Experimental Study of Triaxial Test of Unsaturated Expansive Soil Shear Strength

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Abstract. Based on unsaturated triaxial testing system, with different water content, the strength characteristics of expansive soils of Nanning are studied. Under certain confining pressure, with low water content, stress-strain curve is strain-softening, whereas with high water content, is strain hardening; Under high confining pressure, with low water content stress-strain curve is strain-hardening type, whereas with low confining pressure the stress-strain curve with the increase of axial strain is a slight softening trend. The shear strength of soil has a large sensitivity with moisture content. As the moisture content increases, the expansive soil friction angle decreases linearly. With the increase of water content, firstly its cohesive force increases, it reaches maximum value at the optimum water content, then it decreases with the increase of water content.

Key words: unsaturated soil; water content; triaxial shear strength.

1. Preface
The type and content of clay minerals in expansive soil are not only determine the hydrophilicity, plasticity and expansibility of expansive soil, but also significantly affect the shear strength characteristics of expansive soil. These minerals of expansive soil have different physical properties, chemical properties and structural characteristics, so they have different effects on strength. Rainfall is the main cause of landslide. The close relationship between slope and rainfall has been known for a long time. Most landslides occur in rainy season. As a kind of special soil, the stability improvement of expansive soil slope has been concerned and studied by many scholars, They carried out research from the geotechnical engineering theory, experimental research, finite element numerical simulation, design and construction stages [1-4].

Many scholars have done a lot of research on the treatment and improvement of expansive soil foundation [5-7]. For example: using sodium silicate, artificial sand and disintegrating soft rock to improve expansive soil. However, the purpose of any material improvement is to improve the strength of expansive soil. Based on the expansive soil has the characteristics of water absorption expansion and water loss shrinkage, and its strength changes with the expansion and shrinkage cracks[8-10], the main purpose of the study on the mechanical properties of expansive soil is to provide reliable basic data for the construction on the expansive soil foundation.
Expansive soil is a special kind of unsaturated soil, which is often in unsaturated state under natural conditions. The strength characteristics of unsaturated soil not only have the common characteristics of general cohesive soil, but also have the unique characteristics different from general cohesive soil. It is not only related to the structure, stress path, density and mineral composition of soil, but also closely related to the water content of soil. At present, bishop shear strength formula is the most representative for unsaturated soil strength theory. Based on the study of effective stress theory of unsaturated soil, bishop [11] etc. put forward the expression of shear strength of unsaturated soil.

\[
\tau_f = C' + \left[ (\sigma - u_a) + \chi (u_a - u_w) \right] \tan \phi'
\]

Where, “\( \tau_f \)” is the shear strength of unsaturated soil; “C’” and “\( \Phi' \)” are the effective cohesion and effective internal friction angle of saturated soil respectively; \( \sigma \) is the total normal stress on the failure surface at failure; “\( u_a \)” is the pore air pressure on the failure surface; “\( u_w \)” is the pore water pressure on the failure surface; \( \chi \)” is the empirical coefficient, which is related to saturation, soil type, dry wet cycle, stress path of load and suction.

The shear strength of natural expansive soil is related to the structure and structure of soil in many aspects. It is proved that the shear strength of clay is related to the change of soil water content. However, expansive soil is rich in hydrophilic clay minerals, and its shear strength is particularly closely related to the change of soil water content, that is, the shear strength of expansive soil is particularly sensitive to the influence of water content. In view of the sensitivity of expansive soil to water, based on the unsaturated triaxial system, this paper studies the strength characteristics of unsaturated expansive soil in Nanning city of Guangxi Province under the condition of 80% compaction and different water content.

2. Triaxial test of unsaturated expansive soil

2.1. Sample preparation

The soil sample used in this test is Nanning expansive soil in Guangxi, which is formed by alluvial expansive soil. The soil is gray white and belongs to medium expansive soil. The results of physical properties and chemical composition analysis of soil samples are shown in Table 1 and table 2.

| Tab. 1 Physical and mechanical characteristics of soil sample |
|---------------------------------------------------------------|
| Maximum dry density g/cm³ | Optimal inclusion Water rate % | Liquid limit % | Plastic limit % | Plasticity index % | Free expansion rate % | Permeability coefficient cm/s |
|--------------------------|-------------------------------|---------------|----------------|-------------------|---------------------|-----------------|
| 1.89                     | 15.8                          | 61.4          | 22.8           | 38.6              | 62.5                | 1.18×10⁻⁷       |

| Tab. 2 Analysis on chemical composition of Nanning expansive soils |
|-----------------------------------------------------------------|
| AL³⁺ | Si⁴⁺ | Fe³⁺ | K⁺ | Ca²⁺ | Mg²⁺ | Ti⁴⁺ | Cu²⁺ | Mn²⁺ | Cr³⁺ | S²⁻ |
| 23.64% | 57.63% | 8.85% | 4.24% | 1.37% | 2.32% | 0.91% | 0.74% | 0.09% | 0.03% | 0.19% |

In order to analyze the influence of various factors on the strength characteristics of expansive soil, soil samples with moisture contents of 7.4%, 14.8% and 22.23% under 80% compaction degree were designed. The preparation of soil samples is strictly in accordance with the standard for soil test methods [12].

2.2. Unsaturated triaxial test

In this test, unconsolidated undrained shear test is selected, the suction is controlled at \( S = 50kPa \), and the shear rate is 0.5% strain per minute. According to the different failure forms of samples in the shear process, different failure criteria are adopted. For strain softening specimens, the failure strength is the peak strength; for strain softening specimens, the failure strength is taken as the peak strength; for strain
3. Analysis of test results

3.1. Influence of confining pressure on shear characteristics

The stress-strain curves of unsaturated expansive soil with low water content and high water content under different confining pressures are obtained by fitting the test results, as shown in Fig. 1 and Fig. 2.

![Stress-strain diagram with low water content](image1)

![Stress-strain diagram with high water content](image2)

It can be seen from Fig. 1 that under the condition of low water content and high confining pressure, the curve presents strain hardening type, and even when the strain reaches 15%, the stress-strain curve does not reach a peak value; However, the stress-strain curve of the specimen sheared under low confining pressure shows a weak softening trend with the increase of axial strain. It can be seen from Fig. 2 that the stress-strain curve of the specimen under high water content is strain hardening, at this time, the shear strength of the specimen changes little under low confining pressure. As shown in Figure 2, when the confining pressure is 50kPa and 100KPA, although the confining pressure is doubled, the...
change of stress has no obvious effect. It can be concluded that with the increase of net confining pressure, the shear strength and volume shrinkage of soil sample will be improved.

3.2. Effect of water content on shear properties
The relationship between stress and strain curves of specimens with different water contents under 100 kPa confining pressure is shown in Fig. 3. Under constant confining pressure, the stress-strain curve at low water content is of micro strain softening type, and that at high water content is of strain hardening type. It may be that the plastic deformation of soil sample is small at low water content and larger at high water content. With the increase of shear deformation, cracks appear in the shear plane of soil samples. With the development of cracks, the stress-strain curves show different trends.

![Stress-strain diagram with different moisture content](image)

Fig. 3 Stress-strain diagram with different moisture content

3.3. Effect of water content on shear strength
According to the triaxial test data, the changes of cohesion and friction angle of unsaturated expansive soil with water content are obtained, as shown in Fig. 4 and Fig. 5. With the increase or decrease of water content, the cohesion and friction angle of soil show obvious change trend. The friction angle of expansive soil decreases linearly with the increase of water content; The cohesion of expansive soil first increases with the increase of water content, and reaches the maximum at the optimal water content, and then decreases with the increase of water content. According to the preliminary analysis, the reason for the rapid decrease of cohesion may be that pore water enriches to the fracture surface and eventually forms a thin bound water film, which plays a lubricating role and weakens the cohesion of indirect contact surface of soil particles, thus reducing the shear strength of soil.

![Cohesion changes with different moisture content](image)

Fig. 4 Cohesion changes with different moisture content
4. Conclusion
On the basis of summarizing the shear strength theory of remolded expansive soil, combined with indoor unsaturated triaxial test, the influence of various factors on the strength characteristics of remolded expansive soil is studied:

(1) Under constant confining pressure, the stress-strain curve under low water content is of micro strain softening type, and that under high water content is of strain hardening type; under low water content, the stress-strain curve under high confining pressure is of strain hardening type, and that under low confining pressure is of weak softening trend with the increase of axial strain.

(2) The shear strength of soil is sensitive to the change of water content. With the increase of water content, the friction angle of expansive soil decreases linearly; the cohesion first increases with the increase of water content, and reaches the maximum at the optimal water content, and then decreases with the increase of water content.

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