Stability Analysis of Colluvial Slope under Different Rainfall Conditions

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Abstract. Taking the accumulation slope of a reservoir abutment in western Sichuan as an example, this paper studies the influence of rainfall duration and rainfall intensity on slope stability with the help of GEO-SLOPE (SLOPE/W module) software according to saturated-unsaturated seepage theory and rainfall infiltration theory. The results show that when the rainfall intensity is constant, the slope stability decreases with the increase of rainfall duration, which presents a slightly slow-fast-slow pattern, and that the slope stability gradually decreases with the increase of rainfall intensity under the same rainfall duration.

1. Introduction

A number of studies have been done on the stability of colluvial slope[1~2], but the study of the instability mechanism under different rainfall conditions is rare. Some researchers have made some achievements through experimental analysis, model tests, etc. Tung-Lin Tsai studied the effects of four rain pattern on the slope stability, and found that the rain pattern with the same rainfall and duration but the linear decrease in rain intensity has the greatest impact on the slope stability[3]; then, Ar-ezoo Rahimi found that the rain pattern has a greater impact on the stability of low-permeability soil slope[4]; C B Zhou pointed out that the finite element method for coupling the rainfall pattern, the seepage field and stress fields inside the colluvial slope, it is an important aspect to study the time effect and stability evaluation method of landslide induced by heavy rainfall[5].

Combined with the current research situation, this paper selects the slope of the abutment of a reservoir in western Sichuan as the research object, based on the actual exploration results and saturated unsaturated seepage theory, simulating the characteristics of seepage field and stability under different rainfall by GEO-SLOPE software (SEEP/W and SLOPE/W analysis module), and analyzing the slope stability evolution trend.

2. Overview of the slope and Calculation model

2.1. Overview of the slope

The colluvial slope is located on the right bank of a reservoir dam site in Sichuan Province. It belongs to the original landscape of the Da LiangShan Mountains, the terrain is high in the northeast and low in the southwest, and the stepness is between 14 and 22 degrees. The stratum are dominated by the Upper Permian Leping Formation (P₂l) silty mudstone and sandstone, and the attitude of stratum is
N40～65°E/NW∠3～7°, in addition to the layer, the rock mass also developed four sets of dominant structural planes, which occurrence are: W~NW295°/N~NE∠70-88°, NW345°~NE15°/SW~NW∠70-85°, NE40~55°/ NW∠70~86°, NE1~20°/SE∠72~85°. the right bank abutment is generally a bedding rock slope.

During the excavation of the right bank toe plate, with the change of the air condition of the leading edge of the slope and the influence of rainfall, the local tension crack and collapse occurred on the right bank toe plate slope. Judging from the signs of deformation, the deformation continues. According to drilling exploration and drilling imaging, the leading edge of the deformed slope is basically at the cut-out part of the accumulation body (elevation 2262m); the trailing edge is roughly 2284.5m, the thickness of the accumulation body is about 21.6 m (Fig. 1).

2.2. Calculation model
According to the actual exploration results of the slope, the slope calculation model is established (figure 2). The model grid consists of 4207 nodes and 4245 elements. The boundary conditions are as follows: setting the slope surface as the rainfall infiltration boundary, and the bottom surface and side of the slope as the permeable boundary; for the slope surface, when the rainfall intensity is less than the soil permeability coefficient, the rainfall will be completely absorbed by the soil, and the constant flow boundary will be adopted. The size is equal to the rainfall intensity; when the rainfall intensity exceeds the surface soil permeability coefficient, the flow boundary will forcibly push the excess rainfall into the soil, and then deal with it according to the fixed head boundary, which is equal to the elevation of the node. In addition, according to the indoor screening, shearing and other tests and analogy related engineering experience, the calculation parameters of each geotechnical layer in the model are shown in Table 1.
Figure 2. Calculation model.

Table 1. The value of the calculation parameters of each soil layer in the model.

| Soil layer         | Unit | \( \gamma / (kN \cdot m^{-2}) \) | \( \gamma'/ (kN \cdot m^{-3}) \) | c/KPa | \( \varphi / (\degree) \) | \( k_s / (cm \cdot s^{-1}) \) | \( w_v / (m^3 / m^3) \) |
|--------------------|------|-----------------------------------|-----------------------------------|-------|--------------------------|----------------------------|--------------------------|
| Silty clay         |      | 18.7                              | 19.2                              | 17    | 15                       | 1.32E-04                   | 0.41                     |
| Block gravel soil  |      | 22                                | 22.25                             | 15    | 21                       | 3.62E-03                   | 0.38                     |
| Bedrock            |      | 25.9                              | 26.4                              | 800   | 45                       | 5.10E-06                   | 0.16                     |

3. Rainfall infiltration simulation analysis

The rainfall infiltration process of the slope is closely related to the rainfall intensity, rainfall duration and total rainfall in the area where it is located. According to local climatic data and relevant engineering experience, combined with the requirements of rainfall grading in the local standard *Weather Terms (DB51/T580-2011)* of Sichuan Province, two simulation schemes were designed in this paper (Table 2). Scheme 1: rainfall duration is the same, rainfall intensity is different; rainfall duration 48 hours, rainfall intensity of 10 mm/d, 25 mm/d, 50 mm/d, 100 mm/d; schemes 2: mainly consider the impact of continuous rainfall on slope stability. Therefore, the rainfall intensity is the same, the rainfall duration is different, and the rainfall intensity is 25 mm/d, for 12 days.

Table 2. The value of the calculation parameters of each soil layer in the model.

|    | Identical rainfall duration | Identical rainfall intensity |
|----|-----------------------------|-----------------------------|
|    | rain duration (h) | rainfall intensity (mm/d) | rainfall intensity (mm/d) | rainfall duration (d) |
| 48 | 10                         | 25                          | 25                         | 12                      |
|    | 25                         | 50                          |                            |                         |
|    | 100                        |                             |                            |                         |

3.1 Analysis of Influence of Different Rainfall Intensity on Slope Stability

According to the setting of scheme 1, the seepage field of the slope is simulated in SEEP/W for the same duration (48 h), and the rainfall intensity is 10 mm/d, 25 mm/d, 50 mm/d and 100 mm/d, respectively. Then the variation characteristics of stability coefficient after 48 hours of rainfall were analyzed by coupling SLOPE/W. The results of the calculation are shown in Table 3. The variation curve of slope stability coefficient under different rainfall intensity is shown in Table 2 at the same
Table 3. Slope stability coefficient with rainfall duration (48h) and different rainfall intensities.

| Rainfall intensity (mm/d) | Stability coefficient | Decrease (%) |
|---------------------------|-----------------------|--------------|
| 0                         | 1.102                 | 0.00         |
| 10                        | 1.093                 | 0.82         |
| 25                        | 1.061                 | 3.72         |
| 50                        | 1.005                 | 8.80         |
| 100                       | 0.924                 | 16.15        |

In summary, the influence of rainfall on the stability of the excavation slope is large. With the increase of rainfall intensity, the stability will change from a basic stable state to an unstable state, and even instability failure will occur.

3.2. Analysis of the Influence of Rainfall Duration on Slope Stability

According to the calculation scheme set by scheme 2, when the rainfall intensity is 25mm/d, the rainfall will continue for 12 days, with 1 day as one time step (including the initial step), a total of 13 time steps. The slope stability is calculated when the rainfall lasts for 3 days, 6 days, 9 days and 12 days. The calculation results are shown in figure 4.

It can be seen from Fig. 4 that with the increase of rainfall time, the slope stability is gradually reduced, but the reduction range is different, in the first few days of rainfall, the stability decline rate is slightly slower, and then gradually accelerates, finally, it gradually slowed down. This is due to the fact that under the natural state of the slope, the pore water pressure is small, the matrix suction is large, the soil permeability coefficient is relatively small, the rainfall part forms the surface runoff, and the slope stability declines slightly; When the rainwater infiltrates into the soil, the water content of the soil increases, and the permeability coefficient also increases, as a result, the amount of infiltration increases, the depth of influence continues to deepen, and the stability decreases rapidly; When the permeability coefficient increases to a certain extent, the soil infiltration and permeation amount reach equilibrium, the soil water content rises slowly, and the stability coefficient decreases.

4. Conclusion

Taking the colluvial slope of a reservoir abutment as an example, based on the theory of unsaturated soil mechanics, the finite element method is used to analyze the stability of the slope of the deposit...
under rainfall infiltration, the analysis results provide a reference for the prediction and treatment of the stability of this kind of accumulation body. Different rainfall intensity has a great influence on the stability of the colluvial slope of the deposit. With the increase of rainfall intensity, the stability will change from the basic stable state to the under steady state, and even the instability will occur. With the increase of rainfall time, the slope stability is gradually reduced, but the magnitude of the decrease is different. In the first few days of rainfall, the stability declines slightly slower, then gradually accelerates, and finally slows down.

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