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Numerical Simulation of Rock Breakage and Its Acoustic Emission with Discrete Element Model

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The acoustic emission (AE) is a key parameter to identify the interior micro crake in rock materials. The AE techniques have been applied in geotechnical engineering widely. For the forecast of geodisaster, AE signal is also effective information to estimate the stability of rock slope. In recent years, experimental investigations have been performed to determine the AE characteristics under tensional and compression loads (Rudajev *et al.* [1]; Dai and Labuz [2]). While numerical models have been also developed to simulate the AE in the rock breakage process with finite element analysis (Aberg [3]). Nowadays, the discrete element model (DEM) appears distinct advantage in rock breakage modeling and AE recording (Hazzard and Young [4]; Cai *et al.* [5]; Su *et al.*, [6]).

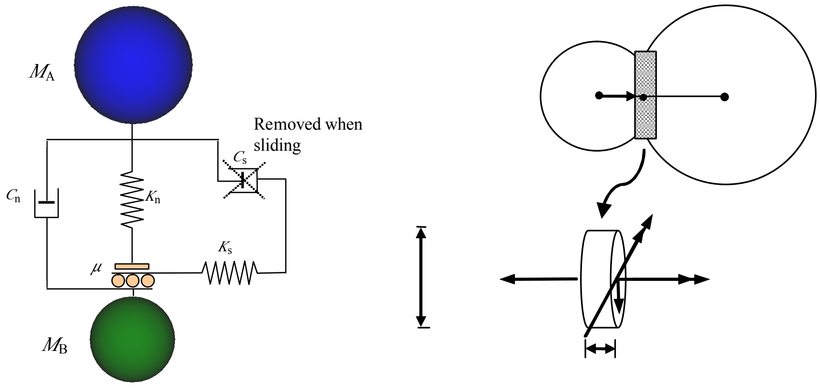
In this study, the DEM is applied to model the breakage of rock specimen under uniaxial compression. For the contact interaction among particles, the visco-elastic linear model with the Mohr-Coulomb friction law is adopted, shown as Figure 1(a). Here M_{A} and M_{B} are the mass of ice particle A and B, K_{n} and K_{s} are the normal and tangential stiffness, C_{n} and C_{s} are the normal and tangential damping coefficients, μ is the friction coefficient. With the contact force model above, the normal and tangential forces of any two contact particles in contact can be calculated. In the DEM simulation, spherical elements are bonded to construct the rock block. Considering the inhomogeneity in rock on micro scale, the bonding strength is set as a normal probability distribution function. The parallel bonding model is introduced to transfer the force and moment between bonded particles, shown as Figure 1(b). A disk between the two bonded particles with thickness L and diameter R is used to model the parallel bonding function. Here, x_i is the location tensor of element; $\bar{F}$ and $\bar{M}$ are the contact force and moment between bonded particles; the superscript n and s means normal and shear respectively. The maximum normal and tangential stresses can be written as

$$\sigma_{\max} = \frac{-\bar{F}^{\mathrm{n}}}{A} + \frac{\left|\bar{M}^{\mathrm{s}}\right|}{I}\bar{R} \tag{1}$$

$$\tau_{\max} = \frac{\left|\bar{F}^{\mathrm{s}}\right|}{A} + \frac{\left|\bar{M}^{\mathrm{n}}\right|}{J}\bar{R} \tag{2}$$

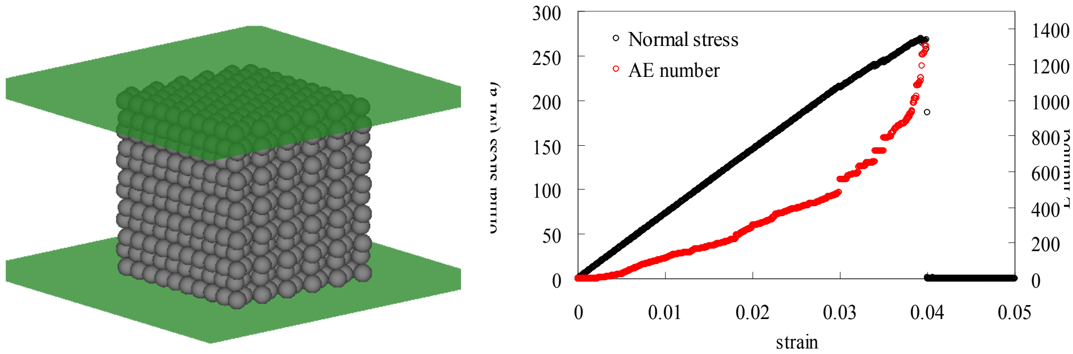
where A, J and I are the area, polar inertia moment, inertia moment, respectively. When the normal or tangential stress exceeds its threshold, the bonded particles will be broken, and an AE number is recorded.

With the contact and bonding model above, the breakage rock specimen under uniaxial compression is simulated with DEM. In this simulation, the spherical particles are packing initially in regular pattern, shown as Figure 2(a). The bottom load panel is fixed, and the top panel is declined as a constant rate. In this compression process, both of the normal stress and AE number increase with normal strain. The AE number presents essentially the breakage degree of the rock specimen, and can be explained with the bonded force chains. From the simulated results, the Kaiser effect can be obtained well. The relationship between AE number and strain will be discussed in details to understand the Kaiser effect in rock damage.



(a) contact force model (b) parallel bond model

Figure 1: Contact and bond force model for spherical elements.



(a) Rock specimen under uniaxial compression (b) simulated AE number and normal stress

Figure 2: Rock sample described with DEM and simulated results

In the next study, the nonlinear contact model and the random packing will be tested to simulate the generation of micro crack and the propagation of macro crack in rock specimen, while the AE characteristics can also be observed during rock breakage. The comparison between numerical results and experimental data will be carried out to calibrate the DEM and to promote the application of AE techniques in geologic disaster forecasting.

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