Research on rainfall infiltration law and slope stability analysis

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Abstract. Rainfall is an important factor leading to slope landslide. Aiming at the problem of slope stability under rainfall, this paper uses the unsaturated seepage theory to dynamically describe the rainfall infiltration effect, and analyzes the distribution characteristics of pore water pressure of slope soil and the change law of slope water level under the action of rainfall, at the same time, deeply analyzes the law of slope stability changes based on strength reduction algorithm. The results show that: with the passage of rainfall time and the increase of rainfall intensity, the slope infiltration depth gradually increased. At the same time, rainfall increased the groundwater level in the slope, and leaded to increased pore water pressure in the slope soil, and the transient saturation zone gradually formed and expanded, and finally leaded to a significant reduction in slope stability coefficient.

1. Introduction

Rainfall is an important factor leading to landslides. The occurrence of a large number of landslides in engineering practice is closely related to rainfall. Therefore, the problem of slope stability under the action of rainfall has become an important issue to be solved urgently in the field of geotechnical engineering [1-2]. The problem of slope stability under the action of rainfall is a complicated process that dynamically evolves with factors such as the duration and spatial changes of rainfall. The rainfall infiltration process is related to many factors such as rainfall intensity, duration, and soil permeability. When the soil permeability of the slope is greater than the rainfall intensity, the actual rainfall infiltration depends on the degree of precipitation. The increase in the water content of the slope has a positive correlation with the degree of precipitation, and eventually gradually stabilizes [3-5]. On the other hand, when the rainfall intensity is greater than the permeability of the slope soil slope, the actual infiltration depends on the infiltration performance of the slope soil itself. At the beginning of rainfall, the slope soil will first form a transient saturation zone near the shoulder of the slope. With the increase of precipitation time and precipitation intensity, the transient saturation zone gradually expanded to the inside and the lower part of the slope, and gradually showed a saturated shell on the entire slope [6]. As the precipitation increases, it expands to the inside of the slope, the affected area gradually increases, and the saturated crust gradually thickens [7]. With the increase of precipitation infiltration, the water content of the soil quality is increased, and the pore water pressure is increased, so that the matrix suction of the soil slope is reduced, and the shear resistance of the soil quality is reduced, which in turn causes the slope stability to decrease [8].
2. Stability analysis of rainfall infiltration slope

The influence of rainfall infiltration on slope stability is mainly reflected in the attenuation of soil strength. In 19th century, the scholar Darcy described the law of water penetration in porous media through a large number of experiments, and pioneered the quantitative study of the law of seepage movement of soil. Darcy's law is still the basic theory for studying the law of soil seepage movement nowadays. In the 1920s, scholars such as Richards and Terzaghi described the basic partial differential equations of water movement in saturated soil based on Darcy's law and continuous equations, forming a classic saturated soil mechanics theory. In the middle of the 20th century, with the gradual maturity of experimental methods, the majority of scholars focused on the theory of unsaturated soil mechanics. Bishop, Jennings and other scholars conducted in-depth research on the mechanical properties and constitutive relationship of unsaturated soil under seepage, and established the effective stress of unsaturated soil based on Mohr-Coulomb strength theory expression.

In view of the characteristics of slope soil strength changes under rainfall, the strength reduction index concept was initially considered in the numerical study of geo-elastoplastic finite element. The shear strength reduction coefficient is interpreted as: The ratio of the highest shear strength that the soil in the slope can express to the true shear stress caused by the external load in the slope is called the strength reserve safety index.

3. Engineering case analysis

The engineering example selected in this paper is located in the tributary area of the Jinsha River in Sichuan Province. The slope has a length of 320 meters, a lateral width of 340m, and an overall thickness of the slope aggregate of 30 meters. The slope is a gentle slope structure along the slope. Based on the analysis of the distribution of avalanche deposits and aggregates in the area, the slope is a landslide of avalanche deposits and terrace deposits. The constituent elements of the slope body are generally sand Clay plus crushed stone and some stones.

According to the slope geological situation and soil mechanical properties, this paper uses ANSYS finite element software to establish the slope model, and analyzes the slope stability changes through FLAC®. The application of the two softwares can describe the yield flow of materials under external load by adjusting the deformation and movement of the grid lines in the model, and can truly simulate the stress-strain relationship of slope rock and soil. At the same time, the strength reduction algorithm embedded in the human software is used to cyclically reduce the strength parameters of the rock and soil until the slope reaches the limit equilibrium state, and finally obtain the slope stability coefficient and the most dangerous slip surface shape. Its advantage is that it can obtain the slope shear strain incremental cloud map and the maximum displacement vector cloud map. It can accurately analyze the mechanical mechanism and slip mode of slope failure, and has good applicability to complex ground conditions. The number of units in this model is 47550, and the number of grid nodes is 43410.

Based on the statistics of rainfall in the area in recent years, rainfall in the area has a clear pattern, with the largest rainfall concentrated in summer and the lowest rainfall concentrated in winter. Among them, summer has the highest rainfall in July, about 305mm, but no rainfall in December and January in winter. The overall data results show that regional precipitation is concentrated from April to September each year, accounting for about 85 percent of the annual precipitation. The largest precipitation generally occurs in July and August each year. According to the characteristics of rainfall distribution, the maximum daily rainfall (95.5mm/h) was used as the research condition to analyze the stability of the slope under the action of rainfall.

After research, the initial stability coefficient of the slope is 1.351. Under the rain intensity of 95.5mm/h, after the slope rains, due to the increase in pore water pressure, the safety factor of the slope gradually decreases. It should be noted that After the rain stops, the safety factor of the slope will not reach the minimum, because after the rain stops, the water flow will also seep. After 48 hours of rainfall, the slope stability coefficient was 1.119, and when the rainfall was 72 hours, the slope stability coefficient reached 1.091. At this time, the slope stability coefficient was the smallest. Later, as the rain gradually drained, the slope stability coefficient gradually increased 120 hours after the rain, the slope stability coefficient
returned to 1.358, and 168 hours after the rain, the slope stability coefficient returned to the initial stability coefficient approximately, indicating that the rainfall was basically discharged. The slope stability coefficient change curve is shown in Figure 1.

![Slope stability coefficient change law](image)

**Fig.1. Slope stability coefficient change law**

## 4. Conclusion

Through the above analysis, the following conclusions can be obtained:

1. During the rainfall infiltration of the slope, the surface of the slope gradually becomes wet, and as the matrix suction decreases, the pore water pressure on the surface of the slope is increasing and a transient saturation zone is formed, which gradually rises from the initial negative pore water pressure to positive pore water pressure. After the rain stops, although it has the function of a drainage hole, because the water flow continues to infiltrate, the pore water pressure on the surface of the slope does not immediately drop, and will continue to rise for a period of time. As drainage continues, the transient saturation zone on the surface of the slope gradually dissipates, and the pore water pressure on the surface of the slope gradually decreases, resulting in a gradual increase in matrix suction.

2. During the rainfall infiltration process, the displacement of the slope is increasing. After the rain stops, although there are drainage measures, the displacement of the slope continues to rise. For the upper part of the slope, the displacement rise is more obvious. After infiltration, the drainage effect of the drainage hole began to be obvious, and the displacement of the slope began to decline. In the process of rainfall infiltration, the impact of rainfall infiltration on the upper part of the slope is greater than the lower part of the slope, and the slope displacement caused by rainfall infiltration increases with the increase of elevation.

3. After the slope rains, due to the increase of pore water pressure, the safety factor of the slope gradually decreases. It should be noted that after the rain stops, the safety factor of the slope may not reach the minimum, because after the rain stops, the water flow may continue infiltration. As the drainage holes continue to drain, the transient saturation area on the surface of the slope gradually dissipates, resulting in a decrease in pore water pressure or an increase in matrix suction, and the safety factor of the slope is also increasing.

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Reference

[1] CAO Lanzhu, WANG Zhen, WANG Dong, et al. Optimization design of slope space shape for multiple coal seams surface mine with weak layer[J]. Journal of Liaoning Technology University, 2018, 37(3): 469-475.

[2] WANG Dong, GUO Funing, CAO Lanzhu, et al. Study on stage-by-stage optimization method for slope parameters of soft rock open-pit mine in composite coal seam[J]. Coal Science and Technology, 2019, 47(10): 75-80.

[3] LI Shigui, HUANG Da, SHI Lin, et al. Numerical modeling of the evolution of slope failure using the limit STR criterion and dynamic strength reduction method[J]. Journal of Engineering Geology, 2018, 26(5): 1227-1236.

[4] XUE Tao, GUO Wei, GUAN Weiya, et al. Three dimensional stability analysis of slopes with rotation angles based on strength reduction method[J]. Journal of Water Resources and Architectural Engineering, 2019, 17(1): 154-158.

[5] ZHANG Xiaoyan, ZHANG Lixiang, LI Ze. Reliability analysis of soil slope based on upper bound method of limit analysis[J]. Rock and Soil Mechanics, 2018, 39(5): 1840-1850.

[6] CHEN Zuyu, ZHAN Chengming, YAO Hailin, et al. Safety criteria and standards for stability analysis of gravity retaining walls[J]. Rock and Soil Mechanics, 2016, 37(8): 2129-2137.

[7] HU Weidong, CAO Wengui. Upper limit limit analysis method for ultimate bearing capacity of ground foundation adjacent to slope based on asymmetry failure mode[J]. China Journal of Highways And Transport, 2014, 27 (6): 1-9.

[8] WANG Genlong, WU Faquan, ZHANG Junhui. Upper bound approach of rigid elements for inhomogeneous soil slope stability analysis[J]. Chinese Journal of Rock Mechanics and Engineering, 2008(S2): 3425-3430.