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Rock failure and its jointed surrounding rocks: A multi-scale grid meshing method for DDARF

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ABSTRACT

DDARF (Discontinuous Deformation Analysis for Rock Failure) is an improved method of DDA (Discontinuous Deformation Analysis method), while there are only uniform grids in the original DDARF, and multi-scale grid meshing method cannot be realized. A multi-scale grid meshing method for DDARF is proposed to rock failure analysis, which balances off between the calculation accuracy and computation time. Simulations with multi-scale grid model and uniform grid model are established respectively, and compared with the laboratory tests; this multi-scale grid meshing method is applied to progressive failure process for jointed surrounding rock, and influence on crack propagation by the different lateral pressure coefficients K_0 of in situ stress is analyzed. It is concluded that this multi-scale grid meshing method for DDARF is feasible and the calculation accuracy can be improved with the same grid number. The proposed method is able to increase the computation efficiency by reducing the computation time when simulating underground cavern excavations, at the same time maintain the calculation accuracy. With increase of the lateral pressure coefficient K_0 of in situ stress, the main cracks propagating zones are moved gradually from both sidewalls of the cavern to the arch crown and floor. This method improves the DDARF to large projects, and it can analyze the progressive failure process of rock more effectively.

1. Introduction

For numerical calculation, it is important to establish models by various means with high quality and high calculation efficiency. Grid form has direct impact on the calculation accuracy and computation time. As grid density increases, the calculation accuracy will increase accordingly, while the computation time will also increase and in many cases the calculation cannot converge or unable to complete. Therefore, the calculation accuracy and computation time should be balanced off to establish the optimal grid density model. During static or response analysis, grid number of stress response should be larger than that of displacement response, and for large projects, the main research area should be meshed more densely than area far away. In a word, different parts of a model may have multi-scale grid density, parts with big variation gradient should be larger, and parts with tiny variation gradient may be smaller (Blaheta and Kolcun, 1994; Tran, 1994; Folino and Spezzano, 2007; Mancini et al., 2006, 2005, 2008; Dimov et al., 2008; Jing, 2003). The model with multi-scale grid density can not only ensure the calculation accuracy of the subject, but also reduce the whole grid number and computation time, accordingly improve the efficiency.

DDA (Discontinuous Deformation Analysis method), originally proposed by Shi (1988, 1999), is widely applied in simulating rock mass. It follows the basic equations of elastic theory and it is as rigorous as the finite element theory. Besides, it can analyze large displacements in blocks as the discrete element method (DEM) does. However, some algorithms in this method fail to solve the failure problems of intermittent jointed rock. To find solutions to these problems, DDARF (Discontinuous Deformation Analysis for Rock Failure) is proposed (Jiao et al., 2010; Zhang, 2007) by analyzing the failure process for intermittent jointed rock. In addition, DDARF has the function of simulating jointed rocks' whole process of crack initiation, propagation, coalescence, and crushing. However, for current version of DDARF, only model with uniform grids can be established, which limits the application of DDARF in large engineering projects. So far, there is no stability analysis on using this method for large practical engineering, because it is difficult to complete the calculation when the grid number becomes larger than several thousand. In this study, a multi-scale grid meshing method of DDARF is proposed, which extends the applicability of DDARF, increases its computation efficiency and maintains acceptable accuracy.

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2. DDARF's improved modeling method based on CAD

2.1. Basic characteristics of DDARF's algorithm

DDA's algorithm has three characteristics (Shi, 1993): (1) displacement's first-order approximation; (2) general balance equation and principle of minimum potential energy; (3) kinematic conditions without overlap and stretching. DDARF is the improved method based on DDA, it has not only the above three characteristics of DDA, but also its own three characteristics (Jiao et al., 2007):

(1) Triangular blocks generated by traveling wave method

Firstly, generate random joint network in the calculation area by Monte-carlo method. Secondly, based on the joint network, add virtual joints for every isolated endpoint until the whole calculation area is split into multiple single-connected subdomains. Thirdly, search for all the subdomains and in every subdomain use traveling wave method to generate triangular blocks. Thus, triangular block system has been accomplished for DDARF.

However, by this method, different parts of the model cannot be defined different grid density according to special computation accuracy, and at the same time, if the total grid number is too much, the computation will not complete, in view of these disadvantages, multi-scale grid meshing method is necessary to balance off between the computation accuracy and the total grid number.

(2) Inhomogeneity of rock realized by Weibull distribution

In DDARF, rock is divided into a large number of tiny block units, physico-mechanical properties of them are non-uniform, which can be described by Weibull distribution. It is assumed that a block system is composed of n blocks, first of all, n random factors ξ_i of uniform distribution in interval $[0,1]$ are generated by linear congruential method; secondly, based on these random factors, using direct sampling method, n elastic modulus η_i of Weibull distribution obtained by Eqs. (1) and (2) are assigned to these n blocks. Similarly, Poisson's ratios of these n blocks can be obtained.

$$\varphi(\eta_i) = \xi_i \tag{1}$$

$$\eta_i = \beta_0[-In(1-\xi_i)]^{\frac{1}{h}} \tag{2}$$

where β_0 represents the mean value of elastic modulus or Poisson's ratio.

(3) Virtual joints' cracking algorithm

If two blocks contact, normal and tangential springs should be added between them to prevent the normal overlap and tangential slip, when the spring force overs the joint strength, springs should be removed, and then the two blocks can move respectively. So, improve the joint strength to maintain the constraint of springs, and then the two blocks will be sticked together. Based on this idea, coherence algorithm is introduced into DDARF, virtual joints (that is, the block boundary of continuous area) are generated during the process of blocks' subdivision, whose bond strength can be reflected directly by cohesion, which is determined by rock's intensity, and its dynamic variation will determine whether crack propagates along the edge of blocks or not. When its cohesion achieves material's tensile strength, it will decrease as opening displacement of the blocks increases. When it reduces to zero, virtual joints will be developed to be true joints.

2.2. Advantages of DDARF's modeling based on CAD

DDARF ingeniously uses the advantage of DDA that the computation does not meet the mathematical difficulties, and successfully simulates the whole process of rock crack initiation, propagation, coalescence and failure. It is suitable for continuous, intermittent, discrete conditions and so on. However, its modeling needs to input model's geometry information manually. When the model is more complex with a larger number of lines, this workload will become considerable. Therefore, auxiliary tool CAD is introduced and the calculation model can be established with the powerful drawing function of CAD, and then imported into DDARF. Cutting files of DDARF can be generated by this method, and can be run directly after minor modification, which has higher degree of visualization and it is easier to grasp, the effect is more obvious for more jointed or complex model especially.

Simulation on fracture network of jointed rock by the improved modeling method of DDARF has the following characteristics:

(1) According to in situ conditions, joint probabilistic models (fixed distribution, uniform distribution, normal distribution and negative exponential distribution) can be established.
(2) Through the visual interface of CAD, complex model or local parts of the model can be modified easily, in order to make the model more in line with engineering.
(3) Cutting files of DDARF can be generated easily by this method, eliminating the multifarious manual work during the modeling process, which has saved time and improved the efficiency.
(4) The operation interface based on CAD is simple, easy to learn and use.

When using this method, model's information such as joint, bolt, block boundary, measured point, material line, fixed point, loading point and so on can be drawn in CAD, and also can be set by writing programs, or even by data file of DDARF.

The specific technical route is shown in Fig. 1.

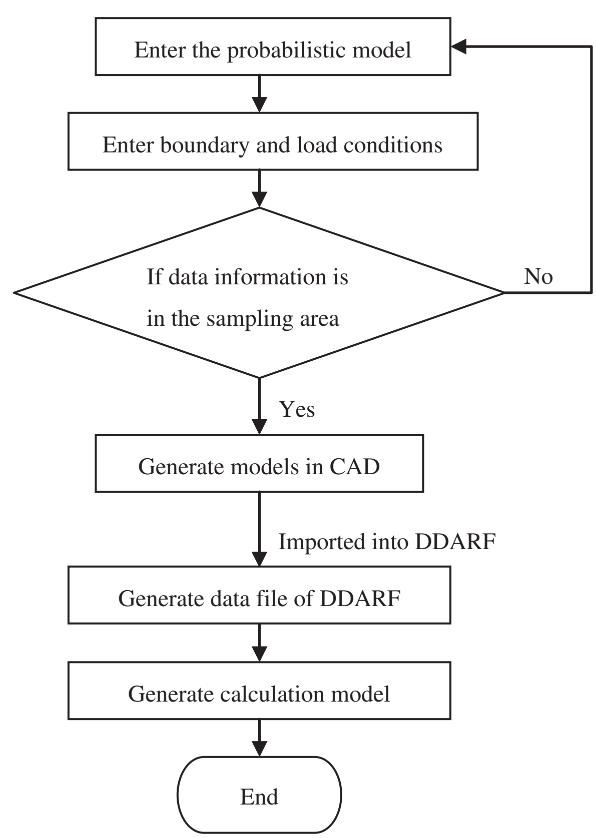

Fig. 1. Improved pretreatment modeling of DDARF.