Analysis and Improvement of Oblique Shear Phenomenon of Direct Shear Apparatus

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Abstract. Direct shear test is an important method to test the shear strength of soil. But the phenomenon of "oblique shear" often appears in the process of test, the soil sample subjected to eccentric pressure and uneven stress distribution, which affect the stability and accuracy of the test. This paper, starts from the construction of the direct shear apparatus, found that the relative displacement between the upper shear box and the axial pressure rod, is one important cause of "oblique shear". Set the steel ring between the lower shear box and the push rod, dose not affect the shear force measurement and can completely fix the upper shear box. There is no relative displacement between the upper shear box and the rod used to apply axial pressure after improvement, and no the phenomenon of "oblique shear". The experimental results are more stable and the coefficient of variation is smaller. The improvement scheme of the direct shear apparatus is simple, the improvement effect is obvious, and the stability and accuracy of the direct shear test are improved.

1. Introduction
The soil parameters are the basis of geotechnical engineering, which directly affects the safety and economic benefits of geotechnical engineering, and laboratory test is an important means to extract it. Soil shear strength (C, φ) is one of the most important parameters of soil, and direct shear test is the most important way to test this parameter, because of it’s simple structure and low cost. But there are some defects in the direct shear apparatus, such as the shear box warping and soil eccentric compression, it affects the uniformity of soil sample stress and makes the test value different from the real value.

Direct shear test was first proposed by Collin in France in 1846, and the prototype of direct shear apparatus was proposed by Bell in England in 1915. The commonly used direct shear apparatus was first proposed by Casagrande in 1932, after the improvement of Golder et al, the stress controlled direct shear apparatus and strain controlled direct shear apparatus appeared one after another, and the commonly used direct shear apparatus appeared[1].

Kishida[2]. Found that during the test, with the increase of shear displacement, the effective shear area gradually decreases and the regularity of normal stress instability on the shear plane has been unanimously recognized by scholars. He ManChao [3] (1986) proposed three calculation methods for effective shear area of soil samples in direct shear test, namely rectangle, circle and ellipse. The revised test results have influence on c and φ values. Yu Kai [4] (2014) proposed a single point area correction
method based on area correction and normal stress correction, and improved the reliability and accuracy of soil shear strength obtained by direct shear test. Pan Chencheng [5] (2017) found that the normal stress and shear stress are unevenly distributed in time and space during the shearing process, which will lead to the deflection of the principal stress in the test, the conclusion is verified by numerical simulation. Dong Jungui [6] set a bearing fixed on the upwarp end of the upper shear box to directly press it, in this way solves the problem of "oblique shear", but increases the vertical load, which leads to the higher shear strength. Liu Jianfeng [7] (2005) propose the non-uniform distribution of normal stress and oblique shear on the shear plane were caused by eccentric force. The larger the eccentric force, the more serious the non-uniform distribution of normal stress and oblique shear on the shear plane.

As one of the most commonly used geotechnical test instrument, direct shear test still has some defects, scholars put forward corresponding correction methods for shear area correction, and achieved good application results, some improvement schemes are put forward to avoid "oblique shear", but led to higher shear strength. Starting from the structure of the direct shear apparatus, this paper first analyzes the defects of its structure, and simply improved it. The test results show that the maximum upwarp displacement of the upper shear box is 24.8% of the thickness of soil sample covered by upper shear box. But after improvement, the shear box has no upwarp and oblique shear.

2. Analysis and improvement of direct shear apparatus’ defect

2.1. Principle of direct shear test

The conventional indoor direct shear apparatus usually adopts the strain control type, and the main components of the apparatus are shown in Figure 1. The soil sample is placed in the shear box, the rod on the upper shear box used to apply axial pressure, then push the lower shear box make the soil sample shear failure. Use the steel ring between the upper shear box and the baffle to test the maximum shear force under different axial compression.

![Figure 1](image)

2.2. Analysis of the structural defects

The reason of the upper shear box warping is shown in Figure 2, due to the deformation of the steel ring under the force, the upper shear box will also move along the shear direction, that lead to relative displacement between axial pressure rod and upper shear box, make the axial pressure lid rotate around the axial pressure rod, also make the soil sample eccentrically compressed, thus influence the accuracy of test result.
2.3. Improvement for the direct shear apparatus

According to the direct shear apparatus’ structural defects, we improved it as shown in the figure 3 below. Move the steel ring to the lower shear box, carry out the shear test by pushing the lower shear box, and make the upper shear box fixed on the baffle to ensure the absolute position of the upper shear box unchanged. These improvement measures make sure no relative displacement between the axial pressure rod and upper shear box. Eventually avoid the upper shear box warping.

3. Comparative test and effect analysis

3.1. Comparative test

In order to verify the improvement effect of direct shear apparatus, clay was taken for comparative test, the axial compressive stress is taken as 50kPa, 100kPa, 200kPa, 300kPa. In order to measure the upwarp of the upper shear box, a dial indicator is placed at the rear edge of the upper shear box, and the deformation of the dial indicator is recorded during the shearing process, as shown in the figure 4 below.
Before the improvement, the maximal upwarp displacement of the upper shear box during the test is shown in Table 1. After the improvement, because the upper shear box is completely fixed, the warpage is 0.0 mm. The maximal upwarp displacement of the upper shear box under different axial compressive stress as shown in the figure 5 below.

| Serial number | Axial compressive stress (kPa) |
|---------------|-------------------------------|
|               | 50   | 100 | 200 | 300 |
| 1             | 2.27 | 2.09| 0.65| 0.60|
| 2             | 2.16 | 2.48| 1.06| 1.20|
| 3             | 2.20 | 2.16| 0.96| 0.88|
| Average       | 2.21 | 2.24| 0.89| 0.89|

Before improvement with the increase of axial pressure, the maximum upwarp displacement average value of the upper shear box under 50kPa and 100kPa axial pressure is greater than under 200kPa and 300kPa axial pressure. The maximum upwarp displacement reached 2.48mm, 24.8% of the soil sample thickness inside the upper shear box.
After improvement since the upper shear box is completely fixed, the upper shear box never upwarp. So the main reason for the upper shear box upward is it’s structural defects the relative displacement between the upper shear box and the axial pressure rod.

The relationship between the vertical pressure and the maximum shear stress before and after the improvement is shown in Table 2, Table 3 and Figure 6.

### Table 2  The test result before improvement

| Axial pressure (kPa) | The maximum shear stress before improvement |
|----------------------|--------------------------------------------|
|                      | First (kPa) | Second (kPa) | Third (kPa) | Average (kPa) | Variation coefficient (%) |
| 1                    | 50          | 73.10        | 77.85       | 76.36         | 75.77                     | 2.62                       |
| 2                    | 100         | 89.42        | 96.77       | 100.49        | 95.56                     | 4.81                       |
| 3                    | 200         | 126.59       | 133.03      | 125.97        | 128.53                    | 2.48                       |
| 4                    | 300         | 238.50       | 242.72      | 262.66        | 247.96                    | 4.25                       |
| Test results         |             |              |             |               |                           | 3.54                       |

### Table 3  The test result after improvement

| Axial pressure (kPa) | The maximum shear stress after improvement |
|----------------------|--------------------------------------------|
|                      | First (kPa) | Second (kPa) | Third (kPa) | Average (kPa) | Variation coefficient (%) |
| 1                    | 50          | 52.70        | 54.19       | 59.55         | 55.48                     | 5.30                       |
| 2                    | 100         | 102.09       | 103.25      | 101.47        | 102.27                    | 0.72                       |
| 3                    | 200         | 162.75       | 166.90      | 173.09        | 167.58                    | 2.54                       |
| 4                    | 300         | 211.68       | 216.67      | 209.24        | 212.53                    | 1.45                       |
| Test results         |             |              |             |               |                           | 2.50                       |

*Test results: c: 33.67 kPa, \( \phi \): 31.8°

### Figure 6  The maximal shear stress under different axial compressive stress

- \( y = 0.6203x + 33.665 \), \( R^2 = 0.9808 \)
- \( y = 0.6622x + 29.351 \), \( R^2 = 0.9058 \)

*Before improvement*

*After improvement*
It can be seen from the comparative tests, after improvement for the clay’s cohesion from 33.67 kPa to 29.35 kPa, 12.8 higher; frictional angle from 31.8° to 33.5°, reduced by 5.3%; average of variation coefficient from 3.53 to 2.5, reduced by 29.2%.

4. Conclusion
(1) The structural defects of the direct shear apparatus lead to the relative displacement between axial pressure rod and upper shear box, make the axial pressure lid rotate around the axial pressure rod, the maximum upwarp displacement reached 2.48mm, 24.8% of the soil sample thickness inside the upper shear box.

(2) Move the steel ring to the lower shear box, carry out the shear test by pushing the lower shear box, and make the upper shear box fixed on the baffle, after these improvement measures, the maximum upwarp displacement of the upper shear box reduce to 0.0mm.

(3) In this direct shear test for clay, after improvement, the average of variation coefficient for maximum shear stress under each axial compression from 3.53 to 2.5, reduced by 29.2%, so the test results were more stable.

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