Determination of the shear strength of interlayer materials in a clastic rock Aera

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Abstract: This study focus on the influence of the shear strength in unsaturated soil under different matric suction. 12 groups of GDS tests under different conditions were executed to analysis the relationship between net confining pressure and deviatoric stress. Then, used the unsaturated soil strength theory to calculated the shear strength of the weak interlayer. The results show that under the same confining pressure and unsaturated conditions, the deviatoric stress increase as the matric suction increases. The total cohesive force and the matrix suction of a linear relationship during the test process, the growth of the slope angle for the matrix suction is 6.6°. Finally, a modified formula for shear strength of the soft sandwich silty clay in this landslide was proposed.

1. Introduction

Determine the strength of the weak interlayer of the soil landslide is the key factor of the slope stability evaluation, because the weak interlayer often is the slip zone. However, quantitative analysis strength of the underground soft interlayer is very difficult, because the strength degradation of the soft interlayer will occur due to the change of the matric suction in the process of rainfall infiltration, which will accelerate the occurrence of the landslide and pose a great threat to the safety of highway and pedestrians[1].

Many scholars used the direct shear test and the conventional triaxial test to analyze the mechanical properties of unsaturated soil in the slip zone [2]. However, it is difficult to consider the effect of matric suction because the shear planes of direct shear test and triaxial tests are fixed. GDS triaxial test can set the matrix suction and stress path to conform to the actual conditions, and can better study the strength of unsaturated sliding soil [3]. At present, there are many studies on the strength of unsaturated soils such as loess, red clay and soft soil at home and abroad [4].

The prototype landslide is located 1.0 km downstream of Nanheng town. The main body of the landslide is composed of collapse deposit, fill soil, silty clay and gravel soil with an average particle size of 0.5 m (accounting for 50~60%), and the underlying bedrock is limestone and sandstone with a dip angle of 28~35°. The main structural traces in this deposit are SW-NE about 56° 0 m wide and 616 m long, with a relative height difference of 224 m, and the total volume was estimated to be 1.2×106 m³. Rainfall in this area mainly occurs in March and June accounting for 53.5% of the annual precipitation. Some of the rainfall is turned into the surface water down flow to Wo river at the foot of the landslide, and others infiltrate into the ground through surface cracks and overburden interstices, forming a weak and muddy sliding surface that is not conducive to slope stability.
2. Strength theory of unsaturated soils base on matric suction

The most representative is the effective stress formula (Eq. 1) proposed by Bishop[5], which uses the effective stress parameter to reflect the correlation between soil saturation and matric suction. This formula applies to soils with saturation more than 20%, silt content is more than 40-50% or clay content more than 85%. Therefore, the effective stress parameter in this theory is not an independent parameter. Therefore, the effective stress parameter in this theory is not an independent parameter, but a parameter closely related to soil properties and saturation, which is used to discuss the uncertainty of the strength of silty clay.

Fredlund[6] used matric suction to consider the effect of pore pressure in unsaturated soil, and based on the assumption that soil particles are incompressible, the shear strength expression of the unsaturated biaxial test variable was proposed.

\[ \tau_f = c' + (\sigma - u_a) \tan(\phi') + (u_a - u_w) \tan(\phi^b) \]  

(1)

Where: \( \tau_f \) denote the shear strength of unsaturated soil; \( c' \) is the effective cohesive force of saturated soil and \( \phi' \) is the effective internal friction Angle of saturated soil; \( \sigma - u_a \) is the net confining pressure. The contribution of matric suction to shear strength \( \phi^b \) is reflected by matric suction correlation Angle.

3. Sampling and experimental

Taufe silty clay was found in 28 boreholes of the Nanhe bridge landslide. In view of the fact that the upper and lower part of the silty clay in the limestone area is disturbed to a large extent in the sampling process, the ring-knife method is used to carry out laboratory tests on physical and mechanical properties in the middle part of the less disturbed formation soil sample, and the results are shown in Table 1.

| Moisture content W/\% | Wet density /g·cm\(^{-3}\) | Dry density /g·cm\(^{-3}\) | Void ratio /e | Plastic limit W/% | Liquid limit W/% | Cohesive force c/kPa | Internal friction angle \(\phi^f(\degree)\) | Modulus of compression E/MPa |
|-----------------------|-----------------------------|-----------------------------|--------------|----------------|----------------|-------------------|------------------|---------------------|
| 25.3                  | 1.98                        | 1.82                        | 0.79         | 22.3           | 37.9           | 24.3              | 26.9             | 12.6                |

The soil sample, with a diameter of 38 mm and a height of 76 mm, was uniformly compacted in five layers, with a compaction degree of 0.9 and a dry density of 1.82 g/cm\(^3\). There were 12 samples in total. The STDTAS-HKUST triaxial test system was adopted. The system consists of one Bishop and Wesley triaxial pressure chamber, three GDS pressure/volume controllers and GDSLAB control software. The test was divided into two stages: consolidation equilibrium stage and shear stage. In the process of consolidation and equilibrium, ambient pressure is applied, pore pressure and pore water pressure are controlled at the same time, and the original suction of the sample is changed so that the suction of the sample reaches the control value. Generally, the consolidation time is relatively long, and the consolidation time of the test sample is about 72 h. According to previous experience and Suggestions in the literature, the shear rate was set at 0.005mm/min. The specific test scheme is shown in Table 2.

| Loading method | Process simulation | Matric suction \(U/\)kPa | Confining pressure \(\sigma/\)kPa | Net confining pressure \((\sigma\)-\(U_a)/\)kPa | Number |
|----------------|--------------------|---------------------------|-------------------------------|---------------------------------------------|--------|
| Shear failure  | Consolidated       | 0                         | 100,200,300                   | 100,200,300                                 | S-1    |
| (stress controlled) | Drained \(\) CD  | 30                        | 150,250,350                   | 100,0,200,300                              | S-2    |
| 60                        | 200,300,400                | 100,200,300                              | S-1    |
| 90                        | 300,400,500                | 100,200,300                              | S-1    |
4. Results

4.1. Shear strength analysis when matrix suction is constant

Fig. 1(a) - (e) shows the deviatoric stress-strain ($\tau - \varepsilon_\tau$) curves under corresponding net confining pressure ($\sigma - u_a$) of 100 kPa, 200 kPa and 300 kPa when the matric suction is 0 kPa, 30 kPa, 60 kPa and 90 kPa, respectively. Under the same matric suction condition, the shear strength increases with the increase of net confining pressure, and the slope of the stress-strain curve is larger before the shear strain reaches 8%, indicating that the strength increases rapidly at the beginning of deformation. When the shear strain exceeds 8%, the growth rate of shear strength slows down, and the soil keeps deformation under certain strength. Under low matric suction conditions, the sliding zone soil has creep characteristics, while under high matric suction conditions, the sliding zone soil has certain hardening characteristics.

![Shear stress and shear strain curves](image)

Fig. 1. Shear stress and shear strain curves under constant matric suction

4.2. Shear strength at a constant confining pressure

Through GDS triaxial shear test, the shear strength of the same confining pressure is compared and analyzed, and the stress-strain relationship of different matric suction under the same confining pressure is verified. The test results are shown in Fig. 2. With the same sampling depth, saturation and pore ratio, the shear strength increased with the increase of matric suction in the 100 kPa, 200 kPa and 300 kPa net confining pressure tests.

Fig. 2 shows that under the same net confining pressure, the shear strength of sliding zone soil changes with the change of matric suction. On the whole, when the matric suction is saturated, the shear strength is the lowest. When the matric suction increases, the shear strength obviously increases. It indicates that the shear strength of slip zone soil will increase with the increase of buried depth or upper load, but the matric suction of slip zone soil will change with the increase of fixed confining pressure (same depth or load).
Fig. 2 Stress-strain relationship curves under different pressure matrix suctions

4.3. Theoretical analysis of Fredlund unsaturated soil strength

According to the requirements of the SL237-1999 "code of geotechnical test"(in China). The triaxial shear parameters shown in table 3. Using the parameters obtained from the above triaxial shear test, the net normal stress was taken as the horizontal coordinate and the shear strength as the vertical coordinate, and the shear envelope curves of the net confining pressures (100 kPa, 200 kPa, 300 kPa) under the same matric suction were plotted. Fig.3 show that the curve of the total internal friction angle $\phi$ and total cohesion $c$ of sliding zone soil under various matric suction conditions were obtained.

Table 3 Triaxial test shear parameters of sliding zone soil (unit:kPa)

| Number | $U_a$ | $\sigma_3$ | $\sigma_3-U_a$ | $\sigma_{1\text{max}}$ | $\sigma_{1\text{max}}-U_a$ |
|--------|------|----------|---------------|-----------------|-----------------|
| S1-01  | 0    | 100      | 100           | 269.34          | 269.34          |
| S1-02  | 0    | 200      | 200           | 482.48          | 482.48          |
| S1-03  | 0    | 300      | 300           | 794.27          | 794.27          |
| S2-01  | 30   | 130      | 100           | 341.94          | 311.94          |
| S2-02  | 30   | 230      | 200           | 573.81          | 343.81          |
| S2-03  | 30   | 330      | 300           | 814.38          | 784.38          |
| S3-01  | 60   | 160      | 100           | 397.09          | 337.09          |
| S3-02  | 60   | 260      | 200           | 663.78          | 603.78          |
| S3-03  | 60   | 360      | 300           | 936.41          | 876.41          |
| S4-01  | 90   | 190      | 100           | 472.56          | 382.56          |
| S4-02  | 90   | 290      | 200           | 720.55          | 630.55          |
| S4-03  | 90   | 390      | 300           | 919.83          | 829.83          |

Fig. 3 shows that when the matric suction is 0 kPa, 30 kPa, 60 kPa and 90 kPa, the total cohesion $c$ is 22.7 kPa, 33.4 kPa, 43.8 kPa and 46.9 kPa, respectively, and the internal friction angles are 20.3°, 21.3°, 22.6° and 24.8°, respectively. The slope of the curve is the tangent value of matric suction Angle $\phi$, and the Y-axis intercept of the curve is the effective cohesive force of saturated soil.
As can be seen from Fig. 4, $\phi' = 20.3^\circ$, $c' = 22.7$ kPa, $\phi^b = 15.5^\circ$, so the shear strength parameter of the consolidated drainage of the sliding zone soil is:

$$\tau_f = 16.7 + (\sigma - u_n) \tan(21.8^\circ) + (u_n - u_u) \tan(6.6^\circ)$$  \hspace{1cm} (2)$$

Fig. 4 The envelope of total adhesion under different suction conditions

Based on the above analysis, when the matric suction is constant, the strain of the sample gradually increases with the increase of deviator stress. When the shear displacement is close to 8%, the slope of the curve slows down. The deviator stress increases gradually with the increase of strain in other curves. The results show that when the matric suction is constant, the shear deformation process of the soil samples in the slip zone is divided into two stages: rapid shear and slow deformation. It reflects that in the triaxial test, the soil particle pores are squeezed and the voids are reduced, and the larger the pressure is, the more dominant the surface tension between the particle skeletons is, and the greater the force to prevent deformation is.
5. Conclusion
In this paper, the GDS triaxial test method is adapted to analyze the strength characteristics and theory of sliding zone soil in the limestone area under complex stress conditions, and the following conclusions are drawn: Under the condition of the same loading rate and the same matric suction, the deviator stress of slip zone soil increases with the increase of confining pressure and goes through two stages of rapid growth and slow growth, indicating that the shear strength of slip zone soil in limestone area is affected by the matric suction; Under the condition of the same loading rate and the same matric suction, the shear strength of the sliding zone soil increases with the increase of confining pressure, indicating that the buried depth and upper load of the sliding zone soil will have a significant impact on the shear strength of the sliding zone soil. The deformation and failure process of sliding zone soil under complex stress conditions can be illustrated by Fredlund unsaturated shear strength theory. According to the theory, when the matric suction is 0 kPa~200 kPa, the internal friction angle is 20.3° ~24.8° and the total cohesive force is 22.7 kPa~46.9 kPa. Moreover, the triaxial shear test results show that the strength of clay is positively correlated with suction, and the matrix suction correlation angle $\phi^b$ is equal to 15.5°, which is within the range of low suction.

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