# Numerical Analysis on Influence of Shield Construction to Neighboring Piles

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**Abstract:** By using the finite element software MIDAS/GTS to make a numerical simulation of shield tunnel crossing neighboring pile, and analyses the deformation characteristics of the single pile and pile in groups. Results show that the major deformation form of the short pile is incline during tunneling. For the long pile, bend is the major form. The farther distance between the single pile and tunnel, the smaller the maximum axial force and bending moment of the pile. The deformation and stress of piles in the front row were larger than those of rear row, and the distribution of horizontal displacement, axial force and bending moment of piles in the same row were almost identical. The horizontal displacement of pile in groups is slightly bigger than the single pile at the same location, and the settlement of the pile in groups is slightly smaller.
**Keywords:** shield tunnel, MIDAS/GTS, strata displacement, pile deformation, numerical simulation.

## 1. Introduction

Shield, as a common method of tunnel construction which has made great improvement, still causes strata displacement and ground subsidence. Due to Metro project locate in the area which is crowded with buildings, and most buildings are in the form of pile foundation, sometimes shield tunnel will drive through adjacent to pile foundations, the shield construction will certainly affect the internal force and deformation of pile foundations, and a certain degree of loss will happen to the stability and the safety of upper structure [1]. Therefore, in order to protect the upper structure and to ensure tunnel construction smoothly, the study aims to unveil the effects of tunneling on adjacent pile foundations which will lead us to acknowledge the serious practical significance of this constructing method. Chen L T、Poulos G and Loganathan (1999) [2] have analyzed the deformation of the piles based on the two-stage method. Loganathan（2000）[3] took advantage of centrifuge experiment, in order to simulate the effects of tunneling on adjacent pile foundations. Zhu Feng-bin (2008) [4-5] make numerical simulation results of pile deformation caused by shield tunneling compared with the results of centrifuge experiments. Ding (2014) [6-7] studied the influence of underground pipeline by shield construction by means of finite element method. Yuan haiping and Zhu dayong（2014）[8] have analyzed the stresses and the horizontal deformation of the piles and the ground settlements under different working conditions purring the process of shield advancing based on the mechanical principle of coupled springs for bridge-pile structures and the finite difference method.

Based on the shield tunneling crossing building foundation on Hefei Metro Line1, this paper will use the finite element software MIDAS / GTS to simulate the effects of shield-driven tunnel crossing pile foundations.

## 2. Numerical analysis on influence of shield tunneling to single pile

In this paper, tunneling-induced single pile`s deformation were analyzed by MIDAS / GTS, and the results were compared with the two-stage method.

### 2.1. Numerical model and related parameters of single pile

The shield tunnel has an outside diameter of 6.0m, lining thickness of 0.3m, grouting thickness of 0.15m, and buried depth of 18m. Considering the area that shield tunneling might affect, the distance of 25m was selected as the left and right margins, and the distance from the center of tunnel to the bottom of model is 19m. The width of the final model is 50m, height is 50m, and length is 45m. In order to facilitate the simulate calculation, the longitudinal length of each tunnel excavation is 1.5m. The soil is divided into four layers, and its constitutive model is Mohr- coulomb [9] physico-mechanical parameters of materials are shown in table1.

**Table1 Physico-mechanical parameters of materials**

| Material | Gravity density (KN/m$^3$) | Elastic modulus (MPa) | Poisson ratio | Cohesion(kPa) | Fric (°) |
|---|---|---|---|---|---|
| Miscellaneous fill | 16.5 | 9.2 | 0.43 | 14 | 19.4 |
| Plastic clay | 19.1 | 17.9 | 0.35 | 15 | 38 |
| Hard plastic clay | 19.7 | 24.8 | 0.33 | 15 | 42 |
| Base rock | 27 | 450 | 0.21 | 35 | 56 |
| Grouting material | 20 | 100 | 0.3 | 291 | 30 |
| lining segment | 25 | 30000 | 0.2 | | |
| Piles and pile caps | 26.2 | 35000 | 0.2 | | |

## 2.2 The results of numerical simulation of single pile's displacement

Numerical analysis changed length and position of the pile to study the features of pile behavior caused by tunneling.

(1)Analysis of single pile's vertical displacement in different lengths

Piles in different lengths were put at right side of shield tunnel, stayed in the same horizontal and the interval between the pile and the tunnel was 5m. As figure 1 shows, when the pile length is 15 m, the change of the vertical displacement along the pile shaft is small and its values are about 5.5 mm. The reason is that piles' axial stiffness is much larger than soil's, so the piles' compression deformation caused by shield tunneling is very small, which makes the whole pile shaft have consistent subsidence trend. When piles' length exceeds 19m, the bottom of the pile is below the embedment depth of shield tunnel and the settlement of strata around piles' bottom is small. Therefore, the vertical displacement of the pile reduces as its length increases.

In addition, as figure 1 shows, single pile's vertical displacement analyzed by two-stage method is larger than the calculation results of MIDAS/GTS, but they have the same change trend. The reason is that without considering the interaction between the pile and the surrounding strata during the calculation process of the two-stage. [10-12]

(2)Analysis of single pile's vertical displacement in different locations

This paper simulates the changes of the piles' vertical displacement in the process of shield tunneling at different locations of the tunnel. As the figure 2 shows, the maximum vertical displacement is located at the top of the pile, as the piles' depth increases, the vertical displacement decreases slightly. In addition, the vertical displacement of the pile increases as its distance to the shield reduces. Before the shield reaches the bottom of the pile, as the figure indicates, the vertical displacement of the pile increases while its distance from it to shield decreases, and the maximum appears in the shield leaving. After that, with the strata restore balance gradually, pile's vertical displacement decreases slightly.

(3)Analysis of single pile's horizontal displacement in different lengths

As figure 3 shows, when the piles' length reaches 15 m, the upper part of the pile inclined towards the tunnel and the bottom of the pile deviate from the tunnel direction, the major deformation form of pile is incline. When the pile's length exceeds 19m, it can be seen from the figure that the curve of the pile's horizontal displacement appeared two turning points, the bending deformation of the pile shaft is more obvious. The reference [13] believes that the reasons for the above-mentioned phenomena is: with the increase of pile's length, it gradually left the influence area of tunnel excavation. In addition, its slenderness ratio also increases, which makes the pile shaft occur significant bending.

(4)Analysis of single pile's horizontal displacement in different locations

The changes of the piles' horizontal displacement in the process of shield tunneling at different locations of the tunnel are shown in the figure 4. Results show that the horizontal displacement of the pile is inversely proportional to the distance from the pile to center of the tunnel. Piles' bending deformation reduces as its distance to the shield increases, and the changes trend of the horizontal displacement along the pile shaft is consistent with the mentioned above.

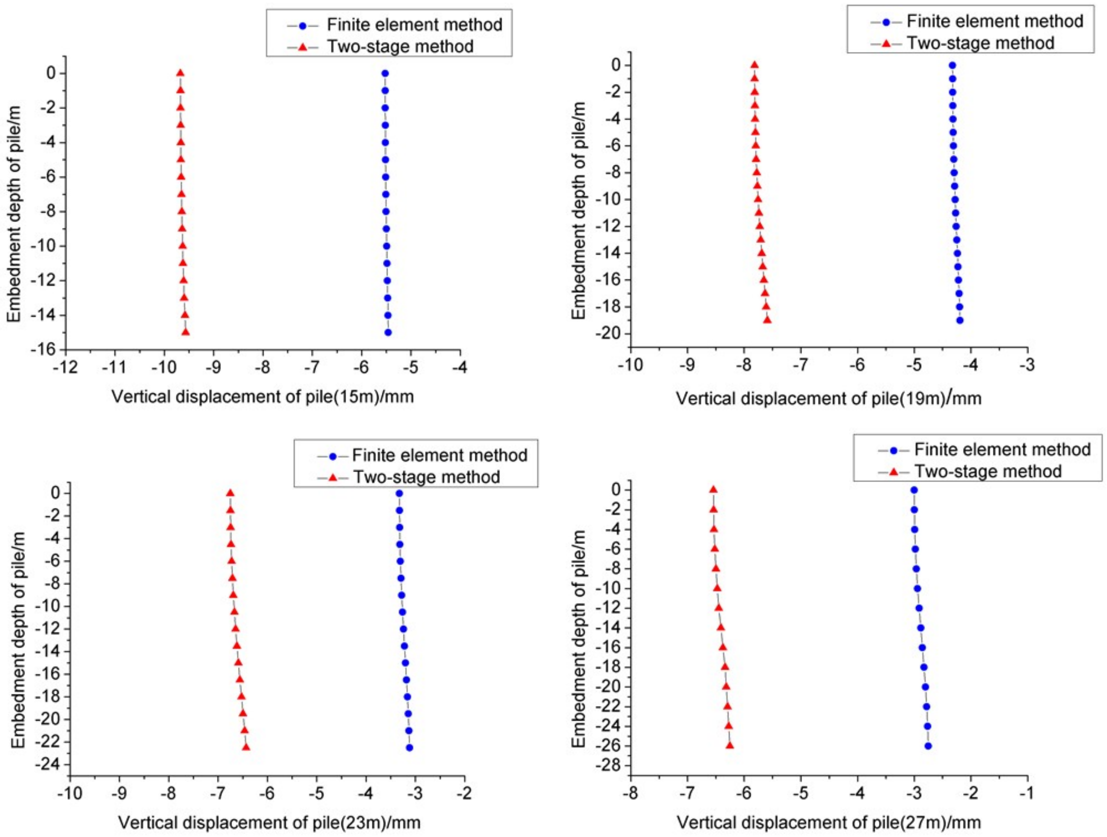


**Figure1 The vertical displacement of the pile in different lengths**

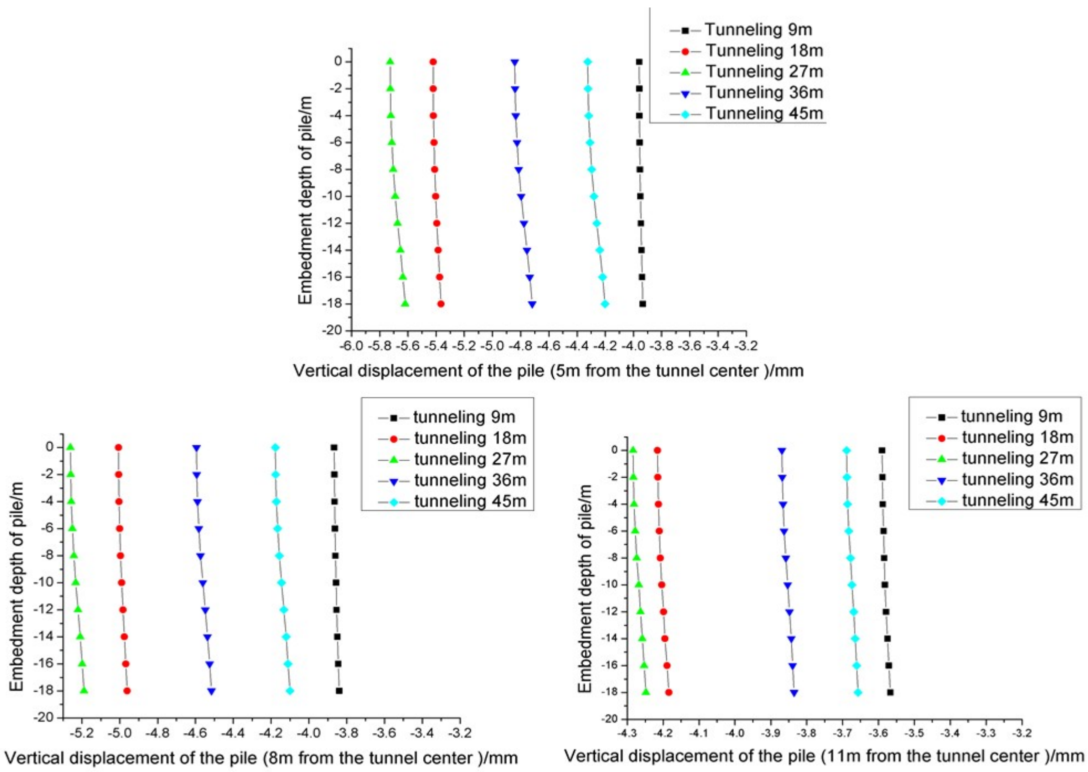


**Figure 2 The vertical displacement of the pile in different locations**

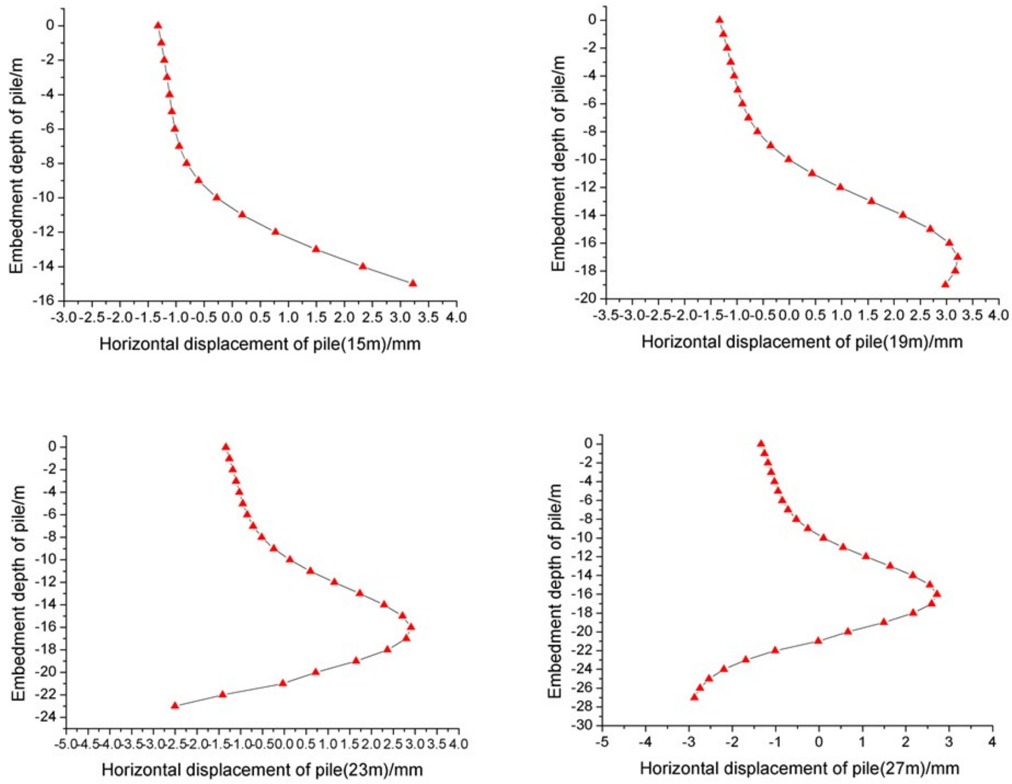


**Figure 3 The horizontal displacement of the pile in different lengths**

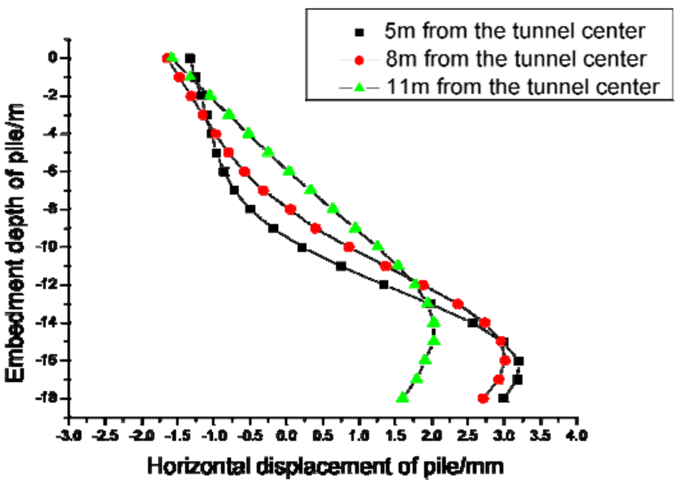


**Figure 4 The horizontal displacement of the pile in different locations**

## 2.3 The results of numerical simulation of single pile's additional axial force

(1)Analysis of single pile's additional axial force in different lengths

As figure 5 shows, when the pile length reaches 15 m, except for the pile top appeared a small portion of axial tension, the remaining part of the piles' stress were performed axial pressure. When the piles' length exceeds 19m. As figure indicates, the additional axial force of pile shaft is mainly for axial pressure. In addition, the upper part of piles' additional axial pressure increases with the increasing value of piles' depth, while the lower part of piles' additional axial pressure reduces as the value of piles' embedment depth increases. The reason is that when the pile is longer, the strata around the upper part of the pile have a significant settlement, and the relative displacement between the strata and pile produced a negative skin friction on the piles' surface, which makes the axial force of pile increase. While the settlement of pile and surrounding strata are equal, the axial force of pile reaches the maximum. Footnotes avoid using footnotes.

In addition, as figure 5 shows, the changes trend of the piles' additional axial force calculated by MIDAS/GTS are similar to those calculated by two-stage method, but the results of two-stage method is larger. The maximum piles' axis pressure which is calculated by two methods are both occur near the tunnels' embedment depth. The reasons for such changes are as mentioned above.

(2)Analysis of single pile's additional axial force in different locations

The changes of the piles' additional axial force in the process of shield tunneling at different locations of the tunnel are shown in figure 6. It indicates that due to the impact of tunneling decreases with the increase in distance between the pile and tunnel, the additional axial force of pile shaft is small. The reasons for such changes are as mentioned above.

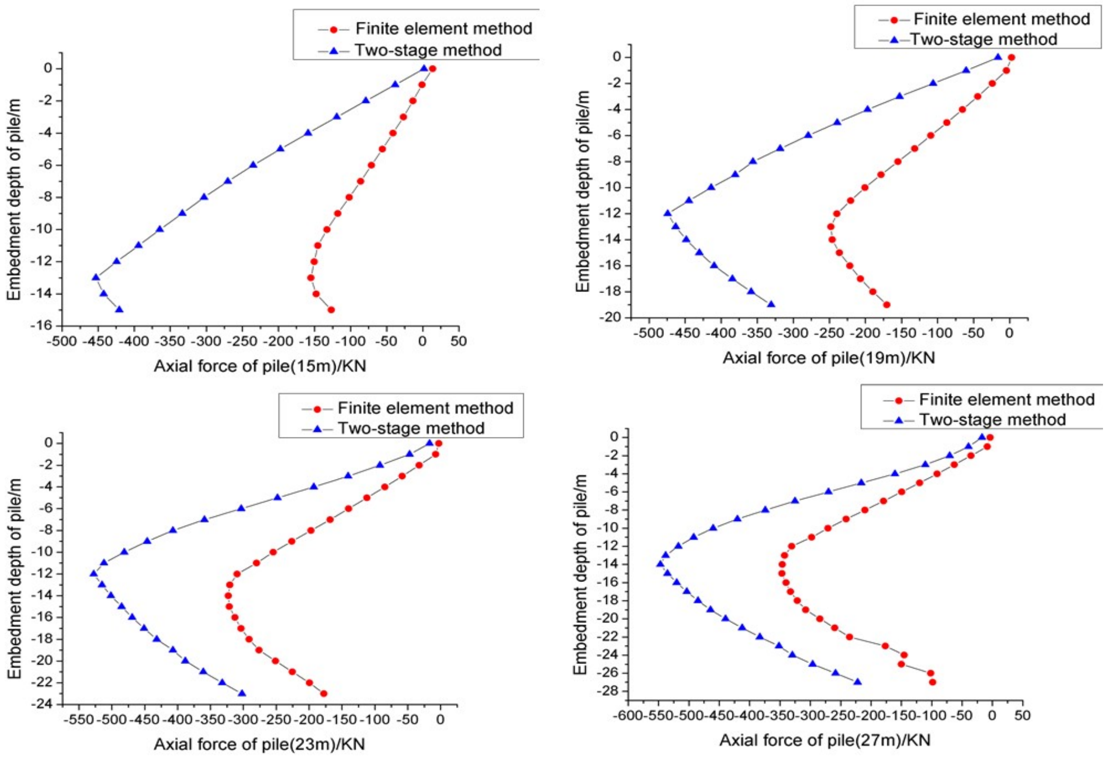


**Figure 5 The additional axial force of the pile in different lengths**

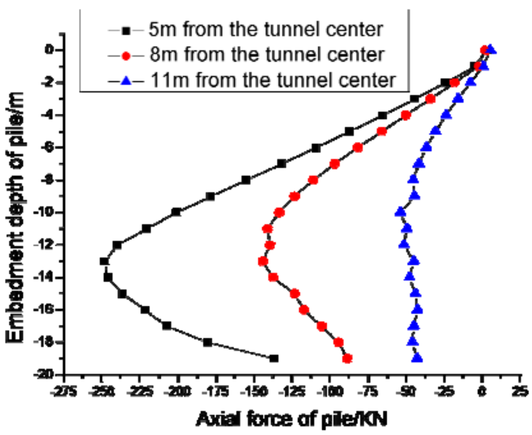


**Figure 6 The additional axial force of the pile in different locations**

### 2.4 The results of numerical simulation of single pile's additional bending moment

As figure 7 shows, piles in different lengths were put at right side of shield tunnel and the interval between the pile and the tunnel was 5m. With the piles' embedment depth increases, there is a little change in the upper part of piles' additional bending moment which caused by tunneling. The piles' additional bending moment increases suddenly when the embedment depth of the pile is close to the tunnel. Later, accompanied with the continuous increase of piles' embedment depth, the additional bending moment of pile begins to decrease. In addition, as figure 7 indicates, piles' maximum bending moment increases with increasing value of its length. It also can be seen from the figure 7 that the maximum bending moment occurs near the tunnels' embedment depth, this is because that the additional bending moment of the pile is related to its horizontal displacement.

When the piles' length are equal, as figure 8 shows, the additional bending moment of it is inversely proportional to the distance from the pile to the center of the tunnel and its value reaches 119.3KN • m while horizontal distance from it to the center of the tunnel is 11m.

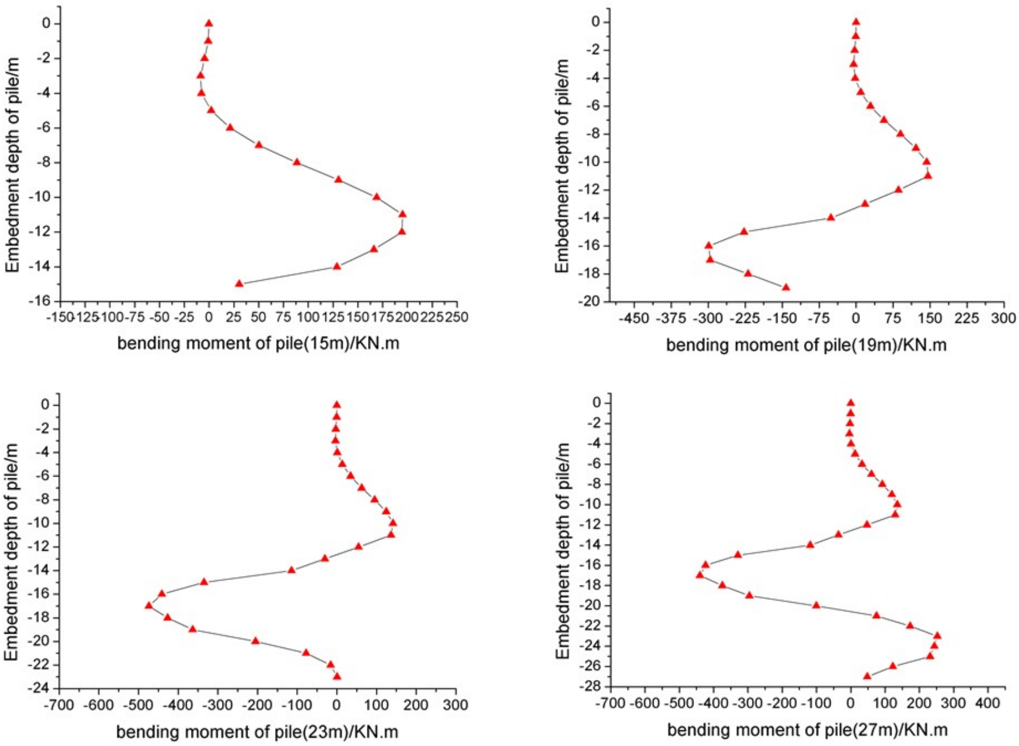


**Figure 7 The bending moment force of the pile in different lengths**

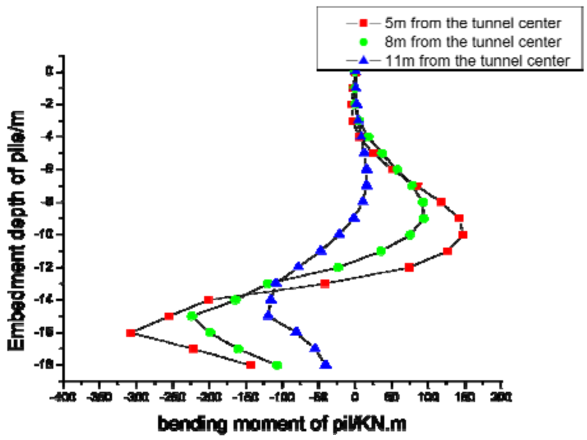


**Figure 8 The bending moment force of the pile in different locations**

## 3. Numerical analysis on influence of shield tunneling to pile in groups

This research is based on shield tunneling construction of Hefei city metro line 1, and uses MIDAS/GTS to analyse the deformation characteristics of the single pile and pile group induced by shield tunneling.

### 3.1. Numerical model and related parameters of pile in groups

The size of the model and physico-mechanical parameters of materials are as mentioned above. Plane positional relationships between group piles and tunnel are shown in Figure 9.

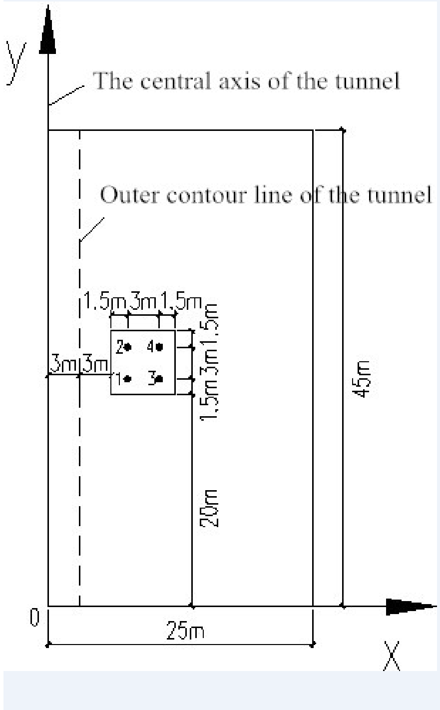


**Figure 9 Plane positional relationships between group piles and tunnel**

### 3.2. Analysis of vertical displacement of pile in groups

As figure 10 shows, the vertical displacement of piles in the front row were larger than those of rear row. Above phenomenon occurs for two reasons: firstly, piles in the front row, which are the closest to the center of tunnel, so the strata subsidence of this area is greater. Secondly, the piles in the front row had a shielding impact on the green field soil displacement. Finally, it makes the vertical displacement of the piles in front row are less than those in the rear row.

In addition, as figure 10 shows, the vertical displacement of each pile along the pile shaft are basically remain unchanged, the reason is that pile's axial stiffness is much larger than soil's. Due to the group piles' contribution to the stiffness of the soil around the pile is greater than single piles' contribution, which makes the vertical displacement of piles in the front row were larger than those of rear row.

### 3.3. Analysis of horizontal displacement of pile in groups

As figure 10 shows, the changing rule of piles' horizontal displacement in the front row was of little difference with the pile in the rear row. The upper part of the pile inclined towards the tunnel while the bottom of the pile deviate from the tunnel direction, and the maximum horizontal displacement occurs near the tunnels' embedment depth. The reason for this phenomenon have been mentioned in the above.

In addition, the horizontal displacement of piles in the same row were almost same, but those of piles in the front row were larger than those of rear row. This is because the center of the tunnel near the front row piles, so the strata's horizontal displacement induced by shield tunneling have great effect on piles in the front row. It also can be seen from the figure 10 that the changing rule of the group piles' horizontal displacement was of little difference with those of single pile at the same position, but the maximum horizontal displacement of pile group exceeded the single pile of the same position.

### 3.4. Analysis of additional axial force of pile in groups

As figure 10 shows, the additional axial force of pile group is mainly for axial pressure. The upper part of piles' additional axial force is proportional to the embedment depth of pile, however, the lower part of piles' additional axial force is inversely proportional to the piles' embedment depth. The maximum additional axial force occurs near the tunnels' embedment depth and the reasons for this phenomenon have been mentioned in the above.

In addition, as figure 10 indicates, the additional axial force of piles in the same row were almost supposed. In contrast to the single pile at the same position, there was a larger maximum additional axial force of the pile in groups, but they have the same changes trend.

### 3.5. Analysis of additional bending moment of pile in groups

As shown in figure 10, the changing rule of the piles' additional bending moment in the front row was of little difference with the pile in the rear row and the maximum additional axial force occurs near the tunnels' embedment depth. This is because that the additional bending moment of the pile is related to its horizontal displacement and this conclusion is consistent with the case of single pile. In addition, the additional bending moment of piles in the front row were larger than those of rear row, and the distribution of bending moment in the same row were almost identical.

In contrast to the single pile at the same position, the upper part of group piles' flexural deformation is more obvious, and the lower part of its flexural deformation is close to the single pile at the same position.

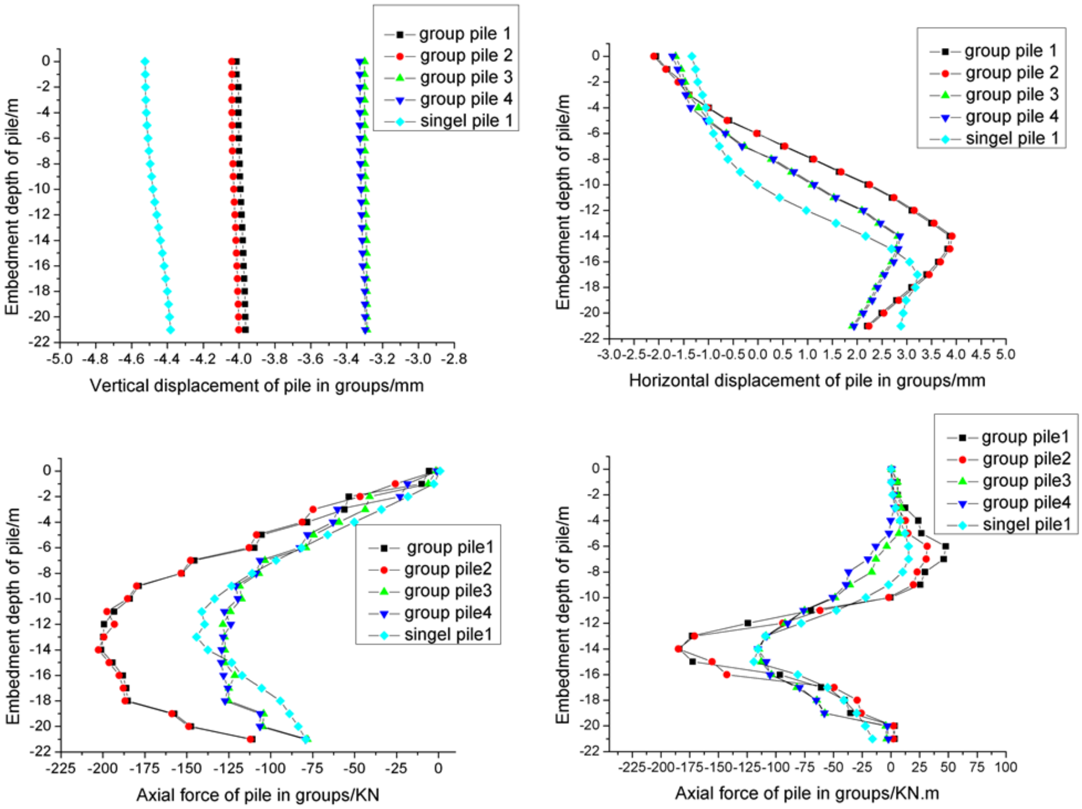


**Figure 10 The mechanical behavior characteristics of pile in groups**

## 4. Conclusions

The major deformation form of short pile is incline during tunneling. For the long pile, bend is the major form. The pile length influence the deformation of a pile observably, especially when the pile end is under the depth of tunnel buried. The farther the distance between single pile and tunnel, the smaller the maximum axial force and maximum bending moment of the single pile. When the distance between them reached a certain degree (12m in this paper), axial force and bending moment of the pile can be neglected. The deformation and internal force of piles in the front row were bigger than those in the back row. As piles located in the same row, the changes of horizontal displacement, axial force and bending moment are basically identical. The horizontal displacement of pile in groups is slightly bigger than single pile at the same location, and the settlement of the pile in the groups is slightly smaller. The maximum bending moment of pile in groups compared with those of single pile at the same location, were basically same, and maximum axial force of pile in groups is slightly smaller.

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