Experiment of the Swell-shrink Characteristic of the Improved Red Clay under the Dry and Wet Circulation

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Abstract. After a preliminary study on the swell-shrink characteristic of the red clay of somewhere in Chongqing under the effect of dry and wet circulation through the laboratory geotechnical experiment, in order to study the swell-shrink characteristic of the improved soil under the function of dry-wet circulation, two admixtures of lime and cement were added to the red clay. The results show that: Under the same load condition, the swell-shrink deformation of the modified red clay decreases gradually with the increase of the number of dry and wet circulation, and finally reach to a stable. Under the effect of the same dry and wet circulation, the swell-shrink deformation of the improved red clay decreases with the increase of vertical load. The conclusions have some reference value for the engineering construction of similar ground soil.

1. Introduction

Red clay is the product of strong chemical weathering of carbonate and basalt in tropical and subtropical regions. It is a regional special soil, which has the characteristics of high liquid limit, high porosity, medium-low compressibility, shrinkage and cracking, compactness and poor water stability [1]. It is widely distributed in China, mainly in Yunnan-Guizhou plateau, Guangdong and Guangxi provinces, and East Sichuan.

Red clay can form strong aggregates in a natural state [2], and it has good engineering properties. However, red clay has some special engineering properties such as high water content, high plasticity and high porosity, etc.. Additionally, much rain in Southwest China, red clay roadbed strength and stability will decline for a long time under the influence of dry-wet circulation, causing some diseases on the roadbed, such as subgrade settlement, swelling and cracking of foundation and subgrade, road shoulder collapse, slope collapse, collapse sliding and landslide [3-4], etc.. In some engineering, during the period of construction, the construction of red clay achieved the design purpose. However, with the passage of time, the engineering problems will also appear, for example, slope sliding, subgrade pavement cracking, etc.. The most basic reason is that the effect of dry-wet cycle and repeated traffic load for the red clay fillers leads to the deterioration of their mechanical properties, the decrease of strength and the decline of stability, thus causing the destruction of roadbed.

For that reason, this paper will improve the red clay and study the swell-shrink characteristic of red clay under the action of dry-wet circulation, and provide reference data for the construction.

2. Experiment materials and methods

2.1. Experiment materials
The soil samples in the experiment were taken from the natural red clay in a region of Chongqing, and its main physical properties are shown in table 1. The mixed materials are lime powder and ordinary Portland cement, and the specific indicators are shown in table 2.

2.2. Experiment methods
The test methods in this paper are as follows:
- The dry and wet circulation test of improved red clay under load was completed by the electric four-unit direct shearing apparatus.
- The soil samples in the experiment were added with lime and cement admixtures according to the mass ratio. According to the reference of the content of improved soil admixtures in literatures [5-9], it was finally determined that the content of lime was 0%, 8% and 14% respectively, and the content of cement was 0%, 4% and 8% respectively. There were 6 proportions in total, as shown in table 3.

### Table 1. Physical properties indicators of soil.

| Soil natural density (g/cm³) | Specific gravity | Liquid limit (%) | Plastic limit (%) | Plasticity index |
|-----------------------------|------------------|------------------|-------------------|-----------------|
| 1.99                        | 2.69             | 63.3             | 36.8              | 27              |

### Table 2. Physical properties indicators of admixture.

|          | lime | cement |
|----------|------|--------|
| moisture content (%) | 7.4  | 1.4    |
| Dry density (g/cm³)   | 0.55 | 1.04   |

### Table 3. The content of admixture in soil.

|          | cement | lime |
|----------|--------|------|
| Content (%) | 0      | 0    |
|            | 4      | 8    |
|            | 8      | 14   |

- The optimum water content of 6 soil samples with different proportions under the condition of compaction was measured, and the samples were prepared by compaction under the optimum water content. The cutting ring (h=20mm, d=61.8mm) cut into the soil sample produced, and made four samples for each proportion.
- Wrap each sample to be sealed in plastic, for 7 days, then take out the samples and put them into the cutting boxes of ZJ electric four-link direct shearing apparatus produced by Nanjing Soil Instrument Factory respectively. Each sample of different proportions was loaded with the loads of 50 kPa and 200 kPa respectively.
- The two samples of each proportion were subjected to four dry-wet circulations under the loads of 50 kPa and 200 kPa. Then recorded the change in height of each sample after four dry-wet circulations. The specific operation was as follows: The consolidation of the sample under load was the first drying state, and the height of the sample was read by the vertical micrometer. Put water into the direct shearing boxes to soak the sample and record the reading of the micrometer after soaking for 24 hours. That was the first dry-wet circulation of the sample. Then the sample was placed in a natural state for 96 hours to dry and dehydrate, that was the second drying state, and then the height of the sample was read by the vertical micrometer. Repeat this way for 4 times dry-wet circulations.

3. Experiment results and analysis

3.1. The experiment results
Under different loads, the height of the samples of the improved red clay with different admixtures changed with the number of dry and wet cycles, as shown in figure 1.
From figure 1, it can be concluded that under the condition of various levels of load, the height of various improved soil samples of saturated water is gradually reduced with the increase of cycle times. The change of height of various improved soil samples in the drying state is just the opposite, and their height is increasing with the increase of cycle times. In the previous two dry and wet cycles, the range of variation of wet expansion height and dry shrinkage height is relatively large, and then decreases gradually. It turns out that the swelling and shrinkage deformation of the improved red clay is not completely reversible during the dry and wet circulation.

(a) The height change of lime improved soil samples in the dry-wet circulation.  
(b) The height change of cement improved soil samples in the dry-wet circulation.  
(c) The height change of pure soil samples in the dry-wet circulation.

Figure 1. The height change of different soil samples in the dry-wet circulation: (a) lime improved soil samples; (b) cement improved soil samples; (c) pure soil samples.

3.2. Analysis of the swell-shrink characteristic of the improved soil

In this paper, absolute swell-shrink rate and relative swell-shrink rate are respectively used to describe their expansion-contraction degree and change trend [10], in order to quantitatively analyze the variation regularities of the swell-shrink deformation of the improved soil during the dry and wet circulation under load. Namely

\[
\eta = \frac{h_i - h_0}{h_0} \times 100\% \quad (1)
\]

\[
\delta = \frac{h_i - h_0}{h_{ef}} \times 100\% \quad (3)
\]
\[ \eta_d = \left( \frac{h_d - h_0}{h_0} \right) \times 100\% \quad (2) \quad \delta_d = \left( \frac{h_d - h_{d(i-1)}}{h_{d(i-1)}} \right) \times 100\% \quad (4) \]

Here, \( h_{wi} \) is the height (mm) of the sample after the \( i \) cycle of water saturation; \( h_d \) is the height (mm) of the sample after 96 hours of \( i \) dry cycle; \( h_0 \) is the height (mm) after consolidation of the sample under the vertical press; \( i \) is the number of cycles; absolute expansion rate \( \eta_{wi} \) and absolute shrinkage rate \( \eta_d \) are the swell-shrink degree and variation of sample during the whole cycle; relative expansion rate \( \delta_{wi} \) and relative shrinkage rate \( \delta_d \) are the swell-shrink degree and variation of sample during the whole cycle during \( i \) cycle; \( h_{wi(i-1)} \) is the height (mm) of the sample after saturation of \( i-1 \) dry and wet cycle.

According to the formula (1 ~ 4) and the test results, the absolute swell-shrink rate and relative swell-shrink rate of the samples under different loads and different proportions were calculated, and the correlation curves were drawn.

### 3.2.1. Study on the swell-shrink characteristic of the lime-improved soil.

The laws of swell-shrink deformation of the improved soil with the lime admixture of 8% and 14% during the dry-wet circulation under loading conditions are shown in figure 2.

![Figure 2](image-url)

(a) relation between \( \eta_d \) and \( i \) under load.  (b) relation between \( \eta_{wi} \) and \( i \) under load.

(c) relation between \( \delta_d \) and \( i \) under load.  (d) relation between \( \delta_{wi} \) and \( i \) under load.

Figure 2. The Laws of swell-shrink deformation of the improved soil with lime admixture of 8% and 14% during the dry-wet circulation under loading conditions: (a) relation between \( \eta_d \) and \( i \); (b) relation between \( \eta_{wi} \) and \( i \); (c) relation between \( \delta_d \) and \( i \); (d) relation between \( \delta_{wi} \) and \( i \).
Figure 2(a,b) and figure 2(c,d) indicate respectively that the change rules of the absolute swell-shrink rate and relative swell-shrink rate of the improved soil with the lime admixture of 8% and 14% during the dry-wet circulation under loading conditions with the cycle times increasing.

From the four pictures, we also can learn the relationship between the absolute swell-shrink rate and relative swell-shrink rate and load under the same dry-wet cycle times, and the relative swell-shrink rate reflects the difference of expansion and shrinkage performance of the sample under different cycle times and the loading condition.

Under the action of 50 kPa and 200 kPa, the absolute swell-shrink rate and relative swell-shrink rate of lime improved soil are obviously smaller than that of pure soil, and its absolute swell-shrink rate and relative swell-shrink rate are the smallest when the lime content is 14%.

That is owing to along with the increase of lime dosage, the content of clay in the soil reduces gradually, and the liquid and plastic limit of the soil reduces gradually, then the strength increases, which effectively restrains its swell-shrink and significantly improves the strength and stability of immersion.

From figure 2, under the condition of 50 kPa and 200 kPa loads, with the increase of cycle times, the absolute swell-shrink rate and relative swell-shrink rate of the sample of each ratio decreases gradually, then tends to be stable, and it's not cumulative. This is due to with the increase of the number of cycles, the water absorption capacity and swell-shrink amplitude reduce gradually. The expansion rate of each proportion in the initial dry-wet cycle is also the largest, because after the soil sample is dried and cracked in the initial state, its structure is damaged, the cohesive force between soil particles is weakened, and the maximum expansion is shown after water absorption.

Under the same number of dry-wet circulation function, both the absolute swell-shrink and relative swell-shrink rate of all specimen of the lime improved soil gradually decreases along with the increase of load. The reason is that, with the increase of vertical load leads to the gap between soil particles reduce, thereby reducing the amount of water intake, limiting the expansion of the sample, and it also shows that the swell-shrink amplitude of the red clay under same dry-wet circulation process decreases with the load increasing.

With the increase of load, the absolute swell-shrink rate and relative swell-shrink rate of the pure soil reduce most obviously, and the absolute swell-shrink rate and relative swell-shrink rate of lime improved soil decreases relatively modest. The reason is that, in the dry-wet circulation process, the water stability of pure soil is poor, and pure soil disintegrates easily, and is affected by the load. After the lime admixture being added to red clay, the relative content of clay of the soil reduces and the soil plasticity also reduces, and the soil particle size distribution is improved, and improved soil has a good overall and has a strong coupling force between particles, and has an overall frame, better water stability, and affected by the load is small.

3.2.2. Study on the swell-shrink characteristic of cement-improved soil under dry-wet circulation.
From figure 1, it can be concluded that under the condition of various levels of load, the height of various improved soil samples of saturated water is gradually reduced with the increase of cycle times. The change of height of various improved soil samples in the drying state is just the opposite, and their height is increasing with the increase of cycle times. In the previous two dry and wet cycles, the range of variation of wet expansion height and dry shrinkage height is relatively large, and then decreases gradually. It turns out that the swelling and shrinkage deformation of the improved red clay is not completely reversible during the dry and wet circulation.

The variation patterns of expansion and shrinkage deformation of the improved soil samples with the cement mixture of 4% and 8% is shown in figure 3.
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Figure 3. The Laws of swell-shrink deformation of the improved soil with cement admixture of 4% and 8% during the dry-wet circulation under loading conditions: (a) relation between $\eta_d$ and $i$; (b) relation between $\eta_i$ and $i$; (c) relation between $\delta_d$ and $i$; (d) relation between $\delta_i$ and $i$.

Figure 3(a,b) and figure 3(c,d) respectively express the laws of the absolute and relative expansion-shrinkage rate of samples with different cement contents under the load with the number of cycles.

Under the load, the absolute and relative swell-shrink rate of cement-improved soil than pure soil is obviously low, and when the cement content is 4% its absolute and relative swell-shrink rate is minimum. This is due to add the cement into pure soil, and the relative content of clay of the soil reduces, and the particle size distribution is improved and the structural connection between soil particles is enhanced, and permeability decreases, thus the swell-shrink amplitude of soil decreases in the dry-wet circulation process.

By figure 3(a,b) and figure 3(c,d), the absolute swell-shrink ratio and relative swell-shrink ratio of the sample decrease with the increase of load under the same number of dry-wet circulation. This is because, with the increase of vertical load leads to the gap between the soil particles reduces, consequently, reducing the amount of moisture inhaled, limiting the expansion of the sample, and it also manifests that the swell-shrink amplitude of the red clay under same dry-wet circulation process decreases with the load increasing. With the increase of load, the swell-shrink extent of the pure soil is the most obvious, but the extent of swell-shrink of cement soil is less. This is because the red clay with the cement admixture, the cement distribution forms the core of solid in the soil, and forms the
hydrated cement skeleton in all the gaps, so as to restrain soil particles, thus its swell-shrink degree affected by the load is small in the process of dry-wet circulation.

4. Conclusions
In this paper, the law of expansion-shrinkage deformation and strength change in the dry-wet cycle of the red clay of lime- and cement-improved under the load was studied, and the following understandings were obtained:

- Under the loading conditions, the swelling and shrinkage deformation of red clay is not completely reversible. The swell-shrink rate is the largest in the initial dry and wet circulation. With the increase of dry-wet circulation times, the relative swell-shrink rate and absolute swell-shrink rate of the samples are gradually decreasing. Its decreasing range is gradually decreasing, and finally tends to be stable.
- Under the loading conditions, with the increase of the dry-wet circulation times, the relative swell-shrink rate and absolute swell-shrink rate of the samples with different matching ratios are gradually decreasing. In a certain range, the absolute and relative swell-shrink rate of soil samples decreases with the increase of the amount of additives in soil, which can effectively reduce the damage caused by swell-shrink characteristic.

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