Research on Deformation Control Measures of Surrounding Rock in Soft Rock Tunnel

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Abstract: In order to study the control measures of soft rock tunnel surrounding rock deformation, based on the restraint effect of shotcrete anchor support on it, a support model was constructed, and numerical simulation was used to compare and analyze the restraint effects of different bolts controlling the surrounding rock deformation. The results show that: With the reduction of the bolt spacing \(d\), the resin bolt has a significant supporting effect compared with the mortar bolt support, the maximum displacement of the surrounding rock is reduced by 70.69%, and the maximum stress is reduced by 58.81%. With the increase of bolt length \(L\), compared with mortar bolt support, resin bolt has a more obvious restraint on surrounding rock deformation. The maximum displacement of surrounding rock is reduced by 57.89% and the maximum stress is reduced by 40.23%. When \(4.5m < L < 6.0m, 0.6m < d < 0.7m\), the resin bolt has a significant effect on controlling the deformation of surrounding rock. In other cases, the use of mortar bolts or resin bolts to support the surrounding rock deformation has little significant difference.

1. Introduction

Rock masses are various complex geological bodies formed after long-term crustal movement and evolution. During tunnel excavation and construction, due to the redistribution of surrounding rock stress, the amount of surrounding rock deformation increases, which leads to various engineering accidents. Bolt support is a commonly used support measure to restrain the deformation of surrounding rock. Different types of bolt support have certain differences in the effect of controlling the deformation of surrounding rock \[1-3\], so they are implemented according to different surrounding rock conditions. The corresponding type of bolt support is necessary.

In terms of large deformation of surrounding rock, scholars have done a lot of research: Chen Jianxun et al. \[4\] studied the change law of tunnel temperature field in cold regions and found that tunnel deformation is inevitable, but did not give reasonable control measures; Liu Gao et al. \[5\] researched on the characteristics and mechanical analysis of the large deformation of the Muzhailing Tunnel, and proposed the thickening of the second lining construction to control the deformation of the surrounding rock; Tao Bo et al. \[6\] conducted changes in the weak surrounding rock of the Wushaoling deep-buried tunnel under high ground stress. Study the law and propose to change the construction process to control the deformation of the surrounding rock; Liu Zhichun et al. \[7\] studied the large deformation mechanism of the soft surrounding rock tunnel and proposed dense bolts to control the surrounding rock deformation. Based on the above research, it can be seen that the current control measures for surrounding rock deformation are mainly to change the construction technology and support method, increase the rigidity, strength and reserved deformation displacement of the...
supporting body to achieve the control of the surrounding rock deformation. However, there are few studies on the control of surrounding rock deformation in different bolt support mechanisms, so it is necessary to study the effect of different bolt support on surrounding rock deformation.

In order to effectively study the control measures of the tunnel under the condition of large deformation, this paper relies on the Xiaowan Tunnel and establishes the analysis model of the supporting effect of different bolts on the surrounding rock through numerical simulation. After comparative analysis, it is concluded that different bolt supporting control The large deformation of surrounding rock is significantly different, and reasonable support suggestions are given [8-10].

2. Building a support model

In view of the deformation characteristics of soft rock and the control effect of spray-anchored support on surrounding rock deformation, two support types have been designed, namely, mortar bolt and resin bolt support. According to the literature [11], it can be seen that mortar bolt and the mechanical mechanism of resin bolt support is the same, the difference is that the force transmission effect of resin bolt is weaker than that of mortar bolt.

This paper analyzes the mechanical mechanism of the bolt based on the elastic theory. Considering that the bolt is a hollow structure, the hollow part of the bolt needs to be added to the calculation model, so that it can be more in line with the actual situation. The calculation model of the mechanical mechanism of the bolt is shown in Fig. 1. Shown. The x direction is selected as the anchoring direction of the bolt, the length of the selected surrounding rock section is L, the diameter of the bolt is d, and the resin wrapped around the bolt is assumed to be a uniform thickness wrapped around the bolt and the thickness is t. Secondly, there is a pulling force on the anchor rod, the magnitude of which is P.

\[
\tau = \begin{cases} 
G\nu & (0 \leq \nu \leq \nu_{\text{max}}) \\
\tau_c & (\nu > \nu_{\text{max}}) 
\end{cases}
\]  

In formula (1): \(\tau\) is the shear stress on the surface of the bolt; \(G\) is the shear modulus of the bolt surface; \(\nu\) is the shear displacement of the bolt surface; \(\nu_{\text{max}}\) is the maximum shear displacement of the bolt surface; \(\tau_c\) is Residual shear stress on the surface of the bolt.

![Fig. 1 Calculation model of hollow anchor](image)

When considering the anchor rod cavity into the calculation model, when calculating the force state of \(L_x\) anywhere in the anchor rod length direction:

Boundary conditions:

\[
\begin{align*}
\sigma_{x=L_x} & = \frac{4P}{\pi d^2} \\
\sigma_{x=0} & = 0
\end{align*}
\]  

Stress variation:

\[
\theta^2 \sigma - \frac{d^2 \sigma}{dx^2} = NP
\]  

2
After putting the boundary conditions shown in equation (2) into equation (3), we can get:

$$
\sigma = A e^{-\alpha} + B e^{-\alpha} + N \alpha^{-2} (P - P_0)
$$

(4)

In formula (4): A and B are the anchor rod coefficients, and their magnitudes can be obtained according to the initial conditions of the anchor rod; P0: the pull-out force in any section of the anchor rod.

From the stress-strain relationship:

$$
\varepsilon = \frac{\sigma}{E} = \frac{du}{dx}
$$

(5)

Through the integral calculation of formula (5), the corresponding anchor deformation displacement expression can be obtained:

$$
u_x = \int_{x_0}^{x} \frac{\sigma}{E} dx
$$

(6)

Equation (6) is the functional expression of the stress and strain inside the bolt. The corresponding parameter values can be given for the design of the anchor rod through the corresponding data.

3. Numerical simulation

3.1. Model establishment and parameter design

In order to study the control measures of large deformation after excavation of soft rock tunnel, the stability of surrounding rock was analyzed by establishing a numerical calculation model, and a two-dimensional model of soft rock large deformation tunnel was established by using MIDAS/GTS NX finite element software. Model physical and mechanical parameters are shown in Table 1.

| Category                | Layer thickness/m | Severe/kN·m⁻³ | Elastic modulus/Gpa | Poisson's ratio | Cohesion/Mpa | Internal friction angle/° |
|-------------------------|-------------------|---------------|--------------------|-----------------|--------------|--------------------------|
| Sandstone               | 14                | 20.4          | 0.042              | 0.25            | 1.46         | 46                       |
| Limestone with dolomite | 27                | 17.3          | 0.014              | 0.32            | 0.026        | 30                       |
| Argillaceous sandstone  | 19                | 16.5          | 0.006              | 0.35            | 0.043        | 37                       |
| Ordinary mortar bolt    | -                 | 81.3          | 200                | 0.30            | -            | -                        |
| Resin anchor            | -                 | 76.6          | 280                | 0.28            | -            | -                        |

When the distance between the local bolts is 0.7m, the numerical calculation results of the tunnel supported by the mortar bolt and the resin bolt are shown in Fig. 2 and Fig. 3. It can be seen from the figure that when the tunnel is supported by mortar bolts, the maximum displacement of the surrounding rock is 0.43m, and the maximum stress on the surrounding rock is 466kN/m²; when the tunnel is supported by resin bolts, the maximum displacement of the surrounding rock is 0.20m, the maximum stress on the surrounding rock is 280kN/m². The calculation results show that, compared with tunnels supported by mortar bolts, the maximum displacement of surrounding rock is reduced by 53.49%, and the maximum stress of surrounding rock is reduced by 39.91%.

(a) Displacement cloud (b) Stress cloud
Fig. 2 The distance between mortar bolts and anchors is reduced to 0.7m

(a) Displacement cloud (b) Stress cloud
Fig. 3 The distance between the resin anchor rods and the anchor rods is reduced to 0.7m
When the local bolt spacing is 0.4m, the numerical calculation results of the tunnel supported by the mortar bolt and the resin bolt are shown in Fig. 4 and Fig. 5. It can be seen from the figure that when the tunnel is supported by mortar bolts, the maximum displacement of the surrounding rock is 0.33m, and the maximum stress on the surrounding rock is 354kN/m²; when the tunnel is supported by resin bolts, the maximum displacement of the surrounding rock is 0.17m, the maximum stress on the surrounding rock is 229kN/m².

When the local bolt lengthening is 6.0m, the numerical calculation results of the tunnel supported by the mortar bolt and the resin bolt are shown in Fig. 6 and Fig. 7. It can be seen from the figure that when the tunnel is supported by mortar bolts, the maximum displacement of the surrounding rock is 0.25m, and the maximum stress on the surrounding rock is 424kN/m²; when the tunnel is supported by resin bolts, the maximum displacement of the surrounding rock is 0.13m, the maximum stress on the surrounding rock is 378kN/m².

When the local bolt lengthening is 7.5m, the numerical calculation results of the mortar bolt and the resin bolt supporting the tunnel are shown in Fig. 8 and Fig. 9. It can be seen from the figure that when the tunnel is supported by mortar bolts, the maximum displacement of the surrounding rock is 0.19m, and the maximum stress on the surrounding rock is 348kN/m²; when the tunnel is supported by resin bolts, the maximum displacement of the surrounding rock is 0.08m, the maximum stress on the surrounding rock is 208kN/m².

4. Conclusions
(1) Compared with mortar bolt support, resin bolt support has a more significant effect of restraining the deformation of surrounding rock. The maximum displacement of surrounding rock is reduced by 51.72%, and the maximum stress of surrounding rock is reduced by 38.31%.

(2) Numerical simulation shows that with the densification or lengthening of the bolts, the support effect of resin bolts is more significant than that of mortar bolts.

(3) Compared with resin bolt support, the maximum displacement of the surrounding rock is about
twice the maximum deformation of the surrounding rock when supported by the resin bolt.

(4) When 4.5m < L < 6m, 0.6m < d < 0.7m, the effect of using resin bolt support is significant. If it exceeds this range, the effect of mortar bolt support or resin bolt support will change. The difference is small.

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