X-RAY IMAGE PROCESSING TO INVESTIGATE VARIATION IN WATER RETENTION STATE OF PARTIALLY SATURATED SAND DURING TRIAXIAL COMPRESSION TESTS

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Summary: An image processing technique was applied to x-ray micro tomography images obtained in triaxial compression tests on partially saturated sand to quantify microscopic characteristics of pore water, such as volume distribution and number of capillary bridges between grains. Variation in water retention state associated with development of a shear band is discussed.

1. INTRODUCTION

X-ray micro tomography enables us to measure nondestructively the three-dimensional structure of an object. In recent years, image processing techniques have been significantly progressed, which make it possible to reveal microscopic behavior and structure of granular soils, such as grain kinematics [1], pore network [2] and so on. Author's research group has applied a x-ray micro tomography technique to partially saturated sand, namely, a mixture of soil particle, pore air and pore water, for the purpose of clarifying of the failure mechanism associated with shear bands. Image processing techniques to quantify local degree of saturation [3] and principal curvature of pore water [4] have been developed and applied to the tomographic volumes obtained during triaxial compression tests on partially saturated sand. It was found that the bulk density and degree of saturation decrease locally when partially saturated sand fails associated with shear bands [5]. This result indicates that water retention capability becomes lower in the shear bands, influencing on the macroscopic responses of partially saturated sand. It is important, therefore, to reveal the variation in water retention state associated with development of the shear band and its link to the macroscopic responses of partially saturated sand. In the present study, in order to investigate particularly the microscopic characteristics of pore water, an image processing technique is applied to x-ray micro tomography images obtained in triaxial compression tests on partially saturated sand with different initial degrees of saturation. This technique makes it possible to clarify the progressive transitions in morphology of pore water and number of capillary bridges between soil particles.

2. EXPERIMENTAL METHOD

Silica sand, whose D_{50} is 456 μm, was used to make specimen for triaxial compression test. Once the water-saturated specimens had been prepared, they were desaturated using a negative water column technique. The x-ray micro tomography facility used in the present study is KYOTOGEO-μXCT (TOSCANER-32250μhdk, TOSHIBA IT and Control Systems Corporation). At the different loading stages of triaxial compression, the entire specimen and the local region of interest focusing on the shear band in the specimen were visualized with two kinds of spatial resolution: micron scale and several tens micron scale. Axial loading was suspended during x-ray tomography for around two hours, after which it was resumed at the same strain rate. Triaxial compression tests using four specimens were conducted under drained conditions for both air and water, and a drained condition for air and an undrained condition for water The former condition assumes that partially saturated soil deforms without any excess pore water pressure due to slow shearing or the high permeability of the soil, while the latter condition assumes that partially saturated soil deforms with excess pore water pressure due to relatively fast shearing or low permeability, respectively. A confining pressure was 50 kPa and a strain rate was 0.1%/min.

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3. IMAGE PROCESSING METHOD

The soil particle phase, the pore water phase and the pore air phase were distinguished from each other by means of a trinarization [3] using the region-growing technique implemented in the 3D image analysis software VGstudioMax3.1 (Volume Graphics GmbH). Then, a morphology analysis was performed to divide the pore water phase into a few assemblies with individual continuity. This analysis comprises three kinds of image processing, namely, erosion, dilation and cluster labeling, implemented in the 3D image analysis software Avizo9.4.0 (FEI).

4. RESULTS

Figure 1 shows transitions in the morphology of pore water phase in the trinarized volumes under triaxial compression of partially saturated sand. The continuous pore water becomes discontinuous as deformation progresses in the case with higher initial degree of saturation. On the other hand, when the initial degree of saturation is lower, the pore water keeps discontinuous from initial condition to the end of loading. Then, the volume and number of pore water clusters are varied progressively under triaxial compression conditions.

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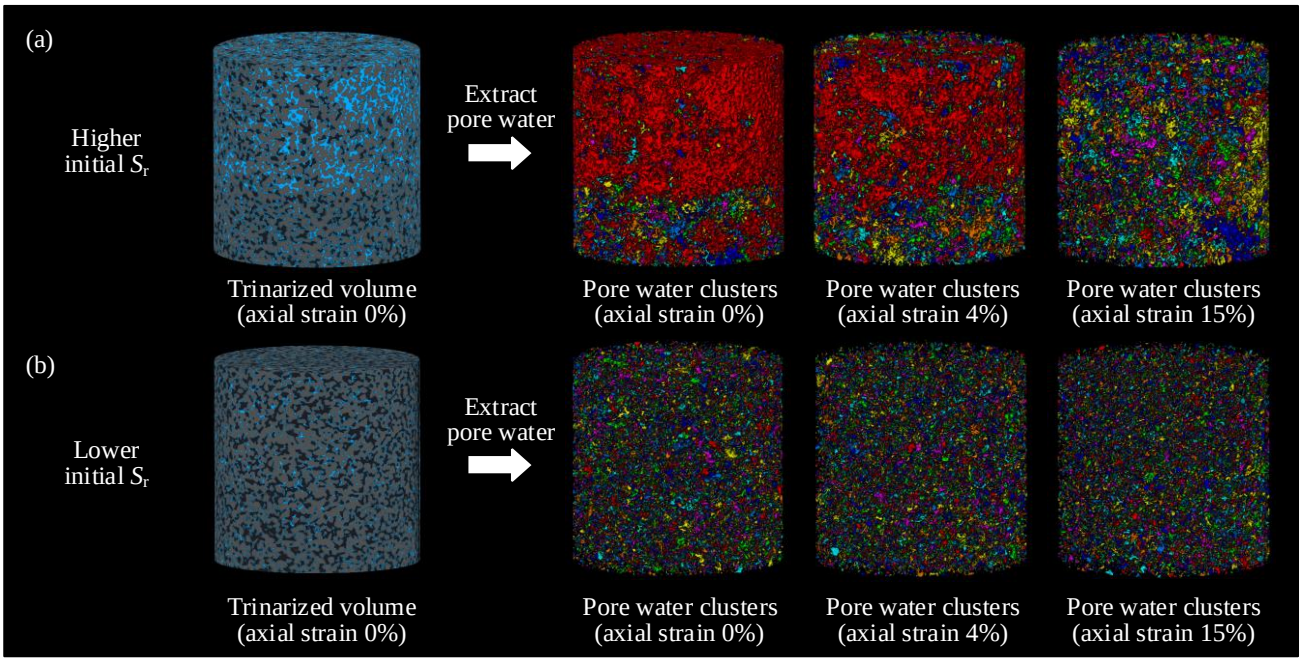

Figure 1: Transitions in morphology of pore water phase at different levels of initial degrees of saturation: (a) higher initial degree of saturation and (b) lower initial degree of saturation