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The effects of installation order on the response of a pile group in silica sand

Alain Le Kouby[a,*], Jean Claude Dupla[b], Jean Canou[b], Roméo Francis[b]

[a]Université Paris-est, IFSTTAR (French Institute of Science and Technology for Transport, Development and Networks), 14-20 boulevard Newton, Cité Descartes, 77447 Champs sur Marne, Marne La Vallée Cedex 2, France

[b]Université Paris-est, Soil Mechanics Research Center (Navier Géotechnique), Cité Descartes 6-8 Avenue Blaise Pascal, 77455 Champs-sur-Marne, France

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Abstract

The pile (and micropile) group effect in sand remains a key issue in civil engineering. This paper describes an experimental study carried out using a calibration chamber and an instrumented model pile installed by jacking. A specific methodology is proposed to study group effect through a generic pile within the group. A pile group can be modeled by a group of five piles, one central pile and four adjacent piles. The central pile represents a generic pile within a group with a large number of piles, and the calibration chamber enables the performance of a parametric study to evaluate the global and local (tip resistance and shaft friction) group effects and quantify them using the efficiency coefficient factors relative to tip resistance and shaft friction. The effect of parameters, such as the pile-to-pile spacing ratio and the installation order on pile group response has been investigated. The instrumented generic pile is designed to study independently tip resistance and shaft friction.

The results show that the installation order has a significant influence on the pile group response. Some recommendations from laboratory tests are proposed to optimize pile installation in the case of a group and benefit from group effect.

Keywords: Pile group effect; Efficiency coefficient; Calibration chamber; Installation order; Model pile

1. Introduction

The group effect on micropiles or piles remain a central aspect of civil engineering research. Indeed, despite the models and advances in calculations, the group effect still relies on models and measurements that can still be discussed.

The ultimate load of a pile group is generally different from the ultimate load of a single pile multiplied by the number of piles. The quantification of this group effect for axially loaded piles is generally based on the evaluation of an efficiency coefficient, defined as the ratio between the axial capacity/stiffness of the group and the axial capacity/stiffness of a single pile multiplied by the number of piles (Vesic, 1969, Fleming et al., 1992, Yetginer et al. 2006, McCabe and Lehane, 2006).

Kezdi (1957) first demonstrated that pile groups in sand can carry higher loads than the sum of loads that can be carried by individual piles.

Since then, many research works have outlined the parameters that can influence the performance of piles group such as pile spacing, length to diameter ratio and number of piles in sand (Cambefort, 1953, Vesic, 1969, Lizzi and Carnevale, 1979, O'Neill, 1983, Liu et al., 1985, Shublaq, 1992, Al Douri, 1992, Phung, 1993, Poulos, 1994, Chow, 1996). Nevertheless, some authors went further with the study of the influence of the pile installation technique (Hansbo, 1993) and the

*Corresponding author. Tel.: +33 1 81 66 82 72; fax: +33 1 81 66 80 01.
E-mail addresses: alain.lekouby@ifsttar.fr (A. Le Kouby), dupla@cermes.enpc.fr (J.C. Dupla), canou@cermes.enpc.fr (J. Canou), rcfnigerialtd@gmail.com (R. Francis).

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installation order (Whitaker, 1957, Kishida, 1967, Briaud et al., 1989, Phung, 1993, Francis, 1997, Lee and Chung, 2005). For the installation order, Whitaker (1957) carried out a comprehensive experimental work in clay soils on a pile group with the central pile installed respectively at the first and at the last phase. The other authors only considered one installation order but they monitored the center, midside, and corner piles to observe their mechanical response during installation and loading.

Kishida (1967) conducted field tests on 24-pile groups with piles 300 mm in diameter and 6 m in length in moderately dense sand with a spacing ratio of 2.5 (ratio between the center to center distance with the pile diameter d), with driving performed from the interior of the group outward so that the densification of the soil mass around the piles would increase as the number of installed piles increased. Bearing capacity tests have also been performed in which each pile is taken as a single pile. The results showed that the bearing capacity of the piles increases with the changing location in the installation sequence until a maximum difference of 200% is achieved between two individual piles.

The loads carried by the piles at the center of the pile group and the piles at the borders and corners have been found to be different due to the deformation characteristics of the soil surrounding the piles and the significance of their densifications relative to their locations in the group (Hansbo, 1993).

Consequently, no simple model has been proposed and data associated with the influence of the installation order are still required. Technical and economic issues surround the choice of a densification method for surrounding soil, including the need to optimize installation order and decrease the number of piles or their lengths.

Field tests are difficult to achieve and generally only represent specific cases. The representativeness of tests carried out in soil tanks is an issue. Therefore, the observations on field tests coupled with the complexity of the group effect determination, have justified the use of laboratory device to achieve more appropriate parametric studies known as the calibration chamber and centrifuge. The current paper focuses on the use of the calibration chamber to achieve parametric studies, especially installation order, to characterize the pile group response in the case of a large number of piles.

Indeed, the initial conditions (density ratio and consolidation stresses) make it possible to simulate the installation of a displacement pile (installed by jacking) in sand, study a pile group segment and perform a local study (Al Douri and Poulos, 1994; Foray et al., 1998; Francis, 1997; Le Kouby, 2003). Liu et al. (1985), Briaud et al. (1989) and Phung (1993) proposed an efficiency coefficient relative to the shaft friction and tip resistance when performing tests with the proper instrumentation.

The main objective of this paper is to propose a specific methodology for studying the group effect on piles in a calibration chamber. A generic pile at the center of a group of five piles represents the pile response of a pile within the group. In addition, a specific instrumentation allows to separate the pile response in terms of shaft friction and tip resistance.

The research work focuses on the influence of pile spacing ratio and installation order. The quantification of group effect is shown through local (tip and shaft) efficiency coefficient. An optimized installation order is also proposed to obtain a more favorable group effect.

2. Testing facilities and procedure

2.1. Testing facilities

2.1.1. Calibration chamber

The experimental setup used in this study is a calibration chamber. The preparation method for the soil sample is similar to the method used in a triaxial test. Accordingly, at first, the soil sample was prepared using the pluviation/raining method and the isotropic/anisotropic (K_0) condition with the independent application of vertical and horizontal stresses through the base piston and lateral membrane (Dupla and Canou, 2003).

Several modifications were implemented to enable the study of models of micropile installed by jacking (Le Kouby et al., 2013).

After the pile installation by jacking, the pile is embedded 500 mm (Fig. 1(a)) within the sand mass so that the 200-mm skin friction gauge is not influenced by the top plate and the tip is at a distance of 10 diameters from the bottom plate, an acceptable distance to prevent the tip from influencing the mobilization of the tip resistance (Puech, 1975). According to the experimental program, the number of piles and the installation order are defined for the pile group (Fig. 2(a)), and the piles are connected to the cap for the next phase.

The loading phase (monotonic compression tests) (Fig. 2(b)) can begin when these initial conditions are set. The left side of Fig. 2(a) shows the data acquisition system.

This loading device is composed of a frame consisting of four columns equipped with two hydraulic jacks. A long-range jack (1 m) located at the top part of the frame is used to install piles by jacking (speeds from 0.1 to 100 mm per second).

A MTS servo-controlled hydraulic actuator with a capacity of ± 100 kN and a displacement range of $\pm 7{,}5$ cm is used for pile loading. This actuator can apply monotonic or cyclic loading and is equipped with a LVDT calibrated at two levels, namely 10% and 100% of the full scale, resulting in good linearity and a small hysteresis.

Monitoring is performed using an MTS system with digital controls and software for testing.

2.1.2. Model pile

The diameter of the model pile is 20 mm, and they are equipped with strain gauges at the tip and at a point 200 mm up the shaft (Fig. 1(b) and (c)). The distance between the end of the shaft gauges and the tip is 120 mm (6 diameters), which is acceptable for preventing the failure surface at the tip from influencing the response of the shaft.

A total load cell is used to obtain the direct force transmitted to the tip. When measuring shaft friction, the principle of friction measurement is slightly different from that used with an electrical friction cone penetrometer. Although the shaft