Study on stability calculation method of red clay slope based on composite sliding surface

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Abstract: The stability of the red clay slope is poor, and the long-term exposure to the atmospheric environment is prone to instability and damage due to the dry-wet cycle. The simplified Bishop method to calculating the stability of the red clay slope is inconsistent with the actual situation. The failure characteristics and mechanism of the red clay slope are analyzed, and the existing problems of the red clay slope stability calculation are pointed out. The red clay slopes in Guizhou Province are dominated by shallow failures. Local collapse and collapse failures are very common. Overall destruction is relatively rare. A stability analysis method for red clay slopes based on composite sliding surfaces (fold-line - circular arc) is proposed. In the stability analysis of clay slope, the soil body is divided into three layers of upper, middle and lower fissure areas, and different strength indexes are selected in different areas. It is recommended to consider the effect of hydrostatic pressure generated by the water column in the fracture on the stability of the red clay slope.

1. Introduction
Residual red clay is widely distributed in Guizhou Province, and the covering thickness is generally 5-7m, and the maximum thickness can reach more than 20m. It is inevitable that a large number of red clay slopes will be encountered in the construction of highways and railways. Engineering practice has proved that the stability of red clay slopes is poor, and some slopes with slope ratios of 1:1 to 1:1.5 still show varying degrees of instability and failure. Engineering and technical personnel cannot yet give a good explanation for this. The simplified Bishop method is the most widely used circular sliding limit equilibrium method in engineering. It assumes that the sliding surface is a cylindrical surface (the section is assumed to be an arc) and the direction of the interbar force is horizontal. The soil above the sliding surface is divided into a number of vertical soil strips, the reaction force at the bottom of the strip can be obtained through the balance of the vertical force, and the stability coefficient can be solved by the moment balance at the same point. The main problems of using this method to calculate the stability of red clay slope:

1.1. The sliding surface of the red clay slope failure is not a circular arc surface: related research shows that the failure form of the red clay slope is not a typical circular arc sliding⁴[6][11]. The traditional stability analysis method assumes that The actual failure of the red clay slope is not consistent. It is debatable to calculate the red clay slope using the traditional homogeneous soil slope stability calculation method.
1.2. *Unreasonable parameter selection*: The method of obtaining strength parameters during stability analysis is derived from the initial strength of the soil obtained from indoor or in-situ tests. In fact, the strength parameters of the soil decrease after different dry-wet cycles and the dry-wet cycle will only affect the strength of the soil at a certain depth of the slope. Therefore, it is not reasonable to use the initial strength index for stability analysis of slope soil.

1.3. *The impact on rainfall infiltration is not fully considered*: The presence of fissure water not only increases the bulk density of the soil, but also reduces the anti-sliding force on the sliding surface. The fissure water column exerts a horizontal thrust on the slope soil. When the fissure is full of water, due to the low permeability coefficient of the red clay, the water column in the fissure will generate hydrostatic pressure and exert a horizontal thrust on the sliding body. If this effect is not considered in the stability calculation, the calculated stability factor will be dangerous.

In summary, the current understanding of the characteristics of instability and failure of red clay slopes is not deep enough, especially the lack of scientific understanding of shallow instability diseases; secondly, the lack of targeted stability analysis methods makes the slope stable The results of sexual calculations are not very reliable. Although many slopes used simplified Bishop method to verify the stability of the slopes, collapse failure still occurred. Therefore, it is very necessary to propose a slope stability analysis method with calculation conditions close to the true state of the red clay slope. Therefore, it is of academic significance and engineering application value to study the stability analysis method of red clay slope.

2. *Failure characteristics and mechanism analysis of red clay slope*

Wu et al. [1] showed that the survey results of Guizhou red clay slopes: The typical failure types of red clay slopes can be divided into three categories: The first category is surface damage represented by gullies and weathering spalling. This type of damage only affects the surface of the slope, but this type of damage will affect stability after long-term stacking. The second type is the shallow instability failure represented by collapse and collapse. This kind of failure is due to the gradual attenuation of the strength of the shallow soil mass under the action of dry wet cycle, and the slope stability gradually decreases. The failure forms are local collapse and collapse with steep top and gentle bottom. The third category is the overall instability failure, and the probability of overall instability of the red clay slope is relatively small. Dry wet cycle is an important factor in the failure of red clay slope. The dry-wet cycle causes the red clay to water loss cracking and water absorb swelling. When the slope is artificially excavated, the natural red clay is exposed to the atmosphere. On a clear day, the water content of the soil surface near the free surface will continue to decrease and decrease, the water film around the soil particles becomes thinner, the soil body loses water and shrinks, and the tensile stress between soil particles increases, forming more developed network cracks, and the initial crack will appear. The formation of the initial crack will provide a channel condition for the transfer of water from a deeper range. This repeated process will make the cracks in the free surface soil further develop. Increased broadening and deepening, reduced shear strength, resulting in the collapse of the soil towards the free surface. Once the long-term precipitation causes the soil to be saturated with water, the static pressure of the crack and the internal pore water pressure increase sharply, and the red clay slope. At this time, the red clay slope will have a wider range of unstable collapse slide. It can be seen that the relaxation-saturated water-collapse effect experienced inside the red clay is the internal cause of slope deformation and cracking, while rainfall and evaporation are the external factors that promote the rapid development of this process [7].

3. *Stability analysis method of red clay embankment slope based on composite sliding surface*

The failure of the red clay slope of the expressway in Guizhou is mainly caused by the collapse of shallow layers, which is represented by collapse and landslide. Relevant research and engineering practice have proved that the actual failure surface of the red clay slope shows a steep upward slope and a slow downward slope, and the unstable sliding surface is a fold-line type, see figure 6 In order to
verify the sliding surface form, FLAC3D software was used for numerical simulation. The results are shown in figure 1-2.

![Figure 1. Failure of Red Clay Slope](image)

![Figure 2. Red clay slope composite sliding failure surface](image)

![Figure 3. Analysis of the overall force of the slope soil](image)

It can be seen that the sliding surface of the red clay embankment slope is composite (fold-line + circular arc), and the sliding surface is parallel to the junction of the strong fissure development area a and the weak fissure development area b. The calculation mode and the force balance state of the sliding body are shown in figure 3-5.
The soil body of the fold-line is calculated by the static balance of the rigid body, and the arc sliding surface is calculated by the strip method. The interaction force between the soil strips only transmits the force $F_N$ in the upper and lower parts of the soil body.

For the first part of the soil, use the rectangular coordinate system in the horizontal and vertical directions, and establish the equation according to the static balance of the sliding body:

\[
\sum F_x = 0, P + N_i \sin \theta - T_i \cos \theta - F_N = 0 \tag{1}
\]

\[
\sum F_y = 0, T_i \sin \theta + N_i \cos \theta - W_i = 0 \tag{2}
\]

\[
N_i = W_i \cos \theta \tag{3}
\]

According to the theory of shear strength, when the stability factor is $K$, the tangential shear resistance and normal reaction force have the following relationship:

\[
T_i = \frac{c_i + N_i \tan \phi}{K} \tag{4}
\]

$P$ is the horizontal thrust generated by the hydrostatic pressure on the crest of the slope to the sliding body:

\[
P = \frac{1}{2} \rho gh^2 \tag{5}
\]

The simultaneous formulas (3), (4), (5), (6) and (7) can be obtained:
The moment balance of the whole sliding body to the center O of the circle is:

Anti-slip torque:

\[ M_T = \sum T_i R = \sum (c_i l_i + W_i \cos \alpha_i \tan \varphi_i) R \]

(9)

Sliding torque:

\[ M_S = \sum W_i R \sin \alpha_i + F_N R_N \]

(10)

Then there is the formula for calculating the stability coefficient of the slope under the composite sliding surface:

\[ K = \frac{M_T}{M_S} = \frac{\sum (c_i l_i + W_i \cos \alpha_i \tan \varphi_i) R}{\sum W_i R \sin \alpha_i + F_N R_N} \]

(11)

where: \( N_i \) is the normal reaction force of the bottom surface of the first part of the soil; \( W_i \) is the first part of soil strength; \( T_i \) is the tangential component of the soil in Part 1; \( l_i \) is the length of the sliding surface of the first part of the soil; \( F_N \) is the internal force at the junction of the first and second parts of the soil; \( \theta \) is slope slope angle; \( N_i \) is the normal reaction force of the bottom surface of Article i; \( W_i \) is Article i soil weight; \( T_i \) is the tangential component of soil in section i; \( l_i \) is the length of section i soil sliding surface; \( c_i \) and \( l_i \) are long-term strength indexes of soil; \( \rho \) is the density of water; \( h \) is the crack depth; \( K \) is the slope stability coefficient.

4. Parameter selection

4.1. In the evaluation of the stability by the predecessors, the initial strength of the slope is often used as the strength index of the slope, or the strength parameters of the soil after different numbers of dry and wet cycles are taken, and they are regarded as the overall strength parameters of the slope. In practice, the dry-wet cycle only affects the strength of the soil at a certain depth on the slope. Therefore, it is not reasonable to use the same overall strength index for slope stability analysis. The red clay slope under dry-wet cycle should be divided into three layers of upper, middle and lower areas. Different strength indexes are selected in different areas to make the slope stability calculation more feasible and reasonable.

4.2. The red clay's water shrinkage in the dry season and water absorption and expansion in the rainy season are prone to cracking. The presence of fissure water increases the bulk density of the slope soil and increases the sliding force of the slope; At the same time, with the increase of water content, the shear strength index of soil decreases, and then the anti sliding force of the slope is reduced; in addition, the fissure water will produce horizontal thrust on the sliding body, and the coupling of these
three actions will reduce the stability of the slope. Therefore, the effect of fissure water should be considered in the stability analysis of red clay slope.

5. Conclusions

5.1. The red clay slopes in Guizhou Province are dominated by shallow failures, local collapse and collapse failures are very common, and the overall failure is relatively rare. A stability analysis method for red clay slopes based on composite sliding surfaces (fold-line - circular arc) is proposed.

5.2. The dry-wet cycle has a significant effect on the stability of shallow layers of red clay slopes. The red clay slope under dry-wet cycle should be divided into three layers of upper, middle and lower areas. Different strength indexes are selected in different areas to make the slope stability calculation more feasible and reasonable.

5.3. The existence of fissure water not only increases the bulk density of the soil, but also reduces the anti-sliding force on the sliding surface, and the horizontal thrust effect of the fissure water column on the slope soil. It is recommended to consider the hydrostatic pressure generated by the fissure water column on the slope stability in the stability analysis.

5.4. This paper also carried out engineering calculation examples to verify that the method proposed in this paper is feasible.

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