Experimental study on shear strength of clay under load

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Abstract. In order to truly reflect the shear strength index of soil in the project, the engineering soil sample was loaded and unloaded on a compression instrument, and then the shear strength $\tau$ of the excavated sample was measured by direct shear test, the shear strength of the soil sample without loading and unloading was compared with that of the soil sample without loading and unloading, and the influence of loading and unloading on the shear strength was analyzed. The results show that the shear strength of cohesive soil decreases within 2 % after loading and unloading, but the shear strength decreases with the increase of compressive stress.

Key words: Clay under load; Shear strength; Experimental study.

1. Introduction
The shear strength index of soil is an important mechanical property index of soil [1]. Soil shear strength and soil composition, soil structure, soil stress state, drainage conditions and other factors related to [2], and soil structure and stress history has a greater impact on soil shear strength. Literature [3] through the laboratory mechanical test of sandstone uniaxial cyclic loading and unloading, it is concluded that the cyclic loading and unloading strength of sandstone is much smaller than that of uniaxial compression strength. For the peak strength of uniaxial cyclic loading and unloading of brittle rock, it is affected by many factors. Literature [4] the axial, radial and volumetric deformation characteristics and poison’s ratio of sandy soil under different conditions were studied by cyclic loading and unloading of sandy soil with triaxial test system. The results show that the change trend of axial and radial strain during loading and unloading cycle reflects the main deformation characteristics of granular materials, especially during the initial loading process, with the loading and unloading process, such deformation gradually decreases, and the action history of cyclic load should be considered in the analysis of soil deformation characteristics under the corresponding load change conditions.

In civil engineering, the shear strength index of soil is obtained by direct shear test in laboratory. In the construction process of foundation engineering, road engineering and water conservancy engineering, the phenomenon of unloading and reloading of the actual soil is common, after foundation pit excavation of the upper building, the mechanical compaction in the process of earth dam heap, after water storage reservoir water level changes on the dam body, roadbed load under the action of settlement deformation and other similar problems can be regarded as the change process of loading and unloading [5]. Therefore, the experimental study on the shear strength of soil under cyclic
loading and unloading is of great engineering significance for determining the bearing capacity of foundation, calculating the earth pressure and checking the slope stability.

2. Research methods
Sampling with ring knife (inner diameter 61.8 mm, height 20 mm). 30 groups of clay soil samples were prepared and numbered TY1 to TY30 respectively. A total of 15 soil samples from TY1~TY15 were tested by direct quick shear test, liquid plastic limit test and moisture content test. A total of 15 soil samples of TY16~TY30 were loaded on the compressor. The loading criteria are all 300kPa. Unload in 1 hour. Then 15 soil samples of TY16~TY30 were tested by direct quick shear test, liquid plastic limit test and moisture content test. ZJ strain controlled direct shearing instrument is used in the test instrument. The constant coefficient of force loop is 1.908 KPA / 0.01 mm.

3. Results analysis

3.1. Direct shear test results of undisturbed soil
The direct quick shear test, liquid plastic limit test and moisture content test were carried out on 15 soil samples from TY1~TY15. The all, up, c, φ, ω of each soil sample were obtained, respectively (Table 1).

In order to reduce the interference of the difference between soil samples to the test data, soil samples which satisfy one of the following three conditions are eliminated.

1). ωL,ωp  above the average value of 5% does not accord with the range of clay soil values;
2). exceeded the average value of the group by 2 parts;
3). c increases with the increase of water content.

According to the shear strength curve drawn from the test results, the following effective experimental data are obtained after finishing:

| Table 1. Direct shear test results |
|-----------------------------------|
| Soil sample number | Water content ω(%) | C(kPa) | φ(°) |
| TY3 | 20.2 | 48.5 | 26.9 |
| TY4 | 20.6 | 41.7 | 26.4 |
| TY1 | 20.7 | 40.3 | 25.9 |
| TY7 | 21.1 | 38.4 | 23.1 |
| TY11 | 21.3 | 33.6 | 22.1 |
| TY12 | 21.4 | 31.8 | 22 |
| TY15 | 21.5 | 30.6 | 21.7 |
| TY5 | 21.2 | 29.3 | 21.4 |

| Table 2. Test results of direct shear after loading |
|-----------------------------------------------|
| Soil sample number | Water content ω(%) | c′(kPa) | φ′(°) |
| TY16 | 19.2 | 42.5 | 25.1 |
| TY21 | 19.1 | 41.7 | 24.4 |
| TY25 | 18.9 | 40.1 | 23.9 |
| TY17 | 18.9 | 39.4 | 23.7 |
| TY19 | 18.3 | 37.6 | 22.8 |
| TY29 | 18.1 | 32.8 | 22.6 |
| TY22 | 18 | 31.6 | 21.9 |
| TY24 | 17.7 | 29.9 | 21.7 |
3.2. Soil sample test results after loading

A total of 15 soil samples from TY16 to TY30 were first loaded on the compression apparatus. After unloading, direct fast shear test, liquid plastic limit test and water cut test are carried out. The ωL,ωp,c,φ and ωo of each soil sample are obtained respectively (Table 2).

In order to reduce the interference between the differences between the soil samples and the test data, the following experimental results are obtained after eliminating the unqualified soil samples according to the previous standard.

According to the Coulomb law, the shear strength of the soil can be expressed as:

\[ \tau = \sigma \tan \phi + c \]  

(1)

According to the test results, the shear strength of the soil samples is calculated. The t function curves corresponding to the two sets of data are plotted in the diagram, respectively. The result is figure 1:

According to the average value of c and φ in Table 1, we get \( \bar{\sigma} = 36.78 \text{KPa} \), \( \bar{\tau} = 23.69 \). According to the average value of \( c' \) and \( \phi' \) in Table2, we get \( \bar{\sigma} = 36.95 \text{KPa} \), \( \bar{\tau} = 23.26 \).

![Figure 1. Contrast curve of shear strength before and after loading](image)

![Figure 2. Change percentage of shear strength before and after loading](image)
In order to clearly analyze the degree of shear strength change of soil samples before and after loading, the shear strength change rate of N under compression stress of 50 kPa, 100 kPa, 200 kPa, 300 kPa and 400 kPa was calculated respectively. \[ n = \frac{(\tau - \tau')}{\tau} \times 100\% \]. Drawing the relation curve of the percentage of the compressive stress and the change of strength, in Figure 2.

From Figure 1, it can be seen that the shear strength curves obtained by the direct shear test after 300 kPa loading are located under the shear strength curve before loading. It shows that the shear strength of soil sample is reduced after 300 kPa pressure stress unloading. As can be seen from Figure 2, the decrease of shear strength of soil samples after loading is less than 2%. With the increase of compressive stress, the intensity reduction rate is decreasing, but the curve is still on the rise. After loading 300 kPa, the shear strength of soil samples not only does not increase in the range of compressive stress from 50 to 400 kPa, but decreases. The trend of soil sample shear strength decreases was slow down, but the overall trend is unchanged. This phenomenon may be damaged after loading and unloading of the original structure of the soil sample. It is similar to the "rubber soil" phenomenon often occurring during the rolling clay soil in the earth and rock engineering.

4. Conclusion
The shear strength of clay soil is less than 2%, and the shear strength of clay soil is reduced by loading and unloading in a certain range of load. With the increase of compressive stress, the shear strength continues to decrease. Therefore, in the actual engineering construction, it is necessary to avoid the disturbance to the original soil samples and strictly prohibit over digging. In the process of earthwork rolling, the optimal water content and rolling weight of the soil should be determined by the experimental analysis, to reduce the adverse effects of overpressure on clay strength.

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