Understanding real world granular material behaviours using in situ imaging and discrete element method simulations. (Ref IAP2-18-183)

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Overview
Understanding the mechanical behaviour of soils at the micro scale is a key challenge in many areas of earth and environmental science, and is critical to the development of sustainable built infrastructure. Granular materials and soils undergo many complex grain scale interactions under normal seasonal environmental cycling such as wetting-drying and freeze-thaw. These often cause changes in material porosity, permeability and strength. An increase in extreme weather events driven by climate change is expected to exacerbate these changes, leading to major deterioration in the mechanical properties of these natural materials. The effects of these changes are soil loss, flooding, land-slides and embankment failures, and places many natural and built landscapes at significant risk. This includes nearly 750,000 houses, 10,200 km of flood defences, 80,000 km of highways and 15,800 km of railway track in the UK alone. Failure is commonplace (e.g. in 2015 there were 143 earthworks failures on Network Rail, >2 per week; the costs are high (e.g. for Network Rail, emergency repairs cost 10 times more than planned works, which cost 10 times more than maintenance); and our vulnerability to these failures is significant. However, the exact causes and timing of failures are poorly understood, and therefore difficult to mitigate.

Developing strategies and methods to mitigate or remove these hazards is a global challenge, and requires the integration of field observation, laboratory experiments and numerical modelling. This project focuses on solving a major limitation in this integrated process. Discrete element modelling (Cundall & Struck, 1979) will allow simulations at particle or aggregate/ped level, to provide an understanding of the multi-scale physics. Currently the DEM models employed are only calibrated against the bulk properties of the samples before and after laboratory experiments (Guo et al., 2017; Sima et al., 2014). As the simulations are trying to model processes happening inside the material, processes we cannot observe in the experiments, we cannot improve, validate and apply the models accurately in real world situations.

This project will use in situ x-ray tomography to image the grain-scale processes during the experiments. As a non-destructive technique that allows us to see inside solid samples, the student will, for the first time, capture and quantify the location, volume and geometry of every soil particle in the sample through time during environmental cycling. Using a series of natural and man-made granular materials this project will then use the observed 3D evolution of the material to develop reliable DEM models, validated and tested against the exhibited mechanical behaviours under different environmental conditions.

This project is closely aligned with ACHILLES, a major new EPSRC programme that works with a number of major stakeholders to understand deterioration processes and the long-term performance of Long Linear (geotechnical) Assets such as road cuttings, and railway embankments and flood protection structures. As such the student will gain unique experience in stakeholder engagement and has
the opportunity to work with industry and have their work make a direct and rapid impact on policy and practice.

**Project objectives**

O1: develop methodologies for collection and analysis of CT data and generation of DEM from that CT data.

O2: quantification of pore and grain scale behaviours in 3D data and iteration of DEM parameters to incorporate real data

O3: to formulate a law explicitly relating particle size and DEM contact parameters to suction so that cracks induced over several cycles of drying and wetting can be investigated;

O4: relate the shrinkage kinetics of a particles to the estimated water content and suction;

O5: perform a parametric investigation of various desiccation cracking scenarios

**Methodology**

The project will extend the existing environmental cell apparatus to enable in situ observation under x-rays. The main series of data acquisition will be performed in the Durham X-ray Imaging laboratory, collecting micron scale resolution 3D images of the materials before, during and after environmental cycling. The priorities will be to follow the grain displacements and changes in microstructure through wetting-drying and freeze-thaw cycles (see Fig 1 for typical outputs from the processing stage).

The time resolved 3D datasets will then be used to generate realistic DEM particle shapes. The so called ‘potential particle’ method will then be employed to generate the 3D particles in DEM (Houlsby, 2009). The open source DEM code YADE (e.g. Figure 2) where the algorithms to generate potential particles and contact detection are implemented will be used to run the simulations (Boon et al., 2012; Boon et al., 2013).

First simulations will be performed employing a periodic cuboidal cell with the material will be subject to hydraulic and thermal cycles at different confining pressures and shear stresses. The second set of simulations aims to validate the method and will entail DEM simulation of the experimental tests at a larger scale from small laboratory containers to lysimeters exploiting synergies with work done in ACHILLES.

**Timeline**

**Year 1**

Training in all aspects of XCT acquisition and analysis and DEM numerical modelling employing open
source code. Preliminary in situ experiments and numerical simulations.

Year 2 Performance of the bulk of experiments investigating the behaviour of a K glacial till under a range of hydraulic and thermal cyclic conditions. Formulation of a law explicitly relating clay particle size to suction and determination of DEM contact laws and relative mechanical parameters on the basis of the experimental evidence gathered.

Development of the first peer review publication.

Year 3 Iteration of experiments and DEM simulations to refine the inferred physical laws ruling particle interactions and validate them against large scale experiments run in the lysimeter from the Achilles team.

Development of 2 papers in international Journals.

Year 3.5 Writing up of the thesis and development of the remaining publications.

Training & Skills

Both institutions require student attendance at a range of workshops, taught courses, seminars and other research and researcher development activities. These include Scientific Writing, Data Management, Time management, as well as specific training in the skills needed for the project. Both institutions also provide training and the opportunity for PhD students to engage with teaching and demonstrating, and the student will have access to taught modules on the Geoscience, Engineering, Engineering Geology and Mapping and Geospatial Data Science MSc Programs to further develop their skills (depending on the academic background of the appointed student). This may include Geotechnical design, Geomechanics, and numerical modelling options. Research training continues through the second and third years, where the focus becoming problem solving, independent and critical thinking, critical evaluation and documenting, and reporting and reflection. Bespoke technical training will be provided by the research supervisors (numerical and experimental). The project will involve development and application of DEM codes development of software, and so would benefit from a student with a strong numerical or computational background.

References & Further Reading


Further Information

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