Analysis of the stability of Zhangjiapo landslide

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Abstract. The Zhangjiapo landslide in Xinling Town; Badong County has obvious deformation and a great hidden danger of safety in the past two years. In order to better treat the Zhangjiapo landslide, I quantify the stability of Zhangjiapo landslide using transfer coefficient method. And this method is compared and verified with the method of strength reduction stability analysis after using Rhino to establish geological model into FLAC3D. The results show that the stability coefficient is basically the same, and the Zhangjiapo landslide is extremely unstable under rainstorm condition. It proves the reliability of the paper’s numerical simulation method in landslide research and provides a reference for the analysis of the landslide. According to the engineering geological characteristics of Zhangjiapo landslide and the influence of deformation area on landslide body, combined with the present situation of landslide, the comprehensive treatment scheme of landslide body "anti-slide pile+reinforcement of landslide front+drain" is put forward from the point of view of protecting environment.

1. Introduction

Landslide is a serious geological hazard. People pay more and more attention to the casualties and economic losses caused by landslide. The landslide disaster in the Three Gorges Reservoir area has the characteristics of wide distribution, high frequency, heavy disaster and strong sudden occurrence [1-3]. Zhangjiapo landslide is located in 12 groups of Loess Slope Community in Xinling Town, Badong County, Three Gorges Reservoir area. In the past two years, the landslide has obvious deformation and further deterioration trend. Once the disaster is caused, it will seriously affect the safety of the existing people's lives and property, and limit the development around the city line. Effective prevention and control work is needed [4].

The stability coefficient of landslide can be obtained by engineering geological survey and quantitative analysis of landslide stability, but it is not accurate enough to determine landslide stability from only one aspect [5-9]. Therefore, the present situation of landslide is simulated by numerical simulation method, and the stability coefficient is obtained. The accuracy of landslide stability coefficient can be verified by comparing the two methods [10, 11].

Taking Zhangjiapo landslide in Xinling Town, Badong County as the research object, the three-dimensional geological model of landslide is established. Based on finite difference software FLAC 3D, the deformation characteristics and stability coefficient of landslide in natural and rainstorm state are studied, and the results of transfer coefficient method are compared and verified with the commonly used transfer coefficient method in engineering, which provides the basis for engineering analysis and prevention [12-14].
2. **Geological conditions of landslides**

Zhangjiapo landslide is located in the middle and upper part of the fan-shaped slope in Xincheng District of Badong County. Elevation 410-600 m for slope distribution. The geographical location is shown in Figure 1.

The outcrop strata in Badong County are mainly Lower Triassic Jialingjiang Formation, Middle Badong Formation and Quaternary. Because of the construction of 209 national highway around the city line, the original geomorphology is changed greatly, the stability of slope body is reduced, and landslide deformation and failure are easy to occur.

3. **Quantitative analysis of landslide stability**

3.1. **Transfer coefficient method**

The transfer coefficient method is simple and easy to grasp. The influence of rainfall on landslide stability can be considered, and it can be used as the preferred method for stability analysis in engineering practice. In this paper, the safety factor is calculated according to the general formula of transfer coefficient method. The problem of landslide stability is regarded as plane strain problem, the sliding force acts on the sliding surface by the shearing strength \( \tau \) parallel to the sliding surface and the normal stress \( \sigma \) perpendicular to the sliding surface, the landslide is regarded as ideal rigid plastic material. Figure 2, 3 show calculated profiles 2-2’ and 3-3’ selected according to drilling data. Profile 1-1’ is similar to profile 2-2’.

![Figure 1. Location of Zhangjiapo landslide.](image)

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![Figure 2. Engineering geological profile 2-2’.](image)

![Figure 3. Engineering geological profile 3-3’](image)
3.2. Calculation parameters
According to the test index, inversion parameters and engineering analogy, the shear strength index of Zhangjiapo landslide stability calculation is determined. The sliding surface \( C = 20 \text{ kPa}, \phi_C = 12 \) in saturated state and \( 25 \text{ kPa}, \phi_C = 15 \) in natural state. According to the drilling data, the natural conditions in the 1-1’,2-2’ sections are no water, and the natural groundwater level in the 3-3’ section is very high.

3.3. Calculation conditions
The sliding zone and lower voluminous rock of Zhangjiapo landslide are relative water barrier, the material of landslide is broken, the surface rainfall is easy to infiltrate, and the groundwater level in landslide will rise soon after rainfall infiltration. The landslide is a non-wading landslide, and the seismic load is not considered. The calculation conditions are divided into the following two types, as shown in Table 1.

| Working condition combination number | Content of load combination |
|-------------------------------------|-----------------------------|
| I                                   | Dead load+Surface load+Current water level |
| II                                  | Dead load+Surface load+Heavy rain levels in 20 years |

3.4. Computing result
According to the Technical Requirements of Geological Disaster Prevention and Control Engineering Survey in the Three Gorges Reservoir Area, the stability state is determined according to the stability coefficient of landslide. As shown in Table 2.

| Stability coefficient of landslide Fs | 1.00<Fs≤1.05 | 1.05<Fs≤1.10 | Fs≥1.10 |
|--------------------------------------|--------------|--------------|----------|
| stable state                         | unstability  | understable  | basic stability stabilize |

The results of the transfer coefficient method are shown in Table 3. For profile 1-1’, 2-2’, because there is no groundwater in the natural state or the groundwater level is low, so the rainstorm state has a great influence on its stability coefficient;

| Profile | Working condition | I   | II  |
|---------|-------------------|-----|-----|
| 1-1     |                   | 1.085 | 0.864 |
| 2-2     |                   | 1.028 | 0.819 |
| 3-3     |                   | 1.002 | 0.99  |

4. Numerical simulation of landslide stability
4.1. Modeling process
Rhino is professional 3D modeling software with high graphics accuracy, it can input and output dozens of file formats. Griddle is Rhino plug-in for generating advanced meshes, which can accurately generate and divide surfaces into different types and sizes of surface meshes in Rhino. Flac3D is a powerful discrete element numerical simulation software, but limited by complex geological modeling. Through Griddle, the 3D modeling function of Rhino can be combined with the numerical calculation
and analysis of FLAC3D. The technical route of this paper is shown in Figure 4. The rhino modeling effect is shown in Figure 5.

![Figure 4. Model pre-processing flow diagram.](image)

![Figure 5. Profile grid in Rhino.](image)

4.2. Building models

4.2.1. Basic principle of strength reduction method. The strength reduction method defines the slope safety factor as the reduction of the strength parameters when the slope reaches the critical failure state. When the slope adopts the Mohr-Coulomb criterion, the strength parameters affecting its stability are $c$ and $\phi$. Divide the original cohesion and internal friction angle of the slope body by reduction coefficient $K$, then numerical analysis. By increasing $K$, repeated analysis until the slope reaches critical failure state. Suppose the cohesion and angle of internal friction are $c^{cr}$ and $\phi^{cr}$ at this time, because the slope is critical, the corresponding safety factor is $K^{cr} = 1$, the original safety factor corresponding to the slope can be obtained as:

$$ F = \frac{K}{K^{cr}} = K = \frac{c}{c^{cr}} = \frac{\tan \phi}{\tan \phi^{cr}} $$

In this paper, we assume that all non-empty regions of the numerical model adopt the Mohr-Coulomb constitutive model, the command Solve fos is used to solve the safety factor in the FLAC3D.
4.2.2. Definition of coordinate system and model scope. The model boundary condition is one-way constraint: along both sides of the aspect is a displacement constraint in the X direction, the bottom of the model is the displacement constraint in the model, the both boundaries perpendicular to the profile are Y direction displacement constraints. Calculation model range: profile 1-1’ X axis direction 333 meters, Z axis direction 160 meters; profile 2-2’ X axis direction 395m, Z axis direction 193 meters; profile 3-3’ X axis direction 340 m, Z axis direction 150 meters. Y axis direction thickness of all profiles is 4 m. The grid consists of 4*4*4 hexahedron.

4.2.3. Determination of calculation parameters. The strata are grouped into L1~L6, as shown in Table 4 and assigned values in the Flac3D according to the stratigraphic characteristics.

Table 4. Parameters of rock and soil.

| Stratigraphic grouping | Name of soil layer                  | Density (g/cm³) | Cohesive strength (kPa) | Internal friction angle (°) |
|------------------------|-------------------------------------|-----------------|-------------------------|---------------------------|
| L1                     | Surface tillage or artificial fill  | 1850            | 5                       | 15                        |
| L2                     | Silty clay or silty clay with gravel| 1900            | 23                      | 14                        |
| L3                     | Gravel soil or broken stone         | 2250            | 2                       | 36                        |
| L4                     | Block stone                         | 2300            | 3                       | 38                        |
| L5                     | Argillaceous siltstone              | 2100            | 4                       | 34                        |
| L6                     | Marl, limestone                     | 2490            | 30                      | 40                        |

4.3. Analysis of landslide stress

Figure 6 shows the maximum principal stress cloud of the model:

Similar to most slopes, the maximum principal stress of the model is “strip distribution”, which decreases from the bottom to the surface, and most areas of the model are basically compressive stress.

4.4. Displacement characteristics of landslide

Figure 7 shows the horizontal displacement of the model landslide:
4.5. Maximum shear strain increment

The maximum shear strain increment cloud is shown in Figure 8:

![Image of Figure 8](8(a) profile 3-3' (I) 8(b) profile 3-3' (II))

Figure 8. Maximum shear-strain increment cloud.

Profile 1-1’ has the largest shear strain increment at the foot of slope, profile 2-2’ has the largest shear strain increment at the back edge of the landslide, profile 3-3’ has the largest shear strain increment at the front edge of the landslide. The maximum shear strain increment of landslide reflects the area of shear deformation in the sliding body, and its penetration can indicate the characteristics of landslide instability. Figure 8 shows that the region with the largest change in shear stress variability within the slope body is arc-shaped, most likely a potential sliding surface.

4.6. Displacement analysis of monitoring points

In order to further grasp the landslide deformation stability, monitoring points were set up at the front, middle and back of the three sections of the landslide, to provide the basis for the analysis of the landslide stability. The location of the monitoring points is arranged as shown in Figure 9.

![Image of Figure 9](9(a) profile 1-1’)

Figure 9. Layout of displacement monitoring points.
The displacement curve of the monitoring point is shown in Figure 10.

The results show that the front and middle of the landslide are the most displacement, and the rear part of the landslide is the first displacement.

4.7. Evaluation of simulation results
(1) Under the rainstorm condition, the shear strain increment of landslide appears obviously through compared with the natural condition, and the shear strain increment through area of the simulation result is consistent with the sliding surface revealed by drilling. Because the shear strain increment basically runs through the whole slope body, the landslide is in an unstable state under rainstorm condition.

(2) According to the location of the initial slide, Zhangjiapo landslide belongs to the rear thrust load caused landslide. This is consistent with the conclusion of engineering geological survey and provides the basis for putting forward targeted landslide prevention and control measures.

(3) The safety factor of three profiles under two working conditions is calculated, which is basically consistent with the safety factor calculated by the transfer coefficient method. The landslide safety coefficient pair is shown in Table 5.

Table 5. Results of the calculation of stability coefficients.

| Method                  | Profile(working condition) | 1-1’ (I/II) | 2-2’ (I/II) | 3-3’ (I/II) |
|-------------------------|----------------------------|-------------|-------------|-------------|
| Transfer coefficient method |                           | 1.085/0.864 | 1.028/0.819 | 1.002/0.990 |
| Numerical simulation    |                           | 1.09/0.87   | 1.04/0.84   | 1.01/0.97   |

5. Conclusion and suggestion
This paper constructs a complex three-dimensional numerical model of Zhangjiapo landslide in Flac3D based on Griddle in Rhino. On this basis, the stability of Zhangjiapo landslide under two working conditions is analyzed by comparing strength reduction method and transfer coefficient method. The study concluded that:

(1) The stability coefficient of the three profiles under the rainstorm condition of Zhangjiapo landslide is less than 1. In view of the possibility of instability under the rainstorm condition, it is necessary to adopt comprehensive prevention and control project.

(2) Zhangjiapo landslide is the rear thrust load caused landslide. The propositional project plan of landslide prevention and control is as follows: the anti-slide pile is arranged outside the steep ridge in
the front of the landslide, the drainage measures are adopted on the periphery of the landslide, and the anti-slip retaining wall is arranged at the front edge of the landslide.

The three-dimensional geological model established by Rhino can directly and truly reflect the actual situation of landslide, but how to divide the grid more accurately, improve the accuracy of numerical simulation calculation, and make the Rhino model provide more accurate pre-processing model for Flac3D is the focus of future research.

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