Optimization Research on Bolting Mode Based on Numerical Simulation

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Abstract

With the further exploitation of coal resources, the shallow coal resources are almost completely mined, and a series of problems faced by the exploitation of deep coal resources, the reserve coal pillars along the empty roadway are easy to produce damage with the change of mining dynamic pressure. Based on the numerical simulation, the influence of the anchoring method on the mechanical characteristics of the reserved coal column element is analyzed. It is concluded that the number of bolts does not significantly improve the peak strength of the anchored, but the residual strength of the anchored is significantly improved. In the three ways of laying bolts, evenly laying out the bolts with less axial force can not fully play, and the symmetric bolts can make the anchors reach the required mechanical properties, the bolts required less in quantity. Although the residual strength of anchored solids is improved by the plus-pile arrangement, the lifting effect is not as good as the symmetrical arrangement.

Keywords

Numerical simulation, bolt layout method, anchor, mechanical properties.

1. Introduction

With the further exploitation and utilization of coal resources, the shallow coal resources are decreasing, which is insufficient to supply the country's energy demand. In recent years, most coal mines have begun to mine deep coal [1]. However, China is a country with a complex geological environment. With the exploitation of deep coal resources, the problem of exposure has gradually increased. As the mining depth increases, the mining area continues to expand, which makes the surrounding rock stress of the roadway increase, and the difficulty of roadway support increases significantly [2], which leads to the problem of the support of the roadway, which is getting more and more attention. For thin and medium-thick coal seams with a thickness of 2m or less, the mining method along the empty roadway is often used [3], but this method will exert great impact pressure on the coal pillars between the roadways. It is easy to cause deformation and breakage of the roadway, which in turn affects production. In order to avoid such situations, the support of penetrating anchor came into being. The utility model can not only improve the ultimate bearing capacity of the coal pillars between the roadways, but also effectively increase the residual strength of the coal pillars and reduce the deformation of the roadway.

However, there are many factors influencing the support of penetrating anchoring, and the comprehensive support effect of each factor is difficult to explore. Among them, for the anchoring parameters, such as anchor material, gasket, anchoring agent and nut, Kang Hongpu [4] proposed that the mechanical properties and matching of bolt components have great influence on the anchoring support, and the destructive point of anchor in the coal mine is determined. The position of the breakage is easy to break, and the reasonable anchoring parameters are determined. Zhai Yingda [5] through the study of the pre-tightening anchor, it is concluded that the transverse pressing force generated by the pre-tightening force on the supporting is not only proportional to the pre-tightening force, but also related to the bolting density and the effective length of the bolt; Mohammadi M etc [6] based on previous experience, summed up the new judge to the ability of anchor support of a given rock mass; Du Z, Qin B, Tian F [7] studied that the anchor makes the principal stress around the roadway significant increased, the material strength is significantly improved. Therefore, the principal stress that the material can carry will be greatly increased. In the case of adequate support, an integral arch that is critical to the stability of the roadway will be formed around the roadway. Wang G, Wu X, Jiang Y, et al [8] proposed a new anchoring method—a bolt that absorbs rock energy. The anchor is mainly composed of smooth steel bars. There is a bolt end near the bottom. The cement and resin are used to fix the end and part of the bolt in the borehole. Once the load exceeds the preset capacity, the smooth part of the bolt will be Will slide as the rock deforms. Under high ground stress conditions, the anchoring system can withstand high loads and can withstand large deformations without serious damage. It provides support for the squeezing and blasting rocks that are often encountered during underground excavation in tunnels and mining areas. Static tensile testing of new bolts has shown that it can be extended to any desired length at high stress levels, absorbing large amounts of energy to maintain the stability of the surrounding rock. Chen et al. [9] discussed the feasibility of using a dish-shaped tray and its combination for yieldable technology of lengthened bolts.

Based on the above research results, in view of the support problems arising from the exploitation of deep coal resources in China, the effects of different anchor bolting methods on bolt support are studied by numerical simulation.

2. Bolt Laying Method

During the stressing process of the anchored body, the anchor rod is substantially an increase in the tensile strength of the rock and soil body. When the rock and soil are deformed by force, the bolt can play a good restraining role, and the phase change increases the tensile strength of the rock and soil. According to Coulomb's theory, the strength of the rock and soil is the anti-friction force on the rupture surface, that is, the cohesive force of the rock and soil and the normal friction on the rupture surface. The role of the anchor is equivalent to an increase in this anti-friction force. If the angle of the fracture surface and the stress distribution of each part on the fracture surface can be further considered, and the bearing effect of the support body will be better improved.

2.1 Mechanism of action on bolts

In the deep coal mining, due to the use of technical conditions along the roadway, the coal pillars between the parallel roadways are subject to the mining dynamic pressure, which causes serious deformation and damage, which poses a great threat to production safety. In order to avoid such phenomena, the thickness of the reserved coal pillars is usually increased to reduce the influence of dynamic pressure on adjacent roadways [10]. However, the reserve coal column will be subjected to a large impact pressure, and the section span is large, the stress of the middle coal pillar is concentrated, and the force is imbalance every position. The penetrating anchors are unbonded, and the both ends are the anchoring sections in the traditional sense, and the middle is the free section. It can use the high-strength trays at both ends to control the deformation and form dynamic constraint control on both sides, which greatly improves the overall bearing capacity. When the penetrating anchor is deformed, a compressive force is formed at both ends of the anchor rod to jointly restrain the deformation of the anchored. At this point, the anchor will be reconverted from the bi-directional stress state to the three-way stress state, thereby achieving a new balance during the stress process. Due to the interaction of the anchor bolts [11], when the axial force of the bolt is less than the ultimate strength of the bolt, the anchor ends of both sides will always provide the lateral pressing force to maintain the shape of the anchored subjects after the rupture. The overall effect is able to continue to withstand loads, thereby significantly increasing the residual strength of the anchored.

2.2 Determination of the way of laying anchors

The coal rock under high stress in the deep part is in accordance with the Mohr Coulomb strength criterion. Therefore, the damage of the reserved coal pillar between the roadways should also comply with this criterion. As shown in Fig.1, in the non-anchored state, the similar material gypsum block is laterally constrained, and the upper side is applied with uniform strain, and the gypsum block is destroyed by pressure. It can be clearly seen that the destructive surface is X-shaped with an angle of 53° and 42°. During loading, due to the uniform force of the gypsum block, the vertical displacement of the gypsum block changes due to elastoplastic destruction, the internal force is not uniformly symmetrical, and the force of each part is not clear, which leads to the layout of the anchor is not targeted, and a better layout cannot be adopted. Therefore, in the numerical simulation, the exploratory simulation needs to be carried out first, that is, the uniform layout is first performed, the stress state and the deformation characteristics of the anchored are analyzed, and then the layout manner of the design anchor is further optimized. In the simulation study, three bolt arrangements, uniform distribution, plum-pile distribution and symmetrical distribution were designed in order. The mechanical characteristics of the anchors in the three modes and the destructive characteristics of the anchors were discussed.

Figure 1 Constraint model and similar experiments without anchor loading damage

3. Numerical simulation analysis

3.1 Model establishment and parameter determination

In view of the mining mode of deep coal utilization along the goaf, the reserved coal pillars between the roadways are in accordance with the bidirectional stress state, and the conditions should be constrained when the model is established. In the simulation, the model is taken from the unit to establish a rectangular model of 200 × 150 × 200 mm (Fig.2) to simulate the reserved coal pillars between the roadways. On both sides of 200 × 150 mm, the displacement in the x direction is constrained as σ_2 in Fig.2, which is the binding force. Add the parameter on the bottom surface that is much larger than the bottom plate of the force model to limit the z-direction displacement of the model. The top plate and the bottom plate have the same parameters, but the top plate is a transfer body that applies a vertical force, and the surface force is as shown by σ_1 in Fig.2.

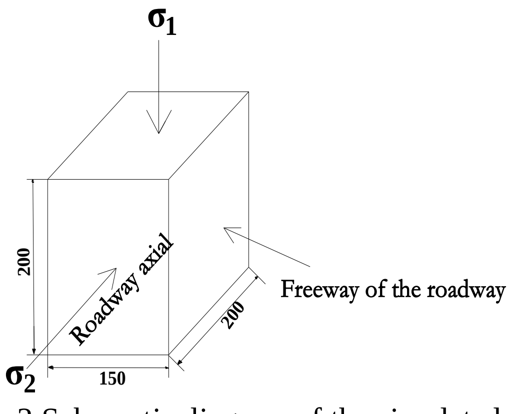

Figure 2 Schematic diagram of the simulated model

The model parameters are crucial for the numerical simulation results and are the key factors affecting whether the simulation results are in line with the actual situation. In this time value simulation, the parameters of the model are shown in Table 1 below:

Table 1 Analog parameter table

Parameter	Roadway surrounding rock	Bolt
Elastic Modulus（GPa）	2.545	200
Poisson's ratio(μ)（g/cm^3）	0.25	0.31
Volumetric weight(γ)（MPa）	1.13	7.85
Cohesion	0.48	——
Internal friction angle(φ)（°）	37	——

3.2 Simulation design and results analysis

The improvement of anchor parameters under various anchoring modes is analyzed by the relationship between the elastic modulus of the anchored before and after the peak intensity and the change of stress-strain relationship and the unstable zone. In the non-anchor state, as shown in the maximum shear stress cloud diagram in Fig.3, the maximum shear force of the model is distributed along the diagonal.

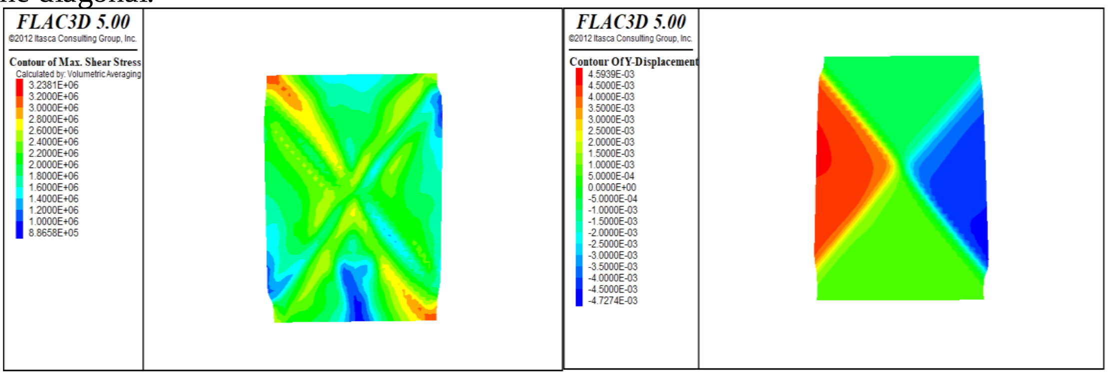

Figure 3 Maximum shear stress map without anchoring and displacement cloud map in Y direction

And the strain in the Y direction of the model reaches 4.72 mm, showing that the amount of displacement near the middle is larger than the displacement near the top of the top. For the authenticity of the simulation test, Fig.3 clearly shows that the model fracture mode and the fracture angle are consistent. For the actual stress-strain law of the unsupported model and the stress-strain law of the model under the simulation test, it can be seen from Fig.4 that the changes of the two curves are basically consistent.

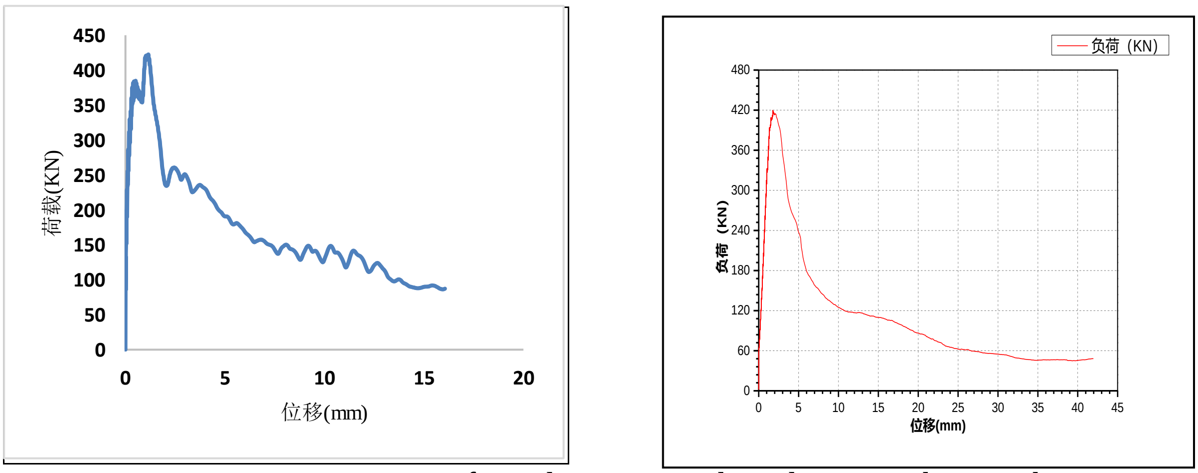

Figure 4 Comparison of simulation test and similar test without anchorage

3.2.1 Uniform distribution

The uniform layout is divided into two schemes for simulation. The scheme1 uses 9 anchor rods for anchoring, and the scheme2 uses 16 anchor rods for anchoring, and the spacing is uniform. The schematic diagrams of the two schemes and their simulated stress-strain characteristics are shown in Fig.5. It can be seen that the peak strength of the anchored has increased after the application of the anchor, but it is not particularly obvious. However, after the anchor is applied, its residual strength is greatly improved [12]. For this part of the strength increase, it must be brought by the anchor. The middle part of the anchor rod plays the biggest role in the process of stress. Taking the second scheme as an example, it can be seen from the bolt force curve diagram 6 that in the scheme1 and the scheme2 the part of the most stressed bolts is in the middle has large effect for the increase of the residual strength of the anchored. For the elastic modulus of the anchor and the unstable zone, the elastic modulus of the solution is 2.69 GPa, and the second is 2.72 GPa, indicating that the ultimate strength of the model after anchoring does not change excessively due to the increase in the number of anchors. In the case of no support, the volume of the unstable zone is 0.012082m^3, the volume of the unstable zone of the scheme1 is 0.012023m^3, and the volume of the unstable zone of the scheme2 is 0.0117982m^3. It can be clearly seen that as the number of anchors increases, the unstable zone of the anchored decreases. Compared with the first scheme, the number of bolts in the scheme 2 is increased by 77.78%, and the volume of the unstable zone is less than 1.96%. And the displacement cloud diagram of the bolt Y direction can further explain that in the anchor the force near the middle part is larger, the effect is more obvious, but the displacement caused by the shear force is the smallest. Taking the second scheme as an example, as shown in the displacement direction of the anchor rod Y direction in Fig.6, it can be seen that the displacement of the bottom anchor is small, and the force on the anchor can also be found that the bottom force is small compared close to the middle, and the part anchor has a small effect.

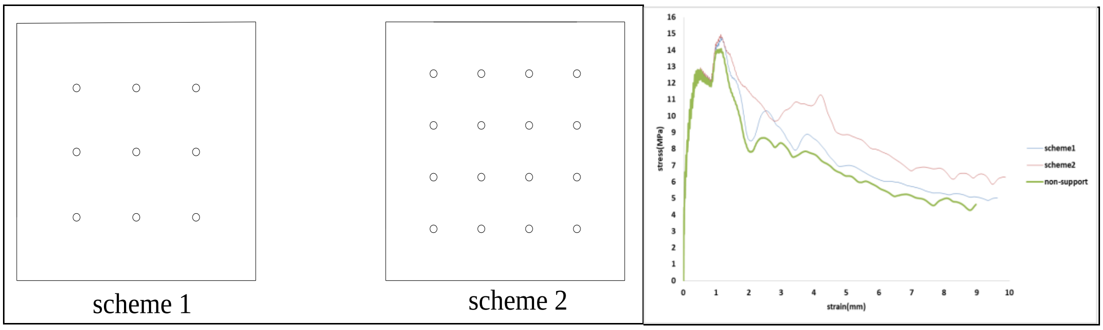

Figure 5 Uniform distribution simulation scheme and stress-strain characteristics of uniform support anchor

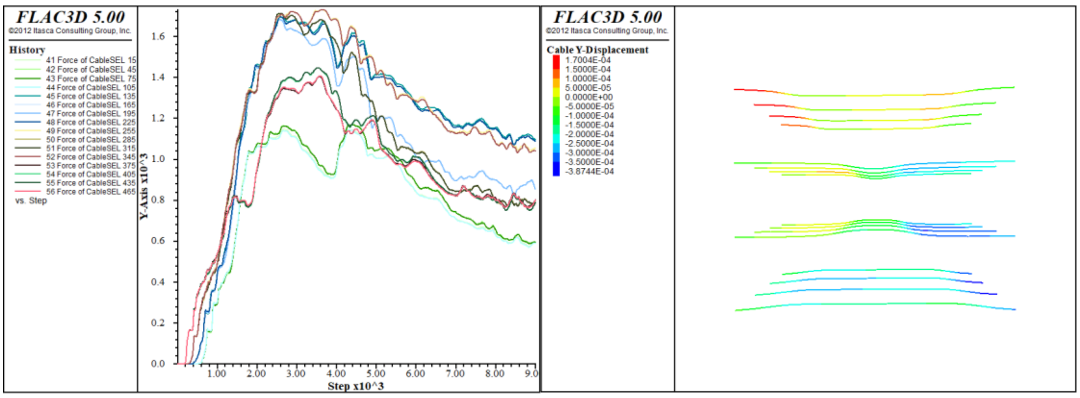

Figure 6 The force curve of the anchor and the displacement diagram of the Y direction of the anchor in the second scheme

3.2.2 Plum pile type distribution

The plum blossom pile layout is divided into three ways. The first scheme is dense in the middle and the upper and lower sides are sparse. The second scheme is uniform in row spacing, and the third scheme is dense in the upper and lower sides and in the middle, as shown in Fig.7.

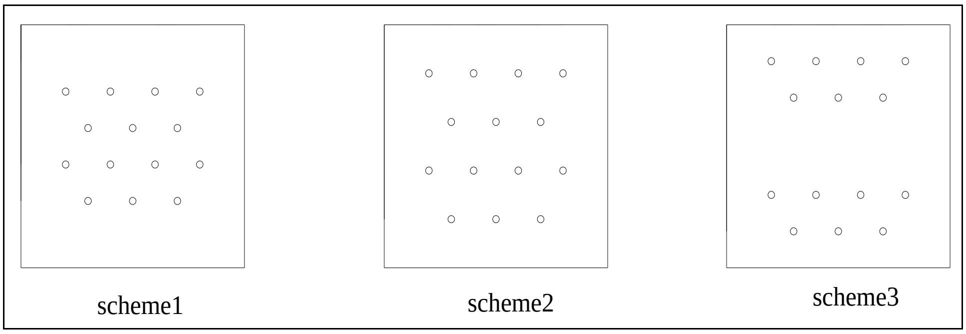

Figure 7 Plum pile anchor layout

In the numerical simulation of the plum pile type anchor bolt, the second scheme has the best effect. As shown in Fig. 8, taking the second scheme as an example, the anchors are evenly stressed on the shear plane, and the residual strength is obviously improved. However, in the uniform layout, the number of bolts in the scheme 2 is increased by two compared with the plum-pile type, and the residual strength is also improved more than that of the plum-pile-laying scheme. The plum-pile layout cannot effectively save the number of bolts to reach the same support effect. The elastic modulus and unstable zone volume of each scheme are shown in Table2 below. The volume of the unstable zone of the scheme is significantly less. Compared with the uniform layout scheme, the volume of the unstable zone is not much different, or even slightly smaller. The elastic modulus is not changed much compared with the uniform layout, indicating that the number of anchors does not improve the elastic modulus of the anchor.

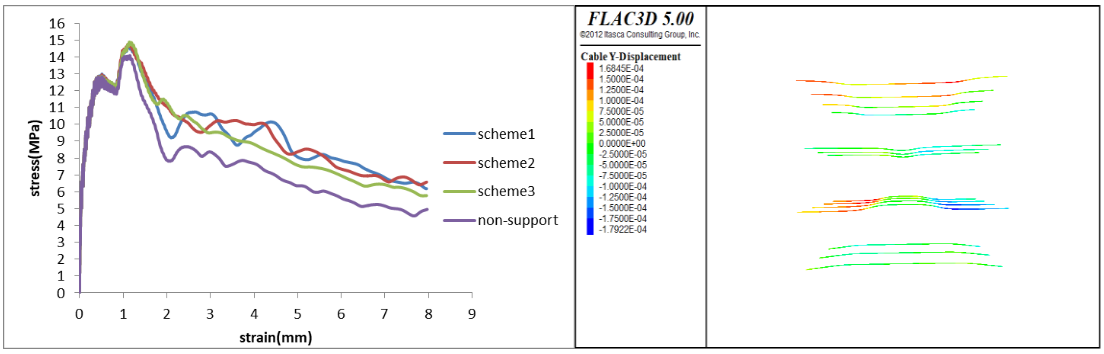

Figure 8 Stress-strain characteristics and in the second scheme Y-direction displacement cloud diagram of anchor

Table 2 Plum blossom pile layout anchor parameters

Parameter \ Scheme	Scheme1	Scheme2	Scheme3
Elastic modulus /GPa	2.65	2.67	2.69
Unstable zone/$\times10^{-3}m^3$	11.84	11.75	12.94

3.2.3 Symmetric distribution

There are three types of symmetric bolting schemes, as shown in Fig.9.

From the stress-strain characteristics of Fig.10, it can be concluded that in the symmetric layout scheme 2, the residual strength of the anchor is obviously larger than that of the first scheme and the third scheme. In the research of uniform layout bolts, it has been found that the axial force of the anchor in the middle part of the anchor is larger, and the symmetrical support better solves the problem that the axial force of the anchor in the middle part is too large, so that after the anchored is destroyed and the residual strength is effectively improved, but the layout does not improve the elastic modulus of the anchor, no longer analyzed, the volume of the unstable zone is shown in Table 3. In the symmetrical layout, taking the second scheme as an example, it can still be seen that the displacement of the two rows of anchors in the middle of the anchor is the largest, indicating that the axial force received by the two rows is still the largest, which is consistent with the axial force curve of the anchor in the simulation.

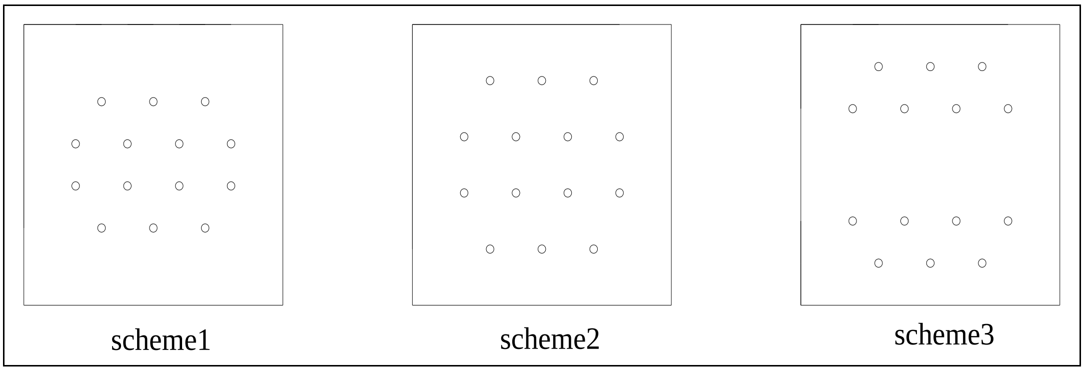

Figure 9 Symmetrical bolt placement

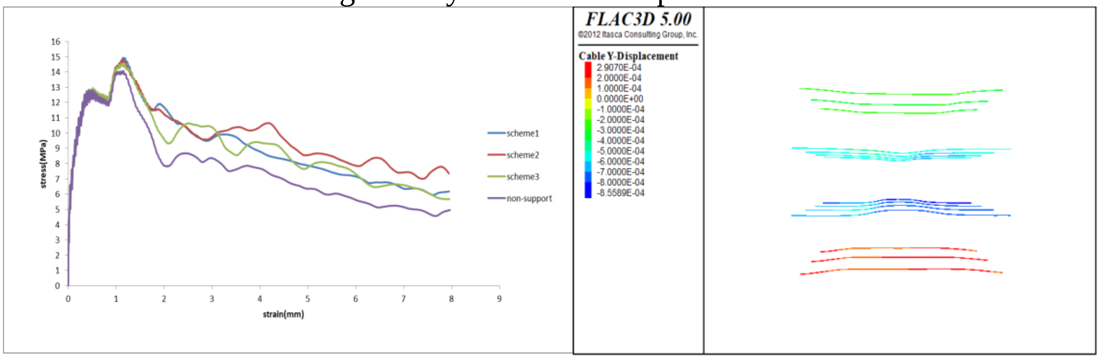

Fig.10 Stress-strain characteristics and in the second scheme Y-direction displacement cloud diagram of anchor

Table 3 Symmetrical layout of anchor parameters

Scheme / Parameter	Scheme1	Scheme2	Scheme3
Unstable zone /×$10^{-3}m^3$	11.72	11.67	13.76

4. Optimization discussion on bolting layout

There are advantages and disadvantages in the three layout methods. The uniform distribution is not enough for the axial force analysis of the anchor, so that the upper and lower anchors fail to fully exert their functions, and the bolt material is wasted in practice. However, it can be clearly seen that even with the increase of the number of bolts, the peak strength is not obviously improved, but the residual strength of the anchor is greatly improved. For the plum blossom pile layout, when the number of bolts is reduced, it shows that the residual strength is decrease compared with uniform. Therefore, the plum blossom pile layout is not the most suitable bolt layout. However, the symmetrical layout exhibits a better advantage, both in terms of anchor parameters and the improvement of its residual strength, which is better than the uniform arrangement of the more number of bolts. This is a great significance for the study of the bolting method to improve the mechanical parameters of the anchor.

5. Conclusion

The peak strength increase of the anchored is almost negligible for the increase of anchors, but the residual strength of the anchor is greatly improved. The anchoring method has a great influence on the improvement of the mechanical parameters of the anchor. Among the three layout methods, the symmetric layout can improve the same mechanical properties of the anchored in the most economical way. It is of great economic importance for actual production. However, the study failed to specify why different bolt layout methods have an impact on the mechanical properties of the anchored. Further research is needed.

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