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Random gravel model and particle flow based numerical biaxial test of solid backfill materials

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ABSTRACT

Fully mechanized coal mining with backfilling (FMCMB) has become a major solution of "green mining". The mechanical properties of backfill materials are key factors of ground control in FMCMB face. To study the strength behaviors of the solid backfill materials, we developed a method of generating random gravel model by using computational geometry algorithms, then coded the generating method into a program with MATLAB software, and implemented several numerical biaxial tests under different confining stresses by using a generated random gravel model and the Particle Flow Code PFC^{2d}. Peak deviatoric stress, post-peak softening, initial contraction and dilation and the relations between them and confining stress can be observed. And the initial elastic modulus of the samples, Poisson's ratio, frictional angle and cohesion can be derived from the numerical biaxial test results. The results indicate a good feasibility study of mechanical properties of the solid backfill materials by random gravel model and particle flow based numerical biaxial test.

1. Introduction

Fully mechanized coal mining with backfilling (FMCMB) is a new mining technology that backfills the gob with solid waste while coal is exploited effectively [1–2]. FMCMB has become a major solution of "green mining" as it can mitigate the ground movement, decrease surface subsidence above the panels and dispose solid waste [3–10].

The mechanical properties of the backfill materials are important factors for control of ground movement in a FMCMB face [6,7,9,11]. The compaction and broken expand characteristics of backfill materials or rockfill have been studied with compaction tests by several scholars, however, the "modulus" derived from compaction tests mentioned above is not a constant and increases with the axial compressive stress as the lateral displacement is fixed, and the strength of materials could not be derived from those tests because macro shearing failure cannot occur with a fixed lateral displacement [9,12–14]. According to our knowledge, the researches on strength of solid backfill materials and their constitutive behaviors are not reported widely.

In fact, the solid backfill materials such as gangue, gangue-fly ash mixture and construction waste, etc., can be envisioned as a kind of rockfill or soil–rock mixture if a proper rock/soil threshold is considered [15]. The strength of rockfill or soil–rock mixture is currently studied by large scaled triaxial tests or direct shear tests and numerical simulation based on Finite Element Method (FEM) or Particle Flow Code (PFC) [15–21]. In the numerical simulation mentioned above, the gravel geometries are represented by random polygons in FEM while the circular particles and particle clusters with regular shapes in PFC. The peak deviatoric stress of rockfills and post-peak behavior in a biaxial or triaxial tests are difficult to simulate with FEM, and the circular particles or regular shaped particle clusters in PFC cannot properly be represented by the gravel geometry.

In this paper, a method of generating the planar random gravel model for solid backfill materials is developed and several numerical biaxial tests are carried out using a random gravel model and Particle Flow Code PFC^{2d}.

2. Computational geometry algorithms of the random gravel model

The solid backfill materials may contain fine-grained fly ash or soil, rock blocks and coarse-grained rock blocks. Only the coarse-grained rock blocks that control the global mechanical properties of the whole model are treated as gravels, while the fine-grained part is regarded as "soil", and the gravels are represented by a series of convex polygons in a planar view.

To generate the random convex polygons and pack them into a model plane by a computer program, several computational

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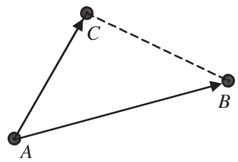
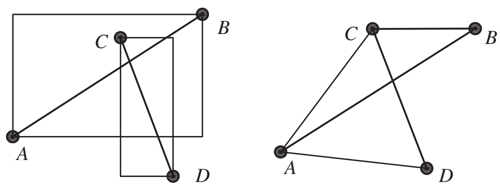


Fig. 1. Two vectors sharing the same start point.



(a) Fast exclude test (b) Straddling test

Fig. 2. Intersect of two line segments.

geometry algorithms relating to the geometrical properties of convex polygons are needed.

2.1. Cross product

Consider two vectors sharing the same start point as shown in Fig. 1 [22].

The cross product of the two vectors is defined as the determinant matrix:

$$S(A,B,C) = \begin{vmatrix} x_A & y_A & 1 \\ x_B & y_B & 1 \\ x_C & y_C & 1 \end{vmatrix} \tag{1}$$

If $S(A, B, C) > 0$, point C is at the left side of AB; if $S(A, B, C) < 0$, point C is on the right side of AB and if $S(A, B, C) = 0$, points A, B and C are collinear. This property of cross product plays a very important role in the algorithms below.

2.2. Intersect of two line segments

If two line segments AB and CD are defined by their ending points, the procedures of determining whether they intersect are shown in Fig. 2.

(1) If the two rectangles in Fig. 2a intersect, then line segments AB and CD may intersect, or else AB and CD cannot intersect at all, this test is called "fast exclude";
(2) If cross products defined by Eq. (1) yield to $S(A,C,B) \times S(A,D,B) \leqslant 0$ and $S(C,A,D) \times S(C,B,D) \leqslant 0$, then line segments AB and CD straddles each other as Fig. 2b shows.

Line segments AB and CD intersect only if both the first exclude and straddling tests are passed.

2.3. Convex checking of a polygon

The convex property of a polygon can be checked by the conception of convex polygon as shown in Fig. 3.The polygon is convex if Eq. (2) is satisfied:

$$S(A_j, A_{j+1}, A_i) > 0, j = 1, 2, \ldots, n; i \neq j, j+1 \tag{2}$$

where n is the total number of vertices.

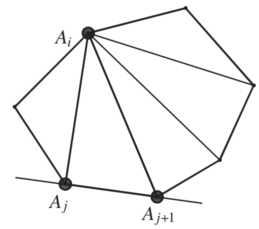


Fig. 3. Convex checking of a polygon.

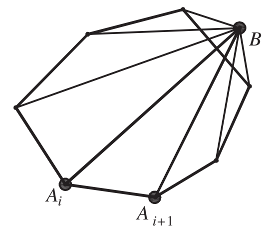
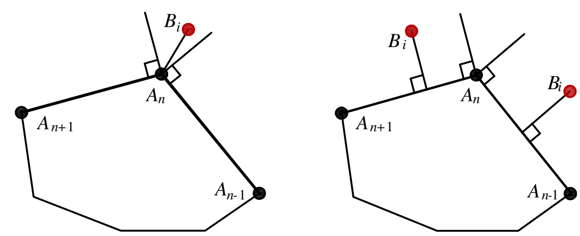


Fig. 4. Judging a point is in or out of a convex polygon.



(a) dist(B_i, A)=dist(B_i, A_n) (b) dist(B_i, A)=dist(B_i, A_nA_{n+1}) or dist(B_i, A)=dist(B_i, A_nA_{n-1})

Fig. 5. Distance from a vertex of one convex polygon to another convex polygon.

2.4. Point and convex polygon

Fig. 4 demonstrates that the method of judging a point is in or out a convex polygon.Define areas as $S_i = S(B, A_i, A_{i+1})$, relation of point B and convex polygon A is determined as follows:

(1) if any $S_i < 0$, then point B is out of the convex polygonal region;
(2) if any $S_i = 0$, then point B is on a edge of the convex polygonal region and
(3) if $S_i > 0$, $i = 1, 2, \ldots, n$, then point B is in the convex polygonal region.

2.5. Shortest distance between two convex polygons

To determine the shortest distance between two convex polygons A and B (provided that A and B do not intersect each other), the distance from a vertex of one convex polygon to another convex polygon should firstly be defined, and this is similar to the distance between a point and a triangle [23].

The definition of distance from a point to a convex polygon is shown in Fig. 5, where B_i is a vertex of convex polygon B, and A_n the vertex of convex polygon A which is nearest to B_i.

The distance from convex polygon B to A is defined as:

$$dist(\mathbf{B}, \mathbf{A}) = \min(dist(B_i, \mathbf{A})) \tag{3}$$