

## TIME TABLE

TIME	Monday September 3	Tuesday September 4	Wednesday September 5	Thursday September 6	Friday September 7
9.00 - 9.45	Registration	Soga	Luding	Roux	Matsushima
9.45 - 10.30	Wan	Soga	Luding	Roux	Matsushima
11.00 - 11.45	Wan	Wan	Radjai	Luding	Luding
11.45 - 12.30	Radjai	Wan	Radjai	Matsushima	Radjai
14.00 - 14.45	Soga	Radjai	Soga	Matsushima	
14.45 - 15.30	Soga	Roux	Soga	Matsushima	
16.00 - 16.45	Luding	Roux	Wan	Radjai	
16.45 - 17.30	Luding	Roux	Wan	Roux	

## ADMISSION AND ACCOMMODATION

Applicants must contact CISM Secretariat at least one month before the beginning of the course. Application forms should be sent on-line through our web site: <http://www.cism.it> or by post.

A message of confirmation will be sent to accepted participants. If you need assistance for registration please contact our secretariat.

The 700,00 Euro registration fee includes a complimentary bag, four fixed menu buffet lunches (Friday not included), hot beverages, on-line/downloadable lecture notes and wi-fi internet access.

A limited number of participants from universities and research centres who are not supported by their own institutions can be offered board and/or lodging in a reasonably priced hotel. Requests should be sent to CISM Secretariat by **July 3, 2012** along with the applicant's curriculum and a letter of recommendation by the head of the department or a supervisor confirming that the institute cannot provide funding. Preference will be given to applicants from countries that sponsor CISM.

Information about travel and accommodation is available on our web site, or can be mailed upon request.

Please note that the centre will be closed for summer vacation the first three weeks in August.

*For further information please contact:*

CISM  
 Palazzo del Torso  
 Piazza Garibaldi 18  
 33100 Udine (Italy)  
 tel. +39 0432 248511 (6 lines)  
 fax +39 0432 248550  
 e-mail: [cism@cism.it](mailto:cism@cism.it)

Centre International des Sciences Mécaniques  
 International Centre for Mechanical Sciences



ACADEMIC YEAR 2012  
 The Nowacki Session

## MULTISCALE MECHANICS OF GRANULAR MATERIALS

Advanced School  
 coordinated by

**Farhang Radjai**  
 Université Montpellier 2  
 France

**Kenichi Soga**  
 University of Cambridge  
 UK

**Udine, September 3 - 7, 2012**

## MULTISCALE MECHANICS OF GRANULAR MATERIALS

This course provides a general introduction to the mechanics of granular materials with focus on the micromechanics and multi-scale approach. The lectures cover a broad range of topics from macro-scale experimental behavior, commonly taught in civil engineering schools, to the grain-scale description and micro-statistical behaviour, which is becoming essential both for a better understanding of the experimental behavior and for the development of predictive models based on physical internal variables. Recent advances in this field have been mostly inspired by an intensive cross-disciplinary research that integrates various concepts and methods from soil mechanics, materials science, powder technology, soft matter physics and statistical physics in a universal framework. This

became possible by new experimental tools, such as 3D imaging techniques and testing devices, as well as discrete element methods (DEM) to simulate large collections of grains. A multi-scale approach in the field of granular materials should be based on the following three different groups of mathematical concepts; 1) continuum mechanics for the formulation of the macroscopic behavior, 2) statistical physics for the description of disordered granular microstructure, discrete (grain) displacement fields and contact forces, and 3) rigid-body dynamics for a grain-scale description of the statics and dynamics of a collection of grains. A first series of lectures will thus be devoted to each framework in order to present the relevant concepts and mathematical and numerical tools. The second series of

lectures will cover both the phenomenological description of the macroscopic behavior as well as the micro-statistical properties of granular materials. These lectures include the quasi-static rheology (stress-strain behaviour), inertial flows, localized and diffuse instabilities and creep behaviour for the former and the statistical descriptors of granular microstructure and force transmission for the latter. The third series of lectures will discuss various micromechanical models and upscaling approaches such as dimensional analysis, averaging techniques, macro-elasticity of a packing of grains and macro-plasticity with physical internal variables. The last series of lectures will cover the influence of grain properties and the micromechanics of clays and cohesive materials with solid and liquid bonding.

The multi-scale modeling of granular media is presently an active area of research. Starting with the most classical aspects of granular mechanics, this course leads very naturally to current modeling challenges and open issues such as the choice of relevant internal variables for granular plasticity, the appropriate coarse-graining volumes and the behaviour of complex granular media in the presence of solid or liquid bonding between grains. This course is of broad interest to researchers and engineers involved in soil mechanics, powder technologies and all kind of granular processing. It addresses doctoral students and young researchers with various backgrounds and applicative areas, with the aim of providing an integrated view of the micromechanics of granular materials.

## PRELIMINARY SUGGESTED READINGS

Mitchell J.K. and Soga K., *Fundamentals of Soil Behavior*, 3rd Edition, John Wiley and Sons, 2005, London. ISBN: 978-0471463023.

*Micromechanics of Failure in Granular Geomaterials*, Soil Construction and Geotechnics, Eds. Nicot, F., Wan, R., ISTE-WILEY, 2009, London. ISBN: 978-1848211285.

*Discrete-Element Modeling of Granular Materials*, Eds. Radjai F. and Dubois F., ISTE-WILEY, 2011, London. ISBN: 978-1848212602.

*Micromechanics of granular materials*, Eds. Cambou B., Jean M., Radjai F., ISTE-WILEY, 2009, London. ISBN: 978-1848210752.

Wood D.M., *Geotechnical Modelling (Applied Geotechnics)*, Spon Press, 2004, ISBN: 978-0419237303.

Agnolin I., Roux J.-N., *Internal states of model isotropic granular packings. II. Compression and pressure cycles. Physical Review E*, 76, 061303 (2007) and *III. Elastic properties. Physical Review E*, 76, 061304 (2007).

*Mechanics of granular materials*, Eds. Oda M. and Iwashita K., Balkema, Rotterdam, 1999, ISBN: 978-9054104612.

Luding S., *Cohesive frictional powders: Contact models for tension Granular Matter* 10(4), 235-246, 2008.

Luding S. and Alonso-Marroquin F., *The critical-state yield stress (termination locus) of adhesive powders from a single numerical experiment, Granular Matter* 13(2), 109-119, 2011.

Nemat-Nasser, S., *Plasticity: A Treatise on Finite Deformation of Heterogeneous Inelastic Materials*, Cambridge University Press, 2004, ISBN: 0521-839793.

Wood, D.M., *Soil Behavior and Critical state soil mechanics*, Cambridge University Press, 1991, ISBN: 978-0521337823.

*Advances in X-ray Tomography for Geomaterials*, Eds. Desrues J., Viggiani G., Besuell P., ISTE-WILEY, 2006, London, ISBN: 978-1905209606.

## INVITED LECTURERS

**Stefan Luding** - University of Twente, Enschede, The Netherlands  
*6 lectures on the discrete element method (DEM) with molecular dynamics, rheology of inertial granular flows, averaging techniques to recover continuum behaviour from DEM simulations, and models of cohesive powders.*

**Takashi Matsushima** - University of Tsukuba, Ibaraki, Japan  
*5 lectures on the experimental observation of granular materials (X-ray CT, LAT), micromechanical models of quasistatic behaviour, effects of grain properties such as size and shape polydispersity, and micromechanics of clays.*

**Farhang Radjai** - Université Montpellier 2, France  
*6 lectures on the statistical-physics tools for the description of disordered systems, discrete element method with contact dynamics, force transmission in granular materials, statistical homogenization of granular plastic behaviour, and micromechanics of wet granular materials.*

**Jean-Noël Roux** - ENPC-CNRS-IFSTAR, Champs-sur-Marne, France  
*6 lectures on the microscopic ingredients of a granular model and dimensional analysis, contact networks and packing geometry, macro-elasticity from micro-elasticity of the grains, and elasto-plasticity of granular media and the possibility of a quasistatic approach.*

**Kenichi Soga** - University of Cambridge, UK  
*6 lectures on the stress-strain behaviour of granular materials, critical state soil mechanics and soil models, and time dependent behaviour of soils.*

**Richard Wan** - University of Calgary, Alberta, Canada  
*6 lectures on the mechanics of continuous media, description of granular media within continuum framework, granular instabilities under homogeneous states of shearing, contemporary failure theories based on the second order work and finite element modeling with failure criteria.*

## LECTURES

All lectures will be given in English. Lecture notes can be downloaded from CISM web site, instructions will be sent to accepted participants.

**MULTISCALE MECHANICS  
OF GRANULAR MATERIALS**

**Udine, September 3 - 7, 2012**

**Application Form**

(Please print or type)

Surname \_\_\_\_\_

Name \_\_\_\_\_

Affiliation \_\_\_\_\_

Address \_\_\_\_\_

\_\_\_\_\_

E-mail \_\_\_\_\_

Phone \_\_\_\_\_ Fax \_\_\_\_\_

**Method of payment upon receipt of confirmation (Please check the box)**

*The fee of Euro 700,00 includes IVA/VAT tax and excludes bank charges*

I shall send a check of Euro \_\_\_\_\_

Payment will be made to CISM - Bank Account N° 094570210900,  
VENETO BANCA - Udine (CAB 12300 - ABI 05035 - SWIFT/BIC VEBHIT2M -  
IBAN CODE IT46 N 05035 12300 09457 0210900).  
*Copy of the receipt should be sent to the secretariat*

I shall pay at the registration counter with check, cash or VISA  
Credit Card (Mastercard/Eurocard, Visa, CartaSi)

**IMPORTANT: CISM is obliged to present an invoice for the above sum. Please indicate to whom the invoice should be addressed.**

Name \_\_\_\_\_

Address \_\_\_\_\_

\_\_\_\_\_

C.F.\* \_\_\_\_\_

VAT/IVA\* No. \_\_\_\_\_

(\* Only for EU residents or foreigners with a permanent business activity in Italy.

**Only for Italian Public Companies**

I ask for IVA exemption (ex law n. 537/1993 - art. 14 comma 10).

**Privacy policy:** I understand that data received via this form will be used only to provide information about CISM and its activities, within the limits set by the Italian legislative decree no. 196/2003 and subsequent amendments.

Complete information on CISM's privacy policy is available at [http://www.cism.it/courses/privacy\\_statement/](http://www.cism.it/courses/privacy_statement/)

I have read the "Admission and Accommodation" terms and conditions and agree.

Date \_\_\_\_\_ Signature \_\_\_\_\_