Research on tunnel ground settlement characteristics by shield method and pipe-jacking method based on numerical simulation

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Abstract. Based on a shield tunnel, the ground settlement by shield method and pipe-jacking method in straight tunnel and curve tunnel was studied. The ground settlement curves by the two methods were analyzed by numerical simulation. Compared with straight tunnel, the ground settlement trough in curve tunnel is shifted to the bending direction by about 0.5D. The overall ground settlement difference between shield and pipe-jacking method is relatively small in straight tunnel, and the settlement in curve tunnel by pipe-jacking method is more than that by shield method. With the excavation of the tunnel, the ground settlement trend in curve tunnel is more obvious than that in straight tunnel. And the settlement difference is relatively large in the middle of the tunnel for both straight tunnel and curve tunnel.

1. Introduction
In recent years, with the rapid development of underground space in China, more and more tunnels are constructed by shield or pipe-jacking method, and relevant research on the ground settlement has been carried out.

Xu [1] analyzed some important factors influencing ground settlement in rectangular pipe-jacking construction; Yu et al. [2] obtained the maximum deformation position of shield tunnel excavation by numerical simulation; Li [3] pointed out that the main factors of stratum settlement are friction, additional stress on the excavation surface and soil loss; He et al. [4] summarized the influence law of ground settlement in shield tunnel; Zhao et al. [5] studied the ground settlement caused by shield excavation in sand and gravel strata; Feng [6] summarized the influence of different construction sequence on shield tunnel; Tan [7] analyzed the value range in modified Peck formula of the correction parameters for the width of the settlement trough and the maximum settlement; Wu [8] obtained the ground loss rate through the back analysis of the Peck formula. In this paper, the ground settlement in straight tunnel and curve tunnel was simulated by shield method and pipe-jacking method.

2. Analysis Condition and Parameters
The numerical simulation parameters are shown as Table 1, which is based on a shield tunnel engineering. The diameter of the shield machine is 8.38 m, the outer diameter of the segment is 8.04 m, the thickness of the segment is 0.4 m, the length is 1.5 m, and the grade of segment is C50.
Table 1. Material parameters.

| Items                        | ρ (g/cm³) | E_s (MPa) | ν | c (kPa) | φ (°) |
|------------------------------|-----------|-----------|---|---------|-------|
| Plain fill                   | 1.9       | 6         | 0.3| 10      | 10    |
| Slightly dense pebble soil   | 2.0       | 25        | 0.24| /       | 38    |
| Medium dense pebble soil     | 2.1       | 38        | 0.23| /       | 42    |
| Dense pebble soil            | 2.3       | 50        | 0.22| /       | 46    |
| C50 Concrete segment         | 2.5       | 20700     | 0.2 | /       | /     |
| Shield                       | 7.85      | 210000    | 0.3| /       | /     |
| Grouting body                | 2.0       | 0.95      | 0.2| /       | /     |

3. Establishment of Numerical Model

3.1. Basic assumption

According to the analysis purpose, the following assumptions are proposed:

- Mohr-Coulomb criterion is adopted in the soil layer, and the soil layer is isotropic and Elastic-Plastic.
- The tunnel segment is linear elastic, the connection of the segments is rigid.
- The tunnel excavation is simulated by passivating soil, and the segment erection is simulated by activating.
- The grouting layer is simulated by changing the properties of the soil element.

3.2. Numerical Model

The influence range perpendicular to tunnel axis is $-3D \sim +3D$ (D is the tunnel diameter) and the influence range along tunnel axis is $-2D \sim -3D$. The model size is set to 120m × 80m × 60m (Width × Length × Height). The mesh map for finite element model is shown as Figure 1, and the model plan sketch is shown as Figure2:

![Figure 1. Mesh map for finite element model.](image1)

![Figure 2. The model plan sketch.](image2)
4. Results and Analysis

4.1. Ground settlement perpendicular to tunnel by shield method

The ground settlement perpendicular to tunnel axis in straight tunnel and curve tunnel are shown as Figure 3 (Y is the distance from analysis section to initial excavation section):

![Figure 3. The ground settlement perpendicular to tunnel axis by shield method.](image)

As can be seen from the figure, the ground settlement curve perpendicular to tunnel axis is not completely symmetrical. With the excavation of the tunnel, the settlement trough in curve tunnel is shifted to the bending direction by about 0.5D, and the maximum settlement is reduced by about 0.7 mm.

4.2. Ground settlement along tunnel axis by shield method

The ground settlement along tunnel axis in straight tunnel and curve tunnel are shown as Figure 4 (X is the distance from analysis section to tunnel axis):

![Figure 4. The ground settlement along tunnel axis by shield method.](image)

From the figure, it can be seen that the ground settlement along the bending direction is more than that deviation from bending direction. With the excavation of the tunnel, the ground settlement trend in curve tunnel is more obvious than that in straight tunnel.

4.3. Ground settlement perpendicular to tunnel axis by pipe-jacking method

The ground settlement perpendicular to tunnel axis in straight tunnel and curve tunnel are shown as Figure 5:
As can be seen from Figure 3 and Figure 5, the ground settlement trend perpendicular to curve tunnel axis by shield method and pipe-jacking method are similar.

4.4. Ground settlement along tunnel axis by pipe-jacking method
The ground settlement along tunnel axis in straight tunnel and curve tunnel are shown as Figure 6:

From the Figure 4 and Figure 6, it can be seen that the ground settlement trend by shield method and pipe-jacking method in straight tunnel and curve tunnel are similar. The ground settlement in curve tunnel by pipe-jacking method is more than that by shield method.

4.5. Ground settlement difference perpendicular to tunnel axis.
The ground settlement difference perpendicular to tunnel axis by shield method and pipe-jacking method in straight tunnel and curve tunnel are shown as Figure 7 (Settlement difference: Settlement by shield method minus that by pipe-jacking method):
As can be seen from the figure, the ground settlement difference decreases with the excavation of straight tunnel, and increases in curve tunnel. And the change trend of settlement difference is obvious in the middle of the tunnel.

4.6. Ground settlement difference along tunnel axis

The ground settlement difference along tunnel axis by shield method and pipe-jacking method in straight tunnel and curve tunnel are shown as Figure 8:

As can be seen from the figure, the range of ground settlement difference in straight tunnel is relatively small. With the excavation of the tunnel, the ground settlement difference increase in the curve tunnel. It shows that the settlement in curve tunnel by pipe-jacking method is more than that by shield method.

5. Conclusion

- Compared with straight tunnel, the ground settlement trough in curve tunnel is shifted to the bending direction by about 0.5D, and the maximum settlement slightly decreases for shield method and pipe-jacking method.
  - The overall ground settlement difference between shield method and pipe-jacking method is relatively small in straight tunnel, while the overall settlement difference increases with the tunnel excavation in curve tunnel. And the settlement in curve tunnel by pipe-jacking method is more than that by shield method.
  - With the excavation of the tunnel, the ground settlement trend in curve tunnel is more obvious than that in straight tunnel. And the settlement difference is relatively large in the middle of the tunnel for both straight tunnel and curve tunnel.

Acknowledgments

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