U-steel and Anchor Cable Combined Support Structure for Deep Large Deformation Roadway

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ABSTRACT
Aiming at the large deformation problem of U type steel support for the roadway in deep high stress soft rock, By means of theoretic analysis and digital imitation, study on U type steel support for soft Rock Roadway. A u shaped steel & anchor rope combined supporting structure was put forward ,with the help of numerical simulation analyzing the structural, results show that the structure control the plastic zone expand effectively, the structure is an effective factor for controlling large deformation in roadway .

KEYWORDS: Deep high stress; Large deformation of roadway; U steel support; Combined support; Numerical simulation

INTRODUCTION
At present, along with the upper part coal resources dried up gradually in our country, it is most necessary to mine deep coal seam. With mining depth increasing, roadway surrounding environment become more severe than before, destruction of roadway that show the characteristics of large deformation, lasts longer, serious floor heave and so on. At current, the compressible U-shape support is widely used in crushing roadway. In practical application, however, due to poor relations with surrounding rock, practical support ability is only 0.2 to 0.3 of theory bearing capacity.
A large number of domestic and foreign experts and scholars practice shows that a single passive support is hard to control the strong deformation of high stress soft rock tunnel.\cite{1-4}. Research on u type steel support of stress status, deformation morphology, stability study, failure mechanism and improved control method. Liu Jianzhuang\cite{5} researched on mechanical mechanism of 29u type steel bracket with different damage forms by analyzing several typical failure characteristics of u type steel bracket that revealed the partial longitudinal stress may play a key role in the accelerated deformation. You Chunan\cite{6} studied on stable yielding problem was to give full play to bearing capacity of u shape steel yieldable bracket. He Guoyi\cite{7-8} proposed on analyzing bearing capacity of bracket according to stress condition of bracket, that to find out key failure parts was precondition of bracket design and reasonable support. Jin Guoqing\cite{9} researched on stability analysis of U shape steel yieldable bracket, and described the scientific of bolt grouting backfilling of shrinkage bracket. Wang Weijun et al. \cite{10-12} presented soft rock dynamic pressure inside and outside the structure coupling theory. Yu Weijian\cite{13-15} proposed by the main compression arch (bolting) and secondary compression arch (intensive anchor support) superimposed together constitute the mechanical model of arch carrier. However, at present the deep high stress conditions of u type steel support and stability mechanism of loss control strategy of control theory and technology were still insufficient, there was not a system, effective control theory and technology.

Therefore, in this paper, taking the deep roadway with large deformation as the research object, the common deep large deformation roadway deformation characteristics were summarized. Based on theory of elastic and plastic mechanics, mine pressure, to analyze plastic zone change regulation with roadway of u type steel support, revealed instability mechanism of u type steel support in deep roadway with large deformation, proposed collaborative supporting structure of u type steel and cable that used in deep roadway with large deformation. Numerical simulation showed that the collaborative supporting structure fully played advantage of u type steel and cable, with good control effect.

### Deep roadway and deformation characteristics

#### Deep roadway

Deep roadway and deep well were two different concepts. Generally consideration: deep well was mine depth that more than 800m. While the deep roadway was decided by mine depth and lithology two factors. Limit depth was defined as line from shallow transition to deep. Deep roadway criterion can refer to Table 1

<table>
<thead>
<tr>
<th>Uniaxial compressive strength of surrounding rock/MPa</th>
<th>Limit depth /m</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;20</td>
<td>150</td>
</tr>
<tr>
<td>20~30</td>
<td>300~400</td>
</tr>
<tr>
<td>30~60</td>
<td>650~700</td>
</tr>
<tr>
<td>&gt;60</td>
<td>&gt;1000</td>
</tr>
</tbody>
</table>

When roadway in shallow, supporting easy, once into deep, surrounding rock deformation showed with characteristics of deep roadway, after roadway construction, it was easy to appear phenomena of large area cracking, caving, two sides falling and floor heave, and with difficult support.
Deformation characteristics

Roadway with shallow to deep, roadway environment will become very complex, due to common influence of high stress, mining and water, roadway deformation will become very serious, deformation and failure characteristics were shown as follows:

(1) Roadway heave amount was large: after roadway excavation, floor with no support state, plus mining and drilling effect, surrounding rock of roadway was broken, squeeze film effect of two sides, extrusion effect of floor high horizontal stress, leading to serious floor heave of roadway.

(2) Roof subsidence amount and two sides convergence amount were large: with horizontal stress increased, two sides corner occurred stress concentration, if two sides support was weak, poor control with early surface deformation of roadway, leading to expansion of the plastic zone moved, unstable creep intensified, resulting in roadway often appeared straight walls shift, convergence amount of side parts large, presented U type steel support leg bending phenomenon.

(3) Surface spray layer of roadway was spalling, and occurred serious distortion, increasing resistance action of late U type steel bracket that must cause the surface layer extension fracture, destruction and stripping.

(4) Continuous creep. Under high stress, roadway deformation with time along with the plastic zone infinite outside moved continuously, performance as surface displacement continued to increase, until the destruction of roadway stability, to achieve balance of nature, and displacement to be maximum.

**Figure 1:** Deformation and failure of roadway

**NUMERICAL SIMULATION**

The numerical simulation and failure mechanism analysis of U type steel support

On the basis of common mechanical parameters (average) about surrounding rock of deep roadway, a roadway model be established with the cross section shape of straight wall arch, net width× height = 4.4 m ×3.5 m, model size: 50 m × 20m × 40 m. Tunnel buried depth
is 850 m, lateral pressure coefficient is 1.0, the vertical stress is the gravity stress, the boundary of around and floor is displacement constraint.

![Model mesh map and U type steel support](image)

**Figure 2:** The figure of calculation model and U type steel support

On the basis of the above model, calculation and analysis of the initial state of equilibrium, to analyze the stress cloud charts of horizontal and vertical.

![Horizontal and vertical stress cloud charts](image)

**Figure 3:** The stress cloud charts of initial equilibrium state

For analyzing dynamic changing process of the plastic zone, different iteration steps is taken from the whole calculation process (step = 200, step = 300, step = 500, step = 1000, step = 1500, step = 1500, step = 6000, step = 8731), which show the change rule of plastic zone size.
As shown in figure 4, in early part of the calculation, surrounding rock of roadway goes into the plastic zone quickly (step=200: the plastic zone is 0.5 m), and the plastic zone expansion speed increasing higher significantly (step=200-500: the plastic zone expanding moved to 1.0 m), mainly because of a gap at the between the tunnel walls and the bracket. U type steel support cannot provide supporting resistance in the initial stage of deformation of surrounding rock. U steel support providing support resistance quickly when surrounding rock contacts with it, which constrains the development of the plastic zone. So the plastic zone is only 1.5 m at the step 500-1500. When the plastic zone expanding to a certain range, although the u-shape support has been involved in regulation of the plastic zone expanding, but the plastic zone has been lost control at this time, u-shape support and surrounding rock must has inescapable overall destruction, that is the changing process of the plastic zone in the step1500-9000, the ultimate range of plastic zone is 3.0 m.

In the process of computing, computer records the displacement of roadway roof, the right side and floor.
As shown in Figure 5, mainly under the action of high stress, roadway surface is weakened, the space between the bracket and the tunnel walls were filled, surface displacement of roadway is only 200 mm at step=200, surface displacement increasing rapidly between step = 200-1000 (roof is 400 mm. The right side is 500 mm, the dip side is 580 mm), when u type steel support has play to surrounding rock, the growth of displacement have already started slowing down(step=1000), but displacement increasing (displacement is 1500mm at step=9000), roadway has been destroyed badly, u type steel support begins to deform at this time.

The advantages and disadvantages of anchor cable bolting

Anchor is a steel strand which one end fixed in deep rock mass of roadway, the other end fixed at surface of the roadway. It is widely used in coal mine roadway support as a key supporting technology at the same time. Based on the relationship between anchor cable and surrounding rock, analysis advantages and disadvantages of anchor rope support technology is anchor cable depend on its high bearing capacity and high prestressing force, which can active control the development of roadway surface displacement in time. But because of its bearing capacity is limited; anchor cable used in less stress and deformation of surrounding rock in roadway is fair. Otherwise, when deformation stress exceeds the anchor cable under load limit, anchor cable will be pulled apart or cause drag mark.

The numerical simulation of U steel & anchor cable combined support structure

In the large deformation roadway of high stress soft rock, in order to solve the above problems, this paper put forward collaborative supporting structure of U steel & anchor cable which is simple, easy to use and reliable.

Channel steel, u steel and flat steel combined to form a powerful, yielding collaborative supporting structure, which not only ensure the scalability of u type steel support, but also contains high prestressed of anchor cable. It is not easy to produce the overall damage and with long life.

Figure 6: u-steel & anchor combined support structure schematic drawing
Numerical simulation of the combined support structure

Merging anchor cable structure and unit model to form a new computing model, through iterative calculation, recording its displacement of plastic zone and surrounding rock, which were analyzed.

![Model mesh map](image1.png) ![U type steel & anchor cable](image2.png)

**Figure 7:** The combined support model of anchor & U type steel

For analyzing dynamic changing process of the plastic zone, different iteration steps is taken from the whole calculation process (step = 200, step = 300, step = 500, step = 1000, step = 1500, step = 6000, step = 7000), which show the change rule of plastic zone size.

![step=200](image3.png) ![step=500](image4.png)

![step=2000](image5.png) ![step=6500](image6.png)

**Figure 8:** the plastic zone distribution of U steel &anchor cable combined support at different iterative steps

As shown in figure 8, in the early part of the calculation, high prestressed stress of anchor rope limit surface displacement of roadway at early stage(step= 200 plastic zone is 0.5 m). When the deformation of surrounding rock increases, the channel steel plate with u-shape
can make appropriate yielding, which protect the anchor cable in a timely manner. U steel support providing support resistance quickly when surrounding rock contacts with roadway surface, plastic area began to expand slowly, until the roadway deformation stability (step=2000-6500:plastic zone moved to 1.8 m).

In the process of computing, computer records the displacement of roadway roof, the right side and floor.

![The displacement curve of U steel & anchor cable combined support](image)

**Figure 9:** The model displacement curve of roadway surrounding rock

As shown in figure 9, mainly because cable pre-stressed control surrounding rock of roadway surface in time, the displacement of right side is only about 10mm at step=200, the displacement of roof also is about 10mm. Between the step 200 and 1000, the surrounding rock in roadway of displacement rate is significantly lower, the displacement is 9 mm (roof), 12 mm (right side), 50mm (floor) respectively. With the combination working of U-shaped steel and anchor cable, the increasing rate of surrounding rock in roadway slows down at step=1000, But displacement always increases. At last, right side displacement is 22 mm, roof displacement is 19 mm, dip displacement is 50 mm, which can keep the roadway normal using in the actual practice.

**CONCLUSION**

(1) U steel support belong to passive supporting structure, though possessed of the high bearing capacity and faster augment of resistance, but because it’s not actively involved in the equilibrium process of secondary stress, which makes it particularly prone to failures.

(2) Anchor cable depend on its high bearing capacity and high prestressing force, which can active control the development of roadway surface displacement in time. But because of its bearing capacity is limited, anchor cable used in less stress and deformation of surrounding rock in roadway is fair. Otherwise, when deformation stress exceeds the anchor cable under load limit, anchor cable will be pulled apart or cause drag mark.

(3) The U shaped steel- anchor rope supporting structure presented in this article, which not only give full play to the advantages of the various components, but also actively involved in the equilibrium process of secondary stress surrounding rock, with the help of numerical simulation for the structural analysis, results show that the structure is an effective factor for controlling large deformation in roadway.
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