Development of new chemical grouting method to improve the injection efficiency and its quality

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ABSTRACT

The chemical grouting methods have been widely used as liquefaction mitigation methods. However, the injection loss due to the leak of chemical liquid from the drilling hole and the injection inhibition due to the borehole wall failure have been often observed. In this study, we developed a new chemical grouting method to overcome these problems. A developed chemical grouting method has two unique technical features. One is the packer which is made up of cloth and rubber. The other is a special sealing material which protects the borehole wall during drilling and is fluidized during the chemical injection. From the trial in-situ injection tests results, it was found that 1) the leak of chemical liquid from the drilling hole has not been observed, and 2) a wide range of chemical grouting has been achieved by about 30% of the injection pressure compared to the conventional Double-Pipe Double-Packer method.

Keywords: chemical grouting, liquefaction, Colloidal Silica, mitigation

1 INTRODUCTION

In recent years, large destructive earthquakes, such as the 2008 Wenchuan earthquake in China, the 2010 Chile earthquake, and the 2011 off the Pacific coast of Tohoku Earthquake, have resulted in multiple geoengineering problems, of which liquefaction is particularly prominent (JGS, 2011; Tokimatsu et al., 2012; Yamaguchi et al., 2012; Huang and Yu, 2013). Ground improvement techniques are commonly used to increase the liquefaction resistance of soils and control potential deformation.

The chemical grouting methods have been widely used as liquefaction mitigation methods in the world. Because the chemical grouting method can be used in constrained sites such as quays in service and existing oil tank foundations. Some preliminary explorations of liquefaction mitigation based on nanomaterials have been conducted and proved to improve liquefaction resistance effectively (Kaga and Yonekura, 1991; Oka et al., 2003; Kodaka et al. 2005; Gallagher et al., 2002, 2007a, 2007b; Huang and Wen, 2015).

Grouting methods are classified by the sealing method to ground packer system and sealing grout system. The ground packer system enlarges the packer mounted on the outside of the injection tube with a filler such as cement bentonite and then injects the chemical grouting material from the space reserved in close contact with the borehole wall as shown in Fig. 1. There are problems such as the leak of chemical grouting material by the lack of contact between the borehole wall and ground packer due to the shrinkage of the packer after enlargement and the injection inhibition due to borehole wall failure. The sealing grout system first injects cement bentonite into the drilled borehole and then injects the chemical grouting material from the inlet tube after the sealing material is cured as shown in Fig. 2. There is also a problem such as the high pressure due to small chemical injection source.

In order to overcome these serious problems, a new chemical grouting method by using Colloidal Silica has been developed to improve the injection efficiency and its quality (Ohno et al., 2019). A developed chemical grouting method has two unique technical features. One is the packer which is made up of cloth and rubber. The other is a special sealing material which protects the borehole wall during drilling and is fluidized during the chemical injection. With the introduction of these new technologies, the chemical leakage from the drilling
hole is significantly reduced. The injection pressured can also be reduced since a large liquid chemical penetration area is secured. The cost is reduced by 30% and the construction time is reduced by 70% compared to the conventional method for the improved volume of 9,000 m³. The trial in-situ injection tests were carried out for sandy ground in Saga Prefecture to confirm the effect of the proposed method.

2 NEW CHEMICAL GROUTING METHOD

The developed injection method is shown in Fig. 3 and the construction process is summarized in Fig. 4. The special sealing material is first filled in the drilled borehole to stabilize the borehole wall and then the chemical grouting material is injected from a large injection area. The leak of chemical grouting material is suppressed because the special packer made up of cloth and rubber does not shrink after enlargement. The special sealing material has the property of fluidizing by the reaction with chemical grouting material. Therefore the injection inhibition due to borehole wall failure and injection high pressure are avoided.

2.1 Development of New Ground Packer

The new ground packer is made up of cloth and rubber. The cloth used for the packer shows an adequate performance against high pressure. The rubber used has water impermeable property and high deformation followability. The structure of the packer with injection hole and pipe is shown in Photo 1.

In order to evaluate the shrinkage after the expansion of the packer, the comparative expansion tests on different packers were carried out. Table 1 summarizes the expansion test cases for different packers.
Table 1. Expansion test cases for different packers.

| Packer material                  | Inflating diameter (mm) | Packer length (m) | Filled volume (ℓ) |
|----------------------------------|-------------------------|-------------------|-------------------|
| i) Nylon and Rubber              | φ 120                   | 1.0               | 11                |
| ii) Polypropylene                | φ 140                   | 1.0               | 15                |
| iii) Nylon and Polypropylene     | φ 165                   | 1.0               | 21                |
| iv) Polyester                    | φ 115                   | 1.0               | 10                |

Photo 2. Expanded packers (one week later).

Cement bentonite was filled into the packer and the expanded diameter of the packer was measured just after the filling and a week later. The diameter of the packer developed in this study just after the filling was 135 mm and was kept same for a week. On the other hand, other three packers did not expand to the set diameters due to the leak of filling material. Photo 2 shows the expanded packers for developed packer and that for the other three packers, respectively.

2.2 Development of New Sealing Material

The special sealing material is made by the super absorbent polymer-based stabilizer (Matsuda and Tanaka, 1989), clay and water. Clay particles are added to increase the density of sealing material. The average particle size of the polymer before water absorption is 35 μm. The polymer expands easily in volume by water absorption as shown in Fig. 5. The polymer can expand due to the osmotic pressure action of ion density when water exists. Fig. 6 shows the mud cake (mud film) formation along the drilled borehole wall. The mud cake is formed along the wall promptly and the failure of the borehole wall is prevented just after the sealing material is filled in the borehole.

3 IN-SITU INJECTION TEST

The trial in-situ injection tests were carried out for sandy ground in Saga Prefecture to confirm the effect of the proposed method.

The fill, sandy silt, fine sand and silty sand layers are deposited from the ground surface at the test site. The soil boring log and N-values are shown in Fig. 7. The ground water table is located about GL -2 m. The target improvement strata are fine sand and silty sand layers between GL -3 m and -9 m. There exist organic soils and wooden slices between GL -2 m and -4 m, and...
several thin silty layers observed below GL -6 m. The grain size accumulation curves and physical properties of target layer soils are summarized in Fig. 8 and Table 2.

Twenty improved spheres with the diameter of 2.5 m were constructed by the developed method. Two improved spheres with the diameter of 1.0 m were also constructed by the conventional double-pipe double packer method to investigate the efficiency and quality of the developed method. The conventional method has a small chemical injection area. Therefore, as the fracture failure tends to occur, the permeation distance of liquid is limited to about 50 cm in radius (1.0 m in diameter). On the other hand, the developed method has a large chemical injection area. Therefore, the permeation distance of liquid can be expanded to 2.5 m in diameter. The low strength cement bentonite material was used as the sealing material for the conventional method. The specifications of the sealing materials for the developed method as well as the conventional method are summarized in Table 3.

The plane and cross-sectional views of improved spheres are shown in Fig. 9. The specifications of improvement for both methods are determined based on preliminary site investigation, trial mix tests and injection tests as summarized in Table 4.

The leak of chemical grouting material from the drilled hole was not observed during and after the injection. The diameter of the packer excavated after the injection test was 120 mm as same as that of drilled borehole and in close contact with the borehole wall was observed as shown in Photo 3.

The injection pressure was monitored during the in-situ injection test by changing the injection rate from 1 to 8 ℓ/min. Measuring points are shown in Fig. 9. The relationship between the injection pressure and the

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### Table 3. Specifications of sealing materials.

| Sealing material          | Content (1000ℓ) | Gel time |
|---------------------------|-----------------|----------|
| Special sealing material  |                 |          |
| Caly                      | 0.15 kg         | Uncured  |
| Water                     | 1.98 kg         |          |
| Low strength cement       |                 |          |
| cement bentonite          | 15.0 kg         | 50~90 min|
| Water                     | 94.6 kg         |          |

### Table 4. Specifications of improvement methods.

| Grouting method          | Developed method | Double Packer Method |
|--------------------------|------------------|----------------------|
| Chemical type            | Colloidal silica (8wt% silica) |                   |
| Grouting ratio           | Fine sand layer : 40.5%, Silty sand layer : 36.0% |                   |
| Diameter of improved body| 2.5m             | 1.0m                 |
| Grouting velocity        | 4 ~ 5 liter/min. |                     |
| Target strength          | $q_u \geq 100$ kPa |                     |

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injection rate for different points are shown in Fig. 10. It is found that the injection pressure by the developed method was much lower than that by the conventional double packer method. The injection pressure for the developed method at the injection rate of 8 l/min. was 0.3 MPa. On the other hand, that for the double packer method was 0.8-0.9 MPa. The injection pressure was reduced 62-66% by applying the developed method compared to the conventional double packer method.

The excavated panoramic view of the improved area by the proposed method is shown in Photo 4 and that by the double packer method is shown in Photo 5. The improved body by the developed method was observed to be spherical and satisfy the target improvement diameter 2.5 m. On the other hand, the improved body by the double packer method did not satisfy the target improvement diameter 1.0 m.

In order to confirm the strength of improved body, unconfined compression tests, triaxial compression tests and cyclic triaxial tests were carried out on undisturbed specimens sampled from improved bodies. The unconfined compressive strength distribution with respect to the depth is shown in Fig. 11 and the relationships between cyclic stress ratio and number of cycles are shown in Fig. 12. The average unconfined compressive strength were 70 kPa which is lower than
achieved by about 30% of the injection pressure compared to the conventional Double-Pipe Double-Packer method.

(4) The constructed stabilized sphere has been observed to satisfy the target improvement diameter 2.5 m.

(5) The liquefaction strength ratio of treated soil was confirmed to be three times that of the untreated soils.

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