Research on consolidation characteristics of ultra-soft clay

A.M Liu¹,²,³, G.L. Ye¹,²,³ & Y.T. Zhu¹,²,³

1. CCCC Tianjin Port Engineering Institute, Co., Ltd., 2. Key Laboratory of Port Geotechnical Engineering, Ministry of Communications, 3. Key Laboratory of Geotechnical Engineering of Tianjin, Tianjin, 300222, China.

ABSTRACT

Ultra-soft clay generally has properties such as a large water content, a large void ratio, a large liquid index, accompanied with physical properties of a small coefficient of consolidation, a low soil strength and a small inner friction angle in quick-shearing test. Under a preload of 80 kPa, the ratio of settlement to soil height reaches 50%, much larger than that for common soft soil. When the consolidation pressure is less than 200 kPa, large changes occur in deformation and void ratio accompanied with a large consolidation rate. When the consolidation pressure exceeds 200 kPa, the rate of change for deformation and void ratio variation tends to be slow.

Keywords: ultra-soft clay, consolidation, void ratio

1. INTRODUCTION

With the rapid development of construction engineering such as coastal ports and industrial buildings, a demand for land increases sharply along the coastal area. Contradiction between demand and land provision has become increasingly prominent. To resolve this contradiction, a large number of land reclamation has been made by hydraulic filling. Since the vast majority of China coastal beaches are mainly blanketed with the muddy soil, the muddy soil is usually used for hydraulic filling. In a filling project, because the water outlet is generally far form the filling inlet for the large filling area, the coarse particles concentrates in the vicinity of the filling inlet while the smaller particles drifts away with water to concentrate around the water outlet, resulting in the ultra-soft clay. The ultra-soft clay features a high water content, high compressibility, and high permeability with a poor vane shearing strength lower than 5 kPa (Li et al. 2009, Liu et al. 2009, Wang and Yin 2009, Zhu et al. 2009).

Due to a short project construction period, the ultra-soft clay is often improved by vacuum preloading technique before drying. In recent years it has been found the soil strength is relatively low though this kind of ultra-soft clay undergoes a large ground settlement due to preloading for 3 ~ 5 months. So it is impossible to meet the requirement of bearing force of 80 kPa for the improved soil ground and a secondary improvement should be made. In order to effectively improve the ground of the ultra-soft clay, a systematic research was carried out for the consolidation characteristics of this kind of ultra-soft clay.

2. MODEL TEST

2.1 Soil properties before test

The soil samples were taken from the Dayaowan Harbor of Dalian Port area, China. The water content of the sample is extremely high, up to 140% ~ 160%, in a flow state with little strength. Its clay content is 42% ~ 49% with a plasticity index of 31~ 36. No mechanical index is obtained thought test since it is very soft in a flow state.

2.2 Test method

The test was conducted with a self-made large-scale consolidation model tank with an inner diameter of 960 mm and a height of 1200 mm. A steel frame with several counterweights was used for loading as shown in Figs 1 and 2. The mud model is 0.9 m high in the tank, and blanketed with a sand cushion of 0.25m thickness. A piece of plastic band drain was inserted into the model for drainage. The model was loaded by three grades for 691 d as shown in Fig. 3.

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2.3 Test results

The test result is shown in Fig. 4. The final settlement of the model mud is 429 mm, under the condition of the lateral deformation constraint, being 48% of the height test mud model. Immediately after every loading, the settlement rate changes obviously and then gradually decreases with an increase of the time. At the last stage of the loading, the settlement does not present obvious changes, denoting completion of a primary consolidation.

A series of 10 conventional consolidation tests were conducted with a maximum consolidation load of 1600 kPa. The test results are shown in Fig. 5. The consolidation coefficient is calculated to be $1.1 \times 10^{-4}$ cm$^2$/s after test. So we can predict the loading duration should last 600 d to reach a degree of consolidation of 95%.

3. LABORATORY HIGH-PRESSURE CONSOLIDATION

3.1 Soil properties and mechanical indexes before test

The ultra-soft clay samples were taken from a site of reclamation project in Shenzhen. It is Quaternary marine sediments, widely covering the western coastal areas and Lingdingyang of the Shenzhen. It is about 3 m ~ 10 m in depth, in a flow-plastic state, dark gray with organic matter content of 5% ~ 10%. The physical indexes of the test soil are shown in Table 1.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mean value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water content (%)</td>
<td>95.7</td>
</tr>
<tr>
<td>Unit weight (kN/m$^3$)</td>
<td>14.8</td>
</tr>
<tr>
<td>Void ratio</td>
<td>2.67</td>
</tr>
<tr>
<td>Liquid limit (%)</td>
<td>51.2</td>
</tr>
<tr>
<td>Plastic limit (%)</td>
<td>27.6</td>
</tr>
<tr>
<td>Plasticity index (%)</td>
<td>23.6</td>
</tr>
<tr>
<td>Liquidity index</td>
<td>2.15</td>
</tr>
</tbody>
</table>

3.2 Test method

A series of 64 high-pressure consolidation tests were conducted with automatic air pressure odometer. Because the soil samples were disturbed with a relative low strength, the loading pressure was applied with 5 kPa and 12.5 kPa as the first and second loading grades and a maximum loading pressure of 3200 kPa. The test sample was 2 cm high and tested with the standard consolidation method and a loading completion standard of 0.005 mm/h. In order to make a full consolidation, another 3-d consolidation was conducted after the completion of the last loading.
3.3 Test results

The deformation and variation of void ratio under different loading are shown in Figs 6 and 7, respectively.

As shown in Figs 6 and 7, the consolidation deformation is about 15.6% of the sample height while the void ratio reduces by 21.4% under consolidation pressure of 5 kPa. The consolidation deformation is about 49.3% of the sample height while the void ratio reduces by 67.3% under consolidation pressure of 3200 kPa. When the consolidation pressure is lower than 200 kPa, the deformation and void ratio undergo a large change with a large consolidation rate, followed with a turn point. After this pressure, the rates of the variation of deformation and void ratio tend to be slow.

Figs 8 and 9 depict the variation of the water content and coefficient of permeability of the test soil under different consolidation pressure. When the consolidation pressure increases from 5 kPa to 80 kPa, it is shown that the water content and coefficient of permeability decrease sharply. Under a consolidation pressure of 80 kPa, the water content decreases from 95.7% to 51.1%, and the coefficient of permeability decreases to be 1/15 of that under a consolidation pressure of 5 kPa. It is also observed that the relation curve of coefficient versus consolidation pressure becomes straight line when the consolidation pressure exceeds 80 kPa, denoting almost little variation in coefficient.

4. CONCLUSIONS

The following inclusions are drawn by the consolidation test result analysis for the ultra-soft clay:

(1) The ultra-soft clay has some typical properties such as having a high water content, a larger void ratio, a larger liquid limit and a larger plasticity index, and typical mechanical characteristics such as small consolidation coefficient, low shearing small strength, and inner friction angle in quick-shearing test.

(2) The ratio of the consolidation settlement of the ultra-soft clay to the soil height reaches 50% under a preload of 80 kPa, much larger than that for common soft soil.

(3) When the consolidation pressure is lower than 200 kPa, the deformation and void ratio undergo a large change with a large consolidation rate; when the consolidation pressure exceeds 200 kPa, variation of the deformation and void ratio tends to be slow.

(4) When the consolidation pressure is lower than 80 kPa, the coefficient of permeability decreases with an increase of the pressure; when the consolidation pressure exceeds 80 kPa, the coefficient of permeability will varies slightly with an increase of the pressure.
REFERENCES


