The Rainfall Seepage and Stability Analysis of a Certain Slope based on Slide Finite Element

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Abstract. Rainfall seepage effect has significant effects on the slope stability, people have done many researches about it, but relating research of using software of Slide for seepage analysis and completing the limit equilibrium calculation is relatively rare. Aiming at a certain slope in the three gorges reservoir area, based on the finite element method in the Slide carried out seepage calculation and stability analysis under the condition of different rainfall, the results show that the slope under the condition of the rainstorm is almost in saturated state, with the decrease of the rainfall intensity, slope unsaturated zone expanded. Rainfall intensity impacts on slope stability significantly, but has little impact on the position where the main sliding zone appears, the slope stability under different rainfall conditions can meet requirements; Slide software can easily complete the seepage model and limit equilibrium calculation, it can improve the efficiency of calculation with the presence of a large number of slopes.

Keywords: slope; limit equilibrium; rainfall seepage; finite element method; slide software.

1. Introduction

Slope stability analysis is one of the classic problems in geotechnical engineering, slopes with rainfall and groundwater cause people more attention [1-2], this is mainly because seepage had a great effect on slope stability result, a large number of engineering accidents indicate that water is the main reason for the slope instability [2-4]. For the stability of slope under the action of rainfall seepage, in recent years, Xu Han [5], Du Mingliang [6] and Chen Ligang [7] and others carried out the slope calculation of seepage and stress field under the fluid-structure coupling , Qi Guoqing, Su Baoyu, etc.[8] established rainfall seepage model and completed the numerical simulation of rainwater infiltration; Wu Hongwei, etc.[9] studied the influence of rainwater infiltration on slope stability parameters; In slope instability mechanism of rainfall infiltration, Bao Chenggang [10], Wang Yan [11] made a deeper discussion; In addition, Wu Li [12] tried to improve the formula of slope safety factor considering the seepage action. In the above researches, fluid-structure coupling calculation process is more complex, in favor of the seepage stress field study and is not convenient to get the intuitive safety factor, even though the strength reduction trial calculation, a large number of slope existing will also affect the analysis efficiency; If seepage factors are put in the calculation formula of limit equilibrium, would cause more assumptions, and can't get a concrete seepage field distributions, so it is not convenient to use. On the basis of the seepage field finite element simulation to do calculation of limit equilibrium, this paper [13] combine numerical simulation with the analysis of the limit equilibrium method. Different tools are used in the calculation and the relating research using Slide software for seepage analysis to complete the limit equilibrium calculation is rare relatively.

The Groundwater (Finite Element Analysis) model in the Slide software is used for rainfall seepage Analysis in this paper, and then complete safety factor calculation directly. It can not only do the seepage calculation in saturated-unsaturated condition, avoid the seepage field deviation which is determined only by the saturation line or coefficient of pore water pressure, but also can do limit equilibrium Analysis more directly and conveniently, improve the efficiency of calculation in a large number of slopes stability Analysis.

2. The Introduction of Analysis Method

2.1 Seepage analysis control equation and boundary conditions.

The slope groundwater with rainfall infiltration has the characteristics of unsteady flow, at the same time of considering the balance equation, we still need continuity equation. Under the condition of assuming that soil is homogeneous and isotropic, gas is continuous, water and soil are incompressible, and ignore the air diffusion and dissolution in the water, the two-dimensional transient seepage flow continuity equation can be made by the condition that the time derivative of the velocity divergence and the constitutive equation of is equal:

$$\frac{\partial v_{wx}}{\partial x} + \frac{\partial v_{wy}}{\partial y} = -m^{w}\frac{\partial u_{w}}{\partial t} \quad (1)$$

Where v_{wx} and v_{wy} are the flow velocity of x and y respectively, u_w is the pore water pressure, t is time, m^w is water volume change coefficient.

Based on Darcy's law of unsaturated soil, Eq. 1 can be improved as type Eq. 2, is the control equation of seepage finite element analysis.

$$\frac{\partial}{\partial x}(k_w\frac{\partial h_w}{\partial x}) + \frac{\partial}{\partial y}(k_w\frac{\partial h_w}{\partial y}) = -m^{w}\rho_{w}g\frac{\partial u_{w}}{\partial t} \quad (2)$$

Where the coefficient of permeability is k_w, h_w is water head, ρ_w is fluid density, g is gravity acceleration, the rest is same with Eq. 1.

Then finite element flow equation can be obtained by numerical integration and the coordinate transformation, as shown in Eq. 3, after working out $\{h_{wn}\}$, we can get pore water pressure, water flow speed, etc.

$$[D]\{h_{wn}\} + [E]\{h_{wn}\} = [F] \quad (3)$$

Among them, $[D]$, $[E]$ are stiffness matrix and capacitance matrix respectively, $[F]$ is flow boundary condition, $\{h_{wn}\}$ is the derivative of the node head to time.

Generally, boundary conditions are divided into two categories, water head is known and flow is known, the first head can be expressed as seepage boundary space function, and the second class boundary conditions, the study of the water head on the border in seepage area is unknown, but flow rate q of the border infiltration in per unit area (when the seepage is negative) is known, and the initial conditions take the water head when $t = 0$.

2.2 The Process of Calculation.

Using Slide software, we can simulate saturated/unsaturated, steady state of seepage field in the Groundwater Analysis module with the Finite Element Analysis, and then switch to the Slope Stability model to complete Stability Analysis directly, a simplified bishop method is adopted in the calculation of limit equilibrium. The specific analysis process is shown in Fig. 1.

3. The Example for Calculation Analysis

This paper selects one upstream slope of three gorges reservoir as the analysis object, the exposure strata of the library section are the Mesozoic Jurassic terrestrial clastic rocks and quaternary loose deposits, main ingredients of clastic rock is argillaceous siltstone, parts are beige powder sandstone with grey black carbonaceous shale and grey green powder sandstone, etc. We can see the conglomerates at the bottom, the fourth quarter of loose debris are mainly the residual talus, colluvium deposits, etc. When Yangtze river is in flood period in the summer and fall season, the water level of the impoundment of the three gorges reservoir is near 145 m basically, rainfall is frequent in the reservoir area, the slope ground water level changes actively, and influents the slope stability obviously.

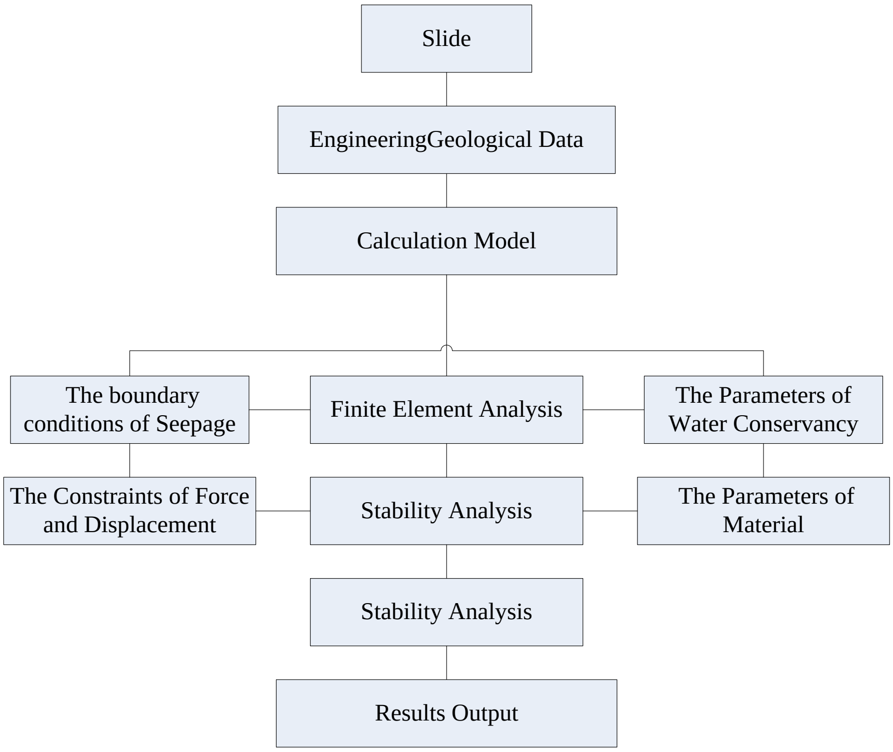

Fig 1 the flow chart of calculation and analysis

3.1 The Calculation Model and Parameters.

According to the geological data, select a typical section of the slope as a calculating object, the slope rock mass physical and mechanical parameters are shown in Table 1, the relationship between the coefficient of permeability in unsaturated zone and matrix suction choses Slide Gardner model commonly used according to the lithology. Stability analysis and seepage field simulation are calculated using the same model, the seepage simulation do grid subdivision in the Slide directly, and Fig.2 shows the grid computing model. In the Fig.2, 1 area is colluvium, 2 areas is sand gravel containing clay, 3 and 4 is sandy pebble layer and the bedrock separately.

Table 1 the Calculation Parameters of Each Reservoir Rock Layers

Types of materials	Angle of internal friction θ (°)	Cohesion c (kPa)	Natural density γ ($kN.m^{-3}$)	Saturation density γ ($kN.m^{-3}$)	Saturated hydraulic conductivity K ($m.s^{-1}$)
Colluvium	21	17.5	19.5	22	9.49×10^{-6}
Clay-containing sand and gravel	29	16	19	21	5.78×10^{-6}
Sand and Gravel overlay	32	0	20	23	1.69×10^{-4}
Bedrock	40	180	25.9	26.4	5.00×10^{-9}

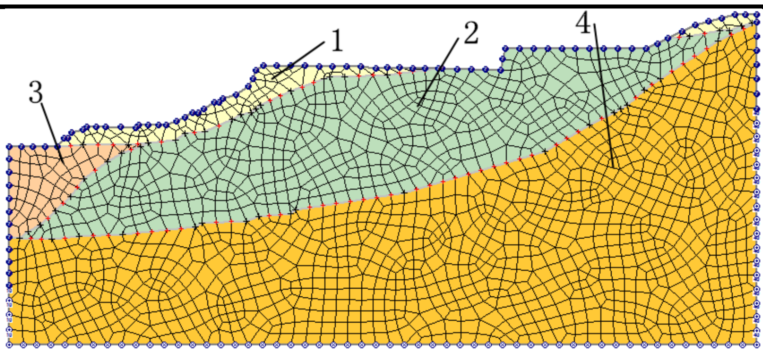

Fig 2 The Model Diagram of a Calculating cross-sectional

3.2 The Analysis of the Calculation Results.

After a rainfall seepage simulation and limit equilibrium calculation, saturation line, velocity vector and the minimum safety factor of the bank slope typical section under the condition of no rain and different rainfall intensity are shown in Fig. 3 to Fig. 6.

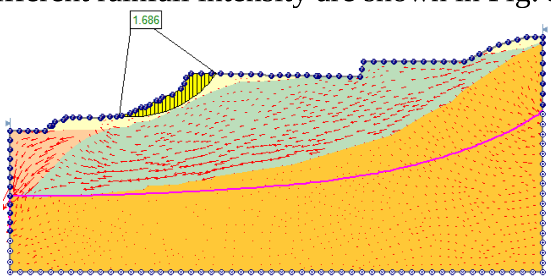

Fig 3 no rainfall

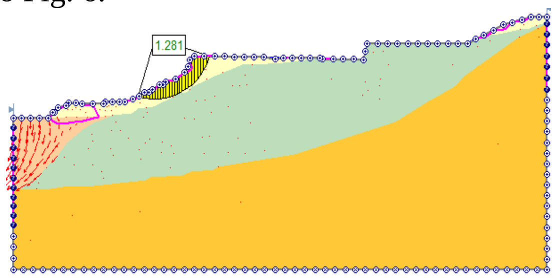

Fig 4 40mm/h

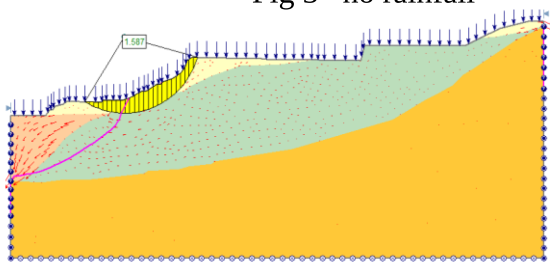

Fig 5 15mm/h

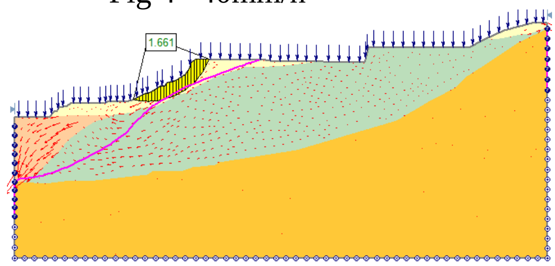

Fig 6 3.34mm/h

The diagram shows that without rainfall, the groundwater in slope body is at the stage of steady seepage, the water level flows down from the 175 m in the right side to 145 m elevation in the left side. When rainfall intensity is 40 mm/h, almost all slopes are in saturated state, unsaturated zone emerges in the local area is mainly because the rain can't stagnate on relative steep slope surface; When rainfall intensity is 15 mm and 3.34 mm/h, the saturation line is off the slope surface, the unsaturated zone emergences, and unsaturated zone is expanded with the decrease of the rainfall intensity; For model 3 area of the sandy pebble layer, the permeability coefficient is larger, the velocity vector is more apparent near this area, and saturation line has fallen.

The minimum safety factor and the decline in value relating to no rainfall in Downhill body under different conditions are presented in Table 2; it is visible that rainfall intensity has an apparent influence on slope stability, when the rainfall intensity is 40 mm/h, safety coefficient decreased by 24.02%. In addition, the rainfall conditions has a small influence on the main position of the sliding zone, they are close under no rainfall and different rainfall intensity, when rain is big or small, the sliding zone is small and the depth is shallow, but when rainfall intensity is 15 mm/h, the sliding zone is larger; When rainfall is 40 mm/h, the phenomenon of instability appears in local small scale of slope steep place and it is mainly because of the terrain and the rainfall erosion.

Table 2 Minimum safety coefficient under different rainfall conditions

Rainfall Conditions	40mm/h	15mm/h	3.34mm/h	No Rainfall
Safety Factor (Fs)	1.281	1.587	1.661	1.686
The Decline of Safety Factor (%)	24.02	5.87	1.48	-
Specification Requires a Minimum Safety Factor [14]	1.10	1.30	1.30	1.30

The calculation shows that the set of minimum safety coefficient of slope body under three rainfall conditions are greater than the minimum value stipulated in the codes, rainfall infiltration damage will not happen and it can satisfy the stability requirement.

4. Conclusions and Prospects

Through rainfall seepage simulation and limit equilibrium analysis of a typical section of a library shore slope in three gorges reservoir area by Slide software, the main conclusions and prospects are as follows:

(1) Using finite element method of Slide software to do seepage simulation in rainfall conditions and on this basis to complete the slope limit equilibrium calculation is a kind of convenient and feasible method, it can improve the efficiency of its stability analysis under the condition of seepage when there are a large number of slopes.

(2) The slope under the condition of the rainstorm (rainfall intensity is 40 mm/h) is almost in saturated state, the local part emerges unsaturated zone because the rain can't stagnate on relative steep slope surface; with the decrease of the rainfall intensity, slope unsaturated zone expanded.

(3) The rainfall intensity impacts on slope stability significantly, when the rainfall intensity is 40 mm/h, safety coefficient decreased by 24.02%, but it has a small influence on the main position of the sliding zone, different rainfall intensity will only affect the scope of the sliding zone; The slope stability can meet the requirements under different rainfall conditions, only in the rainstorm condition, the phenomenon of instability appeared in the local small scope of steep slope surface.

(4) Selected the models in the software directly for the relationship between permeability coefficient and the matrix suction in this paper and did not carry out related experimental research; Rainfall intensity referred to other documents, and will have some difference with the actual situation, it only simulate the stable condition after the water drop, follow-up study can carry out more work in the above aspects.

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