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Experimental Study on the Physical and Mechanical Properties of Red Clay under Dry-Wet Cycles

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ABSTRACT: Red clay, as a typical water-sensitive soil, undergoes significant changes in its engineering properties under dry-wet cycling conditions. To gain a deeper understanding of the physical and mechanical characteristics of red clay under varying cycles of drying and wetting, a series of experiments were conducted, focusing on its shear strength. The test results show a gradual deterioration in the mechanical properties of red clay after five cycles. In the first three cycles, the direct shear tests revealed no significant degradation. However, starting from the fourth cycle, a rapid decrease in shear strength was observed, along with a progressive weakening of the soil structure. These findings provide new insights into the water sensitivity of red clay in engineering applications, offering important guidance for the stability analysis of foundations and slopes in similar environments.

KEYWORDS: Red clay, Water sensitivity, Dry-wet cycles, Shear strength

I. INTRODUCTION

Red clay is a common soil type, widely distributed in southern China. As a special soil, red clay poses inherent challenges in engineering applications, such as poor engineering properties and inadequate drainage capacity. Its unique characteristics include the following aspects: (1) High hygroscopicity: Red clay has a strong ability to absorb moisture from its surroundings. This feature allows it to remain wet for extended periods in humid environments. (2) Poor drainage: Due to the small voids between particles, red clay has poor drainage. When excessively saturated, it is prone to waterlogging, making it difficult to drain excess water quickly. (3) Prone to plastic deformation: The strong adhesion between red clay particles gives it high plasticity, making it susceptible to deformation when wet.

To improve the engineering performance of red clay, many researchers in China have conducted extensive studies and practical applications of various soil improvement methods. Liang Bin[1]et al. proposed that the shear strength of red clay decreases as the moisture content increases. Zeng Jun[2] studied the compaction characteristics and unconfined compressive strength of lime-modified red clay, proposing an "optimal lime content" of 8%. However, lime-modified red clay exhibits limitations such as long treatment time, water sensitivity, restrictions on strength and stability, and environmental impacts. Tang[3] et al modified red clay by adding lime, fly ash, and a lime-fly ash mixture. The results showed that lime, fly ash, and the mixture all improved the cohesion and compressive strength of red clay. The optimal ratio was found to be 1:2:7 (lime, ash, soil), but the cohesion only reached 46 kPa, and the improvement effect of the mixture was not significantly better than lime alone. At higher contents, the modified soil exhibited brittleness, so it is necessary to control the amount of fly ash carefully to avoid adverse effects on the soil's mechanical properties. Weng[4] et al used xanthan gum to reinforce red clay, showing that the optimal dosage for enhancing the macromechanical properties of red clay was 1.5%, with a curing period of 28 days. The compressive strength and cohesion of red clay increased by 93.31% and 79.47%, respectively. While xanthan gum improved the engineering performance of red clay, its high production cost, environmental impacts from waste during production, water sensitivity, and poor durability in moist environments limit its long-term effectiveness. Joel Kimarai [5] tested the feasibility of replacing part of the lime in red clay subgrades with sorghum straw ash. The results indicated that when 15% of the lime was replaced, the CBR and PI values met the recommended

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values for subgrade construction. Song[6] et al investigated the effect of basalt fiber incorporation on the mechanical properties of red clay, finding that the optimal fiber content was 0.3%. However, the improvement in cohesion was limited, with a maximum cohesion of 26.6 kPa, and the increase in friction angle was minimal. The fibers may not disperse uniformly within the red clay, and the typically short lengths of basalt fibers may limit effective bonding with the red clay. Jiang[7] et al analyzed the shear strength of red clay mixed with coconut fiber and found that the optimal fiber content was 0.3%, with an increase in cohesion by 9.13 kPa. Zhang[8] et al studied the effect of different concentrations of Cu^{2+} on the compressibility of red clay from the perspective of bound water. The results showed that Cu^{2+} thinned the water film in the pore water, causing soil particles to bind more closely, enhancing the structural strength and increasing resistance to compressive deformation. Zhou[9] et al applied MICP technology to red clay improvement, and the permeability coefficient of the modified soil decreased by two orders of magnitude. Tan[10] et al conducted experiments on polyurethane (PSP)-treated red clay, discovering that polyurethane improved the strength, stiffness, and toughness of red clay simultaneously. The studies outlined above demonstrate that various methods have been employed to improve the physical and mechanical properties of red clay, ranging from the use of traditional materials such as lime and fly ash to more advanced techniques such as MICP and polyurethane treatment. While these methods show varying degrees of success in enhancing cohesion, shear strength, and durability, they often come with limitations such as brittleness, environmental impact, or high cost, particularly in the case of xanthan gum and polyurethane. Moreover, water sensitivity remains a significant challenge across many treatment methods.

The significance of my research on red clay subjected to dry-wet cycles lies in addressing a critical gap in understanding the degradation of its mechanical properties under natural environmental conditions. The results of the dry-wet cycle tests demonstrate a significant reduction in shear strength starting from the first cycle, with minor changes observed in the second and third cycles, and a further decline beginning from the fourth cycle. This experiment provides important insights into the water sensitivity and long-term performance of red clay. By offering more effective strategies for the stabilization of red clay and infrastructure design, particularly in regions prone to cyclic wetting and drying, this research contributes to improving the reliability and safety of engineering projects across a broad range of applications.

II. EXPERIMENTAL STUDY

In this study, all samples were remolded with a moisture content of 17% and a dry density of 1.7. The dry-wet cycle tests were conducted using a spraying method with a watering can and an oven set at 40°C to simulate real engineering conditions. Each cycle involved spraying the samples with water for 10 minutes, followed by a 24-hour resting period, and then drying in the oven at 40°C for 24 hours. After each cycle, the following experiments were performed:

Direct Shear Test: A strain-controlled direct shear apparatus was used to investigate the effects of five dry-wet cycles on the cohesion and internal friction angle of red clay. Six sets of tests were conducted, each with four samples. The sample dimensions were height H=2.0 cm and diameter D=6.18 cm. Samples were prepared with a natural moisture content of 17% and a dry density of 1.7, by evenly spraying the soil with a watering can and allowing it to cure for 24 hours before testing.

Figure1: dry-wet cycle process

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III. ANALYSIS OF EXPERIMENTAL RESULTS

In its initial state, the red clay exhibits relatively high cohesion, measured at 25.8 kPa, indicating that the soil's internal structure is intact and its shear strength remains largely unaffected. However, after the first wet-dry cycle, cohesion decreases sharply, suggesting that the soil structure begins to degrade as the cycles progress. The expansion and contraction caused by moisture reduce the cohesion between soil particles, gradually weakening the soil's overall stability. Following the second cycle, the change in cohesion is less pronounced compared to the first cycle, indicating a degree of stabilization in the red clay structure. While cohesion continues to decrease, the reduction is not as significant.After the third cycle, cohesion shows a slight recovery, which may be due to the rearrangement of soil particles induced by the wet-dry cycles, or a limited self-restoration process that partially restores cohesion. However, after the fourth cycle, cohesion again declines significantly, reflecting considerable structural damage to the soil, further weakening particle bonds and impairing the overall integrity of the soil. By the fifth cycle, cohesion is nearly lost, indicating that the red clay has become highly unstable, with a marked reduction in shear strength, rendering it incapable of maintaining structural stability. Despite this, it is evident from the figure that the internal friction angle of the red clay remains largely unchanged after five cycles.

The overall trend indicates a progressive reduction in the cohesion of red clay with repeated wet-dry cycles. After the first cycle, there is a significant decrease in cohesion, suggesting considerable damage to the internal structure of the red clay. Although changes in cohesion are relatively minor after the second and third cycles, it continues to decline after the fourth and fifth cycles, eventually approaching zero. This demonstrates that repeated wet-dry cycles severely undermine the structural integrity of the red clay, leading to a substantial deterioration in its engineering properties.

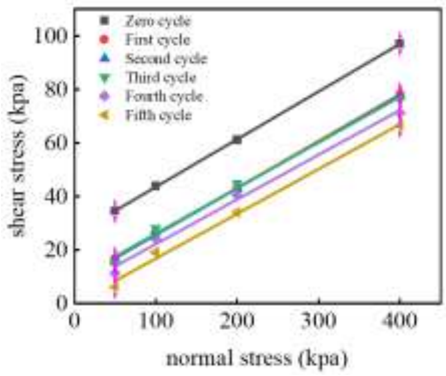

Figure2: shear strength under dry-wet cycles

IV. CONCLUSION

This study conducted five wet-dry cycle tests on red clay to analyze the changes in its cohesion and compressive properties. The results show that the cohesion of red clay gradually decreases with an increasing number of wet-dry cycles. Compared to the initial state, the cohesion and compressive performance of red clay experienced a significant decline after the first cycle, indicating substantial structural damage. During the second and third cycles, the rate of performance degradation was relatively small, suggesting a period of structural stabilization. However, by the fourth cycle, both cohesion and compressive strength dropped sharply again, reflecting further deterioration of the soil structure under repeated wet-dry cycling. By the fifth cycle, the red clay samples had nearly lost their cohesion and compressive capacity entirely, indicating severe structural damage and the inability to maintain sufficient engineering stability.

This study provides valuable insights for the application of red clay in practical engineering, emphasizing the need to address the significant performance degradation that occurs under multiple wet-dry cycles.

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