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Study on the bolt-mesh-anchor support technology for mining roadway in complex coal seam

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STUDY ON THE BOLT-MESH-ANCHOR SUPPORT TECHNOLOGY FOR MINING ROADWAY IN COMPLEX COAL SEAM

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ABSTRACT: The stability of mining roadway is affected significantly by the condition of the surrounding rock and stress regime, which is the key factor for determining the roadway support program. Located in syncline axis, the No.15 seam is a steep seam at - 230 m level in Changgouyu coal mine, the original flexible shield cannot meet the safety and production requirement. The No.15 seam is classified as unstable and relatively complex according to the analytic hierarchy process (AHP). The distribution characteristics of stress in the seam around the synclinal axis before and after mining are analysed by use of FLAC^{2D}. According to the complexity of the coal seam and the stress distribution characteristics, the supporting parameters using bolt-mesh-anchor were selected and implemented successfully in an underground roadway, which can be referred to as in the design of roadway support in similar complicated coal seams.

INTRODUCTION

Mining roadway layout and associated support play a key role in coal mining operations, which are the key technologies directly related to the benefits of coal production and safety. Over the years, researchers in China and abroad have conducted extensive and in-depth studies on the layout, location and support technology of mining roadway (Lu, *et al.*, 1998; Hou and Guo, 1996). Outcomes from these studies made positive contribution to the improvement of roadway support, working conditions of mine workers and the enhancement of coal mining efficiency (He and Yuan, 2004). When the mining roadway is driven in the coal seam, its stability is directly affected the occurrence of mining induced stress of coal seam. In addition, due to the low strength of the surrounding rock and poor bearing capacity of the coal rib, it has been difficult to maintain the integrity of the longwall roadway (Hou, *et al.*, 1999). It is therefore important to give due consideration of the influence factors in the design of roadway support system.

With the increase of mining depth and the complexity of mining conditions, the maintenance of mining roadways in complex coal seam have become increasingly problematic and influenced by geological structure, soft-broken surrounding rock as well as many mining factors (Chen, *et al.*, 2005). At present, the methods of the roadway support can be divided into three categories:

1. Passive support in the form of a variety of metal steel supports, arching and so on;
2. Active support based on bolt and anchor support which can establish function relation with the internal surrounding rock; and
3. Active reinforcement form by grouting which can improve the surrounding rock characters and the mechanical properties of surrounding rock fundamentally.

For complex coal seams, there is a need to understand the weight of all kinds of complex evaluation index for the control of surrounding rock stability. The support program needs to be designed for the major influence factors. A single support form should be adopted as far as possible to reduce the project volume and associated the support costs; if this cannot meet the safety requirement, then a the combination of different support method should be adopted so that their respective advantages can be utilised to promote the stability of surrounding rock.

This paper discusses an evaluation method in relation to the characteristics and support features of steep and complex coal seam, calculates a comprehensive evaluation value. The paper also describes the simulations and analysis of the influence of the syncline for dynamic stress. By considering the coal seam complexity and structure influence, the roadway support is designed and implemented in field application with good results.

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PROJECT OVERVIEW

The No.16 coal seam at - 230 m level is located in the vicinity of axis part and neighboring areas of the two branches of the Changgouyu synclinal in Changgouyu Coal Mine. Because of the effect of strata uplift and subsidence formation caused by ancient and contemporary tectonic movement, the syncline coal seams are formed in the pitching axis direction of due north, dipping at 29°. The coal thickness is 1.0~8.8 m, average 4.5 m. Both coal seam and the surrounding rock have poor stability, significant changes in coal thickness with rock partings, all of these have great impact on the mining and support (Figure 1).

Influenced by geological structure, the stress re-distribution has been strong in the mining roadway, leading to severe deformation of the surrounding rock, support impairment in roadway, especially with the sixteenth and seventeenth anti-eye located at the synclinal axis (as shown in Figure 1). The mining roadway was initially supported with "8" shape flexible support, each support was linked with four or eight steel ropes. Damage in the form of deformation, distortion and fracturing of the support has occurred frequently, therefore significantly compromise the support of roadway. The support is frequently deformed, twisted and cracked in the welding joints (Figure 2, 3) therefore seriously affect the support function. The deformation and guttering of the surrounding strata are increasing seriously, and although the roadway has been repaired for several times, its condition has seriously limits production efficiency and causes threat to production safety.

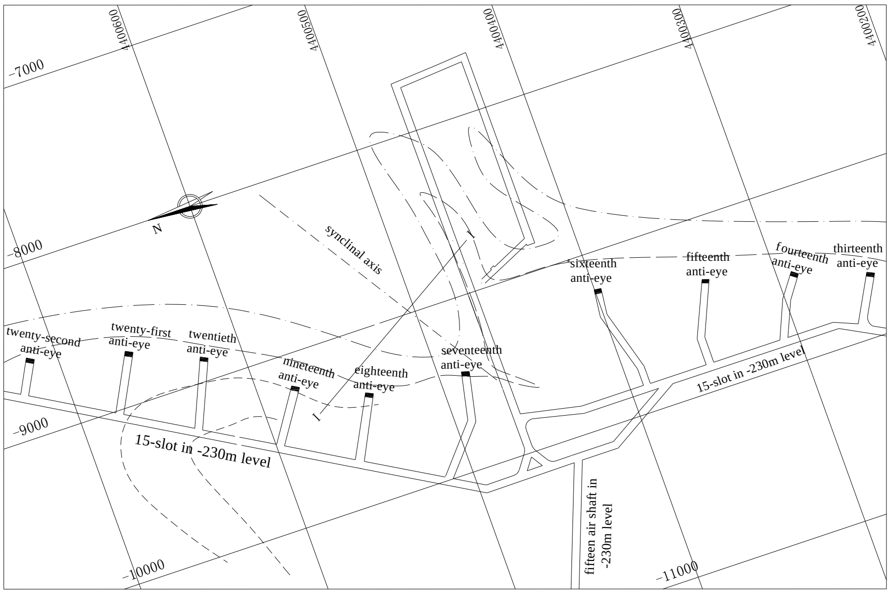


Figure 1 - A plan diagram showing the No.15 coal seam at - 230 m level

Figure 2 - Support crater cracking

Figure 3 - Support twist and deform

EVALUATION OF COAL SEAM COMPLEXITY

Many factors affect the coal seam complexity, these include geological structure, coal seam dip, thickness change the roof and floor condition of coal seam, the layers and thickness of dirt bands, the collapsing of karsts, the intrusion of magma and overburden depth, hydrological and geological condition.

Studies have shown that the coal seam complexity imposes significant influence on the support of the mining roadway (Huo, *et al.*, 2009). Therefore, it is necessary to evaluate the coal mine complexity before designing the roadway support. For this purpose, an evaluation system on the coal seam complexity is established by use of analytic hierarchy process (AHP). There are three steps in this evaluation criterion.

Firstly, identifying the influence index for coal seam complexity by describing the seam characters, the result can be one or zero; Secondly, according to the above index results and the weight of all indexes, calculate the evaluation marks of the indexes by an evaluation model. The total mark of all index influencing the coal seam complexity in which 100 means that the maximum influence on the complexity, and 0 means the minimum influence on the complexity; lastly, classifying the coal seam complexity based on the comprehensive evaluation marks. Based on the study references in China and overseas on the coal seam complexity, and considering the analysis of the influence index coal seam complexity as well as underground engineering applications, the complexity degree of the coal seam is classify as four grades. The classification types and criteria are shown in Table 1.

Table 1 - Classification and criteria of complexity of coal seam

Complexity classification of coal seam	Grade 1 Stable and simple	Grade 2 Relatively stable and fairly complex	Grade 3 Unstable and relatively complex	Grade 4 Extremely unstable and higly complex
Classification criteria (comprehensive evaluation marks)	<25	25～50	50～75	>75

According to the actual geological condition of No 15 coal seam at - 230 m level, the "evaluation system on the complexity of the coal seam V1.0" has been developed in VB6.0 language (Figure 4) (Wang, *et al.*, 2006; 2005). By inputting the identification index value of the complexity, the system produced a evaluation mark of 67 for the coal seam complexity. Comparing this mark with that of Table 1, the No.15 coal seam is classified as grade 3 - instable and relatively complex. Therefore, the following factors should be considered primarily when designing the support for the roadway:

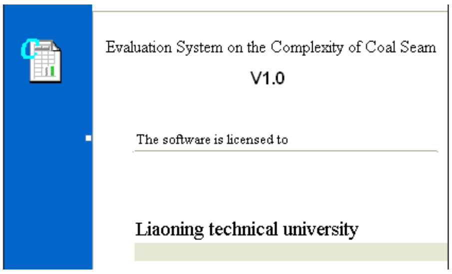


Figure 4 - The evaluation system on the complexity of the coal seam

(1) The support methods, material and engineering must be able to adapt to the changes of coal seam, such as the variation of coal seam dip, thickness, strength of the roof and floor, stress distribution caused by structure, etc.

(2) Giving priority to the flexible and active supports. The flexible supports can produce plasticity deformation, and unleash the energy of partial high stress zone. While the active supports can load weight punctually, strengthen the surrounding strata actively. It makes full use of the support ability of the surrounding rocks.

SIMULATION AND ANALYSIS OF THE STRESS STATE OF COAL AND ROCK MASS AT THE SYNCLINAL AXIS

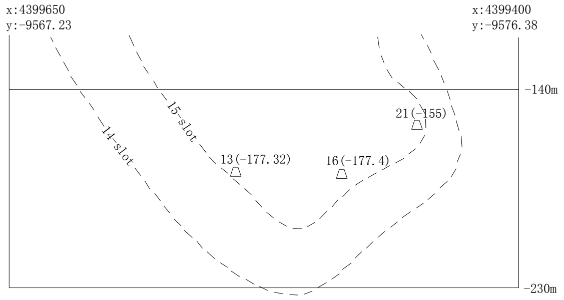
To better understand stress environment of No.15 coal seam and provide the basis data for support, the ground stress of - 230 m level has been measured by use of stress relieving method. The results show that the ground stress field at - 230 m level is horizontal and mainly horizontal compressive stress. It has the presence of regional tectonic stress field with maximum principal stress of 13.82 MPa in the direction of NE90°. According to the measurement of the ground stress and the synclinal relative position, the

Changgouyu synclinal axis is vertical with the inclination of the stress field. Therefore, the synclinal axis is largely affected by horizontal compressive stress of present structural stress field. The coal and rock mass at the axial places are in large stress state.

Figures 5 and 6 respectively show the sectional profile along I-I in the Figure 1 and sectional profile model. By using FLAC^{2D}, the stress state of No. 15 coal seam at – 230 m level synclinal axis is simulated and analyzed before and after mining. The following can be concluded from the analysis of the stress state of coal seam at synclinal axis (Figure7, 8):

(1) The vertical stress distribution of coal seam at synclinal axis increases with the increase of burial depth. The vertical stress does not increase as isogradient, but increases as the shape of coal seam of synclinal axis with the hide depth.

(2) When the both flanks of synclinal axis are mined out, coal seam at the axis is influenced by mining stress, the vertical stress increases by 1.1~1.6 MPa compared with that of prior to mining, and the result is 10.4~11.2 MPa. The roof and floor stress of synclinal axis is larger, the stress near goaf increases to 12.8~13.6 MPa dramatically. The stress concentration factor is 1.20~1.26. The influence range is 10~15 m.



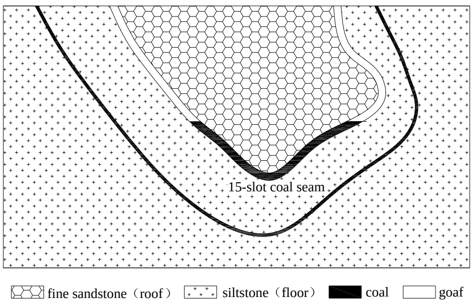


Figure 5 - I-I sectional profile **Figure 6 - I-I sectional profile model**

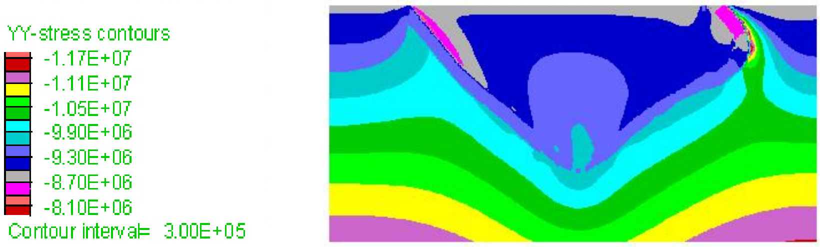


Figure 7 - Vertical stress distribution before coal mining

Figure 8 - Vertical stress distribution after coal mining

The followings can be concluded through the measurement of ground stress and the numerical simulation of stress state at synclinal axis:

(1) The measured principal stress direction is almost perpendicular to the layout of roadway. According to the maximum horizontal stress theory of roadway, one side of the roadway will have concentrated horizontal stress, and the area should be the key control part of the roadway.

(2) The numerical simulation shows that the stress concentration is formed in the synclinal axis coal seam before and after mining. The strength and intensity of the support equipment must be carefully considered.

STUDY ON THE SUPPORT METHOD OF THE MINING ROADWAY OF THE NO.15 COAL SEAM

Design of bolt support

The bolting has many advantages such as loading punctually, excellent support effect, low labour requirement, high efficiency, low capital cost (Wang, *et al.*, 2009; Zha, *et al.*, 2006). Because of that bolting is now widely promoted. Presently the bolting rate of coal roadway in China's state-owned key coal mines reaches 60%, this can be as higher as beyond 90% or even 100% in some coal areas (Kang and Wang, 2007). According to above analysis, the support method using bolting is selected in No.15 coal seam at - 230 m level. According to the distribution of structural stress field and the occurrence condition of coal seam, and considering similar engineering practice, and combining with the principle of asymmetrical support and controlling key part of the steep seam, the support program of 15-slot haulage roadway at - 230 m level is designed as bolt, anchor and metal mesh combined support. The support parameters are: three bolts thread steel for the roof and slope of the roadway respectively, and these bolts are of φ18 mm × 1800 mm. The row spacing is 650 mm, and the pitch spacing is 800 mm; the anchor length is 4000-5000 mm, one for the roof and sidewall respectively. The row spacing is 650 mm. The bolt is screwed on the end, hanging metal mesh on the roof. The original anchor stress of bolt is set as 20 kN, and the anchor is 30~50 kN. The distribution of roadway bolt and anchor is shown in Figure 9.

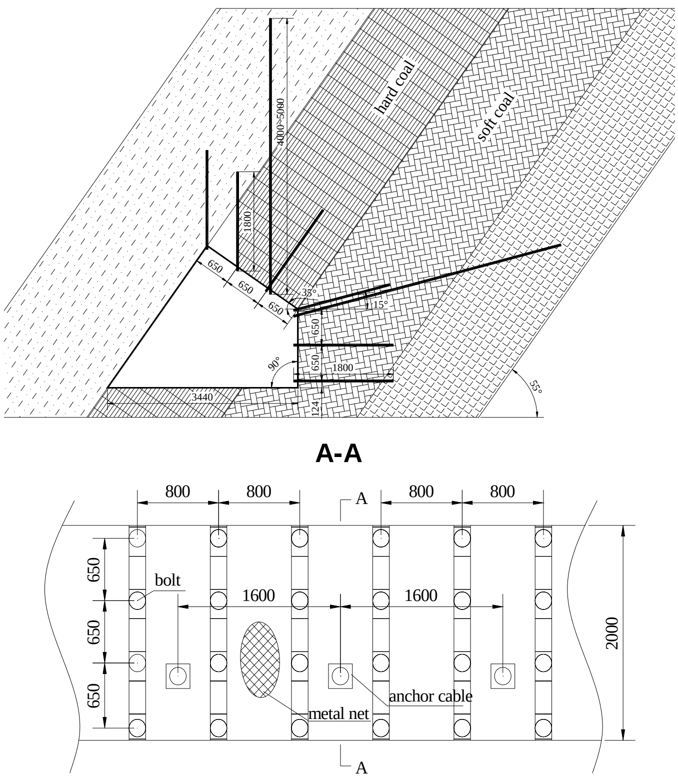


Figure 9 - Roadway geometry and the sectional view of the support (mm)

Pressure observation of the experimental roadway

The designed bolting program is implemented in the experimental roadway which is 100 m long. Pressure monitoring is carried out to determine if the roadway support design is reasonable or not, and provide the basis for further modifying and improving the support parameters.

(1) The monitoring shows that the maximum bolt force reaches 24 kN, anchor 30 kN, which are less than their respective failure load. Because of the anchors are cross-measure placed in deep seam, the coal and rock will experience sliding along the layer interface, it can lead to the anchor to bear shear failure

along the layer. If the sliding is violent, the diameter of anchor should to be increased to improve its shear strength.

(2) The different depth displacement values of roadway surrounding rock are rather limited. The maximum value reaches only 70 mm. The data shows that the designed length of bolt can control the displacement of the roadway deep surrounding rocks effectively. The displacement being limited is due to that the large coal seam dip, the stress along direction of the coal seam bedding caused by gravity will cause sliding of coal seam, so the bed separation along vertical direction of rock plane is less.

After monitoring for almost three months, the support effect in the test roadway is quite satisfactory. The support has greatly improved the maintenance status of the roadway. No maintenance is carried out during face mining. It reduces the labour intensity and the roadway maintenance cost with significant economic benefits.

CONCLUSIONS

(1) The complexity evaluation of the No.15 coal seam at the - 230 m level is carried out by means of "seam complexity analysis system V1.0". The coal seam is graded as III unstable and relatively complex type. It provides the basic data for the selection of support methods.

(2) The numerical simulation is carried out to study the stress conditions in the area of the No.15 coal seam's synclinal axis. The stress is concentrated before and after mining at the axis part of the seam. Hence the strength of the support equipment and support density should be improved appropriately.

(3) In view of the complexity of the No.15 coal seam, the stress condition of synclinal axis and the support characteristics for steep coal seam, the bolt support parameters for mining roadway are determined. Pressure monitoring shows that the support program is reasonable and the field economic benefits are significant.

(4) The coal seam complexity evaluation system has been applied to the research of roadway support deign for the first time, which makes the support method selection and the parameters determination being more scientific.

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REFERENCES

Lu, S, Tang, L and Yang, X, 1998. Anchoring force and anchoring technology of cable, China Coal Industry Publishing House: Beijing, pp 44-45.

Hou, C, Guo, H, 1996. Orientation of technical development of rock bolting in in-seam gate-ways in China. *Journal of China Coal Society*, 21(2):113-118.

He, M and Yuan, H, 2004. Bolt theory and practice of coal mines in China, Science Press: Beijing, pp21-25.

Hou, C, Guo, L and Gou, P, 1999. Coal roadway bolting, China University of Mining and Technology Press: Xuzhou, pp7-17.

Chen, Y, Yu, X and Bai, J, 2005. Discussion on bolt and cable supporting technique of the complex roof, *Energy Technology and Management*, 6:6-7.

Wang, L, Miao, X and Dong, J, 2006. Numerical simulation of bolt-grouting support in soft roadway affected by mining, *Journal of Mining and Safety Engineering*, 23(1):39-42.

Wang, L, Li, M and Wang, X, 2005. Study on mechanisms and technology for bolting and grouting in special soft rock roadways under high stress, *Chinese Journal of Rock Mechanics and Engineering*, 24(16):2889-2893.

Wang, L, Zhang, Z and Zhang, J, 2009. Numerical simulation of bolt-grouting for gob-side entry in complex seam under a high stress, *Journal of Mining and Safety Engineering*, 26(2):145-149.

Huo, B, Zhang, H and Zhang, Z, 2009. Study on evaluation theory about complexity of coal seam, *World Sci-Tech R&D*, 31(3):433-438.

Zha, W, Xie, G and Luo, Y, 2006. Contrast testing study on steeply inclined seam roadway support under different support form, *Coal Mine Safety*, 6:4-6.

Kang, H and Wang, J, 2007. Rock bolting theory and complete technology for coal roadways, China Coal Industry Publishing House: Beijing, pp13-28.