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Stability and remote real-time monitoring of the slope slide body in the Luoshan mining area

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ABSTRACT

Landslides have occurred frequently in the Luoshan mining area because of disordered mining. This paper discusses the landforms and physiognomy, hydro-meteorology, formation lithology, and geologic structure of the Luoshan mining area. It also describes the factors influencing the slope stability of landslide No. III, determines the general parameters and typical section plane, analyzes the stress–strain state of the No. III slope, and calculates its safety factors with FLAC3D under saturated and natural conditions. Based on a stability analysis, a remote real-time monitoring system was applied to the No. III slope, and these monitoring data were collected and analyzed.

1. Introduction

With 20 years of mining history, the Luoshan mining area is located in the city of Lingbao, China. The first landslide disaster in this area occurred on November 1, 1987. The length of its sliding mass was around 192 m, the width ranged from 40 to 80 m, and its total volume was approximately 40 m^3. The height of the landslide wall was approximately 30 m, and the landslide tongues slid forward around 30 m. Three people were killed, and 9 million yuan were lost, a value equal to an enterprise production for 1 year. Since 2001, small-sized landslides occurred more than three times, forming 14 collapse pits with a total volume of approximately 14,393 m^3 and 22 ground fissures with a total length of around 2160 m [1–3].

The Luoshan landslides are divided into sliding areas I, II, III, and IV, as shown in Fig. 1, based on topography, material composition, and sliding direction. Sliding mass III has the following characteristics:

(1) The slope surface consists of steep and the vertical cliffs caused by gob collapse, increasing the risk of landslide.
(2) Ongoing mining activities pose a serious threat to mine production safety and security of personal property.
(3) The landslide volume is about 1.3 million m^3, and the landslide may be considered to be a large-scale and deep-type slide.

2. Analysis of engineering geology condition

The No. III landslide mass, appearing as a concavo-convex fluctuant clinoform with rudimentary land vegetation, is located in the northern part of the Dahu eastern slope. The landslide presents an irregular triangular shape, with a surface slope of 30–40° beneath a steeper slope. The sliding direction is about 290°.

The No. III landslide material can be considered to be within the geotechnical hybrid class. The leading edge and trailing edges of the slide mass consist of the fourth silty clay, and a large area of bedrock is exposed in the central region. The lithological character is fractured migmatitic granite. The slip soil is gravelly, grayish-yellow, earthy kaolinised cataclastic rocks, and core borings break easily when touched. The shear strength is very low. The main lithology of the slide bed is migmatitic granite with grayish-green color, a medium-coarse texture, and massive structure. The higher-strength and dense hard rock is a relatively water-resistant layer. It also has favorable conditions for the convergence of surface water after infiltration.

There is only rudimentary surface water in the mining area, and only one mountain river, the Dahu, runs into the Yellow River to the north. Meteoric water and southern mountainside drainage recharge the groundwater. Surface water and groundwater are not closely connected, and the discharge of groundwater is mainly

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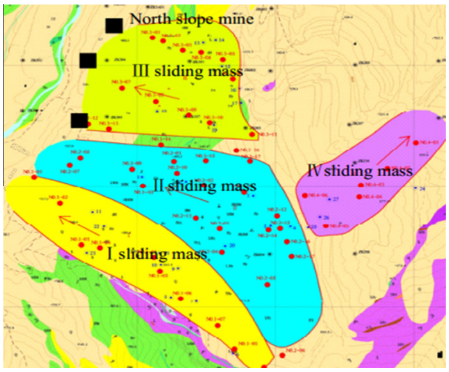

Fig. 1. Distribution of sliding masses.

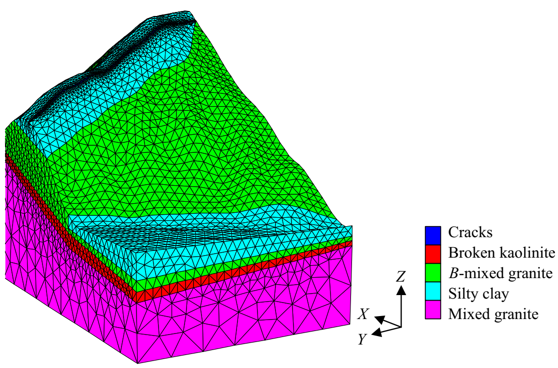

Fig. 2. Overall model of No. III landslide.

by mine drainage. This mine drainage has affected the groundwater in the area, and its level has dropped to below 500 m.

As the result of a selective analysis of the lithological characteristics of the landslide III mass, the slide zone and landslide bed, the main factors affect the stability of landslide III follow:

(1) Topographical and geological conditions lay the material foundation for the initiation of landsliding.
(2) Rainfall acts as a "catalyst" that accelerates the landslide.
(3) Mining activities are the most important factor of the landslide.

3. Numerical analysis of slope stability

FLAC3D is one of the best geo-engineering numerical analysis programs. The finite-difference method and explicit time-step iterative solution are used by FLAC3D, which considers the complexity of the rock–soil body, its variability and heterogeneity, discontinuities, large deformation, large strain, nonlinearity, etc., making it suitable for solving subway excavation and other large deformation problems [2–10]. Considering the complexity of landslide No. III and its engineering geological conditions, the landslide can be considered to be a rock–soil large deformation problem. In this research, FLAC3D was applied to a numerical analysis of the stability of the No. III landslide.

3.1. FLAC3D calculation model

The No. III landslide in the Luoshan mining FLAC3D grid calculation model is shown in Fig. 2. There are 55,900 grid units and 11,104 points in the entire model, and all use tetrahedral units. The horizontal displacement of the model is restricted at each side, and the surface beneath is fixed. The Mohr–Coulomb yield criterion was adopted, and the maximum unbalanced force ratio was set to 1e-5. The calculated parameters of the materials are shown in Table 1.

3.2. Analysis of calculation results

For the Luoshan mining area No. III landslide, the geological model was used to analyze the displacement field and plastic zone characteristics under both natural and heavy rain conditions of the slope and to calculate the safety factor of both slope conditions using the strength reduction method.

(1) Displacement analysis

Figs. 3 and 4 show the slope displacement contours under natural conditions and heavy rain conditions, respectively. From the results, we can see that under natural conditions, the slope maximum displacement is 3.13 cm, which appeared in a silty clay layer at the slope crest, and that there is side-sliding toward the free surface, although the amount of sliding is quite small. The mountain's middle region of the broken mixed-granite layer has a 1 cm displacement, and the slope is relatively stable. However, under heavy rain conditions, the slope maximum displacement is 52 cm, appearing in the silty clay layer at the slope crest with small-scale sliding. The displacement of the middle broken mixed-granite layer increases, compared with the case of natural conditions, to about 20 cm, thus the slope is in an unstable state.

(2) Plastic zone analysis

Figs. 5 and 6 show the plastic zone distribution under both two conditions, respectively. The calculated results show that the whole landslide is basically in a stable state under natural conditions, and only the slope crest and slope toe of silty clay layer partly appear in the plastic zone. A small area of tensile plastic zone appears in the northern part of the valley and at the top of the slope. However, due to the infiltration of rainwater, the physical and mechanical properties of the slope rock mass have changed under heavy rain conditions; the cohesion and internal friction angle have decreased, the rock density has increased, and the slope silty clay layer and the broken mixed-granite layer have reached yield. Additionally, the whole sliding body and sliding-band rock and soil have become a shear plastic zone. There is not only further expansion of the size and depth of the tensile plastic zone at the slope crest, but the broken mixed-granite layer in the middle has partly become a tensile plastic zone. Therefore, the slope is in an unstable state.

(3) Stability analysis

Fig. 7 shows the landslide stability calculation results under natural conditions. The calculated results show that the overall

Table 1
Calculated parameters of materials.

Rock layer	State	Density (kg/m^3)	Cohesion (MPa)	Friction angle φ (°)
Silty clay	Natural	1920	0.046	22.6
	Saturated	1980	0.035	15.6
Broken mixed granite	Natural	2620	0.450	38.5
	Saturated	2675	0.120	30.5
Broken kaolinised rock	Natural	2160	0.020	31.5
(sliding zone)	Saturated	2190	0.016	30.0
Mixed granite	Natural	2620	45.000	44.5
	Saturated	2675	10.000	44.0