A CASE STUDY ON THE CONSTRUCTION AND FIELD LOADING TEST OF WAVEFORM MICROPILE

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ABSTRACT

For improving the behavior of the conventional micropile, a new-concept waveform micropile was suggested. The waveform micropile has a modified construction process, and the waveform shape on the pile shaft is formed through jet grouting. The waveform micropile provides additional shaft resistance due to the shape of the waveform grout body, which was confirmed through a series of experiments and numerical analysis. In this study, 96 waveform micropiles were applied to a bridge abutment construction site, and their field applicability was evaluated based on the construction process and loading test. The paper discusses the details of the design and installation of the waveform micropile, including the loading test results.

INTRODUCTION

Even if the micropile has a small diameter (less than 300 mm), it brings relatively high frictional resistance provided through the high-strength steel bar and the surrounding grout. Micropiles have been widely used to support different types of static and seismic loadings. They are also known as a solution for construction sites located in congested areas. The use of micropiles, however, leads to higher construction costs compared to the use of the other existing foundation types as it requires the use of steel reinforcement. Also, micropiles provide much less tip resistance than skin friction due to their small diameter. Han et al. (2013) suggested the use of a modified conventional micropile named “waveform micropile” for improving not only the cost efficiency but also for extending its application to other areas. As the name implies, the construction process of waveform micropile requires the formation of a grout body with a waveform

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shape through jet grouting. Figure 1 shows a comparison of the conventional micropile and the waveform micropile. The configuration of the waveform micropile can be described with the pile shaft (D_2) and the shear key (D_1) diameters. As grouting instead of the conventional casing is employed in the installation of the waveform micropile, better contact between the waveform grout and the ground was expected to be achieved, and the overall bearing capacity was ultimately expected to increase. Jang & Han (2015) and Jang & Han (2016) examined the constructability and behavior of the waveform micropile through experimental studies. The field and laboratory test results showed that the waveform micropile can be installed under in-situ conditions, and that its bearing capacity significant increases compared to the conventional micropile. The waveform micropile system was applied to a bridge construction site as an abutment foundation. This paper introduces the construction project, from its overview to the detailed issue in the geotechnical aspect related to the construction of the waveform micropile.

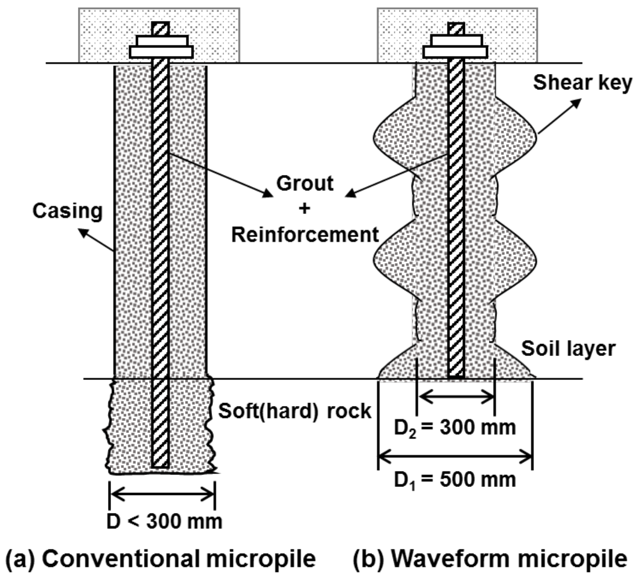


Figure 1. Comparison of micropile configurations

SITE INVESTIGATION AND PILE DESIGN

The waveform micropile system was constructed for the abutment foundation located at the highway expansion site in the City of Gyeonggi, South Korea. The steel pipe pile was originally assigned for use at the site, but it was changed to waveform micropile to obtain constructability at a limited working space near the abutment. A total of 96 waveform micropiles were planned to be installed at location groups A and

B based on the SPT values and loading conditions as shown in Table 1 and Figure 2. To ensure stability against lateral loads such as the live load, and the earth pressure, the upper 2 m of the pile was installed with a steel casing. First, the vertical bearing capacity of the waveform micropiles were calculated using Eq. 1 suggested by the FHWA (Federal Highway Administration) Micropile Reference Manual (FHWA, 2005).

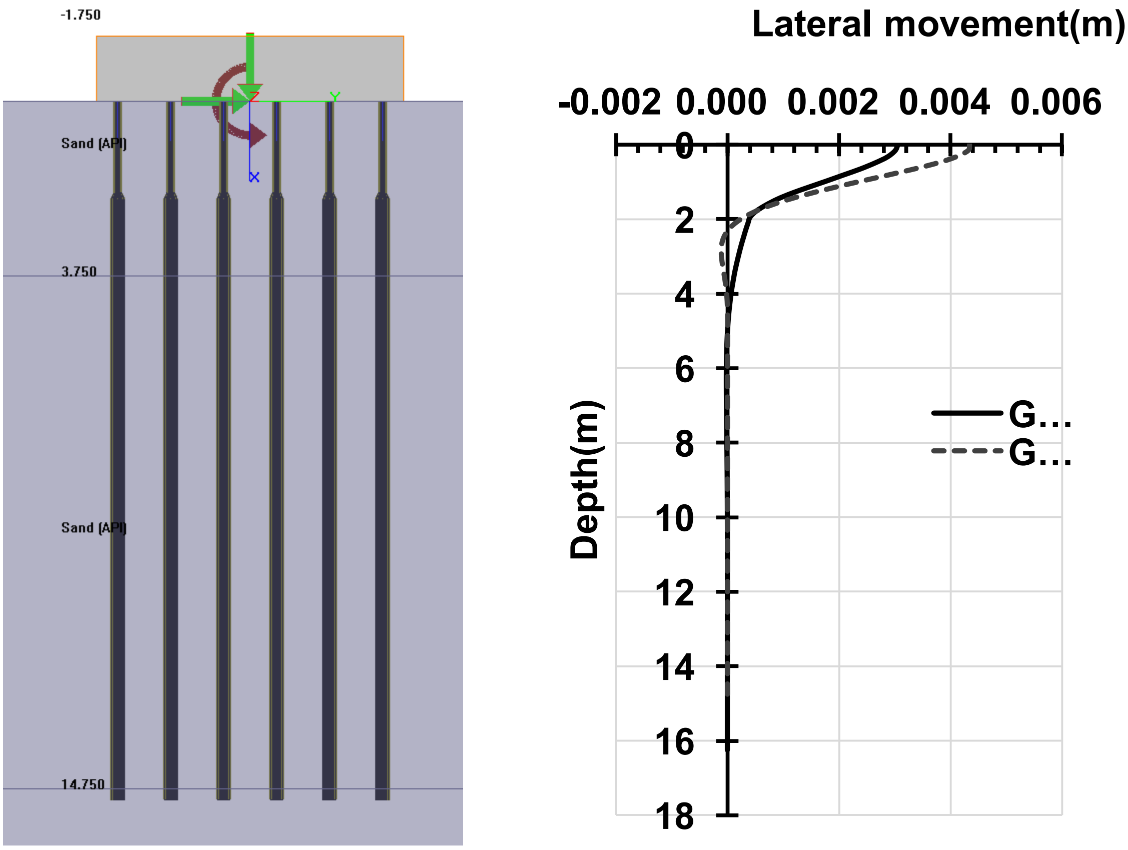
$$Q_a = \alpha_{bond} \cdot D \cdot L / \mathrm{F.S.} \tag{1}$$

Where, α_{bond} is the grout-to-ground ultimate bond strength (kPa), *D* is the diameter of the pile, *L* is the bond length of the pile, and *F.S.* is the factor of safety. The diameters D_1 and D_2 of the waveform micropiles were 500 and 300 mm, respectively. However, for bearing capacity calculation, we assumed a waveform micropile diameter of 300 mm (D_2) in order to obtain a conservative value. The α_{bond} values were selected from the FHWA manual considering the grouting method and the ground characteristics. The allowable design capacity Q_a of the waveform micropiles was determined using an F.S. of 2.5, as shown in Table 1. The results showed that the waveform micropile system was enough to resist the vertical force (P) of 400 kN with the allowable design capacity of about 800.2 kN for group A and 733.2 kN for group B. Then the lateral stability of the pile was evaluated using the software Group v7.0. The analysis result showed that the lateral displacement of piles in groups A and B was very small as shown in Figure 2, which indicated that the waveform micropiles were capable of supporting the lateral force 60 kN for the project site. For the numerical analysis, we also assumed a simplified geometry with a single diameter of 300 mm which corresponds to D_2 of the waveform micropile as shown in Figure 2(a).

Table 1. Design bearing capacity calculation results

Location	**Depth (m)**	**Soil type**	α_{bond} **(kN/m^2)**	**Q_a (kN)**
Group A	2.00	Silty sand with gravel	Casing	
	1.70	Silty sand with gravel	240.0	153.7
	11.0	Silty sand	130.0	539.1
	1.50	Silty sand	190.0	107.4
	Design bearing capacity Q_a/pile			800.2
Group B	2.00	Silty sand with gravel	Casing	
	1.50	Silty sand with	240.0	135.7

		gravel		
	10.0	Silty sand	130.0	490.1
	1.50	Silty sand	190.0	107.4
	Design bearing capacity Q_a/pile			733.2



(a) Pile group modeling (b) Lateral movement-depth response

Figure 2. Lateral movement analysis of waveform micropiles

Figure 3 shows the construction details of the micropiles. A total of 96 piles were installed and 48 piles (24 piles x two locations) at each location for groups A and B, respectively. The layout for each location was 4 x 6, and the minimum center-to-center pile spacing was 2.5 times the shaft diameter D_2 (300 mm) of waveform micropile.

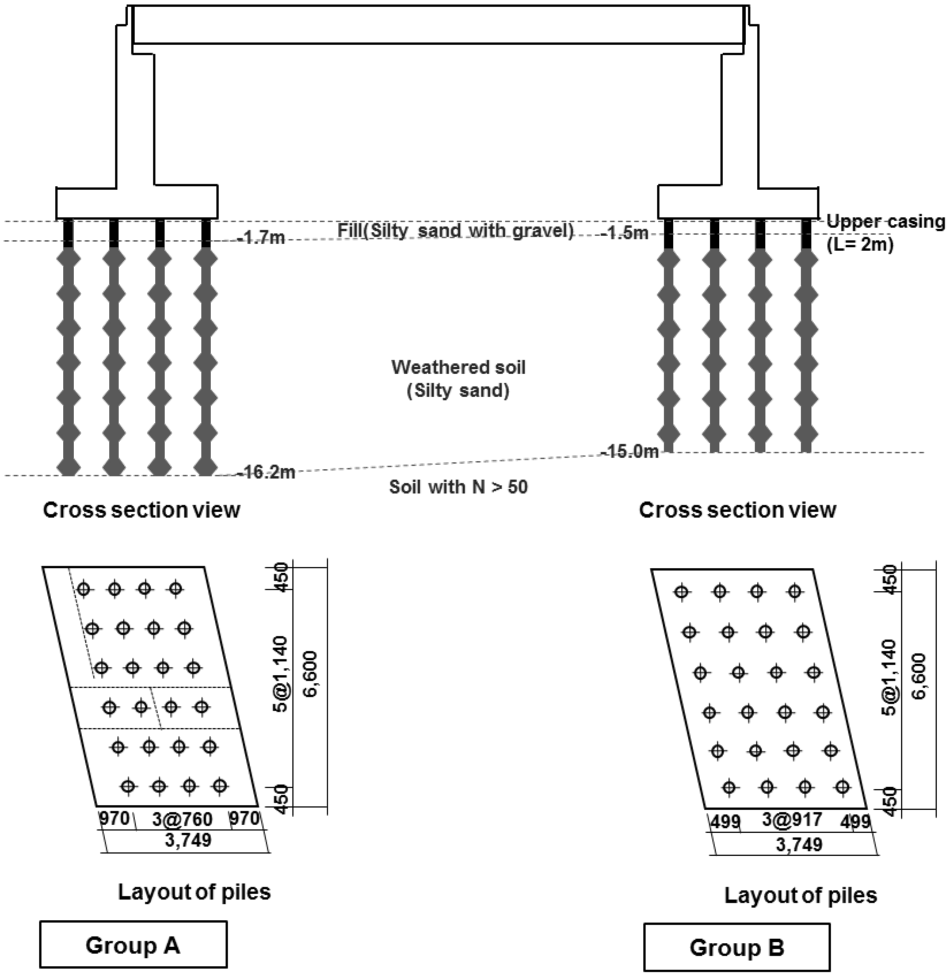


Figure 3. Description of the pile arrangement and layout for the construction

INSTALLATION OF THE WAVEFORM MICROPILE

The general construction process of the waveform micropile consists of the following four steps, as presented in Figure 4.

Step (a) - Drilling the pile shaft up to the required depth using a waterjet

Step (b) - Forming a waveform grout body by enlarging the pile shaft using the jet grouting method

Step (c) - Placing steel reinforcement in the waveform grouting

Step (d) - Completion of construction

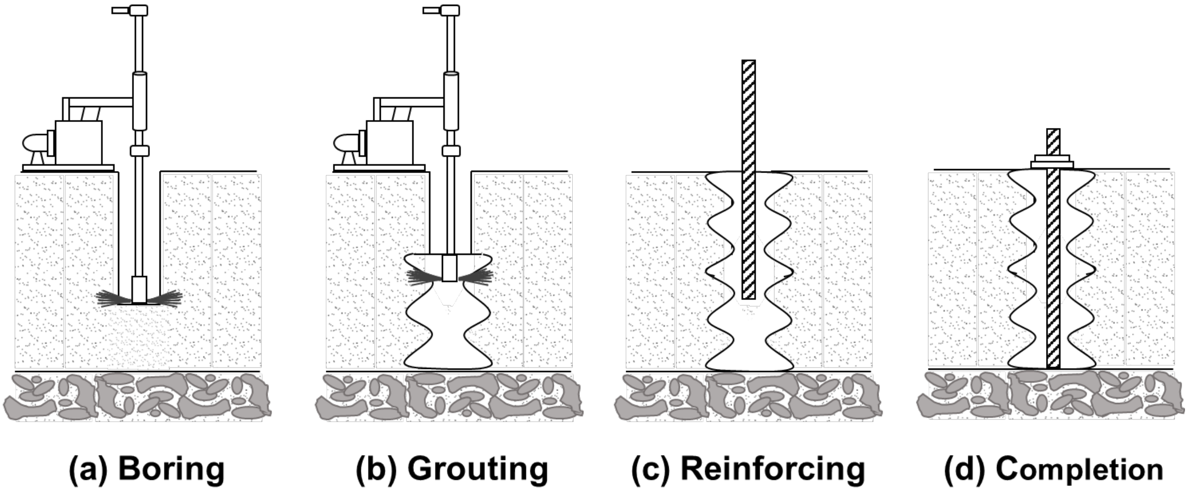


Figure 4. Construction process of the waveform micropile

The installation works of the 96 waveform micropiles in this study were performed with the construction steps. For the shear key formation of waveform grouting, the grouting injection time was controlled for enlarging the pile shaft to 300 and 500 mm, while the grouting pressure was fixed at about 400 bar. Figure 5 shows the construction steps of the waveform micropile: site preparation, pre-installation of the upper casing, drilling, and jet grouting work.

(a) Site preparation

(b) Inserting the casing (L=2 m)

(c) Boring the ground with a waterjet

(d) Jet grouting

(e) Reinforcing with a steel bar

(f) Completion

Figure 5. View of the field construction of the waveform micropile

LOADING TESTS AND RESULTS

The loading tests were conducted to evaluate the stability of the waveform micropiles under the vertical and lateral forces. Figure 6 presents the test facilities for the pull-out and lateral loading tests. Two pull-out loading tests and two lateral loading tests were carried out on a single waveform micropile, which was randomly selected from groups A and B. According to the FHWA manual, the maximum load that can be applied for the proof test for evaluating the vertical pile's stability is about 160% of the design bearing capacity. Therefore, the pull-out loading tests were conducted until the test load reached about 640 kN, following the loading test standards of ASTM D1143-81 (2007). The lateral loading tests were also performed by loading the pile with a 60 kN increasing force. Both tests were very carefully continued while monitoring the movement of the pile head to prevent unexpected disturbance to the piles and the adjacent ground. During the tests, the load-movement response of the pile was measured using displacement transducers (LVDTs).

(a) Pull-out loading test (b) Lateral loading test

Figure 6. Pictures of the loading test of the waveform micropile

Figure 7 and 8 present the test results of the load-displacement curves determined through the pull-out and lateral loading tests, respectively. As the tests were carried out to prove that the piles were properly installed and stabilized, the ultimate bearing capacity could not be estimated. Thus, only the displacement at the design load was verified according to the tolerable movement criteria of abutment foundation as summarized in Table 2. As shown in Figure 7, the pull-out loading test was finished at about 160% (640 kN) of the design load 400 kN. The vertical displacement at the design load was 4.3 mm for group A and 2.2 mm for group B, and therefore it was considered relatively small compared with the allowable vertical movement of 40 mm and 50 mm as presented in Table 2. This indicates that the bearing capacity of the piles are sufficient to resist the loading conditions of abutment. The verification test results for the laterally loaded pile are shown in Figure 8. As explained above, the test load was applied with a step-by-step increasing rate while monitoring the displacement of the pile head to prevent any effect on the pile stability. The final loading step was 130% (76 kN) of the lateral force, and the displacements were 7.9 and 0.5 mm, corresponding to the 60 kN lateral force. The lateral displacements at both locations were small, but the reason why group A showed much smaller displacements seems to be related to the difference in N values between the two groups. Compared to the allowable lateral movement of 38 mm and 25 mm shown in Table 2, it was found that the waveform micropile provides enough stability against lateral loadings (Bozozuk, 1978; Moulton et al., 1985).

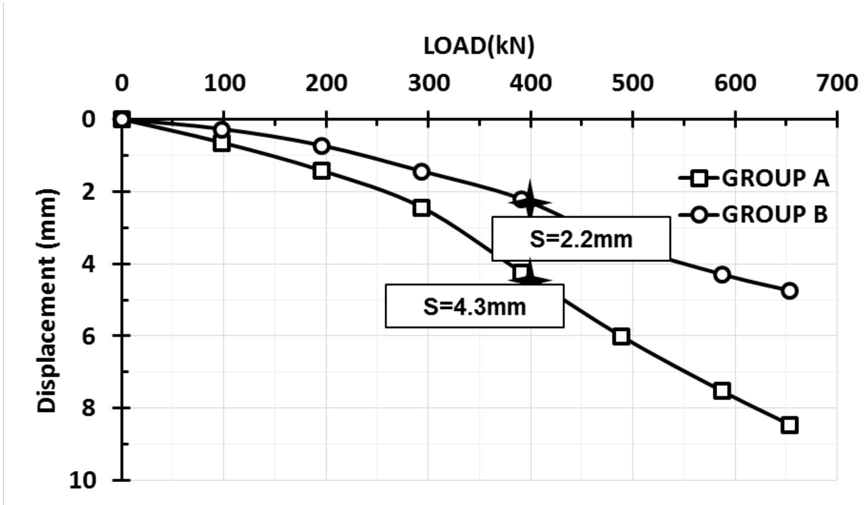


Figure 7. Pull-out loading-settlement relationship for the waveform micropiles

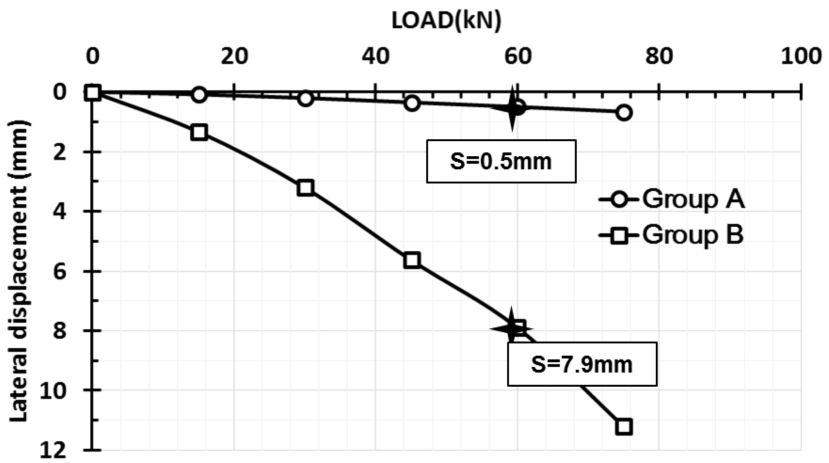


Figure 8. Lateral loading-settlement relationship for the waveform micropiles

Table 2. Tolerable movement ranges for abutment foundation

Criteria	Reference
Vertical movement 40mm Horizontal movement 38mm	Moulton et al., 1985
Vertical movement 50mm Horizontal movement 25mm	Bozozuk, 1978

CONCLUSION

This paper described the field application of the newly developed waveform micropile, which combined the concept of the conventional micropile with the jet grouting method to enhance the pile's performance. From the installation of 96 waveform micropiles for supporting the abutment structure, it was confirmed that the use of the waveform micropile system is an efficient construction method in terms of constructability and construction speed. Loading tests were carried out to verify the vertical and lateral behaviors of the waveform micropile, and the test results demonstrated that the field application was successfully performed.

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