THE EFFECT OF SHAPE IN GRANULAR MATERIALS: A GRAIN-SCALE STUDY OF THE KINEMATICS IN SHEAR BANDS

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Summary: It has been extensively shown in literature that particle shape has an influence on geotechnical properties: it strongly affects both micro and macro-mechanical properties but it is very difficult to study and measure. This paper describes the procedures to numerically quantify the shape of thousands of single particles, to statistically determine the overall shape within a specimen and to investigate the effect of shape on the grains kinematics during triaxial testing.

1. INTRODUCTION

Since the early 1900's, several authors (i.e. Barret, 1980 [1]) tried to characterise the grain shape and to understand its influence on the overall soil behaviour, but only in the recent years the increasing of computer performance has enabled new objective and reproducible ways to study it (i.e. image analysis techniques). Moreover, due to the difficulty to acquire and analyse images of soil particles in three dimensions, the previous studies are based on 2-D measurements. But in order to fully characterise the grain shape, it is necessary to define 3-D shape descriptors, able to take into account the tri-dimensional nature of particles.
This paper details the results from an ongoing effort to systematically exploit high quality 3D images of soil particles obtained using x-rays tomographic inspection of triaxial soil specimens performed at 3SR laboratory based in Grenoble (Andò, 2013 [2]).

2. EXPERIMENTAL METHOD

Two different soils are studied: Caicos and Hostun sands. The specimens, containing about sixty/seventy thousands of grains, are scanned using x-rays with a resolution of 15.56 µm/pixel size. Then, the grey-scale images can be binarised, segmented and finally labelled through image processes (Andò, 2013 [2]). After this procedure, every grain can be extracted from the specimen and numerically studied in three-dimensions in order to calculate firstly its geometry (i.e. volume, surface area, lengths, inertia properties) and then its 3-D shape descriptors (i.e. sphericity, roundness, convexity). Therefore, geometric descriptors of statistical nature can be obtained, some (such as grain size distribution) that have been also traditionally obtained by other means, and others (such as distributions of different 3D shape parameters) for which much less previous data was available.
Furthermore, geometric -i.e. single scan- descriptors can be usefully complemented by kinematic -i.e. multiple scan- descriptors of the acquired database. Several x-rays tomographic images are taken during the execution of a triaxial test (about 15 scans per test), allowing step by step tracking of individual particle positions, thus performing 4-D study. Making use of Digital Image Correlation (Software TomoWarp2, in its discrete approach, developed by S. Hall, E. Andò, E. Tudisco and R. Cailletaud) it is possible to follow every grain during the deviatoric loading thus obtaining the displacements and rotations fields for all the particles within the specimens.

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3. RESULTS

The results of this effort are multiple, firstly an objective description of particle shape is achieved and presented in this paper, applicable to every granular material. It is clear from Figure 1(a) that each grain shape can be individuated and numerically quantified from 3D high-quality images. Systematic application of image analysis procedures for the two sands investigated in this work leads to statistical distributions of selected shape descriptors.

Secondly, the effect of grain shape has been studied by making a direct comparison between the grain shape descriptors and the observed kinematics (rotations in particular) for each grain within the specimens: a dependency has been discovered and is detailed in this paper. Figure 1(b) shows the effect of grain shape on the total rotation measured during triaxial testing: it is evident that Caicos sand (rounded sand) presents sharper gradient of rotation upon localisation than Hostun sand (angular sand), which indeed presents a thicker shear band and a greater average rotation outside the shear band. A similar tendency was qualitatively described by Andò *et al.* (2012) [3], but the purpose of this work is to quantify it.

The final goal of future work will be to use the empirical relations thus obtained as a cornerstone in the calibration of advanced contact-models for DEM applications in geomechanics.

References

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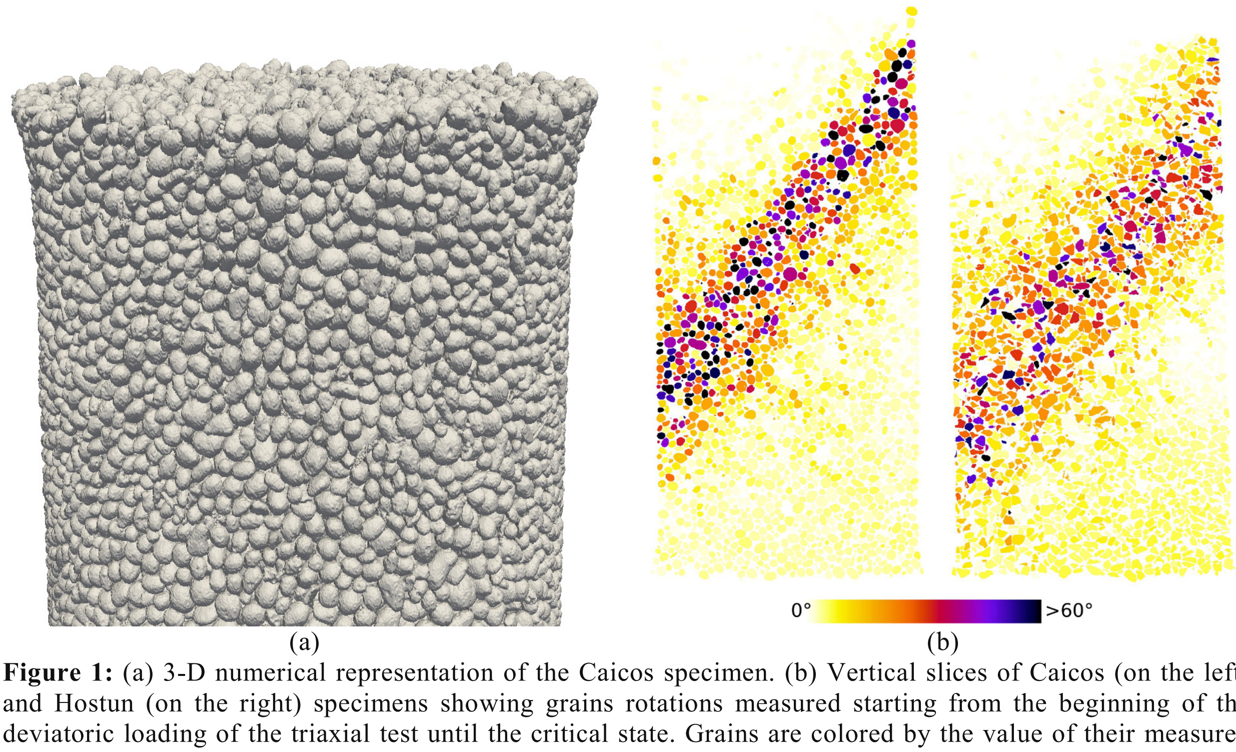

Figure 1: (a) 3-D numerical representation of the Caicos specimen. (b) Vertical slices of Caicos (on the left) and Hostun (on the right) specimens showing grains rotations measured starting from the beginning of the deviatoric loading of the triaxial test until the critical state. Grains are colored by the value of their measured total rotation.