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Detection of contacts between three-dimensional polyhedral blocks for discontinuous deformation analysis

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ABSTRACT

A new algorithm to detect contacts between three-dimensional (3-D) arbitrarily shaped polyhedral blocks for the discontinuous deformation analysis (DDA) method is presented in this paper. The new algorithm includes three main steps, i.e. neighbor search, contact type examination, and entrance candidate identification, all of which are performed using the general features and relations of geometric elements of polyhedra. First, contact detection begins with searching neighbor blocks and vertices potential to be in contact in order to improve the computation efficiency. Then, pairs of neighbor blocks are examined in more detail for four basic contact types. Finally, corresponding contact points and planes for each contact type are identified by general entrance formulas, which is prepared for the subsequent contact force calculations in the program. The new algorithm has been implemented in the original 3-D DDA program and the extended 3-D DDA program can display the results using OpenGL. Three typical contact examples including concave blocks, i.e. vertex-to-concave-edge, convex-edge-to-concave-edge and vertex-to-concave-vertex contacts are provided to verify the new algorithm. Additionally, a practical example in rock engineering, sliding of a tetrahedral wedge, is also presented, and the 3-DDA results are compared with the analytical solutions.

1. Introduction

There are many practical problems in jointed or blocky material, such as rock masses, where discontinuities are dominant in the analysis. The traditional numerical methods, which are mostly continuity based, are clearly not suitable for analysis of such problems.[1] Discontinuous deformation analysis (DDA)[2,3] is a discrete numerical method that can analyze both static and dynamic behaviors of block systems, without any assumption regarding the mode of failure. It allows the simulation of not only translation, rotation and deformation of an individual block, but also large-scale sliding and opening along discontinuities.

With continuous modifications and improvements, two-dimensional (2-D) DDA has been more efficient and suitable to cover practical engineering problems of rockfall,[4–7] landslide,[8–16] tunneling and mining,[17–21] cavern and underground opening,[22–27] masonry structure,[28–30] fracture propagation,[31,32] rock blasting[33–35] and many others.[36–42] However, the applications of 2-D DDA are inappropriate to many practical problems because the majority of discontinuities are not always perpendicular to the cross-section of the model. Therefore, it is desirable to develop three-dimensional (3-D) DDA for practical engineering applications. Up to now, 3-D DDA has been concentrated on basic theory development.[3,43–47]

A contact theory governing the contacts between arbitrarily shaped polyhedral blocks is a major component of 3-D DDA. As indicated in,[48,49] the introduction of the simplex integration method[3] into DDA has made it capable of dealing with any arbitrarily shaped polyhedral blocks in the mechanical calculations. On the other hand, the available contact detection algorithms[50–54] applied in 3-D DDA have provided no suitable solutions to contact points and planes for two arbitrarily shaped polyhedral blocks. Accordingly, a general contact algorithm of arbitrarily shaped

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polyhedral blocks for 3-D DDA is required for practical engineering applications that have or generate concave blocks, such as surficial excavations and underground opening.[55]

In terms of contact plane, the available contact detection algorithms for 3-D DDA can be divided into two categories, i.e. direct and indirect approaches. Direct approaches provide the accurate real contact planes on the basis of the geometric relation between two polyhedral blocks. For example, the closest-points method[50] defines the contact plane based on the closest points between vertices, edges and faces of two convex blocks. The referential plane (RP) method[56] for 3-D distinct element method (DEM) identifies the contact plane according to the contact type and numbers of contact points between two approaching faces of two convex blocks. The main plane (MP) method[51] is modified from the RP method to be applicable in 3-D DDA.

In contrast, indirect approaches attempt to seek approximate virtual contact planes between two convex blocks in order to vanish many complexities in the determination of the real contact plane. For example, the common plane (CP) method[57] as well as its modified versions, the fast common plane method[58] and the shortest link method,[59] is the most widely-used algorithm of this category in DEM, and it was also implemented in DDA recently[52] In this method, two convex blocks are examined separately for contacts with the CP, which is a virtual rigid contact plane and bisects the space between the two convex blocks (Fig. 1a and b). Consequently, the extensive block-to-block contact detection problem is simplified into a much faster block-to-plane contact detection problem.

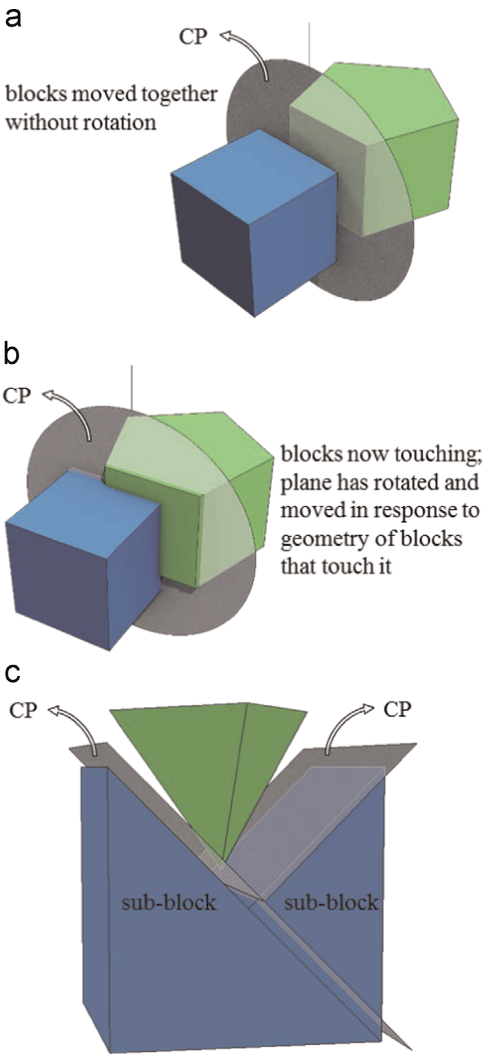

Fig. 1. Illustrations of the CP(s) between two blocks: (a) no contact situation; (b) contact situation and (c) decomposition of a concave block into two convex sub-blocks.

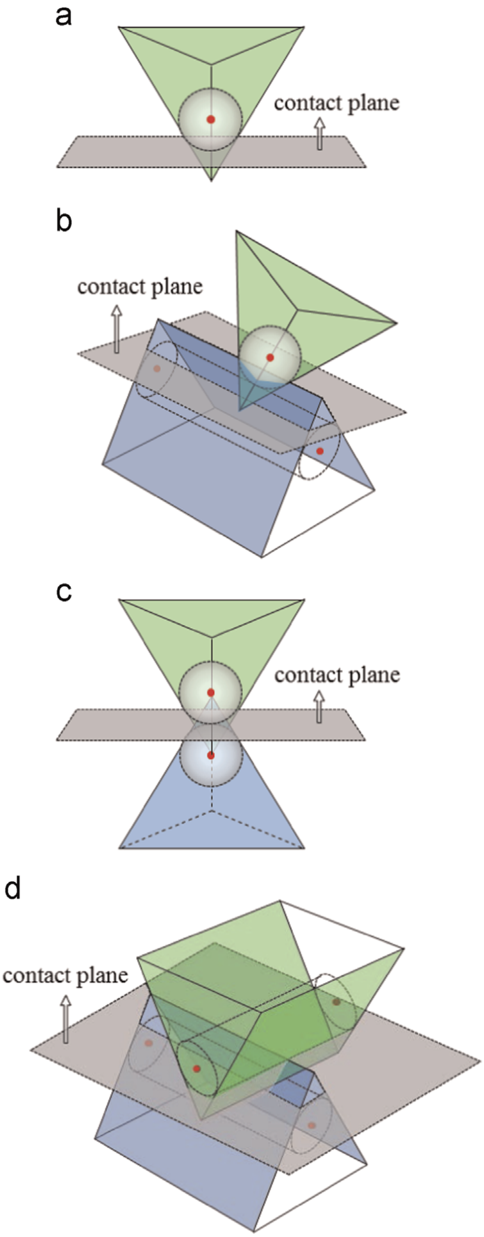

Fig. 2. Illustrations of contact types after rounding process: (a) sphere-to-face; (b) sphere-to-cylinder; (c) sphere-to-sphere and (d) cylinder-to-cylinder.

The rounding scheme[53,54] is an alternative to simplify the contact detection process by virtually installing inscribed spheres and cylinders into convex vertices and edges respectively. In this scheme, contacts between two blocks are finally converted as sphere-to-face, sphere-to-cylinder, sphere-to-sphere and cylinder-to-cylinder contacts (Fig. 2). Consequently, virtual contact planes can be easily determined between the face planes, inscribed spheres and cylinders. Unfortunately, it is difficult to obtain reasonable inscribed cylinders for concave edges or inscribed spheres for the vertices that join more than three faces.

Although the available contact detection algorithms provide sufficient accuracy and efficiency in 3-D discrete simulations, they still cannot be directly applied in this study due to improper solutions to contact plane between two arbitrarily shaped polyhedral