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Study on the Shear Strength Characteristics of Remolded Laterite from Western Henan under Different Moisture Contents

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Abstract: ***In the western Henan region of China, laterite, as a typical type of special soil, plays a significant role in the engineering properties that directly impact infrastructure development and geological disaster prevention in the area. The effect of moisture content on its mechanical properties is particularly significant. To investigate the relationship between the shear strength and moisture content of remolded laterite in western Henan, this study employs a ring shear device to conduct shear tests under various moisture content and vertical stress conditions. The analysis of the shear strength variation with strain reveals that as moisture content increases, the shear strength generally decreases. After exceeding 30% moisture content, the shear strength decreases rapidly. The cohesion decreases quickly at first with increasing moisture content, then more slowly, and finally decreases sharply. The internal friction angle decreases gradually with increasing moisture content, but the rate of decrease accelerates only after the moisture content surpasses 30%. This study provides a theoretical basis for foundation treatment and slope stability assessment in laterite areas.***

Keywords: Remolded laterite, Shear strength, Ring shear test, Moisture content.

1. Introduction

In the field of engineering construction, the accurate assessment of soil mechanics is the cornerstone for ensuring the stability and safety of engineering structures, particularly in regions with complex and diverse geological conditions. The mechanical properties of laterite, especially its shear strength, are key parameters in engineering problems such as slope stability analysis, foundation bearing capacity evaluation, and retaining structure design. Moisture content is one of the most important factors influencing the shear strength of soils, particularly in unsaturated soils, where changes in moisture content directly affect the matric suction within the soil, thereby influencing the effective stress state and shear strength [1]. Gao Ziao used a conventional direct shear apparatus to study the shear strength of unsaturated soils, determining the soil suction using the filter paper method. His findings show that under the same normal stress, both initial and post-shear suction change with moisture content, indicating that moisture content affects shear strength by influencing matric suction [2]. Wang C conducted triaxial tests on unsaturated sandy clay to study the effect of moisture content on soil strength. The results showed that an increase in moisture content leads to a decrease in cohesion and shear strength, with the rate of strength reduction following a pattern of fast initial decrease followed by slower reduction. This is consistent with the theoretical expectation for unsaturated soils, where a decrease in moisture content increases matric suction, effective stress, and shear strength. [3].

Ring shear tests, as a method capable of achieving large shear displacements, are particularly suitable for studying the residual strength characteristics of soils [4]. In slope engineering and landslide analysis, the residual strength of soil is a critical parameter in determining sliding stability. For laterite, its unique mineral composition and structural characteristics may lead to significant structural failure and strength degradation during shearing. Therefore, using a ring shear apparatus to study the shear strength characteristics of laterite, especially its residual strength under large deformation conditions, holds great engineering significance [5]. Miao Haibo used a large ring shear apparatus to study the stress-strain patterns and residual strength characteristics of Jurassic red bed landslide slip zone soil in the Three Gorges Reservoir area, providing experimental evidence for understanding the deformation failure mechanism of red bed landslides [6]. Ring shear tests on sandy clay from an ancient landslide zone, combined with electron microscope scanning technology, analyzed changes in microstructure before and after shearing, exploring the relationship between microstructure and the macro-mechanical characteristics of the soil [7]. Liu Dong integrated ring shear test results with the SPH model to predict the movement range and failure mode of landslides, demonstrating the application value of ring shear tests in landslide prediction. These studies confirm that ring shear tests are an effective method for investigating the residual strength of landslide soils. The shear strength of soils can be influenced by shear rate. Lian B conducted ring shear tests on saturated loess under different shear rates and studied the impact of shear rate on the residual strength of loess. The results showed that increasing the shear rate reduced both peak strength and residual strength of loess [8]. Jeong studied the effect of surface roughness on the shear strength of granular materials using ring shear tests, finding that shear rate and drainage conditions also affect the shear strength of granular materials [9]. Gruchot used a direct shear apparatus to investigate the effects of shear rate and saturation on the shear strength of mineral and man-made soils, concluding that shear rate had a relatively minor effect on shear strength parameters, while saturation had a more significant influence [10]. Merchán improved a Bromhead-type ring shear device to control the total suction of unsaturated soils and studied the residual strength characteristics of unsaturated clays under varying suction conditions. This study showed that suction has a significant impact on the residual friction angle of clay, providing important experimental support for the development and application of unsaturated soil strength theory [11]. Considering the particularities of laterite in the western Henan region and the research objectives, using the ring shear apparatus to study the shear strength characteristics of remolded laterite in this area is an appropriate choice. Ring shear tests can achieve large shear displacements and are capable of determining the residual strength parameters of remolded laterite [12], which is of significant importance for evaluating the long-term stability of laterite slopes.

2. Basic Physical and Mechanical Properties

2.1 Test Soil Samples

The soil samples used in this experiment were taken from the unsaturated original laterite at the newly constructed roadbed of the section from Qiaolou to Fushui on Provincial Road 315 and Provincial Road 238 in Zhengzhou, Henan, with a sampling depth of 1 to 2 meters. Both undisturbed and disturbed soil samples were sealed, labeled, and collected. The undisturbed soil was used for natural moisture content and shear strength tests, while the disturbed soil was used for tests on dry density, particle size analysis, liquid limits, and remolded soil shear strength.

2.2 Basic Physical Tests

The basic physical tests of laterite in this study were conducted in strict accordance with the requirements of the *Highway Geotechnical Testing Specifications* (JTGE40-2007) and the *Standard for Soil Testing Methods* (GB/T50123-2019). The tests performed included the determination of natural moisture content, dry density, particle size analysis, and liquid limits for the roadbed laterite. The specific test details are provided in Table 1, and the test results are presented in Table 2.

Table 1: Basic physical tests

Tests	Test Method	Main Testing Equipment
Natural Moisture Content	Oven Drying Method	Balance, Oven
Dry Density	Ring Cutter Meth	Balance, Ring Cutter, Oven
Particle Size Analysis	Laser Particle Size Analysis	Laser Particle Size Analyzer
Liquid Limit	Combined Liquid and Plastic Limit Test	Liquid-Plastic Limit Combined Tester

Table 2: Basic physical properties of laterite

	Natural Moisture Content (%)	Dry Density (g/cm^3)	Plastic Limit (%)	Liquid Limit (%)	Plasticity Index
Test soil sample	16.81	1.471	24.21	32.99	8.78

The particle size analysis was conducted using the domestic BT-9300LD laser particle size analyzer. The laser particle size analyzer is an instrument based on the principle of laser diffraction, widely used for measuring the particle size distribution of fine particles. Compared to traditional sieve analysis and pycnometer methods, the laser particle size analyzer offers advantages such as high precision, high resolution, fast measurement range, rapid measurement speed, and ease of operation.

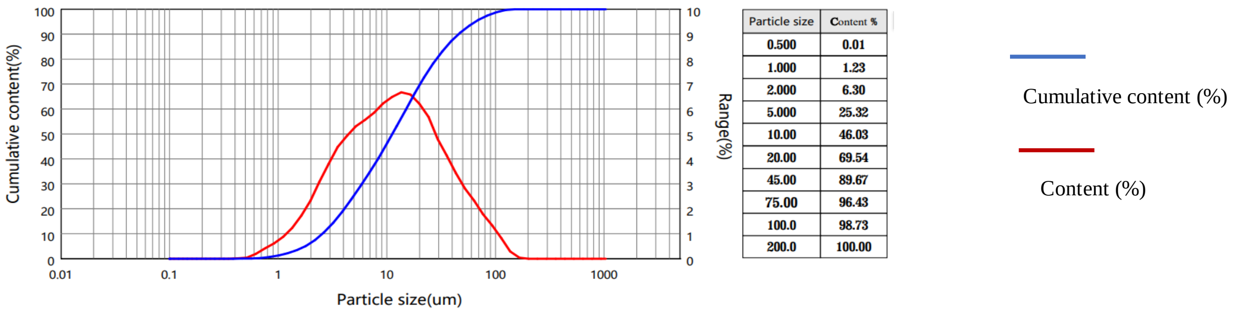

Figure 1: Particle size analysis results of laterite

The test results show that the particle size distribution of the laterite is primarily within the range of 0.6 to 127 microns, accounting for approximately 90%. Key parameters for assessing the soil's particle size distribution (PSD) characteristics include D10, D30, and D60, as well as the uniformity coefficient (Cu) and the curvature coefficient (Cc). The results, shown in Table 2, indicate that the curvature coefficient (Cc) lies within the range of 1 to 3, and the uniformity coefficient (Cu) is greater than 5, suggesting that the sample has a good gradation.

Table 3: Particle Size Analysis Parameters of Laterite

Soil	D_{10}	D_{30}	D_{60}	Cu	Cc
Laterite	2.57	15.21	6.39	5.9143	1.1192

3. Shear Strength Test of Remolded Laterite

3.1 Experimental Apparatus

The ring shear test is an experimental method used to determine the shear strength of soil. In this test, the soil sample is placed in a ring-shaped sample box, and shear force is applied by rotating the lower shear plate. The total area of the shear surface remains constant, and shear displacement can continue to increase until failure occurs. Compared to direct shear tests, the ring shear test better avoids interference from the shear box on the sample, overcoming the issue of uneven stress distribution during shearing, providing more accurate strength data for the soil. In the experiment, the upper shear plate remains stationary, while the lower shear plate rotates at a constant speed. As shear force is applied, cracks develop within the sample, gradually extending and penetrating through the entire sample, eventually forming a continuous shear surface until failure occurs. The failure surface typically appears at the junction of the upper and lower shear plates.

The experiment was conducted using the TKA-RSA-30F dynamic ring shear apparatus, as shown in Figure 2. The instrument mainly consists of the main machine system, control load collection control cabinet, displacement sensor, load sensor, vertical loading device, and torque sensor. The shear stress-shear displacement curve of the soil is obtained through the data acquisition system, and after processing, the shear strength parameters of the soil can be derived. For this experiment, the shear ring size was chosen as 100mm/60mm (outer diameter 100mm, inner diameter 60mm) with a height of 20mm. The samples before and after shearing are shown in the figure above.

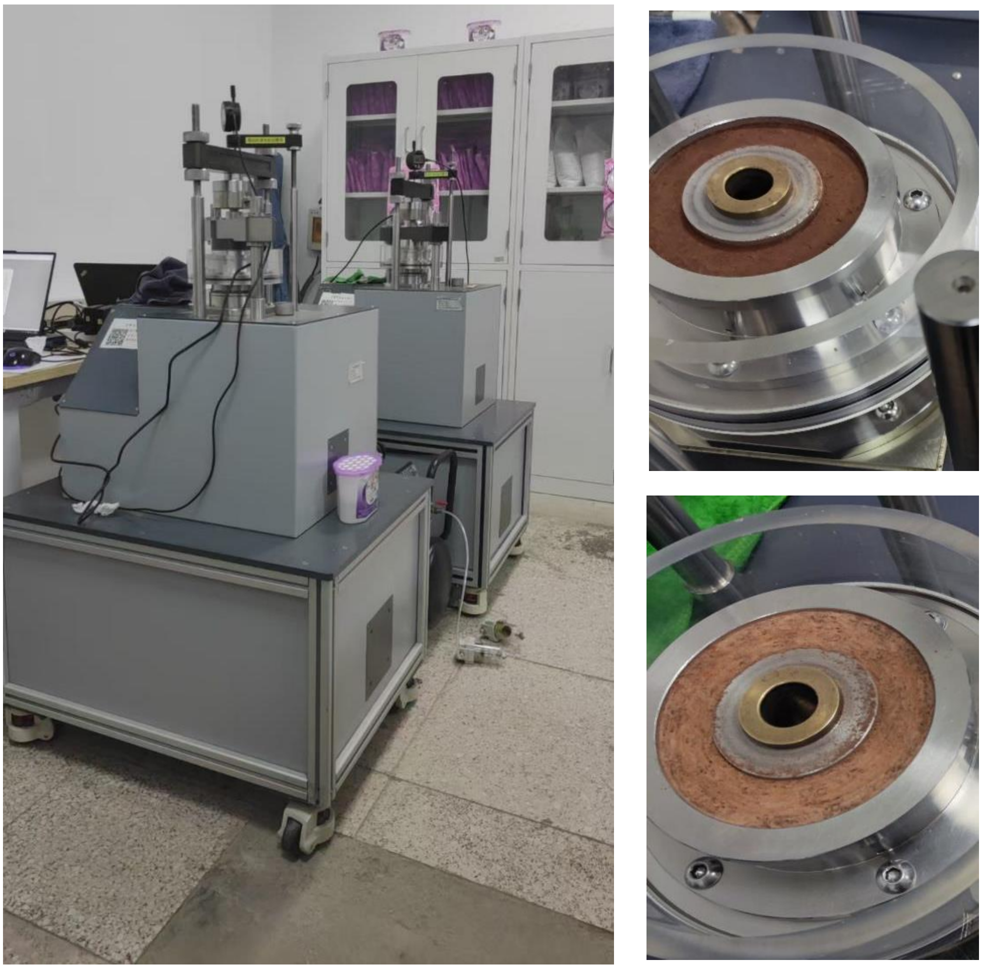

Figure 2: Dynamic ring shear apparatus (Left), Sample before shearing (Top Right), Sample after shearing (Bottom Right)

3.2 Experimental Plan

First, the soil samples were air-dried in a well-ventilated area. After air drying, the laterite was crushed using a wooden grinding rod and then sieved through a 2mm mesh to obtain the soil sample. The soil was then weighed to determine its air-dried moisture content. Based on the required moisture contents (10%, 15%, 20%, 25%, 30%, 35%), the necessary amount of water was calculated and evenly sprayed onto the soil in the form of a mist. After thorough mixing, the soil samples were sealed in plastic bags and left for 24 hours to ensure complete water absorption. The entire process followed the standard procedure outlined in the Soil Testing Regulations. The soil samples were then placed into the shear box and moved to the ring shear apparatus for testing. The test was conducted until the shear stress stabilized and no longer changed. Shear tests were conducted on samples with different moisture contents under normal stresses of 50, 100, 200, and 400 kPa, with a shear rate of 0.7 mm/min.

3.3 Experimental Data Analysis

The figure illustrates the changes in shear stress with shear displacement for six samples with different moisture contents under four different normal stress conditions. It is evident that the shear stress increases rapidly at first and then tends to stabilize as the shear displacement increases. As the moisture content of the samples increases, the average shear stress decreases accordingly. Under all four normal stress conditions, the shear strength at 35% moisture content is significantly lower than that at other moisture contents. For the sample with 10% moisture content, its shear strength is significantly higher than that of other moisture content samples, but only when the vertical stress is 50 kPa.

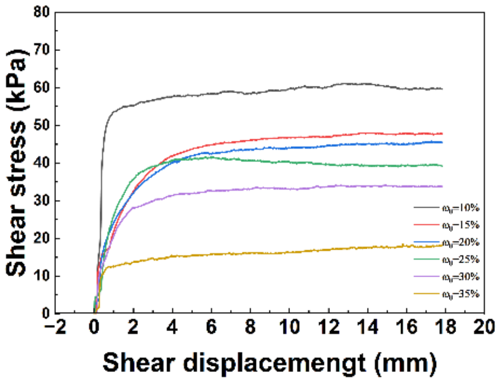

Figure 3: Vertical pressure :50 kPa

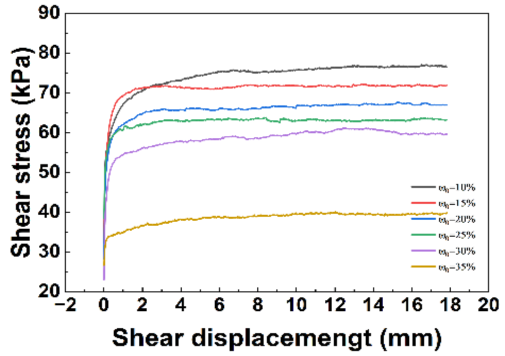

Figure 4: Vertical pressure :100 kPa

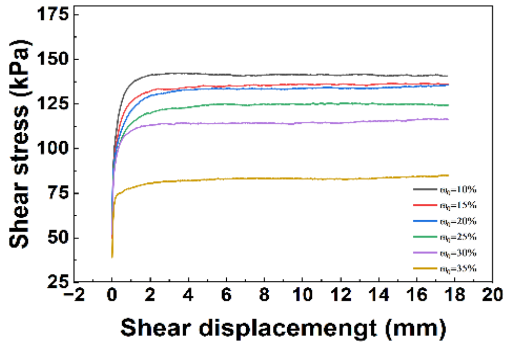

Figure 5: Vertical pressure :200 kPa

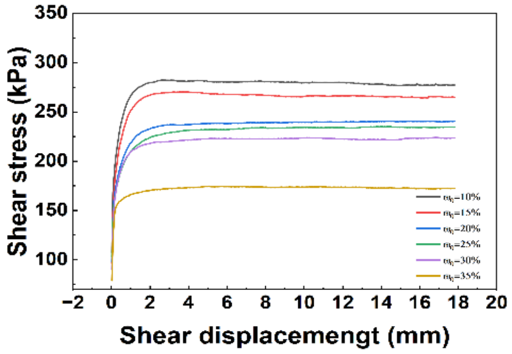

Figure 6: Vertical pressure :400 kPa

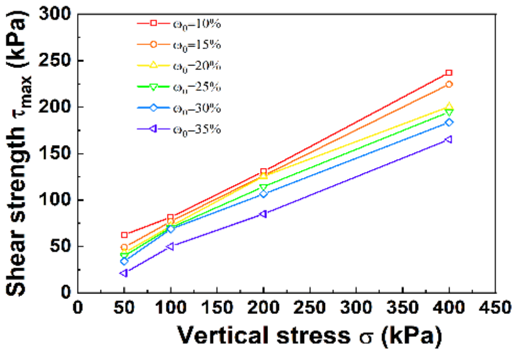

Figure 7: Different moisture content

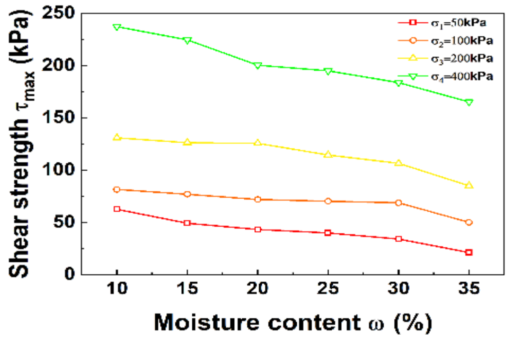

Figure 8: Different vertical stress

The curves in the figure indicate that the shear process can be divided into the initial growth stage and the stable deformation stage. The initial growth stage occurs when the shear displacement is between 0 and 3 mm, during which the shear stress increases rapidly. This is mainly due to the compaction effect of normal stress on the soil, but the shear plane has not yet formed, resulting in a high overall shear strength of the sample. Moreover, the larger the vertical stress, the faster the growth rate and the higher the shear strength. The stable deformation stage occurs after 3 mm, where the soil particles rearrange after entering plastic deformation, and the soil reaches a stable state under prolonged shear with no significant strength reduction. The peak strength equals the residual strength, showing no significant softening characteristics.

3.5 Analysis of the Effect of Moisture Content on the Cohesion of Laterite

Cohesion is one of the important parameters in determining a soil's resistance to shear failure, reflecting the intrinsic bonding ability between soil particles. The variation of cohesion with moisture content for remolded laterite is shown in Figure 9. As seen in the figure, moisture content significantly affects cohesion, with cohesion decreasing as moisture content increases. This is because moisture content has a significant impact on the bonding strength of the common hydration film between soil particles and the cementation of binding materials. In the low moisture content stage (10%–15%), the amount of adsorbed water between soil particles is low, and as moisture content increases, the original stable structure is disrupted, causing a rapid decrease in cohesion. In the moderate moisture content stage (15%–25%), as moisture content increases, the adsorbed water film gradually thickens, enhancing lubrication, but there is still some cementation and matric suction, so the decrease in cohesion is relatively slow. In the high moisture content stage (25%–35%), water gradually fills the pores between the particles, significantly reducing or even eliminating matric suction, which leads to a sharp decrease in cohesion.

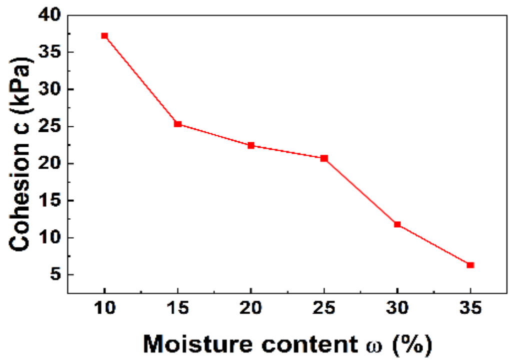

Figure 9: Cohesion vs. Moisture Content Curve

3.6 Analysis of the Effect of Moisture Content on the Internal Friction Angle of Laterite

The internal friction angle is an important parameter in determining a soil's resistance to shear failure, reflecting the frictional forces and interlocking between soil particles to some extent. The variation of the internal friction angle of remolded laterite with moisture content is shown in Figure 10. Overall, the internal friction angle decreases as the moisture content decreases, though the change is relatively small. In certain ranges, specifically between 10% and 30% moisture content, the internal friction angle of laterite gradually decreases as the moisture content increases. However, after the moisture content exceeds 30%, a significant increase in the rate of decrease is observed compared to the previous gradual reduction. Many studies indicate that factors such as mineral composition, density, and structure influence the internal friction angle of soils. The underlying mechanism is complex and not easy to conclude, but it is hypothesized that at high moisture content, water forms a continuous film between the particles, which lubricates the soil, making it easier for particles to slide and thus significantly reducing the internal friction angle.

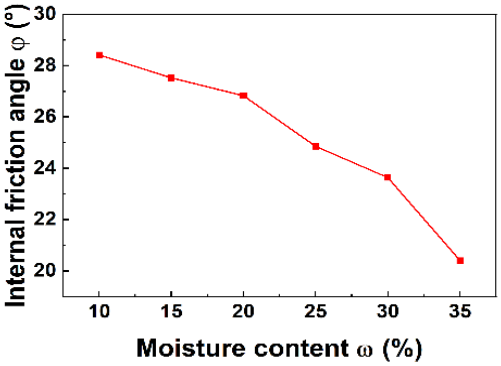

Figure 10: Internal Friction Angle vs. Moisture Content Curve

4. Conclusion

This study focuses on the laterite from western Henan, using an automatic dynamic ring shear apparatus for shear tests to investigate the shear strength characteristics of samples with different moisture contents under various vertical stress conditions. The main conclusions are as follows:

(1) The shear stress-strain curve consists of two stages: the initial shear stage and the stable stage. In the initial stage (shear strain between 0-3 mm), the shear stress increases rapidly, reflecting the friction and cohesion within the soil, with a steep curve and high shear strength. After entering the stable stage (after 3 mm shear displacement), as shear displacement increases, the shear stress stabilizes, indicating that the soil has reached its residual shear strength. Unlike traditional tests, the ring shear test does not exhibit a clear peak shear strength, and the shear stress eventually stabilizes at a lower residual strength level.

(2) As the moisture content of the sample increases, the shear strength decreases. Under the four different normal stress conditions, the shear strength at 35% moisture content is significantly lower than that at other moisture contents. For the sample with 10% moisture content, its shear strength is only significantly higher than that of other moisture content samples when the vertical stress is 50 kPa.

(3) The effect of moisture content on cohesion is significant, with cohesion sharply decreasing as moisture content increases. At low moisture contents (10%–15%), there is less adsorbed water, and the stable structure is disrupted, leading to a rapid decrease in cohesion. At moderate moisture contents (15%–25%), the adsorbed water film thickens, enhancing lubrication, and cohesion decreases more slowly. At high moisture contents (25%–35%), water fills the pores, and matric suction significantly decreases or disappears, leading to a sharp reduction in cohesion.

(4) The overall effect of moisture content on the internal friction angle is minimal, with a general trend of gradual reduction as moisture content increases. Between 10% and 30%, the internal friction angle of laterite decreases slowly with increasing moisture content. However, after the moisture content reaches 30%, the rate of decrease becomes significantly higher compared to the earlier stage.

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