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Contents

Research on the Stability of Slope in Reservoir Area Considering the Rheological Property of Rock Soil Medium

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Abstract: In this paper, we first analyze the typical rheological property of ordinary side slope rock soil medium, and use the three stage curve to describe the relationship between time and strain. Considering the difference to reservoir bank slope deformation slip and ordinary side slope, we established reservoir slope geological model by Flac3D numerical simulation software, and the related parameters and boundary conditions are also given by us. We found that there is a great relationship among water level variation, slope safety factors and rheological property of rock soil medium, we first make a preliminary presumption of this correlation. In order to check our preliminary presumption, what we have used is the cusp model of the nonlinear evolution mechanism of the slope of Professor Siqing Qin, Institute of Geology and Geophysics, Chinese Academy of Sciences. Through model calculation found that the final results are consistent with our preliminary presumption.

Keywords: Reservoir bank slope; Flac3D model; Rheological property of rock soil medium

1. Introduction

In the research of side slope stability, the application of rheological theory is very wide, but there are two limitations on the results. One is the researches on the rheological characteristics of the slope in the reservoir area are few, and about the practicality of this kind of slope, the three stage curve of the classical rheology is in doubt. The other hand, in this research field, people often take reservoir landslide sliding zone soil as a single sample, without considering the correlation between overall deformation of slope with time, such studies usually use Burgers mechanics models can be well described. On the actual situation, despite the rheological property and long-term strength of slip zone soil in slope stability research is very important, but the overall effect of reservoir water on the slope should not be ignored, including slip and deformation [1]. In view of this kind of nonlinear evolution mechanism, it is easy to have a lot of difficulties in the indoor rheological experiments, and the errors of the experimental results is too large. Contrarily, we through the Flac3D finite element difference program modeling analysis, this method is better than the discrete integration method of the finite element method is more reasonable and accurate, and is more suitable for solving the nonlinear large deformation problem of slope. In our research, we took the plane sliding slope as an example considering the dynamic effect of reservoir water to bank slope, and taking advantage of the rheological theory of rock soil deformation law of it. On above basis, we used the cusp model of Professor Siqing Qin to check our results [2].

2. Rheological Property of Rock Soil Medium

2.1. Typical characteristics

Rheological property of rock soil medium separately includes the rheological property of rock and rheological property of soil. If we regard rock soil materials as a whole of isotropic materials to analyses , figure 1 is a typical rock soil mass rheological curve for this materials, the curve describes slope rock soil rheological behavior mainly affected by gravity stress field and horizontal stress field [3]. Figure 1 (a) is the instantaneous elastic deformation of rock soil material under the load, and tends to decay. In this case ,Slope deformation amount can be described as (1).

$$\varepsilon = \varepsilon_0, \varepsilon_0 = \frac{\sigma_0}{G} \quad (1)$$

Where σ_0 is the constant load , G is the elastic modulus of rock soil medium. This process is stable rheological process.

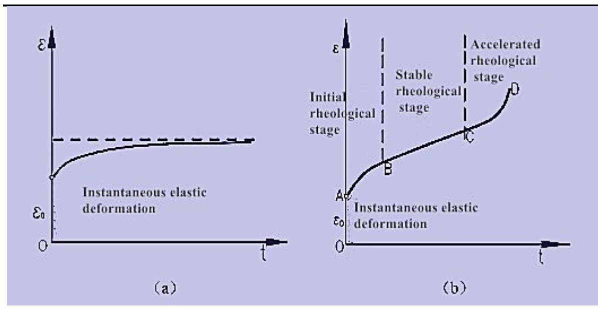

Figure 1. Typical creep curves of rock soil medium

From the figure 1 (b), if continue to increase the stress value, the rheological process began to be violent, the amount of deformation can be expressed as (2).

$$\varepsilon = \varepsilon_0 + \varepsilon_1(t) + \varepsilon_2(t) + \varepsilon_3(t) \quad (2)$$

The meaning of ε_0 is same as above. The posterior segment is unstable rheological segment.

The AB segment in Figure 1 (b) is described decelerating rheological process, $\varepsilon_1(t)$ is the deformation amount, and follows (3).

$$\frac{d^2\varepsilon}{dt^2} < 0 \quad (3)$$

When the load value is increased to a certain value, rheological process gets into uniform speed stage as Figure 1 (b) BC segment, $\varepsilon_2(t)$ is the deformation amount, as in (4).

The CD segment in Figure 1 (b) is described accelerating rheological process and follows (5). This stage is the main process of the slope deformation and damage. Under the heavy load, the rheological behavior will directly bypass the reduction or uniform speed section directly into the accelerating section until the side slope failure.

$$\frac{d\varepsilon}{dt} = const \qquad \frac{d^2\varepsilon}{dt^2} = 0 \quad (4)$$

$$\frac{d^2\varepsilon}{dt^2} > 0 \quad (5)$$

2.2. Flac3D reservoir bank slope model

Based on past research experience, the factors affecting the rheological properties of rock soil except gravity stress and horizontal stress, the main power should consider the action of water on slope [4]. In this paper, we considered three main factors, that is different water level hydrostatic pressure, hydrodynamic pressure and water seepage force. According to the Flac3D finite difference theory, we established the bank slope geological model, as shown in Figure 2. In this model, its rock soil medium was set to ideal elastic-plastic material and meets the yield criterion of Mohr-Coulumb. The initial stress field was set to the gravity field. The stratum is mainly divided into three layers, namely, the upper surface of the clay layer, followed by weak weathered layer and strong weathered layer. We set such displacement boundary conditions for the geological model: X left = 0 meters , X right = 50 meters ; Y left = 0 meters , Y right = 450 meters ; Z = 0 meters, and We can press the Table 1 to enter the parameters of the rock and soil mechanics. According to the research on the mechanism of slope instability of researcher Wang Bin, the permeability coefficient of rock soil is can expressed as a function of stress state, as fallows:

$$k = k\sigma_{ij} = k_{ij}\exp[-\alpha(\sigma_j - p_j)] \quad (6)$$

Where σ is the experimental parameters, which are related to the soil body composition, the σ_j is the stress state of the rock soil medium; the p_j is the seepage force [5].

$$k = \frac{E}{3(1-2\mu)}, \qquad G = \frac{E}{2(1+\mu)} \quad (7)$$

Table 1. Rock- soil body mechanical parameters

Material parameters	E(Elastic modulus)Pa	U(Poisson ratio)	X(Bulk modulus)Pa	G(Shear modulus)Pa	C(Cohesion)Kpa	φ (Internal friction angle)	ρ (Density) kg/m3	ρ_t (Saturation density)kg/m3
Clay soil	9000000	0.3	7500000	3500000	20	18.5	1970	2020
Strongly weathered rock	1700000000	0.25	1100000000	7000000000	15000	30	2570	2590
Weakly weathered rock	3000000000	0.24	19200000	121000000	20000	35	2680	2710

2.3. Calculation of Flac 3D model

The research of Tingguo Zhang [6] and Yunming He [7] shows, there is a close relationship between the safety coefficient value of different water level and the displacement-deformation amount induced by rheological behavior of rock soil medium. In their view, when the sudden macroscopic slip of side slope was happened, the slope overall shear strain increment should be the maximum value. Therefore, we assumed, in our model, the initial conditions of reservoir water level in 227 meters decreased gradually to 217 meters , last to 207 meters, its cross section of X direction was set be 25 meters. From above calculation results, we had chosen the safety coefficient value and the Y-direction total shear strain increment. We can use the series of safety coefficients and shear strain increments to characterize the reservoir bank slope rheological property and instability mechanism. As follows Figure 3, Figure 4 and Figure 5:

The Figure 3, Figure 4 and Figure 5 shows:

The water level at 227 meters, the slope safety coefficient is 1.79, the overall slope is stable, only a small range of local deformation.

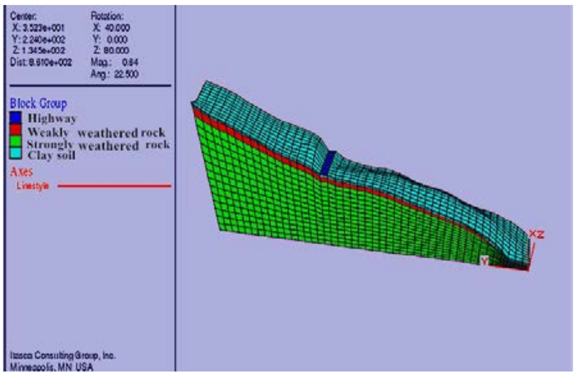

Figure 2. The left view of Flac3D

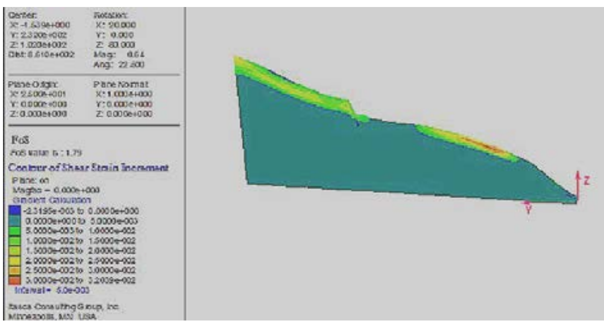

Figure 3. The shear strain increment and safety factor of water level =227 meters

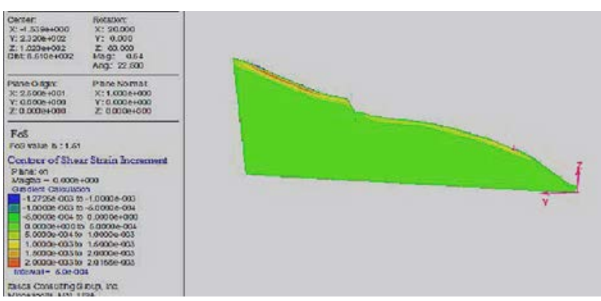

Figure 4. The shear strain increment and safety factor of water level =217 meters

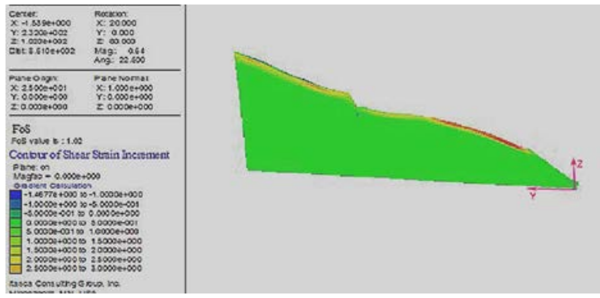

Figure 5. The shear strain increment and safety factor of water level =207 meters

The water level dropped to 217 meters, the slope safety coefficient decreases to 1.51, the slope sliding slightly obviously, the shear strain increment slightly larger.

The water level to 207 meters, the slope safety coefficient is 1.02, the slope is in unstable critical state.

Table 2 is the slope safety coefficient table under different water levels.

Figure 6 is change curve of slope safety factor for water level from 227 meters to 197 meters process.

Table 2. The safety coefficient under the different water levels

Reservoir water level	197	202	207	212	217	222	227
safety factor	0.98	0.98	1.02	1.2	1.51	1.65	1.79

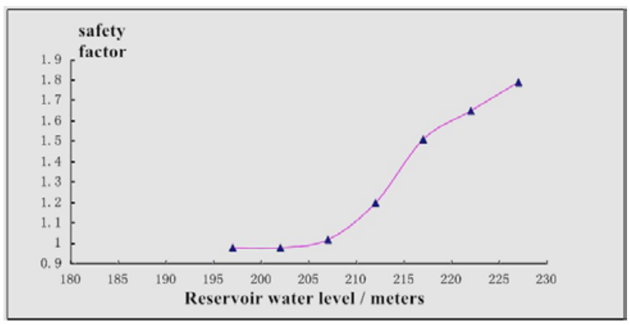

Figure 6. curve of safety factors in different water levels

According to the above results, we done the preliminary presumption: the reservoir bank slope tends to be stable in the process of water level rising, and its slip and deformation limited, rheological property of rock-soil body is also weak. On the contrary, in the process of water level dropping, slope stability was gradually deterioated, and its deformation and slip exacerbates, rheological, property of rock-soil body gets strong.

When the overall shear strain increment at maximum, slope will be unstable.

3. Checkout

3.1. Cusp model of slope

The slope nonlinear evolution mechanism cusp model proposed by Professor Siqing Qin, as fallows:

$$b=\frac{6\exp(\frac{m+1}{m})}{m(m+1)^2G_sl_su}[G_el_eu+G_sl_su\exp(-\frac{m+1}{m})-W_gh\sin\theta] \quad (8)$$

In the formula, m is rock soil material uniformity index, we can through experiment to obtain. G_s and l_s respectively represents the initial shear modulus of slope sliding surface and the sliding surface sliding strain softening medium sliding length. u is sliding displacement of slope deformation. G_e and l_e respectively represents elastic-brittle shear modulus and sliding length of the sliding surface. W_g , h and θ respectively represents the landslide body weight, weak interlayer thickness and dip angle of sliding surface.The basic application of this formula: $b>0$, $b=0$ and $b<0$ respectively corresponding rheological deceleration $\varepsilon_1(t)$, uniform speed section $\varepsilon_2(t)$ and segment of acceleration $\varepsilon_3(t)$. In the light of the side slope under influence of reservoir water, the study found that with the increase of water content of rock soil medium, "m" value decreased; the decrease of the water content, "m" value increased.

3.2. Checking our results

We can extract a function from (9):

$$\gamma(m)=G_el_eu+G_sl_su\exp(-\frac{m+1}{m})-W_gh\sin\theta \quad (9)$$

We set the $\gamma(m)=0$ under normal water level. If comparing the preliminary presumption in 2.3, we can get the following results:

$$\begin{cases}\gamma(m)<0,\ b>0(\text{Water level rising, water content increases} \\ \text{weak flowing property - Rheological behavior of deceleration}) \\ \gamma(m)=0,\ b=0(\text{Uniform speed rheological process}) \\ \gamma(m)>0,\ b<0(\text{Water level droping, water content decreases} \\ \text{strong flowing property - Rheological behavior of acceleration})\end{cases}$$

Obviously, our preliminary presumption consistents with the results of checkout.

4 . Conclusions

Considering the difference of rheological property between reservoir bank slope and other slope, we had taken advantage of Flac3D finite element difference software to establish a typical reservoir bank slope model. We found that bank slope instability mainly depends on the dynamic action of water, and found that there is a great relationship between rheological intensity of slope rock soil medium and slope safety coefficient under the influence of water level . That is , when the water level rising, the safety coefficient of the slope becomes larger, rheological property of its rock soil is weak, and slope displacement deformation small. On the contrary, when the water level dropping, the safety coefficient of the slope becomes larger, rheological property of its rock soil gets strong, and slope displacement deformation larger. When the shear strain increment of the slope reaches the maximum value, the slope is unstable. Considering the change of rate of water content of slope rock soil medium in case of fluctuation of water level , and used slope cusp model of the nonlinear evolution mechanism of Professor Siqing Qin to test the results of this study. Finally, through the judgment the value of "b" parameter and the value of "m" parameter, found that the comparison results are consistent with the results of our study.

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