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Joint reconstruction method for the computational mesh using particles

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Abstract

Meshing geological body with joints is one of the major difficulties of using FEM in slope stability analysis. The traditional method is to divide the body into simply connected domains and triangulation them. However, when the geological body has three groups of joints which are quite common in rock mass, the division and connection are quite complicated. In this article, a new meshing method is introduced. This method uses gravity force instead of geometry constrain to ensure mesh nodes lies on joint faces, and uses non-friction plastic particle to fill the geological body. After get the mesh nodes, constrained Delaunay triangulation (CDT) is used to get triangle or tetrahedron mesh. Joint recovery quality and meshing quality are checked with an example which has crossed joints.

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Keywords: joint recovery; meshing; particles; constrained Delaunay triangulation

1. Introduction

Mesh generation is a necessary preprocess for finite element analysis or finite volume analysis. Spatial decomposition, Delaunay triangulation and advancing front approach and their combination are wildly used [1]. In CAD/CAM field, the main difficulty of meshing is to deal with complex boundaries, such as connections of

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mechanical parts. In rock and soil mechanics field, the main difficulty of meshing is to deal with natural joints embedded in the geological body. Natural joints can be divided into several groups; each group has its own distribution of trace length, tendency and dip angle. And there could be dozens of joints belong to each group in our interesting domain. Fig. 1. shows a geometry model based on the survey data of one rock sample. In this figure, three groups of joints can be identified by their color. These joints could intersect with others, and areas of them have a large range of variation. The aim of our research is to find an automatic procedure that can handle the meshing of geological body which has intersected joints in it.

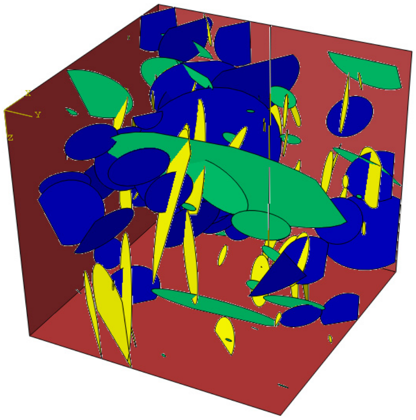

Fig.1. Geometry model of a rock sample

Before using the particle method mentioned later, a scheme of face mesh to volume mesh is used to mesh the sample in Fig.1. This scheme did worked out and generated a computational mesh shows in Fig.2. However, during the step of face mesh, a lot of manual work is needed to clear the intersection line of joint faces, delete joint faces that are smaller than an element face and clear all overlapped triangles. This work is essential to deliver a correct input data to the step of volume mesh and take a lot of time. So an automated method to solve this problem is needed.

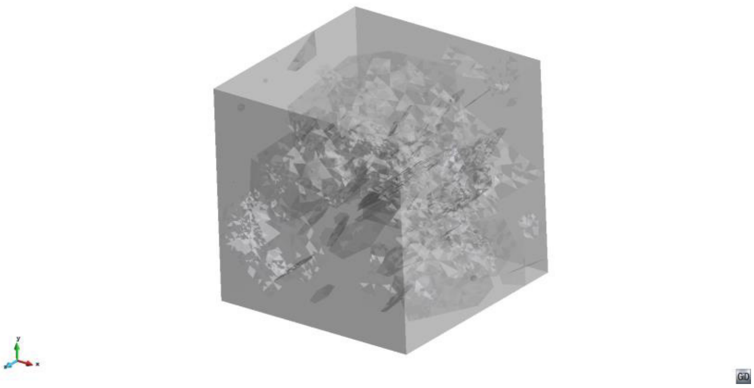

Fig.2. Mesh of a rock sample

1.1. Previous work

As mentioned before, meshing is a necessary preprocess for many kind of numerical analysis. There a lot of researches focus on this subject. Kenji Shimada and David C.Gossard show an automated method of meshing the trimmed parametric surface [2]. Xiang-Yang Li and his colleagues shows a combination of advancing front method and sphere packing method [3]. Xiang-Yang Li's idea of using another algorithm to help meshing algorithm finding a proper place of mesh node enlightened our work. Gary L.Miller and his colleagues also use sphere packing to mesh a domain with three irregular loop holes [4]. S.H.Lo and W.X.Wang expanded this sphere packing method into unbounded 3D domains [1].

2. Particle-Attraction Face method for mesh generation

Most of the existing meshing method can be called geometry method, which means the boundaries and joints are represented by geometry equations, and mesh node or faces are restricted by these equations. This kind of rigid conditions causes trouble when a mesh must satisfy all of them. An idea of using more "soft" conditions appears. Using attraction forces or potential wells to represented boundaries and joints is one of the ways that worth trying, just like the method of using penalty functions to apply boundary conditions.

2.1. Main idea

The particle-attraction face method has two main steps: first step is to find the proper positions of mesh nodes; second step is to triangulation the domain using these nodes. In the first step, elastic particles instead of mathematical spheres are used to represent mesh nodes and a particle flow program developed by Chun Feng is used. In the second step, a free software TetGen is used to generate tetrahedral meshes.

2.2. Progress

Fig.3. shows the progress of particle-attraction face method. Geological data is translated into geometry entities at first, and then a stream of command line is used to generate these faces in the particle flow program. The particle flow program has a function to generate particles in a specific domain. This function can find which part of the domain is not filled well automatically and put more particles in that part. After the 'Filling', a progress can be called 'Shaking' is done. 'Shaking' means apply gravity in -x direction and calculate 2000 steps, then in x, -y, y, -z, z direction successively. Do 'Filling' and 'Shaking' continuously until the domain is completely filled. This may take 2-3 cycles for simple domains, and a bit more for complex ones according to our experiences. The next step is to output the locations of particles into a .a.node file for TetGen to use.

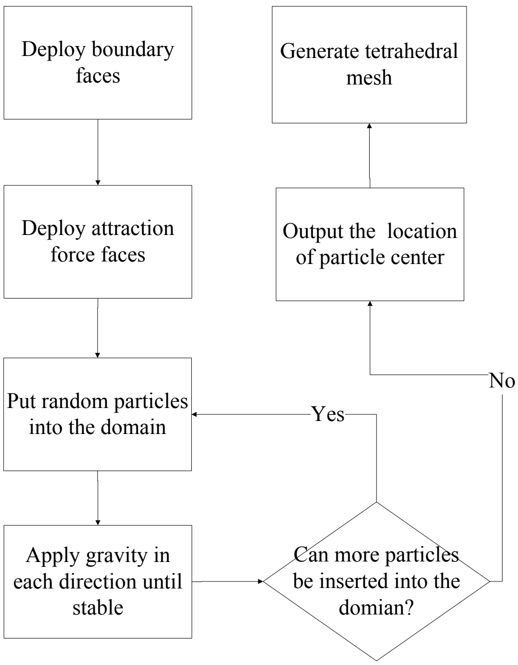

Fig.3. Flow chart of particle-attraction face method

2.3. Algorithm detail

The particle properties used in calculation are: density is 2.5×10^3kg/m^3, Young's modulus is 2.0×10^6Pa, cohesion, friction, local damping and viscosity damping are zero. The contact between particles is brittle, and as cohesion equals to zero there are no pull force between particles.

Boundary faces is rigid and unmovable and Young's modulus of contacts between particles and boundary faces is very high. This treatment guarantees no particles will move out of the domain. Attraction face is a kind of modified boundary face. Attraction face is also rigid and unmovable. Contacts between particles and attraction faces have no Young's modulus, and have an attraction force to all particles within the contact radius. The attraction force is perpendicular to the attraction face and proportional to particle-face distance, and drops to zero out of contact radius. Fig.4. shows the potential of this attraction force, it acts like a potential well. If the well is deep enough, particles drop into this well cannot escape from it.

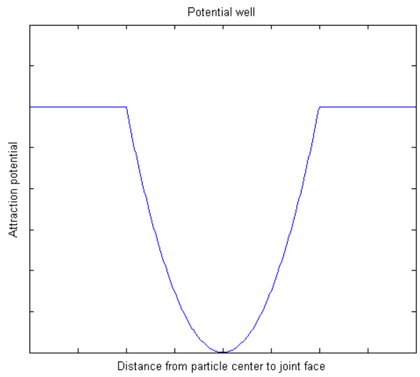

Fig.4. Schematic diagram of potential well

2.4. Tetrahedron mesh generation

To insert nodes into the mesh using constrained Delaunay triangulation in TetGen, a surface mesh is needed. This surface mesh can be obtained using any kind of Delaunay triangulation, by directly meshing the geometry surface of the domain. Here in this article, GiD is used to generate this surface mesh, and a .smesh file is prepared for TetGen. With surface mesh in .smesh file and locations of particles in .a.node file under same name, a –pqi command line of TetGen can be used. This –pqi command means to tetrahedralize a piecewise linear complex, here is the domains defined by the surface mesh, and insert a list of points into it which is the location of the center of the particles, and finally refine the mesh [5].

3. Examples

To evaluate the capability of this particle-attraction face method, a 2D and 3D test is done. Then the quality of the tetrahedral mesh generated from the 3D test is examined.

3.1. 2D test

An example of a rectangle box with a crossed line joints in it is used. Fig.5. (a) shows the particle location after the first ‘Filling’; Fig.5. (b) shows the particle location after the first cycle of ‘Filling’ and ‘Shaking’; Fig.5. (c) shows the final result which takes 3 cycles.

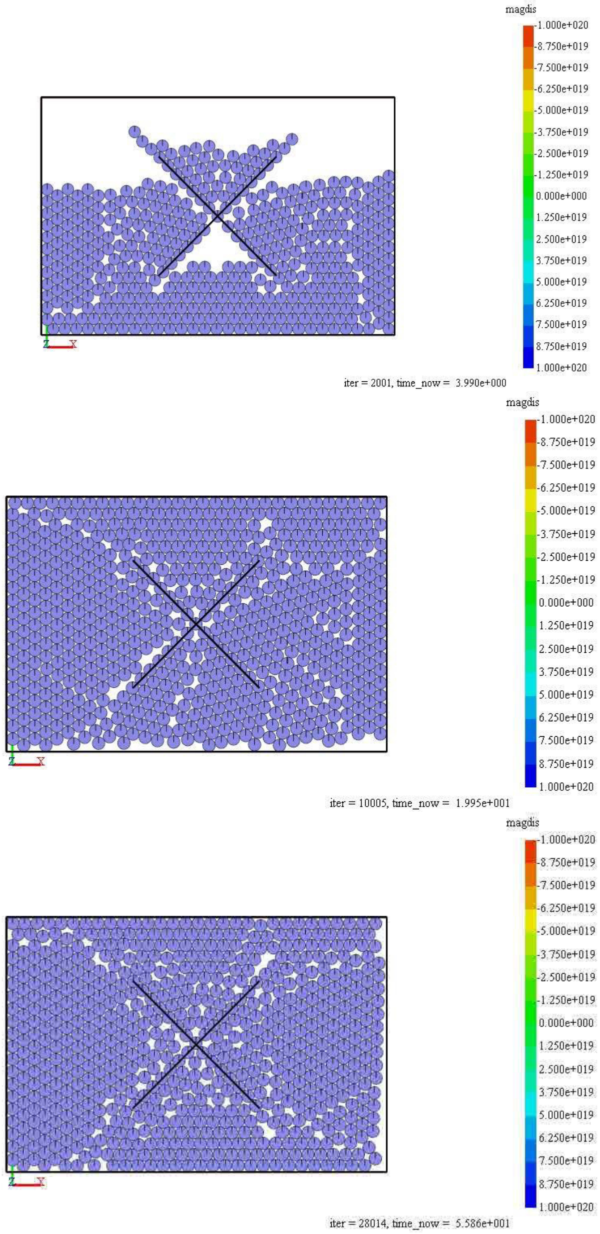

Fig.5. (a) Initial state; (b) After first cycle; (c) Final state

The result of 2D test shows that the cycle of 'Filling' and 'Shaking' can fill a domain in several cycles, and particles in the region away from the joints are packed quite well. Particles at the joints are arranged quite well too: the cross point has a particle; all other particles are arranged one by one along the joints. However there are gaps in the region near the joints, this is understandable because shake force is not large enough to break the arch of particles which landed on the joints. These gaps which is smaller than a particle is a result of compromise: the combination of joint recovery and mesh quality.

3.2. 3D test

An example of a cube with a small plane joint in it is used. Fig.6. (a) shows the model; Fig.6. (b) shows the arrangement of particles in one quadrant near the joint; Fig.6. (c) shows the final result after 3 cycles.

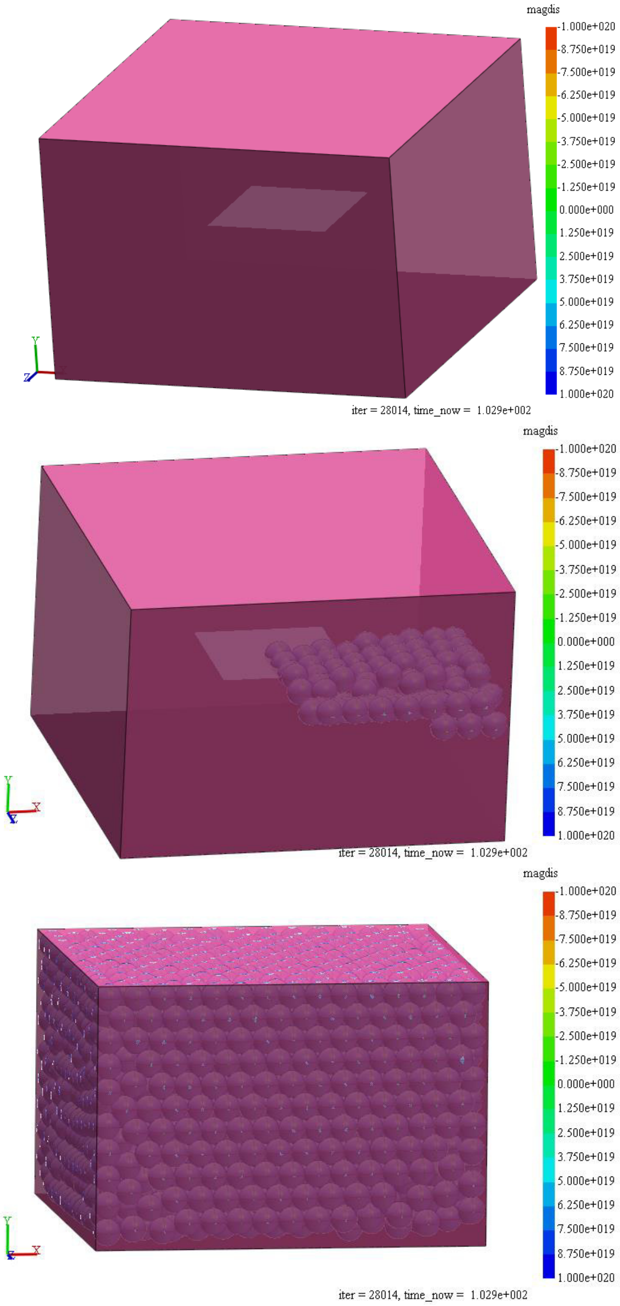

Fig.6. (a) Model; (b) Particles near joint ; (c) Final state

The result of 3D test shows the attraction face has worked, the arrangement of particles is different at the joint face and away from it.

3.3. Mesh quality

Fig.7. shows the exterior view of the mesh generated from the 3D test and the statistics distribution of min dihedral angle. The min minimum dihedral angle is 5.66 degrees and the max minimum dihedral angle is 70.5 degrees and elements has minimum dihedral angle larger than 24.2 degrees occupies 90% of all elements.

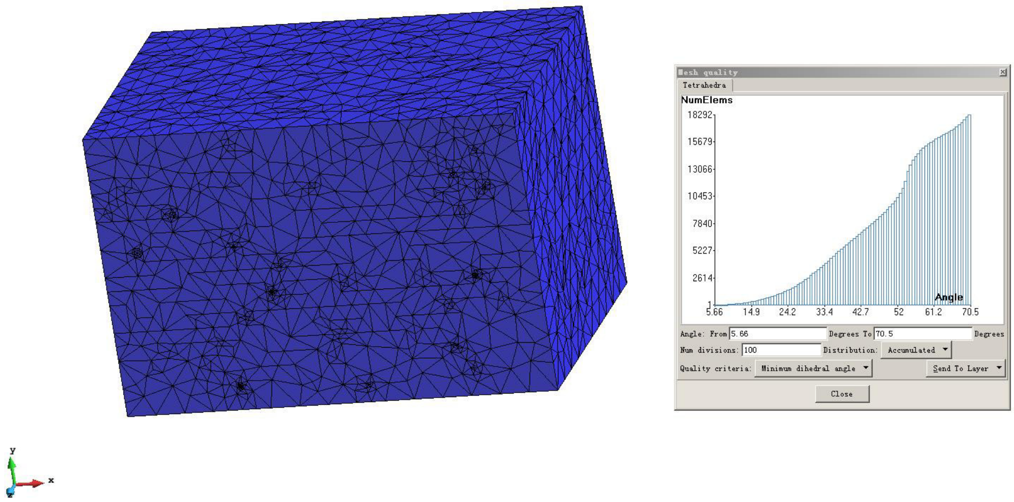

Fig.7. Mesh quality

4. Conclusion

In this article, the particle-attraction face method proves that using penalty forces instead of geometry constrains maybe a solution of represent complex geological joints. And 'Filling' and 'Shaking' particles is a natural way to get well-distanced mesh node. However, computing efficiency and surface treatment is still need to improve until this method can carry out practical problems.

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