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A COMPARATIVE STUDY ON THE RESISTANCES OF BUCKET FOUNDATION IN SAND WITH DIFFERENT INSTALLATION METHODS

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ABSTRACT: Model tests have been performed to investigate the vertical, horizontal and cone tip resistances of bucket foundations embedded in sand with different installation methods; suction force by pump and jacking force by actuator. Micro-cone penetrometer was used to evaluate the variation of the effective stress inside pile after model pile installation. As a result, in vertical pull-out test, the pile installed jacking force method shows 3 times larger resistance than installed suction force method. In horizontal pull-out test, the ultimate horizontal capacity and the slope of load-displacement curve for the model pile installed by suction force were decreased by 22% and 40% respectively compared to the pile installed by jacking force. In cone penetration test, inside cone tip resistance of the pile installed by suction force shows about 40% smaller than that installed by jacking force. It is because the effective stress was reduced due to upward seepage of inner pile in sand by suction force. Therefore, we can see that the effect of installation method on bucket foundation has to be considered to investigate the behavior of it experimentally.

Keywords: Bucket Foundation, Model Test, Vertical Resistance, Horizontal Resistance, CPT

1. INTRODUCTION

The suction installation of bucket foundation into sandy soils induces seepage flow from outside to inside of bucket foundation; therefore, the downward seepage near the outside of bucket pie increases the effective stress while the upward seepage inside the bucket pile decreases the effective stress [1] (Fig. 1).

The seepage effect helps bucket pile installation by reducing the penetration resistance during the installation, on the other hand, reduces the horizontal and vertical capacity of bucket foundation from the significant disturbance at the tip of the bucket foundation. Due to the complexity and difficulty in quantification of the suction installation effects (including seepage effect), many previous researchers generally neglect the effect of suction installation in their experiments. Therefore, in this study, the effects of suction installation on the resistance of bucket pile have been examined.

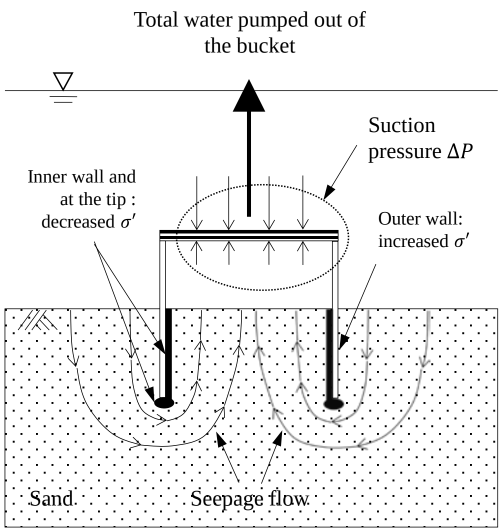

Fig. 1 Effect of seepage gradient on soil effective stress [1]

2. TEST METHOD

To examine the effect of suction installation on the vertical and horizontal behavior of a bucket pile, the model pile was installed both by suction force and jacking force, respectively. When installed by jacking force, model pile had been penetrated into the model ground by actuator. When installed by suction force, model pile had been penetrated by imposing suction force using venturi pump. In this regard, the size of model pile, the penetrating depth, and velocity were controlled equally. The model pile were made of aluminum pipe with 1.2 mm thickness, 60.0 mm diameter and 180.0 mm length. The size of used soil chamber is 100 mm width, 100 mm length and 200 mm height. After the model pile installed, the pull-out test had been performed by using hydraulic cylinder. A displacement had been controlled as 100 mm/min [2], [3]. The vertical pull-out tests were performed after installation in 0 hour, 2 hours, 20 hours to check the set-up effect. The loading location of model piles are 67% of L (L = 180 mm) from the pile top for the horizontal pull-out tests.

Joomoonjin sand from the East Sea in Korea were used in this study (Table 1). For vertical pull-out tests, the model ground was formed as 30% of relative density (D_r) to estimate the resistance in loose state. The model ground of D_r 70% was used for horizontal pull-out tests.

More details of the test program are summarized in Table 2.

Table 1 Engineering properties of Joomoonjin sand

G_s	C_u	C_c	e_{min}	e_{max}	USCS
2.62	1.43	0.9	0.929	0.620	SP

Table 2 Test programs for pull-out tests

Types	D_r	Loading point	Installation method
Vertical pull-out test	30%	Pile top	Suction / Jacking
Horizontal pull-out test	70%	67% of pile length	Suction / Jacking

For each test, a miniature cone penetration test was performed to examine the soil states of inside and outside the bucket pile. The cone penetrometer used in this study consists of 5 mm diameter of lower part and 12 mm diameter of upper part having micro strain gauge (Fig. 2).

Fig. 2 Micro cone (left) and input / output device (right)

3. TEST RESULTS

3.1 Vertical Pull-out Test

The results have been shown in Fig. 3. When comparing the maximum vertical pull-out resistances, the initial uplift capacity shows that the piles installed by jacking force (about 30N) have about 3 times larger resistances than those installed by suction force (about 10N).

Also, the pile installed by suction force after installation in 20 hours indicates about 20% larger resistance than 0 hour. In general pattern, however, it can be concluded that the set-up effect seems insignificant in comparison with installation methods.

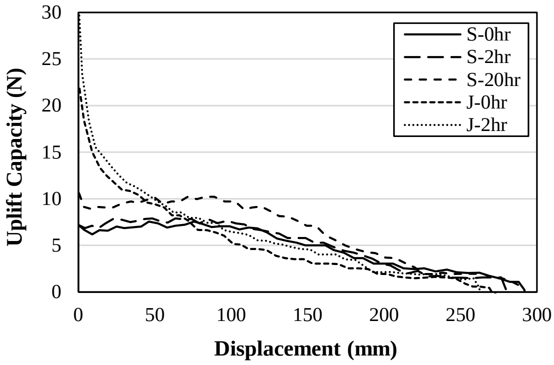

Fig. 3 Test results of vertical pull-out resistances on suction and jacked pile.

3.2 Horizontal Pull-out Test

Figure 4 shows the experimental results of the horizontally-loaded suction model piles installed by suction force and jacking force. The horizontal loading was placed at 67% from the piles' top without any loading inclination. In the Figure, the ultimate horizontal capacity and gradient (or stiffness) of "horizontal resistance-displacement curve" of pile installed by suction force were approximately 10% and 30% lower than those of pile installed by jacking force.

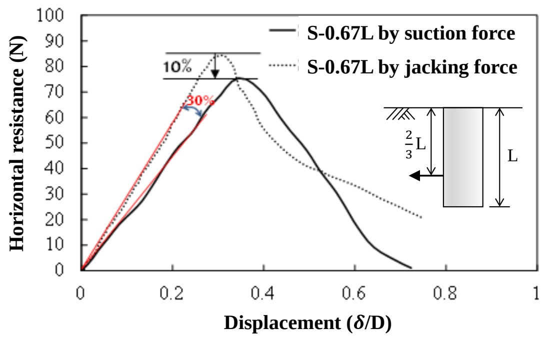

Fig. 4 Horizontal resistance-displacement curves of bucket piles installed by suction force and jacking force.

3.3 Cone Penetration Test

Like the above result, in cone penetration test (CPT), the cone tip resistance of the pile installed by jacking force shows about 50% larger than those installed by suction force (Fig. 5).

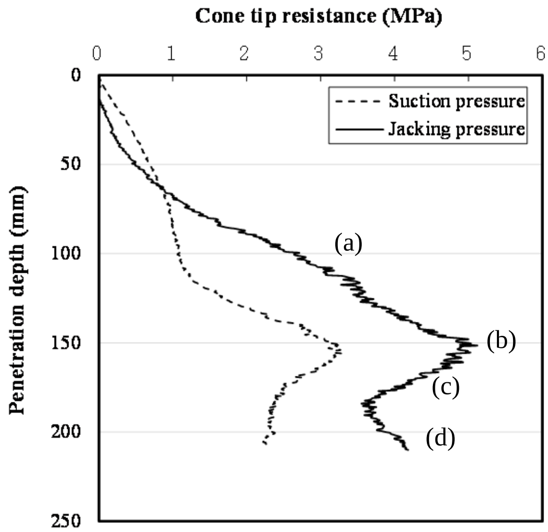

Fig. 5 Cone tip resistances on inside suction and jacked pile

In case of the pile installed by jacking force, before the micro cone escapes from the tip of the pile, the cone tip resistance just increased (Fig. 6a). But in close to the tip of the pile, the cone tip resistance suffered extremely high confining pressure by the pile wall (Fig. 6b). Sequentially, after escaping from the pile tip, the cone tip resistance rapidly decreased due to relaxation from high confining pressure (Fig. 6c). Lastly, after penetrating further, the cone tip resistance increased again due to original model ground (Fig. 6d).

In case of the pile installed by suction force, the pattern of the cone tip resistance were also almost same as Fig. 6a ~ Fig. 6c. In phase of Fig. 6d, however, the increase of resistance was not clear. The reason can be inferred due to the effect of suction installation.

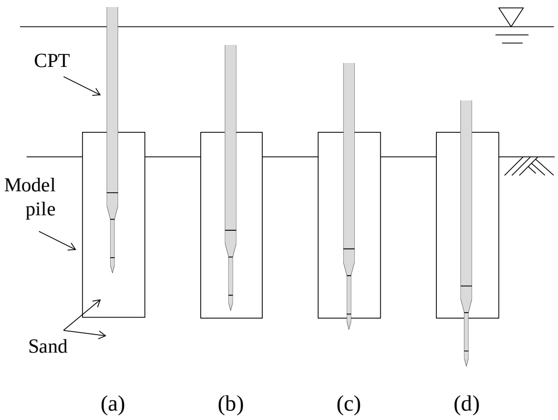

Fig. 6 Sequence of micro cone penetration

Fig. 7 represents the additional CPT results of inside and outside on bucket piles for the measurement of effective stress difference resulting from suction force. The solid and dashed lines in the figure are the CPT test results of the bucket piles installed by suction force and jacking force, respectively. The significant difference in CPT results of the inside and outside of the bucket pile results from the higher cone resistance due to the higher confinement inside of the pile wall.

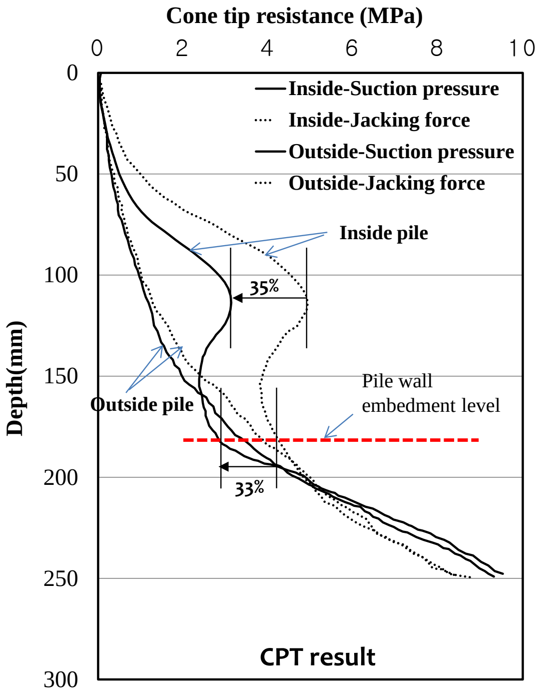

Fig. 7 CPT results of inside and outside on bucket pile by different installations

The suction installation effect on the cone resistances inside of the bucket pile is much greater than those outside of the pile. The CPT test results of outside on the bucket pile indicated that the cone resistances at depths of 100 mm and 200 mm of the jacked pile were 2% ~ 15% higher than those of the suction-installed pile. As also mentioned by [1], the downward seepage of outside on the bucket pile within dense sand (relative density approximately equal to 70%) may not increase the effective stress significantly. Contrarily, the cone resistance of inside on the suction-installed pile was 35% lower than that inside on the jacked pile. The much lower cone resistance inside of the suction-installed pile may be caused from the decreased effective stress induced by the upward seepage, as also insisted by [1]. The cone resistance at the suction-installed pile tip was about 33% less than that at the jacked pile tip.

It can be inferred that the lower cone resistances for suction-installed pile compared to those for jacked pile at any depth contribute to the lower horizontal capacity (about 10% difference as shown in Fig. 4) of the bucket pile. However, more precise and extensive future research is required to identify the lower horizontal capacity for suction-installed pile.

4. CONCLUSION

In this study, the effect of installation methods on bucket pile has been studied. As a result, the resistances of the pile installed by suction force and jacking force shown obviously different on vertical and horizontal pull-out resistances. This can be inferred because of decrease of effective stress caused by seepage flow from outside to inside of the pile. Thus, in the test on bucket pile, it can be concluded that installing methods affect the bucket pile un-negligibly.

In summary, to examine the actual horizontal behavior of a bucket pile in sands, suction effect on the vertical and horizontal behavior of bucket pile plays an important role. Therefore, bucket piles were designed to be installed by suction force.

5. FURTHER STUDY

To verify more effect on the installation methods, it seems necessary more to do test in terms of more detailed relative density, and not only inside resistances, but also outside resistances of the pile. Finally, estimating changed friction angle of the model ground is the goal of this study.

6. ACKNOWLEDGEMENTS

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