Numerical simulations of homogeneous triaxial test of granulates using DEM

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Abstract

Numerical simulations of the behaviour of granular materials were carried out using 3D discrete simulations. A homogeneous triaxial test under constant lateral pressure was modelled. To simulate the behaviour of irregular granulates, clumps (clusters) were used, i.e. each granulate was composed of several connected single spheres. Numerical results were compared with corresponding laboratory tests. The effects of lateral pressure, initial void ratio and a stochastic distribution of spheres on the global material behaviour were investigated.

Keywords: clumps, discrete analysis, granular material, triaxial test

1. Introduction

Granular materials consist of grains in contact and of surrounding voids, which change their arrangement depending on environmental factors and initial density. Their micromechanical and fabric behaviour is inherently discontinuous, heterogeneous and non–linear. The aim of our calculations is to check the capability of a Discrete Element Method to simulate the behaviour of cohesionless sand under monotonic loading during a conventional drained homogeneous triaxial test which belongs to the most important geotechnical tests to determine soil properties. We have used the program YADE developed at Grenoble University based on the so called soft–particle approach [2], [4]. To simulate the behaviour of real sand, a 3D spherical discrete model was used with clumps composed of spheres in order to take into account the grain roughness.

2. Discrete Element Method

DEM is a numerical approach where statistical measures of the macro–mechanical response of the material behavior are computed from the individual motion and mutual interactions of a large amount of discrete elements [2]. It assumes, namely, that a solid material can be represented by a collection of particles interacting among themselves in the normal and tangential direction. The state of every particle in the system and all particle interactions are determined using physical laws. This method provides new insight into constitutive modeling because a physical process which governs the constitutive behavior can be described at the local scale which is usually responsible for the global behaviour.

In our model, the so–called soft–particle approach is used (i.e. the model allows particle deformation which is modeled as an overlap of particles). The dynamic behaviour of the discrete system is solved numerically using a force–displacement Lagrangian approach and tracks the positions, velocities, and accelerations of each particle individually. It uses an explicit finite difference algorithm assuming that velocities and accelerations are constant in each time step. To calculate forces acting in particle–particle or particle–wall contacts, a particle interaction model is assumed in which the forces are typically subdivided into normal and tangential components. The total forces and moments acting on each particle are summed. Next, the problem is reduced to the integration of Newton's equations of motion for both translational and rotational degrees of freedom. As the result, the accelerations of each particle are obtained. The time step is incremented and accelerations are integrated over time to determine updated particle velocities and positions. To maintain the numerical stability of the method and to obtain a quick convergence to a quasi–static state of equilibrium of the assembly of particles, damping forces have to be introduced.

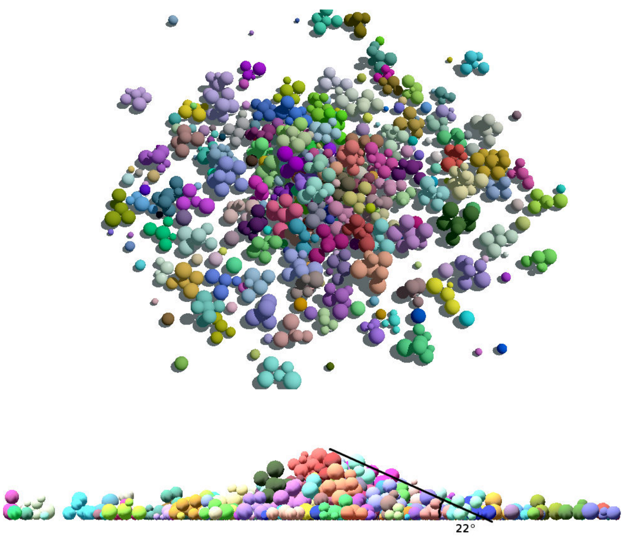

Figure 1: Clumps used in simulation (angle of repose was 22°)

Discrete elements can have different geometries [1], but to keep a low calculation cost, usually the simplest spherical geometry is chosen (dealing with realistic shapes would lead to a prohibitive calculation cost). However, the spherical geometry is too idealized to accurately model phenomena exhibited by real granular materials. It has been shown that spherical particles have a smaller angle of repose and reduced shear strength as compared

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to non–spherical particles [3]. It is due to that the rotation is only resisted by frictional contacts with neighbouring particles whereas for non–spherical particles the rotation tends to be inhibited by mechanical interlocking.

In the paper, spherical elements connected into clumps were used to simulate by the grain roughness. The clumps were created in following way: first initial triaxial compression was performed on spheres until the desired initial void ratio was obtained (e.g. $e_0 = 0.60$), then 4-8 spheres being in contact were connected together to form a single irregular rigid body. Afterwards conventional triaxial compression was performed on clumps. Figure 1 presents the shapes of clumps obtained in simulations.

The following three main local material parameters were needed for discrete simulations: E_c, ν_c and μ. In addition, the particle radius R, particle density ρ and damping parameters α were required. The following local parameters were used in simulations: modulus of elasticity of grain contact $E_c = 0.2$ GPa, Poisson's ratio of grain contact $\nu_c = 0.3$, inter–particle friction angle $\mu = 3^\circ$, mean grain diameter $d_{50} = 0.5$ mm and particle density $\rho = 2600$ kg/m^3.

3. Triaxial Test

Some numerical results of a homogeneous triaxial test for cohesionless sand composed of clumps are presented in Figs.2-4. A cubic granular specimen of $5 \times 5 \times 5$ cm^3 including about 2000 spheres (forming about 300 clumps) with a sphere diameter varying between 0.2 mm and 0.8 mm (d_{50}=0.5 mm) was used (clump size varied between 0.5 mm and 1.5 mm). The top and bottom boundaries moved vertically as loading platens under strain–controlled conditions to simulate the confining pressure $p = 200$ kPa ($e_0 = 0.60$).

Figure 2 shows the stress–strain curve. First, the material shows hardening. After peak, it indicates pronounced softening and next reaches a residual state (as in the experiment). Figure 3 demonstrates the evolution of a global internal friction angle which is 45° (at peak) and 22° (at residual state). In Figure 4, the evolution of the volumetric strain is depicted. After initial contractancy, the granulate indicates pronounced dilatancy (as in the experiment).

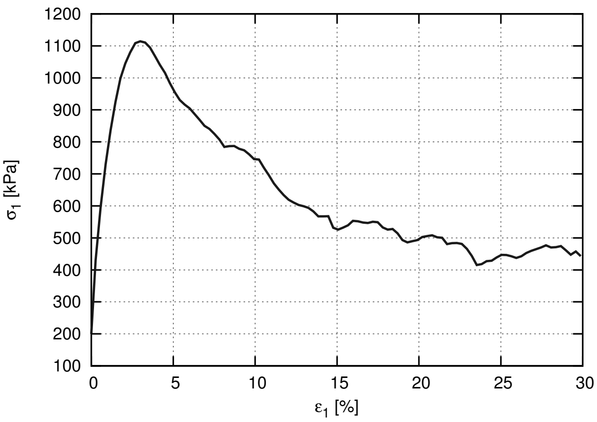

Figure 2: Evolution of vertical normal stress versus vertical normal strain during triaxial test

4. Conclusions

The numerical simulations of a homogeneous triaxial test show that a simplified numerical model based on the discrete element method is capable to reproduce the most important macroscopic properties of cohesionless granular materials without it being necessary to describe the granular structure perfectly. Comparing the numerical simulations with the experimental triaxial tests conducted with different initial void ratios and confining pressures shows that the model is able to realistically predict the experimental results for cohesionless sand.

The model is capable of closely reproducing the behavior of cohesionless soils in the elastic, contraction, and dilatancy phase and at the critical state. At large strains, the granular specimen reaches always a critical state independently of its initial density.

The sand grain roughness can be modelled by means of spheres connected into clumps.

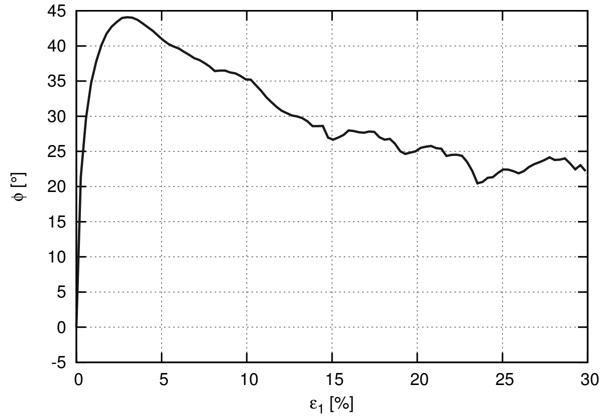

Figure 3: Evolution of global internal friction angle during triaxial test

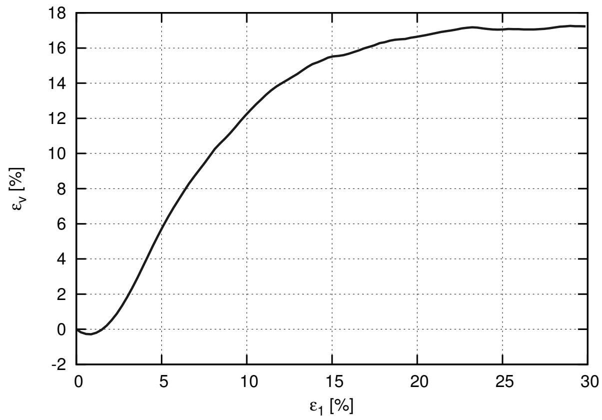

Figure 4: Evolution of volumetric strain versus vertical normal strain during triaxial test

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