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Modeling on spatial block topological identification and their progressive failure analysis of slope and cavern rock mass

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Abstract

Within a certain domain of rock mass, identification of all blocks cut by three-dimensional finite random or fixed discontinuities is a critical basic problem in jointed rock mass researches. Based on general method of spatial block topological identification with stochastic discontinuities cutting, the block identification of slope and cavern rock the different characteristics of simply connected loops and multiple connected loops, how to identify the different block types uniformly is discussed. This paper develops an efficient numerical approach to predict deterministic size effects in structures made of quasi-brittle materials using the GeoSMA-3D[1-3] method. Three jointed rock structures were modelled to validate the approach. Based on these, with classic block theory combined, the technique of block progressive failure analysis of slope/cavern is achieved. Finally, cases of slopes and caverns are studied. The main analysis procedures are given, including 3D discontinuities network simulation, analysis of intersecting lines between discontinuities and surfaces. The process of solving intersecting lines between discontinuities and surfaces of slope/cavern is discussed emphatically. The predicted size effect is in good agreement with site observed data.

Keywords: Rock; Fracture process; Numerical modelling; block theory.

1. Introduction

The creation of an Excavation Disturbed/Damaged Zone (EDZ) is expected around realistic rock engineering openings. Within a certain domain of rock mass, identification of all blocks cut by three-dimensional finite random or fixed discontinuities is a critical basic problem in jointed rock mass

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researches. In recent years, efforts [4-7] along these lines have been made for a potential repository in Discontinuous, Inhomogeneous, Anisotropic and Non-Elastic (DIANE) rock mass for which the combination of numerical modeling and observational validation has led to significant recent advances in our understanding of the evolution of the EDZ. Especially, there has been growing interest in numerically modeling the brittle fracture process in rock. Efforts in this direction are necessary for knowing the fracture mechanism and improving analysis capabilities of the numerical method for engineering use. It is generally accepted that the slip of rock blocks is associated with very complicated progressive failures.

Underground excavations such as tunnels, storage caverns, and underground power plants have been constructed. Three-dimensional (3D) analysis is used for many rock engineering stability problems. Most researches in 3D slope analysis are concentrated on 3D column methods [4-7]. The slope was divided into vertical columns which is the extension of the 2D general limit equilibrium method. The intercolumn shear force of each column can be neglected or assumed to distribute as a certain function. The overall factor of safety can be calculated by force or moment equilibrium of all columns. Block theory provides optimum choices for the orientations, shapes, and arrangements of openings to minimize the danger of block movements [8-10].

Based on these characteristics of rock and general method of spatial block topological identification with stochastic discontinuities cutting, the block identification of cavern rock mass is studied in this paper. This paper aimed to calculate the factor of safety of multiple block systems using vector analysis method in the description of block geometry and force equilibrium equations. This paper briefly introduces the program (GeoSMA-3D) which is developing by the first author and his research group. In this method, the software could identify the quantity of the complicated blocks (including the concave form) which are cut by numerous structure planes. It is shown by example analysis and accuracy test results that the method is effective to search the strong commonality and reliability.

2. Spatial block topological identification

When the geometrical characteristics of rock joints are to be measured relevant arise frequent cases that for the surveyor to reach the target joints or to set up scanlines on the exposed rock face are used to be very difficult. The traditional measuring method is used the measuring tape and compass to get the information of structure plane by contact. This method is inefficient, laborious, time-consuming, and difficult to meet the requirements for rapid construction. Some of tunnel roof cannot fully contacted, measurement data always restricted by engineering. To complement such limits, a new method modified from the multistage convergence photographing technique was developed in this research. Figure 1 shows the rock structure for slope in Liaoning Province, China.

Base on the status of rock stability analysis, using the modern digital photography processing technology and 3D image reconstruction to make analysis, build the three-dimensional imaging of the tunnel face, and make the discrete element method stability analysis at disturbed areas of the tunnel excavation. For the measurement of jointed orientations on the tunnel working face, the detailed implement steps are showed as the following: Digital photography measurement is applied to get the joint plane information of rock mass, which supply sufficient information for further 3GSM analysis. Joint strength parameters which suit this tunnel project rock mass will be obtained. Parameters of rock mechanics information is decided, by using the trace length, geological occurrence of joint fissure information that getting from digital photography measurement. Disturbed zone model is build that after the cut of joints by discrete element method.

Fig. 1. Rock strucuter

Fig. 2. Distribution of jointed cracks information

The above method may see in the reference [1-3]. This new algorithm modified from the multistage convergence photographing technique was developed, to interpret joint orientations revealed on a rock surface using a pair of images photographed by digital camera. To apply a generalized collinear condition equation which defines the relationship between the three-dimensional coordinates of its images, only three ground control points on the photographed rock face and one ground guide point were necessary as input data to determine the parameters of each camera.

Field application was executed at a road slope. Window sampling technique was successfully applied not on the real rock surface but on the images captured. As a result, major joint sets and the areal frequency of each joint set could be obtained (see in the Figure 2). The surveying time needed for one rock surface was no more than 10 minutes, including preparatory and photographing time with two well-trained investigators.

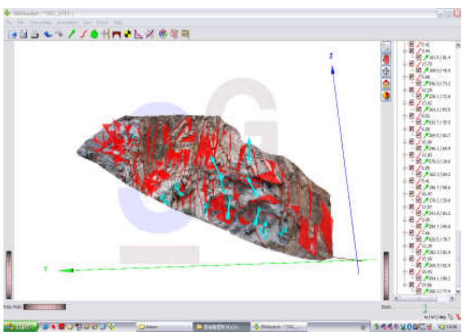

Fig. 3. Photograph modelling

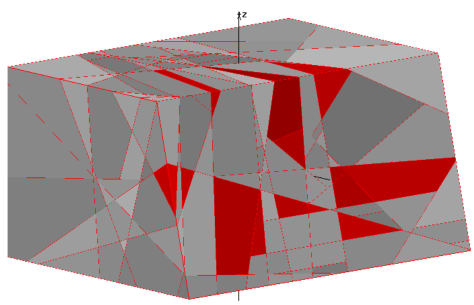

Fig. 4. Spatial unstable blocks owing to excavation face

For rock slopes, a single wedge failure solution, based on the rigid-body mechanics, in three-dimension is a routine tool of rock slope engineering. Multiple blocks, sliding along multiple planes is the most complicated planar type of sliding. Multiple wedges can be formed by the intersection of four or more sets of discontinuities (Fig. 3), and usually find in arch dam abutment (Fig. 4) and high rock slope failure.

3. Numerical modelling

Aimed at the new method of block recognition, based on MFC called OpenGL graphics library, GeoSMA-3D is developed, which has excellent three-dimensional display. GeoSMA-3D is applied in this rock slope project. Figure 5 show the spatial block model using the GeoSMA-3D. The maximum key block by three group structures are analyzed. Secondly, the structural assumption of an infinite length is made under unknown size of structural plane. The possibility of failure block is searched out. It is showed that GeoSMA-3D is scientific by data and images of analysis results, compared with the actual project. Finally, on the preferred plane may be unstable under different sizes of block are analyzed, and may come to the dimensional instability of the structure blocks of the simple correspondence. The possibility of failure block is analyzed under different sizes of preferred plane. The simple correspondence of structural plane size and possibility of failure block is obtained.

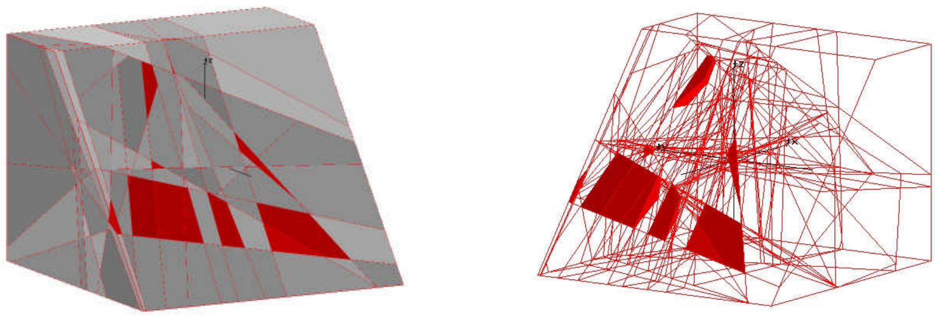

Fig. 5. (a) Blocks modeling using GeoSMA-3D code (b) Key blocks using GeoSMA-3D code

According to the data of rock joints, the program selects distillation function of rock joints automatically to simulate 3D joint network. The traces in any section plane could be shown clearly and mobile blocks could be rendered in 3D form. This program adopts modularized design method, makes use of menu and push button of graphical interface to combine all modules.

As introduced in previous papers [2, 12, 13], a heterogeneous material model has been proposed to characterize heterogeneous rock material. The heterogeneous material model has been fully implemented into the GeoSMA-3D code developed on the basis of the block theory. In the numerical simulation, the numerical model is constructed on the basis of the heterogeneous material model. An external load is slowly applied on the constructed numerical model step by step. Due to the interaction induced by stress redistribution and long-range deformation, a single important element failure may cause an avalanche of additional failures in neighbouring elements, leading to a chain reaction releasing more energy.

4. Numerical modelling of the fracture processes

In this paper, Numerical specimens for the slope progressive fracture process is constructed with the same characteristic parameters of the heterogeneous material model to determine the local physical-mechanical properties and fracture toughness.

Using the principle of block, three-dimension numerical method of block theory is proposed. Block theory is a kind of well-developed method, which is used for analyzing stability of rock mass in recent years. Block theory could resolve some problems as follow: Distinction of blocks, Mobility discretion of blocks and stability analysis of blocks. At the present time, distinction of block is a key link of the block theory's development. There are lots of methods for the link, but a majority of which are really difficult to achieve for computer program.

Fig. 6 shows the simulated force-loading displacement curve and associated seismicity.

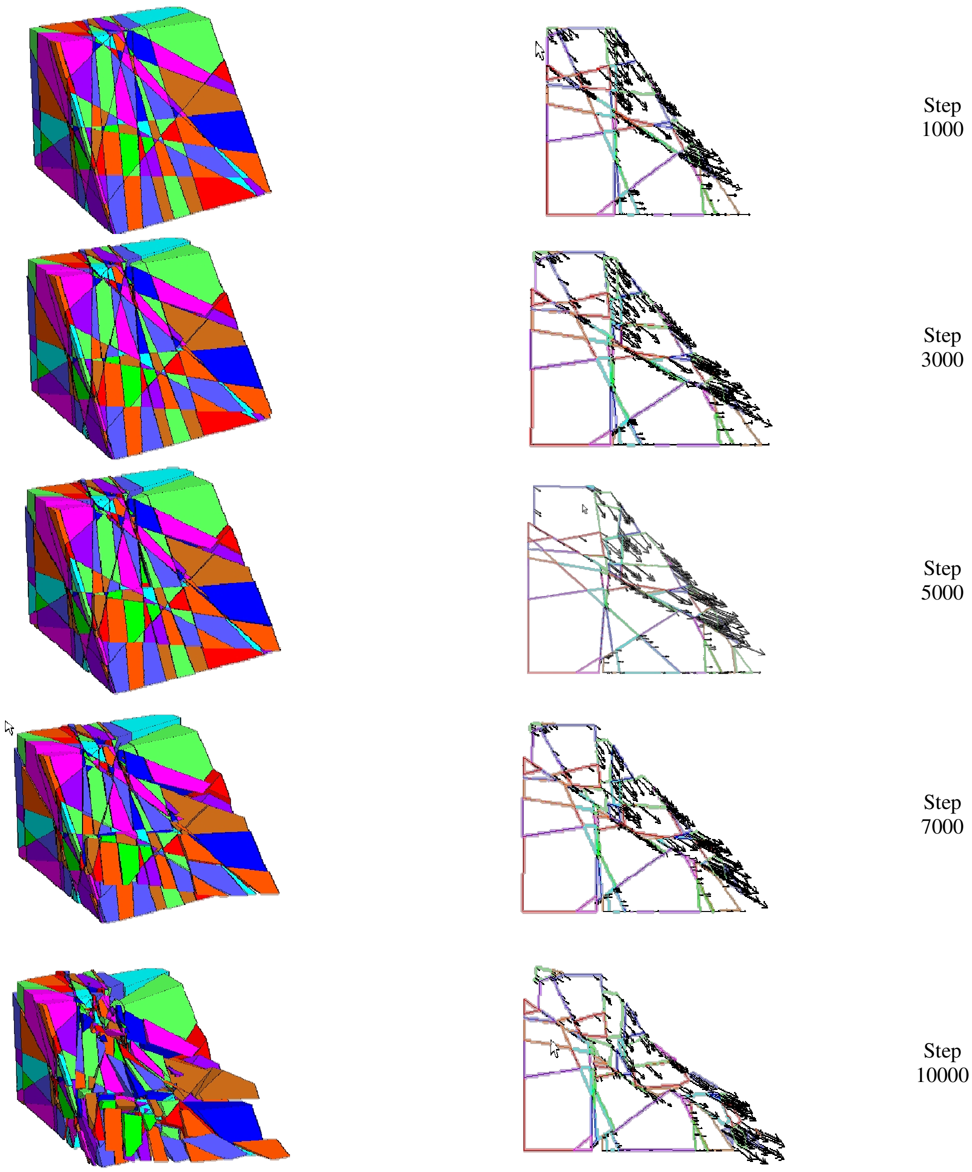

Fig. 6. Progressive fracture process by numerical modelling

Fig. 6 shows the simulated initiation, propagation and coalescence of the fractures at different loading levels. It can be seen that the onset of failure in the specimen subjected to compressive loading is firstly indicated by the formation of a large number of isolated microfractures and then the microfractures begin to cluster and become clearly localized (Fig. 6). This is quickly followed by the development of some macroscopic fracture zones in the post-peak regions. Finally, the interior macroscopic fracture zone forms and becomes interconnected to form slope blocks slide.

5. Conclusions

This paper presents a new approach which could search all complicated rocky blocks (include concave volume) that are cut by numerous structural planes. This method figures out intersecting joint plane and the free face, searches all the complicated rocky blocks, which is of great significance to study rock mass characteristics and push numerical analysis forward. The simulated results not only predict relatively accurate physical-mechanical parameters and fracture toughness, but also visually reproduce the progressive fracture process. The detailed visually shown stress distribution and redistribution, crack nucleation and initiation, stable and unstable crack propagation, interaction and coalescence. It is concluded that the heterogeneous and anisotropic material model is reasonable and the GeoSMA-3D code is stable, repeatable and a valuable numerical tool for research on the rock fracture process.

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