Research on character of screw pile group composite foundation used in high-speed railway

Maocai Zhao[1,*], and *Lu* Zhang[2]

[1]School of Transportation Science and Engineering, Harbin Institute of Technology, Harbin, China
[2]China Road & Bridge Corporation, Beijing, China

Abstract. As a result of rapid development of a high-speed railway and infrastructure in China in recent years, the subgrade deformation and settlement control standards put forward more stringent requirements. Based on ABAQUS 6.14, established finite element model of screw pile group composite foundation. Then obtained the settlement, axial force distribution and pile side resistance distribution of center pile of pile group. Next design parameters sensitive analysis was made, such as pile length, pile spacing and so on, in order to obtain a reasonable design pile parameters by analysis of mechanical behavior.

1 Introduction

The high-speed railway line from Harbin to Mudanjiang is 293.2 kilometers long, with a planned investment of more than 35 billion yuan and a design speed of 250 kilometers per hour. There are 12 stations along the line. Construction of the entire line was start in 2015, and the project will be completed by the end of 2018, with a total duration of 54 months. After the completion of the project, Harbin to Mudanjiang operation time only about 80 minutes. This study is based on the foundation reinforcement project of DK24 750.00-DK25 800.00 section of Harbin-Mudanjiang high-speed railway.

2 Screw pile technology

Screw pile and its forming method are referred to as screw pile technology. The screw pile is called semi-helical bored pipe pumping concrete cast-in-place pile. The process of screw pile forming is shown in figure 1.
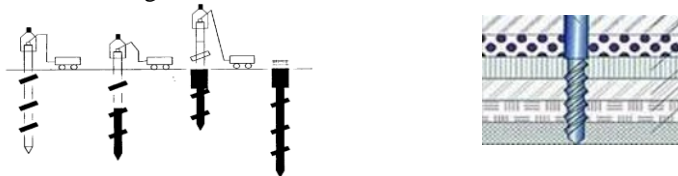

Fig. 1. Screw pile construction procedure diagram

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* Corresponding author: zhao_maocai@126.com

Construction of Zhengzhou-Xuzhou high-speed railway at Yongcheng North Station foundation reinforcement in 2012 was the first time using a new screw cast-in-place pile technology. The excellent bearing capacity of screw pile and the advantages of reducing settlement and deformation of high-speed railway foundation were highlighted for the first time. The cumulative length of using screw pile in high-speed railway foundation reinforcement in China has reached about 500 km.

3 Deformation characteristics of screw pile group composite foundation

3.1 Numerical model of pile group

Using the finite element software ABAQUS 6.14 as the research platform, the numerical analysis model of the screw pile group composite foundation is established, and the settlement of the central pile top, the distribution of the axial force of the pile body and the frictional resistance of the pile side of the screw pile group composite foundation are obtained. The relationship between the working performance of screw pile group (settlement, axial force of pile body and pile side resistance) and pile length $l0$, pile distance D, screw pile thread length l, screw segment ratio k (k=l/l0), pile spacing d, thread spacing S and blade dip angle α are studied in order to find the reasonable parameters of screw pile group design for background engineering. The measured data of geological exploration are shown in Table 1 below.

Table 1. Soil layer material parameter.

No	Soil layer	$\gamma(g/cm^3)$	E(MPa)	μ	c(kPa)	$\Phi(°)$	depth(m)
1	Planting soil	1.95	3.50	0.3	2.9	18.0	-1.1
2	silty clay	1.86	20.55	0.37	10.0	25.6	-6.5
3	silty	1.92	23.76	0.33	8.0	30.5	-12.1
4	silty clay	2.07	24.22	0.41	31	26.8	-14.6
5	Silty, clay	1.96	26.12	0.32	6	31.2	-22.8
6	silty	2.01	28.24	0.31	1	32.5	-24.2.

The simplified model of screw pile group is arranged with 15 piles model and 3 × 5 pile model. The layout of pile group is shown in figure 2.
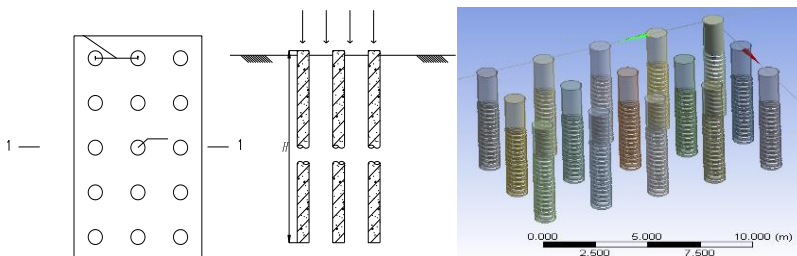

Fig. 2. The simplified model of screw pile group.

3.2 Influence of pile spacing on working characteristics of pile Group Foundation

The model of screw pile group with 2D,3D,4D and 5D pile spacing was established respectively. The parameters of screw pile group are shown in Table 2.

Table 2. The parameters of screw pile group.

l_0(m)	D(m)	E(GPa)	μ	k	S(m)	α (°)
26	0.5	30	0.17	0.6	0.5	25

3.2.1 Analysis of load-settlement relation

The calculation results of the settlement of the central pile top and the load on the top of the pile are as shown in Fig. 3.
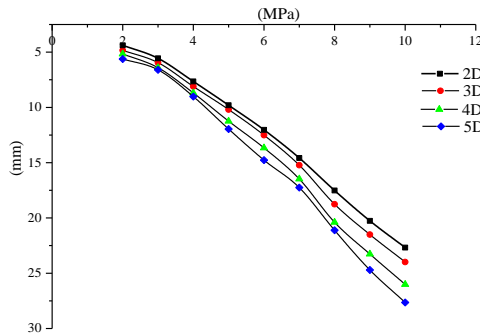

Fig. 3. Load settlement curve of screw group piles with different pile-spacing D.

Figure 3 shows that: 1) in general, with the increase of pile top load, the settlement of pile top increases with the increase of pile top load, and the settlement caused by group piles without destructive instability increases sharply under the condition of fixed pile spacing. 2) under the same load condition, the smaller the pile spacing is, the more obvious is the clamping effect of screw pile on the soil between the foundation piles, so the settlement of the pile top is smaller. But it can be seen that the increase of pile spacing from 2D to 5D is not very significant.

3.2.2 Analysis of pile side friction

In order to further study the influence of pile spacing change on the working performance of pile group, the frictional resistance of central pile of each pile group model is extracted separately, as shown in figure 4.
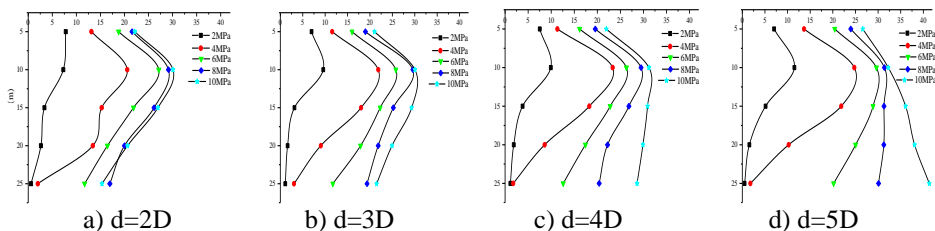

a) d=2D   b) d=3D   c) d=4D   d) d=5D

Fig. 4. The variation of frictional Resistance along the length of the pile with the load exerted on the Center pile.

From figure 4, it can be seen that the lateral friction of pile in pile group also develops from top to bottom with the increase of load: 1) when the pile spacing is below 4D, the center pile side resistance is the largest, the lower side friction is the second, and the upper side friction is next, and four kinds of (pile spacing) can be found in the case of the center pile side friction, the second is the lower side friction resistance, and the latter is the upper side friction resistance. The upper side friction increases with the increase of load, but with the increase of load from 2MPa to 10MPa, the upper pile side friction increases gradually from 7kPa to 25kPA, and there is no softening phenomenon of pile side friction.(2) notice that under the condition of pile spacing 5D and load 10MPa, the pile side friction reaches 26.62kPa, slightly larger than the limit lateral friction 24kPa. the analysis should be that the pressure at the bottom of the pile cap leads to the soil compression of the pile top. Therefore, the increase of soil pressure around the pile results in the increase of lateral friction. 3) from 2D to 5D, the utilization efficiency of pile group piles on soil side friction increases gradually. With the increase of pile spacing, the sensitivity of lateral friction to load increases. At the same time, compared with the 10MPa load, it is found that the larger the pile spacing, the greater the lateral friction, such as from 2D to 5D, and the lateral friction increases from 15.33kPa to 41.32kPa at 25m.

3.2.3 Reasonable pile spacing selection

From the result of settlement and deformation calculation, if the pile spacing is too large, the settlement of pile top will increase, and the deformation of pile group composite foundation will be too large. If the pile spacing is too small, the pile-soil displacement under the pile will be too small, and the frictional resistance of the bottom pile will not be brought into full play, that is, the utilization efficiency of soil around the foundation pile is low. At the same time, the cost of foundation reinforcement will also increase significantly because of the increase in the number of piles.

Therefore, considering the economic and performance factors, the reasonable pile spacing of screw pile group is 4D.

3.3 The influence of pile length on the working characteristics of pile Group Foundation

Considering the engineering background, the depth of foundation bearing layer is 22.8m, and the pile length parameter of numerical simulation is 10m,14m,17m, 20m,23m and 26m. The parameters of screw pile group are shown in Table 3.

Table 3. The parameters of screw pile group.

D(m)	E(GPa)	μ	l0	S(m)	k	α (°)
2	0.5	30	0.17	0.6	0.5	25

3.3.1 Analysis of load-settlement relation

The influence of pile length on the top settlement of central pile under different load levels is shown in Fig. 5.
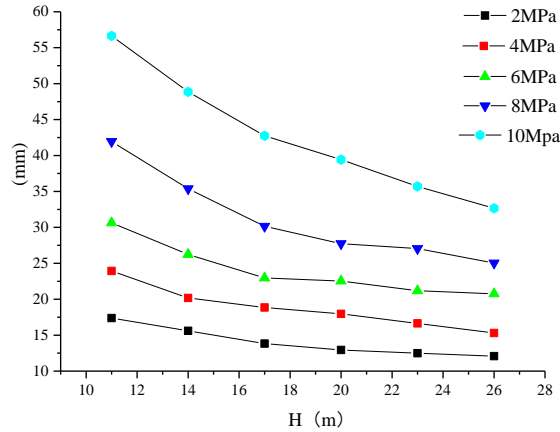
Fig. 5. The influence of pile length on the top settlement of central pile under different load levels.

As you can see from figure 5: 1) as a whole, with the increase of pile length, the settlement of the pile top of the screw pile group decreases from 17.39mm to 12.08 mm. under the load of 2MPa. At the load level of 2MPa, when the settlement of the pile top decreases from 17.39mm to 12.08mm, the settlement of the top of the pile decreases by 8.64mm at the load level of 30.5 and 4MPa, and the settlement of the pile top decreases by 24.0mm, or 42.4mm, when the pile length increases from 10m to 26m at the load level of 36.1mand 10MPa. Therefore, it can be seen that the higher the load level, the more significant the effect of the increase of pile length on the reduction of pile top settlement; 3) when the pile length of screw group pile increases to 20m, the influence of pile length increase on the settlement decrease tends to weaken.

3.3.2 Axial force analysis of pile body

The axial force of the central pile is extracted from different pile length models, as shown in fig.6

a) $l_0=10m$ b) $l_0=14m$ c) $l_0=17m$

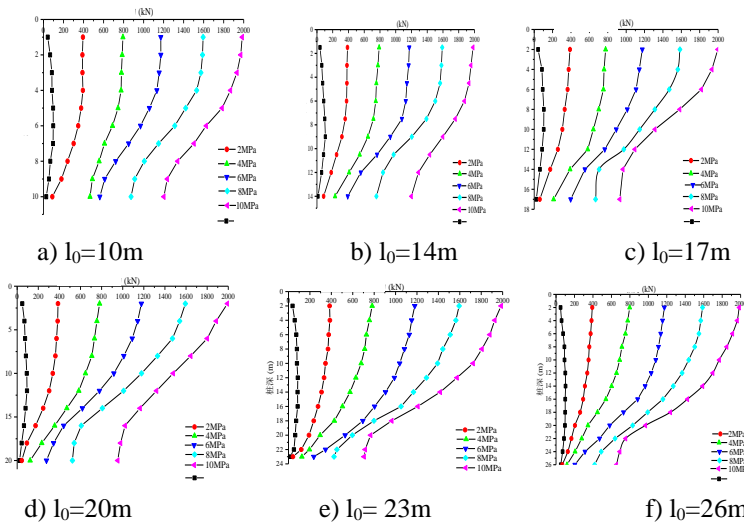d) $l_0=20m$ e) $l_0= 23m$ f) $l_0=26m$

Fig. 6. TheVariation of axial force along the length of central pile with applied load.

As can be seen from fig. 6: 1) with the increase of pile length of screw group, The resistance of central pile under 10m long load is 1201.9kN, while that of 26m long pile has been reduced to 655.1kN. the decrease of pile end resistance has resulted in a large decrease of pile end resistance. The compression deformation is reduced, the settlement of the top of the central pile is reduced. 2) from the simulation results of six conditions, it can be seen that when the load on the top of the pile increases to 4MPa, the axial force of the pile decreases obviously at the end of the pile, which is due to the increase of the resistance at the end of the pile. Under the pile end foundation, the compressive deformation of the horizontal layer increases, which results in the increase of the relative displacement of the pile and soil at the top of the pile, which results in the softening of the pile side resistance. However, the load on the top of the pile with the resistance softening on the side of the 14m pile is increased to 6MPa, 17m,20m,23m and 26m respectively pile side resistance softening is 6MPa,8MPa and 10MPa, respectively. It can be seen that the pile length has a significant effect on the critical load of increasing the pile side resistance softening, and the results show that the pile length has a significant effect on increasing the critical load of the pile side resistance softening. Because of this, the higher the load level, the more obvious the decreasing trend of pile top settlement with the increase of pile length. 3) when the screw pile group grows up to 20m, That is, the difference of axial force between 23m and 26m piles is reduced by 8MPa and 10MPa load. The pile end resistance of 23m long pile is 425.2kN and 705.5kN 26m pile length is 417.9kN and 655.1kN respectively, which decreases by 1.7% and 7.1kN, respectively, and the increase of pile length is belt. The effect of reducing the settlement and the resistance at the end of the pile tends to weaken.

3.3.3 Pile length selection

When the pile length is too large and the pile group is loaded, the compression deformation of the bottom part of the pile is too small, the resistance of the pile side is small, and the increase of pile length when the pile grows more than 23m has no obvious effect on controlling the settlement, and the increase of pile length leads to the increase of concrete content of pile body. The cost of single pile is increased. The pile length is too small to meet the bearing capacity standard.

Therefore, the comprehensive economic and performance factors of 17m-23m length range can not only meet the requirements of settlement and deformation control, but also maximize the bearing capacity of the foundation and the pile body of the screw group, which is an appropriate design range of pile length.

4 Conclusion

Based on the finite element analysis software, the simplified model of 15 screw piles group is established. By controlling the single factor, the paper analyses the pile spacing and pile length of the screw pile group. Due to the length limitation, the analysis of the length of the thread section and the pitch (blade inclination) is not listed in this paper. The design parameters of the further optimized screw pile group are suggested as follows:

1) the suitable pile spacing of screw pile group is 4D, the settlement of pile top is increased due to the pile spacing, the deformation of pile group composite foundation is too large, and the pile soil displacement under pile is too small, and the frictional resistance of bottom pile is not fully brought into play.

2) the suitable pile length of screw pile group is 17-23 m. When the pile length is too large and the pile group is loaded, the compression deformation of the bottom part of the pile is too small, the resistance of the pile side is small, and the increase of pile length when the

pile grows more than 23m has no obvious effect on controlling the settlement. The pile length is too small to meet the bearing capacity standard.

3) when the ratio of screw group pile thread length k is suitable to take 0.7. When k is too small, the friction on the side of the pile is slightly "slow react", that is, with the increase of the load, the friction on the side of the screw pile is slightly dull when it is too small. The increasing speed of pile side friction along the direction of pile length is too slow and too large. The pile body is easy to produce stress concentration after loading, which results in pile side resistance softening, and the strength of the upper pile side soil decreases to residual strength quickly.

4) The suitable pitch of screw pile group is 0.64-0.94m (the appropriate interval for blade inclination angle is 32°-36°). If the pitch is too small, the pile side resistance will decrease and the settlement will increase. If the pitch is too large, the critical load of lateral resistance softening is reduced.

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