The Influence of Soil Saturation on the Geotechnical Test Results

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Abstract

The consistency limits are important properties of soil. The fall cone test method has a good repeatability, and the operator’s judgement has little effect on the results. This paper presents a new sample preparation method, in which the sedimentation method and consolidation test are combined, to prepare the saturated specimens for fall cone test for determining the consistency limits, and the sample prepared by this new method can be considered completely saturated. For the specimens prepared by the previous sample preparation method, the decrease in the water content leads to a decrease in the degree of saturation of soil. The test results show that the specimens prepared by this new method can reach a low water content, and the minimum penetration depths are as low as 2 mm, and the plastic limit could be obtained directly. In addition, the van shear test results show that the unsaturated specimens have larger values of undrained shear strength than the saturated specimens at the same water content, which could explain the difference of consistency limits obtained from different specimen preparation methods.

1. Introduction

The consistency limits are important engineering parameters of soils [1]. There are many methods used to measure the consistency limits, including percussion cup method, fall cone method, and thread rolling method [2–5]. Among those methods, the fall cone method has a good repeatability, and the operator’s judgement has little effect on the results [6]. In many countries, the fall cone method has been used to determine the liquid limit and plastic limit [4, 5, 7–9]. In fact, the essential of the fall cone method is a strength-based method [10], Wood and Wroth have proposed that the undrained shear strength $c_u$ of soil at plastic limit is 100 times that at the liquid limit [11], and the relationship between undrained shear strength $c_u$ and the cone penetration depth $d$ has been derived by Hansbo [12]; this relationship is obtained under the assumption that the soil samples are completely saturated. However, the degree of saturation of specimens is not strictly controlled by using spatulas to mix the sample on the mixing plate, which is introduced in BS EN ISO 17892–12: 2018 [13]. Previous studies have shown that the soil’s shear strength is related to the degree of saturation [14, 15]. Furthermore, the differences of plastic limit and liquid limit between the saturated specimens and unsaturated specimens are not analyzed.

In summary, it appears that the following studies need to be researched:

2. Modification on the specimen preparation method to ensure the degree of saturation of the soil specimens.
3. The mechanism of liquid limit and plastic limit influenced by saturated and unsaturated specimens.

2. Materials and Experimental Produce

The kaolin and bentonite were used in this study. The specimen was prepared from high water content to low water content as near the plastic limit as possible. The fall
cone test was carried out using BS cone (cone angle: 30°, cone weight: 80 g).

In test 1, the specimens were prepared by the method introduced in BS EN ISO 17892-12:2018 and the fall cone tests were performed in the specimen cup. At the end of each fall cone test, the saturation and water content of the specimens were measured. The degree of saturation \( S_r \) was calculated by the formula:

\[ S_r = \frac{w d_s}{e}, \]  

(1)

where \( w \) is the water content, \( e \) is the void ratio, and \( d_s \) is the specific gravity of soil particle.

The degree of saturation was calculated by the formula:

\[ e = \frac{d_s (1 + w) \rho_w - 1}{\rho}, \]  

(2)

where \( \rho_w \) is the water density, and \( \rho \) is the density of specimen.

The remaining soil was spread over a large plate for air drying for the next fall cone test, during this process, localized drying shall be avoided by repeating the process of remixing the soil.

Using the above specimen preparation method, it is difficult to guarantee complete saturation of the specimens. Furthermore, with the decrease of water content, placing the soil into the specimen cup is difficult [6]. Ting et al. [16] adopted sedimentation method to achieve fully saturated specimens. The soil was mixed with distilled water to form a dilute slurry, and then the slurry was pumped into a sedimentation column. The sedimentation was carried out for a period of 3 days, and the consolidation cell preplaced at the base of the sedimentation column. The saturated specimens can be used for the subsequent consolidation stage by removal of the consolidation cell. In this research, the method introduced above was used to prepare the specimens and the sedimentation process was carried out in the consolidation instrument. The heights of specimen rings were 20–40 mm and a pipe was added on the upper part of the specimen ring to increase the initial slurry capacity, as shown in Figure 1(a). After sedimentation for a period of 3 days, a saturated specimen form in the specimen ring, and the upper part is clear liquid, as shown in Figure 1(b). Then, remove the pipe, and carry out the consolidation tests, as shown in Figures 1(c) and 1(d). The specimens with different water content will be obtained by different consolidation pressure and time. When the consolidation process is finished, the fall cone tests will be carried out immediately after removal of the surface water. The fall cone test using the above specimen’s preparation method was named test 2.

3. Results

Relationships between the values of penetration depth and water content for the soils using test 1 and test 2 methods are shown in Figures 2(a)–2(c). It can be seen from these figures that the relationships are linear in the double logarithmic coordinate system. In test 1, the soils were stiff and difficult to mix at low water content, so the minimum depths of penetration are close to 5 mm. In test 2, after a long period of consolidation with high-pressure, the specimens can reach a low water content, and the minimum depths are as low as 2 mm.

In order to calculate the consistency limits, the fitting lines are shown in Figures 2(a)–2(c). Linear relationships between penetration depth and water content are established in the double logarithmic coordinate system. In test 1, the plastic limits at the depth of 2 mm penetration can be obtained by extending the fitting lines. The plastic limits and liquid limits are summarized in Table 1.

As shown in Figure 2 and Table 1, it can be seen that the plastic limits and liquid limits are influenced by the different specimen preparation methods. The values of LL and PL of specimens prepared by test 1 are larger than that of test 2. This is because the fall cone method is essentially reflecting the relationship between the undrained shear strength and the penetration depth of the soil under different water content, and the degree of saturation has an influence on the undrained shear strength.

The degree of saturation of the specimens prepared by Test 1 is shown in Figure 3. As can be seen from Figure 3, the decrease of the specimens prepared by Test 1 in water content also leads to a decrease in the degree of saturation; this phenomenon indicates that the air bubbles were produced during the mixing process. Therefore, even if the water content of the sample is very high, the soil will also be in an unsaturated state when the specimens are prepared by test 1. As shown in Figure 4, the undrained shear strength of the specimens prepared by test 1 and test 2 is measured by van shear test. The specimens prepared by test 1 have larger values of the undrained shear strength than that of test 2 at the same water content. This is because the undrained shear strength of saturated soil is mainly composed of friction and cohesion, and the cohesion is affected by the bound water between the soil particles. However, the undrained shear strength of unsaturated soil is mainly composed of friction, cohesion, and matric suction [17]. The matric suction increases with the decrease of water content in unsaturated soil, so the undrained shear strength of test 1 is larger than that of Test 2. Therefore, the value of fall cone depth obtained from unsaturated soil is smaller than that of saturated soil, and the PL and LL obtained from test 1 are larger than that of test 2. However, when the water content is higher than liquid
Figure 1: Consolidation method for specimen preparation. (a) Slurry before sedimentation. (b) Sedimentation for 3 days. (c) Details for consolidation test. (d) Consolidation process.
Table 1: Plastic limits and liquid limits obtained from fall cone tests.

<table>
<thead>
<tr>
<th>Soil</th>
<th>Test 1</th>
<th></th>
<th></th>
<th>Test 2</th>
<th></th>
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<tbody>
<tr>
<td></td>
<td>PL %</td>
<td>LL %</td>
<td>PI</td>
<td>PL %</td>
<td>LL %</td>
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<tr>
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<td>45</td>
<td>49</td>
<td>95</td>
<td>46</td>
</tr>
<tr>
<td>50% K + 50% B</td>
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<td>86</td>
<td>40</td>
<td>46</td>
<td>85</td>
<td>39</td>
</tr>
</tbody>
</table>

K: kaolin; B: bentonite; PL: plastic limit; LL: liquid limit; PI: plastic index.

Figure 2: Relationship between penetration depth and water content. (a) Kaolin. (b) Bentonite. (c) 50% kaolin and 50% bentonite.
limit, the specimens prepared by test 1 and test 2 are both saturated, so the values of the undrained shear strength derived from the two tests are similar.

4. Conclusions

This paper has focused on the influence of specimen preparation methods on the measurement of the plastic limit and liquid limit; the conclusions are as follows:

1. The sedimentation method combined with consolidation test can obtain saturated specimens of different water content. The fall cone test could be carried out immediately after consolidation instead of pushing soil into the specimen cup. Under the consolidation pressure, the specimens can reach a low water content and the minimum depths are as low as 2 mm, and the plastic limits could be obtained directly.

2. The decrease of the specimens prepared by the traditional sample preparation method in water content also leads to a decrease in the degree of saturation, and this phenomenon indicates that the air bubbles were produced during the mixing process.

3. The results by van shear tests show that the undrained shear strength of the unsaturated soil is larger than that of saturated soil and leads to lower values of penetration depth.

Data Availability

The data that support the findings of this study are available from the corresponding author.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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