The Influence Of Different Grouting Methods On the Surface Environment Of Short Clear Distance Tunnel

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Abstract: Based on a four-line parallel short-clearance subway tunnel in Beijing, this paper takes the finite element method to thoroughly conduct research on the ground settlement caused by the parallel short-clearance tunnel construction. It simulates the effects of four types of reinforcement methods for deep hole grouting reinforcement, deep hole grouting and radial grouting reinforcement, reinforcement of anchor rods, and deep hole grouting reinforcement for tension anchor rods on ground settlement under different clearance conditions. The conclusions suggested that the effect of controlling the ground settlement decreased which proved that the reinforcement of tension anchors is the best, followed by deep hole grouting reinforcements. Grouting is better than radial supplementary grouting combined reinforcement. The surface settlement curve of the four-line parallel short clear-distance tunnel under the Grade VI surrounding rock is in the form of a single peak, as the maximum value shows near the center of No. 2 and No. 3 caves. The numerical simulation is consistent with the field measurement law, which shows that the finite element simulation calculation method is significant in predicting the influence of short clear distance tunnels on the ground settlement during construction.

1. Introduction
The new subway tunnel will be constructed in parallel or through existing buildings (structures) in a short distance, as the cities strive for efficiency of utilizing the urban underground space. The short clear distance tunnel, on account of meeting the overall linear planning in the engineering design, is characterized by technical and economic advantages compared with the multi arch tunnel, which makes it be widely used in many tunnel projects.

For the urban underground tunnel, the key to check the construction quality of the subway project is to strictly control the surrounding environment changes. As the most frequently used advanced reinforcement measure in urban underground engineering, the advanced deep space grouting technology can not only improve the physical properties of the stratum, but also block the water in the water rich silty fine sand stratum, which in a way reduces the influence of the underground water on the excavation process to ensure the safety of the construction. For the multi line parallel short clear distance tunnel, however, adopting the advanced deep hole grouting measures is not enough to control the ground settlement. Therefore, it is necessary to choose the composite reinforcement measures based on the advanced deep hole grouting.
In this section, the piezometric water levels of interlayer phreatic water (III) and confined water (IV) to (VI) are all above the structural roof, and the aquifer mainly consists of silt and sandy soil layers, which greatly impacts on the construction safety of the project. The adverse effects of groundwater on construction are as follows:

1. The construction scope of the project mainly consists of silt and silty fine sand layers, all of which are full of water. The self stability of the stratum is poor, which is prone to collapse of excavation face, roof fall, instability of side wall, water inrush, sand inrush, uplift of tunnel bottom, etc. [1 – 4]

2. The piezometric water level of the confined water (V) and (VI) in this construction site is relatively high, and the part is not less than 10.0m above the structural floor. By empirical calculation, the foundation inrush may occur, and the dewatering and decompression measures shall be considered.

3. There may be water saturated lens in this section, which may risk the construction. Reasonable protective measures shall be taken during the construction.

### 2. Calculation model and parameter selection

The finite element software MIDAS gtsnx is used to build the model. The tunnel invert is 30.38m to the bottom boundary of the model, the distance of tunnel side wall between the left and the right boundary is 42.05m, the upper boundary is taken to the surface, and the model size is determined as 112m (x direction) × 53m (Y direction).

| Table 1 Numerical simulation of physical and mechanical parameters of soil layers |
|-------------------------------|----------------|-----------------|-----------------|---------------|---------------|---------------|
| Soil layer                     | Secant stiffness MPa | Tangent stiffness MPa | Unloading modulus of elasticity MPa | Unit weight kN/m³ | Poisson's ratio μ | Cohesive force kPa | Internal friction angle φ |
|-------------------------------|----------------|----------------|-----------------|---------------|---------------|---------------|
| VI surrounding rock           | 24            | 24            | 72              | 20            | 0.4           | 30            | 20            |
| Deep hole grouting             | 32            | 32            | 96              | 25            | 0.3           | 150           | 24            |
| Deep hole grouting + radial grouting | 40            | 40            | 120             | 25            | 0.28          | 200           | 30            |

Fig. 1 Plan and location of concealed section of line 4  
Fig. 2 Cross section of tunnel in the concealed excavation section of line 4  
Fig. 3 Numerical simulation model  
Fig. 4 Model of deep hole grouting and initial support
Table 2 Physical and mechanical parameters of bolt and initial support

| Material         | Modulus of elasticity MPa | Unit weight kN/m3 | Poisson's ratio μ |
|------------------|---------------------------|------------------|------------------|
| bolt             | 2.1×10^5                  | 22               | 0.2              |
| Initial support  | 3.2×10^4                  | 25               | 0.2              |

3. Analysis of the law of surface subsidence

3.1 numerical simulation

Figure 4 shows the final settlement curve of the surface under different clear distance and reinforcement methods. As given by the Figure, the change trend of the final settlement curve of the surface under different clear distance conditions is basically the same. The maximum settlement value is observed at the left of the tunnel center line. The surface settlement value gradually decreases and the curve form becomes shallow and wide, accompanied by increase of clear distance. It suggests that the increase of clear distance significantly impacts the surface settlement value.

![Figure 4](image)

With the same clear distance condition, comparing between the surface settlement curves of different reinforcement measures, qualitative change in the surface settlement curve form before and after reinforcement with the same clear distance condition is rarely to find, but the settlement value decreases in different degrees. The magnitude of the surface displacement value can be used as the basis for the evaluation of the reinforcement effect, corresponding to different reinforcement measures.

The figure illustrates that the change rule of the surface settlement displacement value with the reinforcement measures in general is: no reinforcement measures > reinforcement of split bolt > reinforcement of deep hole grouting > reinforcement of deep hole grouting + reinforcement of split bolt > reinforcement of deep hole grouting + radial supplementary grouting. For the decrease of displacement value, the deep hole grouting effectively reduces the surface settlement value, while the radial grouting and the influence on the surface settlement of the anchor bolt are corresponding to that of the deep hole grouting. The effect of the rock column grouting and the anchor bolt reinforcement tends to be the same as that of the deep hole grouting only, as net distance between the tunnels increases. It is analyzed that under the condition of weak surrounding rock grade, the deep hole grouting changes the surrounding rock state around the tunnel, improves the overall mechanical properties of the surrounding rock, and significantly impacts the surface settlement value of the tunnel; the radial middle rock column grouting and the reinforcement measures for the tension anchor rod have played a certain role in restraining the surface settlement. The reinforcement middle rock column will not improve the surrounding rock above the tunnel vault, and the mechanical properties of the soil near the surface have an important influence on the tension of the soil column.
It can be seen that if controlling the surface settlement while stabilizing the soil column and, increasing the scope of radial grouting with less effect on the number of anchor bolts are wanted, reinforcing the soil above the tunnel arch is needed. That is to say, increasing the scope of deep hole grouting, making full use of the grouting water plugging and controlling the surface settlement deformation are effective.

Table 3 Comparison of surface settlement values of main measuring points under the condition of 2m clear distance

| Clear distance | Reinforcement method | position       |
|----------------|----------------------|----------------|
| 2m             | No reinforcement     | L1 | -30.2 | L2 | -37.2 | L3 | -35.8 | L4 | -29.7 | Max | -37.5 |
|                | Reinforcement with split bolt |       | -29.3 | -3535 | -34.1 | -28.6 | -35.7 |
|                | Deep hole grouting reinforcement | -16.6 | -19.0 | -17.4 | -14.4 | -19.0 |
|                | Deep hole grouting + split bolt |       | -16.6 | -19.0 | -17.4 | -14.3 | -19.0 |
|                | Deep hole grouting + radial grouting |       | -16.0 | -18.0 | -16.5 | -13.7 | -18.1 |

Table 4 Comparison of surface settlement values of main measuring points under the condition of 4m clear distance

| Clear distance | Reinforcement method | position       |
|----------------|----------------------|----------------|
| 4m             | No reinforcement     | L1 | -28.9 | L2 | -34.8 | L3 | -32.6 | L4 | -26.1 | Max | -35.0 |
|                | Reinforcement with split bolt |       | -26.7 | -32.4 | -30.2 | -25.6 | -32.6 |
|                | Deep hole grouting reinforcement |       | -16.4 | -18.6 | -16.5 | -13.1 | -18.6 |
|                | Deep hole grouting + split bolt |       | -16.3 | -18.4 | -16.4 | -13.0 | -18.4 |
|                | Deep hole grouting + radial grouting |       | -15.6 | -17.6 | -15.5 | -12.5 | -17.6 |

Table 3 and Table 4 are the comparison of the surface settlement values of different reinforcement measures under different clear distance conditions. Five key points are taken in to analysis: point L1 above the vault of tunnel 1, point L2 above the vault of tunnel 2, point L3 above the vault of Tunnel 3, point L4 above the vault of tunnel 4 and the maximum settlement value of the surface.

It proves that effect of deep hole grouting on the surface settlement value is significant. The results show that the control effect of ground settlement changes from small to big: no reinforcement measures < anchor bolt reinforcement < deep hole grouting reinforcement < deep hole grouting + anchor bolt reinforcement < deep hole grouting + radial supplementary grouting reinforcement. In this kind
of parallel short clear distance tunnel, the deep hole grouting obviously reduces the surface settlement. The radial grouting and the pull bolt reduces the surface settlement, but the effect of deep hole grouting is quite significant. The effect of deep hole grouting reinforcement is 12% less than that of anchor bolt reinforcement. It draws conclusion that to control the ground settlement the surrounding rock above the tunnel vault needs grouting reinforcement.

Table 5 Maximum ground settlement under different reinforcement measures (unit: mm)

| Reinforcement method                          | Clear distance |
|-----------------------------------------------|----------------|
|                                               | 2m            | 4m            |
| No reinforcement                             | -37.5         | -35           |
| Reinforcement with split bolt                | -35.7         | -32.6         |
| Deep hole grouting reinforcement             | -19           | -18.6         |
| Deep hole grouting + split bolt              | -19           | -18.4         |
| Deep hole grouting + radial grouting         | -18.1         | -17.6         |

Hence, the reinforcement effect of deep hole grouting is the best in controlling the surface settlement deformation. When the net distance is short, the tension bolt and radial grouting can be used to improve the overall mechanical performance of the surrounding rock of the tunnel.

3.2 comparison of field measurement and numerical simulation

By comparing the final settlement laws of the numerical simulation and the actual project, it is found that the settlement value of the actual project vault is slightly larger than that of the numerical simulation. Table 6 shows the comparison between the numerical simulation and the actual project surface settlement value. Both of the surface settlement curves show a single peak form, and the maximum value is at the vertical center line of the four parallel tunnels. The surface settlement value of Tunnel 3 is greater than that of tunnel 1 and tunnel 4, and the actual surface settlement value of the project is slightly larger than that of numerical simulation. Considering the influence of precipitation, the difference between the two values is not significant, and the change trend is basically the same. Therefore, the analysis shows that the numerical simulation results in some ways reveal the change rule of surface settlement.

Table 6 Comparison table of surface settlement values (unit: mm)

|       | L1    | L2    | L3    | L4    | Extreme value of surface subsidence |
|-------|-------|-------|-------|-------|------------------------------------|
| numerical simulation | -30.32 | -37.99 | -36.76 | -30.15 | -38.4 |
| Field measurement   | -33.63 | -35.21 | -37.31 | -33.32 | -40.19 |

4. Conclusions

The paper studied the surface settlement law of four parallel tunnels with short clear distance under different reinforcement methods, through carrying out the reinforcement methods of deep hole grouting pre reinforcement and radial supplementary grouting after excavation. Through comparative analysis of the stratum settlement under different working conditions, the conclusions are as follows:

1) With different reinforcement measures, the final ground settlement of four parallel tunnels with short clear distance is given as deep hole grouting + radial grouting > deep hole grouting + anchor + deep hole grouting reinforcement > anchor bolt reinforcement > no reinforcement. With the increase of clear distance, however, the advantages of deep hole grouting + radial grouting reinforcement on ground surface settlement control are weakening.

2) The surface settlement curve of four parallel tunnels with short clear distance under grade V1 surrounding rock is in the form of single peak value, and the maximum value shows near the center of
No.2 and No.3 caverns. The settlement value of No.2 and No.3 caverns is higher than that of No.1 and No.3 caverns, which is consistent with the numerical simulation results.

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