Effects of Fracture Seepage on the Stability of Landslide during Reservoir Water Level Fluctuation

H.G. Fan, Q.Q. Liu*, Y. An
Laboratory of Environmental Mechanics, Institute of Mechanics, Chinese Academy of Sciences, Beijing 100190, China
*qqliu@imech.ac.cn

Abstract

The hydraulic conductivity function of fractures is a key scientific question to describe and reveal the process and the role of water seepage reasonably. In this paper, the generation technology of random fracture network and the latest numerical computation method for equivalent permeability tensor of fracture network are applied to analyze the landslide located at Wangjiayuanzi in Wanzhou District of Chongqing by simulating the changes of the seepage field caused by the running of the Three Gorges Reservoir. The influences of the fracture seepage on the seepage field and stability of the landslide were discussed with emphasis. The results show that the fractures existing in the soil increase the permeability coefficient of the landslide body and reduce the delay time of the underground water level in the landslide which fluctuates relative to the water level of reservoir, that causes the safe coefficient of the slope changes more gently than that of the same slope without fractures. It means, if only water level fluctuating condition is concerned, the fractures existing in the soil plays a positive role to the stability of slopes.

Keywords: fracture seepage, random fracture network, equivalent permeability tensor, stability of landslide, reservoir water level fluctuation

1. Introduction

Landslides, as one of the natural disasters occurring all of a sudden, commonly cause severe damage, thus constituting a severe threat to human being's life and property. Among various effecting factors, water is commonly known as one of the major triggers for landslide failures. Especially, the water seepage through fractures which are widespread in rocks and soils has been paid more attention for a long time [1]. Therefore, the hydraulic conductivity function of fractures is a key scientific question to describe and reveal the process and the role of water seepage reasonably.

The stability of slopes around Three Gorges region is a critical issue. According to the statistics, there are large numbers of landslides in Three Gorges reservoir area. The stability of these landslides will affect the normal operation of the plant. In this paper, we will take the landslide located at Wangjiayuanzi in Wanzhou District of Chongqing as an example to investigate the impact of the fracture to the stability of the slope by comparing the result with and without fracture. Figure 1 shows the landslide in Wangjiayuanzi with an apparent landslide boundary feature. The deformation is mainly along the sliding surface for the decline.

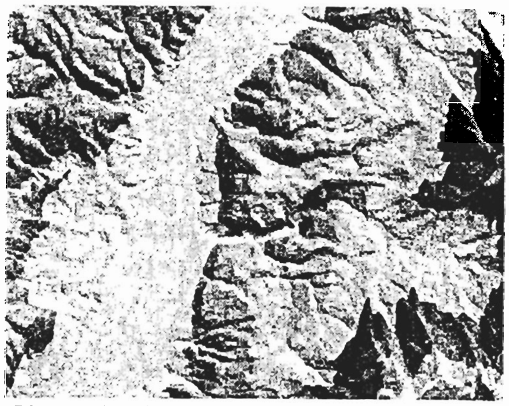


Figure 1 Landslide in Wangjiayuanzi in Wangjiayuanzi

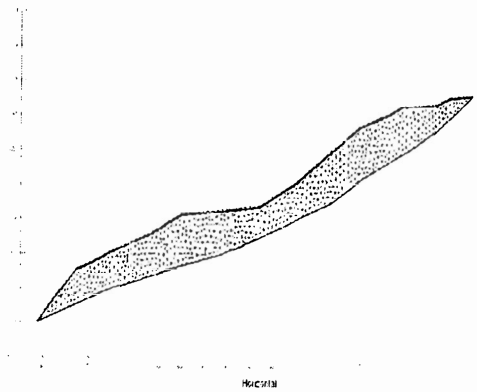


Figure 2 Two-dimensional numerical mesh of the landslide

2. Numerical simulation

Numerical simulation is employed to investigate the effect of the fluctuation of reservoir water on the slope stability in this part. Two-dimensional geometrical model is built for the cross profile of the landslide according to the analysis of the geological conditions. The software GEO-SEEP is used to calculate the change of the seepage field of the landslide when the reservoir water fluctuates. Figure 2 shows the finite element mesh. The head boundary is for the part that affected by the reservoir water and the rest is the impermeable boundary. GEO-SEEP gives the safety factor based on the analysis of stability by limit equilibrium method. In order to simplify the calculation, the water level change in Three Gorges reservoir is shown in Figure 3. The water level is either a constant or linear to the time. As the experimental data of the landslide is currently lack of, the physical and mechanical parameters of the rock-soil are roughly given by engineering analogy [2]: $\gamma = 20kN/m^3$, $c = 15kPa$, $\varphi = 16°$. Considering the effect of the matrix suction on shear strength, $\varphi^b = 13°$ and

k_{sat} =1.0*m*/*d*. Figure 3a shows the water soil character curve. Figure 3b shows the relation between unsaturated permeability coefficient and pore pressure.

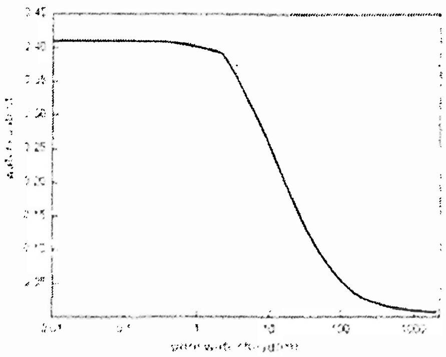
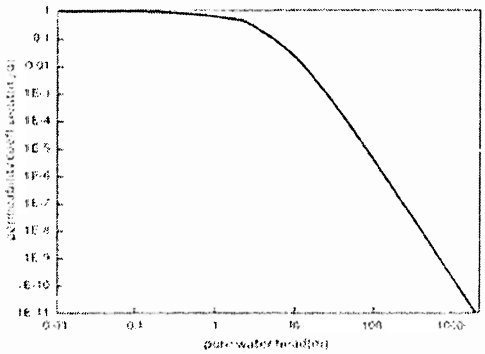


Figure 3 (a) Water soil characteristic curve



(b) unsaturated permeability coefficient with matrix suction

In order to calculate the slope change with the fluctuation of the reservoir water, the initial condition of the seepage should be assumed. For the sake of simplicity, the boundary condition is chosen at the time when the water level is 145m, that is, the water level before filling with water in the Three Gorges reservoir. The initial condition is set as the steady solution obtained from the former condition, which is shown as figure 4.

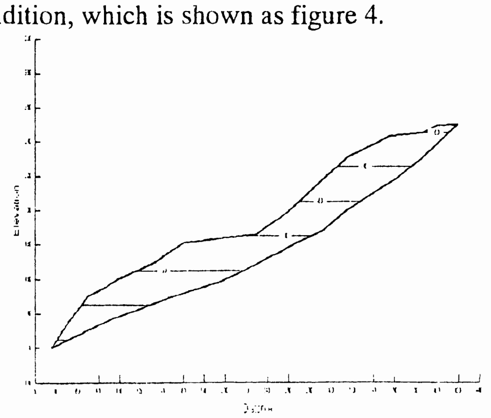


Figure 4 Pore water pressure distribution before filling water

3. Discussion

Figure 5 shows the safety factor of the landslide in four cycles after the reservoir running which has a cyclical variation. The safety factor is going to stable as Figure 5 shows. The elevation in the first day of the forth year is same as the last day of the same year. After that, the safety factor will maintain a dynamic cyclical change, and would not decrease year by year.

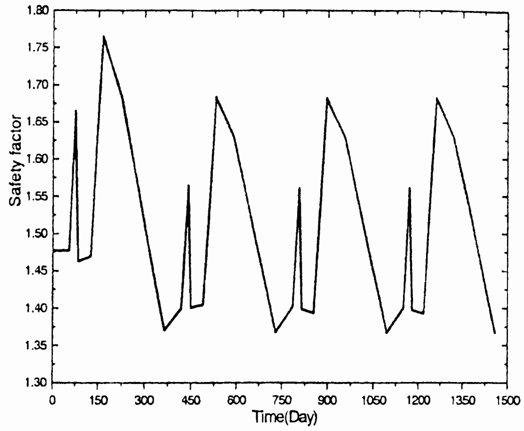


Figure 5 Change of safety factor with time

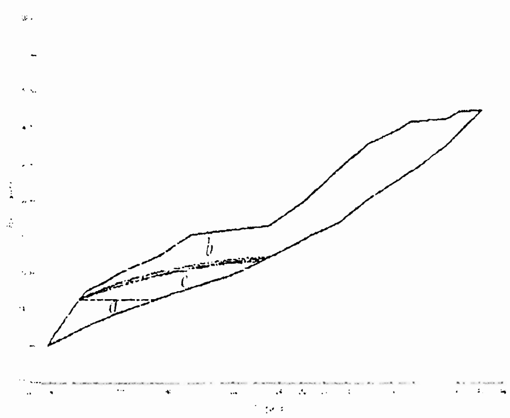
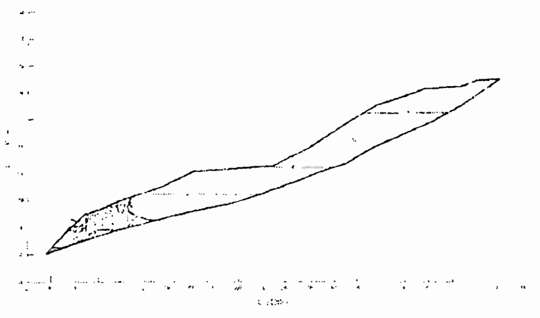
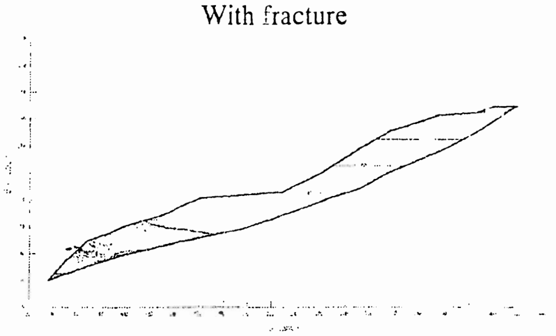


Figure 6 Elevation with distance (a: the first day, b: the 365th day,c: the 730th , 1095th and 1460th day)

In all, the stability of landslide in Wangjiayuanzi will change with the fluctuation of the water level after Three Gorges reservoir starts storing water. The safety factor will increase as the water level goes up and decrease when it goes down. The change of the safety factor will be delayed relative to the fluctuation of water level. After running for four years, the safety factor will not decrease year by year, but goes to a cyclical change with the fluctuation of reservoir water. The minimum factor is 1.367 when the water is beginning to store. The equivalent main permeability coefficients of continuous medium for the fracture network are given: *Kmax*=2.3026 ($10^{-4}m/s$), *Kmin*=0.7414 ($10^{-4}m/s$) and the direction of the main infiltration is θ= -16.27. After unit conversion, *Kmax*=20 (*m*/*d*), *Kmin*=6.4 (*m*/*d*). It should be noted that these are only the saturated fracture network permeability coefficients.



With fracture



Without fracture

Figure 7 Comparison of the pore pressure distribution with and without fracture

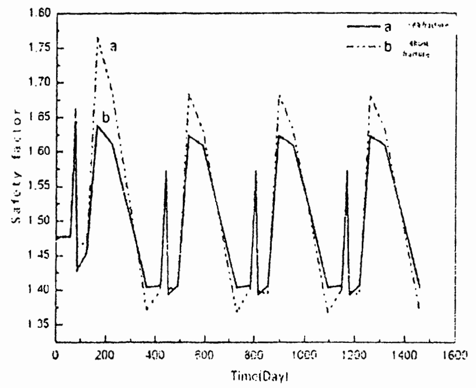


Figure 8 Comparison of safety with and without fracture

Figure 7 shows the comparison of the landslide with and without fracture at the 75th day when the reservoir is increasing. The water level in the landslide increases or decrease with the fluctuation of the reservoir water, but has a delay. The comparison of safety factor with and without fracture is shown in Figure 8. It shows that the trend of the safety factor is still dominated by the water level. The maximum of the safety factor will decrease when the fracture is taken into account and the minimum will increase. This is because the fracture will increase the permeability coefficient and shorten the delay of the underground water level relative to that of the reservoir. The increase of the water level inside the landslide has a negative effect to the stability of the landslide, while it is positive when the water level is decreased. This is reversed for the water level outside the landslide. The increase (decrease) of water level of the reservoir will increase (decrease) the safety factor of the landslide. But the water level inside the landslide has a negative to the safety factor. However, the change of the reservoir is active. The change of water level inside the landslide is passive and has a delay to the reservoir. The combination of these two changes makes the safety factor increase with the reservoir going up. If the delay of the water level inside the landslide relative to the reservoir is shortened, the change of the safety factor is more stable. Figure 8 shows that the safety factor goes into a stable cyclical change from the beginning of the 2nd year and shorten the time to become stable compared to the case without fracture. So the existence of the facture has a positive effect to the stability of the landslide in Wangjiayuanzi if only cyclical fluctuation of reservoir is considered.

4. Conclusion

The preliminary discussion leads to the following conclusions: For slopes composed of soil in which soil structure characteristics influence is weak, i.e. strength loss due to soaking is limited to matrix suction loss, the slope stability enhances along with draw up of the reservoir water level, reduces along with drawdown of the reservoir water level. After the reservoir water fluctuation circulating for several times, the safety coefficient of the slope tends to be a stable periodic variation. The fractures existing in the soil increase the permeability coefficient of the landslide and reduce the delay time of the underground water level change in the landslide which fluctuates relative to the water level of reservoir, that causes the safe coefficient of the slope changes more gently than that of the same slope without fractures. It means, for the slopes composed of soil mentioned above, the fractures existing in the soil plays a positive role to the stability of slopes under water level fluctuating condition.

Acknowledgement

This research was supported by the National Natural Science Foundation of China (No. 10825211, 10932012)

References

1. Sun J.P., Effects of rainfall infiltration and variation of reservoir water level on the stability of slopes, PHD Thesis, Inst. Mech. CAS, 2009

2. Sun J.P., Liu Q.Q., Li J.C., An Y., Effects of rainfall infiltration on deep slope failure, Science in China, Series G –Physics, Mechanics & Astronomy, 2009, 52(1), 108-114.