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Study on stability of the Santai Mountain landslide based on FLAC^{3D} numerical simulation

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Abstract: **A case study of the Santai Mountain landslide in Xuzhou, this paper based on the field engineering geological mapping, drilling and laboratory test. In order to fully understand its formation mechanism and stability, FLAC^{3D}, the three-dimensional finite difference software, is used to combine the limit equilibrium theory to analyze the stability of the landslide under the different working conditions and to predicate the development trend of landslide. The results show that the system is in a stable state under the natural condition, and is in an unstable state under the rainstorm condition.**

Keywords: Santai Mountain Landslide; Stability; FLAC^{3D}; Numerical simulation

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1. Introduction

Landslides are common in mountainous and hilly areas of China, and are often related to the regional distribution of geotechnical soils, such as landslides of flaky metamorphic rocks or stratified rocks in southern and southwestern China, loess landslides in the northwest, and weathered rocks in southern China. Body landslides and expansive soil landslides in the middle and lower reaches of the Yangtze River[1]. With the development of China's social economy, environmental geological conditions are getting worse. In recent years, China's landslide geological disasters have become more frequent and serious, causing widespread concern of engineers and researchers.

Taking the Santaishan landslide in Suqian as an example, on the basis of field engineering geological mapping, drilling and laboratory tests, in order to fully understand its formation mechanism and stability, this paper uses three-dimensional finite difference software FLAC^{3D} combined with limit equilibrium theory to analyze the different working conditions. The stability of the landslide is predicted by the development trend of the landslide. The results show that the landslide is in a stable state under natural conditions. It is unstable under heavy rain conditions, and it is recommended to take effective measures to prevent and control the landslide.

2. Landslide engineering geological overview

The Santaishan landslide is located in the northern suburb of Suqian City. The landform type is mainly composed of hills and alluvial plains. The terrain is undulating, with an elevation of 40~88m. The overall northeast strike is about 1km in length and 140~170m in width. The area is about 0.2km^2. In the middle of the landslide area, there is a slope with a trend that is basically consistent with the direction of the mountain. The slope of the slope is 45~85 °, and the slope height is 10~30m. The elevation of the slope bottom is 45~60m, the elevation of the slope top is 54~88m, and a safety platform is left in the part. The southern part of the landslide area is the original mountain, and most of the area is not mined, and it remains basically the same. The northern part of the landslide area is abandoned by the mine. The area is uneven, the ground elevation is 45~65m, and some areas have artificial landfill. There is a rocky steep slope in the eastern part of the northern part of the work area, and the height difference is generally not more than 10m.

The landslide area is an abandoned mine left over from history. After the mine is disturbed by mining, many rocky steep slopes are formed. The landslide area has an occurrence of 265~278 °∠9~15 °, and its slope is mainly a sloping slope with a slope of 40~80 °. The part is nearly erect, and there are many umbrella-shaped rocks. The slope height is 0~40m. There are many dangerous rock masses at the top, and several 10~30cm wide cracks appear on the trailing edge. The mine slope is mainly composed of the Ordovician Xiaoxian Formation limestone and Jiawang Formation argillaceous dolomite. The pale yellow and light purple-red sheet-like argillaceous dolomite is exposed in the middle of the southern slope, and it is easy to expand and soften when exposed to water.

3. Landslide formation mechanism

Mount Santai is a mining material for dolomite mining. It is one of the building materials supply areas in the surrounding area. After long-term mining and blasting, the vegetation on the mountain has been destroyed, and the slope of the mountain has been seriously damaged. The slope of the slope is 40~80 °. Locally nearly erect, the main landslide section of Santai Mountain is a sloping slope, and the formation is 265~278 °∠9~15 °, the inclination angle of the sliding belt is much smaller than that of the slope; the joint crack of the slope is developed, and the water flow such as rainfall enters the sliding zone through the rock layer and the joint fissure channel, which causes the shale dolomite layer to expand and soften. The formation of a weak interlayer, and the weight of the upper part of the rock and soil body is easy to form a landslide. According to the analysis, the Xiaoxian

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Formation dolomite in the upper part of the slope is the main source of the landslide thrust. The upper part of the sliding zone produces downward thrust for the lower rock mass; while the front edge of the slope body is steep and the upper rock mass is squeezed. Under the driving force, the rock mass is partially visible. Generally, the contact surface of the rock layer has a certain friction and anti-sliding force, which hinders the sliding of the upper rock mass. In the rainy season, due to the saturation, softening and sticking of the rock mass at the contact surface. The cohesion and internal friction angles are greatly reduced, which tends to cause the instability of the sliding body, which will pose a threat to the buildings around the slope.

Table 1. Media parameters of rock and soil model

Lithology	Density /kg/m^3		Cohesion /MPa		Internal friction angle / °		Tensile strength /GPa	Bulk modulus /GPa	Shear modulus /GPa
	Natural	Rainstorm	Natural	Rain storm	Natural	Rainstorm			
Xiaoxian Formation limestone	2700	2750	0.092	0.089	28	26	3.1	7.9	5.1
Jiawang Formation Mud Dolomite	2800	2850	0.061	0.057	30	27	2.4	8.5	4.7
Sanshanzi Formation limestone	2700	2750	0.082	0.075	27	25	3.6	8.6	4.9
Contact surfaces	\		Cohesion /MPa		Internal friction angle / °		Tangential strength /GPa/m	Normal stiffness /GPa/m	\
Slip belt	\		0.030	0.028	30	27	1.2	1.2	\

4. landslide stability analysis

4.1. Numerical simulation analysis

In order to deeply study the stress and deformation characteristics of the landslide body and analyze its stability, this paper uses the FLAC^{3D} software developed by ISTA to simulate the landslide[2,3], which provides a reference for evaluating its stability.

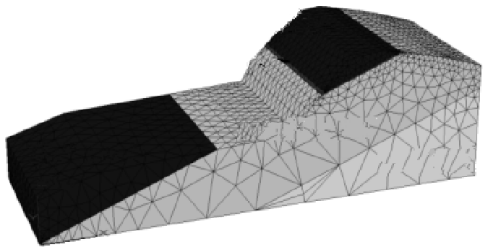

Figure 1. Numerical model.

(1) Model establishment

According to the drilling data, on-site investigation and engineering geological mapping, the numerical model is built to analyze the stress and deformation characteristics of the landslide body, and the model is optimized. The landslide body bedrock adopts the solid element, and the sliding zone is simulated by the contact surface element. The height of the base of the calculation model is 30m. According to the field survey results, the highest point elevation of the trailing edge of the landslide is 74m, the x-axis length is 146m, and the y-axis width is 50m. The model has a total of 13250 units and 3240 nodes. The slope of the model is a free surface, and the surrounding and bottom surfaces are normalized. The landslide body bedrock adopts the elastoplastic model, using the Mohr-Coulomb yield criterion, ignoring the tectonic stress effect, and only considering the slope body's own gravity (Figure 1).

(2) Selection of parameters

Through the indoor test, on-site sampling and analogy of similar projects in the area, the physical and mechanical parameters of the landslide rock and soil are shown in Table 1.

(3) Analysis of simulation results

In the numerical simulation, the criterion of slope deformation and failure is considered[4-6], which is mainly analyzed from three aspects: shear strain increment, displacement and monitoring point displacement curve.

Figure 2. increment of landslide shear strain in natural state.

Figure 3. increment of landslide shear strain under rainstorm condition.

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Figure 4. displacement nephogram displacement of landslide under natural condition.

Figure 5. slope displacement nephogram of rainstorm state.

Incremental analysis of shear strain: Even the town camp and other scholars regard the penetration of shear strain increment as the criterion for determining slope instability[7-9]. When the sliding body is in the natural state (Figure 2), the sloping shear strain increment is concentrated at the two ends of the contact surface of the Xiaoxian Formation and the Jiawang Formation bedrock, but the through surface is not formed, the landslide body is stable overall, and the possibility of slipping is small, and local slippage may occur. When the sliding body is in heavy rain (Figure 3), the shear stress of the sliding belt is concentrated and a complete through surface is formed, which is likely to produce a landslide. According to the analysis, the joint fissures in the weathered limestones of the Xiaoxian Formation in the slope body are developed. Under the rainstorm state, the water flows through the joint fissure channels into the contact surface of the rock strata.

The rainwater causes the argillaceous dolomite to expand and soften, and the physical and mechanical properties of the weak structural plane are reduced, forming a weak In the interlayer, the stability of the landslide is greatly reduced. The topography of the front edge of the slope is steeper. Under the action of the upper rock mass of the weak interlayer on the lower rock mass, the through surface is formed, which is prone to landslide.

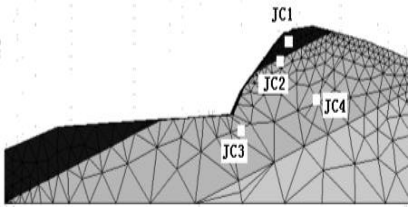

Figure 6. location map of monitoring points.

Displacement analysis: From the natural state of the slope displacement cloud map (Figure 4), it can be seen that under the self-weight condition, the slope is in a stable state, the maximum displacement is 0.01m, and the overall displacement moves in the free direction. In the heavy rain state (Figure 5), a weak interlayer is formed between the Xiaoxian Formation and the Jiawang Formation rock formation, which becomes the main controlling factor for the sliding of the upper rock mass. The overall displacement of the upper rock mass becomes 0.04 m, which is 4 times the original maximum displacement. As the rainfall continues, the slope is likely to slip.

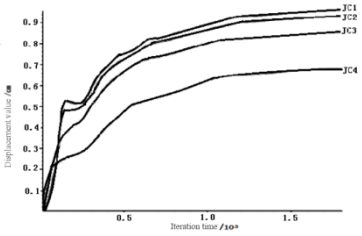

Figure 7. Displacement time curve of monitoring point under natural condition.

Monitoring point displacement analysis: In order to further understand the stability of the landslide body deformation, the author set up the monitoring point JC1 in the limestone of the Xiaoxian Formation of the sliding body, the monitoring point JC2 in the sliding zone, and the monitoring points JC3 and JC4 in the argillaceous dolomite of the Jiawang Formation (Figure 6). From a natural state.

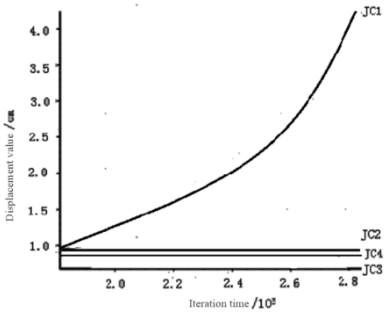

Figure 8. Time displacement curve of monitoring point under rainstorm condition.

It can be seen from the displacement time step curve (Figure 7) that the initial displacement of each monitoring point increases rapidly with time, and then gradually stabilizes. The maximum displacements of the final monitoring points JC1, JC2, JC3, and JC4 are 0.96 cm and 0.92, respectively. 0.82cm, 0.68cm, the displacement of the Xiaoxian Formation limestone in the upper part of the slope is the largest, but at the same time reflects the overall stability of the slope. When it is seen in heavy rain (Figure 8), the JC1 displacement of the monitoring point increases with time, the maximum value reaches 4.25cm, which is about 5 times of the maximum displacement in the natural state, and the monitoring points JC2, JC3, JC4. The maximum displacement value is still stable within 1cm.

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It can be explained that under heavy rain, the rock and soil body above the slip zone is easy to deform and the stability is poor. If continuous heavy rain occurs, the slope body is easy to produce landslide.

4.2. Landslide stability evaluation

At present, numerical simulation and limit equilibrium analysis are the two main methods in the stability evaluation of landslides. The numerical simulation method is based on the strength reduction theory. Considering the elastoplasticity of the rock and soil body without setting the assumed sliding surface, the physics and mechanics parameters of the rock and soil are reduced, and the most dangerous slip surface is obtained after calculation. The stress and deformation characteristics under the limit state are analyzed[10].

In this paper, the stability of landslide is calculated and analyzed by applying FLAC^{3D} strength reduction method[11] and Morgenstern-Price and Biop method in limit equilibrium theory. The analysis is carried out under the conditions of natural and heavy rain, and the calculation results are shown in Table 2. Figure 9 is a shear strain incremental cloud diagram in a natural state with a reduction factor Fos=1.2. It can be seen from Figure 9 that after the strength of the slope is reduced, the shear strain increases and the slope is critically unstable. The calculation results show that the landslide stability calculation results of both the limit equilibrium method and the FLAC^{3D} strength reduction method are consistent under natural and heavy rain conditions. In the natural state, the landslide is in a stable state; in the heavy rain state, the landslide is in an unstable state. The advantage of the FLAC^{3D} strength reduction method is that it can analyze the internal stress and deformation state of the landslide body and the direct presentation of the potential sliding surface.

Table 2. Calculation results of stability

Working condition	FLAC^{3D}--Strength reduction method	Morgenstern-Price	Biop
natural	1.20	1.21	1.18
rainstorm	1.02	1.01	1.02

Figure 9. Fos=1.20 shear strain increent nephogram.

5. Conclusion

(1) By using FLAC^{3D} software to analyze the shear strain increment, displacement and monitoring point displacement of the landslide, it is concluded that the landslide is in a stable state under natural conditions; in the heavy rain state, between the Xiaoxian Formation and the Jiawang Formation A weak interlayer is formed, and the rock and soil body above the landslide slip zone is extremely unstable and unstable. If heavy rain occurs, it is prone to landslide.

(2) The stability of the landslide is compared by the limit equilibrium analysis method and the FLAC^{3D} strength reduction method. The evaluation results are similar and the potential slip surface of the landslide is judged by FLAC^{3D} numerical simulation analysis.

(3) The landslide should be controlled in its deformation process during the treatment process, and the interception and drainage measures should be taken to monitor the deformation of the landslide during the rainy season.

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