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Numerical investigations on flow dynamics of prismatic granular materials using the discrete element method

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The flow dynamics of granular materials is of broad interest in both the geosciences (e.g. landslides, fault zone evolution, and brecchia pipe formation) and many engineering disciplines (e.g chemical engineering, food sciences, pharmaceuticals and materials science). At the interface between natural and human-induced granular media flow, current underground mass-mining methods are trending towards the induced failure and subsequent gravitational flow of large volumes of broken rock, a method known as cave mining.

Cave mining relies upon the undercutting of a large ore body, inducement of fragmentation of the rock and subsequent extraction of ore from below, via hopper-like outlets. Design of such mines currently relies upon a simplified kinematic theory of granular flow in hoppers, known as the *ellipsoid theory* of mass movement. This theory assumes that the zone of moving material grows as an ellipsoid above the outlet of the silo. The boundary of the movement zone is a shear band and internal to the movement zone, the granular material is assumed to have a uniformly high bulk porosity compared with surrounding stagnant regions. There is however, increasing anecdotal evidence and field measurements suggesting this theory fails to capture the full complexity of granular material flow within cave mines.

Given the practical challenges obstructing direct measurement of movement both in laboratory experiments and in-situ, the Discrete Element Method (DEM [1]) is a popular alternative to investigate granular media flow. Small-scale DEM studies (c.f. [3] and references therein) have confirmed that movement within DEM silo flow models matches that predicted by ellipsoid theory, at least for mono-disperse granular material freely outflowing at a constant rate.

A major draw-back of these small-scale DEM studies is that the initial bulk porosity of the simulated granular material is significantly higher than that of broken, prismatic rock. In this investigation, more realistic granular material geometries are simulated using the ESyS-Particle [2] DEM simulation software on cluster supercomputers. Individual grains of the granular material are represented as convex polyhedra. Initially the polyhedra are packed in a low bulk porosity configuration prior to commencing silo flow simulations.

The resultant flow dynamics are markedly different to that predicted by ellipsoid theory. Initially shearing occurs around the silo outlet however rapidly shear localization in a particular direction dominates other directions, causing preferential movement in that direction. Within the shear band itself, the granular material becomes hgihly dilated however elsewhere the bulk porosity remains low. The low porosity within these regions promotes *entrainment* whereby large volumes of granular material interlock and begin to rotate and translate as a single rigid body. In some cases, entrainment may result in complete overturning of a large volume of material.

The consequences of preferential shear localization and in particular, entrainment, for granular media flow in cave mines and natural settings (such as brecchia pipes) is a topic of ongoing research to be presented at the meeting.

References

[1] Cundall, P.A, and Strack, O.D.L (1979), A discrete numerical model for granular assemblies, *Geotechnique*, **29**, No. 1, 47–65.

[2] ESyS-Particle High-Performance Discrete Element Simulation Software, `https://launchpad.net/esys-particle`

[3] Hancock, W. and Weatherley, D.K. (2008), 3D simulations of block caving flow using ESyS-Particle. *in: Proceedings of the 1st Southern Hemisphere International Rock Mechanics Symposium. Southern Hemisphere*

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