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Effective installation of micropiles to enhance bearing capacity of micropiled raft

Tae-Hyun Hwang, Kang-Hyun Kim, Jong-Ho Shin *

Department of Civil Engineering, Konkuk University, 120 Neungdong-ro, Gwangjin-gu, Seoul 05029, Republic of Korea

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Abstract

While micropiles are used in many geotechnical projects, as ground reinforcement rather than as structural elements, field engineers have reported that the bearing capacity of micropiled rafts greatly exceeds the range of common ground reinforcement. This is known to be due to the confining effects of micropiles from the interaction between the ground and the micropiles, which extends the failure area of the ground significantly. Utilizing micropiles as ground reinforcement can excessively underestimate the structural contribution of the footing in a micropiled-raft system to the bearing capacity. This study investigates the support characteristics of a micropiled raft through model tests and a numerical analysis. The support behavior of the micropiled raft is evaluated for various conditions, such as soil type, pile length, and installation angle. It is found that the micropiles modify the failure behavior of the ground considerably, and that the bearing resistance can be enhanced by considering the appropriate failure mode, installation angle, and pile length.

Keywords: Micropiled raft; Bearing capacity; Model test; Numerical analysis

1. Introduction

The use of micropiles has become popular in many geotechnical projects. Micropiles with a diameter of 300 mm or less can generally be installed in small, narrow spaces without limiting the working conditions by factors such as the length of the piles (L) and the installation angle (θ). Due to these engineering advantages, micropiles have mainly been used to increase the bearing capacity or to reduce the settlement in foundation engineering. They have also been used for various other purposes, such as to support new structures and to stabilize slopes (FHWA, 2005).

In the design of foundations, micropiles are often used as ground reinforcement rather than as structural elements. However, field engineers have recognized that the bearing capacity of micropiled rafts greatly exceeds the range of common ground reinforcement. While the use of micropiles for ground reinforcement can bring about the excessive underestimation of the structural contribution to foundations, design guidelines and comments on micropile construction for the purpose of enhancing the bearing capacity are seldom found. Micropiles are typically installed on an existing footing. The micropiled-raft system is composed of micropiles and a raft, whereby the raft sits on top of the existing footing and the piles are driven alongside the footing. Thus, the design concept of micropiled rafts is seen as being similar to that of piled rafts (Poulos and Davis, 1981; Reul and Randolph, 2003), in which the working load is supported by the micropiles and the soil under the footing. According to previous studies on micropiles and micropiled rafts in sand (Tsukada et al., 2006), the support characteristics of the foundation vary depending on the installation angle. It has also been

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* Corresponding author.
E-mail addresses: jhshin@konkuk.ac.kr, jongho-shin@hanmail.net (J.-H. Shin).

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reported that rafts with outward-battered micropiles increase the bearing capacity more than vertical micropiles. This is known to be due to the confining effect of micropiles. Tsukada et al. (2006) investigated micropile behavior according to dilatant or contractive soils; however, the relationship between the micropile behavior and the failure modes that govern the bearing capacity was not fully investigated. Han and Ye (2006) identified the load transfer mechanism of vertical micropiles in clays using a field study. Although the above-mentioned research has contributed to the understanding of the behavior of single micropiles and micropiled-circular rafts (Lizzi, 1982; Iai, 1989; Tsukada et al., 2006), a lack of information remains on various influencing factors, such as the inward-battered installation, the shape of the footing, the length of the micropiles, and soil types (or failure modes).

This study investigates the support characteristics and a new bearing capacity evaluation method for micropiled rafts. By performing a tentative pre-study, using a small-scale physical model, the relationship among the ground failure pattern, the installation angle, and the pile length was considered to be the main influencing factor. Furthermore, particular focus was given to the ground failure modes of the footings in this research.

Fig. 1(a) shows the failure mechanism of a raft foundation, where H_f and L_f represent the scales of the potential failure surface. The depth of the failure surface, H_f, can be derived from a geometric analysis of the failure surface, as follows.

$$H_f = \left\{ \frac{\exp(\xi \cdot \tan \varphi')}{2 \cdot \cos\left(\frac{\pi}{4} + \frac{\varphi'}{2}\right)} \cdot \sin\left(\frac{3\pi}{4} - \frac{\varphi'}{2} - \xi\right) \right\} \cdot B \quad (1)$$

Here, ξ represents angle $\angle cbd$, which is the area of the shear fan. The relation among H_f–φ'–ξ can be evaluated using Eq. (1), as shown in Fig. 1(b). H_f is a parameter related to the length of the installation (L) of the micropile. The pile depth ratio (κ), which is the ratio of the pile length to the depth of the failure surface (H_f), is introduced as follows:

$$\kappa = \frac{L}{H_f} \quad (2)$$

Parameter κ is an important factor relating the ground failure modes and the pile length. Therefore, the parameter is useful for investigating the effectiveness of the micropile installation.

The best method for identifying the behavior of micropiled rafts and for evaluating the bearing capacity would typically be to conduct a field study adopting sophisticated instrumentation. However, the field approach has many restrictions not only in measuring the full behavior, but also in arranging the budget. In this study, therefore, physical model tests are adopted to identify the failure mechanism and the bearing capacity of a micropiled raft. Further investigation of the parameters influencing the bearing capacity is carried out by performing a numerical analysis. Based on the results, design comments on the micropiled raft in medium dense sand and clayey silt are given.

2. Model study on failure behavior of micropiled-raft system

2.1. Physical modeling of micropiled raft

In order to investigate the support characteristics of a micropiled raft, a model test device was built, as shown in Fig. 2. The dimensions of the soil reservoir are $400 \times 1200 \times 800$ (mm). Two soil types, medium dense sand and clayey silt, were considered to investigate the effect of the ground conditions. The sand was alluvial silica sand from the Han River, while the silt was marine clayey silt from the coast of the Yellow Sea in the Incheon area. The uniformity coefficients (C_u) of the sand and the silt were 1.62 and 2.32, respectively. Both soils were dried. The grain size distribution and the soil parameters are shown in Fig. 3(a). The shear strength parameters were obtained from direct shear tests and are shown in Fig. 3 (b). The model ground was constructed using air pluviation from a narrow sand box with heights of 600 mm (sand) and 700 mm (silt). Firstly, the bottom layer was built, then the micropiles were installed, and finally the foundation soil was placed.

The relative density of the soil, D_r, was controlled at about 50%. The density of the soil was measured by sampling soils from the model container. While the soil was

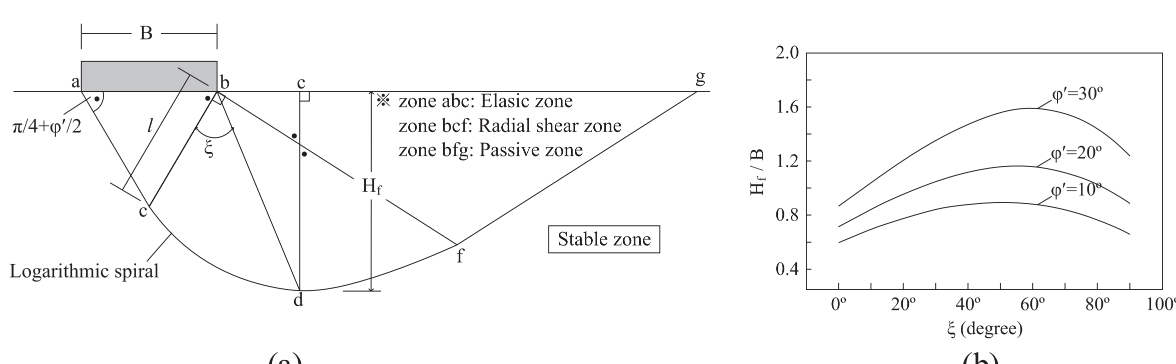

Fig. 1. Potential failure surface under raft: (a) failure mechanism and (b) H_f for sand or silt.

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