Call for an outstanding PhD candidate to work in an international collaborative project

Partially saturated granular materials: from material instability to landslide modeling [DEM simulations of funicular regime]

BACKGROUND

In partially saturated granular materials, capillary bridges (or liquid bridges) form between solid particles. These capillary bridges form the origin of several phenomena observed in unsaturated granular materials, always connected with interparticle capillary forces. These phenomena (stability of granular soils, landslides, powders, photonic crystal production, etc.) involve the formation, deformation and flow of granular materials. The interparticle capillary bridge forces result in an apparent macroscopic cohesive strength (sand castle effect) of moist granular materials, even in the absence of the intrinsic cohesion or confining stress. The drying of granular soils may result in cracking, shrinking, possibly inducing loss of stability at the macroscopic scale (Figs. 1 and 2).

Figs. 1 and 2. Example of soil shrinking and cracking.

OBJECTIVES OF RESEARCH AND RESEACH METHODOLOGY

Transition from pendular to funicular regime

In granular materials, different regimes of capillary bridges are observed, depending on the liquid content. For low liquid content, capillary bridge are present between pairs of particles. This is the pendular regime (Fig. 3; right). The fully saturated case is shown in Fig. 3 (left). In between these regimes (in terms of liquid content) the funicular regime (with coalesced capillary bridges; see Fig. 3, middle) is located. The transition between the funicular regime and the pendular regime induces phenomena that can not be quantified well at present, such as a sudden jump in the capillary force (Fig. 4). This result has been explained qualitatively in (Gagneux and Millet, 2016, 2017).
An objective of the research is to quantify capillary forces in the funicular regime, so DEM simulations for this regime can be performed.

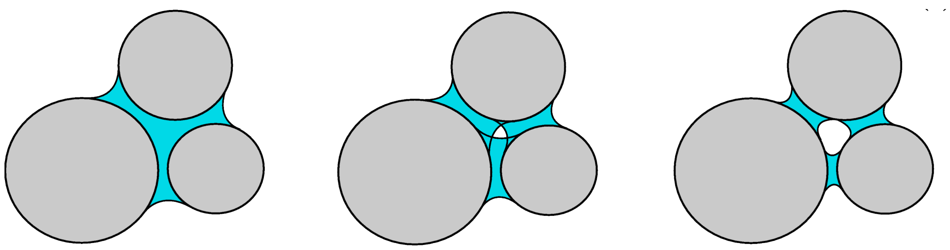

Fig. 3. Different regimes, depending on liquid content. Left: fully saturated; middle: funicular regime; right: pendular regime.

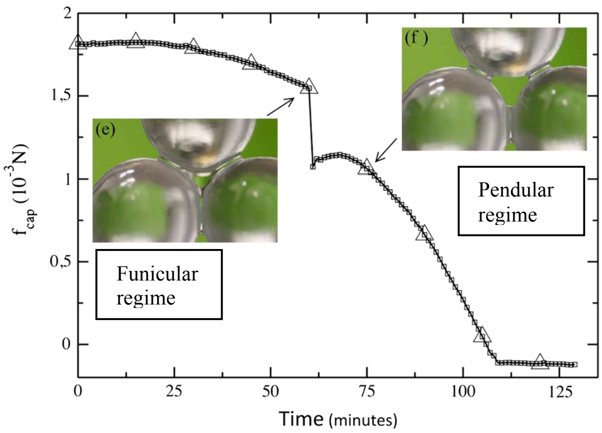

Fig. 4. Transition (due to drying) from funicular regime to pendular regime: sudden jump of capillary force (Gagneux and Millet, 2016).

Description and modeling of capillary interfaces

The proposed work deals with modeling, experimental and numerical analyses of the behaviour of unsaturated granular porous media, in particular for soils. Therefore, accurate description and modeling of capillary interfaces between three phases is required: solid (grains), liquid (water), and gas (air). The geometry of theses capillary interfaces is described by the Young-Laplace equation (nonlinear partial differential equation) that includes the capillary pressure. The capillary bridges thus created induce cohesion forces and so contribute to the stability of unsaturated granular materials.

Some recent results obtained at La Rochelle University (Gagneux and Millet, 2014, 2017; Kruyt and Millet, 2017) make it possible to calculate accurately and rapidly all properties of a capillary bridge between two spheres (parameterization of the interface, volume of the capillary bridge, resulting capillary bridge, …), the capillary pressure being unknown. In addition, an experimental facility for partially saturated granular media has been developed at La Rochelle University (Fig. 5a). The experimental results obtained agree very well with the developed theory (Gagneux and Millet, 2016; Gagneux et al. 2016; Kruyt and Millet, 2017; Nguyen and al., 2018).

Low-g experiments

In collaboration with the French National Center of Space Agency (CNES: https://cnes.fr/en), the experimental facility has been installed in a specific rack to be placed on board in a parabolic flight in microgravity (Fig. 5), to eliminate the influence of the gravity, in order to uncouple the physical phenomena involved.

Fig. 5. Specific rack used in a parabolic flight in microgravity in *zero G Airbus* of the CNES.

The first part on the PhD work consists in extending the modeling to more general cases, including in particular: funicular regime, polydisperse particles or more general particles shapes.
Moreover, a stability analysis of the capillary bridge deformation, when the distance between particles increases, will be performed. To complete this theoretical analysis, image processing with a high speed camera will be performed in order to capture the geometric transition of capillary bridges before rupture.

Discrete Element Method modelling

The new theoretical developments will be implemented in Discrete Element Method software (such as Yade), including in expressions for the capillary forces in the funicular regime and in the pendular regime.
This will make it possible to describe the behaviour of granular materials with higher water contents, as it is considered to be an important aspect in modelling of landslides.

TIMELINE

Year 1

- Literature study on capillary bridge, stability analysis, DEM
- Reporting state-of-the art for introductory chapters of Ph.D. thesis.
- Acquiring ability to work with theoretical modelling of capillary bridges in different configurations
- Acquiring ability to work with the experimental facility at La Rochelle University for capillary bridges.
- Acquiring ability to work on stability analysis of capillary bridges.

Year 2

- Thorough analyses of theoretical modelling of capillary bridges. Resolution of Young-Laplace equation for imposed volume or suction and general configurations.
- Thorough analyses of stability analysis of capillary bridges.
- Careful experiments with the experimental facility.
- Acquiring ability to use DEM software.
- Presentation of results at a scientific conference (to be selected).

Year 3

- Implementation of analytical results obtained in DEM software
- DEM simulations for funicular and pendular regime
- Finalizing the stability analysis of capillary bridges
- Finalizing the development of experimental facility.

- Parabolic flight with the experimental facility developed.
- Publication of the results obtained in international journals
- Reporting results in chapters of Ph.D. thesis.

OFFER

- Working on challenging scientific problems
- Working on variety of topics (theoretical, experimental, simulations)
- Working in an international environment
- Working with international experts, giving rapid and relevant advice

EMBEDDING AND FACILITIES

The PhD project will be executed within the framework of the international research group GdRI Multiphysics and Multiscale Couplings in Geomechanics. The GDRI GeoMech was created in January 2016, continuing the GDR MeGe. During 8 years, this GDR has combined the main French groups involved in the broad field of geomechanics, with a special focus to environmental applications. Taking advantage of the different collaborations and connections that the partners had developed with foreign universities, extending the network in an international perspective was a natural ambition. The goal of the network (GDRI) is thus to gather and promote the French community involved in geomechanics, to strengthen its national and international visibility.
Currently, the GDRI GeoMech involves more than 25 partners, coming from many countries including The Netherlands, Italy, Spain, Canada and China. Structuring the existing community working on Multi-Physics and Multiscale Couplings in Geo-environmental Mechanics, the main lines of research are:

- Catastrophic failures and triggering mechanisms
- Safety of storage reservoirs
- Energetic geomechanics.

Specifically, partners in the current project are:

- Dr. Olivier Millet, University of La Rochelle (France)
- Dr. Niels Kruyt, University of Twente (The Netherlands)
- Dr. Richard Wan, University of Calgary (Canada)
- Dr. Francois Nicot, Irstea, University of Grenoble-Alpes (France).

The PhD student will be stationed at these institutes for various periods, and will benefit from the scientific workshops organized regularly by this international network. Indeed, the GDRI aims spreading and sharing up-to-date information about recent research on the subject, extending international collaborations as well as organizing international scientific meetings and other related events.
The project will be conducted in an open and collaborative environment, aimed at optimizing the advancement of science and the personal development of the PhD student.
Ultimately, the 3-year research will lead to a PhD thesis, to be defended at La Rochelle University.

The student will benefit of the results already obtained at La Rochelle University and University of Twente on the modeling and experimental analysis of capillary bridges (Gagneux and Millet, 2014, 2016; Gagneux and al., 2016; Kruyt and Millet 2017; Nguyen and al., 2018) and of granular assemblies (Kruyt et al., 2014).

Moreover, he/she will be associated to the collaboration initiated with the French National Center of Space (CNES) since 2015. In this framework a parabolic flight in microgravity has been done in October 2015 and a second one has taken place in October 2017. A third flight is planned for the third year of the PhD project.

Collaboration /supervisor:

Olivier Millet, University of La Rochelle, France
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STUDENT REQUIREMENTS

The student must have an M.Sc. degree in Civil, Mechanical or related Engineering discipline. As the project involves theoretical, experimental and simulation aspects, the candidate must possess a corresponding wide range of interests and expertise.

SOME REFERENCES ON THE SUBJECT

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