11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

A NEW STRATEGY TO SIMULATE PARTICLE CRUSHING IN DEM ANALYSIS

Matteo O. Ciantia[1], Marcos Arroyo[2], Antonio Gens[3] and Francesco Calvetti[4]

[1] Department of Geotechnical Engineering and Geosciences, Universitat Politecnica de Catalunya, Barcelona, ciantia.matteo@gmail.com, http://www.etcg.upc.edu/
[2] Department of Geotechnical Engineering and Geosciences, Universitat Politecnica de Catalunya, Barcelona, marcos.arroyo@upc.edu, http://www.etcg.upc.edu/
[3] Department of Geotechnical Engineering and Geosciences, Universitat Politecnica de Catalunya, Barcelona, antonio.gens@upc.edu, http://www.etcg.upc.edu
[4] Dipartimento di Ingegneria Strutturale, Politecnico de Milano, Italy, francesco.calvetti@polimi.it , http://www.stru.polimi.it/IT/

Key Words: *DEM analysis, crushable soils, one-dimensional compression test, particle failure*

The discrete element method (DEM) is progressively gaining acceptance as a modelling tool for engineering problems of direct geotechnical relevance. One area for which the method seems naturally well adapted is that of crushable soils. Grain Crushing is generally modeled using the discrete element method (DEM) via two alternative methods: replacing the breaking grains with new, smaller fragments; or by using agglomerates. The latter, despite being very helpful for the understanding of the micromechanics occurring in a single grain [1,2], becomes an unpractical tool for the modeling of larger scale problems.

Even after selecting the multigenerational, single grain approach, several modelling choices remain open. At a minimum, specification of a particle breakage criteria and a particle spawning procedure are necessary, apart and beyond that of the contact laws that are essential to DEM. A number of extra parameters appear that require calibration in any practical application. Recently ([3]), the authors have proposed and tested a crushable soil DEM model that, while biased towards effective computation, showed good ability to reproduce macroscopic responses of a variety of soils in oedometric compression. The main features of the model are:

- A particle failure criteria inspired by the works reported in [4,5], where the micromechanics of crushing of single and assemblies of particles is addressed, respectively. The end result of their analysis can be summarized as follows: a particle subject to a set of external point forces will reach failure when the maximum force acting reaches a limit condition. It is assumed that the limit strength is variable (normal distribution) and size effects are incorporated through the dependency of the mean strength value on particle diameter, expressed in a Weibull-like form.

- On reaching the limiting condition the particle splits into smaller inscribed tangent spheres. It is clear that, with this way of modeling, crushing does not conserve the mass within the numerical simulation. This is acceptable if the mass lost is formed by finer particles that have a small influence on the macroscopic mechanical response. On the other hand, the mass lost can be still accounted when calculating for instance, porosity or the evolution of grain size distribution with time. For the latter, the deleted mass is assumed to have a fractal distribution with maximum particle size smaller that the smallest particle produced during the crushing event.

- For the contact law, the simplified Hertz-Mindlin formulation is used.

As shown in Figure 1, a good representation of the behavior of silica sand under very high stresses can be achieved with a suitable choice of parameters. However, the good agreement relies on the use of a relationship between particle limit contact force and particle diameter unsupported by experimental evidence. This model limitation is related to the use of a fixed particle independent contact angle. However, there is no need to assume that such angle is a constant. Indeed, a straightforward application of Hertzian contact mechanics to define that angle (Ciantia et al. 2013) results in good reproduction of oedometer test results that are consistent with the results of strength tests on single grains.

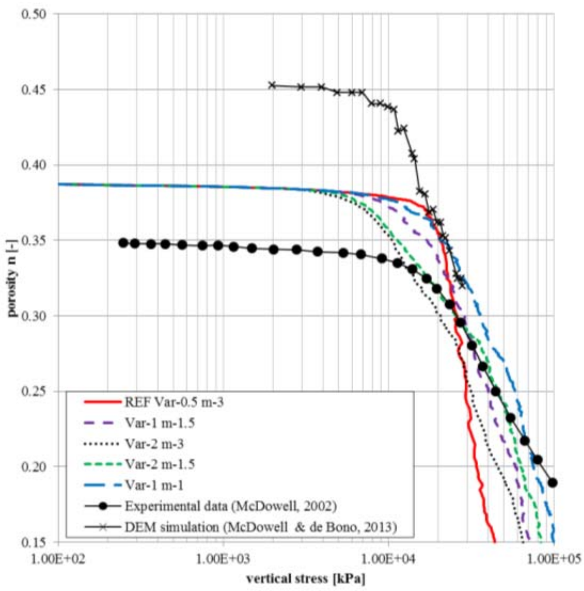

Figure 1. Simulation of the macroscopic response of one dimensional compression using various microstructural parameters

REFERENCES

[1] Y.P. Cheng, Y. Nakata, and M.D. Bolton, Discrete element simulation of crushable soil. *Géotechnique* Vol. **53**, No. 7, pp. 633–641, 2003.

[2] M.D. Bolton, Y. Nakata and Y.P. Cheng, Micro- and macro-mechanical behaviour of DEM crushable materials. *Géotechnique,* Vol. **58**, No. 6, pp. 471–480, 2008.

[3] M. Ciantia, M. Arroyo, F. Calvetti and A. Gens, An efficient approach for DEM modelling of crushing in soils, submitted foo publication, 2014

[4] A.R. Russell and D. Muir Wood, Point load tests and strength measurements for brittle spheres. I. *J. of Rock Mech. And Mining Sciences* Vol. **46**, pp. 272–280, 2009.

[5] A.R. Russell, D.Muir Wood and M. Kikumoto, Crushing of particles in idealised granular assemblies. *J. Mech. Phys. Solids*, Vol. **57**, No. 8, pp. 1293–1313, 2009.