An Experimental Study of the Size Effect’s Impact on Consolidation Behaviors of Dredged Silt

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Research Article

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Abstract

The soil sample size of the consolidation test is different from the actual soil, with the differences shown in their compression and permeability properties. This study thus is to investigate the influence of sample size on the consolidation behaviors of dredged silt. In order to investigate the sample size's impact on consolidation behavior, this study used the automatic air pressure consolidometer to conduct numerous consolidation tests on three kinds of dredged silt samples at different heights in Qianwan, Shenzhen, China. The key findings made the following three significant contributions. (1) The compression curves of samples of different sizes have three stages: small load disturbance, elastic deformation and plastic deformation. The void ratio in the latter two stages decreases with the increase of sample height. (2) The stable strain and compression index of the samples decrease when the samples' height increases. While the sample height has a limited impact on the structural yield stress, its consolidation coefficient decreases significantly with the increase of the sample height. Thus, the size effect's impact on the consolidation coefficient should be considered. (3) Due to the reason that dredged silt and marine silt have different formation processes, stress history, and material composition, the permeability coefficient of dredged silt is greater than that of marine silt. When the consolidation pressure is lower, the consolidation coefficient of dredged silt is less than that of marine silt. The difference between the consolidation coefficient of the two kinds of silt decreases with the increase of consolidation pressure. The difference of the former is greater than the latter.

1 Introduction

The reclamation land projects produce a large number of dredged silt. The dredged silt has “two high, three low and finite strain”, namely high water content and void ratio, low strength and coefficient of permeability and consolidation rate, finite strain and other engineering characteristics. When a vertical drain treatment method is used, the coefficient of compression, the coefficient of permeability and consolidation of dredged silt change according to the magnitude under preloading. It is different from traditional consolidation theory, thus it is essential to study the consolidation behavior of dredged silt. The consolidation behavior of dredged silt has been studied by consolidation test and achieved relevant results. For example, Hu (2020) used GJZ-2 double and medium pressure consolidometer to conduct consolidation tests on two kinds of dredged ultra-soft soil in Shanghai, studied the compression and consolidation characteristics, and developed a linear relationship model between the logarithm of permeability coefficient and void ratio. Lu (2015) carried out consolidation and permeability tests on different kinds of dredged fill in Tianjin Binhai New Area. The GDS consolidation apparatus was used in the study, and obtained the suitable nonlinear compression and permeability relationship for dredged fill in this area. Zhang et al. (2012) analyzed and discussed the variation regularity of three types of large-strain consolidation coefficients with void ratio. Additionally, the condition relationship formulates of variation of large-strain consolidation coefficient with void ratio was used to apply to the analysis of the various characteristics of consolidation coefficient of dredged silt measured by GDS consolidation test (Zhang et al. 2012). Zhang et al. (2010) also conducted the consolidation test of dredged silt in Shenzhen
Bay. They compared the results with the consolidation coefficient of undisturbed silt soil, and found after surcharge preloading treatment, and the dredged silt can achieve the same drainage consolidation rate as the undisturbed silt.

The standard sample used in the consolidation test has a cross-sectional area of 30 cm$^2$ or 50 cm$^2$ and a height of 2 cm. In practical engineering, the depth of dredged fill can reach more than 5 m, and the sample with a height of 2 cm is used to represent the actual soil. It results in differences in the consolidation compression and permeability properties of the obtained soil samples, called the size effect. The soil sample size has an impact on test results during the consolidation test. The difference in size effect on the test results of rock, concrete and other solid materials has been widely concerned and studied (Komurlu 2018; Faramarzi and Rezaee 2018; Xu and Zhang 2021; Celik 2017; Yang et al. 2004; Zhou et al. 1998; Zhang 2016; Han and Liu 2016). It was found the size effect influenced the strength and deformation properties of soft clay soil, residual granite soil, coarse-grained soil and expansive soil.

Zheng (2008) studied the size effect on consolidation deformation properties of soft clay. They conducted consolidation tests on fresh dredged ultra-soft clay soil with different heights by using an automatic air pressure consolidometer and analyzed the influence of sample height on the consolidation deformation rate, consolidation coefficient, compression modulus and compression coefficient of soil samples. Lei et al. (2016) also carried out an experimental on consolidation characteristics of dredged fill soft soil with four different sizes of samples by using modified consolidation apparatus. They discussed the differences in stress-strain relationship, consolidation characteristics and coefficient of secondary consolidation of different sizes of samples. Zhou et al. (2005) designed the consolidation simulation tests of large-size soft clay samples with three specifications. They also discussed the consolidation deformation regularity and size effect of large-size soft clay under different pressures. Finally, they developed a quantitative relationship between the size effect and settlement of soil samples. In 2014, the effects of specimen size on consolidation properties of soft Bangkok clays were studied by one-dimensional consolidation tests of two different sizes (one sample with 60 mm in diameter and 20 mm in height, the other sample with 35 mm in diameter and 20 mm in height) (Kongkitkul et al. 2014). The coefficient of consolidation, compression index and pre-consolidation stress were compared, and the difference in specimen size affecting all parameters was discussed. Chen and Lv (2017) also studied the influence of the size effect of red clay samples on the resilient modulus by laboratory tests and numerical simulation.

Previous research also studied the influence of size effect on residual granite soil's strength and deformation properties. For example, Zheng et al. (2020) carried out the conventional triaxial consolidation undrained shear tests of residual granite soil with the diameter of 39.1 mm, 61.8 mm and 101 mm on coastal. They discussed the influence of sample size on the stress-strain characteristics and strength of granite residual soil in their research. A few years earlier, triaxial consolidation undrained shear tests were conducted on undisturbed and remolded granite residual soil samples with different diameters. The effects of particle size and sample size on stress-strain characteristics and shear strength were studied (Lin and Ke 2017; Lin 2016). Li and Chen (2020) carried out $K_0$ triaxial consolidation...
undrained tests on different sizes of seabed undisturbed strongly weathered granite samples and analyzed the influence of sample size on the stress-strain characteristics and shear strength indexes of strongly weathered granite.

The influence of size effect on stress-strain and strength of coarse-grained soil has also been studied. For instance, the laboratory triaxial compression and direct shear tests show that the size of the specimen has a significant influence on the stress-strain behavior of sands, with larger specimens mobilizing smaller shear strengths (Omar et al. 2014). Li et al. (2008) conducted confining pressure stress path tests on sandstone transition materials with different sample diameters and maximum particle sizes by triaxial apparatus. They, in particular, evaluated the influence of sample diameter and maximum particle size on stress-strain-strength characteristics. Mei et al. (2005) also analyzed the impact of size effect on the deformation of sandy gravel by triaxial compression test and bearing capacity test of two different sizes of sandy gravel mixture, and They found that extensive experiments can eliminate the error of experimental results caused by size effect to a certain extent.

Cerato and Lutenegger (2006) worked with five areas of sand with different properties tested in three square shear boxes of varying sizes (60mm, 101.6mm and 304.8mm). The tests found that the friction angle is dependent on specimen size, and the friction angle decreases as box size increases. Zhu et al. (2012) also conducted triaxial consolidation drained shear tests on three rockfill samples with different diameters to study the influence of sample size on stress-strain and strength characteristics of coarse-grained soil. In addition, Yang et al. (2007) compared and analyzed the shear strength of expansive soil measured by the indoor shear test and field shear test and found differences between the two, namely, the size effect. Yang et al. evaluated the reasons for the formation of the size effect, and the reduction coefficient of shear strength in the indoor test was proposed. Huang (2013) collected a large number of experimental data to study the influence of sample size on the shear strength of expansive soil, and developed the determination method of a reasonable diameter and shear strength indexes $c$ and $\phi$ when determining the shear strength of expansive soil.

Currently, it is known there are few studies on the size effect related to the slurry dredged fill. Thus, this study investigated the dredged silt on the ground surface of reinforcement treatment and land reclamation projects in Qianwan, Shenzhen. In detail, the consolidation tests of dredged silt samples at three different heights were carried out by using an automatic air pressure consolidometer. The differences in compression, deformation, permeability and consolidation properties of different size samples were also discussed. Additionally, the differences in permeability and consolidation properties of regional marine silt and dredged silt were also discussed, which provided a theoretical basis for the engineering practice of dredged silt foundation treatment.

2 Test Scheme

The soil samples were collected from the dredged silt on the foundation by reinforcement in Qianwan Bay, Shenzhen. The soil samples were then sealed in two layers of plastic bags. The plastic bags and soil
samples were put into a hard bucket. Checks were made to ensure the plastic bags were well sealed without obvious water seepage. The soil samples in ten plastic bags were tested respectively. The average value of physical property indexes is shown in Table 1. However, due to the flow plastic state of soil samples, it is challenging to prepare undisturbed samples. The sample thus, was directly filled into the ring knife of consolidation apparatus.

<table>
<thead>
<tr>
<th>w(%)</th>
<th>ρ(g/cm³)</th>
<th>Gs</th>
<th>ε₀</th>
<th>w_L(%)</th>
<th>w_p(%)</th>
<th>I_p</th>
</tr>
</thead>
<tbody>
<tr>
<td>95.7</td>
<td>1.480</td>
<td>2.759</td>
<td>2.666</td>
<td>51.2</td>
<td>22.5</td>
<td>23.6</td>
</tr>
</tbody>
</table>

The automatic air pressure consolidometer was used in the test instrument. Compared with the single lever consolidation apparatus, the apparatus used in this study has the following advantages. (1) Data are recorded in real-time according to the test requirements under the specified time and load sequence. The time square root curve and logarithmic time curve are displayed. The flexibility of the instrument is better, and the test cycle is shorter than the single lever consolidation apparatus. (2) It can automatically collect test data, and the large and small ring knives can be set and loaded respectively to reduce human error and improve test accuracy.

The test was conducted under the condition of double-sided drainage at room temperature. The high-pressure consolidation and standard consolidation test methods were conducted on the samples of different sizes (see Table 2), and the cross-sectional area was 30cm². Due to the low initial strength of the sample, the first and second consolidation pressures were 5 kPa and 12.5 kPa, respectively. The observed deformation was less than 0.005 mm/h, set as the stability standard for each stage load. The next stage load was applied after the deformation was stable under the previous stage load. In order to make the consolidation complete, the final stage load was stabilized, and the consolidation continued for the following three days.
Table 2
Test loading scheme

<table>
<thead>
<tr>
<th>Sample Number</th>
<th>Sample Height(cm)</th>
<th>Consolidation Pressure (kPa)</th>
<th>Group Number</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>S-1</td>
<td>2</td>
<td>5,12.5, 25, 50, 80, 100, 200, 300, 400, 600, 800, 1200, 1600</td>
<td>64</td>
<td>High-pressure Consolidation Test</td>
</tr>
<tr>
<td>S-2</td>
<td>2</td>
<td>5,12.5, 25, 50, 80, 100, 120, 200, 300, 400</td>
<td>64</td>
<td>Standard Consolidation Test</td>
</tr>
<tr>
<td>M</td>
<td>3</td>
<td>5,12.5, 25, 50, 80, 120</td>
<td>64</td>
<td>Standard Consolidation Test</td>
</tr>
<tr>
<td>L</td>
<td>4</td>
<td>5,12.5, 25, 50, 80, 120</td>
<td>64</td>
<td>Standard Consolidation Test</td>
</tr>
</tbody>
</table>

3 Test Results

3.1 Compression Curve

The $e_p$ and $e$-lg$p$ curves of samples with different sizes are shown in Fig. 1 and Fig. 2. It can be seen from Fig. 1 and Fig. 2 that the compression curves of different size samples are the same, and the compression process of dredged silt has gone through three stages: (1) Small load disturbance stage (consolidation pressure $p \leq 12.5$kPa): The compression curve is very steep and the compression coefficient is large. At this time, due to the loose state of dredged silt, great deformation occurs under the minimum consolidation pressure. With the large extrusion of thin film water between particles, the void ratio decreases very obviously, which shows different compression characteristics from general natural soft clay. (2) Elastic deformation stage: With the increase of consolidation pressure ($p = 25 \sim 80$kPa), the soil is continuously compacted to form a new structural strength, which can resist the additional pressure imposed by some parts, and the curve becomes gentle and enters the elastic compression stage. At this stage, the elastic deformation of soil skeleton mainly occurs, with a small amount of film water extrusion, the compression deformation is not large compared with the first stage, and the compression coefficient is not large. (3) Plastic deformation stage: when the consolidation pressure continues to increase, the soil structure is destroyed, and the clay particles are relatively slipped and re-closely arranged. The deformation of dredged silt in this stage is mainly plastic deformation, and the curve presents on an upward concave shape. The greater the consolidation pressure, the more obvious this stage.

In the first stage, the void ratio of samples changed greatly, and there is little difference with the variation in void ratio of samples with different sizes. The change of void ratio of samples with different sizes in the second and third stages is quite different, and the change of void ratio decreases with the increase of sample size.
3.2 Compression Strain

The cumulative stable strain of samples with different sizes under different consolidation pressures is shown in Fig. 3. It can be seen from Fig. 3 that under the same consolidation pressure, the influence of sample size on the stable strain of soil sample is approximately linear, that is, with the increase of sample size (sample height), the cumulative stable strain of soil sample decreases. When the consolidation pressure is small, the linear decrease is not obvious; when the consolidation pressure is large, the linear decrease is more obvious.

With the increase of sample height, the change of cumulative strain is shown in Table 3. It can be seen from Table 3 that when the sample size (sample height) increases from 2 cm to 3 cm, the minimum difference of cumulative strain of the sample is 0.318% at the consolidation pressure of 5 kPa. When the consolidation pressure is 120kPa, the maximum difference of cumulative strain is 2.022%. When the sample size (sample height) increases from 3cm to 4cm, the minimum difference of cumulative strain is 0.242% at the consolidation pressure of 5kPa. When the consolidation pressure is 25 kPa, the maximum difference of the cumulative strain of the soil sample is 1.482%. When the sample size (sample height) increases from 2cm to 4cm, the minimum difference of cumulative strain is 0.56% at the consolidation pressure of 5kPa. When the consolidation pressure is 120 kPa, the maximum difference of the cumulative strain of the soil sample is 2.997%.

<table>
<thead>
<tr>
<th>Consolidation Pressure p(kPa)</th>
<th>Accumulative Strain A(2cm) (%)</th>
<th>Accumulative Strain B(3cm) (%)</th>
<th>Accumulative Strain C(4cm) (%)</th>
<th>A-B (%)</th>
<th>B-C (%)</th>
<th>A-C (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>20.315</td>
<td>19.997</td>
<td>19.755</td>
<td>0.318</td>
<td>0.242</td>
<td>0.560</td>
</tr>
<tr>
<td>12.5</td>
<td>23.400</td>
<td>22.350</td>
<td>20.910</td>
<td>1.050</td>
<td>1.440</td>
<td>2.490</td>
</tr>
<tr>
<td>25</td>
<td>26.140</td>
<td>25.197</td>
<td>23.715</td>
<td>0.943</td>
<td>1.482</td>
<td>2.425</td>
</tr>
<tr>
<td>50</td>
<td>28.880</td>
<td>28.383</td>
<td>27.990</td>
<td>0.497</td>
<td>0.393</td>
<td>0.890</td>
</tr>
<tr>
<td>80</td>
<td>31.795</td>
<td>30.450</td>
<td>29.208</td>
<td>1.345</td>
<td>1.242</td>
<td>2.587</td>
</tr>
<tr>
<td>120</td>
<td>35.495</td>
<td>33.473</td>
<td>32.498</td>
<td>2.022</td>
<td>0.975</td>
<td>2.997</td>
</tr>
</tbody>
</table>

3.3 Yield Stress of Soil Structure and Compression Index

The mechanical properties of structural soil, such as the dredged silt, are pretty different before and after the yield stage, and the structural yield stress is an essential parameter of the dredged silt. Butterfield (1979) first proposed determining the yield stress of the structure by using the double logarithmic coordinates (Butterfield 1979). Later, many scholars confirmed the effectiveness of this method and confirmed that the intersection of the two straight lines was the yield stress of the soil structure (Sridharan et al. 1991; Hong and Onitsuka 1998). In the present paper, the double logarithmic coordinates
method \( \ln(1 + e) \sim \lg p \) proposed by Butterfield has been used to determine the structural yield stress of dredged silt.

The \( \ln(1 + e) \sim \lg p \) curves of soil samples with different sizes are shown in Figs. 4–7. The compression curves in Figs. 4–7 were approximately linearly expressed by two straight lines. The structural yield stress was obtained by processing the curves of samples with different sizes, as shown in Table 4. It can be seen from Table 4 that with the increase in soil sample height, the yield stress of soil samples with different sizes had little difference, with an average of 50 kPa. The reason for this phenomenon is that the yield stress of soil structure is an important index to measure the structural strength of the soil. For the same soil, the structural strength mainly depends on the properties, connection mode and arrangement mode of soil particles. Moreover, it has little relationship with the sample size.

The compression index \( C_c \) can be determined by the slope of the \( e \lg p \) curve in the yield stage of soil structure, which approximates the straight line. The compression indexes of soil samples at different heights are shown in Table 4. It can be seen from Table 4 that the compression index \( C_c \) decreases when the sample height increases. It was found there was little difference in the compression index of samples with different sizes.

<table>
<thead>
<tr>
<th>Sample Size (cm)</th>
<th>Structural Yield Stress ( \sigma_c )(kPa)</th>
<th>Compression Index ( C_c )</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>50.1</td>
<td>0.5335</td>
</tr>
<tr>
<td>3</td>
<td>47.3</td>
<td>0.5276</td>
</tr>
<tr>
<td>4</td>
<td>52.5</td>
<td>0.5206</td>
</tr>
</tbody>
</table>

3.4 Coefficient of Consolidation

The time square root curve was recorded using an automatic air pressure consolidometer. The consolidation coefficient of different sizes of samples under different consolidation pressures was obtained by the “time square root method” (see Fig. 8). Under the same consolidation pressure, when the sample height is more significant, namely, the increase of drainage distance of the soil sample, the consolidation coefficient of the soil sample gradually decreases, and the consolidation rate of the soil sample falls as well. When the consolidation pressure is low \( (p = 12.5kPa) \), the consolidation coefficient of the soil sample (with a height of 2cm) is twice of the soil sample (with a height of 4cm). However, the variation regularity of consolidation coefficient with consolidation pressure for different size samples stays the same. Under the condition of the consolidation pressure being lower than the structural yield stress \( \sigma_c \) (50 kPa), the consolidation coefficient increases when the consolidation pressure increases and reaches the maximum value at the structural yield stress. Differently, while the consolidation pressure exceeds the structural yield stress \( \sigma_c \), the consolidation coefficient of soil samples decreases when the consolidation pressure increases and becomes stable. When the consolidation pressure is smaller than
the structural yield stress, the void ratio of the soil sample is relatively large. It then has high permeability, and the consolidation coefficient of the soil sample is increased. When the consolidation pressure is greater than the structural yield stress, the compression deformation of the soil rises rapidly, and the void ratio decreases rapidly. Consequently, the soil particles are compacted, and the connectivity between particles becomes poor, leading to the change in the permeability of the soil, the fast lowering of the permeability, and the decrease of the consolidation coefficient of the soil sample.

However, it was found that the consolidation coefficient decreases with the increase of soil sample height. The consolidation coefficient measured by the conventional soil sample (with a height of 2cm) cannot be simply used to predict the consolidation rate and consolidation settlement process of dredged silt foundation. Instead, the influence of the size effect should also be further investigated.

### 3.5 Comparative Analysis of Consolidation Coefficient Between Dredged Silt and Marine Silt

Two kinds of silts samples from the same areas, dredged silt and marine silt (see Table 1), were used. These samples have similar initial water content and void ratio in soil samples. These samples were used to compare and analyze the consolidation coefficient and permeability coefficient variation with consolidation pressure. The consolidation and permeability tests were conducted by using the GDS consolidation apparatus to determine the consolidation coefficient and permeability coefficient. The marine silt was collected at a depth of 2m in the shallow water area outside the west channel port of Shenzhen Bay. Moreover, the dredged silt was collected at a depth of 0.5-1.5m on the surface of the silt pond in the reclamation area of Shenzhen airport. Table 5 shows the physical properties of the two types of silt and consolidation pressure under graded loading. Additionally, the particle analysis test and X-ray diffraction results of the three kinds of silt soil samples can be found in Table 6.

<table>
<thead>
<tr>
<th>Silt Sample</th>
<th>$w$ (%)</th>
<th>$\rho$ (g/cm$^3$)</th>
<th>$G_s$</th>
<th>$e_0$</th>
<th>$p$ (kPa)</th>
<th>Sample Size (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine Silt in the West Channel Port of Shenzhen Bay</td>
<td>99.2</td>
<td>1.420</td>
<td>2.67</td>
<td>2.703</td>
<td>25,50,100, 200,400,800</td>
<td>2</td>
</tr>
<tr>
<td>Dredged Silt in Shenzhen Airport</td>
<td>100.63</td>
<td>1.448</td>
<td>2.68</td>
<td>2.712</td>
<td>6,12.5,25,50, 100, 200</td>
<td>2</td>
</tr>
</tbody>
</table>
The variation of consolidation coefficients with consolidation pressure of three kinds of silt samples is shown in Fig. 9. As can be seen from Fig. 9:

(1) The curves of consolidation coefficient of dredged silt measured by different consolidation apparatus in Shenzhen Qianwan and Shenzhen Airport with consolidation pressure were found to coincide with each other, indicating that the two kinds of consolidation apparatus have high reliability in determining the consolidation coefficient of dredged silt. When consolidation pressure increases, the consolidation coefficient of dredged silt increases as well. When the consolidation pressure is less than or equal to 200 kPa, the consolidation coefficient of dredged silt increases to align with the higher consolidation pressure. To be more specific, when the consolidation pressure increases continuously, the consolidation coefficient of dredged silt also increases continuously but slowly until reaching a specific stable value. The consolidation coefficient of dredged silt increases from $0.263 \times 10^{-3} \text{cm}^2/\text{s}$ to $0.510 \times 10^{-3} \text{cm}^2/\text{s}$ when the general preloading load is $50 \sim 300$ kPa, doubling the original value. Therefore, an error will be generated if the constant consolidation coefficient is used to predict the settlement process and consolidation degree.

(2) When the consolidation pressure is less than or equal to 200 kPa, the consolidation coefficient of marine silt under the same consolidation pressure is much greater than that of the two types of dredged silt (see Fig. 9). When consolidation pressure increases, the difference between the two types of silt decreases. It was found that curves of the consolidation coefficient of marine silt and dredged silt met at one point (see Fig. 9). When the consolidation pressure reaches 600 kPa, the consolidation coefficient of dredged silt is greater than that of marine silt. It indicates that the consolidation property of dredged silt is performing worse than that of marine silt in its initial state. However, it can still approach or reach the same drainage consolidation rate as marine silt after preloading treatment.
The difference in consolidation coefficient between dredged silt and marine silt lies in their formation process, stress history and material composition. The dredged silt was fueled by undisturbed marine silt through blowing and mechanical stirring. It then formed under-consolidated soil. The original state of the soil structure has been destroyed, and the current structure is loose. The priority was given to developing the unstable turbulence and granular mosaic structure. A large fracture has also been developed. Compared with the marine silt, mainly composed of granular cementation and honeycomb structure, the dredged silt shows obvious characteristics of macropore overhead. The compression coefficient was found higher under low consolidation pressure, resulting in the consolidation coefficient of marine silt being higher than that of dredged silt.

The scanning electron microscopy analysis shows that the clay minerals of marine silt in Shenzhen were mainly kaolinite, followed by illite and chlorite. The X-ray diffraction test results show that the dredged silt is mainly illite/montmorillonite and kaolinite, with poor hydrophilicity and small hydration film thickness, leading to high compressibility (see Table 6). The physical and mechanical properties show that the water content and void ratio are more significant than marine silt. The void ratio decreases significantly under slight consolidation pressure. The compression coefficient is more significant than marine silt under the same condition. The permeability coefficient also changes significantly, resulting in the consolidation coefficient of dredged silt being smaller than that of marine silt.

Table 6 shows the sum of clay and colloid contents of dredged silt from Shenzhen Qianwan, dredged silt from Shenzhen Airport and marine silt from the western passage of Shenzhen Bay. The particle analysis results are 47.0%, 48.2% and 54.8%, respectively. It was found they are not significantly different from each other. However, it was also found the particle size composition had a significant impact on the drainage consolidation rate of soil. The dredged silt and marine silt had a similar consolidation coefficient in the later stage of the test under high consolidation pressure. The consolidation coefficient of dredged silt was greater than that of marine silt.

### 3.6 Comparative Analysis of Permeability Coefficient between Dredged Silt and Marine Silt

The permeability coefficient was calculated according to the consolidation coefficient of three kinds of silt samples. Figure 10 shows the variation curve of permeability coefficient with consolidation pressure. Two significant findings are:

1. The permeability coefficient of dredged silt measured by different consolidation apparatuses in Shenzhen Qianwan and Shenzhen Airport have the same variation under the consolidation pressure. When the consolidation pressure $p \leq 50kPa$, that is, the consolidation pressure is less than the structural yield stress, the permeability coefficient of dredged silt decreases significantly with the increase of the consolidation pressure. When the consolidation pressure increases, the permeability coefficient of dredged silt stables to a specific value. When the preloading load is $5 \sim 400$ kPa, the permeability coefficient of dredged silt in Shenzhen Qianwan Bay decreases from $5.39 \times 10^{-7}$ cm/s to $2.20 \times 10^{-8}$ cm/s (it
A constant permeability coefficient is used to predict the consolidation settlement process, and a significant error occurs.

(2) Under the same consolidation pressure, the permeability coefficient of two kinds of dredged silt was found to be significantly greater than that of marine silt. The significance is particularly greater when the smaller consolidation pressure $p \leq 50\text{kPa}$. When the consolidation pressure $p = 25\text{kPa}$, the permeability coefficient of dredged silt was three times that of marine silt. When the consolidation pressure increases, the permeability coefficient of marine silt decreases and stabilizes to a certain value. When the preloading load is 25–800 kPa, the permeability coefficient of marine silt decreases from $6.77 \times 10^{-8}\text{cm/s}$ to $3.80 \times 10^{-9}\text{cm/s}$. This value is nearly approximately one order of magnitude smaller than that of the dredged silt.

The difference in permeability coefficient between dredged silt and marine silt is determined by their particle composition and pore characteristics. The particle size test results in Table 6 show that the dredged silt has undergone hydraulic remodeling, gravity separation and clayization in the process of dredger fill. The sum of clayey and colloidal particles is lower than that of marine silt, resulting in high permeability and a large permeability coefficient of dredged silt. In addition, most of the interparticle pores are developed among the dredged silt particles. In particular, when there are more interparticle pores, the micro-layers and fractures are developed. Moreover, the more intergranular pores are, the better the connectivity is, and the greater the permeability coefficient is than that of marine silt.

4 Conclusions

1. The compression of dredged silt samples of different sizes has three stages: small load disturbance, elastic deformation and plastic deformation. There is little difference in the change of the void ratio of samples with different sizes in the small load disturbance stage. When the height of the sample size increases, the change of the void ratio of samples in the elastic deformation and plastic deformation stage decreases.

2. The cumulative stable strain and compression index of dredged silt samples decrease when the height of the sample size increases. The structural strength of soil mainly depends on the properties, connection and arrangement of soil particles. However, the sample size (sample height) has little effect on the structural yield stress of dredged silt.

3. The consolidation coefficient of dredged silt samples (with different sizes) increases with the increase of consolidation pressure, reaching the maximum at the structural yield stress. It decreases with the rise in consolidation pressure and stabilizes after exceeding the structural yield stress. The consolidation coefficient of dredged silt decreases with the increase of sample size (sample height). Thus, the size effect’s impact on the consolidation coefficient should be investigated.

4. There are differences in formation process, stress history and material composition between dredged silt and marine silt. Therefore, under low consolidation pressure, the consolidation coefficient of dredged silt is far smaller than that of marine silt. When the consolidation pressure increases, the difference between the two becomes less, but the consolidation coefficient of the former is larger.
than that of the latter. This finding shows that after high preloading treatment, the dredged silt can approach or reach the same drainage consolidation rate as the marine silt.

5. The permeability coefficient of dredged silt decreases when the consolidation pressure increases, and stables after. The permeability coefficient decreases by one order of magnitude in the range of preloading load. A significant error is generated when the constant permeability coefficient is used to predict the consolidation settlement process. There is a difference in particle composition and pore characteristics between dredged silt and marine silt. Hence, under low consolidation pressure, the permeability coefficient of the dredged silt is greater than the marine silt.

Declarations

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Conflict of interest The authors declare that they have no competing interests.

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Figures
Figure 1

$e$-$p$ curves of soil samples with different sizes

Figure 2

$e$-$\log p$ curves of soil samples with different sizes
Figure 3

Accumulative strains of samples with different sizes under different consolidation pressures
Figure 4

\( \ln(1+e) - \log p \) curves of soil samples
Figure 5

$\ln(1+e)$-$\lg p$ curve of a soil sample of 2cm height

$\sigma_c = 50.1$ kPa
Figure 6

\( \ln(1+e) \)-\( \log p \) curve of a soil sample of 3cm height

\( \sigma_c = 46.8 \text{kPa} \)
Figure 7

$\ln(1+e)$-lg$p$ curve of a soil sample of 4cm height
Figure 8

Consolidation coefficient of samples with different sizes under different consolidation pressures
Figure 9

The variation of consolidation coefficient of three kinds of silt

- Dredged Silt of Shenzhen Qianwan (Automatic Air Pressure Consolidometer)
- Dredged Silt of Shenzhen Airport (GDS consolidation apparatus)
- Marine Silt of Shenzhen Bay (GDS consolidation apparatus)
Figure 10

The variation of permeability coefficient of three kinds of silt