Improved effect of infiltration solidification method of ultra microfine cement on ground with fines

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ABSTRACT

From the experiences gained from the field tests some supplementary methods assisting permeation of cement solutions through silty sand deposits were pursued based on laboratory permeation tests,and one method was found promising.This method employs the injection of water,following infiltration of relatively dense cement solutions which would be terminated by cement particles trapped within micro-scaled silty sand skeletons.In the present study, a series of laboratory three-dimensional permeation tests are conducted to examine this supplementary method in more detail, especially from the viewpoint of improved effectiveness and performance.

Keywords: permeation grouting; microfine cement; infiltration solidification method; three-dimensional permeation test

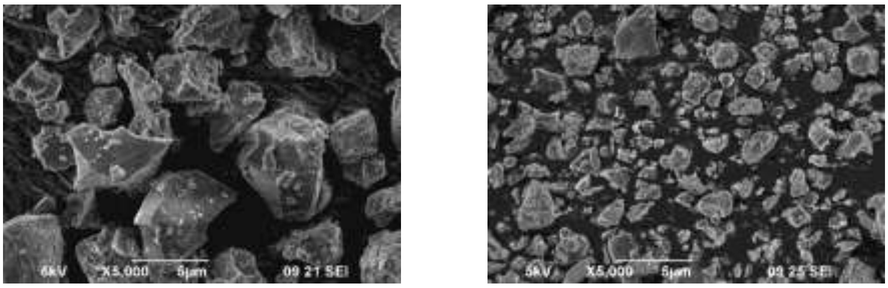
1 INTRODUCTION

In the 2011 Great East Japan Earthquake, damage due to liquefaction was confirmed in a wide range of eastern Japan. Especially damage was great in detached houses that did not take liquefaction countermeasure, about 27,000 cases were damaged. Since the use of ultra microfine cement of the order of 1μm in particle diameter was found excellent in permeability as well as strength development, (e.g. Kanazawa 2012), permeation grouting using this newly developed micro-scaled cement agent has been examined continuously (Hashimoto et al. 2015, 2016, and Wang et al. 2017). From the experiences gained from the field tests conducted at the different two sites, this ground improvement technology was found to work well for relatively clean fine sand deposits, producing sizeable columns of improved soils. However, it may still need some refinement for less permeable silty sand deposits, producing sizeable columns of improved soils. However, it may still need some refinement for less permeable silty sand deposits. In order to overcome the difficulty in applying it to less permeable silty sand deposits, a series of laboratory permeation tests were conducted, and some supplementary methods were examined, which would assist in permeation of cement solutions through silty sands (Hashimoto et al. 2015, and Wang et al. 2017). Based on the results of laboratory permeation tests from results of the authors study, one supplementary method was found promising and worked well. This method employed the injection of water, following infiltration of relatively dense cement solutions which had been terminated by cement particles trapped within micro-scaled silty sand skeletons. In the present study, a series of laboratory three-dimensional permeation tests are conducted to examine this supplementary method in more detail, especially from the viewpoint of cost-effectiveness and performance.

2 MATERIALS

In this study, the authors used ultra microfine cement as grouting materials. In order to improve the permeability of cement-based injection material, it is indispensable to reduce the particle diameter. However, if the particle diameter is simply made smaller than the particle of ultrafine cement (average particle diameter is about 4μm) , the permeability of the cement is not improved. Therefore, development of extremely fine permeable ultra microfine cement (average particle size 1 to 2 μm) which reduced particle size and increased dispersibility of particles was advanced. Figure 1 shows the particle size of ultra microfine cement and microfine cement.

Iwaki silica sand No.7 was used as ground material. Table 1 shows the physical property values of Iwaki silica sand No.7 and Fig. 2. shows the particle size the silica sand has a comparatively large particle size, but it can be seen that it is a material containing a small amount of fine grains.



(a) Microfine cement (b) Ultra microfine cement

Fig.1 . Photomicrograph of grouting materials

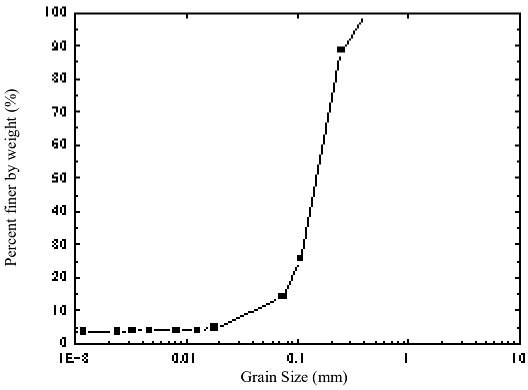


Fig.2. Grain size accumulation curve of Iwaki silica sand No.7

Table 1. Physical characters of Iwaki silica sand No.7

Parameters	Size
Fc (%)	15
ρ_g (g/cm^3)	2.65
e_{max}	1.26
e_{min}	0.713

3 TESTING EQUIPMENT

3.1 Tree-dimensional permeability test

In this study, in order to investigate applicable ground conditions and optimum injection conditions using ultra microfine cement, a simple simulated ground was prepared and an indoor three-dimensional penetration injection test was conducted. Fig. 4 shows a schematic diagram of the test apparatus.

At the time of injection, apply a predetermined pressure from the compressor and operate it constantly so as not to precipitate cement milk with a stirrer. And a flow meter is installed on the way.

3.2 Procedure for making simulated ground

The simulated ground was prepared by the following procedure.

1. Put the water in the pail can about 5 cm high.
2. Scoop the prepared sand with a spoon and saturate with water.
3. Transfer the saturated sample to a pail and slowly drop the sample freely in water with the spoon slowly diagonally.
4. When the input of one layer is completed, compaction is performed to the target height. Also add water so that the water depth is 5 cm.
5. After compacting, disturb the surface of the ground with a spoon.
6. Divided into five layers to prepare specimens.

3.3 Injection method

The injection was carried out as follows.

1. Pneumatic pressure is applied by a compressor, and cement milk being agitated in a high speed shear stirrer is extruded. Pass cement milk through pressure gauge and flow meter and weigh the flow rate over 30 s with a measuring cylinder. In this study, the pressure is adjusted so that the flow rate is about 0.1 L / min.
2. Attach a fine filter to the tip of the injection tube to prevent blockage of the injection tube. Place the injection tube in the middle of the pail. Mark 15 cm from the lower part of the injection pipe so that the outlet of the injection pipe is in the middle of the soil layer and insert it in the ground until the mark disappears.
3. After the pressure adjustment is completed, connect the injection tube to the injection pipe and record the cement milk discharge amount at that time by a flow meter and record it. Record the decrease amount of cement milk and the permeation.

3.4 Experiment condition

In this study, injection was carried out by varying the water cement ratio in order to obtain efficient injection effect on the ground containing fine grains. Moreover, from previous studies, it is shown that improvement efficiency improves by injecting prescribed cement, injecting only water, injecting only water, and injecting cement milk again after injecting predetermined cement in the ground containing fine grains (Hashimoto, et al. 2016). In the present study, the above-mentioned method is referred to as midstream flow. And in this study, we conducted a case of carrying out midstream watering with general penetration injection. Table 2 shows experimental series.

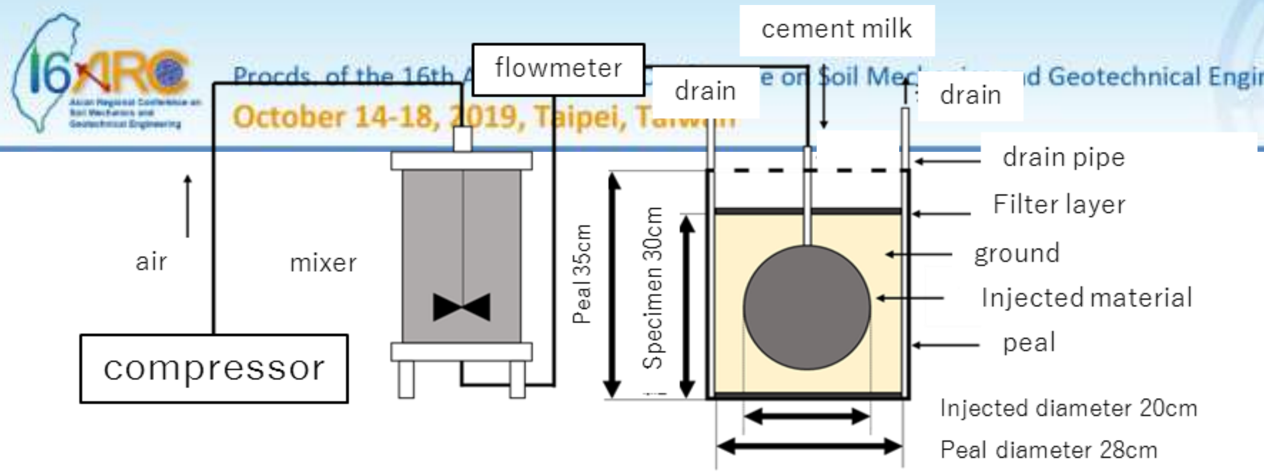


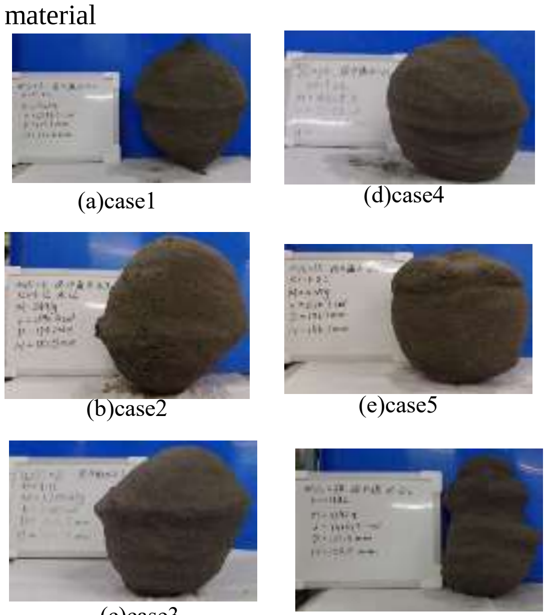
Fig.4. Schematic diagram of indoor three-dimensional penetration injection test apparatus

Table2. Test conditions

Case	W/C	Injection Volume(mL)	Half-way Water filling(mL)
1	8	1941	
2	8	1000	1000
3	8	1000	
4	14	2000	
5	16	1922	
6	20	1672	

4 EXPERIMENTAL RESULT

Figures 5 (a) - (f) show an improved form of indoor three-dimensional penetration injection test conducted in this study. As shown in Fig. 5, most of the improved bodies showed the shape of a sphere. The improved body of case 6 became a columnar improvement rather than a sphere. The reason for this is believed that when injected with cement milk, penetration of the injected material



(a)case1 (d)case4 (b)case2 (e)case5 (c)case3 (f)case6

FIig5. Improvement form

could not be done well. Also, when compared with the improved body with the water cement ratio W / C = 8 and the water cement ratio W / C = 14, 16, the shape of the improved body with water cement ratios of 14, 16 is close to the sphere, The shape was circular, but the improved body with the water cement ratio W / C = 8 had a shape close to the combined cone.

For the mass M and the volume V of the improved body, when the same amount of injection material was injected, the higher the water cement, the smaller the volume V of the obtained improved body, the smaller the mass M accordingly. In the case of water cement 20, the mass and volume of the improved body sharply decreased.

In order to evaluate the improvement effect, evaluation was carried out using the ratio of the design radius to the equivalent radius of the modified sphere (expressed as improvement ratio below). The method of calculating the improvement rate is shown below.

$$\text{improvement ratio} = \frac{R}{R_0},\ \ \mathrm{R} = \sqrt[3]{\frac{3V}{4\pi}},\ \ \mathrm{R} = \sqrt[3]{\frac{3V_0}{4\pi}} \qquad (1)$$

Here, R_0: design radius (cm), V_0: design volume of improved specimen (cm^3), R: sphere equivalent radius of the improved specimen (cm), V: improved volume (cm^3). Fig. 6 shows the improvement rate of each experimental case using equation (1).

The improvement rate of the three cases with water cement w / c = 8 shown in Fig. 6 was found to be the maximum improvement rate of 112.5% in the case of 1 L injected material and 1 L of midstream water injection. Considering the effect of mid-stream water as clogging of the injection material. On the other hand, when plotting the effect of mid-stream water as the diluent of the injection material, the result was 89.4% of the open circle. Compared to the case of injecting 2 L of the injection material, it is conceivable to increase the improvement rate with less injected material due to halfway water flow. In addition, when comparing the results of injecting 1 L of the same water cement ratio 8

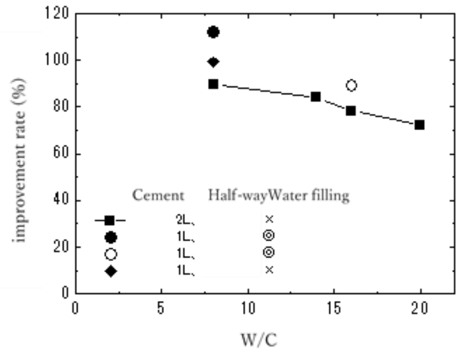


Fig.6. Improvement rate

injection material, the improvement rate increased by about 11% due to the middle water flow. t is conceivable that cement clogging is eliminated by midstream water and the penetration range of the injection material widens.

In the one-dimensional penetration experiment, the penetration and solidification distance was maximized in the case of water cement w / c = 14. However, in the three-dimensional penetration test, when injected with water cement w / c = 14, the improvement rate was about 84%. In the one-dimensional penetration test, the injection material was injected within a predetermined time, and in the three-dimensional penetration test, the injection amount was set and injected at a predetermined flow rate. Because the permeability of water-cement w / c = 14 injection material was improved, it is thought that injected a lot in one dimension and extended the penetration and solidification distance.

In the three-dimensional penetration test, since the injection amount is limited, the injected injection material penetrates and can be condensed and solidified in the range close to the injection port, but it is thought that further injection is necessary because it solidifies further far. Since the phenolphthalein solution used as the assay agent used at this time shows pink color at PH 8.2 to 12, in the experiment case where the water cement ratio w / c = 14, the cement injection material permeated far, but the penetrated injection material there is a possibility that the concentration was low and could not be tested with phenolphthalein solution. If the water cement ratio w / c is even higher than 14, condensation hardly occurs near the injection port, and the injected injected material may not solidify. Therefore, it is considered that as the water cement of the injection material becomes higher, the solidifiable volume becomes smaller, leading to a decrease in the improvement rate.

Currently, the penetration solidification method using cement injection material has not been established yet, and experience values based on the penetration solidification method using chemical liquid are often used at the site. In the permeation solidification method using a chemical solution, in the case where the permeability coefficient k = 1 × 10 -4 or less, even if the injection rate is set to the smallest practically 5 L / min, the possibility of split injection is increased, so that the silt soil layer it is necessary to consider the injection rate when injecting the chemical liquid.

In the field test of the past, site permeability test was carried out, and the permeability coefficient of the injection target layer reached 10 -5 order. Therefore, it is considered that it is necessary to pay sufficient attention to the injection speed when injecting a super fine particle cement injection material having a solidification time equivalent to that of a chemical solution with a so-called gel time in a chemical solution. Iwaki Silica No. 7 used in this experiment has a permeability coefficient of 10 - 3, but tried to inject at a very small injection rate. For the practical smallest 5 L / min, the infusion rate was set to 0.1 L / min in the three-dimensional penetration test. As a result, any improved body realized an improvement rate of 70% or more. In this experiment, an extremely small injection rate was set, but it is considered that an additional case on the injection rate according to the ground condition is necessary for use in actual construction.

5 CONCLUSION

When comparing injection volume 1 L and 2 L, the injection efficiency ratio is low in 2 L case. This is presumed to occur in the ground. In case of halfway water flow, injection efficiency higher than normal injection was confirmed.

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