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# Study on the Influencing Factors of the Shear Strength of Shallow Unsaturated Soda-saline Loessal Soil

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**Abstract:** ***Investigating the shear strength of shallow unsaturated soda - saline loessal soil is meaningful for the evaluation of the stability of shallow slopes in regions where soda - saline loessal soil is distributed. In this study, ring shear tests were carried out on remolded shallow unsaturated soda-saline loessal soil specimens to analyze the influence of water content, clay fraction, and shear rate on the soil's shear strength. The test results indicate that for specimens with a salt content of 0.5%, when the water content increased from 10% to 22%, the maximum reduction in shear strength reached 12.7%. The corresponding maximum reductions for specimens with salt contents of 1% and 1.5% were 11.9% and 11.7% respectively. The soil's shear strength exhibited a decreasing with the increase in water content. When the clay content was increased from 8% to 24%, the maximum increases in shear strength for specimens with salt contents of 0.5%, 1%, and 1.5% were 7.8%, 12.2%, and 10.0% respectively. The soil's shear strength showed an increasing with the increase in clay content. When the shear rate was elevated from 0.1 mm/min to 0.2 mm/min, 0.5 mm/min, 1 mm/min, and 2 mm/min, the shear strength of the 0.5% salt - content specimen decreased from 37.7 kPa to 36.7 kPa, 34.2 kPa, 33.0 kPa, and 31.0 kPa, representing reductions of 2.7%, 3.4%, 3.5%, and 6.1% respectively. The maximum reductions for specimens with 1% and 1.5% salt content were 4.3% and 4.2% respectively. The soil's shear strength decreased as the shear rate increased. These experimental results offer a parameter foundation for the stability assessment of shallow soda - saline loessal soil slopes.***

**Keywords:** Soda - saline loessal soil, Ring shear test, Water content, Clay content, Shear rate.

## 1. Introduction

Extensive areas of soda-saline loessal soil are developed within the western Songnen Plain [1]. Qian'an County, located in the western part of this plain, experiences relatively low annual precipitation, which is mainly concentrated in July and August. As a result, the shallow soda-saline loessal soil remains largely unsaturated for the majority of the year. Investigating the shear characteristics of shallow unsaturated soda-saline loessal soil via ring shear tests offers parameter support for evaluating the stability of shallow soda-saline loessal soil slopes in Qian'an County.

Previous studies on the mechanical properties of slope soils have indicated that soil water content, clay content, shear rate, over-consolidation ratio, and microstructure are significant factors influencing soil slope stability. Zhang [2] pointed out that an elevation in water content results in a reduction in soil shear strength parameters. It is recognized that clay content plays a vital role in the shear strength of unsaturated soil [3]. Ahmad [4] determined that both compaction water content and particle size distribution have an impact on the shear strength of unsaturated soil, and specimens devoid of fines are compacted under residual moisture content, their peak shear strength is higher when sheared at the optimum moisture content. Tian [5] reported that the internal friction angle of unsaturated loess initially decreases and subsequently increases with an increase in clay content, reaching a minimum at a clay content of 24%. Miao and Wang [6] conducted an investigation on sliding - zone soils with varying clay contents in the Three Gorges region of China and demonstrated that the shear strength parameters decrease as the clay content increases. In contrast, Zhuang [7], through strength testing on unsaturated loess, reported a gradual increase in loess strength with an increase in clay content. Wang [8] discovered through experiments that as the shear rate and shear displacement increase, the shear surface tends to become compact and smooth, the porosity of the shear zone gradually decreases, and the shear strength parameters decline.

Current research on the effects of water content, clay fraction, and shear rate on the shear strength of unsaturated soda - saline loessal soil is insufficient. This study will employ ring shear tests to analyze the influencing rules of these three factors on the shear strength of shallow unsaturated soda - saline loessal soil. The results can provide parameter support for the stability assessment of such soil slopes.

## 2. Test Materials and Methods

### 2.1 Test Materials

The soil samples were taken from Suozi Town, Qian'an County, Songyuan City, Jilin Province. The basic physical indicators of the soil samples are shown in Table 1. The clay content was set with reference to the soil clay content in the study area (Qian'an County) [9], which were 8%, 12%, 16%, 20%, and 24%. The water content was set as 10%, 13%, 16%, 19%, and 22%. The clay particles contained in the natural soil samples are illite-smectite mixed layers, and illite powder is selected as the supplementary clay fraction in this study.

In the ring shear test, a normal stress of 50 kPa was set to simulate the soil normal stress level within the range of 2-3 m. Considering that the shear rate lower than 0.1 mm/min has little effect on the shear strength of the soil, and due to the normal stress of 50 kPa during the test, an excessively high shear rate may lead to unstable test results, the shear rates in the test were set to 0.1 mm/min, 0.2 mm/min, 0.5 mm/min, 1 mm/min, and 2 mm/min respectively. The dry density of the samples was set to 1.42g/cm$^3$, and the salt contents were set to 0.5%, 1%, and 1.5%. Sodium bicarbonate powder of corresponding mass was dissolved in deionized water, mixed evenly with air-dried soil samples, sealed with plastic wrap to prevent water loss, and placed in a constant temperature and humidity box for 24 hours to fully mix the soil samples, salt, and water for later use.

**Table 1:** Basic physical properties of test soil samples

| Natural density (g/cm$^3$) | Natural dry density (g/cm$^3$) | Natural water content (%) | Liquid limit (%) | Plastic limit (%) | Particle size distribution (%) | | |
|---|---|---|---|---|---|---|---|
| | | | | | <2μm | 2-50μm | >50μm |
| 1.59 | 1.42 | 12.96 | 35.00 | 18.80 | 10.65 | 75.85 | 13.50 |

### 2.2 Ring Shear Test

The soil samples cured for 48 hours were transferred into the shear box and compacted in two layers. The interface between layers was scarified to inhibit interfacial stratification during sample preparation, thereby minimizing its influence on test outcomes. During shear testing, consolidation was initially performed under a 50 kPa normal stress. Consolidation was deemed complete when the vertical displacement rate fell below 0.05 mm over a two-hour period. Subsequently, under undrained conditions, the effect of shear rate was examined. Specimens designated for investigating clay fraction and water content effects were sheared at a constant rate of 0.5 mm/min until peak shear strength was observed, at which point the test was terminated.

### 2.3 Matrix Suction Test

Based on ASTM D5298-10, matric suction tests were carried out on samples with diverse water contents and clay fractions, and the formula for calculating matrix suction is as follows:

$$\lg(\psi) = \begin{cases} 5.327 - 0.0779 w_f & w_f < 45.3\% \\ 2.412 - 0.0135 w_f & w_f > 45.3\% \end{cases}$$

Where $\psi$ is matrix suction, kPa; $w_f$ is filter paper water content.

## 3. Test Results and Discussion

### 3.1 Effect of Water Content on Shear Strength

During testing, the shear rate was maintained at 0.5 mm/min with a clay content of 8%. Figure 1 presents the test results for samples containing salt concentrations of 0.5%, 1%, and 1.5% under varying water content conditions. For the sample with a salt content of 0.5%, as the soil water content increased from 10% to 13%, 16%, 19%, and 22%, the shear strength decreased from 36 kPa to 34.3 kPa, 32.3 kPa, 29.1 kPa, and 25.4 kPa, respectively. This represents a maximum reduction of 12.7%. Similarly, samples with salt contents of 1% and 1.5% exhibited maximum shear strength reductions of 11.9% and 11.7%, respectively. The shear strength of the remolded soil exhibits a significant reduction with increasing water content within the samples.

The relationship between soil matrix suction and variations in water content and clay content is illustrated in Figure 2. As soil water content increases from 10% to 22%, the corresponding matrix suction decreases substantially from 3193 kPa to 10 kPa. This elevated water content induces a reduction in matrix suction, consequently leading to a decrease in soil shear strength [10].

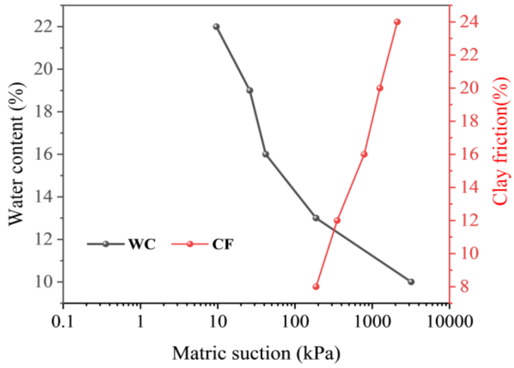


**Figure 2:** Variation curve of matrix suction with water content and clay content

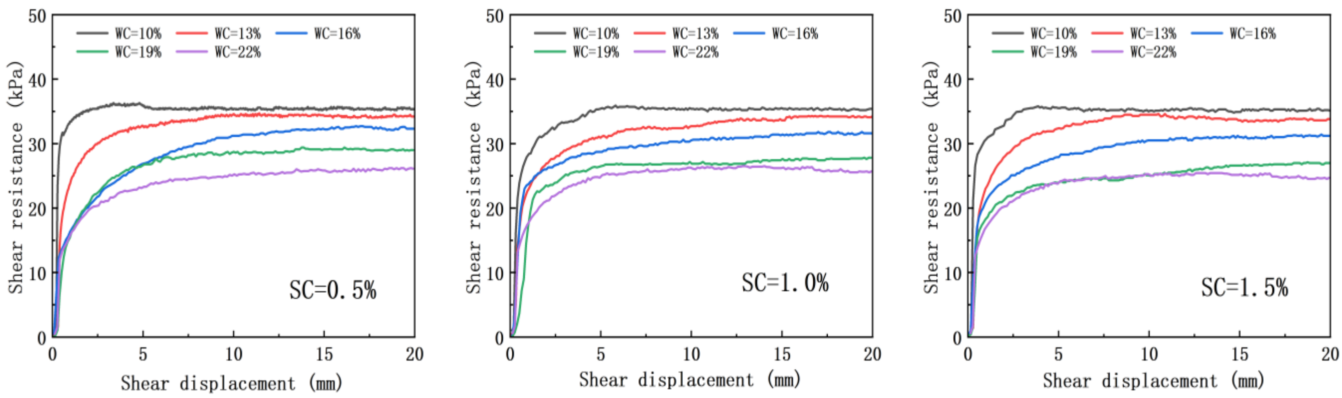


**Figure 1:** Test results of samples under different water content conditions

### 3.2 Effect of Clay Content on Shear Strength

Figure 3 shows the ring shear test results of three types of salt content samples under different clay content conditions. During the test, the water content was controlled at 13%, and the shear rate was 0.5 mm/min. As the clay content of the sample increases from 8% to 12%, 16%, 20%, and 24%, the shear strength of the sample with a salt content of 0.5% increases from 32.8 kPa to 35.8 kPa, 37.7 kPa, 42.3 kPa, and 43.3 kPa, with a maximum increase of 12.2%; the sample with a salt content of 1.5% increases from 32.8 kPa to 36.1 kPa, 39.4 kPa, 41.5 kPa, and 43.4 kPa, with a maximum increase of 10.0%. It is indicated that the shear resistance of soil improves as the clay content increases.

According to the matrix suction test results in Figure 2, the matrix suctions of remolded soil samples with clay contents of 12%, 16%, 20%, and 24% are 352 kPa, 788 kPa, 1256 kPa, and 2113 kPa respectively. This shows that with the increase of clay content, the matrix suction increases, the friction between soil particles increases, and the shear strength of the sample increases.

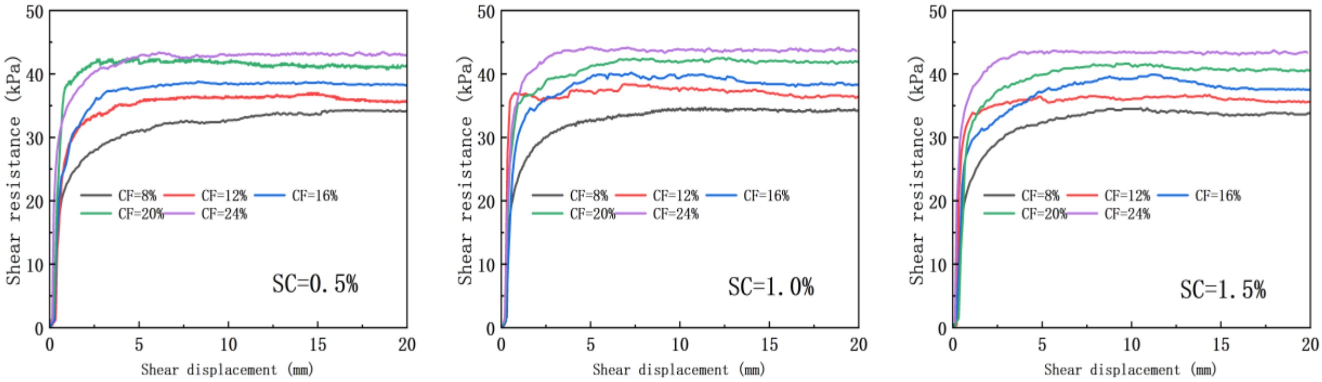


**Figure 3:** Test results of samples under different clay content conditions

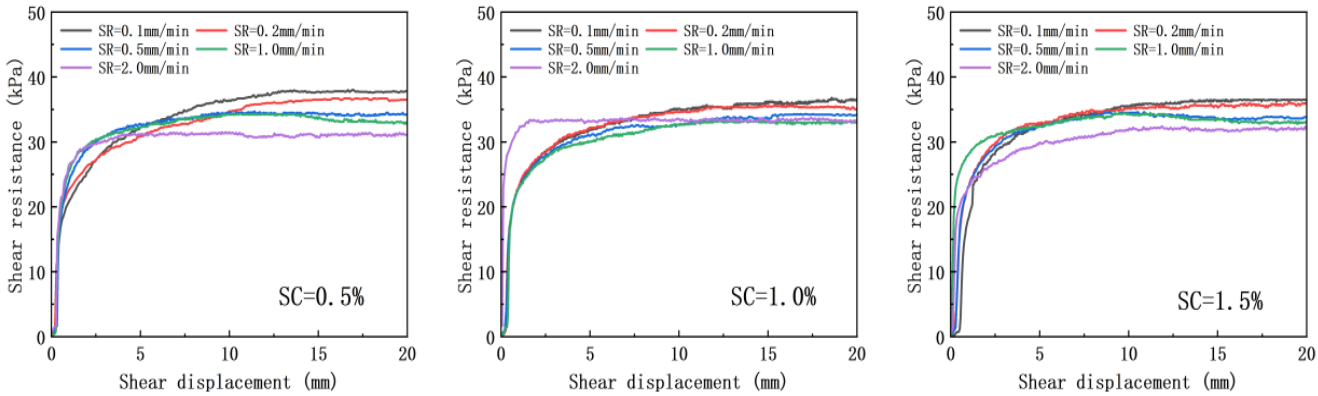


**Figure 4:** Test results of samples under different shear rate conditions

### 3.3 Effect of Shear Rate on Shear Strength

During testing, the water content was maintained at 13% and the clay content at 8%. Figure 4 presents the variations in shear stress observed in ring shear tests for three sample types with varying salt contents under different shear rate conditions. As the shear rate increased incrementally from 0.1 mm/min to 0.2 mm/min, 0.5 mm/min, 1 mm/min, and 2 mm/min, the shear strength of the sample containing 0.5% salt progressively decreased from 37.7 kPa to 36.7 kPa, 34.2 kPa, 33.0 kPa, and 31.0 kPa, representing respective changes of 2.7%, 3.4%, 3.5%, and 6.1%. The maximum strength reductions observed for samples with salt contents of 1% and 1.5% were 4.3% and 4.2%, respectively. These results indicate that increasing shear rate induces a decreasing trend in the shear strength of unsaturated soda-saline loessal soil across all tested salt concentrations.

## 4. Conclusions

In this study, ring shear tests were conducted on remolded samples of shallow unsaturated soda-saline loessal soil to reveal the influence laws of water content, clay content, and shear rate on the shear strength of unsaturated soda-saline loessal soil.

(1) Under low normal stress, changes in water content and clay content both have significant effects on soil shear strength. As the water content increases, the soil shear strength decreases. As the clay content increases, the soil shear strength increases.

(2) When the shear rate increases from 0.1 mm/min to 2.0 mm/min, the maximum decreases in shear strength of samples with salt contents of 0.5%, 1%, and 1.5% are 6.1%, 4.3%, and 4.2% respectively. With the increase of shear rate, the shear strength of unsaturated soda-saline loessal soil decreases to varying degrees.

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