Computers and Geotechnics 63 (2015) 26–32

Contents lists available at ScienceDirect

Computers and Geotechnics

journal homepage: www.elsevier.com/locate/compgeo

Advances in three-dimensional block cutting analysis and its applications

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ARTICLE INFO

Article history:
Received 6 April 2014
Received in revised form 15 August 2014
Accepted 16 August 2014
Available online 15 September 2014

Keywords:
3-D block cutting
Discrete fracture network
Block progressive failure
Geometrical identification

ABSTRACT

Locating all spatial blocks cut by an arbitrary three-dimensional discrete fracture network (DFN) within a rock mass volume is a basic issue in many research fields related to fractured rock masses. In this paper, analysis procedures based on both the oriented rule and the closed rule are described, followed by a description of a proposed method for block progressive failure analysis. Lastly, two engineering cases in which the proposed method is implemented are presented. The results show that the identified blocks may be extremely complicated and may even be composed of thousands of loops (block faces consist of loops); block progressive failure analysis is extremely useful and efficient in determining block-reinforcement measures. Overall, the 3-d block cutting analysis is important progress in block theory and has a large potential for application in fractured rock masses.

1. Introduction

Identifying all spatial blocks cut by an arbitrary 3-dimensional (3-d) discrete fracture network (DFN) within a certain volume of rock mass is a basic issue in block theory [3] and other research fields related to fractured rock masses. Because the number, size, position, orientation, and spacing of fractures that are randomly formed in rock masses vary significantly and continually evolve, the geometrical configurations and features of the resulting blocks are extremely complicated. A key issue in the field is how to identify all closed blocks cut by arbitrarily oriented fractures with finite sizes. The so-called 3-d block cutting analysis method is one solution.

Lin et al. [7] studied the geometrical identification of 3-d blocks using simplicial homology theory and identified the individual block, which is regarded as a polyhedron, using the boundary chain operation of closed surfaces. The correctness of the results was checked by introducing the Eular–Poincáre formula for a polyhedron. Jin and Stephansson [5] and Jing [6] identified both 2-d and 3-d blocks using the basic principles of combinatorial topology, in which a 3-d block is regarded as a complex, which is assembled by a set of simplexes. The algebraic boundary of the complex is the union of the boundaries of all these simplexes, and the boundary edge chain of all closed surfaces of the complex is an empty 0-chain. Ikegawa and Hudson [4] suggested the concepts of the directed body, face vector, and edge vector. Lu [9], Peng and Tang [10], Shi [12] and Elmouttie et al. [1,2] proposed similar algorithms. These studies were based on similar topological concepts, which formed the current theoretical foundations of the 3-d block cutting analysis method.

However, the applications of this method for practical engineering problems have seldom been reported until recently. In this paper, the analysis procedures of this method based on both "the oriented rule" and "the closed rule" are first described. Then, a method for block progressive failure analysis is proposed, and lastly, two engineering case studies, where the proposed method is implemented, are presented. The results show that both the method and the code are extremely useful and efficient and have a large potential in its application in fractured rock masses.

2. Theoretical analysis and key issues

2.1. Topological basis

The basic requirement for 3-d block cutting analysis is that the fractures are of a finite size. The main topological concepts have been introduced by Lin et al. [7] and Jing [6]. Two rules are adopted in our algorithm as the theoretical foundations of the analysis, referred to as the 'oriented' and 'closed' rules. Under these two rules, it is unnecessary to determine if the shape of a block is concave or convex, how many faces are used to construct a single block, or how many edges are required to construct a face.

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http://dx.doi.org/10.1016/j.compgeo.2014.08.009

Table 1
Geometrical parameters of joints in the Baise hydroproject.

Joint set	Average dip (°)	Average dip direction (°)	Average trace length (m)	Average spacing (m)
①	53	202	6.5	3
②	58	330	6	2
③	68	105	5	2.5

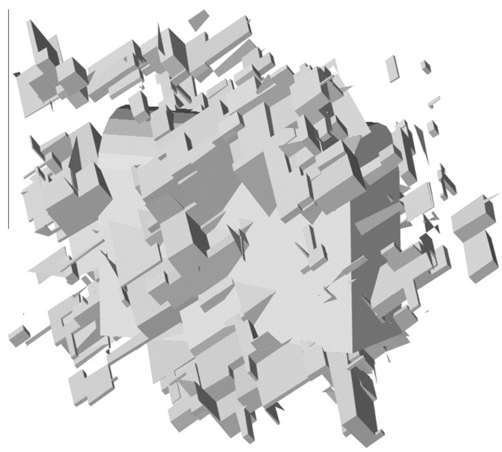

Fig. 1. Identified blocks from one sample from the simulated DFN in the Baise hydroproject.

The oriented rule is derived from the concepts of the oriented edge, oriented face, and oriented block (complex). This rule says that the blocks, loops that form the block faces, and the edges of the loops are all oriented. The closed rule is derived from the properties of the boundary chain operation of a polyhedron and requires three criteria: (1) each edge is shared exactly by two loops with converse directions; (2) all the oriented loops are used only once during closed block identification; and (3) the total volume of all positive and negative blocks is zero. It should be noted that criteria (2) and (3) act cooperatively. For example, a rock mass domain may contain many positive blocks. The normal vectors of all oriented loops of these positive blocks direct inwardly. The outer boundaries of the rock mass domain form a negative block, in which the normal vectors of all oriented loops of this negative block direct outwardly. Although the vertices of the corresponding loops of these positive blocks and the negative block are the same, their directions are opposite. In addition, the total volume of all the oriented blocks is zero.

2.2. Analysis procedures

The primary procedures of the 3-d block cutting analysis are as follows.

(1) Perform Monte-Carlo simulation of the 3-d DFN.
(2) Perform morphological analysis on either the shape of the slope or the tunnel, which are seen as blocks of convex or concave shapes. The slope or tunnel is the studied domain of the rock mass.
(3) Analyse and obtain the intersection lines between faces. Here, the faces are either fractures or surfaces of the slope or tunnel.
(4) Search for the primary closed loops [11,5].
(5) Delete loops that are isolated or partially intersect other loops. The remnant loops share edges with their adjacent loops and are indispensable to form closed blocks. This step is extremely important to accelerate the analysis speed, particularly when the number of loops is large.

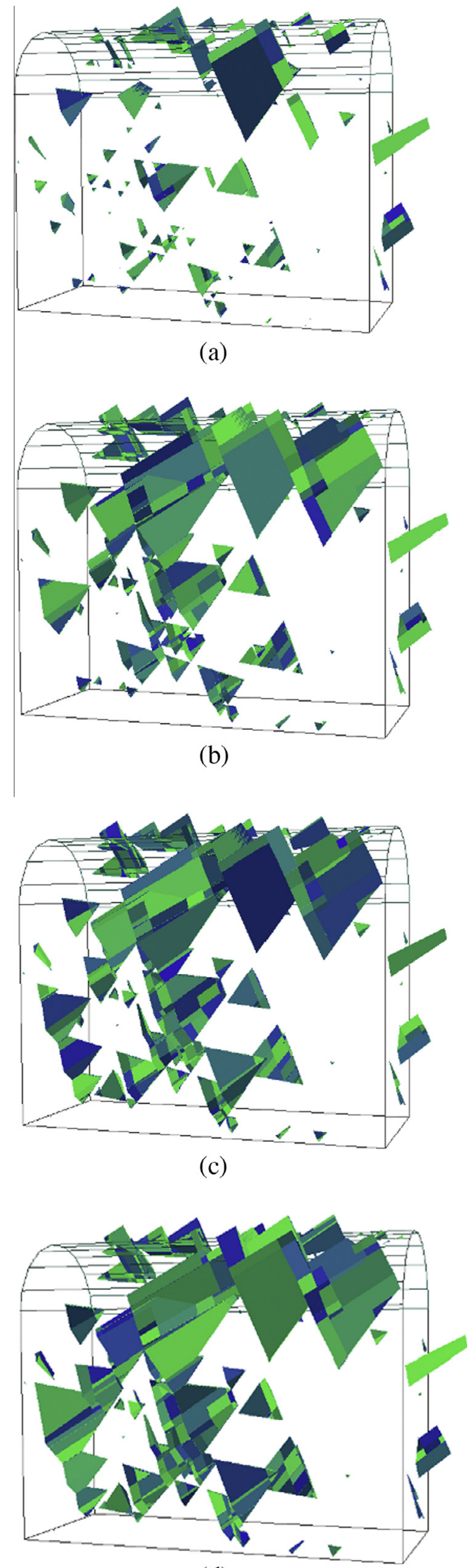

Fig. 2. Block progressive failure analysis: (a) failure blocks from the first batch, (b) failure blocks from the previous two batches, (c) failure blocks from the previous three batches, and (d) failure blocks from all seven batches.