THE DISCRETE ELEMENT METHOD
WITH APPLICATION TO SIMULATION OF GRANULAR FLOW AND DYNAMIC FRACTURE OF SOLIDS

R. Kačianauskas
Vilnius Gediminas Technical University, Vilnius, Lithuania

1. General

The discrete (sometimes referred to asdistinct) element method (DEM) introduced by Cundall and Strack [1] started with its first application to simulate the dynamic behaviour of granular material. Contrary to the methods based on the continuum approach, DEM is based on the Langrangian approach, meaning that particles of granular material are treated as contacting bodies, while dynamical parameters (position, velocity, orientation, etc.) of each body are tracked during the simulation.

Generally, the DEM concept permits numerical simulation of a wide variety of problems ranging in different scales. It comprises fundamental ideas of molecular and multi-body dynamics. On the other hand, DEM may be considered as one of the numerical methods describing the behaviour of continuum in terms of a finite number of discrete parameters. Recently, the DEM has become a powerful tool for solving many scientific and engineering problems.

2. Concept and methodology

The granular material considered in this paper presents a space filled with deformable bodies, termed here as discrete elements. The simple and most popular particle shapes in three-dimensions are the sphere and the ellipsoid. When moving, the particles as contacting bodies impact and deform each other.

Individual bodies change their position due to free rigid body motion or interactions with the neighbouring bodies or walls. The translation and rotation of each body in time t are described by the second Newton's law and expressed in terms of resulting forces acting at the centre of gravity. The most popular inter-particle contact model of frictional visco-elastic body considers a combination of elasticity, damping and friction force effects.

3. Computational aspects

Computational aspects of DEM involve [2-3] basically problem formulation, contact searching, computation of forces and time integration of equations of motion. Problem formulation involves a specific technique to set up the initial and boundary conditions. The explicit time integration technique prevails in the DEM computations.

The main disadvantages of the DEM technique, in comparison with the well-known numerical methods based on continuum approach, are related to computational capabilities limited by a huge number of particles and a relatively small time step used in time integration, therefore, much attention is also paid to software implementation. Improvement of computational efficiency by using parallel implementation is a realistic alternative.

4. Application to granular materials

Several application examples of DEM to dry non-cohesive granular material problems are considered and selected modelling results are presented. Simulation of filling and unsteady/steady discharge processes in three-dimensional hoppers of different geometry is illustrated in details [4].

The microscopic parameters of granular material composed of spherical particles are analysed in terms of their contribution to macroscopic parameters, such as time-dependent evolution of the system kinetic energy, porosity fields, discharge rates as well as wall and material stresses.

Along with spherical particles, the multi-sphere (MS) approximation approach [5] of the 3D axi-symmetric ellipsoidal particle is also illustrated. Performance of the MS approach is examined by solving a piling problem. The deviation of a multi-sphere shape from ellipsoid at the particle level is evaluated.

5. Modelling of solids

DEM is also extensively applied to the simulation of solids, mainly concerning dynamic deformation behaviour and fracture problems. Development of the continuum consistent lattice-type DE model for 2D solids is considered. The proposed DEM approach assumes that deformation behaviour of solid is described by translational motion of particles, while inter-particle forces are expressed in terms of axial forces of the axially deformed connection element.

The FEM technique was applied to the development of the DEM model. By applying a standard constant strain triangle finite element it was shown that Cartesian elastic inter-particle forces may be expressed in terms of stiffness matrices of the triangles incorporated. The developed combined DEM/BEM approach is based on the analogy between the structural and continuum variables in a triangle. The resultant normal elastic force presents the sum of individual edge forces of adjacent triangles. Additionally, each of the edge forces is composed of two components involving influences of the axial and shear stiffness. For isotropic solid, two stiffness parameters may be directly extracted from the stiffness matrix of the triangle.

The suggested approach is independent on the Poisson's ratio and the shape of the triangle lattice. From the physical point of view, conventional mutual interaction of particles is modified by the collaborative interaction of the local particle assembly. Consequently, modification of the algorithm and the DEM code is required. Multi-fracture with randomly distributed tensile strength properties of the material is considered for illustration.

6. Acknowledgements

7. References

[1] P.A. Cundall and O.D.L. Strack (1979). A discrete numerical model for granular assemblies, *Geotechnique*, **29**, 47-65.

[2] R. Balevičius, R. Kačianauskas, A. Džiugys, A. Maknickas and K. Vislavičius (2006). Investigation of performance of programming approaches and languages used for numerical simulation of granular material by the discrete element method, *Comp. Phys. Comm.*, **175**(6), 404-415.

[3] A. Maknickas, A. Kačeniauskas, R. Kačianauskas, R. Balevičius and A. Džiugys (2006). Parallel DEM Software for Simulation of Granular Media, *Informatica*, **17**(2), 207-224.

[4] R. Balevičius, R. Kačianauskas, Z. Mróz and I. Sielamovicz (2007). Microscopic and macroscopic analysis of granular material behavior in 3D flat-bottomed hopper by the discrete element method, *Arch. Mech.*, **59**(3), 231-257.

[5] D. Markauskas (2006). Discrete element modelling of complex axi-symmetrical particle flow, *Mechanika*, **6**(62), 32-38.