Development of a numerical code based on the discrete element method for solid earth simulation

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Development in computer technology gives the chance to research the solid earth dynamics by numerical simulations. The Eulerian methods, such as the finite difference method and finite element method, are used to solve the earth dynamics problems in many cases. However, for the analyses of the formation of faults and foldings accompanying with large deformation or including discontinuity, it is convenient to use the Lagrangian methods (particle based methods). Particle based methods have a demerit that a large number of elements (particles) and resulting a huge computational time are needed for achieving a higher spatial resolution. Thus, the particle based methods are not general for solving solid earth problem numerically. In this study, we develop a numerical code based on the discrete element method (DEM) (Cundall, 1971), one of the Lagrangian type schemes, and demonstrate its applicability to the solid earth simulations. In the DEM, both translational and rotational components of movement of each element are solved with the interaction forces among the elements. Thus, using this method, the dynamics of both the continuum and discontinuum media may be solved more precisely and lower costly than the general particle based methods do. Especially, introducing the spherical (3D) or circle (2D) elements, the computational time is considerably reduced and the DEM has been mainly used for analyses for discontinuum media such as sand and powder. For continuum media analyses, however, the scheme based on the DEM has not yet been established. In order to apply to both continuum and discontinuum media, in this study, the DEM is modified as follows:

1. Introducing the cohesion and failure criterion

Attraction (cohesion) is introduced between connected elements. When the Coulomb-Mohr's criterion is satisfied between elements, the cohesional force disappears and only the repulsive force due to compressing is worked.

2. Introducing two modes of rotation

In the conventional DEM using spherical or circle elements, the adjoining elements only allow rotating in the opposite direction. However, it is natural that the elements consisted of a single continuum rotate in the same direction, when shear stress, or rotational force, is applied. Co-rotation of elements is also expected for the isolated elements in contact, if the moment due to the normal stress is larger than that due to the shear stress. These two modes of rotation of elements are considered in this study.

Using the extended discrete element method developed in this study, first, 2-dimensional shear deformation test is performed. The elements with an equal radius are arranged in the shape of a square. Walls are set in the vertical side and the upper surface is horizontally moved at a fixed speed. Number of elements used in this test is 1 to 1024 (32x32) by changing the size of elements. The shape of the total elements and rotational angle of each element show good agreements with the analytic solutions. Second, test for a bending problem is carried out. The plate having a ratio of length to height to be 10 is fixed at one side on a wall and is bending due to gravity. The number of elements is 10 (10x1) to 2560 (160x16) and two different initial configurations of elements are used. Good agreements with the analytical solutions of bending are found in the results for all the calculations.

The particle method considered only normal force between elements needs a large number of elements to obtain correct solutions and its results are influenced by the initial configuration of elements. The DEM type code developed in this study shows the validity in simulating the deformation of the visco-elastic solids and the usefulness of application to the solid earth simulation.