3-D micro-structure of the grain and water morphology of a standard Proctor compacted granite residual soil

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Summary: X-ray tomography test was performed in order to investigate the micro-structure of a dynamically compacted granite residual soil. 3-D images of both water and soil particles were reconstructed, and two important geotechnical features were analyzed: i) the relationship between the water morphology and matrix suction; and ii) the spatial contact of soil particles. Application of the X-ray tomography to unsaturated soil mechanics is discussed.

1. INTRODUCTION

In traditional soil mechanics and engineering practice, most of the researches concerning the micro structure of soils were limited to the 2-D distribution of soil particles, and the study of the 3-D micro structure in particular the water morphology was much less reported in the literature. However, in the analysis of strength and deformation behaviors of soils, the morphology of water and 3-D micro structure of soil particles are of significant importance. In this paper, we use the high-resolution X-ray micro-computed tomography (μ-CT) to investigate the 3-D micro structure of a Proctor compacted granite residual soil, and the following progresses have been made:

- by mixing the dried soil with CsCl solution, the water phase in the sample can be more clearly distinguished.
- 3-D micro-structure of the sample was reconstructed by the Avizo Fire software, from which the spatial distribution of both water and soil particles was determined. Using the reconstructed 3-D images, 10 typical spatial contact for soil particles was generalized and analyzed.
- Based on 3-D image of the water phase, the morphology of the capillary water between soil particles was determined. Matrix suction was calculated and then compared with the that measured by filter-paper method.
- Some further applications of the X-ray μ-CT in unsaturated soil mechanics, for example the determination of the particle orientation and geometric size are discussed.

2. MATERIAL AND METHOD

The material used in this study was taken from a slope of the metro line No. 21 in Guangzhou, China. As a typical granite residual soil in southern China, the material is rich in quartz and has a liquid limit of 43%, plasticity index of 17. After its arriving at laboratory, the material was successively dried under laboratory condition (T ≈ 20 °C), crushed with a rubber hammer, sieved at 2-mm, and then put in an oven of 105 °C for further drying. The dried particles were mixed with required quantity of CsCl solution. In order to reach a homogeneous water distribution, the wet sample was sealed in a plastic bag for another two days. Then, the wet soil was compacted under Proctor conditions according to ASTM D-698 (2002). At last, the Proctor compacted soil was trimmed into small cylindrical samples prior to the X-ray μ-CT test.

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μ-CT test was performed in Shanghai Synchrotron Radiation Facility (SSRF). The parameters for the test are: energy of the X-ray beam - 27 keV; total scanning images - 720; exposure time - 0.7 second per image. After the test, the original data was imported in the Avizo Fire software to create slice images and then to reconstruct the 3-D structure of the compacted sample, from which the micro-structure of soil particles (spatial contact, orientation) and water morphology (radius of curvature) were analyzed.

3. RESULTS

Figure 1(a), (b), (c), (d) present the 3-D reconstructed structure of the compacted sample, water, soil particle and air phase, respectively. In order to highlight the difference between the water phase and soil particle, a cubic unit with side length of 4.5 mm was selected and the 3-D images were shown in Figure 1(e), (f) and (g).

- With the 3-D image of the water morphology (Figure 1f), the radius of the curvature of the capillary water was determined and the matrix suction was calculated using the Jurin-Laplace equation.
- With the 3-D image of the soil particle (Figure 1g), the spatial contact between different particles was analyzed. Figure 1(h), (i) and (j) give three typical spatial contact relation [sphere-sphere (∞), face-face (||) and face-edge (K)] of real particles and the theoretical generalization.
- Some further issue will be developed or discussed in this paper: i) to give a theoretical generalization of the real soil particles whose geometric size is usually complex; ii) to automatically determine the spatial contact relation of two arbitrary particles.

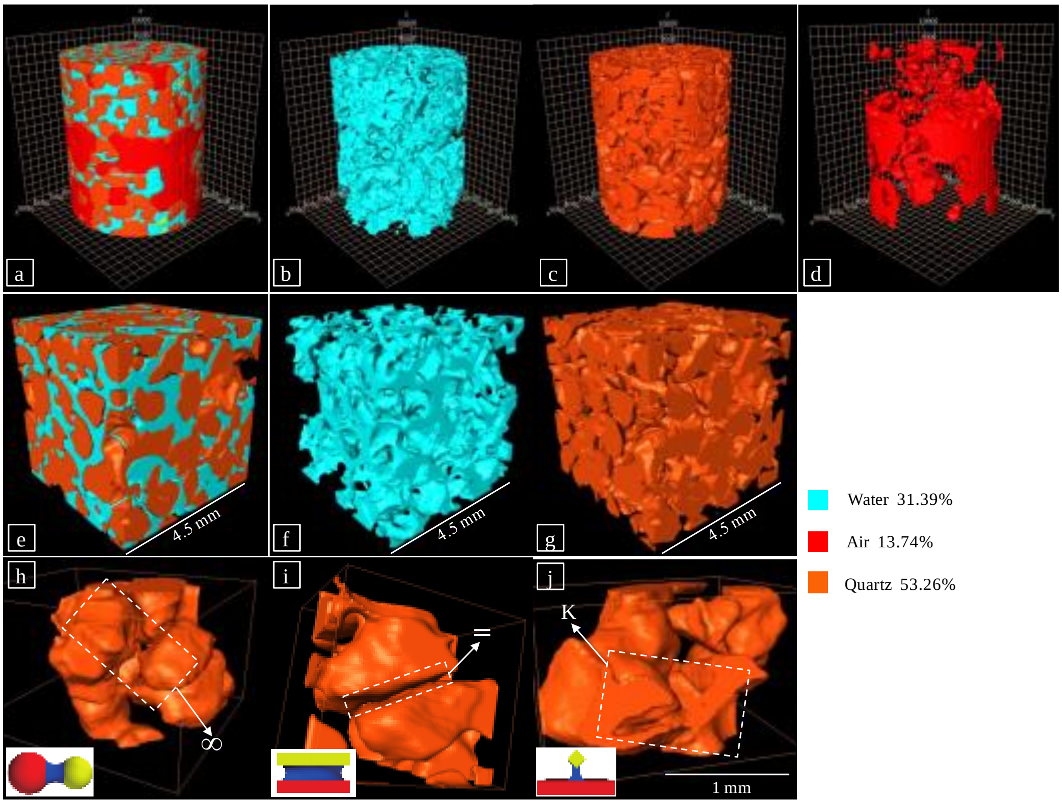

Figure 1 The reconstructed 3-D micro-structure of the compacted granite residual soil