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Experimental Study On Compression Indices Of Gas Hydrate-bearing Sediments

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Abstract

For gas hydrate production, gas hydrate-bearing sediments should be depressurized below the gas hydrate equilibrium pressure. Gas hydrate-bearing sediments are compacted during the depressurization process because additional effective stress evolves due to a decrease in pore pressure. The compaction of a gas hydrate reservoir can lead to several geotechnical problems such as the destabilization of the production well, settlement of the seafloor installation, or slope failure of the production site. Thus, it is important to determine the compression characteristics of gas hydrate-bearing sediments and the geotechnical behavior of gas hydrate-bearing sediments during the gas hydrate dissociation induced by the depressurization. In this study, gas hydrates were synthesized in remolded sediment samples that were originally cored from a hydrate occurrence region in the Ulleung Basin, the East Sea, offshore Korea. The volumetric strain (or change of void ratio) of gas hydrate-bearing sediment samples were measured for different gas hydrate saturations and under different vertical effective stresses. The experimental results reveal the relation between compression (or the slope of a normal consolidation line) of gas hydrate-bearing sediments and gas hydrate saturation. Experimental data for compression indices of gas hydrate-bearing sediments can be applied to numerical modeling for a geotechnical stability analysis of gas hydrate-bearing sediments.

Introduction

Methane hydrate, the most common type occurring in nature, has been found in both permafrost sediments to depth of about 1 km and deep marine sediments at water depth greater than about 300m in continental margins. The vast amounts of gas hydrate reserves have drawn scientific attentions as a potential energy resource.

Sediment is compressed when the load-bearing or cementation effect of gas hydrates is removed due to gas hydrate dissociation or when the pore water pressure is decreased due to the deliberate depressurization associated with gas hydrate production. Therefore, the compressibility of the sedimentary section in the Ulleung Basin is an important factor in evaluating the settlement (or volume change) of sediments during gas hydrate production. When a fully saturated sediment is compressed, most volume change is induced by squeezing water out from the voids. The compression index (C_C) is defined as the slope of the e-log ($\sigma_v{}'$) relation, where e is the void ratio (i.e., ratio of the volume of voids to the volume of solids) and $\sigma_v{}'$ is the vertical effective stress under loading (compression).

Table 1—Description and index properties of the sediment sample tested.

PL (%)	LL (%)	Specific gravity	USCS	Mean particle size (μm)	Specific Surface area (m^2/g)
46	62	2.52	MH	9.4	98

Although host sediments containing natural gas hydrates have been reported to be mostly fine-grained sediments, synthesizing gas hydrate in fine-grained sediments in laboratory has been considered as challenges due to its low permeability and innate heterogeneity when forming gas hydrate in core-scale (Lee et al., 2010). In addition, few geotechanical characterizations have been made particularly for natural deep sediments cored from the Ulleung Basin. We have performed laboratory experiments on gas hydrate-bearing sediments using a sediment sample cored from a hydrate occurrence region in the Ulleung Basin, East Sea, offshore Korea. In this paper, measured e-log (σ_v') relation are presented, and the effects of gas hydrate saturation on the compression index are discussed.

Experimental program

Description of Sediment Sample

The Ulleung Basin is located in the southwestern part of the East Sea. It is a deep, bowl-shaped and back-arc basin. The water depth of the basin ranges from 1500 to 2300 m (Lee and Kim, 2002). The sediment sample recovered from UBGH1-10, where gas hydrates were found to occur between seafloor and 141 mbsf (Kwon et al., 2011), was chosen for this study. The sample was cored from the depth of 121 mbsf. Index properties of the sediment sample are summarized in Table 1. The sample is characterized by high plastic silty soil (i.e., MH by USCS distinction), and has a fairly high specific surface area of 98 m^2/g.

Test Setup

The test setup was designed to synthesize gas hydrate in sediments and to measure geotechnical properties. All the experiments were conducted in a cylindrical, rigid-wall high pressure cell (i.e., volume of 160.8 cm3; internal diameter of 66 mm; internal height of 140 mm) instrumented to measure temperature, pressure, and vertical displacement (Fig. 1). Effective stress, which is an overburden pressure to the soil skeleton, was applied by a loading plate, the force of which was controlled by an external air cylinder. The cell hosted one T-type thermocouple for measuring the temperature of the specimen interior, one pressure transducer for pressure, and one dial guage for vertical displacement. The temperature of the high pressure cell was controlled by circulating temperature-controlled fluids from a refrigerating circulator through a copper tube coiled around the cell.

Experimental procedure

The sediment sample was desalinated by distilled water to remove the effect of salinity on hydrate formation. The sample was partially saturated (water saturations of 28, 47, and 63%) with distilled water to control gas hydrate saturation. After compacting the sample into the cell, an effective vertical stress of ~100 kPa was applied. The partially water-saturated specimen was cooled down to about 1–2 °C at a constant pressure of ~2.75MPa to form hydrate in the specimen. After hydrate nucleation, the sample was kept in the same condition while supplying CO_2 gas and maintaining pressure until no further hydrate formation was indicated by geophysical signatures. More than 24 hours were given for a specimen to be stabilized. Nitrogen (N_2) gas was injected to flush CO_2 gas in pores of sediments and tubes of the testing system to avoid additional gas hydrate formation. Then, distilled water was introduced to water-saturate the specimen and simulate the oceanic hydrate condition without free gas phase in pores. A loading process by increasing vertical effective stress was applied while pressure, temperature vertical displacement, seismic wave velocities and electrical resistivity were measured. This procedure was repeated for different water saturations, thus for resulted hydrate saturations of 28%, 47%, and 63%.

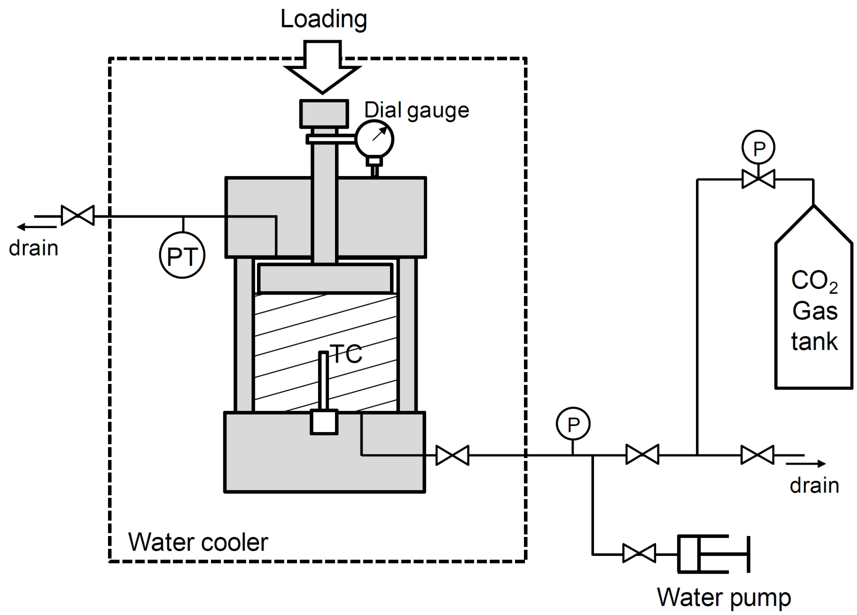

Figure 1—Schematic drawing of experimental setup (PT: pressure transducer, TC: thermocouple).

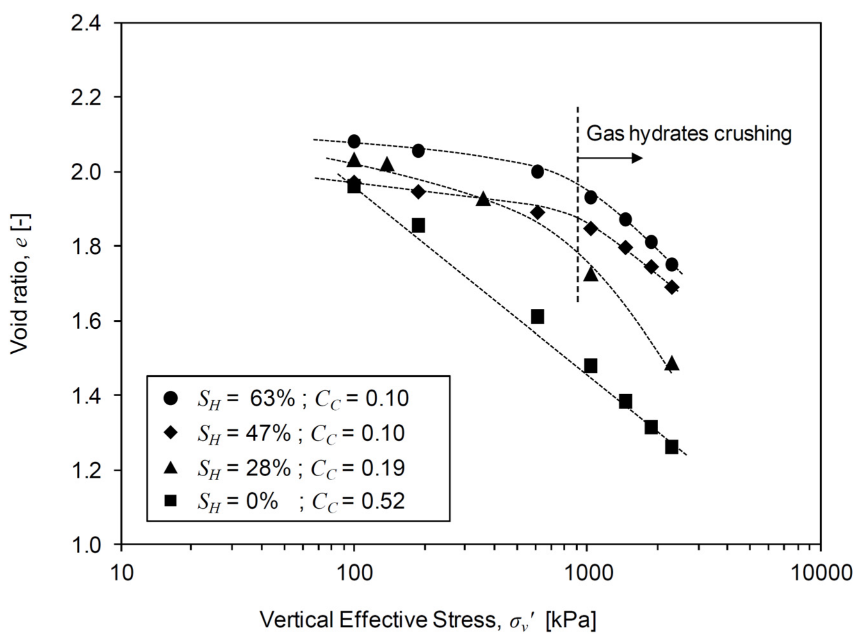

Figure 2—e-log (σ_v') relation of gas hydrate-bearing sediments with different gas hydrate saturation (S_H). Compression index (C_C) is calculated with e-log (σ_v') data which are measured before gas hydrate crushing is occurred.

Results and discussion

Figure 2 shows the stress-volume response of selected samples. Volume change is increased with gas hydrate saturation. The sediment sample with 0% of gas hydrate saturation have high compression indices (C_C = 0.52); this high compressibilities reflect the high plasticity of the silty sediment samples. The volume change behavior of gas hydrate-bearing sediments is affected by gas hydrate saturation and crushing of gas hydrates in pores. Compression indices of gas hydrate-bearing sediments are very low in the range of ~1MPa of effective stress (i.e., 0.1-0.2 for 28-63% of gas hydrate saturations). These low values represent the load-bearing effect of gas hydrates.

Compression indices are decrased with an increase of gas hydrate saturation. Meanwhile, slopes of *e*-log (σ_v') relation is greatly increased if the σ_v' is greater than 1 MPa. This tendency is due to the gas hydrate crushing. The pore volume of the sediment is decreased and large volume change occure because load-bearing gas hydrates are crushed by high effective stress.

Conclusion

This study presents volume change measurements conducted on a clayely-silt sediment containing CO_2 hydrate with different hydrate saturations and under different vertical effective stresses. The objective of this study is to identify effective stress-volume reaction characteristics of hydrate-bearing fine-grained sediments cored from Ulleung Basin, East sea, offshore Korea.

Effective stress-volume reaction of hydrate-bearing sediments is found to be controlled by hydrate saturation. Hydrate saturation showed significant impacts on compression index (C_C). Gas hydrate crushing can be occurred at high effective stress. Crushing of gas hydrates in pores leads an increase of compression index.

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Reference

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