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Influence of installation method on performance of screwed pile and evaluation of pulling resistance

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Abstract

In the present study, we performed installation and pull-out loading tests on screwed piles in sand deposits using a calibration chamber. These tests focused on how the installation method influenced the performance of the piles. The results revealed that the load-displacement relationship strongly depended on the installation method, but that the second-limit uplift resistance was almost unaffected. Next, we observed the movement of the soil near the pile after both the installation and pull-out loading tests. Shear failure of the soil, which occurs in a cylindrical region in the periphery through which the wing plate of the pile passes, regardless of how the screwed pile is installed, was found to be one of the determinants of the pulling resistance. Finally, we evaluated the pulling resistance of the screwed pile based on these soil observations and an analysis of the loading test results. We found that the pulling resistance of the wing plate could be determined based on the change in earth pressure near the pile due to installation and pull-out loading of the pile.

Keywords: Screwed pile; Pulling resistance; Model test; Pile installation method; Soil movement

1. Introduction

A screwed pile is a steel pipe pile with a wing plate around its tip. Such piles can be installed in the ground with low noise, little vibration and without excavating the soil. Furthermore, screwed piles have the advantage that their vertical bearing capacity increases because of the resistance of the wing portion. Piles with various wing shapes have been developed, and their vertical bearing capacities have been examined. Tsuchiya and Kohsaka (2015) and Tsuchiya et al. (2016) investigated the effects of wing position and shape on the vertical bearing capacity for various types of screwed piles used in Japan, and presented the relationship between the vertical load and the displacement of the screwed pile tip based on the results of many loading tests.

Screwed piles are also effective for pull-out loads because of the extra resistance provided by the wing plate. Recently, screwed piles have been used in structures such as a high-rise building subjected to seismic and wind loads, a low-rise building with an underground floor at a site with a high groundwater level, and a mega solar facility.

In-situ pull-out loading tests have elucidated the pulling resistance of screwed piles. Such studies have shown that the pulling resistance depends on how deeply the pile is embedded and the diameter of the wing (Tsukada et al., 1997; Saeki et al., 2000), and have examined the pulling resistance under cyclic vertical loads (Komatsu et al., 2003; Hirashima et al., 2003). Other studies have investigated the pulling resistance of screwed piles by reproducing the process, from installation through pull-out loading, in laboratory tests. Nagata and Hirata (2004) examined the

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Nomenclature

G_s	density of soil particles
ρ_{dmax}	maximum dry density of sand
ρ_{dmin}	minimum dry density of sand
D_{50}	median grain size
U_c	coefficient of uniformity
D_r	relative density of soil
ϕ	internal friction angle of soil
d_0	diameter of pile shaft
t_s	thickness of pile shaft
l	length of pile
d_w	diameter of helical plate
p_w	pitch of helical plate
t_w	thickness of helical plate
A_b	area of bottom plate
A_w	area of helical plate
W_p	weight of pile
σ'_{v0}	surcharge pressure
T_p	installation torque at pile tip
Q_b	load on pile bottom
Q_w	load on pile wing
Q_p	load on pile tip ($=Q_b + Q_w$)
Q_{pu}	the second-limit-uplift resistance of pile tip
q_b	pulling resistance of pile bottom ($=Q_b/A_b$)
q_w	pulling resistance of pile wing ($=Q_w/A_w$)
q_p	pulling resistance of pile tip ($=(Q_b + Q_w)/(A_b + A_w)$)
q_{pl}	pulling resistance of pile tip at load $Q_{pu}/3$
q_{ps}	pulling resistance of pile tip at load $2Q_{pu}/3$
δ	pulling displacement of pile
δ_l	pulling displacement of pile at load $Q_{pu}/3$
δ_s	pulling displacement of pile at load $2Q_{pu}/3$
K_{pl}	vertical stiffness at pile tip at load $Q_{pu}/3$ ($=q_{pl}/\delta_l$)
K_{ps}	vertical stiffness at pile tip at load $2Q_{pu}/3$ ($=q_{ps}/\delta_s$)
H	length of the shear failure zone
ξ	coefficient of lateral earth pressure
$\overline{\sigma}_h$	average horizontal earth pressure
$\overline{\sigma}_{v0}$	average vertical stress created by the density of the sand and the surcharge pressure
σ_v	vertical earth pressure measured by earth pressure cells
σ_h	horizontal earth pressure measured by earth pressure cells
H_p	embedment depth of screwed pile
H_w	embedment depth of pile wing into dense sand in the two-layer case

effect of the ratio of the wing diameter to the pile diameter. Nakazawa et al. (2015) investigated how the embedment depth in the base layer affected performance. Tokimatsu et al. (2012) and Urabe et al. (2015) investigated the influence of both the shaft and wing diameters on the bearing capacity and the pulling resistance during cyclic vertical loading. Wada et al. (2015) studied the influence of the initial loading at the pile head on the pulling resistance under cyclic vertical loading.

Loading tests have also been performed on screw anchors to study their pulling resistance and appropriate methods of calculating their performance (Mitsch and Clemence, 1985; Ghaly et al., 1991a, 1991b). Abbas et al. (2016) presented a comprehensive review of proposed pile design methods.

There is some research for the installation effects on the screwed pile performance. Nagata and Hirata (2005) examined shear failure of the soil due to pulling a screwed pile. They performed pull-out loading tests and observed the movement of the soil near the pile after testing, and explored how the method of installation affects screw pile performance by comparing the pulling resistance of a buried pile and a spirally driven pile. These tests were carried out on piles installed by forward rotation or by boring into homogeneous dense sand. Tsuha et al. (2015) conducted pull-out loading tests on screwed piles in residual soil. They investigated the change in earth pressure and soil strength characteristics around the piles after installation and considered how installation affects screw pile performance. Kanai (2007) carried out cone penetration test in the ground near the pile after a small steel pipe pile with four helical plates is installed in the field, and attempted to evaluate the influence to the adjacent soil due to its penetration. It appeared that loose clayey soils become looser and sandy soils become denser after pile installation. Mosquera et al. (2015) presented numerical analyses to simulate the uplift load–displacement behavior of a single-helix pile installed in dense sand. These analyses were assumed to be disturbed by the helix pile installation. They indicated the failure surface of soil on the pile uplift response was developed in the interface between the disturbed cylindrical volume of soil penetrated during installation and the surrounding undisturbed soil mass. Lutenegger et al. (2014) performed field vane shear tests in clay after the installation of single-helix and multi-helix helical anchors to obtain a direct evaluation of the degree of disturbance produced during installation. They indicated that the undrained shear strength was reduced by the pile installation disturbance, and the degree of disturbance was related to the soil characteristics and the quality of the installation.

Screwed piles are basically installed by screwing the pile into the ground in a forward direction. However, piles are

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