One-dimensional consolidation properties of sedimentary soft rocks from the Boso Peninsula, central Japan using a constant strain-rate loading system

Nana Kamiya
Kyoto University, Kyoto, Japan

Weiren Lin
Kyoto University, Kyoto, Japan

ABSTRACT: Consolidation property is an indicator of load bearing capacity of foundation and also reflects the process of geological evolution. In general, consolidation test has been performed for soil materials in geotechnical area, however we tried to conduct consolidation test using Mio–Pleistocene sedimentary rocks taken from a forearc basin located at a subduction zone. Consolidation yield stress almost increased as porosity decreases, however consolidation yield stress has variation in same porosity and it was increased with depth of sampling point, that indicates the consolidation line of this setting and the consolidation yield stress would record the maximum burial depth of the basin. SEM images show the consolidation fabric which has layer structure and high-resolution X-ray CT images show a deformation during the consolidation test.

Keywords: Sedimentary soft rock, consolidation test, consolidation yield stress, X-ray CT image.

1 INTRODUCTION

Consolidation property is one of the important mechanical properties of sedimentary rocks both in geoengineering and geologic fields. It is an indicator of load bearing capacity of foundation and also reflects the process of geological evolution. In general, consolidation test has been performed for soil materials in geotechnical area to examine the state of underground which is basement of building and to clarify the process of consolidation. Although the test may also be used for soft sedimentary rocks to investigate the tectonic process, e.g. the developmental process of the plate boundary where the crustal movement is violent (Morgan & Ask 2004), only a few such previous researches are available.

To examine the excess pore pressure induced by the marine landslide, the one-dimensional consolidation tests were performed and the consolidation yield stress were estimated using a Pliocene sedimentary rock with around 40% porosity taken from a forearc basin located at a subduction zone (Kamiya et al., 2018). In this study, we report the properties in detail during the consolidation tests using a constant strain-rate loading system and discuss the results of the consolidation tests with the observation of the micro fabric and the consolidation deformation using SEM and X-ray CT images.

2 METHODOLOGY

Siltstones were taken from a post-middle Miocene forearc basin in the Boso Peninsula, central Japan which is located the plate boundary between the Philippine sea plate and the Eurasian plate and developed associated with plate tectonics. The block samples were taken from the outcrops of 8 sampling points. These sampling points are divided into 5 geological formations named Otadai, Kiwada, Ohara, Namihana and Katsuura formations. The cylindrical specimens used in this study are of ~25 mm in diameter and ~20 mm in length. The specimens are vacuumed in water to prepare fully water saturated conditions before tests.

Consolidation tests were performed following Kamiya et al. (2018). During the test, the vertical load, vertical displacement, volume of drainage water, and pore-water pressure were measured and recorded by a personal computer through a data-logger. After the test, the compression index (C_c) and consolidation yield stress (p_c) were estimated using Japanese Standards Association (2009b).

To observe a microfabric of samples, a scanning electron microscope (SEM) image of sample were taken before the test. And X-ray CT images of the specimens were also taken by a micro focus XCT system before and after the test to conform existence of fossil and if any crack(s) was formed during the test. CT images were acquired using HMX225-ACTIS+5 (TESCO Corp.) before the test and Xradia (ZEISS Corp.) after the test. This equipment is owned by Kochi University, Japan. The imaging conditions were a tube voltage of 90 kV, tube current of 50 μA and spatial resolution of ~35 μm.

3 RESULTS ANS DISCUSSIONS

3.1 Consolidation tests

Porosity of the specimens is 35–50%, and bulk density is 1.8–2.0 g/cm^3 (Table 1). Lithological depth was calculated using tuff layers working as key beds in the geological map.

The maximum loads except for BosC30-2 and BosC31-1 were approximately 40 kN which correspond to 80 MPa (Figure 1a). The height of specimens decreased to 3.5–6.0 mm in loading, and them increased approximately 1.5 mm in unloading (Figure 1b). The volume of drainage water changes along with displacement except for BosC30-2, BosC31-1 and BosC19, which is 0.6–1.0 ml (Figure 1c). The water volume of BosC19 didn’t increase during the test. Because the initial porosity of the specimen was low comparing other specimens, there is a possibility that permeability would be low and water drain was difficult in the specimen. Pore-water pressure except for BosC30-2 and BosC31-1 increased to 0.2 MPa in loading and decrease in unloading (Figure 1d), however, pore-water pressure of BosC30-2 and BosC31-1 increased to 1.0 MPa. These specimens were unloaded around 25 kN because the pore water pressure increased to 1.0 MPa which is maximum limit of the apparatus.

The consolidation curves show the over- and normal-consolidation areas, and the curves taken between 50 and 80 MPa were considered to be the compaction curve (Figure 2a). Some specimens’ stress dropped rapidly before yielding. Using these consolidation curves, consolidation yield stress was calculated. The compression index (C_c) values range from 0.38 to 0.68, and the consolidation yield stress is from 5.5 to 20.0 MPa.

Consolidation yield stress almost increased as porosity decreases (Figure 2b), however consolidation yield stress has variation in same porosity and it was increased with depth of sampling point, that indicates the consolidation line of this setting and the consolidation yield stress would record the maximum burial depth of the basin.

Table 1. Initial porosity and bulk density of each specimen, and the consolidation parameter estimated by the consolidation tests. (modified from Kamiya et al., 2018).

Sample ID	Formation	Lithological depth (m)	Porosity (%)	Bulk density (g/cm^3)	C_c	p_c (MPa)
BosC28	Otadai	1568	46.5	1.81	0.42	6.6
BosC21	Kiwada	1931	40.5	1.93	0.40	12.0
BosC26	Ohara	2260	49.6	1.79	0.54	9.4
BosC18	Ohara	2297	46.4	1.85	0.49	9.3
BosC30	Namihana	2522	48.3	1.82	0.63	12.3
BosC20	Namihana	2580	47.8	1.83	0.38	5.5
BosC31	Katsuura	2708	47.7	1.84	0.68	14.1
BosC19	Katsuura	3072	36.5	2.05	0.42	20.0

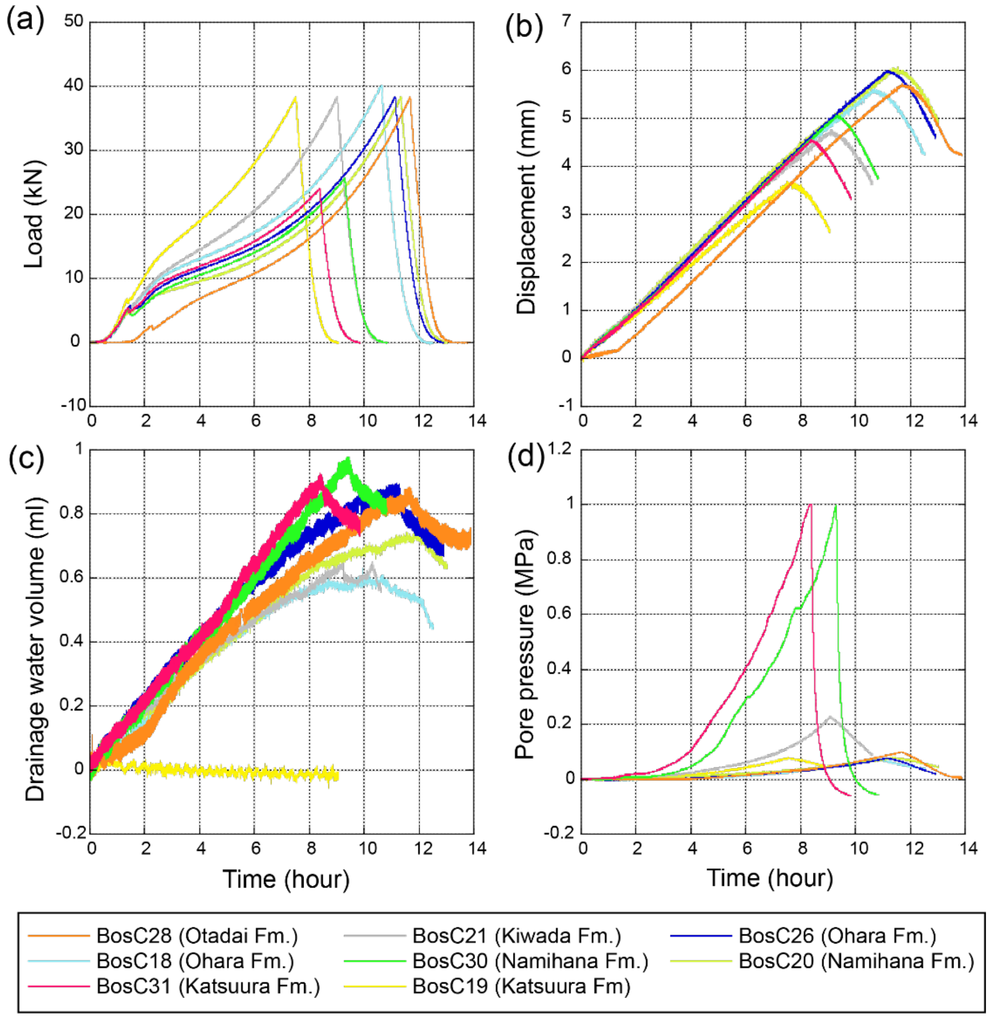
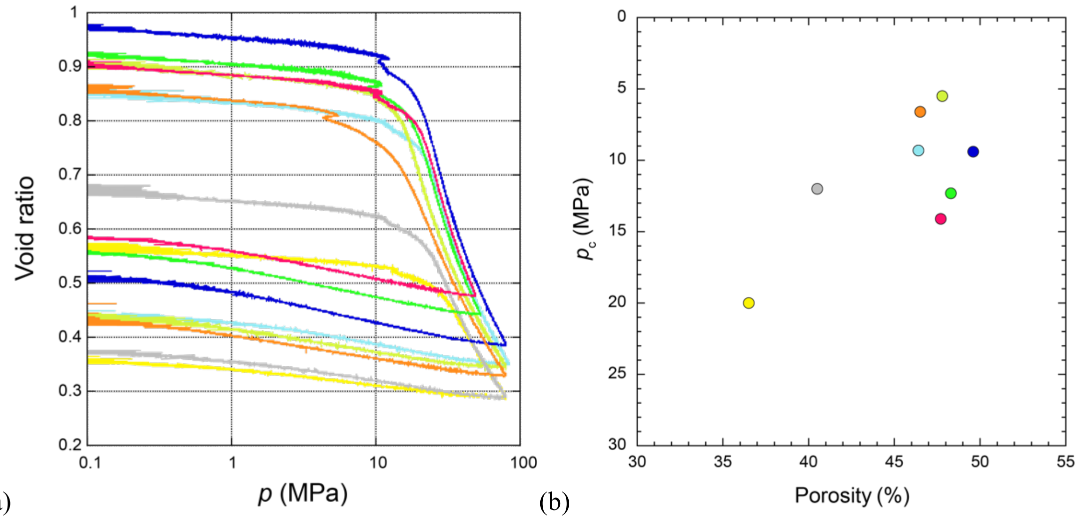


Figure 1. Time process of each parameter during the consolidation tests. (a) Load, (b) Displacement, (c)Volume of drainage water and (d) Pore-water pressure.



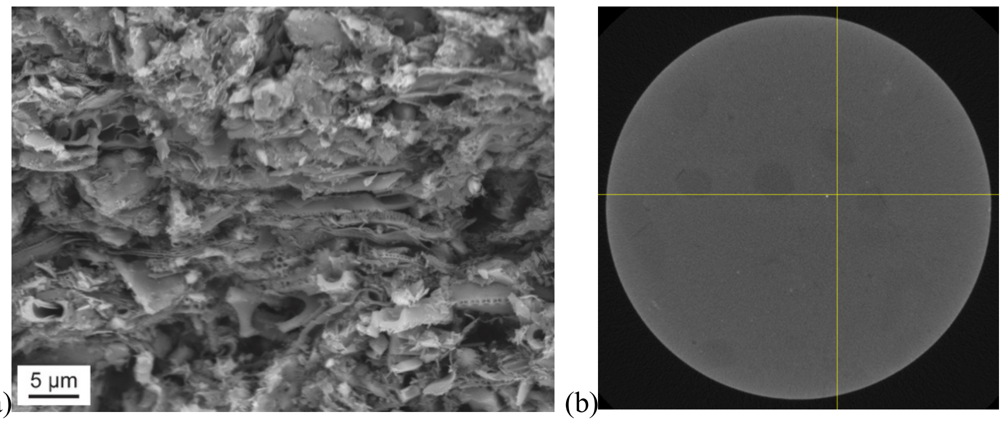
(a) (b)

Figure 2. Results of the consolidation tests. Color legend is same as Figure 1. (a) Consolidation curves (after Kamiya et al., 2018). (b) Relationship between porosity and consolidation yield stress.

3.2 SEM and X-ray CT images

SEM images of the specimens show that clay minerals arrange parallel to the bedding plane and form the consolidation fabric (Figure 3a). And in the samples taken from the Ohara and Namihana formations, clay aggregates fill in pore space. Such clay aggregates characterize the cemented marine sediments (Ujiie et al. 2003). The consolidation curve show overhanging into the high stress area just after the value of yield stress at 50 MPa (Figure 2a). Because the overhanging of the consolidation curves reflects the effect of cementation (e.g. Spinelli et al. 2007), SEM images also show the cementation material.

X-ray CT image show dark area and bright particle in the specimens (Figure 3b). The dark area indicates the trace fossil and the bright particle is mineral named pyrite, because density of the trace fossil is low and that of pyrite is high. The specimens before the test were no crack inside, however, compared with the X-ray CT images taken before and after the test, BosC26-1, BosC30-2 and BosC31-1 have cracks after the tests. These cracks formed from rim of the porous metal, which indicates that stress concentration occurred around the porous metal. BosC28-1 didn't have any cracks both in before and after the test, however the consolidation curve shows a stress drop just before yield (Figure 2). It would indicate that the stress drops show strain softening of the sedimentary soft rock.



(a) (b)

Figure 3. (a) SEM images of sample (Namihana Fm.). Horizontal line corresponds to the bedding plane. (b) X-ray CT image of BosC30 after the test (diameter is ~25 mm). Dark circle, bright particle and dark line show trace fossils, pyrite and crack, respectively.

4 CONCLUSIONS

To examine the consolidation properties of Mio–Pleistocene sedimentary rocks with approximately 35–50% porosities taken from a forearc basin located at a subduction zone, we performed the one-dimensional consolidation tests using a constant strain-rate loading system. As a result, the consolidation curves show the over- and normal-consolidation areas, and, the consolidation yield stress was increased with depth of sampling point, that indicate the consolidation line of this setting. SEM images of the specimens show that clay minerals arrange parallel to the bedding plane and form the consolidation fabric, and some X-ray CT images show the mechanical cracks by the tests. Consolidation yield stress was increased with sedimentary age of specimens, that indicates the consolidation yield stress of soft rocks records a burial process of the sedimentary basin.

ACKNOWLEDGEMENTS

We thank Dr. Masayuki Utsunomiya for advices with sampling in the field. We are also appreciated Prof. Yuzuru Yamamoto for assistance with SEM observations. We are grateful to Dr. Hirose Takehiro and Dr. Osamu Tadai for support with the micro-focus X-ray CT images and the preparation for specimens. Finally, we appreciated Prof. Feng Zhang for assistance with the consolidation test.

REFERENCES

Japanese Standards Association. 2009b. *Test method for one-dimensional consolidation properties of soils using incremental loading.* JIS a 1217: 2009. pp. 1–13.

Kamiya, N., Utsunomiya, M., Yamamoto, Y., Fukuoka, J., Zhang, F. & Lin, W. 2018. Formation of excess fluid pressure, sediment fluidization and mass-transport deposits in the Plio-Pleistocene Boso forearc basin, central Japan. *Geological Society, London, Special Publications* 477, 255–264, DOI:10.1144/SP477.20.

Morgan, J. K. & Ask, M. V. 2004.Consolidation state and strength of underthrust sediments and evolution of the décollement at the Nankai accretionary margin: Results of uniaxial reconsolidation experiments. *Journal of geophysical research* 109, B03102. DOI: 10.1029/2002JB2335.

Spneli, A.G., Mozley, S.P., Underwood, B.M., Hoffman, W.N. & Bellew, M.G. 2007. Diagenesis, sediment strength, and pore collapse in sediment approaching the Nankai Trough subduction zone. *Geological Society of America Bulletin* 119, 377–390, DOI: 10.1130/B25920.1.

Ujiie, K., Tanaka, H., Saito, T., Tsutsumi, A., Mori, J.J., Kameda, J., Bordsky, E.E., Chester, F.M., Eguchi, N., Toczko, S. & Expedition 343 and 343 Scientists 2013. Low coseismic shear stress on the Tohoku-oki megathrust determined from laboratory experiments. *Science* 342 (6163), pp. 1211-1214. DOI: 10.1126/science.1243485.