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Original Research Paper

Determination of large diameter bored pile's effective length based on Mindlin's solution

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ABSTRACT

The calculation equation of large diameter bored pile's effective length is connected with its distribution of pile shaft resistance. Thus, there is a great difference between the calculation results under the different distributions of pile shaft resistance. Primarily, this paper summarizes the conceptualized mode of pile shaft resistance under the circumstance that the soil surrounding the piles presents different layer distributions. Secondly, based on Mindlin's displacement solution and in consideration of the effect of pile diameter, the calculation equation is optimized with the assumption that the pile shaft resistance has a parabolic distribution. The influencing factors are analyzed according to the calculation result of effective pile length. Finally, combined with an engineering example, the calculation equation deduced in this paper is analyzed and verified. The result shows that both the Poisson ratio of soil and pile diameter have impacted the effective pile length. Compared with the Poisson ratio of soil, the effect of pile diameter is more significant. If the pile diameter remains the same, the effect of the Poisson ratio of soil to the effective pile length decreases as the ratio of pile elastic modulus and soil share modulus increases. If the Poisson ratio of soil remains the same, the effect of the pile diameter to the effective pile length increases as the ratio of pile elastic modulus and soil share modulus increases. Thus the optimized calculation result of pile effective length under the consideration of pile diameter effect is more close to the actual situation of engineering and reasonably practicable.

1. Introduction

In order to satisfy the requirement of bearing capacity, the design of highway bridge usually chooses a larger pile length, which would cause a certain waste. A larger number of theoretical and experimental researches show that a large diameter bored pile has an effective length when the pile diameter is fixed. Under the action of vertical load, large

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diameter bored pile would produce compression and relative displacement of piles and soil. In the process of load transferring and spreading to the surrounding soil, the bearing capacity of single pile would not increase after a certain limit. At this point, the length of pile is called effective pile length (Lai and Yang, 2007; Zhang, 2009).

There are several methods to calculate the effective pile length, such as the method of controlling ultimate bearing capacity (Shu and Huang, 2001; Wang and Jia, 2001; Yang and Liang, 2006), the method of controlling pile top settlement (Dai et al., 2012; Zhang et al., 2014; Zhou et al., 2007), the method of controlling pile stiffness (Leung et al., 2010; Tong et al., 2012), and using the finite element method (Chen et al., 2012; Wang et al., 2013; Yang et al., 2014). However, different calculation methods lead to discrepancies among calculation results. Aiming to control the ultimate bearing capacity, the rationality of theoretical calculation result mainly depends on the assumption of pile shaft resistance distribution, which is different in different soil layers. In general, the calculation of effective pile length is based on the assumption that pile shaft resistance is triangular distribution or rectangular distribution, but the actuality differs from these assumptions, which do not reasonably reflect on the effective pile length truly and reasonably. Ding (2005) and Shu and Wang (2001) assumed that the distribution of pile shaft resistance was inverted triangle and deduced the following formula under that assumption.

$$l_e = \frac{3s_{a0}E_pA}{Q_a} \tag{1}$$

$$l_e = (4.7 \sim 5.2)r_0\sqrt{\frac{E_p}{E_s}} \tag{2}$$

where l_e is the effective pile length, s_{a0} is settlement under the working load, Q_a is working Load, E_p is the elastic modulus of pile, E_s is the compression modulus of soil, A is section area of pile, and r_0 is radius of pile.

Sun (2008) assumed that the distribution of pile shaft resistance was double fold triangle, and deduced the following formula of effective pile length based on this assumption.

$$l_e = (4.1 \sim 4.5)r_0\sqrt{\frac{E_p}{E_s}} \tag{3}$$

But the measured data of field test shows that pile shaft resistance does not change linearly with the pile embedded depth.

Wang and Chen (2011) deduced the calculation formula of effective pile length with the assumption that the distribution of pile shaft resistance was parabolic.

$$l_e = d\sqrt{\frac{5E_p(3-2\mu)(1+\mu)}{4E_s}} \tag{4}$$

where μ is Poisson ratio of soil, d is pile diameter.

In Eq. (4), the pile diameter (d) is mainly used in the calculations of elastic compression and the compression coefficient of soil around pile, but it does not reflect the influence of pile diameter. The pile bearing capacity not only depends on the natures of soil around pile, but also the geometric dimensioning of pile. The influence of pile diameter cannot be ignored when the pile diameter is more than 0.8 m. Thus, the calculation result accuracy of large diameter bored pile length needs further validation.

Based on the research of Wang and Chen (2011) and Liu et al. (2014b), this paper considers the effect of pile diameter and deduces the calculation equation of pile effective length with the assumption that the pile shaft resistance distribution is parabolic. Then, the influencing factors are analyzed and the calculation result is verified by the engineering example.

2. Conceptualized mode of pile shaft resistance

Due to the influencing factors such as the distribution of soil around pile and the modulus ratio of pile and soil, the distribution of pile shaft resistance is polytropic and complicated (Qiu et al., 2014). According to statistics, the conceptualized mode of pile shaft resistance along pile can be divided into 6 kinds (Liu et al., 2014a), which are shown in Fig. 1.

The isosceles trapezoidal distribution of pile shaft resistance often occurs for long piles in hard soil layer. When the strength of soil around the pile increases gradually from top to tip of the pile, pile shaft resistance would play fully with the increase of depth. On the contrary, the distribution of pile shaft resistance appears inverted trapezoidal when the strength of soil around pile changes weakly. If the soil around pile is interaction layer of soft and hard sand, or clay, the upper soil is comparatively weak. Then, because of the pile compression, pile shaft resistance of the lower soil layers plays laggingly and increases gradually. At this time the distribution of pile shaft resistance usually presents olive shape. For the middle long pile or long pile, if soil around the pile is hard gravel soil, sandy soil or cohesive soil, pile shaft resistance of lower soil cannot play fully. This moment pile shaft resistance usually presents lantern shape. Garlic shaped pile shaft resistance is more common in the condition that pile side soil is soft at the central and mutation into hard at the lower. Pile shaft resistance of middle long pile or long pile in hard–soft–hard soil usually presents peak–valley shape.

It can be seen that the distribution forms of pile shaft resistance are various and complex. In practical engineering, the distribution of pile shaft resistance is not linear along the whole or part of pile body (Liang et al., 2015; Limkatanyu et al., 2009). For the olive and lantern shaped pile shaft resistance distribution, the practical distribution curve is closer to parabola, which conforms to the hypothesis of pile shaft resistance in this article.

3. Calculation of effective pile length

The value of shaft resistance is assumed equal to 0 at the top of pile and the effective pile length firstly increases and then decreases along the pile. There is no displacement at the point of effective pile length. The distribution of pile shaft resistance is shown in Fig. 2, and satisfied the following Eq. (5) at the depth z.