HOW WELL CAN WE MEASURE THE EVOLUTION OF SAND MICRO-STRUCTURE?

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1. Introduction

Fabric of granular materials plays a fundamental role in its macroscopic behaviour. However, due to technical limitations, measurement of fabric remained inaccessible in real experiments until recently, with the advent of x-ray tomography. In this work, triaxial compression experiments on natural sands are chosen to investigate the evolution of fabric. Two different subsets of the specimen are chosen for the contact fabric analysis: one inside and another one outside a shear band. Individual contact orientations are measured using advanced image analysis approaches within these subsets. The fabric is then statistically captured using a second order tensor and the evolution of its anisotropy is related to the macroscopic behaviour.

2. X-ray micro tomography

With x-ray micro tomography (x-ray μCT) it is now possible to acquire 3D full-field measurements of granular materials at suitable resolutions. In the first applications of x-ray CT to soil mechanics, the distribution of porosity was investigated with the aim of analysing the development of localisation phenomena in the soil specimen [1, 2]. Existing image analysis tools were either modified for the use in soil mechanics or new tools were developed in order to study the kinematics of the soil specimen. Digital Image Correlation (DIC) has been used to determine the deformations in a continuum framework [3, 4]. Particle tracking approaches, such as ID-Track [5], enable the determination of grain kinematics, *i.e.*, displacements and rotations of individual grains. Both approaches have provided a deep insight into the micro-mechanics of the processes governing the overall behaviour of granular materials.

3. Metrology of inter-particle contacts

In our previous work [6], the metrology of inter-particle contacts from images was studied intensively, pointing out the main problems of standard image analysis, quantifying its accuracy and developing strategies to tackle the identified problems. Two major problems in determining contact orientations were identified: contacts are systematically over-detected, mainly due to the partial volume effect, and depending on the chosen segmentation algorithm the determined orientations can be biased and experience significant errors to an extent where a quantitative analysis seems questionable.

In this contribution, these results and approaches are used to extract the contact fabric from images of triaxial compression tests on two different soils. These experiments were already analysed in [7, 8] determining the kinematics throughout the loading with a special focus on the evolution of shear bands. One of the main findings was the importance of grain rotations inside shear bands. In the present study we start from the same images and extract subsets inside and outside the forming shear bands in order to determine what happens to the contact fabric within these regions of the specimen. As stated in [8], “A full micro-mechanical description of the kinematics occurring at the grain scale needs to go beyond grain kinematics", meaning the structure of the contact network, particle orientations and possibly other fabric entities.

4. Main results and conclusions

Fabric is analysed in terms of individual inter-particle contact orientations as well as using a second order fabric tensor [9]. A scalar anisotropy factor [10] is chosen to describe the evolution of fabric throughout the experiments. Before the onset of the localisation process, the contact fabric behaves similarly in both subsets: the anisotropy increases and the orientations start to align with the direction of major principal stress. After the onset of strain localisation, contact fabric in both subsets takes different evolutions as expected. The anisotropy inside the shear band further increases until a peak and decreases afterwards to reach what could be a residual state. The orientations further align with the major stress direction. The anisotropy outside of the shear band decreases close to its initial value after the onset of localisation and presumably oscillates around that value. Both evolutions are expected from the micro-mechanical analysis of the kinematics in [8], where the main changes, especially rotations of grains, were detected inside the shear band, with comparably much smaller and random kinematics happening outside the shear band. These results are mainly similar for the two materials considered, Hostun sand and Caicos ooids. The two evolutions exhibit similar characteristics compared to the corresponding macroscopic stress response. The main differences being the speed at which fabric reacts to the macroscopic loading, and the range of the anisotropy, which is larger for the rounded Caicos ooids. This can be linked to the different shapes of the grains and the inter-particle friction of the two different materials.

Although these findings are striking and crucial for a full micro-mechanical description, they have to be regarded with care. The determination of contact properties in Hostun sand is still problematic, as pointed out in [6]. Further advances on the metrology of contacts in angular granular materials are still needed. Nevertheless, these applications on small subsets open the door to further analyses, *e.g.*, the analysis of a complete specimen rather than subsets, and the investigation of different loading cases, such as cyclic loading, and oedometer or isotropic loading.

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