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Full Length Article

Bearing behavior and failure mechanism of squeezed branch piles

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ABSTRACT

The current practice for the design of squeezed branch piles is mainly based on the calculated bearing capacity of circular piles. Insufficient considerations of the load-transfer mechanism, branch effect and failure mechanism, as well as overreliance on pile load tests, have led to conservative designs and limited application. This study performs full-scale field load tests on instrumented squeezed branch piles and shows that the shaft force curves have obvious drop steps at the branch position, indicating that the branches can effectively share the pile top load. The effects of branch position, spacing, number and diameter on the pile bearing capacity are analyzed numerically. The numerical results indicate that the squeezed branch piles have two types of failure mechanisms, i.e. individual branch failure mechanism and cylindrical failure mechanism. Further research should focus on the development of the calculation method to determine the bearing capacities of squeezed branch piles considering these two failure mechanisms.

1. Introduction

Pile foundations play an important role in supporting structural loads when shallow foundations cannot provide sufficient bearing capacity or where the settlement is a major concern. More efficient foundation design will help to reduce construction costs and contribute to faster construction. Obviously, geotechnical engineers should develop new foundation concepts if foundation costs are to be reduced (Byrne and Houlsby, 2015). In consequence, many new pile foundation techniques have been proposed based on conventional concepts, by changing pile sectional shape to take advantage of foundation soil (rock) and pile bearing capacities, and adopting potential pile materials for more effective reinforcement at lower cost. For instance, engineers have already made full use of pile geometries to improve the axial load capacity of piles, such as tapered pile (Wei and El Naggar, 1999; El Naggar, 2004), pipe pile (Lehane and Gavin, 2001), helical pile (Elsherbiny and El Naggar, 2013; Byrne and Houlsby, 2015; Khazaei and Eslami, 2017), X-shaped pile (Lu et al., 2012; Zhou et al., 2017), Y-shaped pile (Lu et al., 2016), squeezed branch pile, and so on, which are all successful examples of pile geometry modification.

The squeezed branch pile was developed from the conventional circular pile (Yang et al., 1999). It contains a central rounded shaft with at least one branch (enlarged part) located on the shaft based on the distribution of soil strata, as shown in Figs. 1 and 2. Generally, the branch or plate is penetrated into the relatively hard soil layer using the hydraulic squeezed machine (Fig. 3). The three-dimensional (3D) static pressure is applied to the soil around each branch or plate. Thus, pile expansion cavity, soil compaction, pile cavity perfusion and branch integration in the pile all affect the pile-soil bearing behavior.

The squeezed branch piles are significantly more efficient than conventional circular piles. Hence, many theoretical analyses, and laboratory and in situ experiments have been conducted to investigate the pile bearing behavior and calculate the bearing capacities of squeezed branch piles. Qian (2003) and Qian et al. (2005) investigated the loading transfer behavior of squeezed branch piles under static load and exciting force of earthquake. In their studies, the influential factors of squeezed branch piles were analyzed. Yuan et al. (2006) compared the bearing capacities of squeezed branch pile, squeezed plate pile and conventional circular pile through field investigation. They suggested that the squeezed branch pile was the most efficient one among them, followed by the

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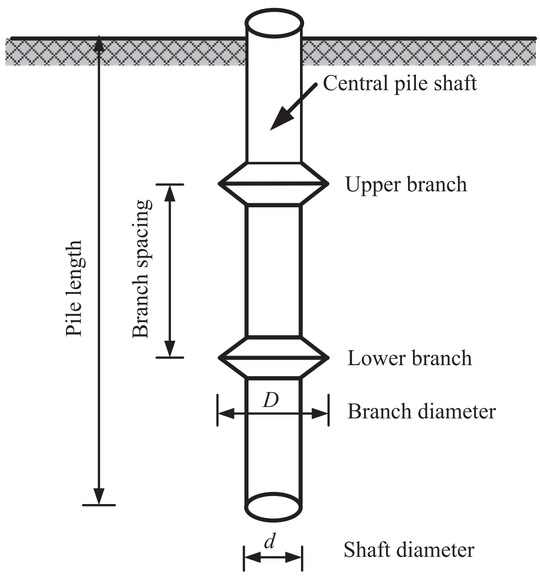

Fig. 1. Schematic diagram of squeezed branch pile.

squeezed plate pile and conventional circular pile. For example, a pile foundation project in the Eastern Expressway of Ningbo, China showed that the squeezed branch piles can save over 30% construction materials compared to conventional straight piles, while achieving the same compressive bearing capacity (Yuan et al., 2014). Furthermore, the squeezed branch piles were also found to be effective in anti-pulling as well as resisting axial compression (Qian, 2003; Gao, 2007; Gao et al., 2007; Zhang et al., 2008). Gao (2007) and Gao et al. (2007) investigated the squeezed branch pile responses in collapsible loess through field load test, and showed an excellent response under lateral loading, suggesting that the squeezed branch piles were reliable and excellent for collapsible loess. The squeezed branch piles provide improved vertical and horizontal bearing, as well as anti-pulling capacities, because the branches can provide greater frictional resistance.

Although the squeezed piles have been used for a considerable time, there is sparse information available on branch-soil-pile interaction and failure mechanisms, due to the fact that they are not widely used around the world. Therefore, further study is required on squeezed branch pile characteristics and bearing capacity.

This paper aims to evaluate the bearing responses of squeezed branch piles, and to explore the effects of branch position, spacing, number and diameter on pile bearing capacity. We also investigate the soil failure patterns around the branches. The results will provide valuable insight into underlying failure mechanism and load transfer regularity for squeezed branch piles.

2. Field test

2.1. Site description

This project is located at the top of the front alluvial fan of Taihang Mountain, China. The site has been surveyed by extensive investigation programs, including several field and laboratory tests. The area is mainly composed of clayey soil, with a silt and gravel layer of Quaternary alluvial deposit. The soil is divided into nine main layers from top to bottom (Nos. ①, ②, ③ and ⑤-⑩) and eight substrata (Nos. $⑤_1$, $⑤_2$, $⑥_1$, $⑦_1$, $⑧_1$, $⑨_1$, $⑨_2$ and $⑩_1$). Field and laboratory tests are performed for soil properties at different depths, as shown in Table 1.

The squeezed branch piles with 0.7 m in diameter and 32 m in effective length are investigated in this study, and each pile has two branches of 1.4 m in diameter. All piles are constructed using C40 grade concrete.

Fig. 2. Photo of excavated branch pile (Gao et al., 2009).

Fig. 3. Hydraulic squeezed machine.