Measuring System of Improved Diameter in High Pressure Injection Mixing Method

Masatoshi UNO
Civil Engineering Technology Division, Shimizu Corporation, Tokyo, Japan
Email: uno@shimz.co.jp
Shiho SAIMEN
Kanto Branch, Shimizu Corporation, Saitama, Japan
Email: saimen@shimz.co.jp
Juichi ISE
Civil Engineering Technology Division, Shimizu Corporation, Tokyo, Japan
Email: j.ise@shimz.co.jp

ABSTRACT

The high-pressure injection agitation method is a construction method to improve the soil by creating an improved columnar body by injecting with a jet of grout. Confirmation of such improved diameter is usually performed by check boring after the ground improvement, which takes time and becomes one of the reasons of the delay to deal with poor construction and troubles. We have developed a high pressure injection measuring system that can physically confirm the improved diameter by extruding a feeler into the improved body during construction. By use of this system, it is possible to deal with the insufficient diameter of completed improved body, which is to immediately recover its quality during the construction.

Key words: *measuring system, improved diameter, high-pressure injection, measuring rod tube*

1. Introduction

As for the improved diameter of the high-pressure injection stirring method, it is common to check boring after construction and confirm the molded shape. However, it takes time with this method to confirm the improved diameter, and the response is also delayed when the shortage of improved diameter is detected.

Therefore, we have developed a system that can immediately measure the improved diameter after completion of construction to confirm the molded diameter immediately after construction, which leads to assure better quality and shorten the work period.

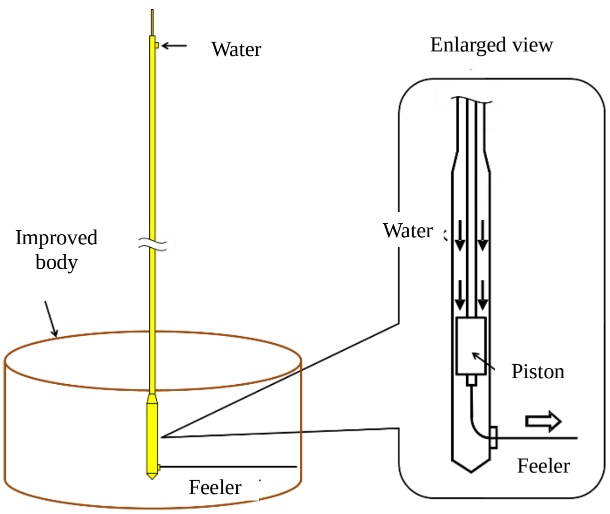

Fig. 1 The outline of the measurement system outline

Fig. 1 shows the outline of the measuring system and **Fig. 2** shows the photo of the measuring rod tube.

In this paper, we report the results of mock-up field experiments and verification test, which were conducted to verify the validity of this system.

2. Outline of measuring system method

The overall view of the measuring system is shown in **Fig. 3.** In this system, a measuring rod tube is inserted into an unconsolidated improved body immediately after the injection, a feeler is pushed out by water pressure from the tip part of the feeler-device, and the distance from the rod to the ground is measured by the feeler contacting to the ground. The improved diameter is confirmed by multidirectional measurement with changing the direction of the feeler. The measurement data is stored on the cloud server via Internet. **Fig. 4** shows the water pressure measuring system used for the measurement. This system injects a water from the water pump into the measuring rod tube, extrudes the feeler into the unconsolidated improved body, and measures the water supply pressure at the same time. Soft ground improved by injection is softer than the original ground until solidification progresses, allowing feeler to penetrate with less resistance. However, when going out of the area of injection and entering the base ground, resistance increases. When the feeler contact with a harder material than the unconsolidated improved body (which is the ground), the water injecting pressure increases so that it detects the end of the improved body.

3. Mock-up Field Experiment

3.1. Outline of experiment

Fig. 5 shows the schematic view of the mock-up experiment. A mock improved body was prepared for this experiment. There were two purposes in this test; firstly to check whether this system is capable to measure the accurate distance by using a sheathing board which is set at a known distance; secondly to know the limitation of the applicable (vane shear) strength of the improved body or maximum elapsed time for this system, by measuring the vane shear strength at each elapsed time.

3.2. Method

Three different samples of viscous soil, sandy soil, and sandy soil mixed with gravel were used to prepare the mock improved body. A sheathing board was installed into this body at a distance of 1.75 m from a measuring rod tube, as an alternative to the improved end, assumed to be the ground. Then, we confirmed a change in water injecting pressure at the position of the sheathing board and the measuring error in the distance measuring sensor.

Fig. 2 The measuring rod tube

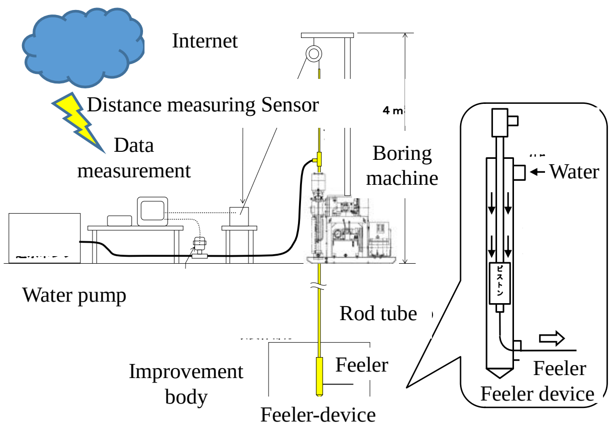

Fig. 3 The overall view of the measurement system

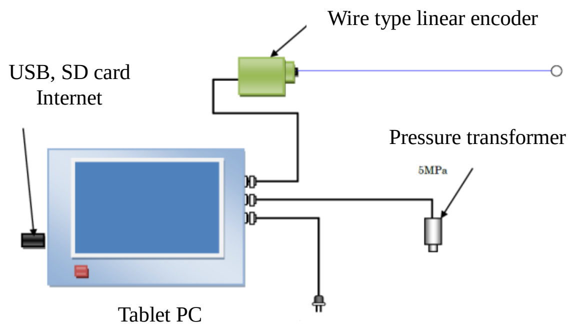

Fig. 4 The water injecting pressure measuring system

In addition, we investigated the elapsed time and the vane shear strength after mixing the mock body, and the accuracy of each value in the measuring device at that time, and obtained the limitation to measure each value.

Regarding the distance from the rod to the board, it was set at 1.75 m as a radius of improved diameter assumed to be 3.5 m.

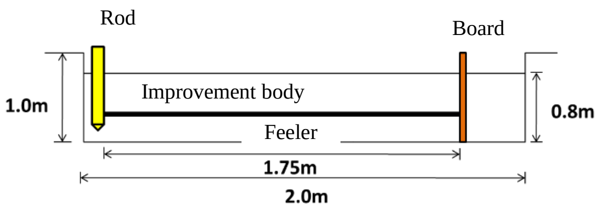

Fig. 5 The schematic view of the mock-up experiment

3.3. Materials and mixture

The applied materials and mixtures are shown in **Table 1**. Each sample soil from A to C shown in the table was mixed with a solidification slurry (W / C = 100%) at a volume ratio of 1:1 to prepare a mock improved body. **Fig. 6** shows the distribution of particle sizes in the sample soil.

Table 1. The mixtures in each material

Type	soil:A	soil:B	soil:C
Soil	clay	sand	Mixed sand with gravel
Kibushi clay	7	5	5
Silica powder	3	2	2
Kashima Silica Sand 3B	-	3	2
Kashima gravel 2-8 mm	-	-	1
Water (water content ratio)	30% added	20% added	18% added
wet density (g/cm3)*	1.70	1.79	1.83

*The wet density indicates the density after mixing sample soil and grout slurry (W/C = 100%) at 1: 1 by volume.

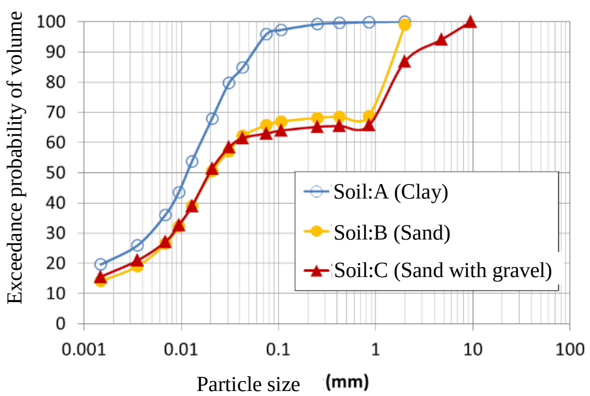

Fig. 6 The distribution of particle sizes in the sample soil

3.4. Results

Fig. 7 shows the experimental situation. **Fig. 8** shows the measured results of water pressure at an elapsed time of 120 min after mixing the mock body by each sample soil. A large response was observed in the water injecting pressure at 1.75 m from the rod, where the board was installed in every sample body. Therefore, it was demonstrated that the diameter of the improved body can be confirmed by this system.

Fig. 9 shows the measured results of water injecting pressure at the limitation of the measuring devices. The injecting pressure reacted at the point of 1.75 m from the rod which was the installation position of the board, but the pressure still kept rising thereafter. In this state, it was confirmed that the feeler folded over and damaged in the rod tube. This similar tendency was found in all the sample soils, and it was assumed that the feeler could not move within the improved body when it contacted the sheathing board and also the mock body exceeded a certain shear strength. Therefore, in this experiment, the vane shear strength at this time was judged as the measuring limitation of the measuring devices.

Fig. 10 shows the growth of the vane shear strength of mock improve body using Clay (soil: A), Sand (soil: B), Mixed sand with gravel (soil: C), and the measured limitation of the measuring device is also shown.

Fig. 7 The experimental situation

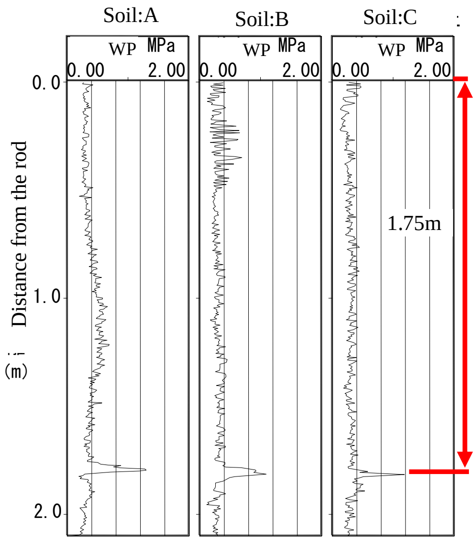

Fig. 8 Water injecting pressure at 120min.

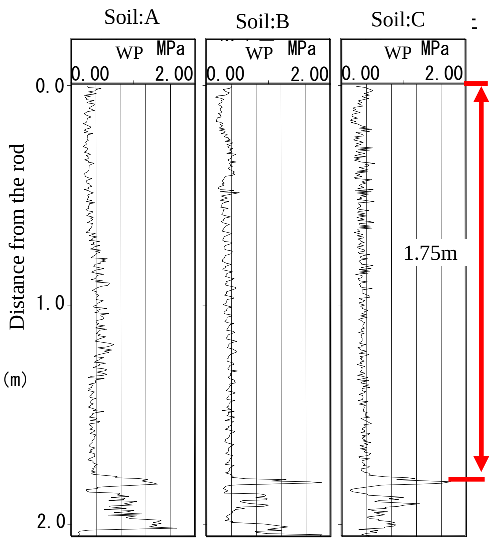

Fig. 9 Water injecting pressure as the limitation

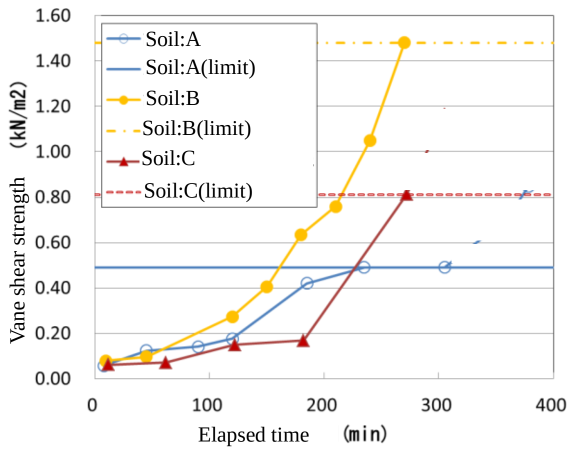

Fig. 10 The growth of the vane shear strength of mock improve body in each type of soil

The measured limitations were 0.49 kN/m^2 for the body with clay soil, 1.48 kN/m^2 for that with sand soil, and 0.81 kN/m^2 for that with mixed sand with gravel., The measurement limit values of the simulated advanced body varied depending on the type of soil sample, however it was found that rough measurement was possible in the condition that the measurement limit value was less than 0.4 kN/m^2.

The measured limitation of the elapsed time was merely a reference value, considering that the air temperature at the time of this experiment was around 10 degrees and might not be equal to the underground temperature in actual construction. Therefore, it is a future task to grasp the limitation of the elapsed time.

3.5. Summary

By using this developed measuring system, it was discovered to be possible to measure the improved diameter after completion of construction when the vane shear strength of the unconsolidated improved body was less than 0.4 kN/m^2, which seemed to be the measuring limitation, varying somewhat depending on the type of the soil to be improved.

4. On-site test

4.1. Objectives

The on-site test was carried out at the site of construction of the Hanko Shorenjigawa-nishi Open Cut Tunnel. High-pressure injection stirring construction method was planned at the lower part of the bridge of Route 43. The Specification with an improved diameter of 2.3 m was designed at that site. We confirmed the improved diameter by this measuring system to verify its effectiveness and validity during the trial construction.

4.2. Outline of on-site test

(1) Construction:
Shorenjigawa-nishi Open Cut Tunnel site
(2) On-site test position:
Within the area of the 24 BL test site (**Fig. 11**)
(3) On-site test period:
December 8 to 10, 2010
Improvement drilling: June 9, 2011
(4) Improved Specifications:
Table 2 shows the improved specifications.

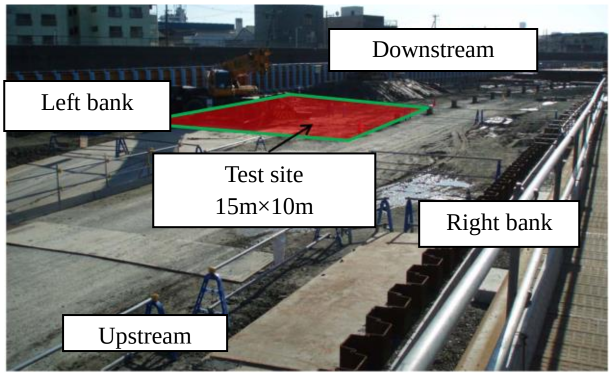

Fig. 11 24 BL test site for onsite test

Table 2. The improved specifications

Design improvement diameter	φ2.3m
Design improvement strength	q_{uf}=770kN/m^2
Viscosity	Cu=20～30kN/m^2 less than (OP-9.0m～-10.5m)
Improved depth range	GL-5.6m～-7.1m (1.5m)

4.3. Results

After the construction of the trial improvement body, measurements by this system were made at the ground improvement place.

Table 3 and **Fig. 12** show the measured results. According to the Table 3, there are differences in measured absolute values on the upstream side and the downstream side. The diameter of the improved body from the upper side to the downstream side is 2.28 m, while that from the left side to the right side is 2.47 m. It was confirmed by this system that the former diameter was slightly lower than the value of the planned 2.3 m but could be concluded that both were almost created as planned.

The difference in measured absolute values between the upstream side and the downstream side depends on the fact that the position of the measurement rod installation biased somewhat toward the upstream side. In this system, however, even in such situation, it was also confirmed that the improved diameter could be grasped by inverting the measuring direction

Table 3. Measured results

	Measurement (m)		Ave. (m)	Diameter (m)	Plan (m)
	1st	2nd			
Up	0.915	0.905	0.91	2.28	2.3
Down	1.395	1.350	1.37		
Left	1.130	1.120	1.13	2.47	
Right	1.345	1.325	1.34		

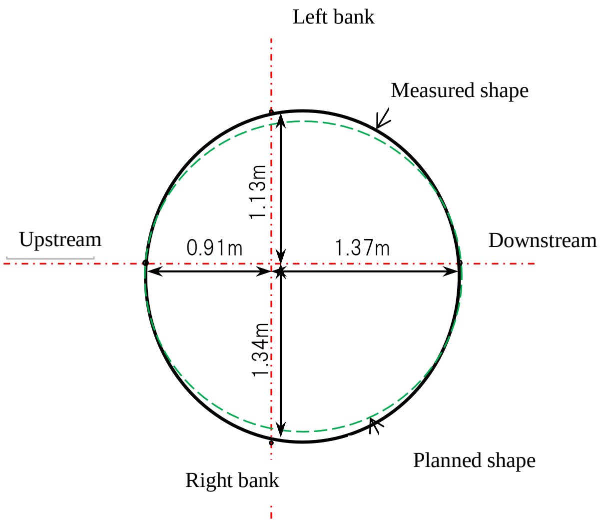

Fig. 12 The monitoring result

4.4. Confirmation by drilling improved body

The drilling was carried out after curing of the refinement. **Fig. 13** shows the improved body after digging. The measured result was 2.4 m in the diameter of the refiner and 2.38 m in the upstream and downstream direction. The average diameter of the measured results was 2.39 m.

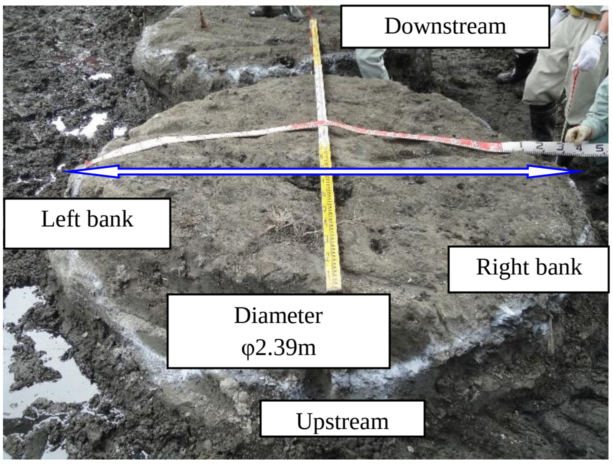

Fig. 13 Improved diameter verified by digging improved body

Table 4. Comparison of measured results by digging

	Diameter evaluation result		
	Up-Down direction.	Right-Left direction	Average diameter
plan	2.3m or more	2.3m or more	2.3m or more
Measurement system	2.28m	2.47m	2.38m
Actual measurement	2.38m	2.40m	2.39m

4.5. Summary

Table 4 shows the comparison between the result of the measuring system of the improved diameter and that measured after actually being dug out.

The difference between the result by measuring system and by the excavation was 10 cm on the upstream side and 7 cm on the right side left side. The difference were range of error. From this result, it was discovered that measurement by this system could be performed with high accuracy.

5. Conclusion

From the results of mock-up field experiments and on-site test, it was found that the improved diameter of the high pressure injection machine could be measured with high accuracy immediately after construction by the measuring system of the improved diameter. However, the measurement becomes impossible when the improved body exceeds a certain hardness due to the measuring limitation in the actual construction. It is necessary to take measures such as mixing retarders in the slurry in order to adjust the time to the measuring limitation by also taking the measuring time into consideration.

In the future, the remaining task to accumulate achievements by actual construction and to modify this system is hoped to be accomplished.

6. Acknowledgements

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References

Seimen, S., Ise, J., Nozu, T., Abe, M. 2012. Development of an improved diameter measurement system in high pressure injection stirring method. Summary of the 67th Annual Academic Lecture Meeting of the Japan Society of Civil Engineers Conference, VI-486. (in Japanese)

Shimizu Corporation, Raito Industry Co., Ltd. 2012. Improved diameter measurement system. Construction Planning, No. 752, pp. 86. (in Japanese)

Construction Industry Research Committee. 1998. Revised Groundwater Handbook, pp. 120.