Numerical Study on Karst Treatment Technology of Wuhan Metro Line 6

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Abstract. Taking Wuhan Metro Line 6 karst crossing area as the research object, combined with on-site survey data, a reasonable karst treatment technical plan is proposed. The finite difference numerical calculation method was used to carry out numerical calculation research on the treatment effect of karst treatment technology in the study area. The research results show that after grouting reinforcement, the maximum settlement of tunnel segments is 19.5mm, which is 73% less than before reinforcement, and the treatment effect is better. The lining deformation is within the allowable deformation value after the reinforcement of the three rows of jet grouting piles. The maximum value of the stress of the jet grouting piles is lower than the design value of the shear strength of the high jetting walls, indicating that the treatment technology can play a good supporting role when completely collapsed Without destruction.

1. Introduction
Under the control of geological structure, there are four near-west-north-west-northwest soluble rock bands distributed from north to south in the urban area of Wuhan, which belongs to the susceptible area of karst ground subsidence in southeastern Hubei. There have been many accidents of karst ground subsidence in recent decades. Many subway lines have been built and are under construction in Wuhan, such as Wuhan Metro Line 2, Line 3, Line 6, Line 8, Line 27, and they all have karst problems to varying degrees. In subway construction or operation, karst caves and loose soils can induce roadbed collapse and karst ground collapse.

In view of the karst geological problems encountered in subway construction and operation, many scholars have conducted a lot of research from the formation mechanism and governance measures. The research results have an important guiding role for such problems, but there are still relatively few numerical studies on the treatment effect of treatment technology in the karst crossing area of Wuhan Metro Line 6 currently. Therefore, this paper takes the karst crossing area of Wuhan Metro Line 6 as the research object, combined with the survey data, puts forward a reasonable treatment technology plan, and uses the finite difference numerical calculation method to study the treatment effect of various treatment technologies for the karst treatment of the project Provide a reliable theoretical basis.
2. Project Overview
The geomorphic unit of the site where the karst crossing area of Wuhan Metro Line 6 belongs is the first terrace of the Yangtze River, and the terrain is relatively flat. The ground elevation is generally between 22.0 ~ 24.1m, and the maximum height difference is 1.5m. Two parallel subway tunnels are arranged along the subway, with a tunnel spacing of 15 m, a circular cross section, a hole diameter of 6 m, and a roof depth of 9.7-17.0 m. The shield method is used for construction.

According to the site survey data, the site cover soil layer is composed of artificial fill, karst cave deposits, Quaternary residual slope accretion, Quaternary Holocene alluvium, Quaternary Pleistocene alluvial, and alluvial strata. The bedrock is mainly Triassic limestone and marl, Permian limestone, siliceous rock, carbonaceous shale, Carboniferous limestone, quartz sandstone, Devonian quartz sandstone, Silurian mudstone, Siltstone. Limestone fissures and karst are developed in the field area, and karst caves and karst troughs are developed in some areas, where filled with soft-hard plastic clay, the karst cave has a thin roof and a thick sand layer. There is a large fault in the study area, which is heading northwest and west, and the rock mass in the fault zone is extremely broken and strongly dissolved.

There has been historical ground collapse near the site, which may cause ground collapse due to construction disturbances and changes in groundwater dynamic conditions. During the construction of the tunnel, it will face the problems of karst foundation collapse and karst ground collapse. The former poses a threat to the safety of the subway project, and the latter causes damage to the surrounding buildings and traffic including the subway project.

3. Karst treatment technology for subway shield tunnel

3.1. Grouting technology
Cavity grouting filling has the advantages of simple operation, simple process, good treatment effect and strong applicability. Karst grouting is the use of grouting fluid that can form a certain strength consolidation body after solidification, and is injected into karst cracks, karst caves and soft plastic clay pores under a certain pressure. First, fill karst caves and karst fissures, and then close the rock and soil interface to form a water-proof curtain to block the connection between the upper layer of stagnation water and karst water. If there is a weak interlayer in the soil, then strengthen the weak interlayer. After the grouting filling liquid solidifies, the rigidity and strength of the rock layer and soil are changed, the deformation of the rock and soil is constrained, and the strength is improved, so as to achieve the effect of controlling the overall settlement of the foundation and reducing the deformation.

3.2. Strata reinforcement technology
In order to avoid the collapse of the karst ground during the construction of the subway through the karst area, in addition to the treatment of the karst caves in the high-risk area along the line, the stratum needs to be reinforced in a targeted manner. The main purpose of the reinforcement is two points: 1) cut off the overlying soil layer Hydraulic and seepage channels with karst caves; 2) reinforce the overlying loose soil layer, especially the silty sand layer, to prevent seepage and sand-carrying effect caused by karst collapse outside the high-risk area from affecting the stability of the tunnel segment structure.

Karst water blocking refers to the formation of a water-proof curtain body with a certain strength at a suitable location, which forms a certain degree of protection for shield tunnels and stations, and prevents karst from being disturbed by construction disturbances, pumping and drainage, subway operation vibration and other external disturbances. The area collapsed. High pressure rotary spray method and deep mixing cement anti-seepage soil can be used to prevent seepage. As shown in Figure 1, its main function is to isolate the horizontal hydraulic connection between the sand and the karst development area within the tunnel's influence area to prevent groundwater. Under the action of seepage, sand loss or limestone erosion damage in the line area can also maintain the relative stability of the sand surrounding the tunnel when the karst collapses in the nearby area, and delay the impact of
karst collapse on the tunnel structure to a certain extent.

In order to avoid the collapse of the karst ground in the subway crossing area and in addition to the treatment of soil and karst caves in high-risk areas along the subway, the stratum must be targeted and reinforced to block the pore pressure water and karst fissure water and the overlying sand and the seepage channel of the karst cave, in order to achieve the effect of strengthening the overlying sand. Generally, the stratum reinforcement technology used in sandy soil layers is rock face grouting. The grouting curtain on the rock face is a horizontal reinforced isolation curtain. It is mainly treated by grouting and strengthening the soil and rock joints of the karst stratum within a certain range along the subway tunnel, in order to achieve the effect of improving the strength of the rock face soil and seepage control. The grouting curtain covered with rock face can be combined with grouting and filling to treat cave collapse. The grouting curtain can effectively block the seepage channel of sand and rock and the small karst leakage channel that has not been explored in the geological survey to ensure the stability of the overlying sand.

![Image](image_url)

(a) High-pressure rotary spray  
(b) Deep mixing

Figure 1 Strata reinforcement technology

4. Research on numerical calculation of grouting technology

4.1. Calculation model
The grouting technology simulation uses the Mohr-Coulomb model. With the help of FLAC3D software, the numerical analysis model is established to study the effects of different karst treatment technologies. According to the geological data on the crossing area, the calculation model of grouting treatment technology is established as shown in Figure 2. The ground center is set as the coordinate zero point, and the model size is 50m×12m×39m. The model is divided into three layers: ①clay layer, thickness 6m; ②sand soil layer, thickness 28m; ③bedrock layer, thickness 5m. The diameter of the tunnel is 6m. The shape of the cave is a truncated cone with a diameter of 1m at the bottom and a diameter of 3m at the top.
4.2. Calculation parameters
Through field tests and indoor routine physical and mechanical test analysis, the physical and mechanical parameters are determined as shown in Table 1, and the groundwater level is set 5m below the ground.

Table 1 Calculation parameters of grouting technology

| Stratum       | Bulk modulus K (MPa) | Shear modulus G (MPa) | Friction angle φ (°) | Cohesion c (kPa) | Severe γ (kN/m³) |
|---------------|----------------------|-----------------------|----------------------|------------------|------------------|
| clay          | 3.7                  | 1.7                   | 18                   | 25               | 19               |
| sand          | 9.2                  | 5                     | 32                   | 6                | 18               |
| bedrock       | 22600                | 11100                 | 42                   | 670              | 25               |
| grouting material | 7700                | 5800                  | -                    | -                | 25               |

4.3. Calculation results
It can be seen from Figure 3 that when the cave does not exist, the maximum settlement of the tunnel segment is 18.4mm. However, when the circular table-shaped karst cave with a diameter of 3m collapses (Figure 4), the maximum settlement of the tunnel segment is 73.5mm, and the maximum settlement value becomes 4 times the original, which greatly exceeds the maximum allowable deformation of the segment Deformation value.

It can be seen from Fig. 5 that after grouting reinforcement of the karst cave, the maximum settlement of the tunnel segment is 19.5mm, its settlement value is reduced by 73% compared with before the grouting reinforcement, and does not exceed the maximum allowable deformation value of the vertical deformation of the segment lining. This shows that the effect of karst grouting reinforcement is well.
5. Research on numerical calculation of stratum reinforcement technology

5.1. Calculation model
The formation reinforcement Simulation technology use the Mohr-Coulomb model, and the FLAC3D software is used to simulate the reinforcement measures of three rows of jet grouting piles 6m away from the outer contour of the tunnel to calculate the deformation status of the pile under the condition of karst collapse on the outside of the pile. Based on the limit state of karst collapse, it is assumed that the collapse occurs on the left side of the bottom of the jet grouting pile, and a numerical model is established as shown in Fig. 6(a).The model is divided into two layers: ① sand layer with a thickness of 28m; ② bedrock layer with a thickness of 10m.The size of the numerical model is \( L \times 15 \times 38 \)m, where \( L = 58 + B \) (spin-spray pile width) and the tunnel diameter is 6m. According to the on-site sand angle of repose test and related collapse examples, the sand layer collapse angle is 40°.

5.2. Calculation parameters
Through field tests and indoor routine physical and mechanical test analysis, the physical and mechanical parameters are determined as shown in Table 2.
5.3. Calculation results

The simulation results of the three-row piles are shown in Fig. 7. According to Fig. 7(b), the deformation of the tunnel segment lining after reinforcement is within the allowable deformation value, and the reinforcement method has a good protection effect on the tunnel. It can be seen from Figure 7(a) that the main stress point is located at the center wall toe and both sides of the wall, the maximum stress is 228.79kPa, and the stress value of the two walls is below 200kPa, both of which are lower than the design value of high-spray wall shear strength of 260kPa. This shows that the three rows of jet grouting piles can play a good supporting role and not be destroyed when completely collapsed.

| Parameter | Stratum       | Bulk modulus K (MPa) | Shear modulus G (MPa) | Friction angle φ (°) | Cohesion c (kPa) | Severe γ (kN/m³) |
|-----------|---------------|----------------------|-----------------------|---------------------|-----------------|------------------|
|           | sand          | 9.2                  | 5                     | 32                  | 6               | 18               |
|           | bedrock       | 22600                | 11100                 | 42                  | 670             | 25               |
|           | jet grouting pile | 8000               | 6000                  | -                   | -               | 25               |
6. Conclusion

(1) The karst crossing area of Wuhan Metro Line 6 may cause ground collapse due to construction disturbances and changes in groundwater dynamic conditions. Grouting treatment technology and stratum reinforcement technology are common methods for treating soil, karst cave and overlying loose soil.

(2) The numerical calculation results of the grouting treatment technology show that after grouting reinforcement of the cave, the maximum settlement of the tunnel segment is 19.5mm, and its settlement value is reduced by 73% compared with before the grouting reinforcement, and the segment lining within the maximum allowable deformation value of vertical deformation, grouting reinforcement has a good control effect.

(3) The numerical calculation results of the stratum reinforcement technology show that the deformation of the tunnel segment lining after the reinforcement of the three rows of jet grouting piles is within the allowable deformation value range. The maximum stress is lower than the design value of the shear strength of the high-spray wall, indicating that the three-row rotary jet piles can play a good supporting role and not be destroyed when completely collapsed.

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