The Impact of Cement on the Mechanical Properties of Expansive Soil

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Abstract: Expansive soil is a type of clay soil that expands when wet and shrinks when dry, exhibiting extremely unstable properties. This often causes uneven swelling and shrinking deformations in buildings, leading to cracks, tilting, and even destruction. This paper explores the ameliorative effect of cement on expansive soil by conducting direct shear tests under different moisture contents. The tests demonstrate that cementing expansive soil causes a decrease in the particle size distribution, and a noteworthy divergence in the shear stress-shear displacement relationship curves between the two types of soils is observed as the moisture content fluctuates. The cohesion disparity is slight, yet the angle of internal friction alteration with varying moisture content is considerable. Adding cement to expansive soil can significantly enhance the stability of the soil, making engineering projects safer.

Keywords: Expansive Soil; Cement; Moisture Content; Cohesion; Angle of Internal Friction

1. Introduction

The South-to-North Water Diversion Project is a major endeavor to tackle the unequal distribution of water in China and to foster local economic growth and social advancement. The expansive soil canal section of the middle route of the South-to-North Water Diversion Project has a total length of 346.85km, which is approximately 27% of the main canal's 1266.495km length. For experiments, the paper chooses a segment of the South-to-North Water Diversion Project's middle path.

Shear strength is the ultimate strength of a soil body during shearing. It is an important indicator of the mechanical properties of the soil. Many scholars have conducted direct shear tests on expansive soil with different materials added at various moisture contents to study the changes in the properties of expansive soil before and after the addition of materials. Yue Peng et al.[1] found that the shear strength, compressive strength, and maximum dry density of expansive soil increased after sand was mixed in, reducing the optimal moisture content of the expansive soil, with the shear strength parameters showing a trend of first increasing and then decreasing; Wang Xiaoyan et al.[2] found that the shear strength of remolded expansive soil at different moisture contents first increased and then decreased as the moisture content increased; Shen Rong et al.[3] found that adding ultra-high molecular weight polyethylene fibers to expansive soil reduced its free expansion rate and significantly increased its shear strength in unloading expansion rate tests and rapid direct shear tests; Guo Kunlong et al.[4] added iron tailings sand, calcium carbide slag, and a composite material of iron tailings sand and calcium carbide slag to expansive soil for direct shear tests, controlling the mix ratio and moisture content to study their impact on shear strength parameters, finding that both iron tailings sand and calcium carbide slag improved the shear strength of expansive soil, with the combined improvement method being more pronounced; Zhou Rui et al.[5] found that adding rubber particles of different sizes and masses to expansive soil showed the most significant improvement in shear strength when the added rubber particles were 1~2mm in size and comprised 10%~15% of the mix; Zhao Lijun et al.[6] found that adding PP fibers to cement-modified expansive soil significantly improved its shear strength; Han Jing et al.Ren Keyi et al. discovered that the shear strength, internal friction angle, and cohesion of expansive soil all augmented with the addition of varying amounts of cement and lime to the soil, as demonstrated by direct shear tests conducted by [7,8] found that adding graphene to clay effectively improved the clay's cohesion, but had a minor effect on the internal friction angle of the clay; Wang Chuang et al.Bian Minjia et al. discovered noteworthy disparities in the shear stress-shear displacement relationship curves of soil with residual slope at varying moisture levels near the plastic limit.At varying moisture levels, Zhang Haiming et al.[9] conducted extensive direct shear tests on remolded unsaturated silty soil, discovering that both the internal friction angle and cohesion of the remolded unsaturated silty were approximately quadratic and linear, respectively. Meanwhile, [10] had previously conducted direct shear tests on silty clay, discovering an approximate quadratic relationship between its moisture content and cohesion. soil first increased and then decreased as the soil moisture content increased [11].

There have been remarkable research results at home and abroad in the aspect of cement modified expansive soil. Fewer studies have been conducted on the disparity between the broad soil in the middle section of the South-to-North Water Diversion Project and the expansive soil after cement was added.

Physical index of soil

Obtaining the soil that had been utilized in a canal segment of the South-to-North Water Transfer Project's middle route. Upon survey, it was found that the canal slope deeper than 1m in this section consisted of cement-modified expansive soil, while the part below 1m was expansive soil. The cement-modified expansive soil appeared as a lighter yellowish-brown color with noticeable cement clumps within the soil matrix; the expansive soil was a distinct yellowish-brown color. Indoor tests determined that the liquid limit of the cement-modified expansive soil was 26.5%, the plastic limit was 45.0%, and the plasticity index was 14.1. For the expansive soil, the liquid limit was 22.8, the plastic limit was 49.8, and the plasticity index was 27.1.

The particle size distribution curves of cement-modified expansive soil and expansive soil are shown in Figure 1. As can be seen from Figure 1, the particle size distribution curve of the expansive soil is more gradual and better graded. The limiting particle size (d60) of the modified soil in the canal embankment is 0.0195mm, and d30 is 0.0084mm; the limiting particle size (d60) of the canal embankment expansive soil is 0.0167mm, and d30 is 0.0056mm.

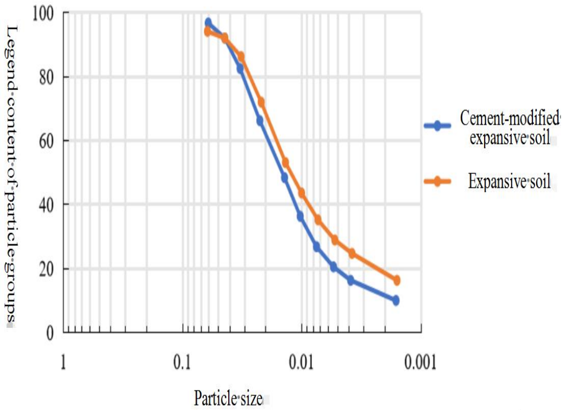


Figure 1. Curves of Cement-Modified Expansive Soil and Expansive Soil Particle Size Distribution

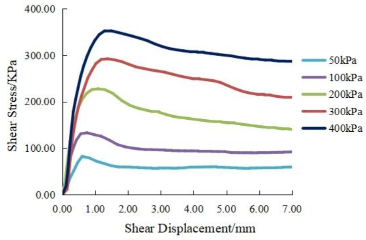
2. Direct Shear Test

2.1 Direct Shear Test Scheme

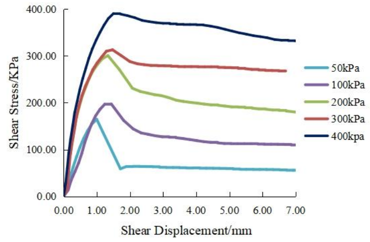
In the experiment, direct shear specimens were prepared by controlling the dry density. The dry density of cement-modified expansive soil was controlled at 1.52g/cm³, with moisture contents prepared at 6%, 12%, 18%, 24%, and 32.89% (saturated). For the expansive soil, the dry density was controlled at 1.62g/cm³, with moisture contents prepared at 6%, 12%, 18%, 24%, and 30.18% (saturated). Five samples of soil types, each with its own moisture content, were prepared and subjected to vertical pressures of 50kPa, 100kPa, 200kPa, 300kPa, and 400kPa for direct shear tests. These tests were conducted on an FDJ - ZO type unsaturated soil direct shear apparatus, with a shear rate of 0.8mm/min. If a peak value appears within a shear displacement of 6mm, take the peak value as the shear strength under this vertical pressure. Should the displacement of the shear be 4 mm, the shear stress is the strength of the shear under this vertical pressure.

2.2 The Relationship between Stress and Displacement

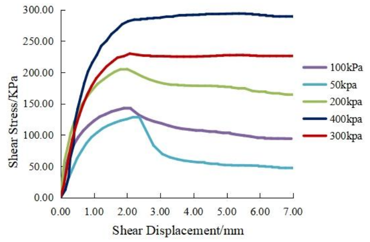
The stress-strain curves of cement-modified expansive soil and expansive soil at different moisture contents are shown in Figures 2 and 3, respectively.



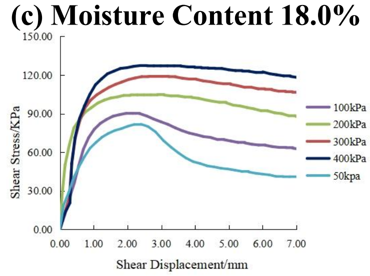
(a) Moisture Content 6.0%



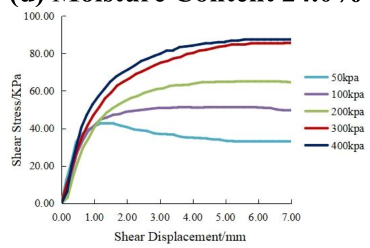
(b) Moisture Content 12.0%



(c) Moisture Content 18.0%

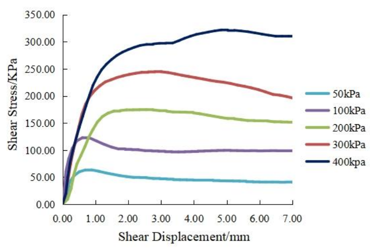


(d) Moisture Content 24.0%

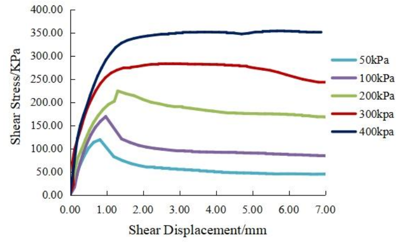


(e) Moisture Content 32.89%

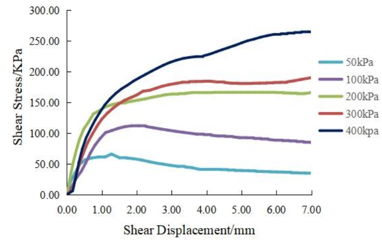
Figure 2. Shear Stress-Shear Displacement Relationship Curves of Cement-Modified Expansive Soil at Different Moisture Contents



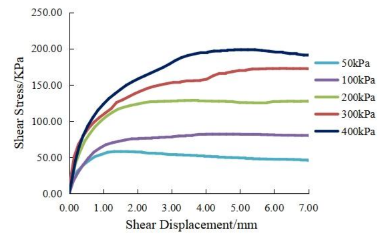
(a) Moisture Content 6.0%



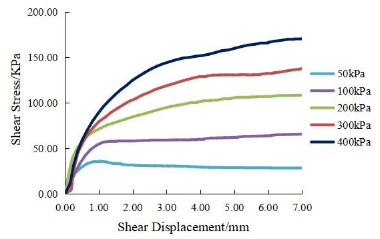
(b) Moisture Content 12.0%



(c) Moisture Content 18.0%



(d) Moisture Content 24.0%



(e) Moisture Content 30.18%

Figure 3. Shear Stress-Shear Displacement Relationship Curves of Expansive Soil at Different Moisture Contents

In cement-modified expansive soil, when the moisture content is above 18%, the shear stress-shear displacement relationship completely shows a shear hardening behavior. At moisture contents below 18%, taking a moisture content of 12% as an example, the shear stress-shear displacement curve gradually shows a shear hardening behavior with increasing vertical load. There are certain differences between expansive soil and cement-modified expansive soil. In expansive soil, when the moisture content is above 18%, the shear stress-shear displacement relationship does not fully show a shear hardening behavior. For example, at a moisture content of 24.0% and a vertical load of 50kPa, the shear stress-shear displacement curve still shows a shear softening trend under lower vertical loads. At a moisture content of less than 12%, the shear stress-shear displacement curve displays a shear softening behavior, yet when the moisture content surpasses 12% it gradually exhibits a shear hardening as the vertical load rises.

2.3 The Impact of Moisture Content on the Shear Strength of Cement-Modified Expansive Soil

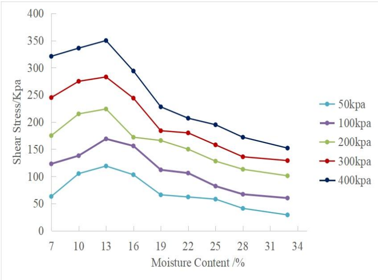


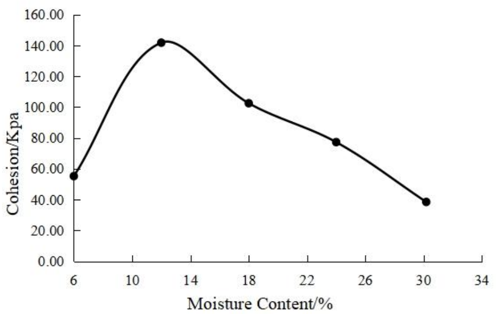
Figure 4. The Relationship Curves between the Shear Strength of Cement-altered Expansive Soil and Moisture Content, under Varying Vertical Pressures Are Depicted

In Figure 4, we can clearly see that the change of shear strength of expansive soil with water content is not a simple linear relationship.

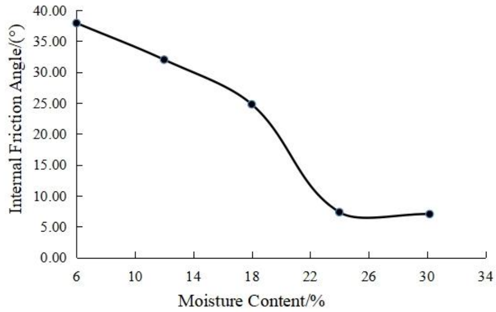
The shear strength initially rises with the rise of water content, then declines. When the moisture content of the plastic reaches its limit, the rate of decrease in shear strength diminishes. Under a certain moisture content, the shear strength also gradually increases with increasing vertical pressure.

2.4 Impact of Moisture Content on Shear Strength Parameters

Figures 5 and 6 demonstrate the correlation between the internal friction angle and cohesion of cement-modified expansive soil and expansive soil at varying moisture levels.

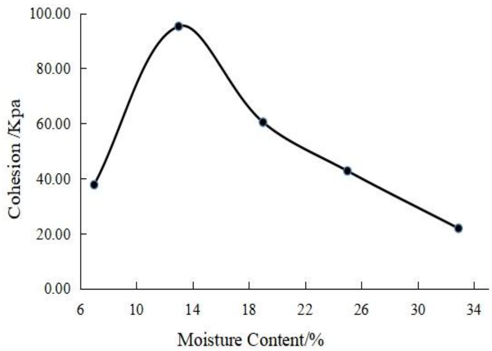


a. The Relationship between Cohesion and Moisture Content of Cement-modified Expansive Soil

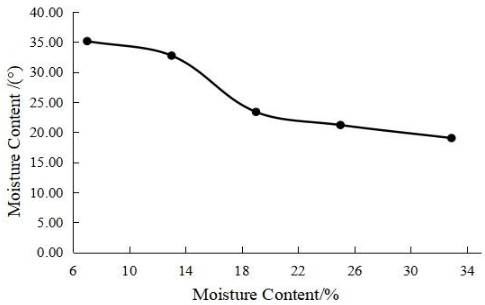


b. The Relationship between Internal Friction Angle and Moisture Content of Cement-modified Expansive Soil

Figure 5. The Moisture Content of Cement-Modified Expansive Soil and Shear Strength Parameters Are Illustrated



a. The Relationship between Cohesion and Moisture content of Expansive Soil



b. The Relationship between Internal Friction Angle and Moisture Content of Expansive Soil

Figure 6. The Moisture Content of Expansive Soil is linked to Shear Strength Parameters

It is evident from Figures 4 and 5 that the relationship between cohesion and moisture content for both cement-modified expansive soil and expansive soil is not a simple linear one. The cohesion of both increases with moisture content initially and then decreases, showing a trend similar to a quadratic parabola. This trend can be expressed by the following formulas:

$$c=-0.1841w^2+5.827w+22.9 \ldots\ldots (1)$$

$$c=0.4582w^2+14.943w-4.0031 \ldots\ldots (2)$$

where c represents the cohesion of the soil in kPa, and w is the moisture content of the soil in %.

From Figures 3 and 4, it can also be observed that the variation in the internal friction angle with moisture content for both cement-modified expansive soil and expansive soil is not a simple linear change. The expansive soil shows a larger variation with a range of up to 30.8824°, whereas the variation for cement-modified expansive soil is smaller, which is only 16.115°.

3. Conclusion

After adding cement to expansive soil, there will be obvious changes, among which there will be obvious differences in particle gradation, shear stress-shear displacement relationship curve and shear strength parameters with water content before and after adding cement to expansive soil. The shear strength of expansive soil does not change linearly with water content.

The particle gradation curve of expansive soil is gentler than that of cement modified expansive soil, indicating a better grading of the expansive soil. At lower moisture contents, the shear stress-shear displacement relationship curve of expansive soil shows a more pronounced shear softening trend compared to that of cement-modified expansive soil. As the moisture content increases, the shear stress-shear displacement relationship curve of cement-modified expansive soil exhibits a more evident shear hardening trend compared to that of expansive soil.

As the moisture content increases, the shear strength of cement-modified expansive soil shows a trend of increasing at first and then decreasing. After reaching the plastic limit moisture content, the rate of decrease in shear strength slows down. The shear strength of soil rises with the augmentation of vertical pressure at a given moisture content. The cohesion of cement-modified expansive soil and expansive soil is not significantly disparate, yet the disparity in the internal friction angle's variation with moisture content between the two types of soil is more pronounced in expansive soil.

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