DEVELOPMENT OF FINE PARTICLE INJECTION METHOD FOR LIQUEFACTION CONTROL

Tokyo City University	Student Member	○Jemy Chua
	Regular Member	Shoma Hara
	Regular Member	Naoaki Suemasa
Kyokado Engineering	Regular Member	Takamitsu Sasaki
Sato Kogyo	Regular Member	Koichi Nagao

1. INTRODUCTION

Countries around the world experiences constant ground movement. Those situated in the pacific ring of fire especially experiences significantly more intense and frequent ground motions. This raises concerns and hazards like soil liquefaction, which continuous to be a concern for sandy-loose ground and high water table level areas.

Numerous countermeasures for soil liquefaction are currently available, but most require large spaces and use less sustainable materials. Permeation grouting is a compact and undestructive method that enables improvement of ground via injecting grout solutions into the ground. Studies show that some industry wastes contain beneficial compounds that can be utilized for many different purposes. And a recent study determined that a particulate injection mixture, made from industry by-products, is sufficient to reinforce the ground to prevent liquefaction. Permeation grouting, however, raises a new problem, that is the ability of pumps to efficiently administer the solution into the ground. This paper aims to assess the performance of the mono pump in injecting fine particulate solution or suspension grout in the soil strata.

2. EXPERIMENTAL METHOD

The particulate injection material used in this study is a mix made with blast furnace slag powder (BS), gypsum ($CaSO_4$), and magnesium oxide (MgO) having a ratio of 9:1:1 by weight, respectively. All material used in the mixture was in its dry or powder form. The mix has been confirmed in a previous study which when mixed properly with the sample, can sufficiently meet the soil strength requirement for soil liquefaction mitigation.

In this experiment, one-dimensional injection experiment using a long specimen was conducted using the above formulation. This is to investigate the quantity and distribution of fine particles in the pore spaces and the distance of which the particles can penetrate when injected. A cylindrical specimen 5cm in diameter and 100cm in height was made with silica sand no. 6 with a relative density of 60%. The samples were compacted with a mallet every 10cm to ensure homogeneity. As shown in Fig. 2, the sample was between 2 filter layers separated by 4 mesh screens. After the preparation, the sample was saturated with de-aired water. Upon complete saturation, the particulate injection mixture was prepared at 2% powder/weight. To avoid premature hardening and reaction, the mixture was injected within 10 minutes of preparation. A constant injection rate of 1.67mL/s were set for the pump. A total of 3 pumping stages and 2 intervals were implemented for the pumping tests. The specimens were demolded around a week after and stored until a total of 28 days of curing time was achieved before the samples were subjected to uniaxial compression tests.

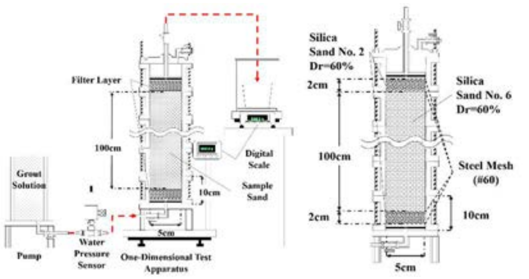

Fig. 1 & 2. Grouting Setup and Sample Preparation.

Fig. 3 & 4. Mono Pump and Piston Pump.

3. RESULTS AND DISCUSSION

3.1. Particulate Mixture Injection

To assess the pumping performance of the mono pump, it is compared to a more common pump which is the piston pump. For an even test, similar conditions were set to both the piston and mono pump. In Fig. 5, the injection pressure and volume vs time of the piston pump can be seen. Note that the interval time was removed for viewing ease. The first injection lasted approximately 2500s having a maximum injection pressure of around 50kPa. The second part rose to a pressure of around 280kPa, which was the max allowable pressure of the pump. With this, the commencement of the third injection was terminated. Since it was stopped midway due to excessive pressure, the total injected volume reached approximately 8800mL only, which was about 9 times the pore volume. From Fig. 6, it can be said that the solution penetrated up to about 70cm, judging from the discoloration. However, some samples broke from demolding, indicating that the mixture injected was insufficient.

Keywords: Permeation grouting, suspension grout, mono pump, liquefaction control

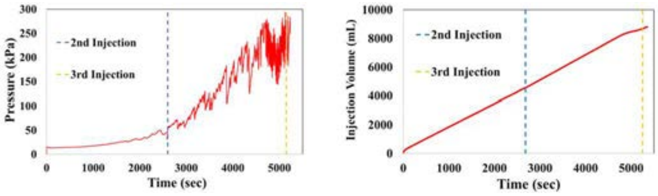

Fig. 5. Pressure and Volume vs Time Graph of Piston Pump.

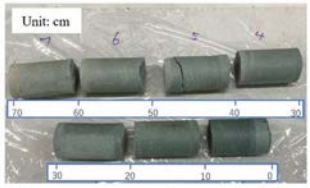

Fig. 6. Piston Pump Samples.

In the case of the mono pump, the duration of the first and second injection were about 3000s, as shown in Fig. 7. As opposed to the piston pump, the injection pressures were only about 36kPa and 177kPa for the first and second injection, respectively. Since the mono pump can handle greater pressures, the third injection was able to commence and reached 400kPa. While the pump was still able to handle the injection pressure, something like a crack was noticed so the injection was terminated. The volume injected was also more than the piston pump but behaved similarly at the latter stages of injection, wherein the flow started to decrease. This may be due to settling and clogging of the fine particulates. The total volume injected reached about 15,000mL, or more than 16 times the pore volume. Using the coloration as guide again, the solution penetrated up to around 90cm, as shown in Fig. 8. These two tests showcase that mono pump can handle higher pressures and that it can administer more grout solution into the ground. One of the reasons that the mono pump performed better is in the agitation of the grout mixture. The fine particulate in the grout settles quickly and so proper agitation is crucial. While the piston pump is also equipped with a stirrer at the bottom, it was still not as effective in agitating the grout mixture as with the mono pump.

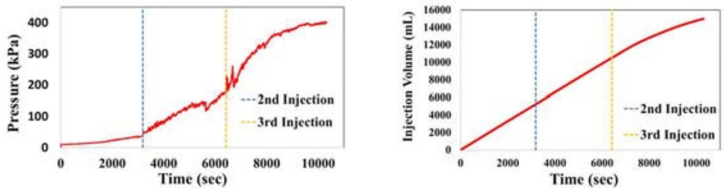

Fig. 7. Pressure and Volume vs Time Graph of Mono Pump.

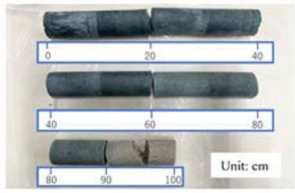

Fig. 8. Mono Pump Samples.

3.2. Uniaxial Compression Test

Since the strength improvement is dependent on the overall concentration and distribution of the grout, uniaxial compressive tests of the mono pump samples were done to assess the strength and the results were tallied in Fig. 9. As expected, the farther the sample from the point of injection, the less particulate was able to infiltrate the soil and thus results in less developed strength. Some samples like 3rd and 5th sample experienced increased strength than their precursor, this may be due to the clogging of some parts resulting to uneven distribution of the suspension solution. From Fig. 10., the concentration of the grout can also be visually confirmed, which shows that the parts nearer the injection port contains the highest concentration.

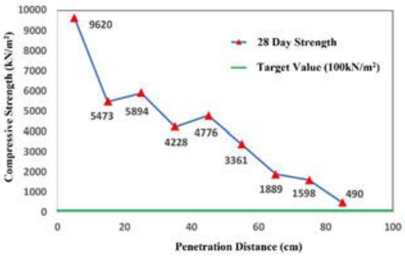

Fig. 9. Compressive Strength of Mono Pump Samples.

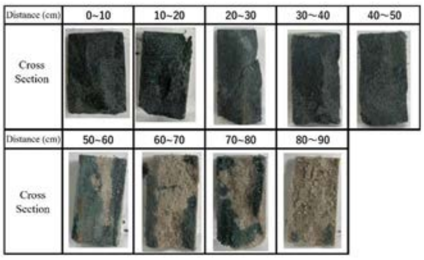

Fig. 10. Cross section of Mono Pump Samples.

4. CONCLUSION

The type of pump used in permeation grouting has a significant effect on the overall volume of grout injected. Mono pump provides superior agitation and is capable of injecting at higher pressures, resulting to an increase in the total volume of grout injected. While higher pressure is proven to be desirable as this minimizes clogging on the injection point and increase penetration distance, a limit must still be specified to avoid excessive pressures that may be detrimental to the soil strata. From both tests, it can be determined that the developed strength is dependent on the distribution and penetration distance, that the farther it is from the point of entry the less concentrated the grout becomes. In the future, the study aims to understand more about the clogging phenomenon and explore possible means of enhancing the flow of the grout by altering some variables like flow and pressure and tackling other types of pumps.

REFERENCES

田代 伶, 微粒子注入工法の実用化に向けた注入材の検討及び浸透特性の把握,東京都市大学大学院修士論文,2 章 p.9-29 20222)

堺孝司，高炉セメントを用いたコンクリート表面の青色斑点，開発土木研究所月報. (457) https://dl.ndl.go.jp/

山崎浩之，善功企，河村健輔：溶液型薬液注入工法の液状化対策への適用，港湾空港技術研究所報告 Vol.41，No.2 pp.119-151, 2002