

# Study on He bolt (cable) Support in Soft Rock Tunnels Based on ABAQUS

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**Abstract.** A certain tunnel has a surrounding rock classification of Grade V, characterized by poor integrity and significant settlement deformation. Therefore, using high-strength, high-performance support bolt (cable) is an important measure to enhance the stability of the tunnel. Based on this, this paper employs ABAQUS software, combined with a unit deletion algorithm and Mohr-Coulomb yield criterion, to study the supporting effect of He bolt (cable) in soft rock tunnels. The research results indicate that He bolt (cable) support can effectively reduce horizontal and vertical displacements at the arch foot and arch bottom during the tunnel excavation process, thereby enhancing the stability of the surrounding rock. Furthermore, He bolt (cable) have a significant impact on controlling stress concentration in the surrounding rock and suppressing deformation, providing a theoretical basis and technical reference for the support design of soft rock tunnels.

**Keywords:** ABAQUS; unit deletion algorithm; Mohr-Coulomb; He bolt (cable).

## 1. Introduction

In underground engineering, the stability of surrounding rock caused by tunnel excavation is one of the key factors affecting engineering safety and long-term operation. Especially under soft rock conditions, tunnel surrounding rocks often exhibit significant settlement and deformation, leading to increased construction difficulty and costs. Therefore, effectively controlling the deformation of surrounding rocks in soft rock tunnels and ensuring the stability of the project has become a pressing technical challenge in the engineering community [1-3].

In soft rock tunnel engineering, traditional support methods, such as the anchor-spraying support system, have been widely used [4,5]. However, with the increase in project scale and excavation depth, the deformation problem of surrounding rocks in soft rock tunnels has become increasingly complex, and traditional support methods are gradually proving inadequate in dealing with large deformations of soft rock surrounding rocks. To address this, researchers both domestically and internationally have proposed various improved support technologies to enhance the deformation resistance and long-term stability of tunnels. Among these, He bolt (cable) has gradually become a research focus for soft rock tunnel support due to its unique mechanical properties and excellent support effectiveness [6-8].

The He bolt (cable) is a new type of anchor that possesses constant resistance and large deformation capabilities, demonstrating significant advantages in addressing large deformations and stress concentration issues in soft rock tunnels. Its basic principle is to maintain a relatively constant support force during deformation through structural combinations, effectively controlling the displacement of the surrounding rock and reducing the stress concentration effect [9,10]. Furthermore, the support performance of the He bolt (cable) has been validated through multiple experiments and practical engineering applications, particularly showing good results in deeply buried tunnels and soft rock strata. Compared to traditional anchors, the He bolt (cable) exhibits better adaptability and safety when dealing with creep, slip, and large displacements of surrounding rocks.

This paper utilizes the ABAQUS numerical simulation software, combined with the unit deletion algorithm and Mohr-Coulomb yield criterion, to establish a three-dimensional numerical model of tunnel excavation. It simulates and analyzes the support effect of the He bolt (cable) in soft rock tunnels. By studying the stress and displacement of key parts such as the tunnel arch foot, arch crown,

and arch bottom, the research results provide a reliable theoretical basis for the application of the He bolt (cable) in soft rock tunnels.

## 2. Engineering overview

This paper focuses on a specific tunnel, which is approximately 234 meters deep and has a total construction length of 5,710 meters. The surrounding rock grade of the tunnel is mainly classified as Grade V, characterized by easily fragmented rock that tends to soften and collapse when encountering water, leading to poor stability and significant settlement deformation, making construction difficult (Fig. 1).

The tunnel began construction in October 2018 and was completed on September 28, 2020. During the construction process, geological hazards such as landslides, water intrusions, and collapses occurred frequently. Therefore, conducting research on the support provided by He bolt (cable) in the tunnel is of great significance for ensuring the safety and stability of tunnel construction and operation.



Fig. 1 Tunnel construction diagram

## 3. Model establishment

Based on the special properties of the tunnel's geological layers, rock bolts are used as the main support method to achieve the effect of "strong support and early closure." The numerical simulation process in this paper consists of three steps: (1) Establishing a self-weight stress equilibrium analysis step for the rock mass where the tunnel is located, to simulate the stress distribution state unaffected by excavation disturbance. (2) Using the element deletion method in ABAQUS software to simulate the excavation of the tunnel entrance and the support effect of the rock bolt. In this step, an embedded method is used to simulate the contact state between the bolt and the surrounding rock. (3) Performing iterative calculations to analyze the support effect of the He bolt (cable) on the tunnel.

In actual cases, elements may disappear due to damage and fracture. To simulate this situation, the ABAQUS software platform provides a function for element deletion. In this paper, the direct deletion technique is utilized to simulate the disappearance of the rock mass in the tunnel entrance area, implemented through the \*MODEL CHANGE, TYPE=ELEMENT, REMOVE command statement.

### 3.1. Surrounding rock model establishment

Based on the ABAQUS software platform, a two-dimensional calculation model of the tunnel is established using a plane stress calculation mode (Fig. 2). The dimensions of the surrounding rock are set to  $300 \times 400$  m, with a density of  $2500 \text{ kg/m}^3$ , elastic modulus  $E=0.8 \text{ GPa}$ , Poisson's ratio  $\mu=0.3$ , internal friction angle  $\phi=35^\circ$ , and cohesion  $C=0.22 \text{ MPa}$  (Table 1). A structured mesh division is employed, dividing the surrounding rock into a total of 4683 mesh elements, with the mesh type being CPS4. The model is vertically constrained at the bottom and horizontally constrained on both sides.

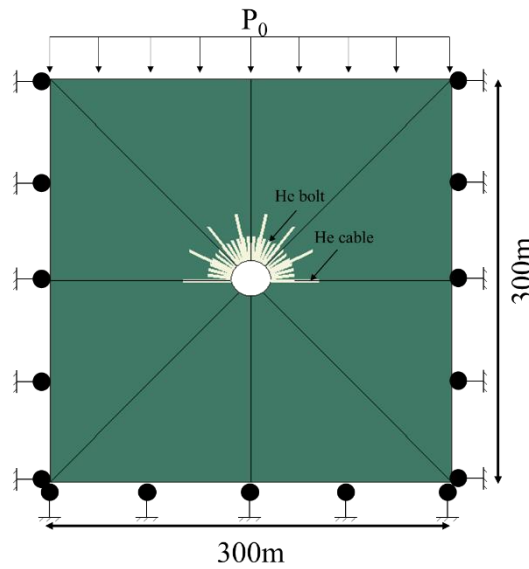


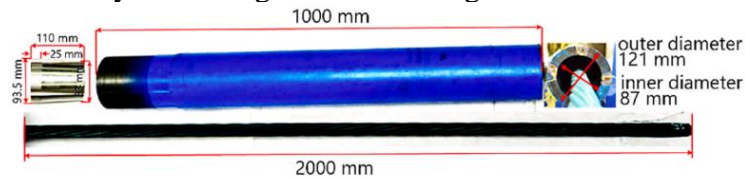
Fig. 2 Tunnel calculation model

Table 1. Mechanical properties of surrounding rock

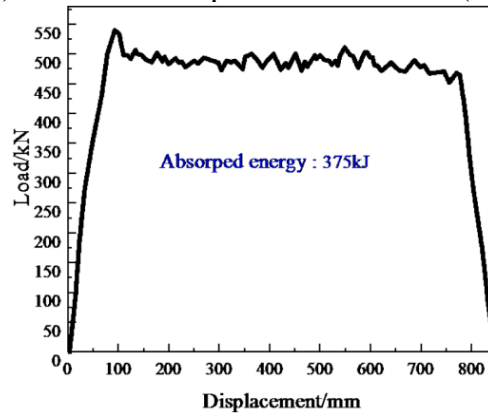
Surrounding rock	$\rho$	$E$	$\mu$	$\phi$	$C$
	500 kg/m <sup>3</sup>	0.8GPa	0.3	35°	0.22MPa

3.2. Mechanical model of He bolt (cable)

According to Fig. 3, the static tensile curve of the He bolt (cable) is divided into two stages: the elastic stage and the constant resistance stage. In the elastic stage, the tensile force of the bolt (cable) is linearly related to the elongation, exhibiting good elastic characteristics. Once the applied tensile force reaches a certain critical value, the bolt (cable) enters the constant resistance stage. In this stage, although the bolt (cable) continues to bear load, the tensile force remains relatively constant. This constant resistance characteristic enables the bolt (cable) to provide sustained support even under large deformations, effectively stabilizing the surrounding rock.



(a) Structural composition of He bolt (cable)



(b) Static tensile curve of He bolt (cable)

Fig. 3 Mechanical Properties of He bolt (cable) [11]

### 3.3. Mohr-Coulomb yield criterion

The surrounding rock is simulated using a plasticity model, and the yield criterion is as follows:

$$f = (\sigma_1 - \sigma_3) - (\sigma_1 + \sigma_3) \sin \varphi - 2c \cdot \cos \varphi = 0 \quad (1)$$

Where  $\sigma_1$  is the first principal stress of the element;  $\sigma_2$  is the second principal stress of the element;  $\sigma_3$  is the third principal stress of the element;  $C$  is the cohesion; and  $\phi$  is the internal friction angle. The principal stresses are the solutions to Eq. (2), and the calculation formulas are as follows:

$$\sigma_i^3 - I_1 \sigma_i^2 - I_2 \sigma_i - I_3 = 0 \quad (2)$$

Where  $I_1$  represents the first invariant of the stress tensor,  $I_2$  represents the second invariant of the stress tensor, and  $I_3$  represents the third invariant of the stress tensor.

## 4. Result analysis

### 4.1. Tunnel displacement analysis

As shown in Fig. 4(a), the horizontal displacement distribution of the tunnel is primarily concentrated at the arch foot, with the maximum horizontal displacements at the left and right arch feet both reaching 22.06 cm. This characteristic of symmetrical structure results in a symmetrical distribution of displacements, indicating that the arch foot locations should be a key focus area during design and monitoring processes. Over time, the displacement at the arch foot may affect the overall stability of the tunnel, necessitating enhanced monitoring.

Fig. 4(b) displays the distribution of vertical displacements in the tunnel, with the maximum vertical displacements occurring at the arch bottom and arch top. The arch bottom displacement reaches 24.63 cm, while the arch top displacement is 16.86 cm. This highlights the importance of monitoring the arch bottom displacement during tunnel construction and maintenance, as its displacement value is significantly greater than that of the arch top. The distribution trend of vertical displacements suggests that there may be certain weaknesses in the load-bearing capacity at the arch bottom, necessitating strengthened support measures to ensure the long-term stability of the tunnel.

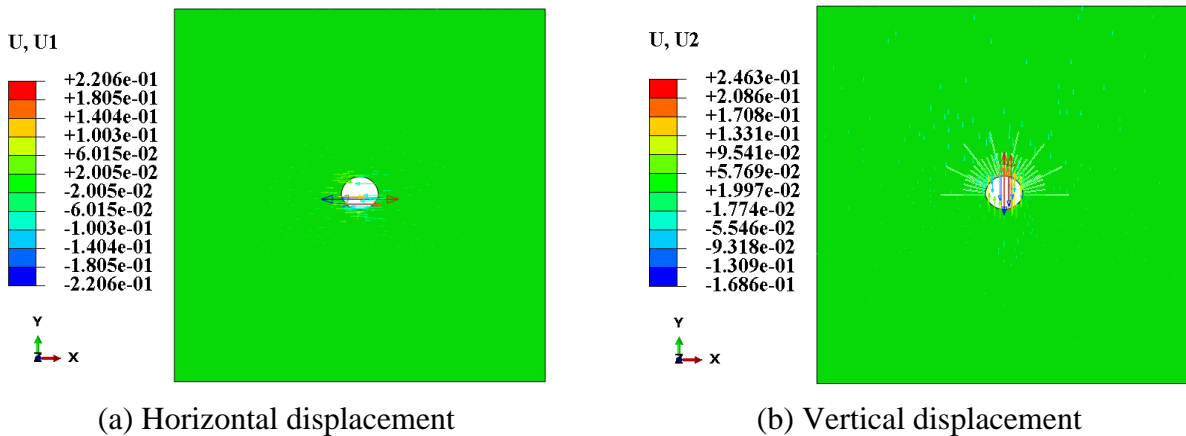
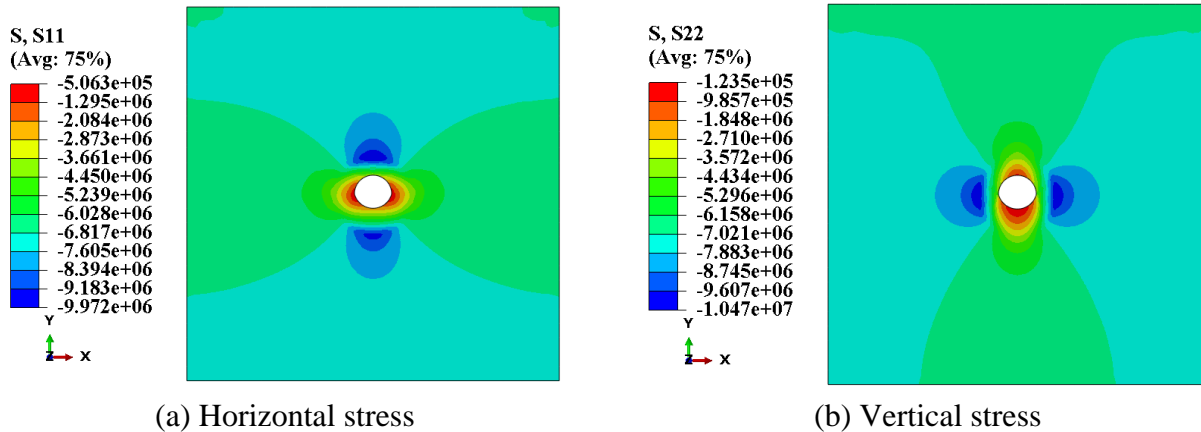


Fig. 4 Displacement after tunnel excavation (Unit: m)

### 4.2. Tunnel surrounding rock stress analysis

From Fig. 5(a), it can be seen that the horizontal stress in the tunnel is mainly concentrated at the arch foot, with a stress value reaching  $5.06 \times 10^5$  Pa. This indicates that the arch foot area bears a significant lateral pressure and is one of the key locations for stress concentration. From Fig. 5(b), it can be observed that the vertical stress in the tunnel is primarily concentrated at the arch bottom and arch top, with the arch bottom exhibiting the highest stress of  $1.84 \times 10^6$  Pa, indicating that it endures a substantial vertical load. In contrast, the vertical stress at the arch top is relatively low, measured at  $1.23 \times 10^5$  Pa. Therefore, it is evident that the arch foot and arch bottom of the tunnel are critical points

for stress distribution, and special attention should be given to reinforcing and supporting these areas during the design phase to ensure the stability and safety of the tunnel structure.



**Fig. 5** Stress Distribution of tunnel surrounding rock (Units: Pa)

## 5. Conclusions

Using ABAQUS numerical simulation software, along with the element deletion algorithm and Mohr-Coulomb yield criterion, this study established a three-dimensional numerical model of He bolt (cable)-supported soft rock tunnels and simulated and analyzed the stress and deformation behavior of the surrounding rock during tunnel excavation. The results indicate that:

(1) The horizontal displacement at the left and right arch foot of the tunnel reaches a maximum of 22.06 cm, while the vertical displacement at the arch bottom is the largest, reaching 24.63 cm, and the arch top displacement is 16.86 cm. The He bolt (cable) support scheme demonstrates significant effectiveness in controlling the deformation of soft rock tunnels, effectively improving the stability of the surrounding rock.

(2) The stress distribution shows that horizontal stress is highly concentrated at the arch foot, with a maximum stress of  $5.06 \times 10^5$  Pa, while vertical stress is primarily concentrated at the arch bottom and top, with the maximum arch bottom stress value of  $1.84 \times 10^6$  Pa. This indicates that after tunnel excavation, the arch foot and arch bottom experience considerable stress concentration, necessitating the strengthening of the support system design to further enhance the stability of the surrounding rock.

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