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Stress-dependant characteristics of deep marine sediments recovered from the Ulleung Basin, East Sea, Korea

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ABSTRACT

Although the necessity of exploration in deep sea increases to develop the natural resources, not many geotechnical studies have been performed to explore the geotechnical characterizations of the sediment in Korean deep sea. Comprehensive laboratory tests are conducted to investigate index properties and stress-dependant characteristics of the deep marine sediments recovered from the hydrate occurrence regions during the Ulleung Basin Gas Hydrate Expedition 2 (UBGH2) in the Ulleung Basin, East Sea, Korea. Stress-dependant characteristics are measured by using an instrumented oedometer cell incorporated with shear wave measurements. The index properties of specimens are measured and compared with previous results: the measured water contents range within 25-35%, which are close to a low boundary of previously reported values; the sediments tested are classified as either CL/OH or CH/OH with high silt fraction (~80%). The stress-dependant mechanical properties represent a bi-linear behavior with the vertical effective stress. The hydrate presence significantly affects on the mechanical properties. The experimental results provide important geotechnical properties of deep marine sediments retrieved from the Ulleung Basin and design parameters for construction of the production facility.

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1. INTRODUCTION

A drilling exploration in the deep-sea area is widely processed to develop a new energy resource advance in the world. Many geological studies including the stratigraphy, sedimentary environment, chemical composition, and micropaleontological studies have been carried out with the exploration of the oil resources from the late 1970s in the Ulleung Basin (Chough et al. 1985; Lee et al 1993; Hiller et al. 1996; Bahk et al. 2000; Kim et al. 2003). Since the presence of the gas hydrate had been confirmed during the Ulleung Basin Gas Hydrate Expedition 1 (UBGH1) in 2007, geotechnical properties of the deep marine sediment are important factors to access the safety of gas production facility and productivity from the hydrate-bearing sediment. However, with the exception of some studies (Kwon et al. 2011; Lee et al. 2011), few studies were performed to explore the geotechnical characterization of the deep marine in a domestic sea.

In this study, comprehensive laboratory tests are conducted to investigate the stress-dependant characteristics of deep oceanic sediments recovered from the hydrate occurrence regions during the Ulleung Basin Gas Hydrate Expedition 2 (UBGH2) in the Ulleung Basin, East Sea. The index properties of the specimens including the specific gravity, water content, and Atterberg limits are measured and compared with previous results. Stress-dependant characteristics are measured by using an instrumented oedometer cell incorporated with the shear wave velocity measurement.

2. SAMPLE DESCRIPTION AND INDEX PROPERTIES

Natural deep marine sediments were recovered using the drilling vessel D/V Fugro Synergy at 10 sites in the Ulleung Basin. 8 core samples from two boreholes (UBGH2-6B and UBGH2-6C) were selected and used to characterize index properties and stress-dependant properties in this study. Sample information including the hole-core-section numbers and corresponding sample depth are summarized in Table 1. Index properties were obtained for all tested samples. Consolidation test were performed for selected samples to determine consolidation characteristics and stress-dependant properties.

It is well known that index properties can give a baseline to understand the behavior of the specimen. The mechanical properties can be estimated by using the well-known empirical correlation with index properties. Furthermore, index properties can be used to predict the hydrate occurrence in the sediments because the grain size, its chemical composition, and pore fluid characteristics affects on the morphology, extent, and growth of natural gas hydrate (Winters et al. 1999).

2.1. Water contents and specific gravity

Soil media are composed of interacting discrete solid elements. The voids left by the particle are filled by a second phase that often consists of one or more fluids (e.g. air, water, electrolyte, and/or organic compound). The content of second phase in whole media is important because the macroscale behavior of particular material is controlled by the interactions between particles, affected by the quantity of the fluid phase (Santamarina et al. 2001).

Water content ω can be defined in terms of weight or volume. The gravimetric water content is determined by oven drying method (ASTM D2216). Dry temperature is reduced to 80℃, considering organic materials in the specimens. The measured water contents are in a relatively narrow range of 25-35%, except 6B-8H-3a. These values are close to a low boundary of previously reported values: ω=24.98-161.02% for sediments in the Ulleung Basin (Kwon et al. 2011).

The specific gravity of a solid particle G_s, which is defined as the unit weight of the solid material normalized with respect to the unit weight of water, depends on the composition material of the sediment. The specific gravity is measured using a pycnometer (ASTM D854). The measured values range G_s=2.58-2.65. Previously reported values for the Ulleung Basin are in similar range (Lee et al. 1993; Kwon et al. 2011; Lee et al. 2011).

The porosity n can be evaluated from the measured natural water content and specific gravity when the degree of saturation S is assumed as 100%: $S \cdot n/(1-n) = \omega \cdot G_s$. The porosity values are summarized in Table 1. The porosity determined by the laboratory test is in good agreement with the neutron porosity logging data in the field (data not shown).

2.2. Atterberg limits and soil classification

Atterberg limits are commonly used in the geotechnical engineering for the classification, identification, and description of fine-grained soils. Selected specimens were tested to measure Atterberg limits (ASTM D4318). The measured values of liquid limit LL=46-68% and plastic limit PL=19-25% are plotted on the plasticity chart with previously reported values for this region in Fig. 1. Measured values for the specimens fall above A-line and the sediments are classified as either CL/OH or CH/OH, which corresponds to a diatomaceous clay reported by Lee et al. (2011).

Hole-Core-Section	Water depth [m]	Depth [mbsf]	ω [%]	Atterberg limits			USCS	G_s	Porosity	σ_{pf} [S/m]
				LL [%]	PL [%]	PI [%]				
6B-8H-3a	2157	54	45.04	46.27	25.48	20.79	CL or OL	2.63	0.54	41.3
6B-9H-1a	2157	62	35.86	52.28	23.41	22.87	CH or OH	2.62	0.48	41.9
6B-14H-3a	2157	102	25.79	48.87	17.29	31.58	CL or OL	2.58	0.40	41.9
6B-16H-3a2	2157	112	30.45	48.31	19.12	29.19	CL or OL	2.61	0.44	42.4
6B-26H-1b	2157	173	35.87	67.37	21.42	45.95	CH or OH	2.61	0.48	42.4
6B-27H-3b	2156	181	36.24	68.56	24.20	44.36	CH or OH	2.60	0.49	42.4
6C-9H-3c	2157	162	32.04	12.13	NP	-	ML	2.65	0.46	41.9
6C-10H-2c2	2157	169	33.18	18.47	NP	-	ML	2.64	0.47	42.2

Table. 1. Index properties of the Ulleung Basin

Note: ω is the water content. LL, PL, and PI denotes the liquid limit, plastic limit, and plastic index, respectively. USGS is the unified soil classification system. G_S is the specific gravity, σ_{pf} is the electrical conductivity of the pore fluid. NP means non-plastic. The samples in the gray rows were recovered from the hydrate occurrence depth.

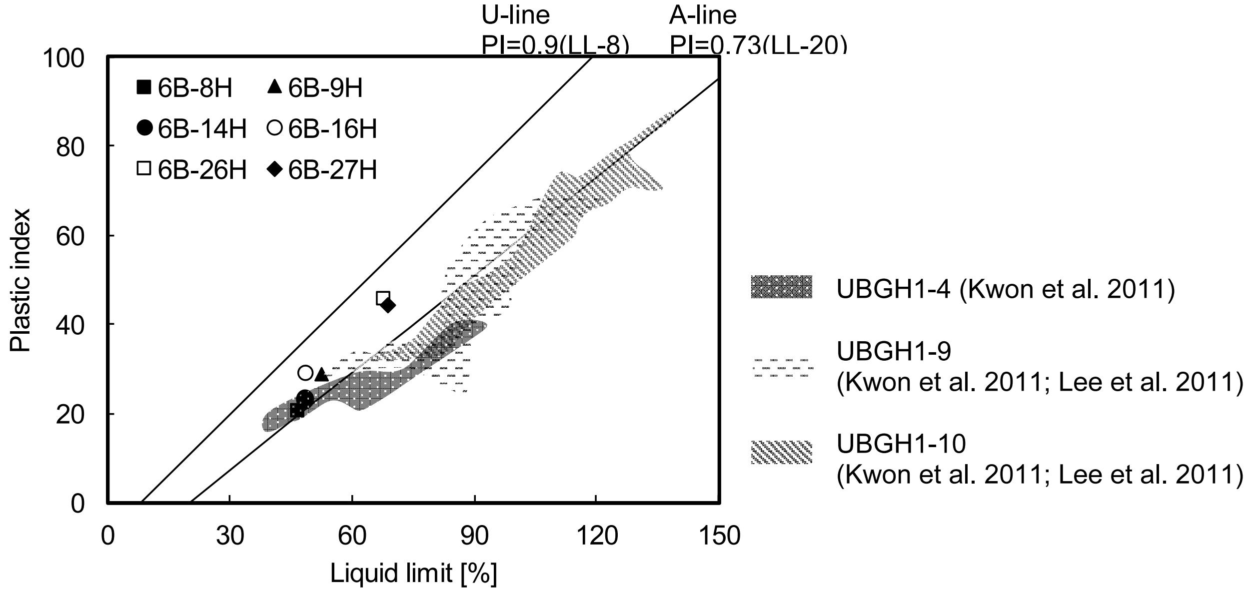

Fig. 1. Plasticity chart.

3. STRESS-DEPENDANT MECHANICAL PROPERTIES

3.1. Experiment equipment and process

The stress-dependant properties are measured by using an instrumented oedometer cell, which is housed shear wave transducers. To minimize additional disturbance, a core liner was used as the oedometer cell in this study. After the specimen was placed into the oedometer cell, the specimen was saturated for 24 hrs with an electrolyte. The electrical conductivity of electrolyte is identical with that of the pore fluid measured in the field. Consolidation test (ASTM D 2435) was conducted to measure the stress-volume response. After settlement was measured, shear wave was immediately measured.

3.2. Compressibility

Fig. 2 shows the stress-volume responses during loading and unloading for four selected specimens (6B-14H-3a, 6B-16H-3a2, 6C-9H-3c, and 6B-26H-1b). A bi-linear behavior is observed with the vertical effective stress, as shown in Fig. 2. Relatively high initial void ratio for 6B-9H and 26H result partly from the hydrate existence. As shown in Fig. 2, the hydrate existence significantly affects on the initial void ratio, compression index C_C, and swelling index C_S of the specimens. High specific surface from internal pore structures also cause high compressibility in hydrate-bearing sediments (Lee et al. 2010). The internal pore structures of specimens from Ulleung basin are primarily due to the abundance of diatoms. The values are even higher than those from Gulf of Mexico (Lee et al 2008), implying our specimens have significantly high portion of diatoms.

3.3. Shear wave velocity

For selected specimen, shear wave velocities calculated from the measured shear wave signal are plotted with the vertical effective stress in Fig. 3. Bender elements are used to transmit and receive the shear waves in this study. Shear wave velocities measured at each loading stage show a power function increase with the vertical effective stress: $V_s=48.5(\sigma'_V)^{0.218}$ for 6B-16H and $V_s=39.4(\sigma'_V)^{0.275}$ for 6C-9H. Relative high value of the exponent β=0.275 for 6C-9H reflects changes in the interparticle contact during loading, probably due to the disturbance of the specimen by the hydrate dissociation. Similar results are reported in specimens from hydrate-bearing regions in Gulf of Mexico (Lee et al, 2008). Higher specific surface also cause the higher β exponent in hydrate-bearing sediments (Lee et al. 2010).

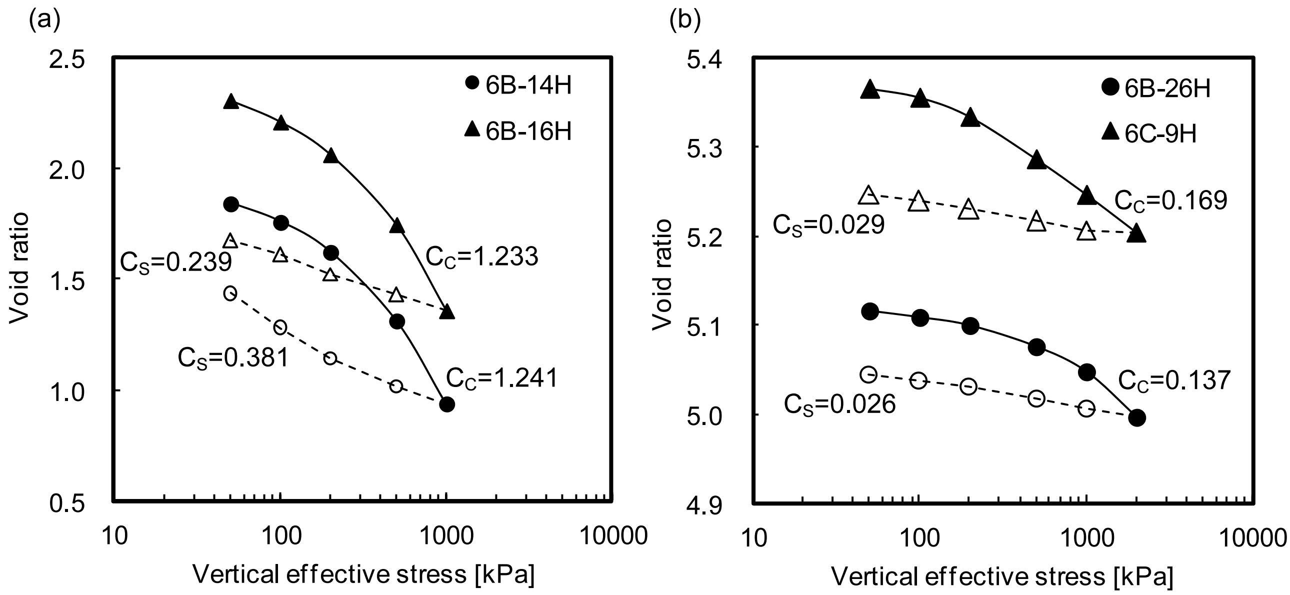

Fig. 2. Stress-volume response during loading (solid symbols) and unloading (empty symbols): (a) 6B-14H and 16H; (b) 6B-9H and 26H.

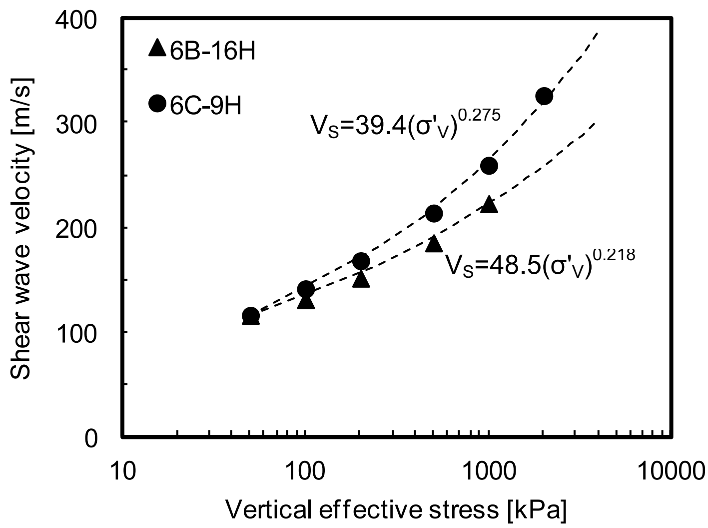

Fig. 3. Evolution of shear wave velocities during loading.

4. CONCLUSION

In this study, a series of laboratory are conducted to investigate index properties and stress-dependent geotechnical properties of the deep marine sediments retrieved from the hydrate occurrence regions during the Ulleung Basin Gas Hydrate Expedition 2 (UBGH 2) in the Ulleung Basin, East Sea. The measured water contents are in a relatively narrow range of 25-35%, that are close to a low boundary of previously reported values. The sediments tested in this study are classified as either CL/OH or CH/OH with high silt fraction (~80%).

Relative high initial void ratio is observed for 6B-9H and 26H resulted from the hydrate existence. The hydrate existence significantly affects on the consolidation characteristics of the specimens. Void ratio, and shear wave velocity show a bi-linear behavior with the effective vertical stress: shear wave velocity increases with increasing in vertical effective stress, and relative high value of the exponent for 6C-9H reflects changes in the interparticle contact during loading, probably due to the disturbance of the specimen by the hydrate dissociation.

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