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Effect of Frozen-thawed Procedures on Shear Strength and Shear Wave Velocity of Sands

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ABSTRACT

The artificial ground freezing method, which is known as the most effective method to obtain undisturbed cohesionless soil samples, have to freeze the sand deposits. The objective of this study is to compare the shear strength and the shear wave velocity in frozen-thawed and unfrozen specimens through the undrained triaxial compression test. Frozen and unfrozen specimens are prepared by Jumunjin sand with similar relative density (Dr). Shear wave velocity is measured during each the saturation, consolidation and shearing phases of the triaxial compression tests. The results show that the shear wave velocity decreases with an increase of the B-value during the saturation process, but in the process of consolidation and shearing the velocity changes in accordance with the effective stress. Shear wave velocity is slightly lower for frozen-thawed specimen than for unfrozen specimen. The frozen-thawed specimen shows lower deviatoric stress and shear strength values than the unfrozen specimen. This study provides implications for the effects of freeze-thaw process on the shear strength, shear wave velocity, and friction angle of sand specimens.

1. INTRODUCTION

Geotechnical investigation and accurate understanding of soil behavior are essential to build an infrastructure economically and safely. In order to estimate reasonable strength parameters of soils, comprehensive laboratory tests using undisturbed sample obtained in the field is most commonly used. In the case of a sand deposit, artificial ground freezing method is known as the most effective way to obtain undisturbed samples (Kim 2005).

Several studies using frozen sand specimens were carried out to investigate effects of the freeze-thaw process. Yoshimi (1978) suggested that freeze-thaw process of the

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sandy soils have negligible effects on the strength and deformation under drained condition. Yoshimi (1984) suggested that there is no significant effect on liquefaction strength from the confining stress between 5kpa and 98kpa during the thawing process. Sasitharan (1994) reported that there is no expansion of the sandy-silt mixture during freezing, it is negligible change in shear wave velocity. In most of previous studies, however, the specimen were frozen and thawed on the pedestal.

In this study, undrained triaxial compression tests are conducted to evaluate the strength parameters of frozen specimens. For the experimental study, frozen and unfrozen specimens are prepared using by Jumunjin standard sand with similar relative density of 80%. Frozen specimen, which is trimmed to the desired size, is thawed on the pedestal under low effective stress. After the specimen is completely thawed, undrained triaxial compression tests for unfrozen specimen are performed with same procedures. Shear waves are measured by bender elements installed on the each pedestal during whole triaxial test procedure (saturation, consolidation, shear phase).

The purpose of this study is to investigate the characteristics of the strength and shear wave velocity of the artificial frozen specimen using a triaxial compression test. This paper describes the method of specimens preparation and configuration of triaxial compression test system for measuring the shear wave. Moreover, the results of triaxial compression tests and shear wave velocity of each phase are described.

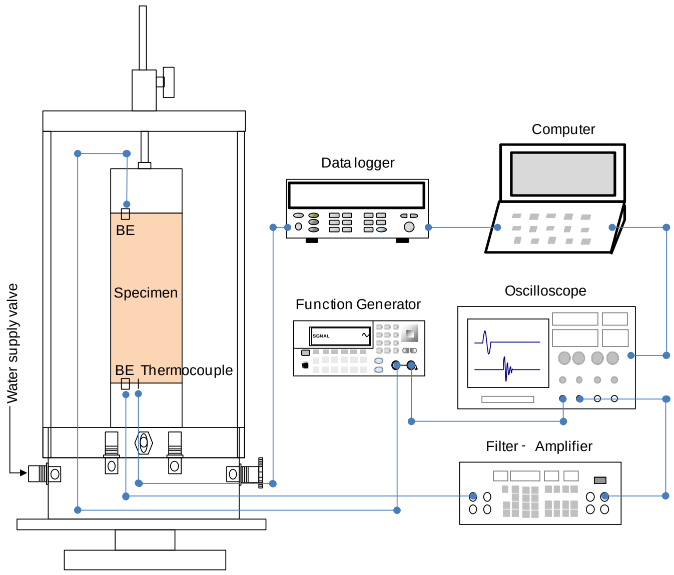

Fig. 1 Temperature and elastic wave measurement system

2. EXPERIMENT SETUP

2.1 Specimen preparation

Jumunjin sand is used to prepare test specimens. To minimize the size effects (Lee 2008) and avoid swelling of the specimens during freezing due to fine particles (Sasitharan 1994), Jumunjin sand are sieved to obtain a median grain size (D_{50}) of 0.45mm. The maximum (e_{max}) and minimum (e_{min}) void ratios are calculated to be 0.94 and 0.67, respectively (ASTM D4253 and ASTM D4254). The specific gravity (G_S) is

2.66 (ASTM D854). Because, to applied an artificial ground freezing method in the field, the sand deposit is placed below the groundwater, the unfrozen and frozen specimens are prepared by the water pluviation method with similar relative density (Dr≈80%). The height of specimens is approximately 100 mm and the diameter is 50 mm. The specimen is frozen in a -50℃ refrigerator. After 24 hours, specimen is taken out from the mold and trimmed to be a desired size for a triaxial test.

2.2 Triaxial test system for measuring the shear wave and temperature

Fig. 1 shows a schematic drawing of a triaxial test system for measuring the shear wave and temperature. On the top and bottom pedestals, a pair of bender element is installed to measure the shear wave during triaxial tests. Bender elements have been widely used in laboratory experiments due to excellent coupling between a soil and transducer (Lee 2006). Input signals are generated by a function generator and propagated through specimen. Received signals are filtered and amplified by filter-amplifier, displayed on oscilloscope, and recorded in computer. Porous stones are installed on the pedestal to minimize the disturbance due to pore water drainage. To measure the temperature of specimen during thawing phase, thermocouple(k-type) is installed on the bottom pedestal. From the data logger and computer, the temperature is measured and recorded for every minute.

3. TEST PROCEDURE

Frozen specimen is thawed on the pedestal under a constant cell pressure of 10 kPa. When the temperature of the specimen measured on the bottom pedestal is same as the room temperature, the frozen specimen is considered completely thawed. After the frozen specimen is thawed, the undrained triaxial compression test is conducted by the same procedures with unfrozen specimen (ASTM D4767). To remove the air bubbles in the specimen and increase the B-value, the deionized and de-air water is circulated into the specimen before consolidation. The de-aired water is flushed from the bottom to top pedestal under low pressure difference. During the circulation phase, the cell pressure and pore pressure are kept to be 10 kPa and 0 kPa, respectively. During the saturation phase, cell pressure and pore pressure increase 20 kPa increments up to 500 kPa sequentially in order to increase the B-value. When the B-value reaches to be 0.95, the specimens are assumed to be fully saturated. In the consolidation phase, the specimens are consolidated to the confining stress of 80 kPa. The specimens are sheared with an axial strain rate of 0.2 %/min.

During the triaxial tests (saturation, consolidation and shear phase), shear waves are continuously measured. Shear wave velocity is described as Eq. (1)

$$V = \frac{L}{\Delta t} \tag{1}$$

where, Δt is the initial arrival time of shear wave and L is the distance from the end of the bender element. After the end of the triaxial test, dry weight of specimens is measured to reaffirm the relative density.

4. EXPERIMENTAL RESULTS AND ANALYSES

4.1 Undrained triaxial test

Table 1 are summarized the results from undrained triaxial tests and Fig.1 shows typical measured deviatoric stress and excess pore water pressure versus axial strain. The frozen-thawed and unfrozen specimens show slightly different behaviors through the undrained triaxial compression test. For both specimens, the excess pore water pressure slightly increases at the beginning, then gradually decreases until negative state like a dense sandy soil. Deviatoric stress tends to decrease when the specimen goes through a frozen-thawed process. The excess pore pressure of the frozen-thawed specimen shows larger decrement than unfrozen. Shear strength for the frozen-thawed specimen is lower than unfrozen one due to possibility of changing particle arrangement and stress history during frozen-thawed process. Meanwhile, the internal friction angle, which is one of the strength parameters, is quite similar regardless of frozen-thawed process, as show in Table 1.

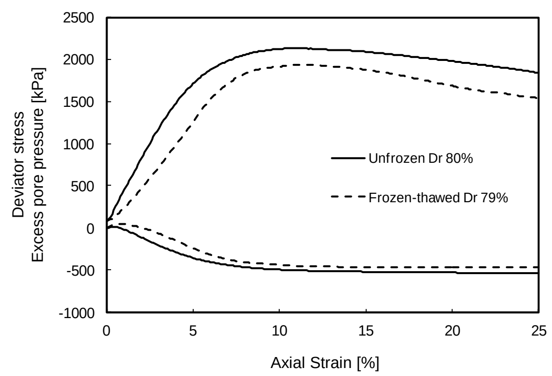

Fig. 2 Deviator stress and excess pore pressure versus axial strain

4.2 Shear wave velocity

Shear wave velocity is proportional to the effective stress (Roesler 1979). In saturation phase, the shear wave velocity through frozen-thawed specimen is lower than unfrozen one but they decrease a little when B-value rises as shown in Fig. 3. Kim (2006) studied relation between B-value and shear wave velocity, the result shows that they are inversely proportional. Due to B-value is an indicator for measuring the degree of saturation, it is implied that the shear wave velocity is reduced by decreasing the effective stress.

On the other hand, during the consolidation phase, the shear wave velocity starts to increase with increasing in the confining stress as shown in Fig. 4. Due to the same amount of effective stress is applied to frozen-thawed and unfrozen specimens, shear wave velocity increases by the same amount in consolidation phase. Fig. 5 presents the variation of the effective stress and shear wave velocity during the shear phase. As axial strain increases, horizontal effective stress increases up to specific value due to decrease of the excess pore water pressure. The vertical effective stress goes up until maximum value which represents specimen failure, then gradually decreases. Similarly, the shear wave velocity increases at the beginning of the shear phase until the effective stress reaches to a failure state, and then it maintains the peak value continuously. The result from the triaxial tests shows that shear strength and shear wave velocity in frozen-thawed specimen are lower than those of the unfrozen specimen.

Table 1. Result of undrained triaxial compression test (at failure)

	Strain [%]	Deviator stress [kPa]	Shear strength [kPa]	Excess pore pressure [kPa]	Friction angle [°]
Frozen-thawed Dr 79%	11.2	1401.2	768.4	-452.88	34.5
Unfrozen Dr 80%	10.5	1547.5	774.1	-502.4	34.6

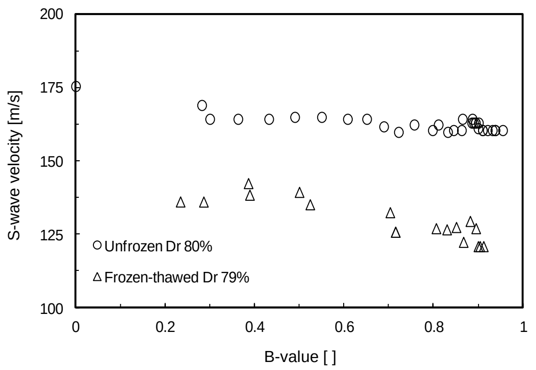

Fig. 3 S-wave velocity versus B-value during the saturation phase

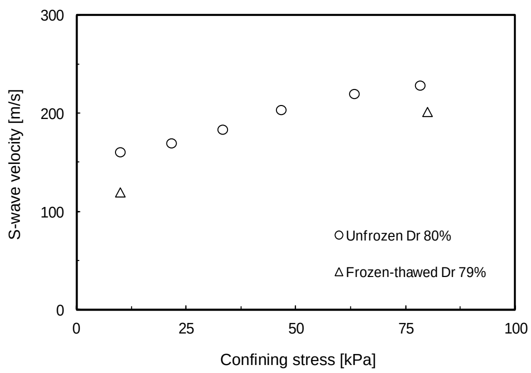

Fig. 4 S-wave velocity versus confining stress during the consolidation phase

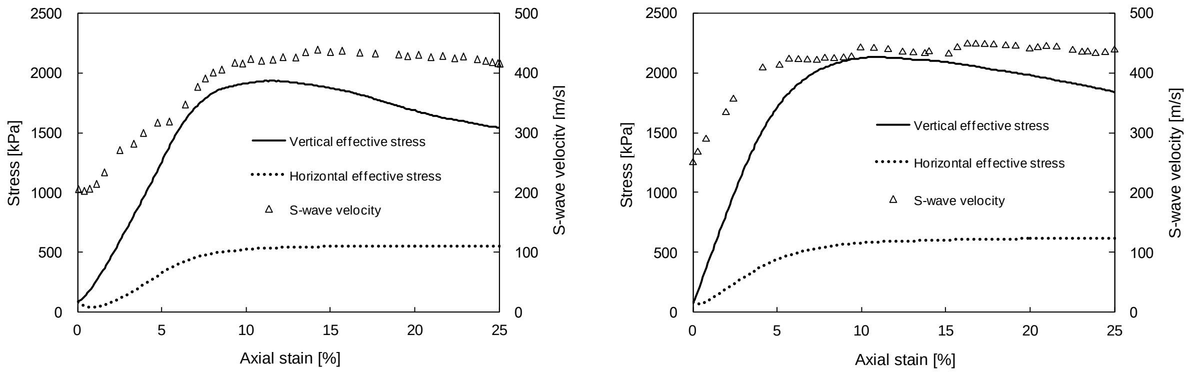

Fig. 5 S-wave velocity versus axial strain during the shear phase

5. SUMMARY AND CONCLUSION

The objective of this study is to estimate the effect of frozen-thawed procedure on shear strength and shear wave velocity of sand through undrained triaxial compression test. Frozen and unfrozen specimens are prepared using the Jumunjin sand with similar relative density (Dr≈80%). Frozen specimen is thawed on the pedestal under a low effective stress. The frozen specimen is completely thawed, undrained triaxial test are performed as same as unfrozen specimen. During the triaxial compression test, shear wave velocity is measured continuously for each procedure. From the measured shear strength and shear wave velocity during triaxial tests, the following conclusions are observed:

(1) The result from undrained triaxial compression test shows that freeze-thaw process decreases the deviatoric stress and shear strength of the specimen. However, the process does not affect change of the internal friction angle.

(2) During the saturation process, the shear wave velocity tends to decrease with increase of B-value

(3) In consolidation and shear phase, the shear wave velocity increases with the effective stress. Measured shear wave velocity of frozen-thawed specimen is a little smaller than unfrozen specimen value.

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