EFFECT OF GRAIN SHAPE ON CREATION OF VORTEX/ANTI-VORTEX-STRUCTURES IN GRANULAR BODIES USING DEM

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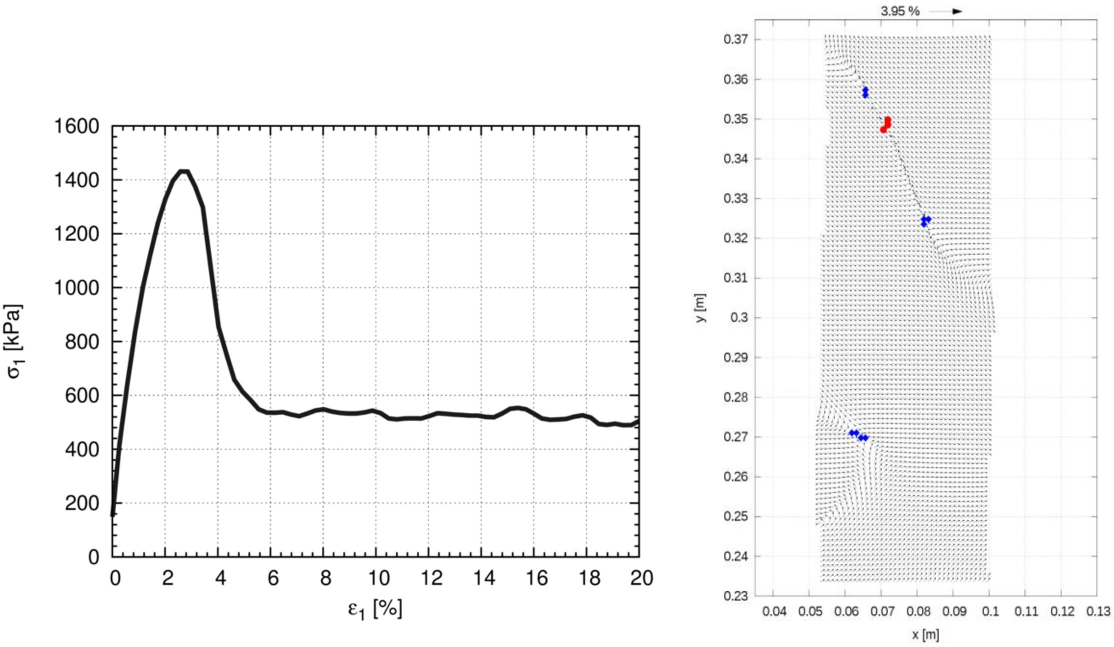
1. Introduction

Granular vortex structures (swirling motion of several grains around its central point) were frequently observed in experiments on granular materials and in calculations using the discrete element method (DEM). They became apparent when the motion associated with uniform (affine) strain was subtracted from the actual granular deformation. The dominant mechanism responsible for the vortex formation was the buckling of force chains [1], [2]. The collapse of main force chains lead to the formation of larger voids and their build-up to the formation of smaller voids [2]. The vortices have been mainly observed in shear zones [2], which are the fundamental phenomenon in granular bodies. However, a precise mechanism behind the vortex evolution and shear localization still remains elusive.

2. DEM calculations

The objective of this paper is to report the DEM results of comprehensive studies of the two-dimensional (2D) granular vortex- and anti-vortex-structures during in a vertical section of the 3D granular specimen during quasi-static drained plane strain compression of cohesionless sand (simulated by clusters of spheres) by taking shear localization into account. The plane strain compression test is the most important geotechnical laboratory test to experimentally investigate shear localization in granular materials. It may be identified as a typical 2D boundary value problem, i.e. the effect of the granular specimen depth on the shear zone pattern is assumed to be negligible. The calculations were carried out with clusters of spheres in order to approximately capture an irregular shape of granulates. Our previous DEM 3D calculation results on plane strain compression using spheres with contact moments [3] showed that the 2D vortex- and anti-vortex structures mainly appeared in the main inclined shear zone. Their occurrence did not depend on the specimen depth. The anti-vortices turned out be the best precursor of the location of shear zones since they appeared from the beginning of the deformation process, i.e. significantly earlier than e.g. based on the average cumulative grain rotation. The predominant period of left-handed vortices and anti-vortices in the entire strain range was mainly 15% of the global vertical strain. The 2D vortex- and anti-vortex structures were determined by a method based on orientation angles of displacement fluctuation vectors of neighbouring single spheres [4]. The proposed method used for the detection of 2D granular vortex/anti-vortex-structures was very effective. This method detected all vortex and anti-vortex-structures regardless of the displacement vector length. The number of vortex/anti-vortex-structures in methods based on the divergence and curl of the displacement field strongly depends in contrast on the displacement vector length [2]. Therefore we used the same method in this paper in order to investigate the effect of the grain shape on the results of micro-structural events. A three-dimensional discrete model YADE developed at University of Grenoble was applied [5]. The DEM global results were compared with the corresponding experimental data from plane strain compression tests performed at Karlsruhe University with real the so-called Karlsruhe sand. The DEM analyses were solely carried out with initially dense sand for one confining pressure and initial void ratio. In order to accelerate the computation time, some simplifications were assumed: large particles, linear particle distribution, linear normal contact model and no particle breakage.

The paper consists of 2 main parts. In the first part, the DEM results of a plane strain compression test were summarized to show the capability of DEM to realistically simulate shear localization in sand during this test. The shear zone was detected in an usual way based on the continuous local volume's increase (dilatancy). In the second part, the formation of vortex and anti-vortex structures was discussed with respect to the shear zone formation. The major contributions of the manuscript is the detection of a shear zone in granular bodies with irregularly-shaped grains based on zones of non-uniform displacement fluctuations, including vortex- and anti-vortex structures.



a) b)

Figure 1: DEM results for plane strain compression with initially dense sand (simulated as clusters of spheres): a) vertical normal stress σ_1 versus vertical normal strain ε_1 and b) distribution of single vortices and anti-vortices in normalized displacement fluctuation vector field for vertical normal strain ε_1=3.95% (red circle - left-handed vortex, blue circle - anti-vortex)

3. References

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