Effect of Dry-Wet Cycle on Stability of Granite Residual Soil Slope

Wang De-Yong1,2,3,4, Zeng Qing-Jun1,2,3, Wang Jing1,2,3, Zhou Mi4

1CCCC Fourth Harbor Engineering Institute Co., Ltd., Guangzhou 510230, China;
2Key Laboratory of Environmental Protection & Safety of Communication Foundation Engineering, CCCC, Guangzhou, 510230, China;
3Southern Marine Science and Engineering Guangdong Laboratory, Zhuhai, 519082, China;
4State Key Laboratory of Subtropical Building Science, South China University of Technology, Guangzhou, Guangdong 510640, China

Abstract: The dry-wet cycle has a significant effect on the shear strength of the granite residual soil, which will affect the stability of the slope. A numerical model of the road cutting slope considering the strength change of the granite residual soil under conditions of dry-wet cycle was established. The numerical model was compared with the previous research results to obtain a good agreement, indicating the validity of the model established. Then several influence factors such as the number of cycles, initial cohesion, friction angle, initial slope angle, excavation slope angle and other factors are considered, and the parameter analysis of the stability development of the road cutting slope with the strength changes of the granite residual soil under dry and wet cycling conditions is considered. The research results show that the dry-wet cycle has a great impact on the stability of the road cutting slope of granite residual soil, which reduces the slope stability by about 10-30%. The conclusions of this paper provide a certain theoretical guidance for the design and application of the roadside slope engineering of granite residual soil.

1. Introduction
There is a large area of granite residual soil in South China. The stability assessment of granite residual soil slope is often involved in road cutting projects. In the destruction of road cutting slopes, most of the road cutting slopes collapsed after heavy rain, which indicates that heavy rainfall is the main cause of slope damage; however, some road cuttings did not fail during a heavy rainfall, but the intensity of Collapse occurs when the rainfall is much weaker than the heavy rain, which indicates that the slope soil’s anti-sliding ability has been weakened under the repeated action of wet-dry.

Many scholars have carried out systematic research on the soil properties of the residual soil of the slope in the dry and wet cycle state through model tests, and have obtained a common understanding: the dry and wet cycle makes the cohesion of the soil have a greater degree of attenuation, and the friction The angular influence is not obvious [1-7]. Many scholars have revealed the effects of rainfall intensity and rainfall on slope stability through numerical simulations and model tests. The main common conclusion is that slope stability gradually decreases with the increase of rainfall and rainfall intensity. Some Chinese and foreign scholars have considered the influence of void pressure, matrix suction, and water level on the slope through a large number of experimental studies, theoretical
analysis, and numerical simulations, and proposed the influence of these influencing factors on the slope [8-11].

The above research often considers natural slopes. For newly constructed road cutting projects, the slopes are often under the combined effect of unloading and dry and wet cycles. The corresponding slope failure mechanism has certain uncertainty, which gives engineers a certain degree of uncertainty. Created a huge challenge.

In this paper, the finite element numerical simulation method is used to analyze the parameters of the road cutting slope expansion system of the granite residual soil under the dry and wet cycling conditions. The cycle number, initial cohesion, friction angle, initial slope angle, excavation slope angle, etc. are considered. Influence of factors.

![Fig.1 Schematic diagram of simulated model](image)

2. **Finite element numerical model**

2.1. **Geometric parameters and models**

The schematic diagram of the slope excavation project is shown in Fig.1. The initial slope angle $\beta_1$, the cutted slope angle $\beta_2$, the slope height is $H$, and the original width of the slope is $W_{ini}$, the road width formed by cutting is $W_{cut}$.

The calculation model uses a two-dimensional plane strain model. In the numerical model, the soil depth and the left side of the slope foot are 1$W_{ini}$ to eliminate the boundary effect. The bottom and left and right sides of the model use hinge constraints and rolling constraints, respectively. All analyses use 15-node high-precision triangular elements [12].

2.2. ** Constitutive relations and material properties**

The soil body is modeled as elastic-plastic soil material in accordance with the Mohr Coulomb's constitutive model. The parameters to be determined are Young's modulus $(E)$ and Poisson's ratio $(\nu)$. These two elastic parameters define the assumed elastic response below the failure envelope, while the friction angle $(\phi)$ and the dilatancy angle $(\Psi)$ describe the plastic response at failure. The plastic parameter used in the model is the shear strength $c$ of the residual soil, which defines the size of the yield surface, and the permeability coefficient of the soil is $k$. The elastic parameters $(E, \nu)$ of the residual soil are considered to be independent of the stress and use constant values throughout the process. The calculation parameters in this paper are shown in Table 1.
### Table 1 Table of calculation parameters

| parameters group | $H$ | $\beta_1$ | $\beta_2$ | $W_{ini}$ | $W_{cut}$ | $C_{ini}$ | $\varphi$ | water level | Influencing factor |
|------------------|-----|-----------|-----------|-----------|-----------|-----------|-----------|-------------|-------------------|
|                  | m   | °         | °         | m         | m         | kPa       | °         | °           |                   |
| 1                | -   | 20        | -         | -         | -         | 12.38     | 20        | -           | model validation  |
| 2                | 50  | 20        | 35        | 137.4     | 15        | 38.5      | 30        | 10          | cycle times       |
| 3                | 50  | 20        | 30,35,40  | 137.4     | 15        | 38.5      | 30        | 10          | cut angle         |
| 4                | 50  | 15, 20    | 35        | 103.03,   | 137.4     | 15        | 38.5      | 30          | initial slope angle |
| 5                | 50  | 20        | 35        | 137.4     | 10, 15    | 38.5      | 25,27,30  | 10          | cutting width     |
| 6                | 50  | 20        | 35        | 137.4     | 15        | 38.5      | 30        | 10          | friction angle    |
| 7                | 40,50,70 | 20        | 35        | 137.4     | 15        | 38.5      | 30        | 10          | slope height      |
| 8                | 50  | 20        | 35        | 137.4     | 15        | 38.5      | 30        | 10          | water level       |
| 9                | 50  | 20        | 35        | 137.4     | 15        | 30,35,40  | 30        | 10          | Initial soil strength |

## 3. Results and discussion

### 3.1. Validation model

In order to verify the applicability of the numerical model calculation results, the numerical model calculation results were compared with standard slope calculation examples. The standard example information is as follows: a soil slope with a slope angle of 45 degrees, a height of 10 m, a cohesive force of 12.38 kPa, a friction angle of 20 degrees, a water level at the bottom of the slope, and a natural gravity of the soil of 20 kN/m³ [13]. The comparison of soil flow and its safety factor is shown in Figure 2. According to the strength reduction method, the safety factor of the model slope in this paper is 1.0069, and the result in Roth et al. Is 1.0060, as shown in the figure. The results differ by 0.1%, so the safety factor calculation results are consistent. Through the comparison of the above instability patterns and safety factors, it can be concluded that the numerical simulation analysis of the finite element model in this paper is reliable. Comparative verification has confirmed the reliability of the numerical model in this paper.

![slip surface (Roth et al., 1999)](image1)

**Fig. 2 Validation model**

### 3.2. Parameter analysis

#### 3.2.1. Impact of the number of wet and dry cycles
Fig. 3 reveals the change of the safety factor with the number of dry and wet cycles. It can be seen from the figure that as the number of dry-wet cycles \( N \) increases from 1 to 5, the safety factor of the slope before and after cutting will decrease. The safety factor before cutting the slope changed greatly during the first two wet and dry cycles, and then fell quickly, but then stabilized. However, the safety factor after cutting slope continued to decrease. Since the dry-wet cycle mainly affects the soil on the surface of the slope, the cohesion of the soil decreases with the increase of the number of dry-wet cycles, and the safety factor of the slope also decreases \[^{14}\]. After several dry and wet cycles, it has a weak effect on soil parameters. From the calculation results, the displacement cloud diagrams after excavation under the conditions of \( N = 1 \) and \( N = 5 \) are extracted. It can be seen that when \( N = 1 \), the sliding surface of the slope failure is overall sliding, so the safety factor is large; when \( N = 5 \) At the same time, local sliding occurs at the excavation surface, and the top of the slope will also be displaced, and the safety factor will decrease.

3.2.2. Effect of initial slope angle
Figure 4 shows the changes in the safety factor of slopes with initial slope angles of 15º, 20º, and 25º after one, three, and five wet and dry cycles, respectively. It can be seen from the figure that the slope safety factor before and after the slope both decreases with the increase of the original slope angle. When \( N = 1 \), the initial slope angle is increased from 15º to 30º, and the safety factor after slope reduction is reduced from 2.13 to 1.49, which is a 30% decrease. It can be seen that the initial slope angle has a great influence on the stability of the slope. At a certain slope angle, the safety factor decreases after cutting. Compared with the safety factor before cutting, the safety factor after cycle 5 is much lower than that of cycle 1, that is, after repeated drying when the parameters of the wet cycling soil are relatively weak, the effect of slope cutting on slope stability is greater.

3.2.3. Effect of cut angle
Figure 5 shows the change of the safety factor after slope cutting under different dry and wet cycles with the slope cutting angles of 30º, 35º, and 40º.
3.2.4. Effect of cutting width

Figure 6 shows the influence of the width of the cuttings on the safety factor after cutting when the initial slope angle is 20° and the cutting angle is 35°. The cutting widths are 10m, 15m, and 20m, respectively. It can be seen from the figure that the safety factor gradually decreases with the increase of the width of the cuttings. When the width of the cut is increased, the excavated soil is increased. Although the slope angle remains the same, the height of the local slope at the foot of the slope increases after the cut, and the length of the entire slope decreases, and the sliding surface becomes shorter. Shallower, resulting in both local and overall stability of the slope. From the calculation results, the displacement cloud diagrams for the case where the width of the road cutting is 10m and 25m when N = 5 are extracted. It can be seen that when the width of the road cutting is 10m, the sliding surface of the slope failure is overall sliding, so the safety factor is large. When the width is 25 meters, local slip occurs at the new slope formed by the excavation face, and the safety factor decreases. The decline can reach 20%.

3.2.5. Influence of original slope height

In order to explore the influence of the original slope height on the safety factor, the safety factors for the slope heights of 40m, 50m, and 70m, the original slope angle of 20°, and the cut angle of 35° were calculated, as shown in Figure 7. It can be seen from the figure that with the increase of the slope height, the safety factor before and after the slope is gradually reduced, and the overall decrease trend is relatively gentle, and the safety factor is higher than N when N = 1. The safety factors of N = 3 and N = 5 decrease with increasing slope height. This shows that under other conditions, the greater the slope height, the smaller the safety factor, and the greater the impact of the slope height when the soil strength is high.
3.2.6. Influence of friction angle
In order to investigate the influence of the friction angle on the safety factor, the friction angles in the soil material parameters were calculated at 25º, 27º, and 30º, and the calculation results are shown in Figure 8. It can be seen from the figure that as the friction angle increases, the safety factor before and after the slope increases almost linearly. Increasing the friction angle can significantly increase the safety factor of the slope, indicating that the friction angle has a great influence.

3.2.7. Impact of water level
Under rainfall conditions, rainwater infiltrates from the outside, which raises the water level line inside the slope. In order to study the influence of the water level line on the safety factor of the road cutting slope, under the condition that the other conditions are unchanged, different water level line angles of 5º, 7º, 9º, 10º, and 11º are set in the model. The safety factor before and after cutting is shown in Figure 9. It can be seen from the figure that, as the angle of the water level increases, the safety factor before and after the cut decreases sharply. In the process of rising water level, the generated pore water pressure will reduce the slope stability and weaken the strength parameters of the sliding surface. The angle of the water level line is increased, that is, the hydraulic gradient is increased, the stronger the seepage effect occurs inside the slope, and the stability of the slope is decreased sharply.
3.2.8. Influence of initial strength of soil

During the dry-wet cycle, the initial strength of the soil has a great influence on the strength of the soil after the dry-wet cycle, which affects the safety and stability of the slope after the dry-wet cycle.

![Graph showing effect of initial strength of soil on safety factor](image)

Figure 10 shows the safety coefficients of the slope before (Figure 10a) and after cutting (Figure 10b) after the slope has been cut at different initial soil strengths of 30°, 35°, 38.5°, and 40° after different dry-wet cycles. It can be seen from the figure that with the increase of the number of cycles in the same soil, the safety factor of the slope decreases rapidly at the beginning, and then gradually stabilizes. And comparing the two graphs before and after cutting, it can be seen that with the increase of the number of cycles, the safety factor before cutting is more stable than that after cutting. In different soils, with the increase of the initial strength of the soil, the safety factor gradually increased before and after cutting. It shows that increasing the initial strength of the soil is an important controlling factor for the stability of the road slope.

4. Conclusion

This paper uses the finite element method to establish the dry-wet cycle under different parameters to study the stability of granite residual soil cutting slope, and draws the following main conclusions:

1. With the increase of the number of wet and dry cycles, the safety factor of the road cutting slope begins to decrease rapidly, and then stabilizes. When the soil parameters are weak after repeated dry-wet cycles, slope cutting has a greater impact on the stability of the slope, which reduces the slope stability by about 10-30%.

2. The larger the initial slope angle of the road cutting slope, the more unstable the slope is; the effect of the cutting angle on the stability of the road cutting slope is more complicated. Different rules appear under the superposition of the triple action of the soil's own strength.

3. With the increase of the width of the road, the safety factor gradually decreases, with a maximum decrease of about 20%.

4. With the increase of the slope height, the safety factor before and after the slope is gradually reduced, but after several dry and wet cycles, the effect on the stability of the slope is small.

5. With the increase of the water level angle, the safety factor before and after the slope is sharply decreased.
Acknowledgements
CCCC 2018 Applied Basic Research Project "Study on Stability of Residual Soil Slope and New Anchorage Protection Technology under the Seepage, Pipe Flow" (2018-ZJKJ-PTJS01) and CCCC4 Fundamental research project “Research on key technologies for the filling of shale and siltstone backfill roadbeds in highways of South China" (2018-A-06-I-08), and Pearl River Rising Star Project "Research and Development of New Environmentally Friendly Retractable Drainage Body and Engineering Performance Index Testing Technology Research" (201906010068).

References
[1] Yang H P, Wang X Z, Xiao J. Influence of wetting-drying cycles on strength characteristics of nanning, Chinese Journal of Geotechnical Engineering, 2014, 36 (5) : 949-95
[2] YANG H P, XIAO D. The influence of alternate dry-wet effect on the strength characteristic of expansive soils. Journal of Changsha University of Science and Technology (Natural Science), 2005(02):3-7+14.
[3] Jian W B, Hu H R, Luo Y H, et al. Experimental study on deterioration of granitic residual soil strength in wetting drying cycles [J]. Journal of Engineering Geology, 2017, 25(03):592-597.
[4] Cheng J M, Wang Y M, Miao S C, et al. Property study of solidified loess under wet-dry cycles [J]. Journal of Engineering Geology, 22(2): 226−232
[5] Huang Z, Fu H L, Wei B X, et al. Low Stress Shear Strength Characteristics of Expansive Soil Under Constant Amplitude Dry Wet Cycle Conditions, Journal of Sichuan University, 2016, 48(01): 70-77.
[6] Cui Kerui, Li Guofeng. Effect of dry-wet cycle on strength characteristics of expansive soil in Maanshan Road, Hefei. Chinese Journal of Geology, 2013, 37 (04): 625-638.
[7] Zhang Fangzhi, Chen Xiaoping. Research on the effect of repeated dry and wet cycles on the mechanical properties of unsaturated soils. Chinese Journal of Geotechnical Engineering, 2010, 32 (01): 41-46.
[8] Duncan J M, Wright S G, Brandon T L. Soil strength and slope stability. John Wiley & Sons, 2014.
[9] Cho SE, Lee SR. Evaluation of surficial stability for homogeneous slopes considering rainfall characteristics. Journal of geotechnical and Geoenvironmental engineering, 2002, 128(9): 756-763
[10] Zhao Jingang. Study on stability and mechanism of fill slope of expansive soil under rainfall-evaporation cycle. Northwest University, 2013.
[11] Travis QB, Houston SL, Marinho FAM, Unsaturated infinite slope stability considering surface Flux conditions. Journal of geotechnical and geo-environmental engineering, 2010, 136(7):963-974
[12] Roth W H, Dawson E M, Drescher A. Slope stability analysis by strength reduction. Géotechnique, 1999, 49(6): 835-840.
[13] Dawson EM, Roth WH, Drescher A. Slope stability analysis by strength reduction. Géotechnique, 1999, 49: 835-840.
[14] Zhou Jian. Experimental study on characteristics of reinforced expansive soil and slope wet-dry cycle. Nanjing University of Technology, 2012.