Correction of Axial Force Distribution Function of Flexible Single Pile

Jie Xiao, Ping Hu *
School of Civil Engineering and Architecture, University of Jinan, Jinan, China
*Corresponding author e-mail: pinghu2002@163.com

Abstract. By introducing the stiffness ratio between the pile end soil and the pile side soil, the existing axial force distribution function is modified, and the axial force of the model pile is calculated by the modified distribution function. The calculated results are consistent with the experimental results, indicating that the modified axial force distribution function can more accurately reflect the axial force variation of the single pile.

1. Introduction
With the development of economic construction in China, there are more and more high-rise buildings, long-span bridges and highways, and the wider use of pile foundations. In practical engineering, pile foundations are generally pile group foundations except a small part of single pile foundation with large diameter, and the working characteristics of pile group are closely related to the characteristics of single pile. Therefore, it is necessary to study the single pile.

In actual engineering, due to the pile-side frictional resistance, the axial force of the pile gradually decreases with the increase of the depth of soil penetration, and the speed of its decay speed reflects the magnitude of the pile-side frictional resistance. The factors that affect the frictional forces on the side of the pile include the nature of the pile passing through the soil layer and the aspect ratio of the pile. Liang Jinguo[2] proposed the axial force distribution function of single pile based on the above viewpoints. However, the axial force distribution function he proposed did not consider the effect of the stiffness ratio of the soil at the end of the pile. This paper considers the influence of the stiffness ratio of pile-end soil and pile-side soil, and revises the existing axial force distribution function to make it more accurately reflect the variation of the axial force of a single pile.

2. Correction of axial force distribution function of flexible piles
In this study, the bearing capacity of a flexible single pile under static load was analyzed by using the axial force distribution function of a single pile by Liang Jinguo et al. [2]. Assuming that the axial force of a single pile at any section under vertical load is $F_N(z)$, the definition of the axial force distribution function of a single pile is:

$$f_N(z)=\frac{F_N(z)}{Q} \quad (0\leq z\leq L, \ 0\leq f_N(z)\leq 1) \quad (1)$$

In this formula: $z$ is any section of the pile body; $f_N(z)$ is the axial force distribution function of a single pile; $F_N(z)$ is the axial force at the z section;
Q is the vertical load acting uniformly on the top of the pile; 
The axial force distribution function at any section z is:

\[ f_N(x) = 1 - \left( \frac{kr}{\eta^2 + (kr)^2} \right)^{3/2} \]  

(2)

Because the calculation result of the single pile axial force distribution function does not take into account the influencing factors of the stiffness of the soil at the end of the pile, and the difference between the calculated value and the test result, this paper makes a correction based on the single pile axial force distribution function. The modified single pile axial force distribution function is used to analyze the test results of the bearing behavior of the flexible single pile under static load. The axial force distribution function at any section z after considering the stiffness ratio \( E_b/E_s \) of the pile-end soil and pile-side soil is:

\[ f_N(x) = 1 - \left( \frac{nk^3}{\eta^2 + (nk)^2} \right)^{3/2} \]  

(3)

In this formula: k is the correction coefficient and the resistance at the pile end is determined, \( k = \sqrt{\frac{(1-\alpha_p)^2/\eta^2}{1-(1-\alpha_p)^2/3\eta^2}} \); \( \alpha_p \) is the terminal resistance sharing ratio; 
\( \eta = \frac{r}{L} \), r is the radius, and L is the pile length; 
\( x = \frac{z}{L} \), z is any section of the pile body; 
n is the correction coefficient, which is obtained by linear fitting of the graph, and is related to the stiffness ratio \( E_b/E_s \) of the pile-end soil and pile-side soil:

\[ n = a \frac{E_b}{E_s} \cdot x + b \]  

(4)

The coefficient in the formula can be obtained by linear fitting in Figure 1: \( a = 0.77, b = 0.39 \); When the pile is a friction pile, \( a = 0.96, b = 0.47 \);

The share ratio of pile tip resistance in the axial force distribution function is shown in Figure 2, and it can be seen that as the load increases, the share ratio of pile tip resistance also increases. When the pile top load is the same, as the pile diameter increases, the share ratio of pile tip resistance decreases. When the bearing layer is dry sand with a pile diameter of 3.5cm, 5.0cm, and 6.0cm, the share ratio of pile tip resistance to the load on the pile top is 7.16% ~ 25.79%, 9.44% ~ 25.41%, and 6.69% ~ 26.52%. When the bearing layer is a compressed material, the share ratio of pile tip resistance are 4.4% ~ 17.37%, 4.71% ~ 17.08%, and 4.73% ~ 18.05%. This shows that the stiffness of the bearing layer at the end of the pile has an effect on the share ratio of pile tip resistance. The greater the stiffness of the bearing layer, the larger the share ratio of pile tip resistance.
3. Verification of axial force distribution function of flexible single pile

It can be known from Figure 3 and Figure 4 that under the condition of different pile end bearing layer stiffness, the measured axial force distribution diagram and the axial force distribution function of the axial force distribution function are basically the same. The calculated value of the axial force is in line with the measured value. The maximum relative error is 11.835%. When the pile-end bearing layer changes from compressed material to dry sand, that is, the stiffness ratio \( \frac{E_b}{E_s} \) of the pile-end soil and pile-side soil increases, the load-sharing ratio at the pile end changes significantly. The revised axial force distribution function takes into account not only the effect of the aspect ratio of the pile and the ratio of end resistance, but also the effect of the stiffness ratio \( \frac{E_b}{E_s} \) of the soil at the end of the pile. The change law of the axial force reflected by the force distribution function is more accurately.

![Figure 3. Axial forces at different load levels when the pile ends are dry sand](image-url)
4. Conclusion
In this paper, the axial force distribution function is modified by considering the stiffness ratio of the pile-end soil to the pile-side soil. The results show that the influence of the pile-layer soil stiffness in the axial force distribution function can more accurately simulate the axial force of the pile body law of change.

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References
[1] Seed, H.B. and Reese, L.C., The Action of soft Clay Along Friction Piles [J]. ASCE, transactions, 1957.
[2] Liang Jinguo, Ding Jihui, et al. Analysis of bearing behavior of single pile based on pile axial force distribution function [J]. Geotechnical Engineering Technique. 2015, 29 (6): 306-310.
[3] Xi Ningzhong. Numerical analysis of the influence of pile end soil stiffness on pile side resistance [J]. Chinese Journal of Geotechnical Engineering, 2011, (33): 174-177.
[4] Ai Z Y, Han J. Boundary element analysis of axially loaded piled embedded in a multi-layered
soil [J]. Computer and Geotechnics, 2009, 36(3): 427-434.

[5] Liu Kaifu, Xu Jiapei, Cao Linglong. Numerical analysis of bearing behavior of composite foundation with rigid flexible piles and reinforced cushions [J]. Journal of Zhejiang Sci-Tech University (Natural Sciences Edition), 2018, 39(3): 372-377.

[6] Zhao Chunfeng, Liu Fengming, Qiu Zhixiong, etc. Bearing behavior of single pile under combined action of vertical and horizontal loads in sand [J]. Chinese Journal of Geotechnical Engineering, 2015, (01): 183-190.