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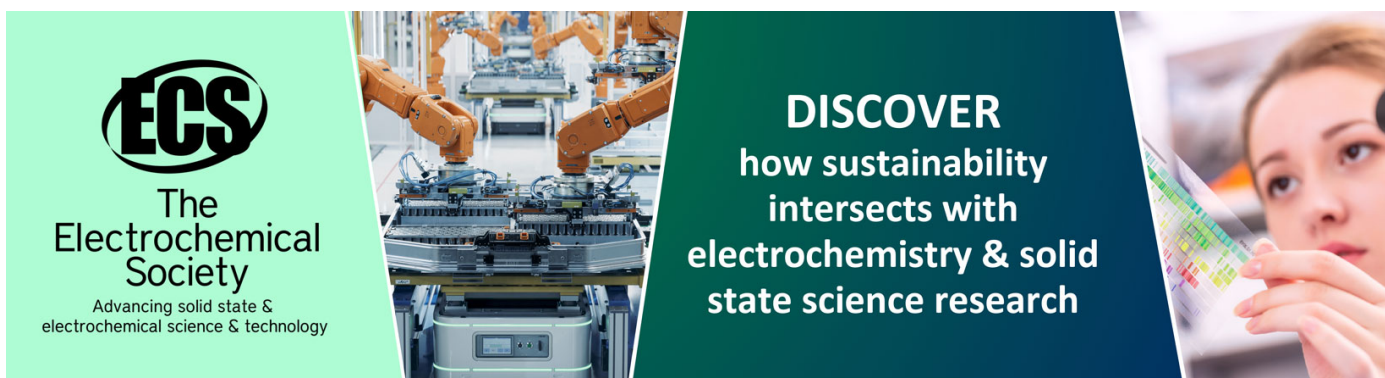
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Stability analysis of heterogeneous slope with concealed fault zone

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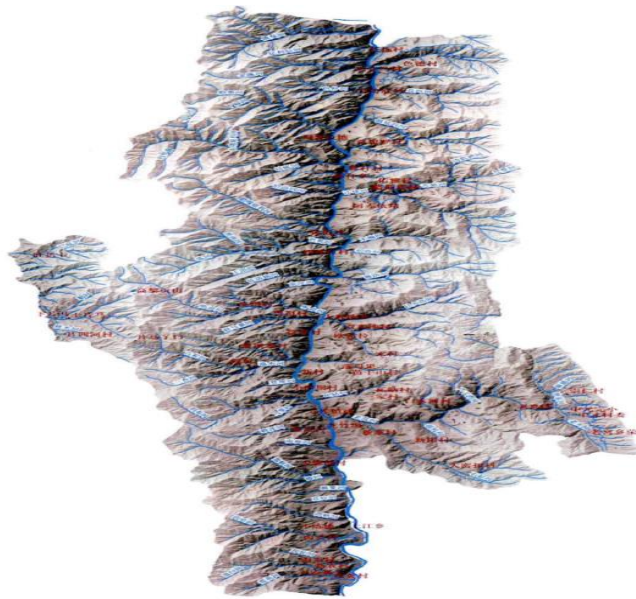
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Abstract: Combined with the heterogeneous slope of the concealed fault zone at the dam site of a hydropower station in Nujiang River, a numerical analysis model is established by FLAC3D to study the influence of the content of fault gouge and fault breccia in the concealed fault zone on the stability of the slope. The results show that the safety factor increases linearly with the increase of internal friction angle when the cohesion is fixed, and linearly with the increase of cohesion when the internal friction angle is fixed. The variation of safety factor of internal friction angle is greater than that of cohesion. If the content of fault breccia is high, the safety factor is high. If the content of fault gouge is high, the safety factor is low. Comprehensive safety factor of concealed fault zone of local strength reduction method is basically consistent with that of FLAC^{3D} concealed fault zone, and the heterogeneous slope is basically in a stable state.

1.Introduction

The slope of the dam site of a hydropower station in Nujiang River is located in the upper and middle reaches of the Nujiang River. Because it is located in the Himalayan tectonic belt, the crust rises violently and the rock mass is deformed and damaged, a typical alpine oolitic landform is formed. Figure 1 shows the upper and middle reaches of the Nujiang River, according to the study of Lu Han^[1]. Because of the complex geological structure, the lithology is complex and changeable. There are many kinds of bad geological action of slope, such as landslide, fault, collapse, dangerous rock fall, debris flow. Therefore, the Nujiang River Basin is a high frequency area where landslide geological hazards occur. Upper and Middle reaches developed accumulation slope, and it is mainly distributed in the slope area where the lithology of the Quaternary loose deposits is relatively weak, which has the characteristics of integrity and concealment of slope shape and poor stability of engineering disturbance^[1].





1Figure 1 Part of the upper and Middle reaches of the Nujiang River

2.Engineering overview of the study area

A hidden fault slope in this paper is located at a proposed hydropower project dam site in the middle reaches of the Nujiang River. The dam site is a typical "U" valley topography ", as shown in figure 2. According to the relevant literature, the lithology of the dam site is changeable, the left bank and the right bank are dolomite and basalt, respectively. The contact zone of basalt and dolomite produces fault zone, fault mud and fault breccia are mainly developed in the fault zone, and the fault zone is covered with Quaternary deposits, which has the characteristics of hidden fault zone slope.



Figure 2 Satellite map of Nujiang dam site

3.Mechanical parameters of rock and soil

The parameters of rock mass mechanics mainly refer to the physical and mechanical data of triaxial compression test rock mass of Zhou Hongfu[2]. According to the comprehensive analysis of the recommended indexes, the mechanical parameters of the Concealed fault zone under the Quaternary overburden of the slope in the study area are: the average elastic modulus is 665 MPa. The average Poisson's ratio is 0.46, and the standard value of 80% guarantee rate is 0.35. Average bulk density 2.344Kg·m⁻³. The average cohesive force is 0.13 MPa, the standard value of 80% guarantee rate is 0.12 MPa; and the range of mechanical properties of some basalt and dolomite is obtained according to the commonly used list of physical and mechanical parameters of rock and rock. The mechanical properties of rock and soil are shown in Table 1.

1Table 1 Mechanical Properties of Rock Soil

Name of rock and soil	Elasticity	Poisson	Bulk density	Adhesion	Internal
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	E / modulus M Pa	μ per cent	$\gamma / \text{k g} \cdot \text{m}^{-3}$	Force c / MPa	$\mu /$ of rubbing angle ($^{\circ}$)
Hidden fault zone	665	0.35	2.344	0.12	31.5
Basalt	83000	0.56-0.61	-	10-50	35-50
Dolomites	32000	0.39-0.56	-	20-50	50-55

The values of Poisson's ratio, bulk density and cohesion of 5 samples at different positions of concealed fault zone are different^[2]The test value of elastic modulus is more discrete^[2]This is mainly caused by the different content of fault gouge and fault breccia. If the content of fault breccia is low and the content of fault gouge is high, the test value is low, whereas the test value is on the high side, as shown in Table 2, the mechanical parameters of samples at different locations of concealed fault zones.

2Table 2 Mechanical parameters of samples at different locations of Concealed fault zones

	Elasticity E / modulus M Pa	Poisson μ per cent	Bulk density $\gamma / \text{k g} \cdot \text{m}^{-3}$	Adhesion Force c / KPa	Internal $\mu /$ of rubbing angle ($^{\circ}$)
Sample number					
No .1	609.7	0.52	2.36	130	46.8
No .2	487	0.61	2.35	40	54.9
No .3	831.7	0.35	2.31	220	31.5
No .4	780.3	0.49	2.32	170	44.1
No .5	614.3	0.32	2.37	80	28.8

4.FLAC^{3D}Numerical Simulation of Slope Stability Analysis

4.1.FLAC^{3D}Basic principles

FLAC3DThe basic principle of finite difference software is Lagrangian difference method. In order to meet the needs of various engineering analysis ,12 kinds of constitutive models of rock and soil are built in the software, among which, The most common constitutive model of rock and soil in slope stability engineering is the Moore-Coulomb model in plastic model[3]。

4.2.Establishment of computational models

The geometric model [4] of the slope with concealed fault zone is established according to the engineering geological conditions of the basalt and dolomite contact zone at the dam site in the upper and middle reaches of the Nujiang River. The slope length is 2.5 m, the slope height is about 1 m, the slope is 40, as shown in figure 3.

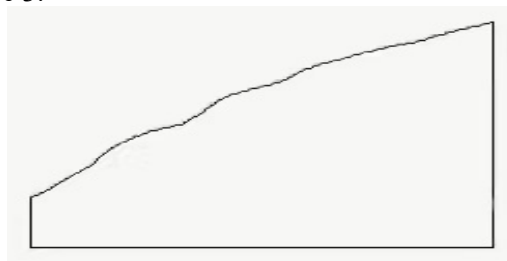


Figure 3 Geometric model

Calculation modelThe mechanical properties of the rock and soil required for establishment are shown in Table 1 and Table 2The failure condition is based on the Mole Coulomb model in the plastic

model[5]. Due to the failure to obtain accurate mechanical properties of Carboniferous basalt and Triassic dolomite in the dam site, it is proposed that the Rayleigh wave time domain signal propagation characteristics of formation models of contact zone basalt and dolomite be set the same. The purple color region represents the concealed fault zone, the slope of the fault zone is about 40° , and the overall slope of the lower part of the fault zone is less than 10° . The Rayleigh wave propagation characteristics of the calculation model are shown in figure 4.

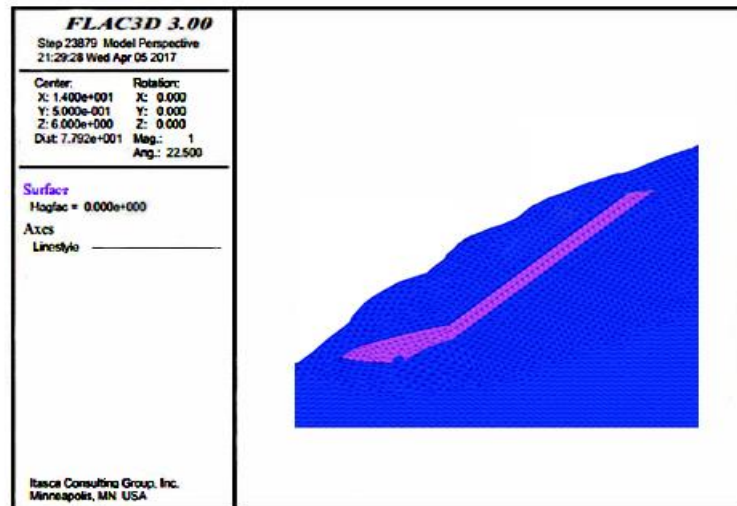


Figure 4 Calculation model

4.3. Results and analysis

The characteristic simulation of strain displacement [6,7] concealed fault zone is carried out according to the FLAC3D software, a preliminary analysis of the strain increment cloud map from Figure 5, and there is a large gap in dependent variable of different positions in the concealed fault zone. This is mainly due to the different content of fault gouge and fault breccia at different locations. The slope of the top and middle of the concealed fault zone is about 40° , and the middle part is larger than the top and bottom due to the high content of fault gouge; the top fault breccia is higher, the strain is smaller; and the bottom slope is less than 10° , the strain is smaller than the middle and bottom. Therefore, the stress variables in the middle of the concealed fault zone $>$ the top strain of the concealed fault zone $>$ the bottom strain of the concealed fault zone.

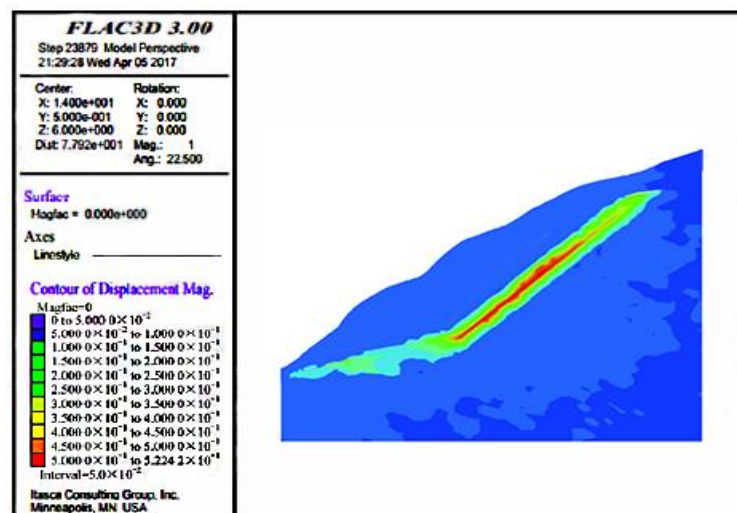


Figure 5 the strain increment cloud map

According to figure 6 displacement change cloud map, the middle layer displacement is larger than

the top and bottom because of the high fault gouge content, and the top fault breccia content is higher, then the displacement is smaller; The bottom slope is small, and the displacement is smaller than the middle and bottom. Therefore, the displacement in the concealed fault zone > the displacement at the top of the concealed fault zone > the displacement at the bottom of the concealed fault zone.

5. Analysis of Slope Stability in Hidden Fault Zone

5.1. Principle of local strength reduction method

The local strength reduction method is a method to calculate the safety factor by calculating the strength reduction method for the local soil, potential slip surface and weak soil layer of the slope [8]. As follows (1) and (2) are the formula [8,9] of strength reduction method [8,9].

$$c_F = \frac{c}{F} \quad (1)$$

$$\mu_F = \arctan\left(\tan \frac{c}{F}\right) \quad (2)$$

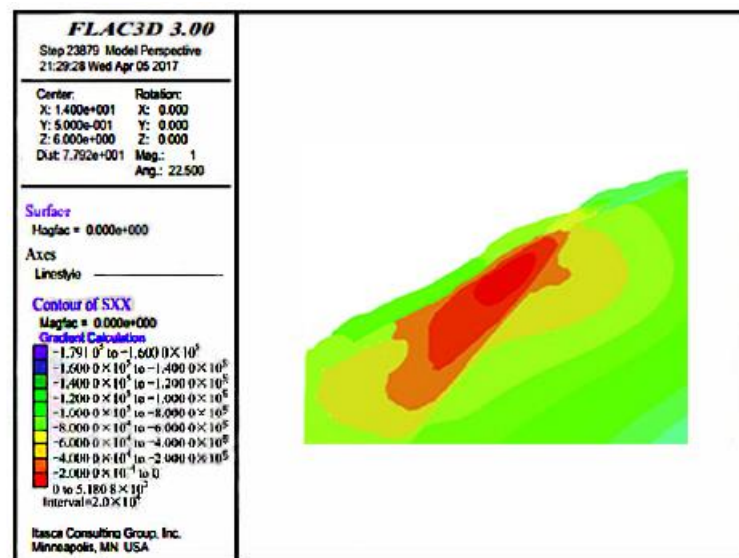


Figure 6 Clouds of displacement change

The c and μ in the formula are the indexes of shear strength (cohesion and internal friction angle) of the specimen in the concealed fault zone before the local slope strength is reduced; c_F and μ_F are the shear strength index of the sample after the local slope strength is reduced, and the F is the safety factor when the local slope model is just unstable [9].

According to FLAC3D local strength reduction of the hidden fault zone of the heterogeneous slope, the comprehensive safety factor of the plastic through zone is 1.212, and the heterogeneous slope is basically in a stable state.

5.2. Effect of internal friction angle and cohesion on safety factor of non-homogeneous slope in concealed fault zone

According to the calculation results, when the cohesive force is fixed, the influence law of the internal friction angle on the safety factor is drawn into figure 7, and when the internal friction angle is fixed, the influence law of the cohesive force on the safety factor is drawn into figure 8.

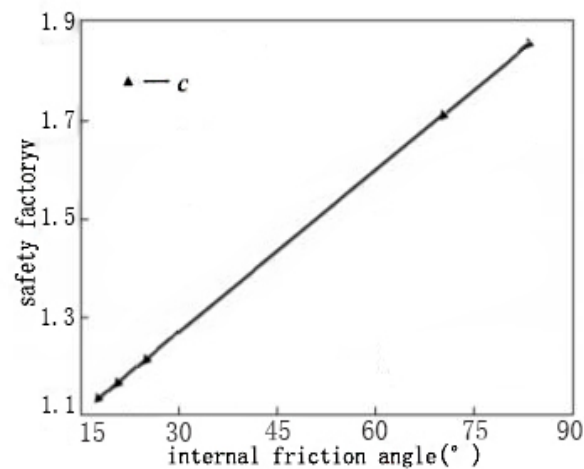


Figure 7 Graph of the relationship between internal friction angle and safety factory

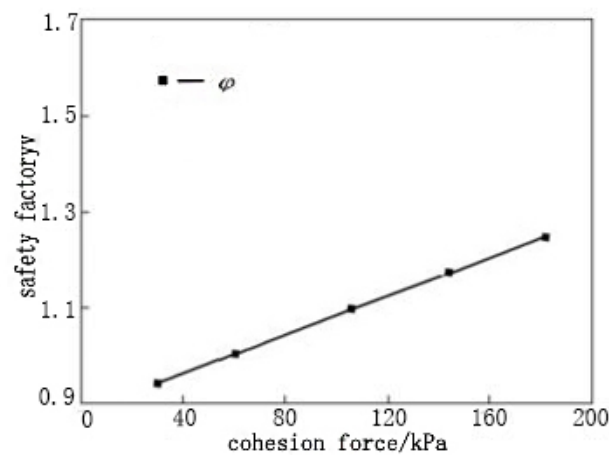


Figure 8 Graph of the relationship between cohesion force and safety factory

5.3. Effect of shear strength on safety factor

Using the local strength reduction method combined with the above geometric model, Through the collected shear strength (cohesion and internal friction angle) data of 5 samples at different positions of the fault gouge and fault breccia of the concealed fault zone of the heterogeneous slope, the shear strength and safety factor of the 5 specimens in Table 3 after local strength reduction are obtained, and based on the different content of fault mud and fault breccia of 5 samples in different positions of concealed fault zone, the influence [10] on the safety factor of local position and the comprehensive safety factor of concealed fault zone are analyzed.

Table 3 Shear strength and safety factor after local strength reduction

c_F of cohesion/ KPa	33.00	66.01	107.26	140.26	181.52
μ_F of internal friction angle / (°)	86.3	25.5	17.9	69.0	21.6
F safety factor	1.521	0.984	1.026	1.517	1.186
F_r of comprehensive safety factor	1.247				

Combined with the data analysis of Table 3, Figure 7 and Figure 8, it can be seen that the safety factor of different positions in concealed fault zone is different, and when the local safety factor in concealed fault zone is very high, the breccia content of fault in this position is high. On the contrary, the content of fault mud is high; when the cohesion is fixed, the safety factor increases linearly with the increase of internal friction angle; when the internal friction angle is fixed, the safety factor

increases linearly with the increase of cohesion force; The change range of the safety factor of the internal friction angle is greater than that of cohesion.

6. Conclusion

The safety factor is different at different locations in concealed fault zone; When the cohesion is constant, the safety factor increases linearly with the increase of internal friction angle; When the angle of internal friction is fixed, the safety factor increases linearly with the increase of cohesion; The change range of the safety factor of the internal friction angle is greater than that of cohesion; If the content of fault breccia is high, the safety factor is high. If the content of fault gouge is high, the safety factor is low; The comprehensive safety factor of hidden fault zone by local strength reduction method is 1.247 and that of hidden fault zone FLAC3D numerical simulation is 1.212, then the comprehensive safety factor of hidden fault zone by local strength reduction method is basically consistent with that of FLAC3D hidden fault zone, and the inhomogeneous slope is basically in a stable state.

Acknowledgments

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References

- [1]H Lu, Early Identification and Stability Analysis of Accumulated Landslide in Lushui Section of Nujiang River Basin. Beijing: China University of Geosciences (Beijing) ,2020.
- [2]H.F Zhou, Y.T Wei. (2020) Analysis of Characteristics of Soft Structural Surface Construction in Permafrost Region under Intermittent Dynamic Shear. Journal of Southwest Jiaotong University, 1-7.
- [3]T.Y Sun, Analysis of Slope Stability Based on FLAC^{3D} and Numerical Simulation of Support. Beijing: China University of Geosciences (Beijing) ,2020.
- [4]C.B Liu, Z.X Yan, G.H Zhang, J.X Wang, (2020) Influence of Weak Interlay Parameters on Stability and Anchorage of Rock Slope. Journal of China Three Gorges University(Natural Sciences), 42(04):28-34.
- [5]R.H Zhao, Y Zhou, W Wang, T Li.(2020)Influence of Occurrence Characteristics of Weak Interlay on Slope Stability. Safety in Coal Mines,2020,51(03):227-230.
- [6]J Cai, Y.F Yan, J.Z Chen, S.M Dong, P Cao.(2019)Slope Stability Analysis Based on FLAC^{3D} Platform——Taking Puyang Coal Mine No .1 dump as an example. Journal of Geological Hazards and Environment Preservation,2019,30(01):54-60.
- [7]W.D Han, Y.G Shi.(2019)Slope Stability Analysis and Research Based on FLAC^{3D} of Opencast Mine. Coal Technology,2019,38(09):51-53.
- [8]M Liao, Y Xie, Y Chen, R.H Wang.(2020)Stability analysis of heterogeneous slope based on local strength reduction method. Sichuan Water Resources,2020,41(03):30-32.
- [9]J.S Yao, P Cai.(2020)Comparative Study of Integral and Local Strength Reduction Method in Slope Stability Analysis. Journal of Water Resources and Architectural Engineering,2020,18(02):76-81.
- [10]H.C, Jiang.(2017)FLAC^{3D}Analysis of Factors Influencing the Safety Factor of Subgrade Slope. Journal of Railway Science and Engineering,2017,14(11):2358-2362.