The invalidation mechanism of bolt-mesh support in soft coal roadway

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Abstract

The bolting is easy to go out of force in soft coal roadway. Based on the field measured data, the reason of bolt pre-stressed hysteresis descending in soft coal roadway was analyzed in detail by theoretical analysis and field measurement. Closely encircling the changing law of anchorage force during the bolt bearing course, the reason of the low initial anchorage force in soft coal roadway, the effect of surrounding rock deformation on bolt anchorage force and the circulating hysteresis descending of anchorage force as well as the impact of the structure stability on bearing structure of the bolt-mesh support were analyzed. The analyzed results show there exists a great amount of bolt pre-stress hysteresis descending in soft coal roadway because of remarkable difference between bolt and soft coal deformable capability. Thus, many comprehensive measures should be taken to effectively control the initial loose deformation of non-anchorage rocks between two bolts, to achieve higher initial anchorage force and to prevent anchorage force losing during bolt bearing course. At the same time along with increasing the bolting strength, the structure compensating measures should be taken to ensure the structure stability of the bolt-mesh support and to realize the high-strength stable bolting.

Keywords: soft coal seam; bolting; pre-stress; anchorage force; hysteresis

Through research on tackling key problems in the “Eighth-Five Years” period and “Ninth-Five Years” period continuously for many years, the bolting technology used in the coal roadway in China is developed from the general end bolting to the high-strength pre-stressed bolting [1-5], and it has formed a whole set of bolting technology in the coal roadway [6-9], which is suitable to the characteristics of the coal mines in China. Thus, the bolting has been applied extensively. However, the applied range of bolting is limited to I~III kinds of coal roadway. Though conducting a great lot of experiment studies in the IV~V kinds of coal roadways and also obtaining the definite successful experiences, but under the conditions of such surrounding rocks, the supporting problem of coal roadway still can not be solved by bolting safely. There are following problems of bolting in the coal roadway [10-11]:

1) The actual bearing force of bolt is lower than the bolt strength, even though the applied density of bolt is very big; the supporting effect is not good because of the quite strong deformation of the surrounding rocks.
2) The delamination of roof can not be controlled effectively, and the roof fall accident occurs often. The reason of strong deformation of surrounding rocks and roof fall are not caused by the bolt strength which is not enough. A large number of the engineering practices indicated that it is impossible to control the strong deformation of the soft coal roadway effectively by simply increasing the bolt strength [12-13].

The history of bolting development showed that a key for developing bolting is to increase the anchorage force. The lower anchorage force in the soft coal roadway has impacted on the extensive application of bolting. However, why is the bolting in the soft coal roadway easy to go out of force and what is the reason resulting in invalidation? These will be analyzed as follows.

1. Hysteresis descending of pre-stress

A large number of the engineering practices indicated that the pre-stress of high-strength bolt in the soft coal roadway is very easy to be losing after bolt installation, and this similar testing has been carried out in a coal mine of Zhengzhou Coal Mining Group Co. The installed hydraulic pillow of bolt while installing the bolt has a pre-stress of over 1~3 t in the early period of bolt installation, but the reading of hydraulic pillow of a majority of bolts is zero before long. In fact, the smaller deformation of surrounding rocks will result in complete losing of the bolt pre-stress because of the remarkable difference between bolt and soft coal deformable capability. For the medium hard rocks, the deformation capability of the surrounding rock is equal to that of high-strength bolt in the quantity level, and the pre-stress of high-strength bolting not easily loses. However, the pre-stress of high-strength bolting in the soft coal roadway very easily loses due to the strong deformation capability of the soft coal seam.

Now taking the usual F20×2200 mm bolt made by screw thread steel as an example, usually the bolt adopts the lengthening anchorage due to the limitations of machinery and so on. There is about 0.8~1.2 m long non-anchorage bolt between inside and outside anchorage segments, according to 1 m length for calculating, the initial pre-stress of bolt is usually 1~3 t, according to 2 t for calculating, the stress and strain of bolt can be calculated as follows:

\[
\sigma = \frac{F}{S} = \frac{2t}{\pi R^2} = \frac{2t}{3.14 \times 10^{-4}} = 63.69 MPa
\]

\[
\varepsilon = \frac{\sigma}{E} = \frac{63.69 MPa}{200 GPa} = 0.318 \times 10^{-3}
\]

The elongating capacity of 1 m long bolt between inside and outside anchorage segments is

\[
\Delta l = l \times \varepsilon = 1m \times 0.318 \times 10^{-3} = 0.318 mm
\]

The calculating results indicated that when the deformation of coals between inside and outside anchorage segments along the direction of bolt length in the soft coal seam is not smaller than 0.318 mm, the pre-stress of bolt would be lost, and it is very easy to occur in the soft broken coal seam.

Although the bolting with high-strength pre-stress has the hysteresis descending of pre-stress, but it can not show that to realize the bolt pre-stress supporting is unimportant. Contrarily, a mass of engineering practices and theoretical analysis indicated that the high-strength pre-stress anchorage is the basis for realizing the ideal working condition of bolt and the important means to realize the bolting with high performance. At the same time, the bolting with high-strength and pre-stress is also the necessary condition to realize the bolting with high performance, but it is no the sufficient condition to realize the bolting with high performance, thus, there are still many other factors impacting on the bolting performance.

2. Analysis of bolt working performance

The change of the working characteristic curve of bolt [3] is mainly dependent on: ① property, structure and strength of the anchored rock; ② the stress level of the surrounding rock; ③ the anchored length, anchored mode, bolt parameters and so on; ④ the wire mesh, metal band and beam as well as other auxiliary components, and ⑤ the damaging course of the surrounding rock such as collapse, fracture, delamination, rheological behaviour and displacement of the anchored rocks.

From the view of the bolting system, the bolt strength, anchorage mode, protecting surface components and pre-stress level have the important impacts on the anchorage force and its change. The anchorage force of bolt is dependent not only on the yield strength of the bolt component, but also on the anchored ability of the surrounding
rock, and the anchorage force of bolting depends on the mechanical property of anchored rocks to a great extent.

2.1. Early low anchorage force of bolt in soft coal roadway

The anchorage force [4] means the tensile stress (KN) borne by bolt after bolt installation due to the anchorage effect. The initial anchorage force means the anchorage capability of bolt in initial stages of rock deformation (deformation size of the surrounding rock is smaller than 30 mm in this stage).

The initial anchorage force of bolt has the great effect on the working anchorage force of bolt as shown in Fig. 1. The strong initial anchorage force not only can avoid the comedown of surrounding rock own carrying capacity, but also increase the own carrying capacity of anchored surrounding rock obviously. Along with deformation of the surrounding rock, the working anchorage force of bolt would be rapidly increased as shown the curve 1 in Fig. 1. From Fig. 1, it can be seen the own carrying capacity of surrounding rock is brought into full play, so that the equilibrium between the roof pressure and the own carrying capacity of roof can be achieved as soon as possible and the self-stability of the surrounding rock is realized. If the initial anchorage force is low, the anchorage force of bolt in initial stages would be influenced, and the speed of increasing resistance is decreased notably during bolt bearing, the bolt can not always bring into the due effect as shown the curves 2 and 3 in Fig. 1.

In roadway with big deformation of the surrounding rock, the damaging course of the surrounding rock has very big impact on the working state of bolt. A majority of soft coal roadway possesses the deformation of 100~200 mm before bolt bearing [11]. Although there is the hysteresis descending of pre-stress in the soft coal seam, but it is very important to control the loose deformation in initial stages effectively. In fact, many coal roadways have been unstable if the bolting brings not into action, namely, because the initial deformation may be not controlled effectively and the deformation of roadway is very rapid up to about 200 mm, at the same time, the anchorage force of bolt has got into the attenuation state and the continuous deformation can not be controlled effectively, finally, the bolting results in invalidation. Therefore, the loose deformation of the surrounding rock in the soft roadway at the initial stages of roadway excavation should be controlled effectively. The higher initial anchorage force should be realized by using the integrated measures such as improving the roadway figuration, protecting the surface and enhancing the pre-stress and so on. In view of shotcrete which would impact on the coal quality, enlarge the difficulty of the supporting technology and increase the supporting cost, the flexible mesh is mostly adopted as the bolt-mesh support in the soft coal roadway, and usually the shotcrete is not adopted, because the protective surface effect supported by bolt-mesh is very poor, so that the initial anchorage force is also lower.

2.2. Impact of rock deformation on anchorage force

The anchorage effect of bolt is that the bolt is bound together the surrounding rock by using the anchorage agent to form the inside anchorage head, and the surrounding rock can be reinforced by the anchorage effect of the inside and outside anchorage heads. Thus, the operating state of bolt, namely the exertion of the anchorage capability is closely relevant to the relationship of interaction between them. The maximum shearing force of anchorage agent in unit length is calculated by following formula [14]:

![Fig. 1. Changing curves of initial anchorage force of bolt](image-url)
\[
\frac{F_{\text{max}}}{L} = S_{\text{bond}} + P \times \tan(\theta) \times \text{perimeter}
\]

where \( \frac{F_{\text{max}}}{L} \) is the maximum shearing force of anchorage agent in unit length;

- \( S_{\text{bond}} \) is the binding strength of anchorage agent;
- \( p' \) is the surrounding rock pressure perpendicular to bolt;
- \( S_{\text{friction}} \) is the friction angle;
- Perimeter is the perimeter of bolt.

From the above formula, it can be seen the maximum shearing force of anchorage agent in unit length depends on the binding strength of anchorage agent and the friction resistance relevant to the surrounding rock pressure \( p' \) (namely hold swathing force). Obviously, if the binding strength of the anchorage agent is greater, the maximum shearing force of anchorage agent is also bigger, so when the hold swathing force \( p' \) is greater, the maximum shearing force of anchorage agent is also bigger.

The binding force of the anchorage agent with the surface of bolthole wall in the soft coal roadway is poor, for example, the main mining coal seam in Zhengzhou Mining Group is the bituminous coal with loose grain shape. Such coal seam presents the dry loose state after excavation on the contrary, the cementation ability of the coal seam after the coal seam infusion water is enhanced. When carrying out the bolt-mesh support in such coal seam, only a layer is bound between the bolthole wall and the anchorage agent after anchorage. The action between the surrounding rock and anchorage agent is mainly the friction force. The non-anchorage surrounding rocks among bolts are very easy to cause the deformation due to lower strength of the soft coal seam and the poor protective surface effect of the bolt-mesh support as shown in Fig. 2, so that the surrounding rock stress transfers to the depth and the surrounding rock pressure within the anchorage range is decreased, namely the hold swathing force of the surrounding rock to bolt is decreased. The maximum shearing force of anchorage agent in unit length is reduced, so as to decrease the anchorage capability of bolt greatly.

The calculating results indicated that the maximum shearing force of anchorage agent in unit length is 1.6 times at zero of the surrounding rock pressure, if the surrounding rock pressure is 3 MPa. When the surrounding rock pressure is 10 MPa, the maximum shearing force of anchorage agent in unit length is over 5 times at zero of the surrounding rock pressure. It is obvious that the surrounding rock pressure \( p' \) is significant to exert the anchorage effect of bolt. Therefore, the bolt length, the anchorage depth and the hold swathing force of the surrounding rock to bolt in the soft coal roadway should be increased to exert the anchorage capability of bolt. At the same time, it also shows that application of the bolt-mesh support is conditional.

2.3. Circulating hysteresis descending of anchorage force in soft coal roadway

In the soft coal roadway, the discrepancy of the actual working characteristic curve with theoretical curve of bolt

![Diagram showing the effect of surrounding rock deformation on anchorage force](image-url)
is greater due to the poor anchorage performance and the continuous great deformation of the surrounding rock. Thus, how to make the bolt has the rather ideal operating characteristic and to fully exert the anchorage force of bolt is the key to improve the bolting.

In the soft coal roadway, the damaging course of the surrounding rock would impact greatly on the bolt working. The bolt will result in invalidation along with the deformation of the surrounding rock during bolt bearing; moreover, it is no sudden invalidation. If the non-anchorage rocks among bolts result in the loose deformation, the anchorage force of bolt would make the rocks within the anchored range result in creep deformation, relaxation or compression-shear damage, so that the load borne by splint is lowered, thereby the anchorage force of bolt is also reduced. However, under the action of the anchorage force of bolt, the fracture rock blocks within the anchorage range can cause the extrusion and tooth each other to restrain the deformation of the surrounding rock within the anchorage range. But, the deformation of the non-anchorage rocks in the soft coal roadway would be further caused owing to the poor protective surface effect of the bolt-mesh support, and such deformation course would be developed from the rock surface to the depth of rock if such deformation may be not controlled effectively, so that the circulating hysteresis descending of anchorage force occurs during bolt working.

The changes of measured anchorage force of bolt along with the surrounding rock deformation in Zhengzhou Mining Group are shown in Fig. 3. From Fig. 3 it can be seen that the anchorage force results in circulating hysteresis descending course from increase to decrease time after time. The anchorage force of bolt during bolt bearing is not big; it also reflects that the anchorage performance of bolt under the condition of the soft coal seam is poor.

3. Bearing structure stability of bolt-mesh support

Anciently, it was proper to stress the significance of the bolt-mesh support with high-strength pre-stress. It also is the basis for forming the bearing structure of the bolt-mesh support with high performance and stability. If the high-strength pre-stress anchorage might be not realized, so it is difficult to form the reliable bearing structure of the high-strength bolt-mesh support. However, only to realize the high-strength pre-stress anchorage is not enough, also from the point of view of the structure stability of bearing structure of the bolt-mesh support, some measures should be taken to ensure the structure stability of the bolt-mesh support according to the surrounding rock conditions and the possible deformation damaging characteristics of the surrounding rock [15].

There exist two types of invalidation of the bolt-mesh support, firstly, the bolt-mesh support results in invalidation due to the low strength of the bolt-mesh system or the stronger deformation capability of the surrounding rock, secondly, the bearing structure of the bolt-mesh support results in invalidation caused by the unstability of bearing structure of the bolt-mesh support. The strength of the bolt-mesh support with high-strength pre-stress was stressed from the point of view of increasing in the supporting resistance of the bolt-mesh support in the past, and the bearing structure stability of the bolt-mesh support was not taken into account. The high-strength

![Anchorage force/MPa](image)

**Fig. 3. Relation between bolt anchorage force and surrounding rock deformation**
pre-stress anchorage is the necessary condition, but no sufficient condition to form the bearing structure of the bolt-mesh support with high-strength and stability. Under many conditions the bolt-mesh support results in invalidation mainly caused by the unstability of the bearing structure of the bolt-mesh support. Thus, only the bearing structure of the bolt-mesh support is stable, the bearing structure of the bolt-mesh support can achieve the high-strength stable supporting.

4. Conclusions

The invalidation causes of the bolt-mesh support in the soft coal roadway are all-round, and main causes are as follows:

(1) There exists a great amount of bolt pre-stress hysteresis descending in soft coal roadway because of remarkable difference between bolt and soft coal deformable capability.

(2) The deformation of the surrounding rock makes the rock stress transfer to the depth of the surrounding rock, so that the hold swathing force of the surrounding rock to bolt is decreased and the anchorage performance of bolt is also reduced. Moreover, the rock stress transfers continuously to the depth and the anchorage force continuously loses along with the persistent deformation of the surrounding rock in the soft coal roadway, so the circulating hysteresis descending of the anchorage force during bolt bearing appears.

(3) The bolt-mesh support invalidation mainly caused by being difficult to form the reliable bearing structure and the unstability of the bearing structure of the bolt-mesh support under many conditions. Thus, under the precondition of increasing in the supporting strength, the measures should be taken to improve the structure stability of the bearing structure of the bolt-mesh support.

References