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Developments in micromechanical modelling of granular materials

Editorial Note

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We are honouring the memory of Ioannis Vardoulakis through this special issue of *Granular Matter*, which is devoted to developments in micromechanical modelling of granular materials.

Ioannis Vardoulakis will be forever remembered as an innovative experimentalist, a brilliant mechanician, an enthusiastic scientist, a devoted teacher, and above all an exceptional human being. The impression he made on those fortunate enough to meet him was indelible. These qualities are encapsulated in the first article, Gerd Gudehus' "in memoriam" [1]: a thoughtful and comprehensive account of the exceptional career of Ioannis Vardoulakis, and his unique approach to rational geomechanics.

To showcase the breadth and depth of Vardoulakis' scientific contributions, and the influence these have had on current thinking and innovations in the science of granular media, we have organised the remaining fifteen articles into five groups, each unified by a particular theme.

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Professor Vardoulakis during the 8th International Workshop on Bifurcations and Degradation in Geomaterials 2008, at Lake Louise, Alberta, Canada (photograph: I. Einav)

The first group epitomises the influence of his work in the development of Cosserat (or micropolar) continuum theory. Inspired by early discussions with Vardoulakis and his team, Alonso-Marroquin [2] presents a micromechanical derivation of the Cosserat continuum based on intra-granular stress, giving special emphasis to the asymmetry of stress, a favourite preoccupation of Vardoulakis. Papanicolopulos and Veveakis [3] contribute with a Cosserat-type plasticity theory, by integrating several ideas and concepts proposed by Vardoulakis: equivalent continuum, fabric averaging, and the energetics of rolling and sliding dissipation. Mühlhaus et al. [4] develop a non-coaxial Cosserat continuum model based on a double-slip mechanism, a model that has interesting applications in describing deformation of the lithosphere.

The second group of papers is devoted to the microstructural behaviour of granular media. Vardoulakis championed these inquiries, and was instrumental in closing the gap between physicists and engineers working in the broad science of granular media. Indeed, the close collaboration he fostered between different disciplines helped to elucidate many of the complexities of soil behaviour, including segregation, contact force networks, buckling of force chains, plug formation, and ratcheting. Inspired by Einav's personal communications with Vardoulakis on the ancient art of processing grain flour, Marks and Einav [5] introduce a cellular automaton for segregation, of core importance to flour milling. Tordesillas et al. [6] contribute a beautiful mathematical formulation of the buckling of force chains in granular media, based on ideas imported from structural mechanics. Kadau et al. [7] present a micromechanical description of one of the most fascinating phenomena displayed by granular materials: the collapse of quicksand. This description recalls Vardoulakis' contributions to our understanding of liquefaction, internal sand erosion, and sand production. Magnanimo and Luding [8] develop an intriguing constitutive model that captures anisotropy of the fabric, and reproduces the complex ratcheting response of cyclic-loaded soils. Walker et al. [9] present a characterisation of strong and weak phases of granular media using percolation theory, a method drawing on the last face-to-face conversation Tordesillas had with Vardoulakis on micropolar continua. Schwartz and Blumenfeld [10] introduce the notion of "Da Vinci" fluid, which is distinguished from ordinary fluids in that energy is dissipated by solid friction. A key feature of their model is its ability to handle unstable flows with a formulation that leads naturally to formation and growth of plug regions.

The third group reveals Vardoulakis' influence in experimental geomechanics. Tagliaferri et al. [11] present a study of bio-cementation that exemplifies Vardoulakis' enthusiasm for innovative experimental devices, shared by one of the authors (Viggiani). Their work is based on the use of tomography for three-dimensional visualisation of shear band formation. In the same spirit, Hall et al. [12] report on an experimental method that uses x-ray diffraction to visualise intergranular contact strains, hinting at the exciting possibility that the measurement of inter-particle forces in natural granular materials is imminent.

The fourth group celebrates Vardoulakis' pioneering work on bifurcation and localisation in geomaterials. Nicot et al. [13] present an investigation of instability of soils. They use second-order work to characterise landslides, the topic of many discussions between one of the authors (Darve) and Vardoulakis. Sulem et al. [14] examine instabilities of geomaterials, incorporating microstructure in a Cosserat continuum model. A key element of this effort is their consideration of heat, which has an important effect on instabilities observed in the hardening regime.

The fifth group reflects Vardoulakis' involvement in various studies of granular systems using the discrete-element method. Matsushima and Chang [15] propose a particle-shape index to quantify the effect of particle shape on material behaviour. Nitka et al. [16] develop a two-scale numerical scheme mediated by a homogenisation method: they use discrete-element modelling to capture behaviour in the small-scale regime, and finite-element modelling in the large-scale regime.

This special issue has drawn together contributions of exceptional quality. We are grateful to all authors and reviewers for their commitment to achieving a fitting tribute and an enduring testament to Iaonnis Vardoulakis' science and life.

References

1. Gudehus, G.: In memoriam Ioannis Vardoulakis. Granular Matter (2011). doi:10.1007/s10035-010-0231-6
2. Alonso-Marroquín, F.: Static equations of the Cosserat continuum derived from intra-granular stresses. Granular Matter (2011). doi:10.1007/s10035-011-0264-5
3. Papanicolopulos, S.-A., Veveakis, E.: Sliding and rolling dissipation in Cosserat plasticity. Granular Matter (2011). doi:10.1007/s10035-011-0253-8
4. Mühlhaus, H.B., Shi, J., Olsen-Kettle, L., Moresi, L.: Effects of a non-coaxial flow rule on shear bands in viscous-plastic materials. Granular Matter (2011). doi:10.1007/s10035-011-0254-7
5. Marks, B., Einav, I.: A cellular automaton for segregation during granular avalanches. Granular Matter (2011). doi:10.1007/s10035-010-0247-y
6. Tordesillas, A., Hunt, G., Shi, J.: A characteristic length scale in confined elastic buckling of a force chain. Granular Matter (2011). doi:10.1007/s10035-011-0252-9
7. Kadau, D., Andrade, J.S., Jr, Herrmann, H.J.: A micromechanical model of collapsing quicksand. Granular Matter (2011). doi:10.1007/s10035-010-0236-1
8. Magnanimo, V., Luding, S.: A local constitutive model with anisotropy for ratcheting under 2D axial-symmetric isobaric deformation. Granular Matter (2011). doi:10.1007/s10035-011-0266-3
9. Walker, D.M., Tordesillas, A., Thornton, C., Behringer, R.P., Zhang, J., Peters, J.F.: Percolating contact subnetworks on the edge of isostaticity. Granular Matter (2011). doi:10.1007/s10035-011-0250-y
10. Schwartz, M., Blumenfeld, R.: Plug flow formation and growth in Da Vinci fluids. Granular Matter (2011). doi:10.1007/s10035-011-0248-5
11. Tagliaferri, F., Waller, J., Andò, E., Hall, S.A., Viggiani, G., Bésuelle, P., DeJong, J.T.: Observing strain localisation processes in

bio-cemented sand using x-ray imaging. Granular Matter (2011). doi:10.1007/s10035-011-0257-4
12. Hall, S.A., Wright, J., Pirling, T., Andò, E., Hughes, D.J., Viggiani, G.: Can intergranular force transmission be identified in sand? First results of spatially-resolved neutron and X-ray diffraction. Granular Matter (2011). doi:10.1007/s10035-011-0251-x
13. Nicot, F., Hadda, N., Bourrier, F., Sibille, L., Darve, F.: Failure mechanisms in granular media: a discrete element analysis. Granular Matter (2011). doi:10.1007/s10035-010-0242-3
14. Sulem, J., Stefanou, I., Veveakis, E.: Stability analysis of undrained adiabatic shearing of a rock layer with Cosserat microstructure. Granular Matter (2011). doi:10.1007/s10035-010-0244-1
15. Matsushima, T., Chang, C.S.: Quantitative evaluation of the effect of irregularly shaped particles in sheared granular assemblies. Granular Matter (2011). doi:10.1007/s10035-011-0263-6
16. Nitka, M., Combe, G., Dascalu, C., Desrues, J.: Two-scale modeling of granular materials: a DEM-FEM approach. Granular Matter (2011). doi:10.1007/s10035-011-0255-6