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Numerical Simulation Analysis of Secondary Slip of Earthquake-Induced Landslide

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Abstract. The western region of China has a complex and diverse regional geological environment, which has formed a variety of geological disasters such as landslides and debris flows, accompanied by earthquakes. Taking a landslide in Banma County, a certain area Province as an example, this paper collects and surveys the local geological environment data and the basic characteristics of the landslide, and uses the three-dimensional finite difference software FLAC3D to simulate the stability of the landslide in the natural state and the possibility and danger of re-induction under the action of future earthquakes. The quantitative analysis shows that the landslide is in a basically stable state in the natural state. Under the seismic load of local VII. degree intensity, the slide body was revived along the boundary as a whole, the middle and upper parts were obviously deformed, and the failure deformation occurred again, and the sliding body had more obvious deformation damage and sensitivity relative to the surrounding bedrock.

Keywords. Landslide, earthquake, numerical simulation, secondary slip

1. Numerical Analysis Software

Earthquakes are not only natural disasters with huge destructive power, but also induce other secondary disasters such as landslides, collapses or mudslides when earthquakes occur, which will cause huge loss of life and property to the local people [1]. In the past work results, it is mainly the qualitative assessment of the local geological disaster risk, and there are few researches on the factors of the landslide revival after the earthquake.

With the development of information technology, numerical analysis has become a means of analyzing landslides [2-3]. People have developed a series of numerical simulation software based on numerical calculation methods and applied them in the field of engineering geology. Common ones include FLAC, SURFER, GOCAD, ANSYS, etc. [4], among which the application of FLAC3D is the most eye-catching. FLAC3D is a finite-difference program based on the three-dimensional explicit finite-difference method (Lagrangian method), which has broad application prospects in the field of geotechnical engineering [5]. Combining relevant theoretical foundations,

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establish a rigorous calculation model, and further clearly understand the mechanism of earthquakes on geological disasters such as landslides, so as to combine quantitative calculation.

Banma County is located in the southeast of Certain area, on the edge of the Certain area-Tibet Plateau, and is a county with many geological disasters. This paper will conduct numerical simulation analysis on the performance of an ancient landslide in this county under the action of earthquake load.

2. Regional Geological Conditions and Natural Stability of Landslides

2.1. Basic Geological Conditions of Landslide Area

The landslide area is located in the hilly area of the Make River Basin in Banma County. The left bank of the river is relatively flat, while the right bank is relatively high and steep. The relative height difference is about 300m. The landslide body is covered with a layer of Quaternary residual slope gravel soil, with an average thickness of 4m and a gravel content of about 50%; the exposed bedrock is the upper Triassic sandstone and slate interbedded formation (T3byb) The calcareous slate and silty slate are interbedded, with well-developed slabs and 4556 occurrences; the formation lithology is complex and the geological environment is fragile [6].

According to the Zoning Map of Seismic Motion Parameters in China, the peak acceleration of earthquake motion in Banma County is 0.10~0.15g, which is equivalent to the basic earthquake intensity VII degree. If it slides again under the action of the earthquake, it may endanger the river, cause diversion, and cause great harm to the lives and properties of the people on the left bank.

2.2. Basic Characteristics of Landslides

The coordinates of the landslide are 32°53′09.77″N, 100°47′48.36″E, and the altitude is 3558m. It is located on the right bank of the Ma Ke River. The landslide is tongue-shaped in plan and develops on the left side of the upstream and downstream of the landslide. There is a gully or groove-like terrain, in the shape of a "V", 2-6m wide, 5-12m deep incision, and no perennial flowing water; a crack in the middle of the slide is about 20m long, 13cm wide, and strikes 120°; The edge has a chair-shaped landform with obvious features.

The elevation of the front edge of the landslide is 3780~3790m, the elevation of the trailing edge is 3495~3510m, and the average slope is 30°. There are three relatively gentle slopes, which are three-level platform landforms, with an average slope of 15°~25°, and the scales are 90m in length, respectively. 80~400m wide; 50m long, 40~200m wide; 120m long, 50~500m wide. The sliding body is 680m long, 180~820m wide, the overall slope is about 50°, the rear wall height is about 50~100m, and the overall slope is 50°~60°. With an average thickness of 40m and a volume of 1.36×107m3, it is a large landslide.

2.3. Stability under Natural Conditions

The slide body is mainly moderately weathered calcareous slate and silty slate, which is a rocky landslide, but the surface is made of Quaternary residual slope gravel soil, the main sliding direction is 55°, and the sliding surface is arc-shaped , the overall middle and rear part is steeper, and the front edge is gentler. Studies have shown that the landslide was formed due to the sliding deformation of the bedding slope, and small-scale sliding of the Quaternary gravel soil layer was found in the surrounding area, indicating that the landslide in the study area is not stable in the natural state [7-8].

3. Natural Static Calculation and Dynamic Analysis of Landslide Under Earthquake in FLAC3D

In the natural state, the landslide is mainly under the action of the gravity field, so the dynamic calculation takes the static calculation under the gravity field as the initial condition. The difference between static calculation and dynamic calculation lies in the selection of parameters and boundary conditions. In addition, dynamic calculation needs to import the acceleration (or stress, velocity, etc.) time history data of earthquakes

3.1. Static Calculation of Landslide under Gravity Field

Based on the on-site measurement and drilling of the landslide, a 3D model of the landslide was established and imported into FLAC3D, as shown in figure 1.

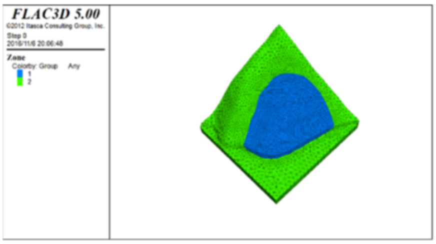

Figure 1. Landslide model.

This calculation uses the Moore-Coulomb constitutive model. In FLAC3D, the sliding surface is divided into contact surface elements. The selection of model calculation parameters is shown in table 1.

The boundary conditions of the static calculation of the landslide adopt the displacements in the X and Y directions of the surrounding constraints, the displacements in the X, Y, and Z directions are fixed on the bottom surface, and the empty surface is a free surface.

Under the natural gravity of the landslide, the maximum unbalanced force converges rapidly at the initial stage, and finally converges to below 10-6 (system default), as shown in figure 2 which reflects that the landslide is in a stable state. The displacement of the landslide under natural gravity is shown in figure 3. The maximum displacement is in the middle of the landslide, which can reach 15.9 cm, which is consistent with the 13 cm wide crack in the middle of the landslide investigated on site.

In the natural state of the landslide, the phenomenon of shear strain concentration appeared, and the maximum value of shear strain was 3.7862E10-3, and there was no phenomenon of shear strain penetration. Generally speaking, the landslide is basically stable in its natural state.

Table 1. Model calculation parameter table.

	group number	ElasticModulus(10^4MPa)	Poisson's ratio	Cohesion(kPa)	Internal friction angle(°)	density(kg/m^3)
sliding mass	group 1	3	0.27	72	23	2400
sliding bed	group 2	5	0.25	1100	44	2650
sliding surface	interface 1	3	0.27	90	29	

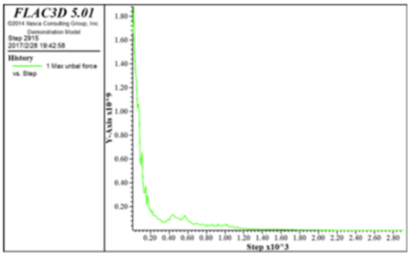

Figure 2. Convergence characteristics of maximum Unbalance force in static calculation.

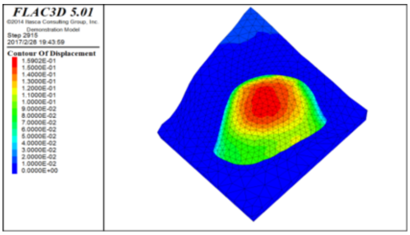

Figure 3. Distribution characteristics of landslide displacement under gravity field.

3.2. Dynamic Analysis of Landslide under Earthquake Action

FLAC3D can be used to simulate and calculate the completely nonlinear dynamic response of landslides under the action of external earthquakes. On the basis of the previous static calculations, the dynamic analysis mainly considers the following three aspects:

- Input of dynamic load
- Damp setting
- Boundary conditions

3.2.1. Input of Dynamic Load

The shaking process of an earthquake is a dynamic process with a certain duration. The earthquake acts through the bottom surface of the landslide and propagates along the rock and soil mass. The force generated during the propagation process and the state (size, direction, etc.), FLAC3D allows the dynamic load input to include acceleration, velocity time, stress and other time histories.

Here the seismic data is imported using system functions, which is generally used for dynamic load input with irregular discrete distribution (filtering and baseline correction are required).

The basic seismic intensity of the landslide area is VII, which is equivalent to a peak ground acceleration of 0.10~0.15g. By analogy, the approximate artificially synthesized acceleration time-history data is selected as the input source of seismic load. The seismic wave this time uses horizontal vibration (the x direction of the model), with a peak value of 0.12g. Spectrum analysis by SeismoSignal software is used to obtain the "frequency-velocity spectrum" diagram, as shown in figure 4. It can be seen that the seismic wave energy is mainly concentrated in 0~10Hz, so the components greater than 10Hz are filtered, and the baseline correction is performed to make the cumulative velocity and cumulative displacement approximately equal to zero, and then imported into FLAC3D, as shown in figure 5.

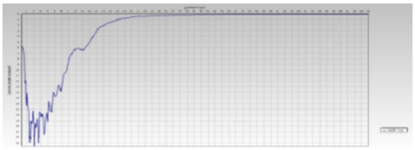

Figure 4. Input the frequency - velocity spectrum of seismic wave.

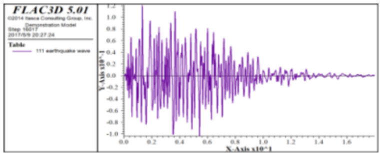

Figure 5. Input FLAC3D seismic wave acceleration the spectrum.

3.2.2. Damping Setting

The internal friction of the rock and soil mass and the breaking and sliding of the potential contact surface will play a damping role in the transmission of dynamic loads. Therefore, in the process of dynamic calculation, it is necessary to set the damping to represent the natural state of the rock and soil mass. There are Rayleigh damping, local damping and hysteretic damping in FLAC3D. Practice shows that the acceleration response law simulated by Rayleigh damping is better in line with the actual situation, but the calculation time step is small, and there are many model units in this calculation, which will greatly increase the dynamic calculation time, so local damping is used. In addition, uniform motion does not cause error resistance, and damping has nothing to do with frequency, which is also an important reason for choosing local damping.

The Rayleigh damping in the software needs to set the minimum critical damping ratio min and the minimum center frequency min. According to experience and "frequency-velocity spectrum", the former takes 3% and the latter takes 1.9Hz.

The local damping coefficient αL can be determined according to the empirical formula:

$$\alpha_L=\pi\xi_{min}$$

Among them, the value of the critical damping ratio ξmin can refer to ξmin in Rayleigh damping, which is 3%.

Therefore, in this dynamic analysis, the local damping coefficient αL is taken as 0.0942.

3.2.3. Boundary Conditions

In dynamic problems, the selection of model boundary conditions is an important part. The model boundary is considered to be rigid and will reflect waves, and the reflected waves will superimpose with the original waves, changing the properties of the original waves, and then affecting the results of dynamic simulation. FLAC3D provides two boundary conditions, static boundary and free field boundary, to reduce reflected waves. In this simulation, a static boundary is set at the bottom of the model, and a free field boundary is set around it.

The static boundary can absorb most waves with an incident angle greater than 30°, while waves with a relative incident angle less than 30° can only be partially absorbed. In this dynamic calculation, the following command is used to set the static boundary at the bottom of the model:

apply nquiet squiet dquiet ran z -0.001 0.001

The free field boundary is a circle of one-dimensional and two-dimensional grids wrapped around the model, as shown in figure 6, the two grids are assumed to be infinitely extended in the normal direction, and together form the free field boundary, which corresponds to the corresponding main model grid one-to-one.

The free-field boundary grid and the main body grid of the model are coupled through a damper, and the free-field boundary extends infinitely in a specific direction, which is equivalent to providing an infinite site, so the waves on the model boundary will not be reflected and distorted.

3.2.4. Simulation Result Analysis

The performance of the landslide under earthquake action can be obtained through numerical simulation analysis. Here, the instability state of the landslide is predicted mainly based on the shear strain criterion on the shear zone and the displacement and deformation rate criterion.

(1) The shear strain criterion on the shear band

When people analyze slope stability, they usually consider the through shear zone as the potential sliding surface. When the shear strain is within the small deformation range of less than 10-5, the deformation of most soil rocks shows recoverable and purely elastic characteristics, which may be caused by the natural vibration of rock mass under dynamic action. In the medium deformation range of 10-4~10-2 magnitude, the rock mass exhibits elastoplasticity and produces irreversible permanent deformation. Combined with this engineering example, it is considered that the landslide will be unstable along the shear zone when the shear strain value on the shear zone reaches the magnitude of 10-4 or more. As shown in figure 7.

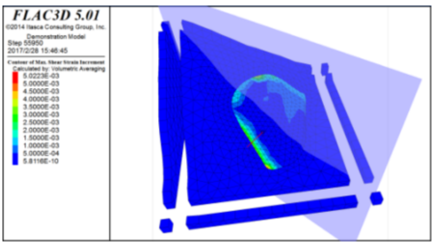

Figure 6. Distribution of shear strain increment and landslide mass after earthquake.

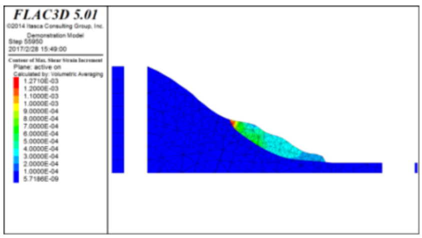

Figure 7. Schematic diagram of shear strain slice position of increment slice of landslide mass after earthquake.

It can be seen from figure 8 that after the landslide experienced the ground motion load with the peak acceleration of 0.10~0.15g, a shear strain concentration area appeared on the left side of the original sliding surface, and the maximum value could reach 5.0223E-03, which is the most likely place of destruction. From the schematic diagram of the slice, it can be seen that the shear strain is more concentrated on the upper part of the sliding surface (the maximum value is 1.2710E-03), and the shear strain gradually decreases along the sliding surface, but the values are all in the range of 10-4 order of magnitude, reaching the condition of shear band instability.

(2) Displacement magnitude and deformation rate criterion

The occurrence of landslides is accompanied by deformation and failure. Judging the deformation and damage of landslides from the displacement and deformation rate of the particles on the landslide is more intuitive and clear. However, there is no unified understanding of the displacement and deformation rate of landslide failure. According to the existing actual engineering experience, the critical displacement of clay landslide is about 2.00cm, and the critical displacement of rock landslide is about 1.50cm. Combined with the actual situation, the critical displacement value of the rock landslide of 1.80 cm is used here, supplemented by the deformation rate value of the order of 10-4mm/s as the criterion for the failure of the landslide.

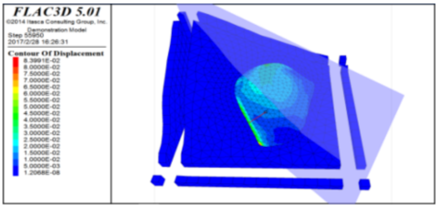

Figure 8. Shear strain increment distribution and slice position of landslide body after earthquake

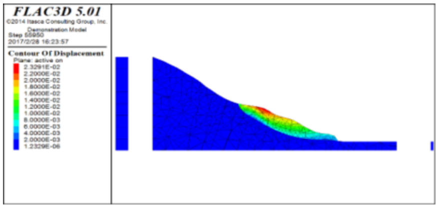

Figure 9. Schematic diagram of landslide displacement slice after earthquake action

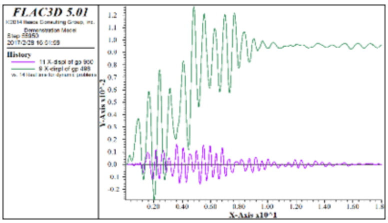

Figure 10. Time history diagram of displacement in the x-direction of monitoring points for bedrock and sliding mass after earthquake action.

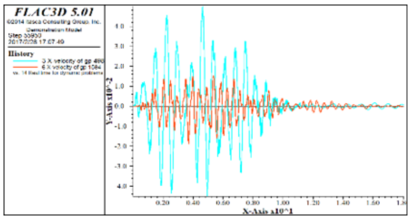

Figure 11. Time history diagram of x-direction velocity at monitoring points of bedrock and sliding mass after earthquake action.

Figure 8 shows the distribution characteristics of the overall displacement of the landslide after the earthquake. The extreme value of the displacement is 8.399 cm at the lower left of the sliding surface, and the general displacement is 1.5~4.0 cm in the center of the sliding body; Figure 9 shows that the deformation starts from the surface of the sliding body , until destroyed.

Figure 10 is the X-direction displacement time history diagram of the bedrock (curve 9 X-displ of gp 498) and sliding mass (curve 11 X-displ of gp 950) monitoring points after the earthquake. During the entire 18s earthquake, The particles in bedrock fluctuate with earthquake action near the origin, showing a recoverable elastic structure; the displacement of the particles in the sliding body gradually increases with the earthquake fluctuation, and after 4.4s of the earthquake, there is a permanent displacement to the free surface. In the subsequent earthquake vibration, the fluctuation of the particle gradually becomes smaller, indicating that the particle has been destroyed. Figure 11 shows that no matter it is bedrock or sliding mass.

4. Conclusion

The characteristic data of the landslide were obtained through field survey, the numerical model of the landslide was established, the relevant mechanical parameters were given, and the stability of the landslide under the action of the earthquake was analyzed by the numerical simulation method.

(1) According to the static calculation and analysis, in the natural state (gravity stress field), the maximum displacement of the landslide is in the middle and upper part of the sliding mass, and the displacement is 15.9 cm, which is in good agreement with the results of the field survey; the shear strain is concentrated on the sliding surface In the middle and upper part, but it has not yet penetrated, and the maximum unbalanced force converges well, indicating that the landslide is in a basically stable state.

(2) Under the earthquake load of local seismic intensity VII degree, the sliding body revived along the boundary as a whole, and the middle and upper part of the sliding body deformed obviously, and the failure and deformation occurred again. This was due to the relatively poor mechanical properties of the sliding body itself. , the parameters of the sliding surface will also decrease due to the cumulative vibration of the seismic load.

(3) The Mohr-Coulomb model is used to simulate the landslide that has slipped. The results show that under the same seismic action conditions, the sliding body is more sensitive to earthquake action than the surrounding stable bedrock, and has a significant amplification effect.

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