Measurements of particle displacements in sand during a triaxial test studied by X-ray computed tomography: a preliminary study

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1. Introduction

Mechanics of granular materials is used in various engineering fields such as geotechnical engineering. Recently, advanced imaging techniques have been developed to characterize the microstructure like magnetic resonance imaging (MRI), X-ray computed tomography (CT), acoustic emission (AE) and laser aided tomography (LAT). In particular, these techniques were used to study the motion of particles during mechanical test (e.g. Matsushima et al.2006). In many studies, some added particles made in a material appearing with a high contrast in final images (marker particles) are used to detect material flow (e.g. Nielsen et al.2003). One of the limitations is a possible influence of the markers on the behavior (global and local) of the specimen. The objective of this study is to use “natural” markers during a triaxial test i.e. measuring the displacement of marker particles naturally present in the studied material. Displacement data are measured by using X-ray Computed Tomography (CT) which allows of imaging the internal features of an object in three dimensions. The studied material is Yamazuna sand because it has got large particles with a high density which might be used as “natural” markers. This paper presents a preliminary study (one-dimensional compression test) performed to validate the method i.e. studied material and image analysis process.

2. Experimental conditions and material

One-dimensional compression test was conducted by using a triaxial test apparatus specially designed to perform in situ test i.e. mechanical test and tomography measurement at the same time (Otani et al.2000). The specimen was dry with a relative density of 90%. Its size was 50mm in diameter and 100mm in height. As the objective was to validate the method and not to perform a complete mechanical test, only one single loading step in the “before peak” domain was applied. The test has been stopped at a level of axial strain of 10%. Only the upper part of the specimen was scanned on a thickness of 10 mm, before and after loading. The study used an industrial X-ray CT scanner (Toshiba-23200 min). The voltage used was 150kV with a spatial resolution of 0.073x0.073x0.3mm^3. Note that a hardware filter (0.2mm thick piece of copper) was used to reduce beam hardening artifact (Lenoir et al.2007). Yamazuna sand is a sand close to a gravel. Some physical properties and the grain size distribution curve are respectively shown in Figures 1 and Table1.

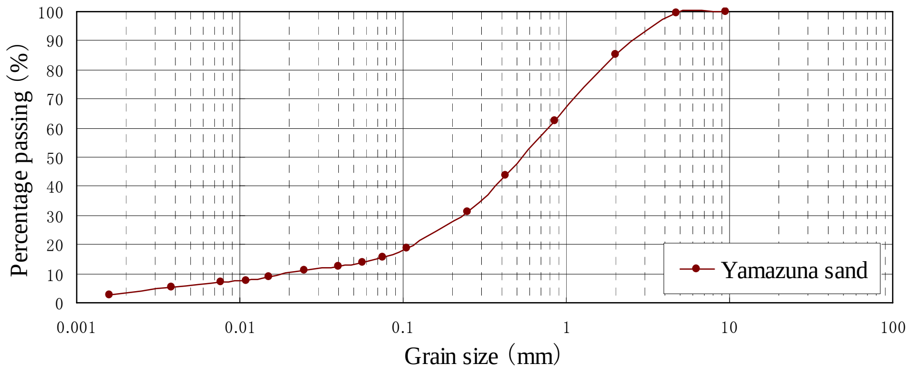

Figure 1: Grain size distribution

Table1 : Some physical properties

ρ_s (t/m^3)	2.695
ρ_{dmax} (t/m^3)	1.615
ρ_{dmin} (t/m^3)	1.256
D_{50} (mm)	0.55
U_c	54.2

3. Image analysis method and results

The first step of the image processing is to isolate the largest particles in the specimen. This segmentation process is done by thresholding i.e. choosing a grey level to transform a grey tone image in a binary one. This process is crucial since it corresponds to an important loss of information and strongly influences the final results. Different methods of thresholding have been tested and the most appropriate is the famous Otsu’s process. This is done with the free software ImageJ (http://rsb.info.nih.gov/ij/) by using the plugin *Multi Otsu Threshold*. Then, a process of erosion is applied to separate connected particles. Figure 2 presents on the left the initial image in grey level (white pixels represents high density material and black pixels, no solid material i.e. air in this case), on the middle the same image after the Otsu’s thresholding process and

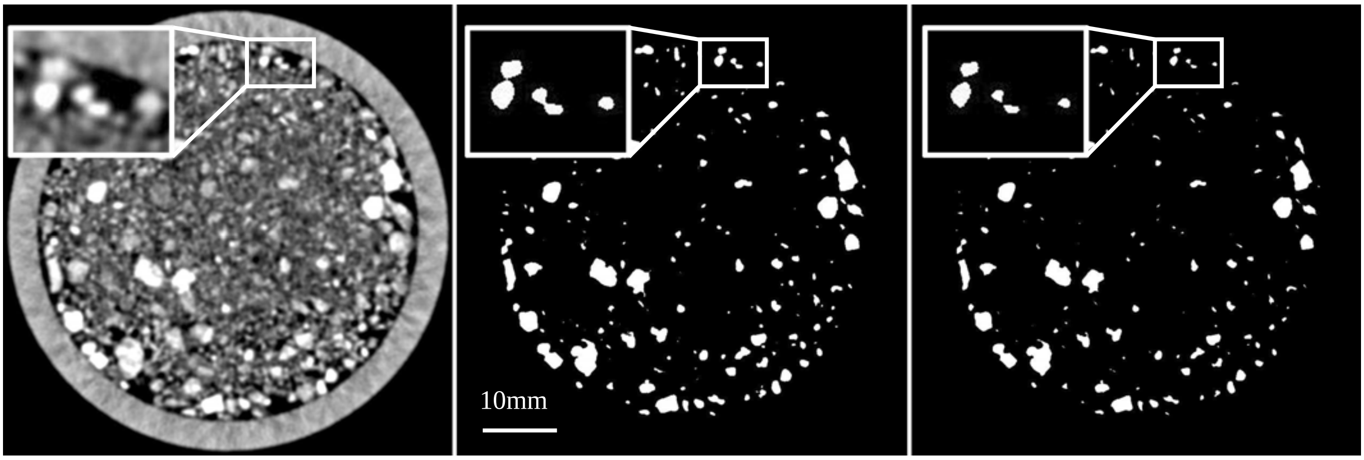

Figure3: Image processing. At the left, initial tomographic image. In the middle, binary image obtained after the segmentation process. At the right, image obtained after one erosion process to separate the connected particles

on the right, after of the process of erosion. Some focuses of a specimen region are also shown in the upper left corners. Particles are well extracted from the background and separated thanks to the erosion process. Once binary images are obtained, the positions of the largest particles (in this case, with a volume more than 4000 voxels) are measured by using the plugin *3D Object Counter* in ImageJ. Then, displacement of the particles can be computed from the positions at different steps of loading.

Figure 3 shows obtained displacements (symbolized by arrows). All the particles principally move in the loading direction with a value lightly less inferior than the applied load. This difference mainly corresponds to the compression of the first part of the specimen at the beginning of the loading. The results are coherent with a homogenous strain obtained by a loading in the “before peak” domain and confirm the efficiency of the method. However, the image processing is time consuming as it is not completely automatic. Indeed, once the particles positions are obtained for each step of loading, the correspondence between the particles in the data files has to be done by hand. Besides, the erosion process does not separate all particles. Efforts have to be done to improve the image processing by for example applying some image processing filters before the segmentation process in order of improving the contrast between the largest particles and the background.

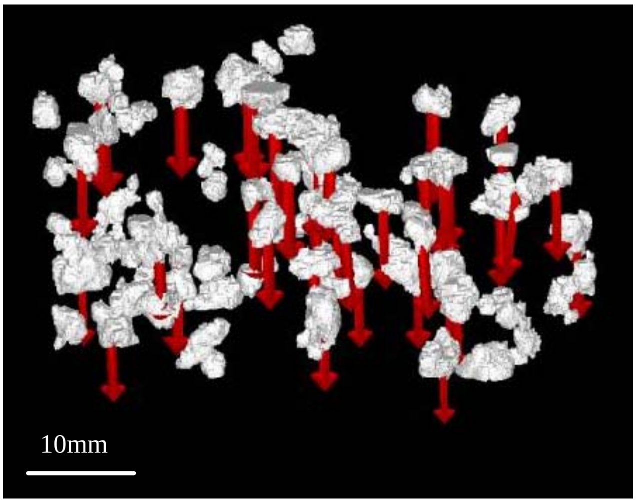

Figure 3: Displacements in 3D of the largest particles

4. Conclusions

A preliminary test has been performed to validate the idea of measuring displacement of large particles in a sand during a triaxial test. Particle displacements are well measured by image processing and confirm that Yamazuna sand is a good candidate. A complete triaxial test can now be performed with scans of the specimen at different steps of loading.

5. References

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