

Load Transferring Characteristics of Expanded Pile with Cement Mortar Mixture for Pipe Pile

Shijie Hou^{1,*}, Benlin Ying², Yonghao Zhang³

¹ Zhengzhou Metro Group Co., Ltd., Zhengzhou 450000, China

² China Railway Seventh Group Zhengzhou Engineering Co., Ltd., Zhengzhou 450052, China

³ School of Water Conservancy and Transportation, Zhengzhou University, Zhengzhou 450001, China

*Corresponding author e-mail: Houshijie@163.com

Abstract. Two kinds of interface shear force transmission models of expanded pile are introduced in combination with FRIC subroutine. ABAQUS is used to carry out numerical analysis to study the load transfer characteristics of expanded pile under vertical load. The results show: the load on the top of the pile is transmitted by the strong cohesive force between the pipe pile and the expanded interface. Under the vertical load, the axial stress of the pipe pile in the expanded pile gradually decreases with the increase of depth, and the axial stress of the expanded part increases first and then decreases with the depth. With the increase of pile length, pipe pile diameter or expansion thickness, the axial stress of pipe pile increases as a whole. With the increase of pile length, the axial stress of the expansion body increases gradually, and with the increase of pile diameter or expansion thickness, the axial stress of the expansion body decreases gradually. The axial stress of the pipe pile in the equal core part of the non-equal core expanded pile gradually decreases with the increase of depth, and the axial stress of the expanded body increases with the increase of the pile length.

Keywords: FRIC subroutine, load transfer characteristics, shear force transmission models.

1. Introduction

An expanded pile is a composite pile composed of a pipe pile and an expanded part. According to the different construction technologies, pipe pile types or packaging materials are called stiffened composite pile [1], pipe pile soil-cement composite pile [2], concrete core soil-cement mixing pile[3], and soil-cement combined pile[4], etc. Such pile types have the advantages of a small construction environmental impact, good bearing performance, and low cost [5].

At present, the research on the expanded pile focuses on the bearing performance. Jamsawang et al.[6] studied the influence of the cross-sectional area of the inner core and the length of the inner pipe pile on the ultimate bearing capacity of the stiffened composite pile through field tests and gave two failure modes for the stiffened composite pile. Bergado et al.[7] carried out numerical modeling of the bearing performance of stiffened composite piles. Simulation analysis explored the effects of the length of the pile on the total pile length and the ratio of the cross-sectional area to the total area on the bearing capacity of a single pile. The effects of the ratio of pipe pile length to total pile length and the ratio of pipe pile cross-sectional area to total area on the bearing capacity of a single pile are discussed. Wonglert et al.[8] used numerical simulation and laboratory model tests to study the effects of inner core length, interface size, and material on the bearing performance and settlement deformation of rigid composite piles and proposed three failure modes for rigid composite piles. Concerning the study on the load transfer law of the expanded pile, Dong Ping et al.[9] believe that when the rigid composite pile bears a vertical load, the load transfers from top to bottom, forming a "double-layer diffusion mode". Li Jinjun [10] further studied the load transfer mechanism of rigid composite piles, and the results showed that part of the load borne by precast concrete pipe piles was transferred to the external pile by the friction resistance on the contact surface of the inner and outer piles, and the other part of the load was transferred to the deep soil-cement piles by pipe piles. The



load transfer system with decreasing modulus formed by reinforced concrete pipe piles, expanded cement soil mixing piles, and soil around piles makes rational use of material properties and has good economic benefits.

The expanded part of the pipe pile is made of a special cement mortar material that has good fluidity and compressive strength up to more than 20 MPa. Two construction methods can be adopted: the grouting around the pipe pile and the extrusion and expansion of the pre-grouting pipe pile. This kind of expanded pile has high strength of expanded material, strong construction adaptability, and adopts prefabricated pipe piles, which improves the prefabricated assembly rate of foundation engineering, so it has high engineering popularization and application value.

2. Numerical Model

The soil layer and its basic physical and mechanical parameters in the full-scale test site of a cement mortar mixed pipe pile with an expanded pile are shown in Figure 1.

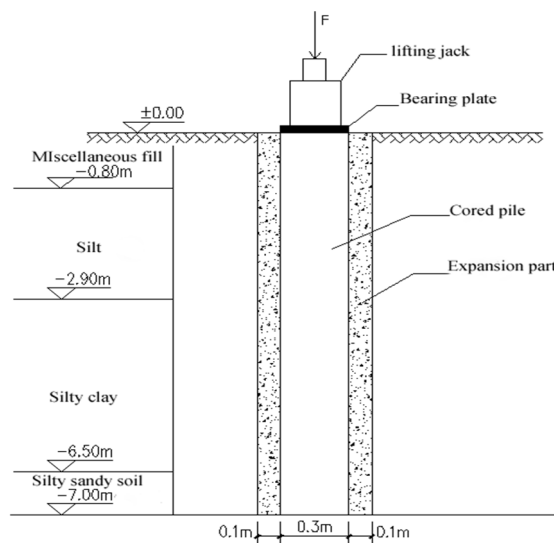


Figure 1. Diagram of test loading and vertical arrangement of measuring points

The test pile and the expansion part are equal in length, both 7.0 m; The pile diameter is 500 mm, the pipe pile diameter is 300 mm, and the radial thickness of the expansion body is 100mm. The core pile is a PHC pipe pile, and the cubic compressive strength of the expanded cement mortar mixture reaches above 8.0 MPa. The test pile was constructed by injecting pipe pile around the pile, and the vertical loading test was carried out using the slow sustained load method.

The interface mechanical model was introduced by the FRIC subroutine to define the friction model to calculate the load deformation of the expanded pile. The force transfer model and parameter value were adopted for the contact surface between the pipe pile and the expanded part, and the pile-soil contact surface followed the shear softening model. The mesh division of the finite element model is shown in Figure 2.

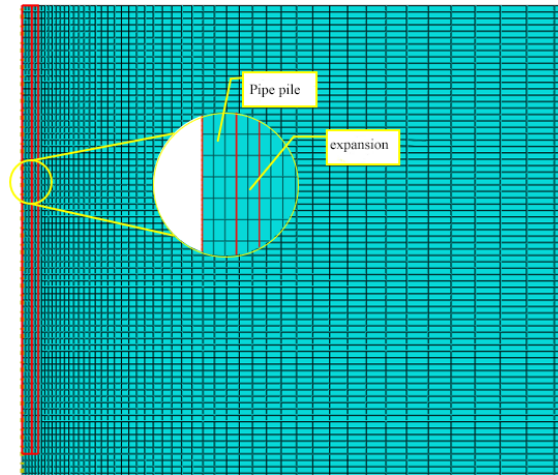
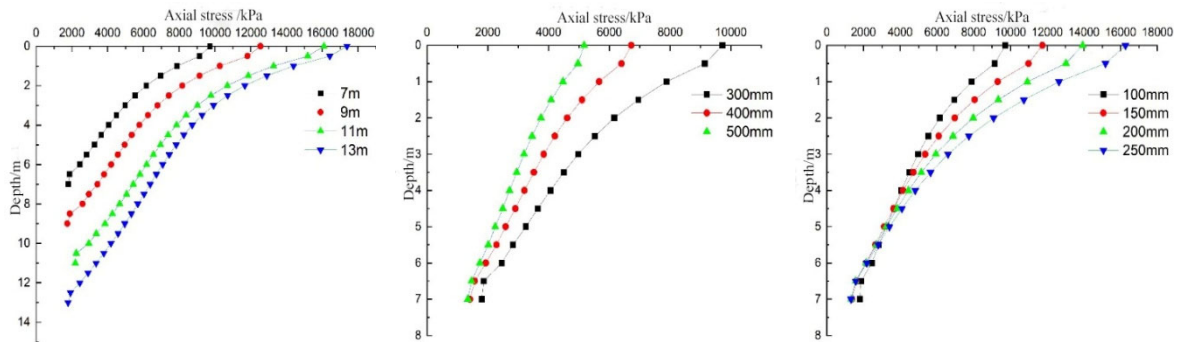


Figure 2. Grid division diagram

3. Load transfer law of equal-core expanded pile

Taking the pile top settlement of 40mm as the ultimate bearing capacity standard, the influence of changing pile length, pipe pile diameter, and expansion thickness on the load transfer behavior of a single pile is analyzed.

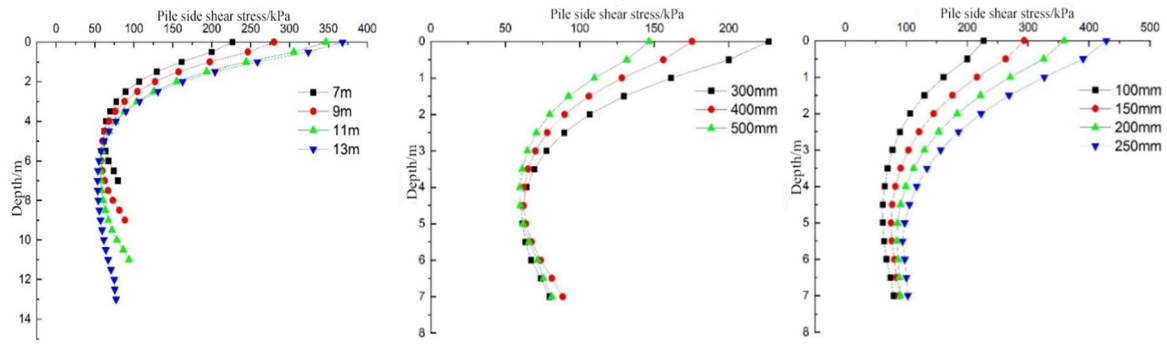
As shown in Figure 3, the axial stress distribution of pipe piles remains unchanged when the pile length, pipe pile diameter, or expansion thickness are changed. With the increase of pile length, pipe pile diameter, or expansion thickness, the axial stress of the pipe pile increases as a whole, and the increase of pile length on the lower part of the pipe pile is more significant than that on the upper part, while the increase of pile diameter or expansion thickness is the opposite.



(a) different pile length (b) different pipe pile diameter (c) different expansion thickness

Figure 3. Core pile axial force distribution curves of expanded pile under ultimate bearing capacities

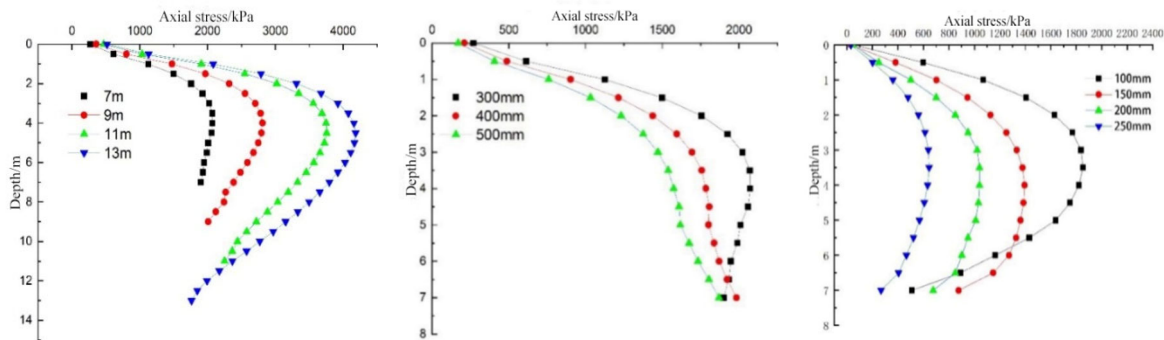
As shown in Figure 4, when pile length, pipe pile diameter, or expansion thickness are changed, the distribution law of lateral shear stress of the pipe pile is large in the upper part and small in the lower part, decreases rapidly, and then increases slightly along the depth direction. With the increase in pile length, the lateral shear stress of the pipe pile increases obviously in the upper part of the pile but decreases in the lower part. With the increase in pipe pile diameter, the lateral shear stress of the pipe pile decreases obviously in the upper part of the pile but changes little in the lower part. By increasing the thickness of the flared body, the pile lateral shear stress increases significantly in the upper part of the pile and very little in the lower part. .



(a) different pile length (b) different pipe pile diameter (c) different expansion thickness

Figure 4. Distribution diagram of pile side resistance

As shown in Figure 5, when pile length, pipe pile diameter, or expansion thickness are changed, the axial force of the expansion body presents a distribution law of small upward and large downward. With the increase in pile length, the axial stress of the expansion body increases gradually, and the axial stress curve of the expansion body shows a trend of increasing and decreasing. With the increase of pipe pile diameter or expansion thickness, the axial stress of the expansion body gradually decreases, and the axial stress curve of the expansion body presents a trend of increasing, slowly decreasing, slowly increasing (decreasing), or increasing and decreasing.



(a) different pile length (b) different pipe pile diameter (c) different expansion thickness

Figure 5. Axial force distribution of expanded part

The distribution of axial stress in the expansion body shows that most of the load transferred from the upper part of the pipe pile to the expansion body is not transferred to the soil around the pile but is converted into the axial force of the expansion body. When the expansion body transfers the load, part of the load is transferred to the soil around the pile, which is obvious in the lower part of the pile, while a small part of the load is transferred to the soil at the end of the pile. Therefore, the load presents the transmission characteristics of "pipe pile, expansion body, and soil around the pile", and the expansion body acts as a good load transfer medium.

4. Load transfer law of non-equal-core expanded pile

By changing the length of pipe pile and the length of pipe pile, respectively, three kinds of long core pile and short core pile with different lengths of pipe pile are established. In terms of load transfer characteristics, the vertical load transferred by the upper part of the pipe pile and expansion body is balanced by the side shear stress and the end resistance, which are the same as those of a single pile. In the following sections, the load transfer characteristics of pipe piles and expansion bodies are mainly studied.

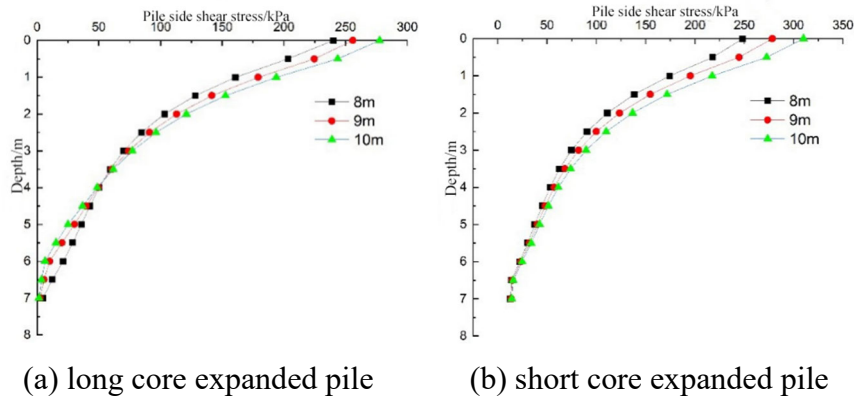


Figure 6. Side resistance of equal core pipe pile of unequal core expansion pile

As shown in Figure 6, the lateral shear stress of pipe piles in two kinds of expanded piles presents a distribution law of large upper and small lower. With the increase in length of the pipe pile or expanded pile, the lateral shear stress of the two kinds of expanded pile increases obviously in the upper part. In the lower part, the long-core expanded pile decreases, while the short-core expanded pile remains basically unchanged. The lateral shear stress curve of the two kinds of piles decreases along the depth direction, and the decay rate is faster with the longer pile.

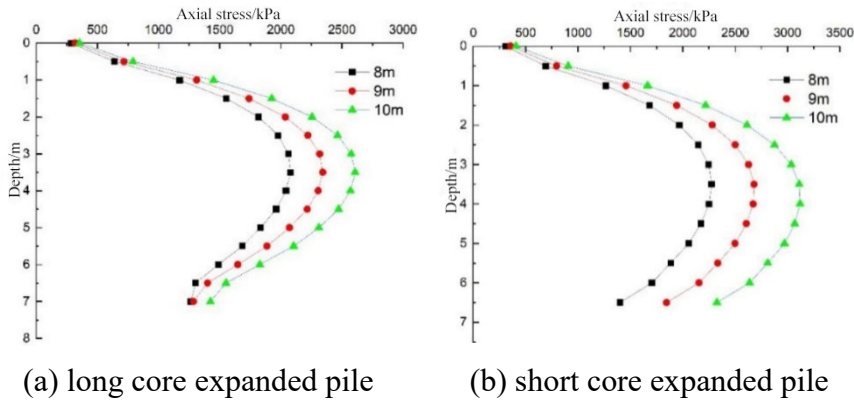


Figure 7. Axial force of equal core part of non-equal core expanded pile

As shown in Figure 7, the distribution law of the axial stress curve of an expanded pile first increases and then decreases along the depth, and the axial stress also increases with the increase in pile length.

As shown in Figure 8, the axial stress of pipe piles of two kinds of expanded pile gradually decreases with the increase in depth, and the decreasing trend is more obvious on the pile body, where the end of the curve is close to vertical.

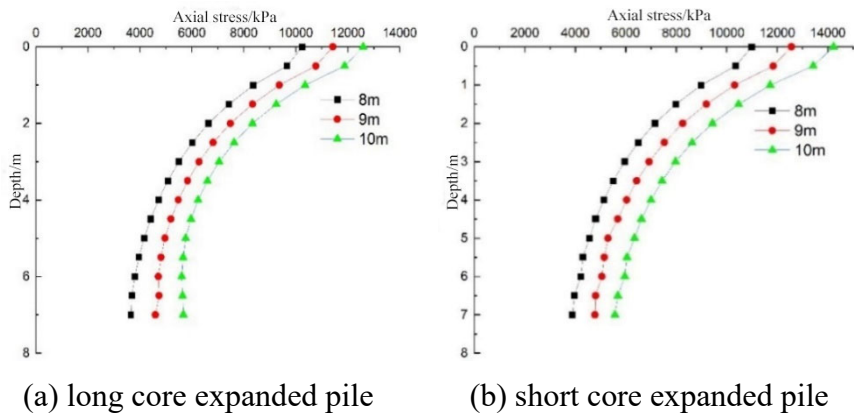


Figure 8. Axial force of equal core pipe pile of unequal core expansion pile

5. Conclusion

Based on a full-scale test and an interfacial shear force transfer model, the load transfer behavior of a pipe pile with a cement mortar mixture under the influence of different parameters is simulated and analyzed. The main conclusions are as follows:

- (1) Pipe pile cement mortar mix expanded pile through the strong bond between pipe pile and expanded interface synergistically transfers pile top load. Compared with the pipe pile, the stress level of the expanded part of the pile is lower, and the strength of the expanded material can meet the requirements of the common load of the pile.
- (2) Under vertical load, the axial stress of the pipe pile in an expanded pile gradually decreases with the increase in depth. The axial stress of the expanded part increases first and then decreases with the depth. The load is characterized by "pipe pile, expansion body, and soil around pile".
- (3) With the increase of pile length, pipe pile diameter, or expansion body thickness, the axial stress of the pipe pile increases as a whole. With the increase of pile length, the axial stress of the expansion body gradually increases, while with the increase of pipe pile diameter or expansion body thickness, the axial stress of the expansion body gradually decreases. With the increase of pile length or expansion thickness, the load transfer efficiency of the top of the pipe pile increases, but with the increase of pile diameter, the load transfer efficiency of the top of the pipe pile decreases.
- (4) The load transfer law of non-equi-cored piles in equi-cored piles is consistent with that of equi-cored piles, while the load transfer law of non-equi-cored piles is the same as that of single piles. With the increase in pile length, the axial stress of the two kinds of pile expanders increases gradually, but in the equal-core part, the load proportion transferred by the long-core expanded pile decreases while the load proportion transferred by the short-core expanded pile increases.

References

- [1] Li Yiqiu. Analysis and research on vertical bearing characteristics of rigid composite pile[D]. Tianjin:Hebei University of Technology, 2018.
- [2] Li Juncai, Zhang Yonggang, Deng Yaguang, et al. Study on load transfer law of tube-cement-soil composite pile [J]. Journal of Rock Mechanics and Engineering, 2014, 33(S1): 3068-3076.
- [3] Dong Ping, Chen Zhengzhou, Qin Ran. Application of cement-soil-mixed pile with concrete core in soft soil foundation [J]. Journal of Geotechnical Engineering, 2002(2): 204-207.
- [4] Wu Mai, DOU Yuanming, WANG Enyuan. Experimental study on load transfer of cement-soil composite pile [J]. Journal of Geotechnical Engineering, 2004(3): 432-434.
- [5] Chen Kun. Experimental study and numerical analysis on the length of stiff-mixing pile pipe [D]. Tianjin: Tianjin University, 2006.
- [6] Jamsawang P, Bergado D T, Voottipruex P. Field behaviour of stiffened deep cement mixing piles[J]. Proceedings of the Institution of Civil Engineers - Ground Improvement. 2011.
- [7] Voottipruex P, Suksawat T, Bergado D T, et al. Numerical simulations and parametric study of SDCM and DCM piles under full scale axial and lateral loads[J]. Computers and Geotechnics, 2011, 38(3): 318-329.
- [8] Wonglert A, Jongpradist P. Impact of reinforced core on performance and failure behavior of stiffened deep cement mixing piles[J]. Computers and Geotechnics. 2015, 69(9): 93-104.
- [9] Dong Ping, Qin Ran, Chen Zhengzhou. Finite element study of concrete-cored soil-cement mixed pile[J]. Geotechnical Mechanics, 2003(3): 32-36.
- [10] Li Jinjun. Experimental study on load transfer law of stiffly mixed pile [D]. Tianjin: Tianjin University, 2006.