FIELD VERIFICATION STUDY FOR MICROPILE LOAD CAPACITY

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ABSTRACT

In this paper, two sets of pile load tests performed for verifying a recently proposed micropiling method. The results of the pile load tests are presented in term of the point of load-bearing capacity and load-transfer characteristics. Generally, micropiles consist of thread bar or hollow-steel-pipe together with surrounding cement grout. Due to its small diameter, they obtain their bearing capacity from frictional resistance between grout and ground rather than tip resistance. In this study, two sets of field load test results were analyzed for two different types of micropiles subjected to compressive loading. The two different micropiles have the conditions; (1) thread bar reinforcement with gravity grouting and (2) hollow-steel-pipe reinforcement with pressure grouting. The first set of micropiles was installed to the depth of soil layer to understand the effect of the pressure grouting technique on frictional load-transfer mechanism. The second set of micropiles was installed to the depth of rock layer to verify the amount of bearing capacity for the proposed method. The analysis results for the first set indicate that the unit frictional resistance at soil layer along pile length was more evenly distributed for pressure-grouting micropiles than that of the gravity grouted micropiles. The bearing capacity results obtained from the second set show the pressure-grouting micropile mobilizes more bearing resistance than that of gravity-grouting micropile.

Keywords: Micropile, grouting, field construction, load bearing capacity

1. INTRODUCTION

For the purpose of seismic retrofitting for structural foundations, micropiling method has provided a good solution attributed to its constructability for limited working area. It is a general practice in Korea that micropiles are constructed with gravity grouting method and designed for frictional resistance between bearing-rock and structural grout (Choi et al. 2008a; Choi et al. 2009). Correspondingly, the frictional resistance in upper-soil layer is generally ignored in the design procedure. This fact might cause socket length of the pile to be extended.

In order to provide better frictional resistance in upper soil layer, a pressurized grout micropiling method was proposed as a part of building renovation research project. The key idea of the proposed method is to wrap woven geotextile outside of hollow-steel pipe and to obtain better contact between ground and pile-structure by the aid of pressurized grouting technique in upper soil layer (Choi et al. 2008b; 2008c). The additional procedure of pressurized grouting for micropile construction makes higher frictional resistance/adherence to be developed and better quality pile to be built in the ground.

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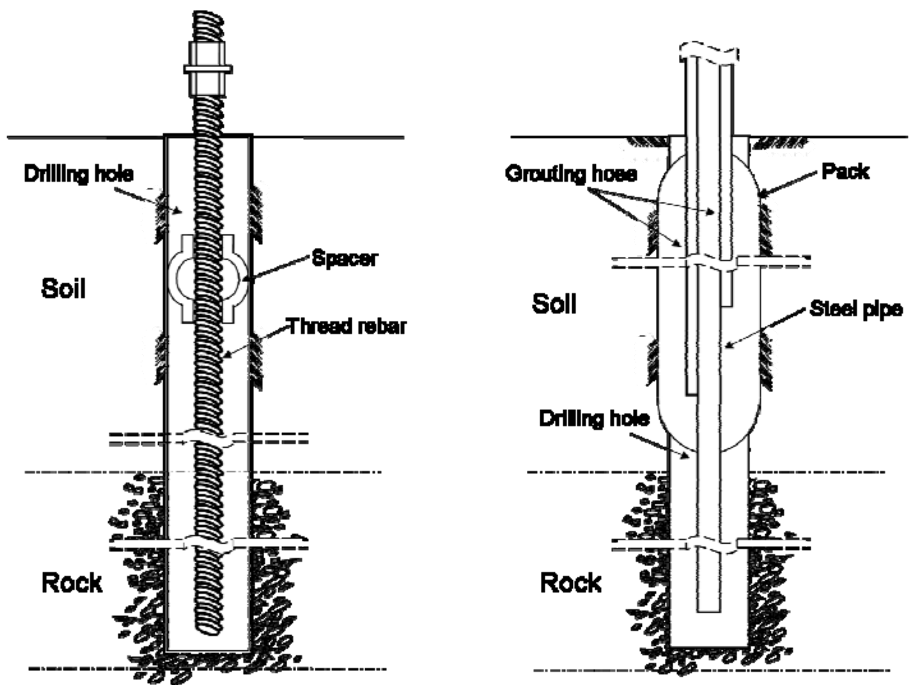
This paper presents two verification studies for the proposed micropiling method. The first set of field load tests were performed for two type of micropiles (conventional and proposed types) which were installed to the depth of soil layer to understand the effect of such pressure grouting technique on frictional load-transfer mechanism. The second set of micropiles was installed to the depth of rock layer to verify the amount of increased bearing capacity for the proposed method.

2. FIELD INSTALLATION AND LOAD TEST SETUP

2.1 Conceptual description of micropiles

According to the FHWA(2005) classification, a conventional micropile studied herein is classified as Type-A and the proposed micropile is similar to Type-C. Hereafter, they are referred to as TAM(Type-A-Micropile) and GPM(Geotextile-Pack-Micropile), respectively. Figure 1 shows TAM and GPM micropile schematics installed for this study.



(a)TAM (conventional type) (b)GPM(pressure grouting type)

Figure 1. Schematics of two type of micropiles

Figure 1(a) shows TAM schematic in which a steel casing is inserted to ground for the purpose of preventing the hole-collapse. The steel casing is pulled out during gravity grouting process. Design bearing capacity for this type is mainly obtained from skin friction between the ground and the pile perimeter in the rock-socketting zone, while the frictional resistance in the upper soil layer is ignored with the assumption that steel-casing recovery might cause the loss of grout in the upper layer.

Figure 1(b) presents the GPM schematic in which the pressure-grouting technique in the upper soil layer is involved during construction process. The pressure-grouting process enables to maximize the frictional resistance between the loose soil and the pile structure via wrapping the pile perimeter with woven geotextile and preventing the loss of grout. Grout is injected to the hole and inside of the pack in two steps; i) gravity grouting and ii) pressurized grouting. The fact of pressure-grouting and preventing the loss of grout leads to the tight contact between pile perimeter and the surrounding loose soil layer. As a result, higher frictional resistance is mobilized at the interface when it is subject to axial loading condition. The proposed technique might require more complex process for grouting, but the increased frictional capacity of pile is worth of doing additional work.

2.2 Field construction

Two different types of micropiles, TAM and GPM were installed in two different fields to compare frictional resistance mechanism and load-bearing capacity. Installation details are described in this section.

Figure 2 presents the reinforcing rebar used for TAM (refer to figure 2a) and the reinforcing hollow steel pipe used for GPM (refer to figure 2b), respectively. The threaded-rebar was OD of 50mm, yield strength of 500 MPa, and unit length of 3.0m. The hollow steel-pipe reinforcement has OD of 82.5mm, thickness of 11mm, and yield strength of 482 MPa.

(a) Thread bar for TAM (b)Hollow steel pipe for GPM

Figure 2. Reinforcement types used for field installation

The cement used for grout is Portland-cement (Korea Standard L 520-1) manufactured by Hanil-Cement in Korea. One percent of additive was used to increase workability of grouting material and water-cement ratio (w/c) of 45% was used.

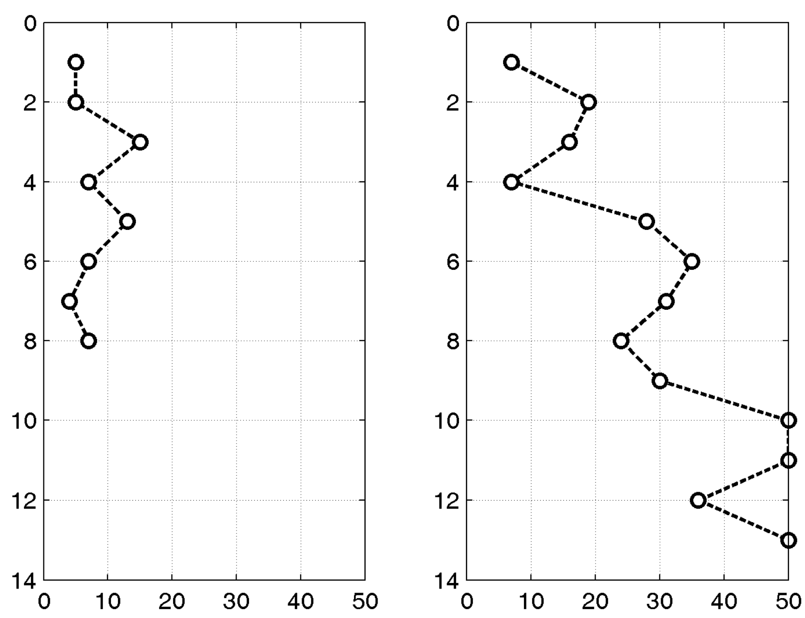
The GPM installation requires several on-site work procedures. They are, i) D=10mm punching holes with 90° for one cross section with 70cm interval along steel-pipe length for pressure grouting, ii) taping the holes for preventing reverse flowing from outside of the steel pipe to inside during gravity grouting, iii) wrapping geotextile-type pack outside of the pipe.

Bored holes were drilled to the depth of 8.0m for Set 1 and 14.5m for Set 2 using water-rotary casing drill together with a down-hole-hammer. The dimensions of the drill casing was ID=155mm and OD=180mm. TAM micropile was constructed with the following procedures; 1) boring hole with a steel casing, 2) inserting thread-rebar reinforcement, and 3) injecting grout with gravity in the manner of bottom-up together with removal of the steel casing. GPM micropile construction procedures consist of 1) boring hole with a steel casing, 2) gravity grouting-filling hole, 3) inserting reinforcement, 4) removing the steel casing, and 5) pressure grouting $(\Delta p = 0.1 \sim 0.2MPa)$.

Table 1 presents a summary of the ground conditions for the two sites corresponding to pile installation depths. As shown, the upper soil layers for two sites consists of similar geologic materials. Figure 3 presents the SPT-N values for the two sites obtained from site investigations.

Table 1. Ground conditions for two test sites

Test Set	Location	Pile length	Ground description along piling depth
Set 1	Seoul, Korea	8m	0~4.5m : Fill, Loose silty sand 4.5~8.0m : Native deposit, Loose silty sand
Set 2	Jeonju, Korea	14.5m	0~2.8m : Fill, Loose silty sand and gravel 2.8~10.6m : Native deposit, Medium to dense silty sand and gravel 10.6~13.0m : Weathered layer, Very dense silty sand 13.0~14.5m : Rock, RQD 81%



(a) N values for site 1 (b) N values for site 2

Figure 3. SPT N values for two sites

2.3 Load-test method

For field load tests, the verification test method dictated in FHWA (2005) was employed for the loading schedule which includes cyclic loading and unloading process. Equipment and load testing methods were set up to meet ASTM D1143. To minimize the intervention between piles and anchors during running the test, a distance of at least 2m was spaced.

3. FIELD LOAD TEST RESULT

3.1 Test Set 1

The distributions of the axial load along the depth of the micropiles for TAM and GPM are presented in Figures 4 and 5, respectively. Transferred loads were obtained using ten strain gauges spaced at 70cm along the pile length. Non-linear tangential elastic constants corresponding to Fellenius(2001) were used to evaluate the force from the measured strain. For all cases, the piles tend to behave as conventional friction-type-pile in which the load transfer into the ground before reaching the yielding load is evenly distributed along pile length. It is shown that 50%~70% of the yielding load was supported by the friction resistance down to the depth of 6m. The applied load reached to almost zero at the end of pile. It means that end bearing capacity did not develop at the pile tips.

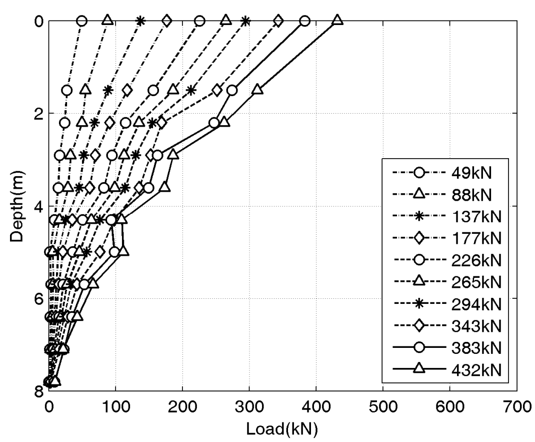


Figure 4. Load transfer behavior for TAM

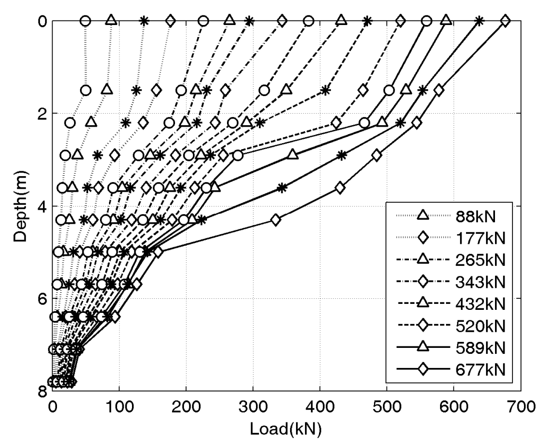


Figure 5. Load transfer behavior for GPM

For TAM, the load transfer near the ground surface varied considerably. Non-uniform pile diameter or non-uniform adhesion between pile and ground might be a main cause for this phenomenon. The load transfer mechanism of TAM is compared to the load transfer of GPM shown in Figure 5 in that the applied load tends to be evenly distributed along the depth. In the case of GPM, idealized load distribution was observed for all load steps in that the curves are overall straight up to the depth of 3~5m where ground condition changes from soft to stiff. This fact reveals that GPM distributes the applied loads evenly well along the pile depth. Most stiff soil condition at the depth of 3m (highest SPT value was observed during site investigation as shown in Figure 3(a)) might cause more load to be transferred in this zone.

It is interesting to note that the overall shape of load transfer curves for the two different micropiles are comparable to each other. Closer look to Figures 4 and 5 indicates that the overall shape of GPM curve appears to be downside concave which contrasts with upside concave for TAM. This observation suggests that the GPM micropile exhibits superior stiffness and load carrying performance in the soil layers at this site.

According to FHWA(2005), ultimate load bearing capacity for Test Set 1 was obtained when the settlement rate, *dS*, meets Eq. (1).

$$dS = 0.15 mm / kN \tag{1}$$

Figure 6 shows a direct comparison of load-displacement curves for both TAM and GPM types subjected to axial compressive loading condition. The trend line of load-displacement curve was obtained via curve-fitting with exponential function given in Eq. (2).

$$S = Ae^{\lambda L} \tag{2}$$

where *S* and *L* are settlement and load data set, respectively, and *A* and *λ* are coefficients to minimize the fitting errors.

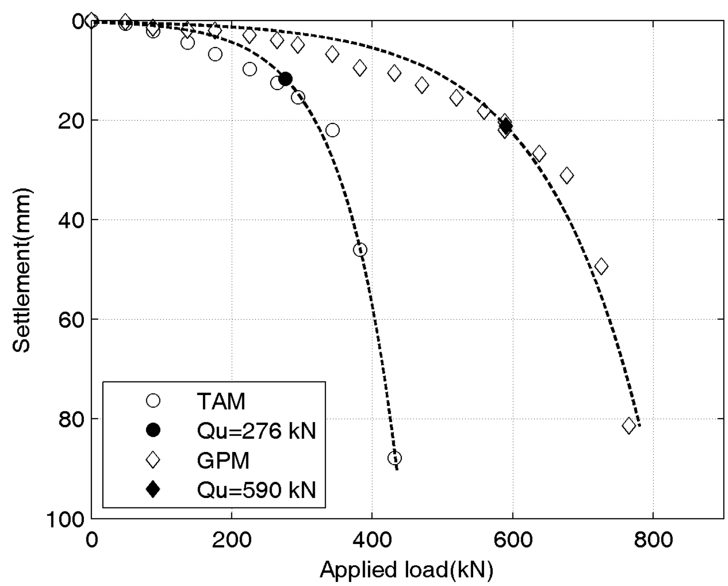


Figure 6. Load vs. displacement curves for the two types of micropiles.

The ultimate loads (when $dS = 0.15 mm / kN$) were obtained at 276kN and 590kN for TAM and the GPM, respectively. Direct comparison of the ultimate bearing load denotes that the ultimate load of GPM is more than 200% of that of TAM. This higher bearing capacity might be attributed to the pressurized grouting method and tight bonding quality between grout and surrounding ground. Based on the analysis of the bearing capacity and the load transfer mechanism, it is concluded that GPM pile provides higher bearing capacity with good load transfer characteristics along the entire pile length.

In order to observe the frictional resistance along micropile length, unit skin friction was estimated at the ultimate loading stage. Figure 7 shows the analysis results of the unit bond strength distribution along the depth. It is clearly identified that the characteristics of axial load distribution along the depth depends on the pile type. In case of GPM, denoted with diamond marker, the unit bond strength developed highly along full length of the pile. However, the unit bond strength for TAM, marked as circle, is relatively much less than that of GPM. This higher friction for GPM is attributed to the pressurized grouting procedure during installation. The pressure grouting procedure enabled the grout-soil bonds to be increased and the lateral confinement of the pile to be greater. Based on these observations, it can be inferred that GPM provides better micropiling technique than TAM.

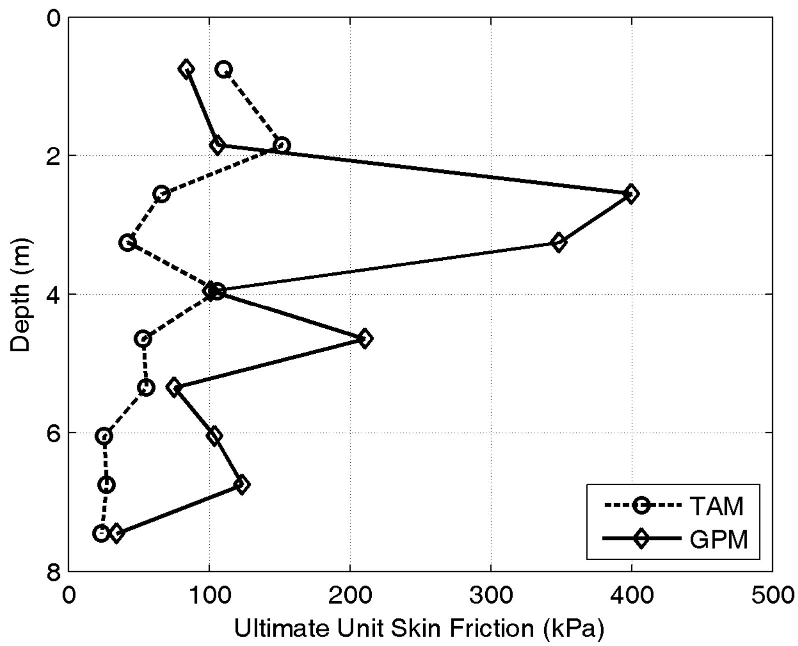


Figure 7. Unit skin friction along depth when ultimate compressive loading was applied

Now, the ultimate skin friction value for GPM was directly compared to SPT value at the site. Because friction value and SPT-N are different type of properties, N-value at 5m and skin friction of GPM at 4.7m are used as scaling factor as

$$Factor = \frac{N_{at\ 5m}}{f_{at\ 4.7m}} \tag{3}$$

The unit skin friction of GPM in Figure 7 is multiplied with the factor of Eq. (3) and plotted in Figure 8 together with SPT value from the site investigation. It appears that the ultimate skin friction for GPM, *i.e.,* pressure-grouting micropile, developed with similar trends to soil strength. In other word, GPM micropile makes the surrounding soil strength to be fully activated upon loading. Of course, TAM result was compared to SPT value in the same manner, but they were not comparative.

4. FIELD LOAD TEST RESULT – TEST SET 2

As described in Section 2.2, field load tests for Set 2 were performed for GPM and TAM. Test piles were installed to bearing rock layer. It is more realistic condition for field application. From the surface, the ground condition consists of 2.8 m of sand fill, 7.8m of silt and sand deposit, 2.4m of weathered soil, and soft-hard rock layer.

Ultimate load-bearing capacity was estimated when the head of micropiles settled 25.4mm(1 inch). It was attempted to obtain ultimate bearing load using Eqs. (1) and (2), but the conditions of $\dot{S} = 0.15mm/kN$ subjected to exponential curve fitting do not locate within the meaningful range of loads. The ultimate bearing capacities based on $S = 25.4mm$ criteria for GPM and TAM were 1417kN and 1188kN, respectively, as shown in Figure 9. Because the tested piles were highly slender enough to buckle at the top, the pile heads were protected using D=50cm cap. Nevertheless, pile bucking at shallow zone occurred for both piles. Based on the test results, GPM provides 120% higher bearing capacity comparing to that of TAM. This higher resistance might be attributed to the additional friction developed in the soil layer as discussed for Set 1 test results.

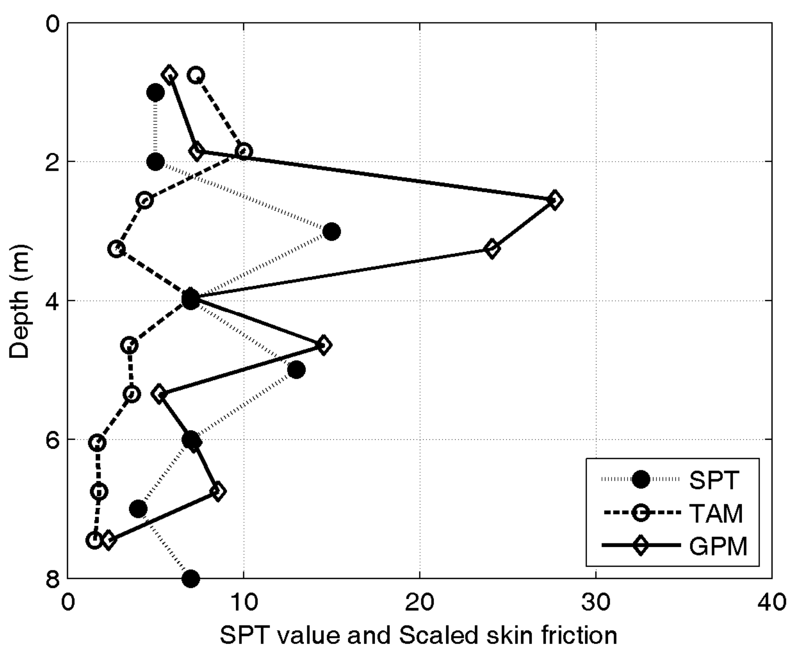


Figure 8. SPT value and scaled skin friction at ultimate loading stage.

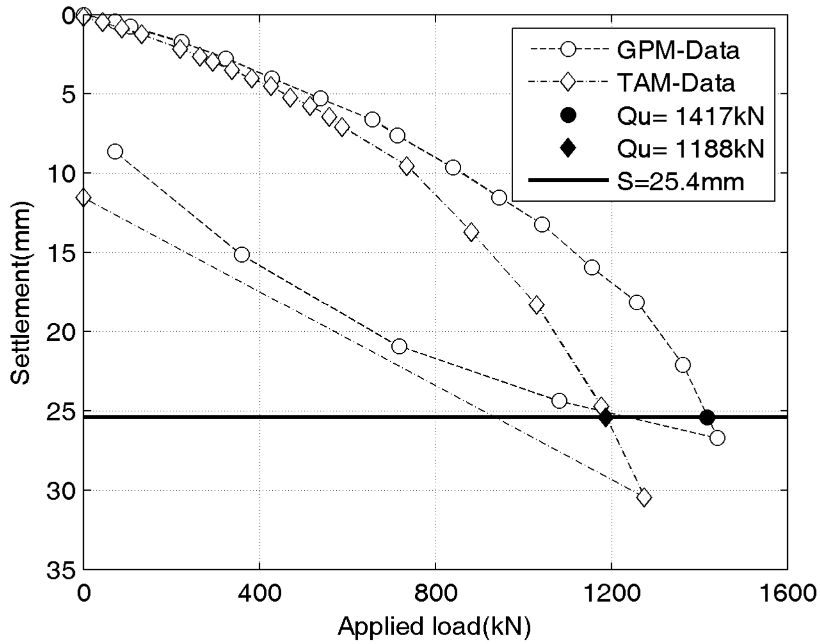


Figure 9. Load vs. Settlement results for Test Set 2

4. CONCLUSION

Two sets of field verification studies were performed to evaluate the load bearing characteristics of two different types of micropiles. The two types are gravity grouting micropile (TAM) and pressure grouting micropile (GPM). One set of load-tests verified that the frictional characteristics at soil layer can be improved by aid of pressurized grouting method. The other set of field load tests showed GPM provides higher ultimate load bearing capacity when its tip is installed to the rock layer. Based on the two sets of field load tests, the followings can be concluded:

- The pressure grouting micropile provides better load transfer mechanism as it makes surrounding soil strength to be fully mobilized upon axial loading. This fact may be attributed to the better mutual bond between the grout and the surrounding ground due to the step-by step pressurized construction for micropile.
- The unit skin friction developed in pressure grouting micropile was scaled to be compared with SPT value. The result implied that the developed ultimate skin friction varies in a similar trend to soil strength. Based on this observation, it is concluded that the pressure grouting micropile is an appropriate micropile construction method.
- Based on field load test results of Set 2, the pressure grouting method (GPM) provides at least 20% higher ultimate bearing capacity than that of the gravity grouting method (TAM), in case the pile tips are installed to bearing rock layer.

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