IMPULSE-BASED SIMULATION OF PARTICLE FLOW DURING SUBSURFACE BLOCK-CAVE MINING

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Summary In this paper we apply the low-cost and accurate impulse-based method, to simulate the collision of rock fragments in a subsurface mine. Its main advantages are not requiring full geometric intersection checks, ease of implementation, computational efficiency, and not relying on arbitrary penalty parameters. We show that the method is energy-conservative for elastic, frictionless collisions, and demonstrate its application to simulate gravity flow of particles around a single draw point during block caving.

IMPULSE BASED METHOD

Many reseachers have contributed to the development of the impulse-based method (e.g. Hahn, 1988; Baraff, 1994; Mirtich, 1996). Here, the impulse-based method introduced by Guendelman (2003) is introduced. As shown in Fig.1, body 1 collides with body 2. $\mathbf{r}_1 = \{r_1^x, r_1^y, r_1^z\}^T$ and $\mathbf{r}_2 = \{r_2^x, r_2^y, r_2^z\}^T$ are vectors from the center of mass to the contact point; $\mathbf{n} = \{n_x, n_y, n_z\}^T$ is normal direction of collision. The velocities of body 1 and body 2 at the contact point can be represented as $\mathbf{u}_1 = \{u_1^x, u_1^y, u_1^z\}^T$ and $\mathbf{u}_2 = \{u_2^x, u_2^y, u_2^z\}^T$.$\mathbf{p}_1 = \mathbf{p}$ and $\mathbf{p}_2 = -\mathbf{p}$ are a pair of impulses which are applied to body 1 and body 2, respectively, to change their velocity and avoid penetration: $\mathbf{p} = \{p_x, p_y, p_z\}^T$. To consider friction during collision, firstly assume that there is no tangential velocity after the collision:

$$\mathbf{u}_f = -e(\mathbf{u}_b\mathbf{n})\mathbf{n} \tag{1}$$

where $\mathbf{u}_b = \{u_b^x, u_b^y, u_b^z\}^T$ and $\mathbf{u}_f = \{u_f^x, u_f^y, u_f^z\}^T$ are the relative velocities at the contact point before and after collision. e is coefficient of restitution, which lies between 0.0 and 1.0. When the relative velocity after the collision is determined, the impulse $\mathbf{p}$ is computed by

$$\mathbf{p} = \mathbf{K}^{-1}\triangle\mathbf{u} \tag{2}$$

where $\mathbf{K}$ is the collsion matrix defined by Mirtich (1996). Here, we define two tangential directions: $\mathbf{t}$ and $\mathbf{r}$:

$$\mathbf{r} = \frac{\mathbf{n} \times \mathbf{u}_b}{|\mathbf{u}_b|} \tag{3}$$

$$\mathbf{t} = \mathbf{n} \times \mathbf{r} \tag{4}$$

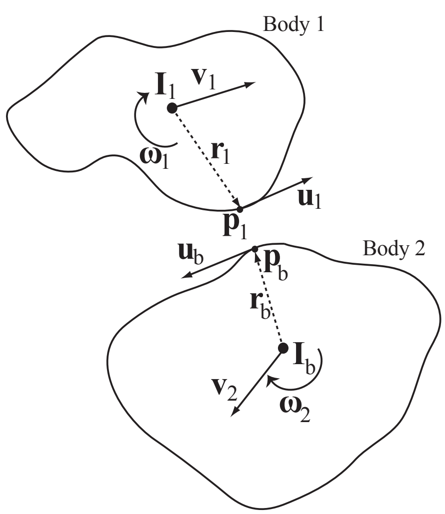

Figure 1. The collision of two bodies

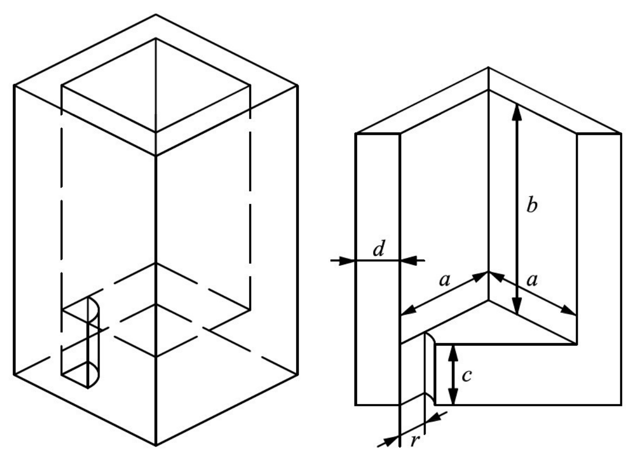

Figure 2. Sketch for a single draw point

The impulse obtained by Eq.(2) is only applied when the static condition is satisfied:

$$|\mathbf{pt}| < \mu|\mathbf{pn}| \tag{5}$$

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where μ is the coefficient of friction.When the static condition is not satisfied, the impulse is recomputed. It also constrains the relative velocity after collison to be exactly the inverse of the relative velocity before collision in the normal direction. Then, the magnitude of impulse can be computed:

$$|\mathbf{p}| = -\frac{(\mathbf{u}_b\mathbf{n})\mathbf{n}(e+1)}{\mathbf{n}^T\mathbf{K}(\mathbf{n}-\mu\mathbf{t})} \tag{6}$$

Then the impulse can be defined as

$$\mathbf{p} = |\mathbf{p}|\mathbf{n} - \mu|\mathbf{p}|\mathbf{t} \tag{7}$$

SIMULTATION OF GRAVITY FLOW OF PARTICLES IN THE VICINITY OF A SINGLE DRAW POINT

Here, the gravity flow of ore particles and waste particles in the vicinity of a single draw point is investigated with the impulse-based method. To simplify the simulation model, only a quarter of the model is treated. Its geometric parameters are shown in Fig.2. The width of the heap of particles is $a \times a$, where $a = 20m$. The draw point is a cylinder whose radius is $r = 5.6m$. The depth of draw point is $c = 11.6m$. The thickness of wall is $d = 5m$. Each particle has the same shape and contains 16 tetrahedra. The radius of particle is approximately $3m$. As shown in Fig.3, the ore particles are represented in purple, whereas the waste particles are in brown. Fig.3 is the initial state of the simulation. The height of ore particles and waste particles are $12m$ and $15m$ respectively. Firstly, the computational model with $\mu = 0$ and $e = 0.8$ is investigated. The numerical result after 900 simulation steps is shown in Fig.4. This results are agree with the restults of discrete element method (Brown, 2003). In our model, we choose $\mu = 0.0$ and $e = 0.0$. In this case, the energy of the system should be conserved. In Fig.5, the energy error of this case is shown. It is seen that relative error is less than 2×10^{-3}. Therefore, the impulse-based method is able to conserve energy.

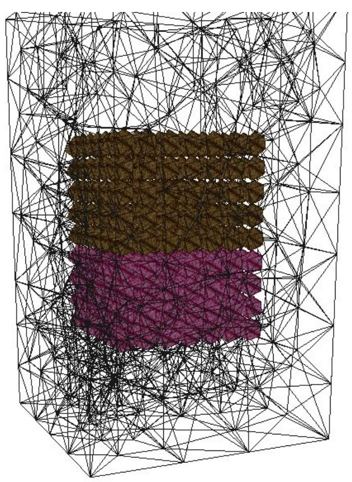

Figure 3. Initial state of simulation

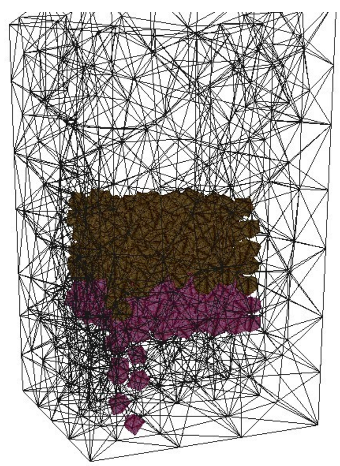

Figure 4. Simulation after 900 steps, $\mu = 0.0$ and $e = 0.8$

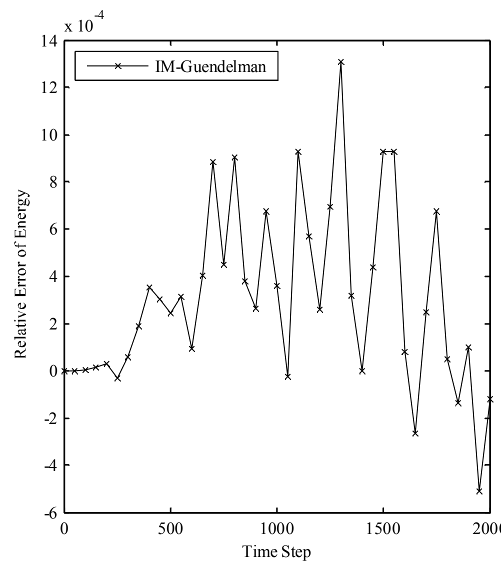

Figure 5. Energy error, $\mu = 0.0$ and $e = 0.0$

CONCLUSIONS

In the present work, the impulse-based method is used to simulate the collision of rock fragments in a subsurface mine. Some conclusions are obtained. Firstly the impulse-based method is able to simulate complex movements of a great number of particles around a single draw point. Secondly, the impulse-based method introduced by Guendelman is able to conserve energy.

References

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