPa. The relationship curve of sludge consolidation yield stress and organic matter content is shown in Figure 8. It can be seen that the consolidation yield pressure of sludge decays exponentially with the increase of organic content.
Based on the above, it can be seen that the organic content has a significant impact on the compressibility of sludge. As the organic content increases, the compressibility of sewage sludge increases. The compression coefficient and index of sludge both increase exponentially with the increase of organic content. The consolidation yield stress of sludge decreases exponentially with the increase of organic content. The particles of organic matter are generally smaller than most clay mineral particles, the molecular structure is flocculent, and the particles will attract each other and connect into clusters [8]. Moreover, the organic matter in the sludge mostly exists in the ionic state of fulvic acid. This acid ion adheres to the surface of the soil particles, forming a layer of adsorption film on the surface of the soil particles, which makes it have strong water absorption and water retention, thereby hindering the cementation between the clay particles and reducing the permeability of sludge. The presence of a large amount of organic matter will make the bound water film in the sludge thinner and produce a large amount of bound water. At the same time, the specific surface area of the organic matter is larger, which plays a role of water retention on the sludge and hinders drainage and consolidation of the sludge [10], ultimately affecting the compression properties of sewage sludge.

4. Conclusion
In this paper, a standard consolidation test of sewage sludge with different organic content is carried out to explore the influence of organic content on the compression properties of sludge. The main conclusions are as follows:

(1) With the increase of organic content, the compressibility of urban sludge increases. The compression coefficient and index of sludge both increase exponentially with the increase of organic content.

(2) There is an obvious "inflection point" in the $\ln(1+e)$–$\lg p$ curve of urban sewage sludge, which has a certain consolidation yield stress. As the organic matter content increases, the consolidation yield stress decreases exponentially.

(3) Organic matter has a flocculent structure with a large specific surface area. It is easily adsorbed on the surface of the clay particle clusters, hinders the cementation between the clay particles and reduces the permeability of the sludge. At the same time, it has a water retention effect on the sludge and hinders drainage and consolidation of sludge, and ultimately affects the compression properties of sewage sludge.
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