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Micro-focus X-ray CT scanning of chemically improved sand

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ABSTRACT: In order to improve the loose sand mechanical properties as the countermeasures against the earthquake induced liquefaction, a chemical solution, i.e. a liquid glass material solution is frequently employed and injected into the loose sand foundation in Japan. The volume change of a liquid glass material has been observed during the chemical gel reaction of the liquid glass material in the laboratory test. The volume change of liquid glass material is assumed to affect the mechanical properties of the chemically improved sand.

In this study, the micro-focus X-ray CT scanning technique has been used to investigate the effect of the volume change of liquid glass material on the density variation of the chemically improved sand specimen. The specimen has been prepared by using a silica sand sample and the neutral-acid liquid glass material. In the X-ray CT scanning of the material, the output value to be measured is the value called GL (Gray Level), which is proportional to the X-ray absorption amount and the density of the tested material. By using this relationship, the density distribution within the specimen has been obtained. The effect of volume change of a liquid glass gel material on the mechanical characteristics of chemically improved sand has been investigated by using the correlation between the GL values and the material densities.

1 INTRODUCTION

Japan is situated in one of the world major earthquake affecting regions and frequently attacked by the large scale earthquake induced damages. In the 1995 Hanshin-Awaji great earthquake and the 2011 East Japan great earthquake, the serious damages have been observed due to the liquefaction of the loose saturated sand foundations[1)].

One of the liquefaction countermeasure methods frequently used in Japan is the chemical grouting method, particularly in the case of the improvement of the foundations just below the exiting superstructures. In the chemical grouting method, the liquid glass material solution is injected into the loose saturated sand deposit and the pore water is replaced by the injected liquid glass solution. The chemical gel reaction of the liquid glass solution with the reactant takes place within the pores of the loose sand and the mechanical characteristics of the original loose sand deposit is much improved by the interaction between the liquid glass gel material and the sand particle skeleton, i.e. the strength increase and the permeability reduction of chemically improved sand.

The mechanical characteristics improvement has been practically investigated by using the small cylindrical specimens (Diameter 5 cm × Height 10 cm) prepared within the mold container in the laboratory. However, the unconfined compression test results obtained from the small cylindrical specimens under the same test conditions have been frequently scattered with wide range of variation. The reason for these scattered results is assumed to be the complicated interaction between the liquid glass gel and the sand particle skeleton.

Particularly, the long term volume shrinkage of a liquid glass gel is known to take place and is assumed to affect the mechanical characteristics of chemically improved sand. It is necessary to understand the interaction mechanism of the sand particle – liquid glass mixture to secure the long term performance of chemically improved sand as the liquefaction countermeasure.

In this study, experimental investigations have been carried out to obtain the long term volume change characteristics of a liquid glass solution during the sol-gel chemical reaction process. The density variation within the small cylindrical specimen of the chemically improved sand has been directly inspected by using the micro-focus X-ray CT scanning technique, in order to investigate the interaction between the liquid glass gel and the sand particle skeleton.

2 EXPERIMENTAL PROCEDURE

2.1 *Volume change characteristics of a liquid glass gel material*

Table 1 indicates the liquid glass mixture components employed in this study. The experimental procedure to

Table 1. Liquid glass mixture components.

Liquid A		Liquid B	
Na_2SiO_3	250 (ml)	Reactant	23.75 (ml)
Water	650 (ml)	Additive	16.25 (ml)
		Water	60 (ml)

Table 2. Physical properties of a silica sand.

ρ_s(g/cm^3)	2.62
Maximum void ratio e_{max}	0.713
Minimum void ratio e_{min}	0.469
D_{50} (mm)	0.85

obtain the volume change characteristics of a liquid glass gel material during the sol-gel chemical reaction process is as follows.

1) The liquid glass solution is prepared by mixing a liquid A and a liquid B, as shown in Table 1 and it takes 6 hours for the sol-gel chemical reaction of a liquid glass solution to be completed and lose its liquidity, i.e. named as a gel time.
2) 50 ml of the liquid glass solution is poured into the volumetric flasks of 100 ml contents, as shown in Fig. 4. Two types of volumetric flasks are used to investigate the effect of the material property of flask on the volume change characteristics of a liquid glass gel. One is made by a glass material and another is made by a plastic material.
3) Two types of volumetric flasks with a liquid glass solution are put into an incubator, whose internal temperature is kept at 20 degrees.
4) At specific time period elapsed from the mixing of a liquid glass solution, water is added into the volumetric flasks so that the total volume of the added water volume and the liquid glass gel amounts to 100 ml. Initial measurement is carried out at 6 hours after the mixing of a liquid glass solution.
5) The volume change of a liquid glass gel is obtained by subtracting the volume of added water from the total volume of 100 ml. The rate of volume change (%) of a liquid glass gel is calculated by dividing the volume change of a gel by the initial liquid glass solution volume of 50 ml. During this process, some of the liquid glass gel material can be mixed with water and lost.

The time elapsed from the mixing of a liquid glass solution is represented by the gel time ratio, as shown in Eq. (1).

$$\text{gel time ratio} = (\text{elapsed time}) / (\text{gel time}) \quad (1)$$

2.2 *Micro-focus X-ray CT scanning of chemically improved sand specimen*

Table 2 indicates the physical properties of a silica sand sample used in this study. Chemically improved

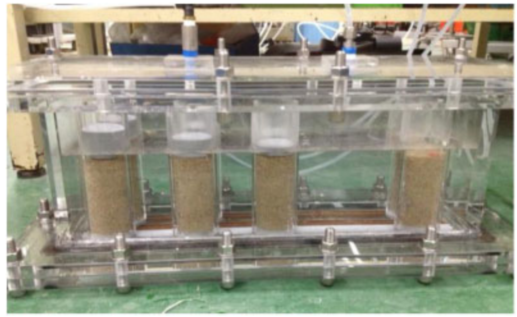

Figure 1. Vacuum permeation apparatus.

sand specimens are prepared by using the vacuum permeation apparatus, as shown in Fig. 1. The method of sample preparation is as follows.

1. A mass of silica sand particle is poured into the small transparent plastic cylinder with the internal diameter of 5 cm to attain the specified relative density of 80%.
2. Vacuum of around −40 kPa is provided with the top of a large transparent container, which contains multiple small transparent plastic cylinders filled with silica sand particle.
3. A liquid glass solution is supplied from the bottom of a large transparent container and the silica sand particle within the small cylinder is submerged with a liquid glass solution under the application of the vacuum.
4. After the sol-gel chemical reaction of a liquid glass has been completed, small plastic cylinders with chemically improved sand are removed from the large container. Small plastic cylinders are dismantled to obtain the cylindrical specimen of chemically improved sand.

The values of degree of saturation of chemically improved sand specimens have been observed to be greater than 95%.

According to Kikuchi et al.[2], the micro-focus X-ray CT scanning technique has been used for the observation of internal structure of geomaterials and a good correlation between the values of GL (Gray Level) obtained from the X-ray CT scanning and the density of specimen has been found. The X-ray CT scanning technique is assumed to be employed to obtain the density distribution within the chemically improved specimen.

Figure 2 demonstrates the micro-focus X-ray CT scanning device used in this study. At the specific time period elapsed from the mixing of a liquid glass solution as in the same as the observation of a volume change of a liquid glass gel material, the X-ray CT scanning has been carried out by using the chemically improved sand specimens prepared as mentioned above.

The digitized images of the specimen cross section obtained from the X-ray CT scanning are used to obtain the distribution of GL values for that cross section.

Figure 2. Micro-focus X-ray CT scanning device.

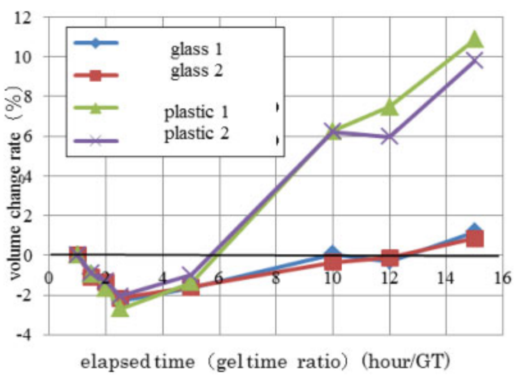

Figure 3. Relationship between liquid glass gel volume change rate and elapsed time.

GL (Gray Level) values represent the degree of X-ray absorption of the material and are proportional to the material density.

3 RESULTS AND DISCUSSIONS

3.1 *Volume change characteristics of a liquid glass gel material*

Figure 3 indicates the time-dependent volume change characteristics of a liquid glass gel material. In this figure, the elapsed time is represented by the gel time ratio defined by Eq. (1). Up to the gel time ratio of 2.5, the volume expansion of around 2~3(%) has been observed for both glass and plastic flasks. Then, the volume of a liquid glass gel material has been monotonically decreased.

Particularly in the case of a plastic made flask, the value of the volume shrinkage amounts to around 10(%). In the case of a glass made flask, the amount of volume shrinkage is limited to around 1(%).

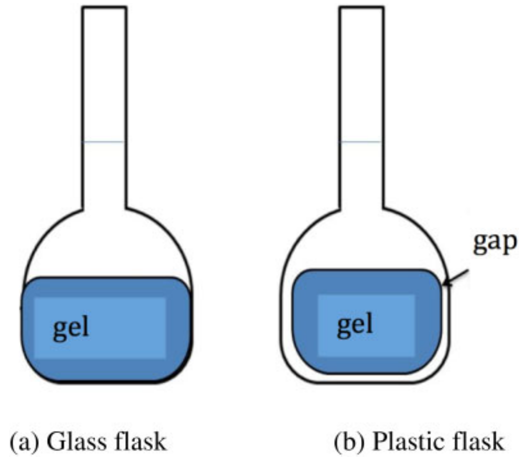

Figure 4. Difference in the geometrical shape of a liquid glass gel due to volume shrinkage.

The reason for the difference of the liquid glass gel material volume shrinkage between the plastic made flask and the glass made flask is assumed to be as follows. Figure 4 indicates the front view of the flask schematically, which includes the liquid glass gel material. This figure compares the difference in the geometrical shape of a liquid glass gel material observed during the volume shrinkage. In the case of plastic made flask, the gap between the liquid glass gel material and the internal face of the plastic made flask has been observed. In the case of glass made flask, a liquid glass gel material has been observed to contact closely to the internal face of a glass made flask. The volume shrinkage of a liquid glass gel material takes place more freely in the case of plastic made flask. Since the chemical component of a glass made flask is the same as that of a liquid glass material, the interface chemical affinity of a liquid glass gel material to the glass made flask is assumed to be much greater than that to the plastic made flask.

3.2 *Micro-focus X-ray CT scanning of chemically improved sand specimen*

Figure 5 demonstrates an example of the digitized image of the specimen cross section of chemically improved sand specimen obtained at around a top of the specimen (h = 10(cm)). In this figure, the internal circular shaped white colored brighter area indicates the chemically improved sand specimen, whose density and the GL value is higher than other area. Outside of this internal white circular area, the external darker area indicates the plastic cylinder, whose density and the GL value is smaller than that of chemically improved sand specimen.

From these digitized images, the digitized cell is assumed to be chemically improved sand, whose GL value is greater than 45000. The total number of cells with GL value >45000 is assumed to represent the cross-sectional area at the specific height of

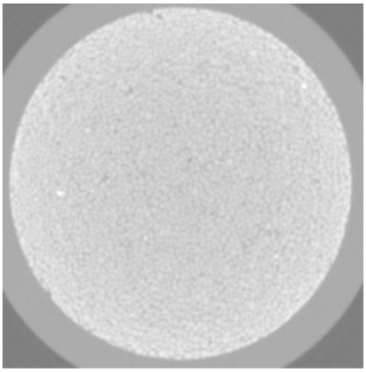

Figure 5. Digitized image of the specimen cross sections of chemically improved sand (h = 10 cm).

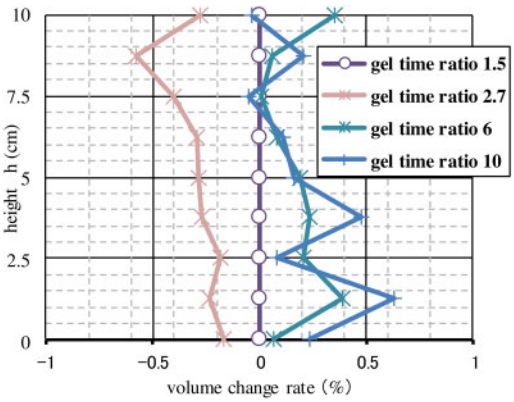

Figure 6. Volume change rate distribution along the specimen height.

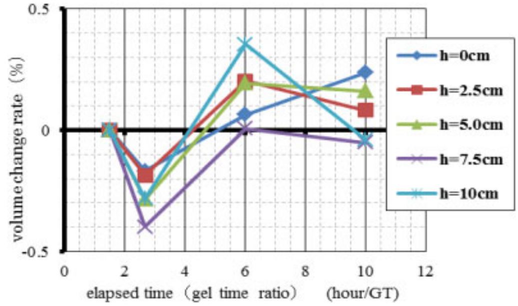

Figure 7. Time dependent volume change variation of chemically improved sand specimen.

the chemically improved sand specimen. The volume change rate of the chemically improved sand with unit thickness can be obtained as follows.

$$\text{rate of volume change} = (a - b) / a \times 100\ (\%) \qquad (2)$$

where, a: the initial number of cells with GL value >45000 at gel time ratio of 1.5 and b: the number of cells observed at the specific time period.

Figure 6 shows the volume change rate distribution along the specimen height. Figure 7 demonstrates the time dependent volume change variation at the specific height of chemically improved sand specimen.

The volume expansion of the chemically improved sand specimen has been observed at around the same time period of gel time ratio 2.5 as observed in the liquid glass gel material. After that time period, both the chemically improved sand specimen and the liquid glass gel material have exhibited the volume shrinkage. Therefore, the volume change characteristics of a liquid glass gel material are assumed to affect the volume change of chemically improved sand specimen. However, the magnitude of volume change of chemically improved sand specimen is smaller than that for a liquid glass gel material and is close to the value for the glass made flask. Since the chemical component of the silica sand is the same as that of the liquid glass, the volume change of a liquid glass gel material is limited due to the chemical affinity at the interface.

4 CONCLUDING REMARKS

1. The great magnitude of volume change of a liquid glass gel material is observed during the chemical gel reaction. Particularly in the case of a plastic made flask, the value of the volume shrinkage amounts to around 10(%). In the case of a glass made flask, the amount of volume shrinkage is limited to around 1(%).
2. The volume change of a liquid glass is assumed to affect the volume change characteristics of chemically improved sand specimen through X-ray CT scanning. However, the magnitude of volume change of chemically improved sand specimen is smaller than that for a liquid glass gel material and is close to the value for the glass made flask. Since the chemical component of the silica sand is the same as that of the liquid glass, the volume change of a liquid glass gel material is limited due to the chemical affinity at the interface.

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