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# DEM MODELLING OF COHESIVE AND CEMENTITIOUS MATERIALS – MODEL CONCEPTUALISATION, CALIBRATION AND VALIDATION

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**Summary.** The discrete element method (DEM) has been increasingly used to study granular materials. This paper describes the use of DEM to study the behaviour of cohesive and cementitious materials. We propose a mesoscopic scale approach whereby a visco-elasto-plastic frictional adhesive contact model was developed to represent a cohesive granular material such as clay and an inter-particle bonded contact model was developed to represent a cementitious granular material such as rock or concrete.

## 1 INTRODUCTION TO THE MESOSCOPIC COHESIVE AND BONDED DEM MODELS

Cohesive and cementitious granular materials are common in nature, such as soils and rock, and also in many industries including chemical, food, pharmaceutical, construction and mining. Computer simulation using the Discrete Element Method (DEM) is a powerful tool to study and provide new insights into the behaviour of these materials. However, the success of this approach is dependent on the capabilities of the simulations to reproduce the real behaviour of the material. In this paper, we present an investigation using a mesoscopic scale modelling of cohesive and cementitious materials by means of the Discrete Element Method.

A visco-elasto-plastic frictional adhesive contact model was developed recently at the University of Edinburgh and used to reproduce the key mechanical behaviour of a cohesive granular material [1-4]. The contact model reflects the physical phenomena of adhesive contact forces in fine cohesive particles and accounts for both elastic and plastic contact deformation with the adhesion being dependent on contact plasticity.

For cementitious granular materials, one chief advantage of DEM over continuum based techniques is that it does not make assumptions about how cracking and fragmentation initiate and propagate since a DEM system is naturally discontinuous. An inter-particle bonded DEM contact model based on the Timoshenko beam theory which considers axial, shear and bending behaviour of the bond was developed to produce a realistic representation of a cemented granular material [5].

## 2. MODEL SCALING, CALIBRATION AND VALIDATION

The suitability of the viso-elasto plastic adhesive contact model was investigated by simulating different bulk tests of cone penetration, confined compression and unconfined loading to failure of a cohesive material. Furthermore, the scaling laws of the contact model parameters to produce the same load-deformation behaviour invariant of the particle size used in the simulations were further investigated [3,4]. Besides, a scientific calibration methodology for the contact model parameters was developed based on relatively simply bulk experiments. The results show that the DEM contact model is capable of reproducing the macroscopic mechanical behaviour of cohesive materials including the characteristic stress history dependent strength observed in real cohesive solids. Moreover, the developed calibration methodology for the contact model parameters was validated against bulk test experiments showing good quantitative predictions of the unconfined strength of the material. Finally, the behaviour of the cohesive material in a large scale application involving blade cutting was investigated. In this case, upscaling of particles size following the scaling laws found for the contact model parameters were applied in order to reduce the computational time of the simulations. The study demonstrates a successful application of DEM simulation of a large scale application of a cohesive granular process using a DEM model with appropriate scaling laws and material characterization experiments.

The bond model was first verified by simulating both the bending and dynamic response of a simply supported beam. The loading response of a concrete cylinder was then investigated and compared with the Eurocode equation prediction. The results show significant potential for the new model to produce satisfactory predictions for cementitious materials. A unique feature of this model is that it can also be used to accurately represent many deformable structures such as frames and shells, so that both particles and structures or deformable boundaries can be described in the same DEM framework

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## REFERENCES

[1] S. Thakur, J. Morrissey, J. Sun, J. Chen, J. Ooi, “Micromechanical analysis of cohesive granular materials using the discrete element method with an adhesive elasto-plastic contact model”, Granular Matter 16 (2014), 383 – 400

[2] S. Thakur, H. Ahmadian, J. Sun, J. Ooi, “An experimental and numerical study of packing, compression, and caking behaviour of detergent powders”, Particuology 12 (2014), 2–12.

[3] A. Janda and J.Y. Ooi, “DEM modelling of cone penetration and unconfined compression in cohesive solids” Powder Technology, (2015).

[4] S. Thakur, J.Y. Ooi and H. Ahmadian, “Scaling of discrete element model parameters for cohesionless and cohesive solid”, Powder Technology, (2015).

[5] N. J. Brown, J.-F. Chen and J.Y. Ooi, “A bond model for DEM simulations of cementitious materials and deformable structures”, Granular Matter 16 (2014), 299–311.