Research on the Mechanical Properties of Loess in Northern Shaanxi Province and Deterioration Process of Its Mechanical Performance

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Abstract. The regional research is conducted on the mechanical properties and mechanical performance of loess in loess slope of the northern Shaanxi Province, China. On the precondition of conforming to the related technical regulations, the related equipment was purchased or self-designed and machined to conduct large-scale in-situ direct shear test and participatory shear test on a high loess slope in northern Shaanxi Province, China. Through the multiple field shear tests of loess and red soils on a four-level platform of side slope in engineering tunnel, the relation curves of shear stresses of two soil types with the shear displacement were comparatively analyzed, and the change laws of relation curves of shear strength index and shear rate of soil samples with the displacement were obtained. The deterioration development laws of soil mass were revealed through the in-situ test, thus laying the data foundation for analyzing the sliding mechanism of slopes and the interaction between anti-slide piles and soil around piles.

1. Introduction

What are the most commonly used to determine the residual strength are the field direct shear method and laboratory test method.

The field direct shear test has an early start at abroad. Skempton [1] took the lead in carrying out a field direct shear test on Walton Wood landslide mass, and the strength parameter obtained by test was very approximate to the result obtained through the inversion method. In 1970, Skempton implemented the field direct shear test at three different positions of a landslide mass nearby Swinton, UK, compared the result with the inverse calculation result, and further verified this law. Wen [2] found that the gravel content had a great bearing on the residual strength through a comparative analysis of laboratory shear test results and field in-situ shear test results.

Fruitful research results have been achieved in China, too. For instance, taking slip soil in a typical landslide in the Three Gorges Reservoir Region and a side slope with high artificial fill in Panzhihua Civil Airport as the study objects, Li W S [3] and Zhang G H [4] conducted large-scale field direct shear tests respectively, summarized the factors influencing the shear strength of slip soil, and explored their influences on the shear strength.
In a study of Wulong County Government on ancient landslides, Zhang K et al. [5] proposed that the residual strength value could approximately reflect the shear strength of slip soil in case of certain creep deformation of slip zone or landslide mass, which was proven through a field test.

Zhang Y C et al. [6] conducted a field horizontal push-shear test of slip soil (silty clay) on a landslide mass in Guangdong, compared with the laboratory repeated direct shear test results, and found that the field direct shear test could ensure the natural moisture state and structural state of soil mass, and the result was more approximate to the real strength value of soil mass.

Hu Z Q et al. [7] compared the field shear test and laboratory direct shear test results of a practical project, and found that the shear strength obtained through the field direct shear test should be used as the basis of the slope governance.

Based on the large-scale field direct shear test and laboratory quick direct shear test, Liu Z S et al. [8] studied the influence of strength parameters on the calculation result of landslide stability coefficient, and stated that the stability calculation with the strength parameter obtained through the large-scale field direct shear test accorded with the actual state of slip mass to a greater extent, and the parameters were more reasonable than those in the laboratory quick direct shear test.

Zhang L [9] believed that slip soil, with diversified features, was under complicated and ever-changing environment. As the laboratory test was restricted by all kinds of conditions, he studied the influence of moisture content on the strength characteristics of slip soil through a large-scale field direct shear test, and found that the internal frictional angle was reduced with the increase of the moisture content, and the cohesion increased but not all the time, but instead, after the moisture content reached a certain value, the cohesion started declining until disappearing.

In order to obtain the shear strength characteristics of different geological sections (phyllite and gravel) on a slope that already collapsed in Zhouqu, Zhang Q [10] sheared the phyllite and gravel samples on the field, compared the results with the geological exploration report and empirical values obtained through the laboratory field and found that the strength parameters acquired by different methods were different, especially the cohesion was the maximum in the field direct shear test. Due to great disturbance and small size of soil samples in the laboratory test, their shear strength values were reduced. Under different engineering geological conditions, and the parameters obtained by experience also differ a lot from the reality, so the results of field direct shear test were more reasonable.

In comparison to the laboratory direct shear test, though being restricted by the site conditions and required for more input of manpower, materials, financial resources and time, the field direct shear test generates a minor disturbance on the soil samples, which are much larger than the laboratory test samples, thus weakening the size effect of soil samples to the greatest extent.

2. Large-Scale In-Situ Direct Shear and Residual Shear Testing Program

2.1 Selection of test points
The Huangling-Yan’an Expressway section in Shaanxi territory of national expressway Baotou-Maoming (G65) line was taken as the engineering background. As the four-level platform on the slope of Wanhua Tunnel along the line was broad, the field shear test was carried on this platform for multiple times. As shown in Figure 1. One sample was prepared in each of the four test pits in the area I, and the normal stress was set as 50, 100, 200 and 300 KPa, respectively. One sample was prepared in each of the three test pits in the area II, and the normal stress was set as 50, 200 and 300 KPa, respectively.
2.2 Test contents
In this study, the residual strength of soil mass was acquired through the multiple shear tests that conformed to the actual motion state of landslide. To be more specific, after each shear test was completed, the soil sample was not thrust back, and the upper load was controlled at the central position of soil sample. When the vertical deformation was stable, the shear load was applied for the next shear test until the stable value of shear stress was within 10% in the two shear tests. The tests were carried out using consolidated quick shear method and horizontal pushing method by combining the field situation according to the related testing regulations.

2.3 Test steps
The test steps mainly includes preparatory work, preparation of shear test sample, installation of vertical loading device, installation of shear loading device, installation and debugging of measurement system and shear of soil sample.

(1) Preparation of shear test sample
The test sample was roughly cut into an earth pillar slightly larger than the shear box, and an earth pillar sample (60 cm×60 cm) was finish-cut.

(2) Installation and debugging of vertical loading device, shear loading device and measurement system
The installation drawing of shear equipment is as shown in Figure 3 and the field equipment installation flowchart is displayed in Figure 4.

![Figure 3: Schematic Diagram of Field Shear Equipment Installation](image)

1—jack 2, 3—steel baseplate 4—roller row 5—I-shaped steel girder 6—shear box 7—dial gauge 8—pile-loading platform 9—pile-loading

Figure 3: Schematic Diagram of Field Shear Equipment Installation

(a) Upper pile-loading  (b) Displacement measurement system

Figure 4: Flowchart of Field Equipment Installation

(3) Vertical loading
The acting force and counter force are the principles of the application in vertical load. Enough earth bags were placed on the pile-loading platform to ensure that the upper platform was kept stable when the jack applied force to the upper pile load. The normal stress applied onto the soil sample could be controlled through the readings of jack oil pressure gauge.

(4) Shearing of soil samples
The test was performed using the consolidated quick shear. The soil samples were sheared according to the related test regulations after the vertical load was applied and the dial gauges used to measure the shear displacement and horizontal displacement were debugged.

3. Large-Scale In-Situ Direct Shear and Residual Shear Test Results and Analysis
The basic physical indexes of soil samples in the test pits are listed in Table 1.
The particle composition of soil was determined via laser particle size analyzer. The percentages of clay, silt and sand are presented in Table 2, and the accumulation curves of soil samples are displayed in Figure 6.

Table 2: Percentages of Clay, Silt and Sand

| Test area | Sample position | Clay (%) (<0.002 mm) | Silt (%) (0.002 mm<d<0.075 mm) | Sand (%) (0.075 mm<d<0.25 mm) |
|-----------|----------------|----------------------|--------------------------------|-------------------------------|
| Area I    | 1# pit (50 KPa) | 12.56                | 77.56                          | 9.88                          |
|           | 2# pit (100 KPa)| 11.93                | 80.05                          | 8.02                          |
|           | 3# pit (200 KPa)| 6.385                | 73.25                          | 20.365                        |
|           | 4# pit (300 KPa)| 9.58                 | 79.27                          | 11.15                         |
| Area II   | 5# pit (50KPa)  | 15.2                | 77.56                          | 9.24                          |
|           | 6# pit (200 KPa)| 11.93                | 80.05                          | 8.02                          |
|           | 7# pit (300 KPa)| 6.385                | 73.25                          | 20.365                        |

The particle composition of soil was determined via laser particle size analyzer. The percentages of clay, silt and sand are presented in Table 2, and the accumulation curves of soil samples are displayed in Figure 6.
According to the laboratory compression test results, the e-p curves and e-lgp curves of soil samples in the areas I and II are displayed in Figure 7 and 8.

Figure 6: Accumulative Curve Chart of Field Soil Samples

Figure 7: E-p Curve

(a) E-p curve in area I  (b) E-p Curve in area II
Test results of area I and analysis are as below:

The shear stress-shear displacement relation curves of four soil samples in the area I under different normal stresses are as shown in Figure 9. The following could be obtained:

Under the normal stress of 50 and 100 KPa, the weak softening type was presented in the three shear tests of soil samples, which was manifested by the brittle failure. In the first shear process, the shear stress increased sharply with the increase of the shear displacement before the peak value, and the stress-strain relation was approximately a straight line, indicating the approximately linear deformation. After the peak strength, the decrease amplitude of shear stress was very small, and the peak strength was reached only under the normal stress of 50 KPa and shear displacemnt of 2.5 mm. When the shear displacement was within 10-100 mm, the shear stress was almost unchanged, and the shear stress declined by 1% when it was finally stabilized. The peak strength was reached only under the normal stress of 100 KPa and initial shear displacement of 2.6 mm, and the shear stress declined by 3% under the stable state. The shear stress was basically stable when the shear displacement was within 20-100 mm in the second and third shear tests, and it could be taken as the residual strength. Under the normal stress of 200 and 300 KPa, the strain hardening type was manifested in the first shear test, which was embodied by the plastic failure, and the strain softening type appeared in the second and third shear tests.
The shear stress-shear displacement relation curves of soil samples in the area I under four-stage normal stress are as shown in Figure 10. Under the same number of shear times, both peak strength and residual strength increased with the increase of the normal stress.

4. Conclusions

Based on the results and discussions presented above, the conclusions are obtained as below:

(1) The hardening and softening of soil mass are significantly affected by the moisture content. When the moisture content rises, the strain characteristic of soil mass is transited from the strain softening type into hardening type. Under the same moisture content and normal stress, the strain softening and hardening phenomena are remarkable with the increase of the shear rate.

(2) The peak shear strength and residual shear strength of soil mass are reduced with the increase of the moisture content. In the consolidated slow shear process, the peak shear strength index and residual shear strength index are both reduced with the increase of the moisture content. Under the consolidated quick shear mode, the residual cohesion firstly increases and then decreases with the increase of the moisture content, while the residual internal frictional angle is reduced.

(3) With the increase of the plasticity index (reflecting the clay content), the peak cohesion and peak international frictional angle of soil mass increases, while the residual cohesion and residual internal frictional angle present the opposite trend.
(4) In the shear rate-shear displacement relation curves during the multiple shear tests, the displacement at the mutation point of shear rate is consistent with that corresponding to the peak point of shear stress, and thus it is deemed that the mutation point of shear rate can be regarded as a criterion for judging whether the shear surface is penetrated.

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