MICRO-SCALE 3D-DIC OBSERVATION ON HIGH-PRESSURE TRIAXIAL COMPRESSION TEST FOR GAS HYDRATE-BEARING SEDIMENT

Jun Yoneda*[1], Daiki Takano†[2] & Yusuke Jin[1]

[1] Department of Energy and Environment, National Institute of Advanced Industrial Science and Technology, Japan
[2] Geotechnical Engineering Division, Port and Airport Research Institute, Japan

Keywords: Digital image correlation, gas hydrate, morphology, shear band

Summary: Three-dimensional digital image correlation (3D-DIC) was conducted using x-ray computed tomography images to investigate failure mechanism of gas hydrate-bearing sandy sediment which is considered as next generation energy resource. The test was conducted under high-pressure triaxial condition which simulated deep seabed. 3D-DIC detected micro-scale deformation and volumetric change of sand and gas hydrate effectively in the shear band.

1. INTRODUCTION

Gas hydrate is an ice-like compound in which a large amount of natural gas is trapped within the cage of water molecular. It is known that the gas hydrate is stored in the pore space of sandy sediment in the deep seabed or permafrost. Gas hydrate is stable under high pressure and low temperature condition. Using this physical and chemical property, depressurization method is proposed for extracting natural gas from gas hydrate that the production well is drilled into the gas hydrate rich sandy layer, causing the gas hydrate to become dissociated into natural gas and water. This gas production process may have several geo-mechanical issues such as settlement of seabed due to depressurization, cementing force loss by dissociation of gas hydrate, fines migration of gas flow. Currently, several constitutive models of hydrate-bearing sediment based on hypothetical particle-level mechanisms have been proposed for gas production [1]. However, the microstructural behaviors of hydrate-bearing sediments have not been reported due to the experimental challenges posed by the high gas and water pressure and low-temperature conditions. As a part of a Japanese National hydrate research program (MH21, funded by METI), we developed a novel microtriaxial testing apparatus, and the mechanical behaviors of hydrate-bearing sediments with different hydrate saturation were visualized using microfocus X-ray computed tomography [2]. In this previous study, patchy hydrates were observed in the sediment at Sh = 39%. The obtained stress–strain relationships indicated strengthening with increasing hydrate saturation and a brittle failure mode of the hydrate-bearing sand. Localized deformations were quantified via two-dimensional image processing at the submillimeter and micrometer scale. Shear planes and particle deformation and/or rotation were detected, and the shear band thickness decreased with increasing hydrate saturation. But in fact, compression and shear behaviour is performing in three-dimensional space. Some grains have not been detected because of complex movement in the shear band. In this study, we applied three-dimensional digital image correlation (3D-DIC) which was developed by Takano et al. [3] for investigating real micro-mechanism of failure on gas hydrate-bearing sediment.

2. EXPERIMENTAL METHOD

MH can exists only under certain high pressure and low temperature. Therefore, testing apparatus have to control both temperature and pressures. Figure 1 (a) shows schematic diagram and exterior views of developed Micro-triaxial testing apparatus. This system can apply 10MPa of cell pressure and 10MPa of pore pressure. High pressure triaxial cell is made by duralumin with 1mm thickness and 11mm of inner diameter. Thermostat controls brine to make sample's temperature constant which flows into the clearance between high pressure triaxial cell and acrylic cell. Axial loading is operated by water syringe pump for miniaturization of testing apparatus to set up whole chamber on the turn table of micro focus X-ray CT. Sample size is 5mm in diameter and 10mm in height. Sealing sleeve and small mold is set up on the pedestal and moisture Toyoura sand is tamped inside them. The

* e-mail: jun.yoneda@aist.go.jp
† e-mail: takano-d@ipc.pari.go.jp

water content of Toyoura sand (average particle size D_{50} = 0.2 mm) for target hydrate saturation which is volume occupancy in pore space and volume corresponded to a target initial bulk density. The sediment of Krypton gas hydrate saturation 63% was formed and compression test was conducted under triaxial condition that the cell pressure 10 MPa and pore pressure 9 MPa. The more details were reported in previous work [2]. Figure 1 (b) shows X-ray CT images under axial strain ε_a=9% (after peak), 14%, 19% (critical state) during compression. 3D-DIC [3] was applied for these compression stages.

3. RESULTS AND CONCLUSIONS

The maximum shear strain tomography is obtained in Figure 2 (b). Based on the results, the localization which is shear banding is evaluated quantitively in each deformation stages. This results suggest brittle failure mode of hydrate-bearing sediments in this 5 mm small sample in 3D spaces. Volumetric change in the localized shear band will be presented in future work which may proof real micro-mechanism of failure on gas hydrate-bearing sediment. This time, it is confirmed that the 3D-DIC can be applied effectively in high-pressure testing which simulated in-situ stress and temperature conditions of deep seabed.

Acknowledgements

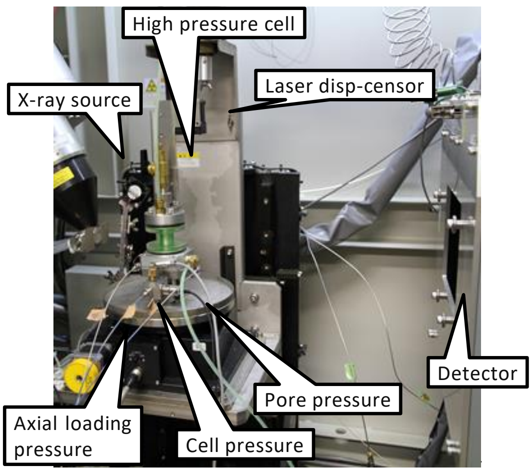
All image file set for 3D-DIC in this paper is properly cited and referred to in the reference list, are available from the authors upon request (jun.yoneda@aist.go.jp). The data are archived at the Methane Hydrate Project Unit in AIST.

References

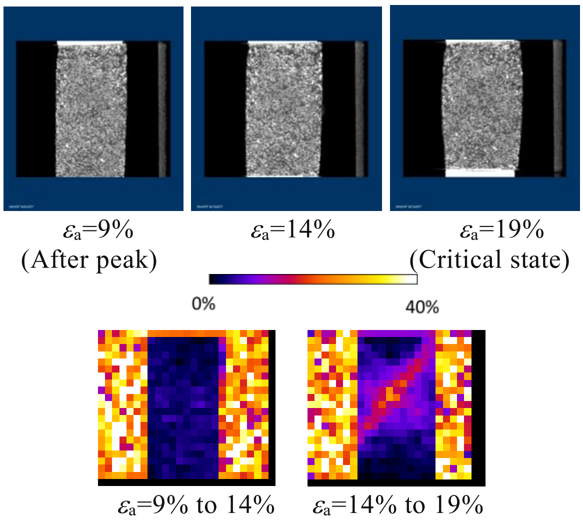
[1] S. Kimoto, F. Oka, T. Fushia, and M. Fujiwaki,, A chemo-thermo-mechanically coupled numerical simulation of the subsurface ground deformations due to methane hydrate dissociation, *Comput. Geotech.*, 34(4), 216–228, doi:10.1016/j.compgeo.2007.02.006., 2007.

[2] J. Yoneda, Y. Jin, J. Katagiri & N. Tenma, Strengthening mechanism of cemented hydrate-bearing sand at microsxales, *Geophysical Research Letters*, 43, 7442-7450, 2016.

[3] D. Takano, N. Lenoir, J. Otani & S.A. Hall, Localised deformation in a wide-grained sand under triaxial compression revealed by X-ray tomography and digital image correlation, *Soils and Foundations*, 55(4), 906-915, 2015.



(a)



(b)

Figure 1: (a)Micro-triaxial testing apparatus. (b) X-ray CT images [2] and 3D-DIC result. Maximum shear strain.