# Effect of Dry-Wet Cycle on Slope Stability of Laterite Subgrade

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**Abstract.** In order to explore influencing factors of stability of laterite subgrade slope under the action of dry and wet cycle, the indoor direct shear tests of compacted laterite under different dry and wet cycles were carried out, and the strength parameters were obtained. The stress correction method was introduced to analyze the influence of the number of dry and wet cycles on the strength of laterite and the influence of stress correction on the analysis results. Based on the results of direct shear tests, Geostudio finite element software was used to simulate the stability and influencing factors of laterite soil subgrade slopes of different heights under different dry and wet cycle times. The results show: (1) The shear strength of laterite decreased with the increasing of the number of dry and wet cycle times, and the shear strength index of laterite after stress correction was added compared with the before correction. (2) With the increasing of the times of dry and wet cycles, the slope stability coefficient gradually decreases as an exponential function. The stability coefficient after correction is increased compared with before correction, and it have great significance to improve the reliability of direct shear test data by using stress correction method in landslide treatment and filling engineering. (3) The stability coefficient of the subgrade slope decreases monotonically with the increase of slope height, and the smaller the slope height of the slope, the better the overall structural stability.

**Keywords:** Compacting Laterite · Dry-Wet Cycle · Direct Shear Test · Stress Correction · Slope Stability

## 1 Introduction

With the continuous improvement of China's traffic network, highway engineering as an important facility to promote the development of local economy, its construction scale is expanding day by day, and the stability of roadbed slope directly affects the smooth passage and safety of highway [1]. Periodic dry-wet alternation will cause the weakening of the strength parameters of the subgrade soil mass, resulting in the decline of the slope anti-sliding ability. When the sliding force of the slope soil mass is greater than its anti-sliding force, the slope will slide and lose stability, thus inducing landslide accidents [2–4]. In recent years, many scholars have conducted a series of studies on the

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influence of dry and wet cycling on the stability of soil slopes through laboratory tests and finite element simulation software. Lian [5] et al. studied the creep characteristics and long-term strength parameters of loess after dry-wet cycle by triaxial creep tests, which the correlation between the failure mechanism of loess landslide and the creep behavior and structure of loess after dry-wet cycle (creep tests) and SEM tests was discussed in detail. Ma Jiangping [6] analyzed the influence of wet and dry cycles on soil mechanical properties of roadbed slope by dry and wet cycle indoor tests and direct shear tests. Wang Deyong [7] studied the stability characteristics of cut slope considering the strength variation of granite residual soil under the condition of dry-wet cycle using numerical software.

In light of the above study, the rainfall evaporation cycle causes the erosion of fine particles of the roadbed, which will reduce the stability of the roadbed slope and affect its long-term service performance. Therefore, it is necessary to study the influence of dry and wet cycling on the stability of laterite roadbed slope. In this paper, the direct shear tests of laterite under different dry and wet cycles are carried out, and the stress correction method is introduced to obtain the change law of laterite shear strength under dry and wet cycles before and after stress correction. Then, the stability of laterite roadbed slope is analyzed by using the direct shear test results before and after correction, and the rule of slope stability safety factor varying with the number of dry-wet cycles is discussed. The research results of this paper have certain theoretical reference significance for landslide control and subgrade filling projects.

## 2 Test Scheme

### 2.1 Test Soil Sample

The test soil was taken from a roadside site of a highway in Nanchang City. According to the indoor soil tests, the basic physical properties of red soil were determined as shown in Table 1.

**Table 1.** Basic physical properties of red soil.

| Natural moisture content(%) | Natural dry density(g·cm$^{-3}$) | Plastic limit(%) | Liquid limit(%) | Plastic limit index Ip | Specific gravity(g·cm$^{-3}$) |
|---|---|---|---|---|---|
| 21 | 1.7 | 21 | 49 | 28 | 2.7 |

### 2.2 Experimental Methods and Equipment

The red soil was crushed, dried and screened, and the ring knife sample with 21% water content and a dry density of 1.7 g/cm$^3$ was prepared by static pressing the sample. The dry and wet cycle times were controlled as 0,1,3,5, and the dry and wet cycle of the sample was realized by combining wetting and drying. Dry and wet cycle method: the prepared ring knife sample was soaked in water for 4 h (this is "wet"); The humidified sample is then dried to initial mass in the oven and then stopped drying (this is "dry"). After completion, seal curing for 24 h to make the moisture inside and outside the sample evenly distributed. The ZJ strain controlled direct shear instrument was used to perform fast shear tests on the samples that completed the controlled dry and wet cycles. The test results are listed in Table 2.

**Table 2.** Shear strength of laterite under different dry-wet cycles.

| Vertical pressure (kPa) | Shear strength (kPa) | | | |
|---|---|---|---|---|
| | 0 times | 1 times | 3 times | 5 times |
| 100 | 120.21 | 63.33 | 36.21 | 32.23 |
| 200 | 151.68 | 102.38 | 57.26 | 43.99 |
| 300 | 183.91 | 132.72 | 76.22 | 62.57 |
| 400 | 213.3 | 151.3 | 87.22 | 78.12 |

## 3 Analysis of Shear Strength Index of Red Soil Sample Under Dry and Wet Cycle

In the process of direct shear test, with the increase of shear displacement, the effective shear area gradually decreases (see Fig. 1), and the distribution of shear stress and normal stress on the shear plane also gradually changes. The whole direct shear test is a dynamic process, so there will be certain errors in the index of soil shear strength obtained by direct shear test [8, 9].

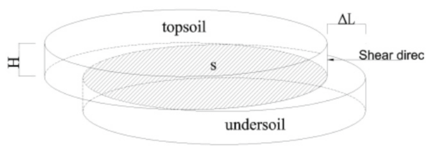


**Fig. 1.** Shear process diagram

According to the single-point area stress correction theory of direct shear test [10], stress correction expressions (1) and (2) were used to correct the shear strength data in Table 2 to obtain more accurate shear strength indicators. The results are reported in Table 3.

$$\tau^* = \alpha\tau$$

$$\alpha = \left[\frac{1}{90}\arccos\left(\frac{x}{2r}\right) - \frac{x}{2r}\sqrt{4-\left(\frac{x}{2r}\right)^2}\right]^{-1} \quad (1)$$

$$\begin{aligned} \sigma^* &= \sigma + \mathrm{CR}\beta \\ \beta &= \frac{\mathrm{h}(1-\alpha)}{\Delta L} n \end{aligned} \tag{2}$$

where, α is the shear stress correction coefficient; x is the staggered distance of the upper and lower shear boxes; r is the radius of the sample in the shear box; β is the correction factor of normal stress; C is the dynamometer coefficient; R is the dynamometer meter reading; h is the height of the sample on the upper part of the shear box (10mm); ΔL is shear displacement.

**Table 3.** Modified shear strength of laterite under different dry and wet cycles.

| Number of D-W cycles | Corrected stress (kPa) | Normal stress (kPa) | | | |
|---|---|---|---|---|---|
| | | 100 | 200 | 300 | 400 |
| 0 | σ* | 72.95 | 165.87 | 258.62 | 352.01 |
| | τ* | 131.02 | 165.33 | 200.46 | 232.50 |
| 1 | σ* | 85.75 | 176.96 | 270.14 | 365.96 |
| | τ* | 69.03 | 111.60 | 144.66 | 164.92 |
| 3 | σ* | 91.85 | 187.12 | 282.85 | 380.38 |
| | τ* | 39.47 | 62.41 | 83.08 | 95.07 |
| 5 | σ* | 92.75 | 190.10 | 285.92 | 382.42 |
| | τ* | 35.13 | 47.95 | 68.20 | 85.15 |

By collating the direct shear test data of the samples corresponding to the vertical stresses at all levels before and after stress correction under different dry and wet cycles, the relationship between the shear strength of red soil samples under different stress conditions before and after correction can be obtained, as presented in Fig. 2.

Table 3 and Fig. 2 show that the normal stress on the corrected effective shear plane is less than before the correction, and gradually increases with the increasing of the times of dry and wet cycles, while the shear stress on the corrected effective shear plane is greater than that before the correction. It can be seen from the changes of the shear strength with the number of dry and wet cycles under different normal stresses that the shear strength under different stress conditions decreases as a whole with the increasing of the number of dry and wet cycles, that is, the shear strength is negatively correlated with the number of dry and wet cycles, which is consistent with the existing test results[11].

As shown in Fig. 3, the dry-wet cycles led to a continuous decrease in the shear strength parameters. After five dry-wet cycles, the cohesion decreased by 74.23 kPa and the internal friction Angle decreased by 8.42°. Among them, the first dry-wet cycle cohesion decays the most, from 89.4 kPa in the initial state to 38.87 kPa, and then the variation decreases. The reason is that under the action of dry and wet circulation, damage cracks occur in the soil, and the cracks destroy the integrity and continuity of

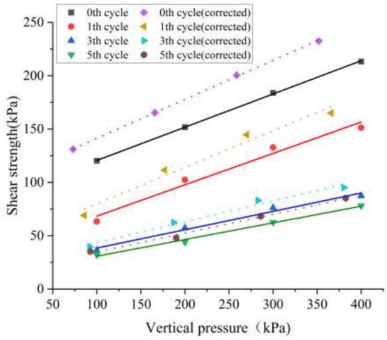


**Fig. 2.** Shear strength of laterite before and after correction.

the red clay, greatly weaken the bond strength of soil particles, and cause the cohesion of the soil to drop sharply.

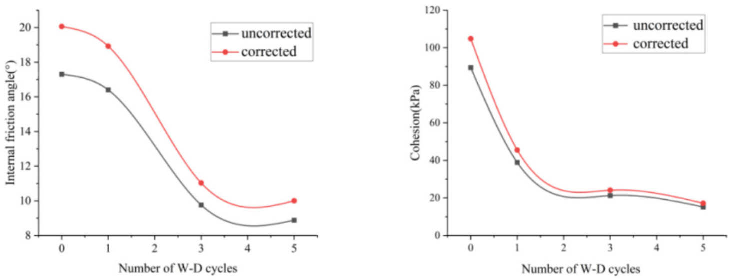


**Fig. 3.** The cohesiveness of red soil changed with the number of dry and wet cycles before and after correction.

In addition, the shear strength index of soil after the single-point area stress correction is improved compared with that before the correction. Taking the dry-wet cycle as an example, the cohesion and friction Angle of soil are increased by 17% and 16% respectively compared with that before the correction, indicating that there is a large error in the data of the shear strength index in the direct shear test without correction. The application of stress correction can improve the accuracy of the soil shear strength index obtained by the direct shear test. The reliability of stability analysis of laterite subgrade slope is improved.

# 4 Influence of Wet and Dry Cycles on the Stability of Laterite Roadbed Slope

## 4.1 Numerical Analysis Model

The dry and wet cycle has a significant effect on the shear strength of laterite, and also affects the stability of laterite roadbed slope. In order to further study the influence rule of laterite roadbed slope stability under the condition of dry and wet cycling, the test results were applied to Geostudio finite element analysis software, which used simplified Bishop method for slope stability analysis, to calculate and analyze the simplified roadbed slope based on an example.

The top width of the roadbed is 12m, and the height of the roadbed is H. According to the requirements of the Code for Design of Roadbed (JTG D30-2015) that the height of the lateritic roadbed slope should not exceed 10m, the slope platform is set as 2 m, the slope rate of the first grade roadbed side is 1:1.5, and the rest is 1: 1.75 (as shown in Fig. 4), respectively simulate the slope stability of the common slope height of 8 m, 9 m, 10 m three horizontal standards.

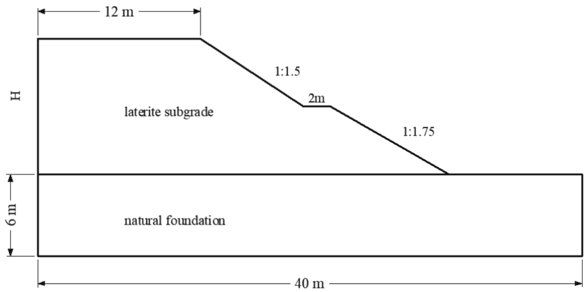


**Fig. 4.** Slope calculation model.

The bottom of the model is fixed and the soil layers on both sides are subject to horizontal constraints. The constitutive model adopts the Moore-Coulomb model. The model is divided into two layers, the upper layer is filled with compacted red soil, the lower layer is natural foundation, and the material of each layer is assumed to be homogeneous.

### 4.2 Calculation Parameters

According to the data obtained from the indoor dry and wet cycle tests and the relevant literature consulted, the mechanical parameters of each layer of the slope are shown as Table 4, where $c_n$ and $\phi_n$ are the cohesion-force and internal friction Angle of the soil during the NTH cycle.

**Table 4.** Mechanical parameters of each layer.

| | Cohesion (kPa) | Internal friction Angle (°) | Unit weight (KN·m$^{-3}$) |
|---|---|---|---|
| Laterite subgrade | $C_n$ | $\phi_n$ | 20 |
| Natural foundation | 200 | 28.4 | 23.5 |

### 4.3 Analysis of Calculation Results

The strength parameters of red soil under the action of dry and wet cycles are substituted into the above compacted red soil roadbed slope model for stability analysis. The most dangerous sliding surface of red soil roadbed slope with a height of 10m under different dry and wet cycles is illustrated in Fig. 5. From the Figure, as the number of dry and wet cycles increases, the position of the most dangerous sliding surface moves to the edge slope surface.

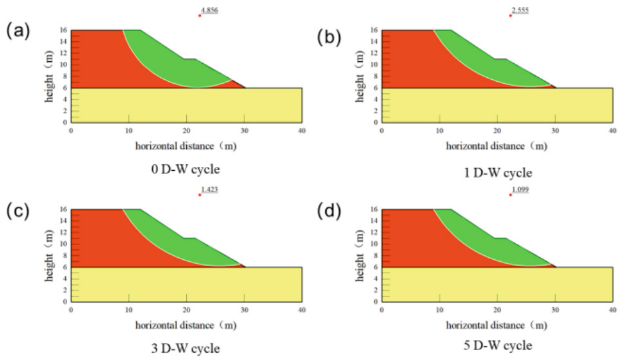


**Fig. 5.** The most dangerous slip plane with a height of 10 m in the dry and wet cycle downhill slope.

From the test data, it is obtained that the stability coefficient of laterite roadbed slope at different slopes varies with the number of dry and wet cycles, as illustrated in Fig. 6. It can be seen from the calculation results in the Figure, before the dry-wet cycle, the slope is in a stable state as a whole, and the stability coefficient is greater than 4, so the slope is relatively safe at this time, while the stability coefficient begins to decline after the dry-wet cycle. Taking the slope height of 8m as an example, the safety factor of the slope becomes 3.010, 1.674 and 1.283, respectively, after the first, third and fifth times of wetting and drying. The slope coefficients decreased by 49.6%, 72% and 78.5% respectively after one, three and five times of wetting and drying. It can be seen that the damage effect of dry and wet cycles on soil stability increases with the increase of cycles.

The combination of rainfall and evaporation is one of the important reasons for slope instability in laterite roadbed. The cyclic action of rainfall and evaporation not only destroys the structural bond between soil particles, but also causes the erosion of laterite structure, which leads to the gradual reduction of the strength of soil in the roadbed slope. During the evaporation process, water escapes, solid particles keep the same size, move and rearrange, which reduces the void space and hardens the soil to produce shrinkage cracks (see Fig. 7). The formation of cracks exposes the deep soil to the atmosphere and expands the channel of water infiltration and evaporation, which is an important prerequisite for slope instability. In the rainfall stage, continuous rainfall forms runoff, which flows into the inclined body along the crack, has the function of scouring, carrying fine particles, softening the soil, and making the crack cut deeper

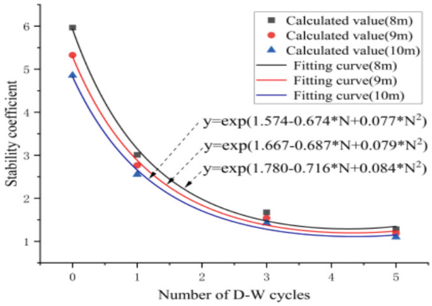


**Fig. 6.** The stability coefficient of laterite subgrade slope changes with the dry-wet cycle.

into the soil. In addition, under the action of continuous rainfall, the soil body weight increases, the sliding force increases, and the shear strength decreases, which ultimately leads to the landslide and instability failure of the roadbed slope[12] Therefore, in order to ensure the stability of the roadbed slope during the operation period, it is necessary to do a good job of slope waterproofing and regular site survey to find cracks and seal them in time to prevent rainwater from pouring into the roadbed slope and reducing the soil strength, thus causing landslides.

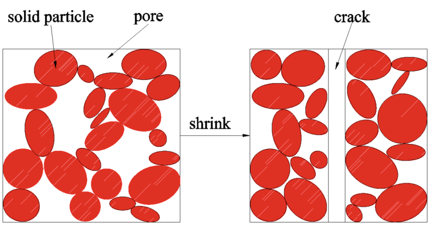


**Fig. 7.** Diagram of soil shrinkage and cracking.

Figure 6. Also shows that with the increase of the number of dry and wet cycles at different slope heights, the stability coefficient of laterite roadbed slope presents a trend of first rapid and then slow decline, and the change law of this coefficient with the dry and wet cycles can be described by exponential function (3), and the fitted correlation coefficient $R^2$ is greater than 0.99.

$$Fs = e^{A+BN+CN^2} \quad (3)$$

where: Fs is the stability coefficient; N is the number of dry and wet cycles; A, B and C are the fitting parameters of the exponential function.

The slope model with slope height of 10m was used to calculate and analyze the change of stability coefficient of red soil subgrade slope under different dry-wet cycles before and after stress correction, and the results are shown in Fig. 8. According to the Fig. 8, the stability coefficient of homogeneous laterite subgrade slope after correction changes with dry-wet cycles similar to that before correction. The stability coefficient decreases rapidly under the first three dry-wet cycles, and then the decreasing speed slows down and gradually tends to be flat or slightly decreases. In addition, the stability coefficients obtained after modification are increased by 17.2%, 16.9%, 13.5% and 12.9% respectively. Therefore, using stress correction method to improve the reliability of direct shear test data is of great significance in landslide control and fill engineering.

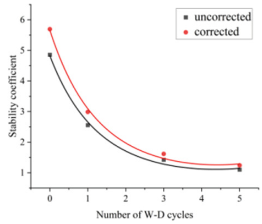


**Fig. 8.** The stability coefficient of laterite subgrade slope changes with the dry-wet cycle before and after correction.

The variation of the stability coefficient of laterite roadbed slope with different slope heights is shown in Fig. 9. From the Fig., the stability coefficient of roadbed slope decreases monotonically with the increase of slope height, that is, it decreases with the increase of slope height. The smaller the slope height of the slope, the better the overall structural stability. With the increase of slope height, the stability coefficient of the roadbed slope decreases from 1.283 to 1.099, and the slope will become unstable and fail. This is mainly because with the increase of slope height, the corresponding slope soil body weight increases, and the sliding force along the slope side gradually increases. In order to maintain the stability of the slope, the anti-sliding force is also required. Therefore, when the side slope height increases, the original balance between sliding force and anti-sliding force is destroyed, which leads to the reduction of the safety factor of slope stability.

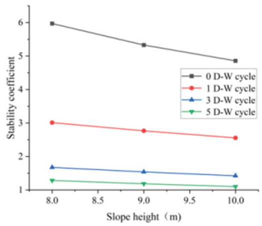


**Fig. 9.** Variation of stability coefficient of laterite subgrade slope with different slope heights.

## 5 Conclusions

In this paper, direct shear tests are carried out on the laterite samples that are made by soil taken from the site in Nanchang city, and the accuracy of the strength parameters obtained by tests is improved by stress correction method. Then, the test results are applied to the numerical analysis model for the stability analysis of laterite roadbed slope, and the influence of dry and wet cycling on strength parameters and slope stability is discussed and analyzed. The following conclusions are obtained:

- Under different stress conditions, the shear strength of laterite decreases as a whole with the increase of the times of dry and wet cycles, and the shear strength index of laterite after stress correction is improved compared with that before correction. The stability coefficient calculated by the stress correction method is increased compared with that before correction. Therefore, using stress correction method to improve the reliability of direct shear test data is of great significance in landslide control and fill engineering.
- With the gradual increasing of the number of dry and wet cycles, the stability coefficient of the slope decreased significantly, and the overall stability of the laterite roadbed slope showed a downward trend, along with the slope tended to become unstable after 5 dry and wet cycles.Therefore, in the remediation and treatment of laterite subgrade slope and other projects, the relevant parameters should adopt the value of attenuation after multiple dry and wet cycles, otherwise the safety and quality of the project cannot be guaranteed enough.
- The stability coefficient of roadbed slope decreases monotonically with the increase of slope height, and the smaller the slope height of the slope, the better the overall structural stability.

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## References

1. Nong, M.: Stability analysis and protection measures of roadbed high slope. J Western Transport. Sci. Technol. **1**(10), 8–11+33 (2021)
2. Du, J., Tong, F.: Effects of dry-wet cycle and rainfall on the stability of loess slope. J. Guangxi Univ. (Nat. Sci. Ed.). **45**(04), 783–791 (2019)
3. Yang, X., Chen, D., Liu, Y.: Fracture evolution and slope stability of granite residual soil under dry-wet cycle. J. Xiamen Univ. (Nat. Sci. Ed.) **61**(04), 591–599 (2022)
4. Liu, G.: Influence of dry and wet cycle mechanism on stability of weak expansion geotechnical slope. J. China Water Transp. **20**(04), 247–248 (2020)
5. Lian, B., Wang, X., Zhan, H., et al.: Creep mechanical and microstructural insights into the failure mechanism of loess landslides induced by dry-wet cycles in the Heifangtai platform. China. J Eng. Geol. **300**, 106589 (2022)
6. Ma, J.: Influence of dry and wet cycling on soil mechanical properties of roadbed slope. J. Highw. Road China (02), 104–105+108 (2023)
7. Wang, D., Zhou, S., Han, Y., et al.: Research on the stability of granite residual soil slope under dry and wet cycle. J. Highw. **66**(01), 1–6 (2021)
8. Kai, Y., Xin, Y., Yongshuang, Z., et al.: Analysis of direct shear test data based on area and stress correction. J. Chin. J. Rock Mech. Eng. **33**(01), 118–124 (2014)
9. Cheng, L., Song, Q., Li, L., et al.: Study on shear strength index of wheat stalk soil under direct shear test considering stress correction. J. Sci. Technol. Eng. **17**(33), 319–327 (2017)

10. Lei, S., Hui, H.: Analysis of shear stress-shear displacement and strength of soil considering shear area correction. J. Mech. Pract. **44**(03), 640–645 (2022)
11. Chen, J.S.: Crack evolution of red clay under dry and wet cycle and its influence on shear strength. J. Hydrogeol. Eng. Geol. **45**(01), 89–95 (2018)
12. Gao, Q.F., Zeng, L., Shi, Z.N.: Effects of desiccation cracks and vegetation on the shallow stability of a red clay cut slope under rainfall infiltration. J. Comput. Geotech. **140**(1), 104436 (2021)

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