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Effect of Freezing Direction on the Liquefaction Strength of Crushable Volcanic Soil

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ABSTRACT

The objective of this study is to clarify the effect of freezing direction on liquefaction strength of a crushable volcanic soil. Frozen specimens which were subjected to different freezing direction were prepared with a newly developed model test apparatus. A series of undrained cyclic triaxial tests for a crushable volcanic coarse-grained soil was conducted after the frozen specimen was thawed in the triaxial apparatus. Based on experimental results, it was found that liquefaction strength of the soil depends on freezing direction. The liquefaction strength of the specimen subjected to freeze in parallel to short axis of soil particle was lower than that of the specimen subjected to freeze in vertical to short axis.

Introduction

Many disasters due to freeze-thaw action and frost heaving occur during snow melting season in Hokkaido Island, which is located at north part of Japan. Along with climate condition, geography has influence on the disasters. Japan is a volcanic land and is covered by volcanic product. Hokkaido Island is also widely distributed by volcanic coarse-grained soils. Since most of these soils are friable porous material, particle breakage occurs due to freeze-thaw action and even low stress levels. This particularity of composed particle leads to the potential for natural disasters. Therefore, researches on effect of freeze-thaw action on mechanical behavior of crushable volcanic soils subjected to one dimensional freeze-thaw are in progress (Ishikawa et al. (2010), Ishikawa et al. (2011)). In addition to these researches, it is necessary to examine the effect of freeze direction on mechanical properties of soils in order to clarify the mechanism of these disasters because freezing direction is complicated in the ground of slope, backfill of retaining wall and so on. Not only the static strength, but also the liquefaction strength of volcanic coarse grained soil is considered to be affected by the direction of freezing.

This study aims in clarifying the mechanism of effect of freezing direction on liquefaction strength of volcanic soil. Specimens of crushable volcanic coarse-grained soil were frozen in different freezing directions using a newly developed model test apparatus. Frozen specimens were thawed and then undrained cyclic triaxial tests have been performed using triaxial apparatus. In order to elaborately examine the effect of freezing direction on liquefaction strength sieving analysis and single particle crushing tests has been performed.

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Methodology

Test sample

The material used in this study is collected from natural deposits of Tomakomai, Hokkaido. The material is a coarse volcanic soil (hereafter referred to as ‘Kashiwabara volcanic soil’). Figure 1 shows the grain size distribution curve and physical properties of Kashiwabara volcanic soil. Kashiwabara volcanic soil has low values of both maximum and minimum dry density because its constituent particles are very porous on account of having many internal and inner voids. Previous studies indicated that Kashiwabara volcanic soil shows remarkable particle crushability under low stress level (Miura et al. (1996a), Miura et al. (1996b)). Figure 2 shows the ratio of long axis to short axis. As shown in Figure 2, Kashiwabara volcanic soil is mainly composed of flattened particles.

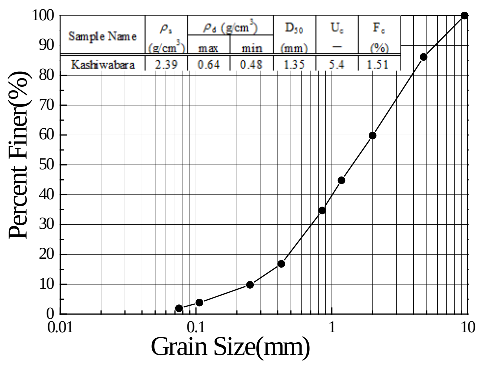

Figure 1: Grain size distribution.

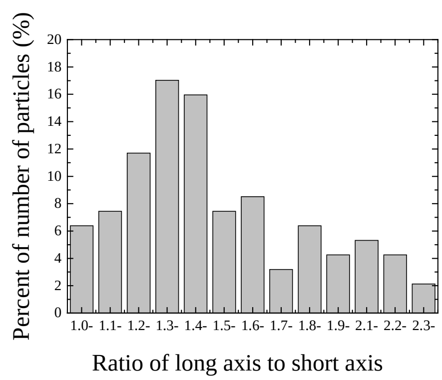

Figure 2: Ratio of long axis to short axis.

Model test apparatus

A new model test apparatus has been developed in order to make specimens frozen in different direction. Figure 3 shows schematic diagrams of the apparatus. The soil container can be inclined at arbitrary degree angle (from 0 to 90^{o}). Temperature of top and bottom plate, which have plumbing path, can be controlled by using low temperature bath. The soil in container can be frozen unidimensionally.

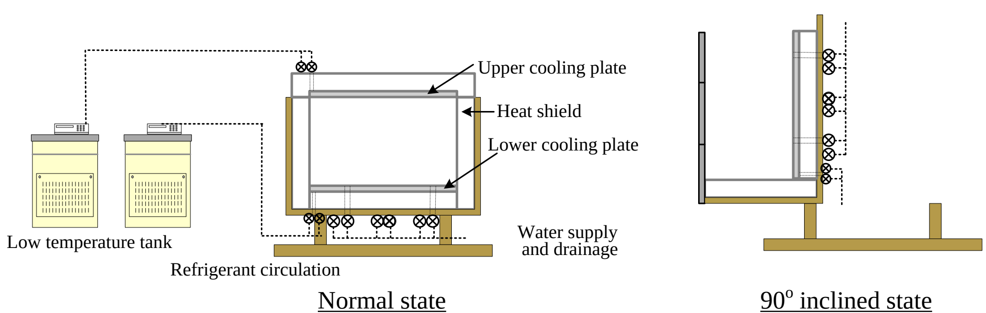

Figure 3: Model test apparatus.

Preparation of specimen

Four types of reconstituted specimens subjected to freeze and thaw were used in order to examine the effect of freezing direction on the liquefaction strength. Reconstituted specimens, which have no freeze-thaw history, have been used in order to compare the liquefaction strength of freeze-thawed soil specimens. Reconstituted specimens (170mm in height and 70mm in diameter) were prepared by air pluviation method in triaxial cell.

The specimens subjected to freeze and thaw used in this study are illustrated in schematic diagram as given in Figure 4. In general, particles of specimen prepared by air pluviation method are deposited in long axis of particle parallel to horizontal line. The soil specimens in which the particles are deposited in a direction parallel to short axis are defined as V specimen and particles deposited in a direction parallel to long axis are defined as H specimen. Freezing direction parallel to long axis of the particles is noted as H direction and parallel to short axis of the particles is noted as V direction. These freezing directions in specimens are denoted as suffix of the specimen names i.e. V_V, V_H, H_V and H_H. Freezing direction parallel to short axis and long axis of soil particle is noted as V_V, V_H for specimens in which the particles are aligned parallel to short axis and as H_V, H_H for specimens in which the particles are aligned parallel to long axis.
The specimens were prepared in the following manner. In case of V_V, H_V specimens, air dried soil was deposited into the container by air pluviation method with the container kept at normal state (no inclination). While, in case of V_H, H_H specimens, with the container inclined at an angle of 90 degree from normal state, soil was deposited in the same way as V_V and H_V specimens. After depositing soil, the container was returned to normal state.

Next, de-aired water has been added from the bottom of the container and the soil was submerged in water for 24 hours. Gravity dewatering has been performed for 24 hour in order to prevent disturbance of the soil by frost expansion and to adjust degree of saturation to 65%. After these procedures, the soils were kept in low temperature by means that the top and bottom plates of container were set to 1°C. After temperature been distributed equally, the soil was frozen from bottom with constant freezing velocity of -1°C/h. After frozen line penetrate to top of the soil, the cylindrical specimens (height in 170mm, diameter in 70mm) for triaxial test were trimmed from the frozen soil from the container.

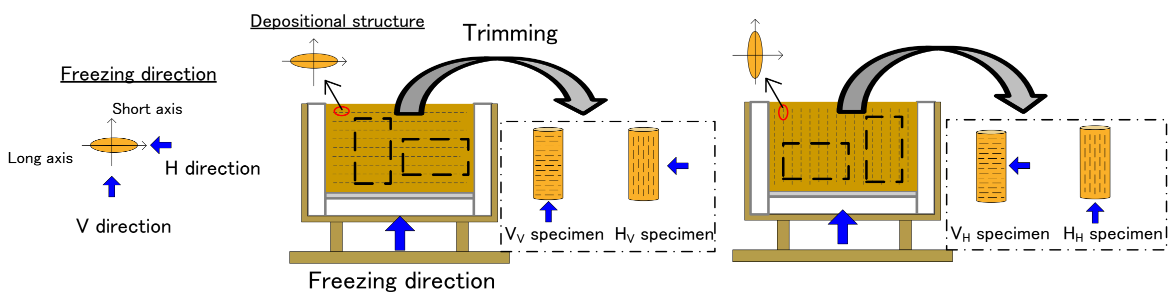

Figure 4: Schematic diagrams of specimens.

Cyclic undrained triaxial test

In case of frozen specimen, after the specimen was set in triaxial cell and enclosed a membrane, the specimen was melt under confining pressure of 20kPa. Carbon dioxide was permeated through the specimen. Subsequently de-aired water added from the bottom of the specimen. Back pressure was applied to the specimen in order to saturate the specimen. A back pressure of 200 kPa was then applied to ensure the saturation of all the specimens and achieve a pore water pressure coefficient B-value of 0.96 or more. Following the saturation, the specimen was isotropically consolidated under a specified effective confining pressure (σ_c') of 49 kPa by applying a designated confining pressure (σ_c) of 249 kPa and pore water pressure (u_w) of 200 kPa until volume strain became smaller than 1.0×10^{-4}%/min. A series of undrained cyclic triaxial tests was performed to obtain liquefaction strength according to Method for cyclic undrained triaxial test on soils (JGS 0541, 2009).

Single particle crushing test

Single particle crushing tests (Miura et al. (1999)) for the freeze-thawed volcanic soil were conducted to evaluate the direction of freezing on the hardness of the individual particles. Freeze-thawed samples were prepared using the same method as undrained cyclic triaxial test. As a sample of the single particle test, 100 particles having size capable of performing the test were extracted at random. The size of particles ranged from 2.5 mm to 10.0mm. Next, soil particle was gently pinched between loading rods in the direction of the short axis of the elliptical particle as shown in Figure 5.

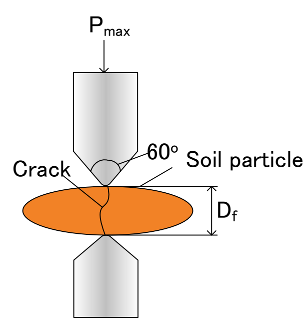

Figure 5: Single particle crushing test.

Accordingly, the strength of single particle crushing (S_t) in this study is given in the form of the crushing strength at point loads, calculated from the following equation proposed by Hiramatsu et al. (1965).

$$S_t=0.9\cdot P_{max}/D_f^2 \quad (1)$$

where, P_{max} is the maximum axial load and D_f is the particle height at failure.

Results and Discussions

Undrained cyclic triaxial test results

Figure 6 shows the cyclic stress ratio $\sigma_d/2\sigma'_c$ versus the number of loading cycles N_c to double amplitude axial strain DA=5% obtained from cyclic undrained triaxial tests, which were conducted on unfrozen, V specimens and H specimens respectively. Reconstituted specimen which shown in Figure 6(b) is same as shown in Figure 6(a) because only V direction reconstituted specimen can be prepared. Liquefaction strength of V and H specimens, which have a freeze-thaw history, decreased in comparing with reconstituted specimen. As for V direction specimen (Figure 6(a)), liquefaction strength of specimens which had a freeze history is smaller than that of specimens which have no freeze history. Moreover, in comparing V_V specimen and V_H, the strength of V_V is smaller than that of V_H specimen. As for H specimen (Figure 6(b)), the strength of H_V is smaller than that of H_H specimen. In the case of specimen which had a freeze history, V and H specimen have in common that liquefaction strength of specimens trimmed in direction parallel to short axis is smaller than that of specimens trimmed in direction parallel to long axis. From this observation it is evident that freezing and thawing has influence on liquefaction strength, moreover freezing direction has influence on liquefaction strength.

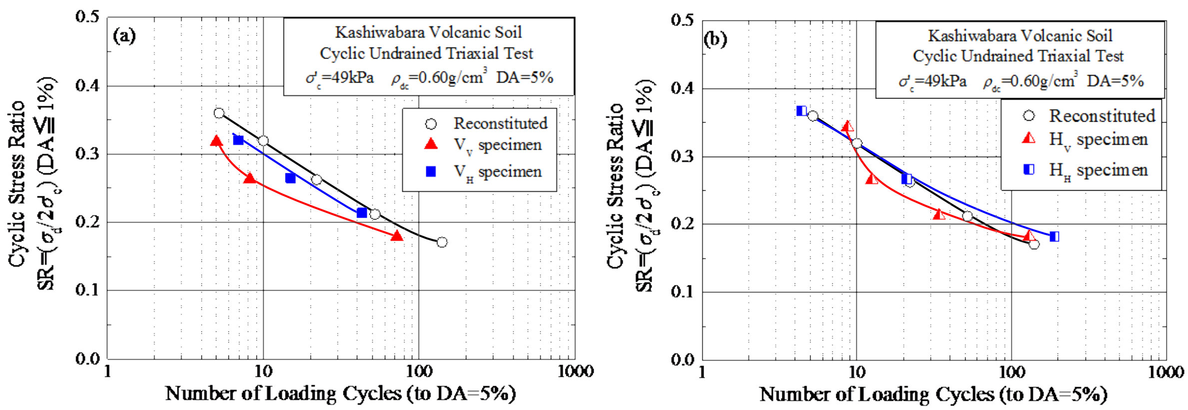

Figure 6: Liquefaction strength (a) V specimen (b) H specimen.

Effect of freezing direction on particle breakage

Crushable volcanic soil is known to decrease in liquefaction strength due to particle breakage (Yagi and Miura (2001)). The amount of particle breakage can be evaluated by increment of fine content. The increment of fine content (ΔF_c), which is the change in the fines content (F_c) of the tested specimens from that of the original specimens follow Equation 2 (Nakata et al. 1998).

$$\Delta F_c = F'_c - F_c \qquad (2)$$

where, F'_c, F_c are the fines contents before and after testing.

Figure 7 shows increment of fine contents, which has been obtained from the sieve analysis, after completion of cyclic undrained triaxial tests. Increment of fine content of all of the specimens which have freezing history is higher than that of reconstituted specimens which have no freezing history. Particle breakage occurred due to freeze-thaw.

In comparison with same depositional structure (V_V vs V_H, H_V vs H_H), increment of fine contents of specimen, which were frozen in parallel to short axis, is slightly higher than that of specimens, which were frozen in parallel to long axis. Therefore, difference in freezing direction is considered to have influence on particle breakage.

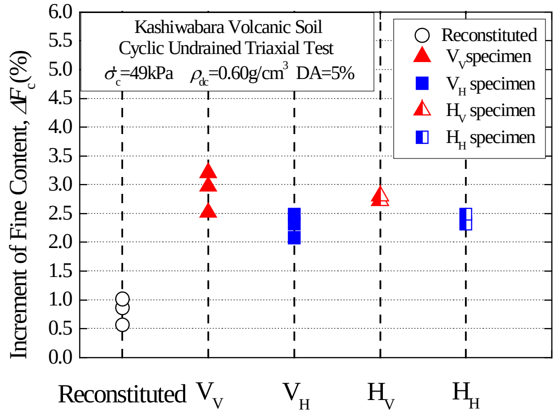

Figure 7: Increment of fine content.

The effect of the freezing direction on the particle crushability of Kashiwabara volcanic soil is discussed in more detail. Figure 8 shows the relationship between the strength of single particle crushing and the particle height at failure (D_f) obtained from single-particle crushing test on Kashiwabara volcanic soil exposed to different freezing direction, along with the results of the regression analysis using Equation 3 (Miura et al. (1999)).

$$S_t = m \cdot D_f^{\,n} \tag{3}$$

where, m and n are regression constants corresponding to the material properties and freezing direction.

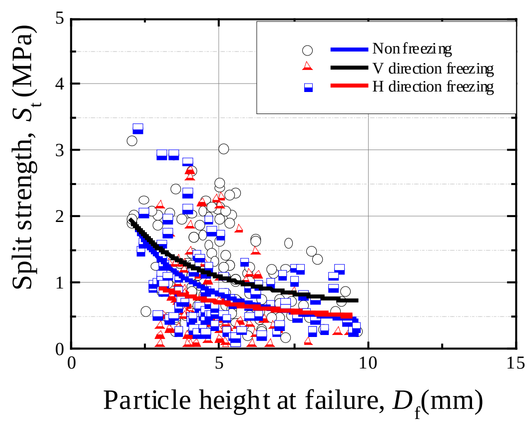

Figure 8: Split strength.

Comparing with reconstituted specimen and specimens which have a freeze-thaw history, soil particle subjected to freeze thaw were reduced in split strength. Kashiwabara volcanic soil is a porous soil material and has many voids in particles. Particle breakage may occur because of expansion of water retained in inter voids due to freezing. Moreover, split strength of specimens frozen in V direction is lower than that of specimens frozen in H direction under 7mm. This indicates that freezing direction have influence on particle strength. There is a possibility that the difference of particle breakage due to different freezing direction were attributed to the specific structure of soil particle of Kashiwabara volcanic soil.

Some soil particles of Kashiwabara volcanic soil are aggregates of acicular particles as shown in Figure 9. In general, freezing expansion of soil occurs mainly parallel to freezing direction. Therefore, it can be presumed that particle breakage due to different freezing direction occurs as shown in Figure 9. When freeze penetrate parallel to short axis of particles, particles breakage occur because pore water retained in inter void expands and exfoliates acicular particles. On the other hand, when freeze penetrates parallel to long axis of particles, pore water expands along with acicular particles so that inter voids are broken and expanded. In addition to incremental fine content shown in Figure 7, as compared with the latter case, the case of freezing direction parallel to short axis of particle is considered to break more and decrease the split strength. As a result, difference of particle breakage due to freezing direction and amount of particle breakage has influence on liquefaction strength of soil.

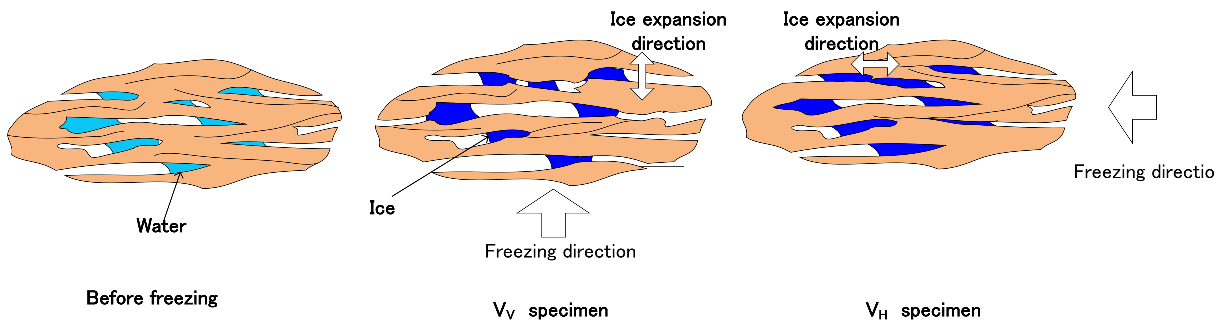

Figure 9: Schematic diagrams of particle breakage.

Conclusions

In this study, undrained cyclic triaxial tests were conducted in order to figure out the effect of freezing direction on liquefaction strength. The following conclusions were obtained.

- Freezing direction has influence in liquefaction strength of Kashiwabara volcanic soil. On the assumption that particles of specimen prepared by air pluviation method are mainly deposited in long axis of particle parallel to horizontal line, liquefaction strength of specimen frozen in direction parallel to short axis of particles tends to decrease in comparison with that of specimen frozen in direction parallel to long axis of particles.
- Specimens frozen in direction parallel to short axis of particles tend to increase in fine content. On the process of freezing, the composed soil particles are weakened.
- Freezing direction seems to have influence on particle breakage of crushable volcanic coarse-grained soil.

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