IMAGE PROCESSING TO QUANTIFY MICROSCOPIC CURVATURE OF PORE WATER IN PARTIALLY SATURATED SOIL

Ryunosuke Kido[*1], Yosuke Higo[†2]& Fukushi Takamura[‡2]

[1]Department of Civil and Earth Resources Engineering, Kyoto University, Japan
[2]Department of Urban Management, Kyoto University, Japan

Keywords: partially saturated soil, pore water, curvature, image processing

Summary: In the present study, curvatures of pore water inside and outside a shear band of partially saturated sand are quantified through micro x-ray CT image processing. Interface between pore water phase and pore air phase is extracted from trinarised images focusing on the shear band developed under triaxial compression, and then the curvature of the interface has been quantified. Change in the curvatures of pore water inside and outside the shear band and difference between them are discussed.

1. INTRODUCTION

It is known that partially saturated soils collapse with clearer shear band and stronger strain softening than dry soils and fully saturated soils due to loss of suction, especially under lower confining pressure (e.g., [1]). A key to understanding this mechanism is to investigate the progress change in effect of suction on strength and stiffness of partially saturated soils associated with development of shear band. Suction is a negative pressure, which attributes to surface tension and curvature of pore water. Some theoretical formulas and models to estimate suction or capillary force acting at liquid brides between grains have been proposed (e.g., [2]). There has, however, been few studies that tried to directly measure curvature of pore water from microscopic point of view. In the present study, curvatures of pore water inside and outside a shear band of partially saturated sand are quantified by means of x-ray CT image processing. Micro x-ray tomography used in triaxial compression test of a partially saturated sand specimen under drained condition for both air and water provides three-phase microstructural change where a shear band appears. Interfaces between pore water phase and pore air phase are extracted from three-phase segmented images obtained by trinarisation [3] taking partial volume effect into account, and then maximum principal curvatures for the interface are calculated. Through the x-ray CT image processing, change in curvatures of pore water inside and outside the shear band and difference between them are discussed.

2. TEST SAMPLE AND TESTING PROGRAM

The sample used in this study is silica sand whose physical properties include a maximum void ratio of 1.013, a minimum void ratio of 0.694, a particle density of 2.64 g/cm^3, a D_{50} of 438 μm. The size of specimen was 35.0 mm in diameter and 70.0mm in height. Specimen was prepared by water pluviation technique with relative density of 90.6 %. The specimen was initially almost water-saturated, and suction was applied by negative water column [4] to desaturate specimen. Initial degree of saturation of the specimen was 54.6 % and suction at the top of the specimen was 0.98 kPa. Triaxial compression test was conducted under drained condition for both air and water. Axial strain rate was 0.10 %/min and the confining pressure was 50 kPa by air pressure without any back pressure. Microfocus x-ray CT device used in this study is KYOTOGEO-μXCT [1]. In this study, micro x-ray images were obtained where a shear band develops with the spatial resolution (voxel size) of 12.3×12.3×14.0 μm at the specified axial strains. The axial loading was stopped during tomography to avoid moving of the specimen, and then the loading was resumed with the same axial strain rate.

* e-mail: kido.ryuunosuke.87n@st.kyoto-u.ac.jp
† e-mail: higo.yohsuke.5z@kyoto-u.ac.jp
‡ e-mail: takamura.fukushi.56s@st.kyoto-u.ac.jp

3. IMAGE PROCESSING METHOD

Fig. 1 describes a procedure of the image processing. X-ray images focusing on region of interest volume out of the specimen where a shear band develops are obtained with relatively high spatial resolution. Then the soil particle phase, the pore water phase and the pore air phase are segmented by trinarisation technique which takes partial volume effect into account [4]. The local cubic volumes 4.2 mm on a side (350×350×300 voxel) inside and outside the shear band are extracted. Interfaces between the pore water phase and the pore air phase are extracted out of each volume, which are composed of tiny triangle elements. Maximum principle curvatures whose inverted values are closer to the radius of a sphere locally fitting the interface are calculated. In this study, trinarisation and curvature analysis are applied to x-ray images obtained at axial strains of 9 %, 12 %, 15 % and 18 %.

4. RESULTS

As the validation work for curvature analysis proposed in this study, water-retention curve during drying and wetting process [5] is compared with a relationship between curvature of pore water and degree of saturation given by curvature analysis for x-ray images obtained in the water-retention test [5]. It reveals that this analysis makes it possible to discuss the relative values of curvature of pore water. It is found that density and degree of saturation inside the shear band are larger than those outside the shear band at each axial strain. On the other hand, curvatures of pore water inside and outside the shear band do not vary with increase in axial strain, and there is not so much difference between them. It indicates that the suction levels inside and outside the shear band are almost the same.

References

[1] Higo, Y., Oka, F., Sato, T., Matsushima, Y. & Kimoto, S. Investigation of localized deformation in partially saturated sand under triaxial compression using microfocus X-ray CT with digital image correlation, *Soils & Foundations*, 53, 181-198, 2013.

[2] Soulie, F., Cherblanc, F., El Youssoufi, M.S. & Saix, C. Influence of liquid bridges on the mechanical behaviour of polydisperse granular materials, *International journal for numerical and analytical methods in geomechanics*, 30, 213-228, 2006.

[3] Kido, R & Higo, Y. Evaluation of distribution of void ratio and degree of saturation in partially saturated triaxial sand specimen using micro x-ray tomography, IMS-CHUBU, JGS special publication, 2016. (to appear)

[4] Vanapalli, S.K., Nicotera, M.V. & Sharma, R.S. Axis Translation and Negative Water Column Techniques for Suction Control, *Geotechnical and Geological Engineering*, 26, 645-660, 2008.

[5] Higo, Y., Morishita, R., Kido, R., Khaddour, G. and Salager, S. Local water-retention behavior of sand during drying and wetting process observed by micro x-ray tomography with trinarisation, The 15th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering, JGS special publication, 2 (16), 635-638, 2015.

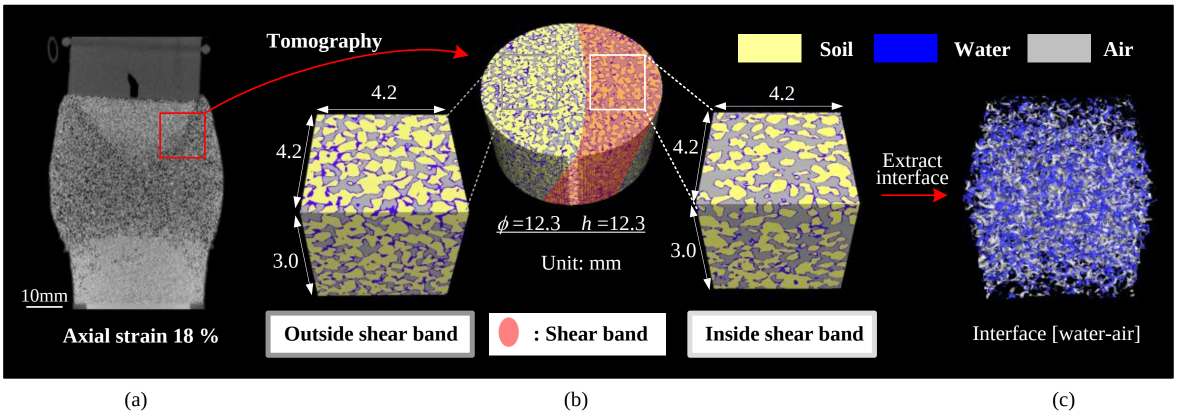

Figure 1: A procedure of image processing:(a) Local tomography area out of the specimen (b) Trinarised image inside and outside a shear band (c) Interface between the pore water phase and the pore air phase.