Simulation of rock failure and earthquake process on mesoscopic scale

YuCang Wang[(1)], XiangChu Yin[(2)], Xue-Zhong Chen[(2)],KeYin Peng[(2)], and ZiPing Song[(3)]

(1) LNM, Institute of Mechanics, Chinese Academy of Sciences, Beijing, China (e-mail: yin@imech.ac.cn; phone: +86-10 62545533-3184; fax: +86-10 62561284).
(2) Center for Analysis and Prediction, China Seismological Bureau, Beijing, China (e-mail: yinxc@sun.ihep.ac.cn; phone: +86-10 6252-8760; fax: +86-10 6256-1284).
(3) Beijing Earthquake Bureau, China.

About our model

On the basis of Lattice model of Mora and Place, Discrete Element Method (DEM) and Molecular Dynamics approach (MD), we studied another kind of discrete model to simulate the fracture of brittle solid (especially under pressure) and earthquake process. In our study,the material is also discretised into a number of round particles linked by interaction and arranged into the same triangular lattice, the particles are the smallest mesoscopic units which can not be broken,the size of particles range from mm(grains) to km(geological blocks). But our model is little more complex:not only radial force F_r but also tangential force F_s and bending moment M are transmitted between the adjacent particles,so every particle is described by three variances : position x,y and spin θ ,and there are three kinds of relative displacement between every adjacent particle pair,that is, radial displacement Δr, shear displacement Δs and torsion $\Delta\theta$. If we use the linear relation of force and displacement, we have

$$F_r = K_r \Delta r \tag{1}$$
$$F_s = K_s \Delta s \tag{2}$$
$$M = K_m \Delta\theta \quad , \tag{3}$$

where K_r,K_s,K_m are radial , tangential and bending rigidity.

Chosen of mesoscopic parameters

We have demonstrated that under the condition of small strain, in order to make the Young modulus of elasticity and Poisson ratio of macroscopic material to be E and ν, the mesoscopic parameters should be chosen according to

$$K_r = \frac{\sqrt{3}E}{3(1-\nu)} \tag{4}$$

$$K_s = \alpha K_r \tag{5}$$

$$K_m = \frac{r_0^2 E}{6\sqrt{3}} \quad , \tag{6}$$

where

$$\alpha = \frac{1-3\nu}{1+\nu} \tag{7}$$

$$\nu = \frac{1-\alpha}{3+\alpha} \quad , \tag{8}$$

where r_0 is the diameter of the particles.
From the equations above, we know that the material of ν form 0 to $\frac{1}{3}$ can be modeled, and if the tangential force is neglected ($K_s = 0$), $\nu = \frac{1}{3}$, only when r_0 is very small, can the contribution of K_m be neglected.

Fracture criteria and state after fracture

The link between two adjacent particles can break in three different way alone:
When radial extension force exceed the maximum value F_{r0}, it will break,
or,when tangential force exceed the maximum value F_{s0}, it will break,
or,when moment exceed the maximum value M_0, it will break.
But generally three kinds of interaction always exist at the same time, considering the fact that the radial force may effect the tangential fracture and bending fracture,we used the following criteria similar to Coloumb's criteria to judge if the link will break:

$$\frac{F_r}{F_{r0}} + \frac{F_s}{F_{s0}} + \frac{M}{M_0} \geq 1 \quad . \tag{9}$$

There are four kinds state between the neighbouring particles: (A) intact ,(B) sliding,(C) locked by static fiction ,(D) departing
the table below shows whether the forces and moment can be transmitted or not:

A	can	can	can
B	can only when $r \leq r_0$	sliding friction,$f_d = \mu_d F_r$	can't
C	can only when $r \leq r_0$	static friction, by section 4	can' t
D	can't	can't	can't

Where F_d means sliding frictional force and μ_d is sliding frictional coefficient .

the states can change according to :
(1) $A \rightarrow B$,when (9), $r \leq r_0$,and $V_t \neq 0$.

(2) $A \to D$,when (9), $r \geq r_0$.
(3) $B \to C$,when $V_t = 0$.
(4) $C \to B$,when $f_s \geq \mu_s F_r$.
(5) $B \to D$,when $r \geq r_0$.
(6) $C \to D$,when $r \geq r_0$.
(7) $D \to B$,when $r \leq r_0$,and $V_t \neq 0$
(8) $D \to C$,when $r \leq r_0$,and $V_t = 0$

Where F_s means static frictional force, μ_s is static frictional coefficient,and V_t is relative tangential velocity.
(1) and (2) mean the process from intact to broken.
(3) and (4) mean exchange between static and sliding frictional state.
(5) and (6) mean departing process.
(7) and (8) mean contact process of two un-linked particles.

Calculation of static friction

When two particles are locked by static friction, if the tangential rigidity is chosen to be infinite, the friction force can only be determined by the resultant force excluding this friction force,but sometimes the resultant force is unknown when it includes the static friction force between this particle and other particles which depends upon the frictional state and need to be determined. In our model, the tangential rigidity is not infinite, but a finite one, the friction force can be easily decided by the relative tangential displacement according to the principle of DEM.

Resolution of equation of motion

The differential scheme of MD is also used just like Mora's model, with the only difference of adding rotation equation about θ.

Some initial results

Considering that there usually is great compressive stress in the place where earthquakes occur, the failure process of brittle rocks under the compressive stress has been modeled, X-shaped failure patterns (homogeneous materials) and cleavage (materials with some random initial defects) have been gained under uniaxial pressure and the effect of confining pressure on failure patterns was discussed, that is, the bigger the confining pressure is, the more ductile the failure process tends to be, and the bigger the breaking stress is, and the more groups of shear bands there are, and the wider the shear bands are, and the bigger the angle between two groups of main shear bands is.
In addition, the dynamic expansion of close oblique crack which has been more studied is also simulated. All the results are similar to the rock experiments. Some basic seismic activity, such as epicenter distribution, M-t charts, b values, frequency, energy release, are gained using this model . Spatial and temporal inhomogeneity, abundant pre-shocks and after-shocks are also observed. At last, some influential

factors of b values are discussed, and the results are: inhomogeneity is the main factor which effects the b values: the more inhomogeneous the material is, that is, the more cracks there are, or the bigger difference between the number of long crack and small cracks is, the bigger the b values are .

Acknowledgments

This research was funded by the National Natural Science Foundation of China (Grant No. 19732060), the Earthquake Association Foundation (Grant No. 95-07-435), and the Laboratory of Nonlinear Mechanics, Institute of Mechanics, CAS.

References

[1] Herrmann, D.W., 1989, *Computer simulation methods in theoretical physics,* Springer-Verlag, second edition

[2] Cundall, P.A., Strack, O.D.L., 1979, *A Discrete Element Model for granular assemblies,* Géotechnique **29**, 47-65.

[3] Mora,P. and Place,D., 1994, *Simulation of the frictional stick-slip instability,* Pure Appl. Geoph. **143**, 61-87.

[4] Mora, P. and Place, D., 1993, *A lattice solid Model for the nonlinear dynamics of earthquakes,* Int. J. Mod. Phys. **C 4**, 1059-1074.

[5] YuCang Wang, 1998, *Mechanics simulation of seismogenic process from mesoscopic to macroscopic Scale,* Doctoral dissertation,Geophysics Institute, China Seismological Bureau