Investigations of quasi-static vortex-structures in 3D sand specimens based on DEM and Helmholtz-Hodge vector field decomposition

J. Kozicki* and J. Tejchman†

* Gdansk University of Technology
Narutowicza 11/12, 80-213 Gdansk, Poland
e-mail: jkozicki@pg.gda.pl

† Gdansk University of Technology
Narutowicza 11/12, 80-213 Gdansk, Poland
e-mail: tejchmk@pg.gda.pl

ABSTRACT

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) [1], [2]. The vortices were observed to form in association with the onset of peak stress. They appeared only occasionally, quickly dissipating. They became apparent in experiments and calculations when the motion associated with uniform (affine) strain was subtracted from the actual granular deformation. They are reminiscent of turbulence in fluid dynamics, however the amount of the grain rotation is several ranges of magnitude smaller (~0.01°-0.1°) than the fluid vortex rotation and granular flow is too slow to induce inertial forces characteristic for turbulences in fluid. A dominant mechanism responsible for the vortex formation was the breakage of force chains [1]. The collapse of main force chains lead to a formation of larger voids and their build-up to a formation of smaller voids. The vortices have been mainly observed in shear zones which are the fundamental phenomenon in granular bodies [2].

The paper presents some three-dimensional simulation results of granular vortex-structures in cohesionless initially dense sand during plane strain compression. The sand behaviour was simulated using the discrete element method (DEM). A 3D spherical discrete model YADE, developed at University of Grenoble, was used. Sand grains were modelled by spheres with contact moments to approximately capture the irregular grain shape. In order to detect vortex-structures, the Helmholtz-Hodge decomposition of a vector field from DEM calculations was used [3]. The Helmholtz-Hodge decomposition allowed for separating a vector field into the sum of three uniquely defined components: curl free, divergence free and harmonic. It proved to be an objective, universal and effective technique for identifying all vortex-structures during granular flow which was directly based on single grain displacement increments (but not on displacement fluctuations). The method did not use any additional non-objective parameters. A large number of spheres was however required to avoid the effect of boundary conditions assumed .In addition the predominant periods of vortices during deformation were determined. The vortices were strongly connected to shear localization. They localized in locations where shear zones ultimately developed. An early prediction possibility of shear localization through vortex-structures may open new perspectives for a detection of impending failure in granular bodies (inherently connected with shear localization) within continuum mechanics.

REFERENCES

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