Acta Technica 62 (2017), No. 5B, 557–568

Analysis on minimum reserved thickness of safe rock pillar during uncovering coal seam in rock crosscut

Zhenzhen Jia[2], Tao Feng[2], Qing Ye[2], Chunshan Zheng[3]

Abstract. During the development of roadway in coal mines, it often passes through coal seam, therefore, the safe rock pillar must be reserved to ensure the construction safety of roadway before uncovering coal seam. In order to accurately obtain the thickness in different geological and mining conditions, influencing factors on the minimum reserved thickness of safe rock pillar were analyzed from the physical- mechanical properties of coal, the influence of blasting operations, gas pressure in coal seam and ground stress on strata. The reserved thickness of safe rock pillar was studied theoretically from section modulus, shear stress and the energy of coal and gas outburst, then the calculation formula was obtained. The uncovering coal seam in rock crosscut in Mengjin coal mine was chosen to verify the adaptability and feasibility of the deduced formula. Results showed that the minimum thickness design of safe rock pillar can shorten the construction time, reduce production cost, and make the mining area succeed smoothly, which has significant social and economic benefits. Therefore, the deduced formulas can provide theoretical guidance for the minimum thickness design of safe rock pillar in engineering practice and provide the theoretical evidence for amending relevant items in "Coal Mine Safety Regulations in China".

Key words. Uncovering coal seam in rock crosscut, safe rock pillar, minimum reserved thickness, gas and coal outburst.

1. Introduction

More than 95% of coal mines are underground in China, coal and gas outburst is the most common accident. During uncovering coal seam in rock crosscut, the

[1]Acknowledgement - This work is financially supported by the National Natural Science Foundation Project of China (51704111 and 51374003) and the Hunan Provincial Natural Science Foundation Project (2016JJ6038 and 16C0653). Their supports are greatly appreciated.

[2]Workshop 1 - School of Resource, Environment and Safety Engineering, Hunan University of Science and Technology, Xiangtan, Hunan, 411201, China

[3]Workshop 2 - School of Mechanical and Mining Engineering, the University of Queensland, Lucia, QLD, 4072, Australia

strength of coal and gas outburst is large, which brings extensive effect and serious damage, for example, during uncovering coal seam in rock crosscut in Zijiang coal mine, the coal and gas outburst accident resulted in 22 deaths. An especially serious accident of coal and gas outburst occurred in uncovering working face in Tonghua coal mine, resulting in 30 deaths and 79 injures. There are more coal and gas outburst accidents without casualties [1]. With the increase of mining depth, the outburst under the condition of uncovering coal seam in rock crosscut is increasingly dangerous. A lot of the effective outburst prevention measures have been adopted during uncovering coal seam with coal and gas outburst. Statistic results showed that coal and gas outburst during uncovering coal seam in rock crosscut is related to the thickness of the reserved safe rock pillar. Therefore, before uncovering coal seam, the safe rock pillar must be reserved to ensure the safety of roadway construction, the reserved thickness of safe rock pillar is 5 m according to "*Coal Mine Safety Regulations in China*". However, in different ground stresses, geological and mining conditions, the minimum reserved thickness of safe rock pillar should be different, so the stipulated thickness is not reasonable. However, how to determine the minimum reserved thickness of safe rock pillar during uncovering coal seam in rock crosscut is difficult.

The accident of coal and gas outburst during uncovering coal seam in rock crosscut is serious, in order to avoid coal and gas outburst accidents in uncovering coal seam, many scholars have done a lot of researches and many prevention measures have been directly adopted in uncovering coal seam in rock crosscut. For example, a novel forecast indicator was proposed to validate the outburst prevention effect, which can provide a possible method to quickly validate the outburst prevention effect in the process of uncovering coal seam in rock crosscuts [2]. Liu has theoretically identified that the energy stored in tectonic coals with high-pressure gas is the main driving force of outburst during uncovering coal in rock crosscut [3]. So a renovated approach was brought forward based on the gas drainage borehole in uncovering coal seam in rock crosscut, the regular project of draining coal seam gas in rock crosscut was taken as the current regional innovative projects for preventing the outbursts [4]. Using the self-developed and three-dimensional simulation experiment system of coal and gas outburst, the uncovering coal process of rock crosscut in fault structure zone was simulated[5]. Simulation- experiment system of coal and gas outburst in uncovering coal seam in rock crosscut was designed, the experiment results reflect the change of stress and gas pressure. Mechanism of the "strong-soft-strong" structure for rock crosscut in uncovering coal seam was studied, the results show that a soft circle isolates and absorbs deeper stress while a strong circle holds the residual stress and gas pressure. The structure strength is higher when these are used together. When the soft circle is 4 m and the strong one is 2 m, the effect on emission of coal and gas outburst is best [6]. To reinforce the broken surrounding rock of horizontal roadway in -655 m, the model of column-hemispherical penetration formula in view of Bingham fluid of time-dependent behavior of viscosity was established based on some related assumptions. By adjusting the supporting scheme, optimizing blasting construction, the time of uncovering coal seam was shortened approximately 1/3, which realized the rapid uncovering coal seam and effectively alleviated the pressure of excavation replacement of coal mine[7]. The above results show that a lot of anti outburst measures have been adopted and a large number of research outcomes have been obtained during uncovering coal seam in rockcrosscut. However, the outcomes about theoretical analysis on the minimum reserved thickness of safe rock pillar in detail are less. Previously, the experience data or formulas are used to determine the reserved thickness of safe rock pillar, which results that the thickness sometimes is too large or too small. When the reserved thickness is too large, uncovering coal seam by one-off blasting is difficult; when the thickness is too small, the outburst accidents may happen in process of roadway construction.

To avoid the outburst and reduce the cost of uncovering coal seam, it is quite essential to calculate the reliable minimum reserved thickness of safe rock pillar in different geological and mining conditions, which has the theoretical and realistic significance for rapid uncovering coal seam. Therefore, according to the deficiency of existing research, the minimum reserved thickness of safe rock pillar is studied by theoretical analysis and engineering tests in this study, results may provide theoretical guidance for determining the minimum reserved thickness of safe rock pillar in engineering practice.

2. Analysis on the Influencing Factors

During uncovering coal seam in rock crosscut, the minimum reserved thickness of safe rock pillar is influenced by many factors, which are complex and interactive, resulting in many difficulties to determine the minimum reserved thickness of safe rock pillar [1]. Firstly, the compressive strength and shearing strength of rock are determined by its physical and mechanical properties. The rock permeability is generally poorer than coal seam permeability, therefore, gas pressure, gas energy and elastic potential energy in coal seam are high, and coal seam is in the three-dimensional closed state of compression. When the crosscut drivage is near coal seam, gas content, gas pressure and gas energy will be changed suddenly [8]. Secondly, under the action of ground stress, coal seam accumulates considerable storage energy, which is the energy source of coal and gas outburst. When the stress changes, the storage energy may be released, which causes the coal's state change and makes coal broken completely. Thirdly, the change of gas pressure can bring the effective stress change of rock, so that the elastic modulus, Poisson ratio and other mechanical parameters decrease with the increase in gas pressure [9]. Gas content and gas pressure in coal seam is high, the more gas energy stores in coal seam [10]. Apparently, the larger gas pressure and pressure gradient are, the more easily coal and gas outburst occurs; thus gas increases the tendency of coal and gas outburst and also accelerates the instability process of coal, namely, gas pressure is the main impetus to make coal thrown towards roadway. Fourthly, blasting operations destroy rock, reduce rock strength and change physical and mechanical properties of rock. In addition, gas pressure and expansion of explosion gas make cracks extend to the surrounding of the blasting hole, and form a certain crack zone, which provides conditions for the rheology of coal and rock, and the occurrence of coal and gas outburst.

3. Formula Deduction of Minimum Reserved Thickness of Safe Rock Pillar

The rock pillars are subject to three-dimensional force before uncovering coal seam in rock crosscut, therefore, To theoretically obtain the minimum reserved thickness of safe rock pillar, the simplified mechanical model of coal and rock mass is adopted (as shown in Fig. 1), the reserved safe rock pillar is considered to be a fixed beam under uniform load. In this model, the length of the fixed beam L is the height of the reserved safe rock pillar (i.e. the height of roadway), the width of the fixed beam h is the vertical width of the reserved safe rock pillar, the height of the fixed beam b is the thickness of the reserved safe rock pillar, $L>>h$, $L>>b$, E is the elastic modulus, $P(t)$ is the vertical ground stress, $s(t)$ is the horizontal ground stress, $q(t)$ is gas pressure, $P(t)$, $s(t)$ and $q(t)$ are a function of time.

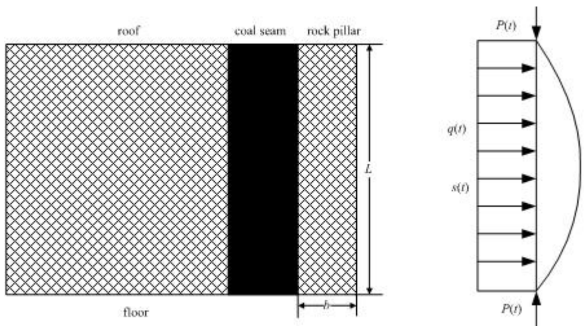

Fig. 1. Simplified model of coal and rock mass

According to the materials mechanics, the section modulus of the fixed beam W is obtained by: $W=hb^2/6$. The maximum bending moment of the fixed beam M_{max} appears at its ends and can be obtained by: $M_{max}=qL^2/12=(P\pm b)L^2$, where, q is the uniform load, P is the vertical ground stress, γ is the volume fraction, γb is the weight of the reserved safe rock pillar. The equilibrium equation is: $WK_P=M_{max}$, where, K_P is the tensile strength of the rock. Thus, it can be obtained as follows.

$$R = 1 \tag{1}$$

Solving equation (1), it can be obtained: $b = L(\sqrt{\gamma^2 L^2 + 8K_P P} \pm \gamma L)/(4hK_P)$. When the dip of coal seam is larger, γb can be ignored, thus it can be obtained: $b = 0.05L\sqrt{3P/(hK_P)}$, if the safe coefficient k is considered, it can be gottenas follows.

$$b = 0.05kL\sqrt{\frac{3P}{hK_P}} \tag{2}$$

In generally, the length of rock pillar is always greater than its thickness, while in formula (2), the length L of rock pillar is less than its thickness b. Therefore, the reserved safe rock pillar must be amended when it is regarded to be a fixed beam. In addition, the reserved safe rock pillar is used to be a support, the tensile strength of rock can be obtained from the test, but the tensile strength of rock mass $K_P$is influenced by many factors, thus K_P is more difficult to be determined in practice, so the practicability of formula (2) is limited.

As shown in Fig. 1, gas pressure in coal seam cuts off the reserved safe rock pillar along the circumference of tunneling face, the equilibrium equation is $(q+s)z = \tau.b.u$, it can be gotten as follows.

$$b = \frac{(q+s)z}{\tau \cdot u} \tag{3}$$

Where, q is gas pressure, Kg/cm^2; s is the horizontal ground stress, Kg/cm^2; z is the area of tunneling face, m^2; u is the circumference of tunneling face, m; $\tau$is the shear strength of the reserved safe rock pillar, Kg/cm^2.

Coal and gas outburst is an instability failure caused by the change of gas energy and deformation energy stored in coal into kinetic energy, the instability failure includes coal collapse and gas overflow. The released energy includes the elastic strain energy caused by ground stress and gas energy stored in coal and pores[2]. The atmospheric pressure is ignored, because it is far less than ground stress and gas pressure, hence, gas pressure $q(t)$ is the comprehensive reflection of gas energy, etc. Ground stress and gas energy varies with time after instantaneous tunneling.

From Fig. 1, the simplified rock pillar is bent under the combined action of horizontal ground stress and gas pressure, the curve of bending deflection $f(s)$ of rock axis can be expressed by Fourier series $f(s) = \sum\limits_{n=1}^{\infty} Y_n \sin n\pi s/L$. Because the first term of Fourier series plays a major role in mechanical system, under condition of two order approximation, $f(s)$ can be expressed as follows.

$$f(s) = \frac{Y}{b} \sin \frac{\pi s}{L} \tag{4}$$

Where, s is the arc length, Y is the deflection of axis midpoint.

The total potential energy of any structural system consists of strain energy and the work done by the load on the corresponding displacement; therefore, combined with the conditions of model, the potential energy function of the reserved safe rock pillar V can be described by:

$$V = U + W_1 + W_2 + W_3 \tag{5}$$

Where, U is the strain energy of the reserved safe rock pillar, W_1 is the work done by the vertical stress $p(t)$, W_2 is the work done by gas pressure $q(t)$, W_3 is the work done by the horizontal stress $s(t)$.

It is assumed that deformation obeys the assumption of plane cross section, then the strain is $\epsilon = y/R$; therefore, the stress of the cross sectionσ can be calculated by: $\sigma = Ey/R$, where, R is the curvature radius of the neutral line, y is the distance of the point on the section from the neutral line. The moment M on the cross section is $M = bE/R \int_0^h y^2 dy$. Defining the inertia moment of the fixed beam $J = b \int_0^h y^2 dy$, thus U can be expressed as follows.

$$U=\int_0^L\int_0^h\frac{1}{2E}(\frac{M}{J})^2y^2bdydx=\frac{EJ}{2}\int_0^L K^2(x)dx \tag{6}$$

Where, K is the curvature of the fixed beam and can be described by $K=\frac{d}{ds}(\arcsin\frac{df}{ds})=\frac{d^2f}{ds^2}\sqrt{1-(\frac{df}{ds})}^2$. Therefore,

$$U=\frac{EJ}{2}\int_0^L(\frac{d^2f}{ds^2})^2\left[1-(\frac{df}{ds})^2\right]^{-1}ds \tag{7}$$

Under the action of the vertical ground stress, the compression ratio of the fixed beam ΔL is

$$\Delta L=L-\int_0^L\sqrt{(ds)^2-(df)^2}=\int_0^L\left[1-\sqrt{1-\left(\frac{df}{ds}\right)^2}\right]ds \tag{8}$$

Therefore, the work done by the vertical ground stress $p(t)$ is

$$W_1=-p(t)\Delta L=-p(t)\int_0^L\left[1-\sqrt{1-\left(\frac{df}{ds}\right)^2}\right]ds \tag{9}$$

The work done by the gas pressure

$$W_2=-\int_0^L q(t)f(s)ds=-\frac{2q(t)YL}{\pi} \tag{10}$$

The work done by the horizontal ground stress s(t) is

$$W_3=-\int_0^L s(t)f(s)ds=-\frac{2s(t)YL}{\pi} \tag{11}$$

Putting equation (7), equation (9), equation (10) and equation (11) into equation (5), it can be gotten as follows.

$$V=\frac{EJ}{2}\int_0^L(\frac{d^2f}{ds^2})^2\left[1-(\frac{df}{ds})^2\right]^{-1}ds-p(t)\int_0^L\left[1-\sqrt{1-\left(\frac{df}{ds}\right)^2}\right]ds-\frac{2q(t)YL+2s(t)YL}{\pi} \tag{12}$$

The integrand in equation (12) is developed according to Taylor series, equation (12) can be approximately described by rearrangement as follows.

$$V=\frac{EJ\pi^6}{16L^5}Y^4+\frac{\pi^2}{4L}\left[\frac{EJ\pi^2}{L^2}-p(t)\right]Y^2-\frac{2q(t)YL+2s(t)YL}{\pi} \tag{13}$$

Defining $Y = \frac{2L}{\pi}\sqrt[4]{\frac{L}{EJ\pi^2}}x$, $a = \frac{L}{\pi}\sqrt{\frac{L}{EJ}}\left[\frac{EJ\pi^2}{L^2} - p(t)\right]$, $b = -\frac{4L^2}{\pi^2}\sqrt{\frac{L}{EJ\pi^2}}\,[q(t) + s(t)]$, equation (13) can be described as follows.

$$V = x^4 + ax^2 + bx \tag{14}$$

The elastic modulus of rock mass changes very little before uncovering coal seams in rock crosscut; thus, in practice, it is generally regarded as a constant. Because the stress system of coal has a recombination process, the change of ground stress and gas pressure is rather obvious; therefore, ground stress and gas pressure cannot be considered as a constant, $p(t)$ and $q(t)$ are used to describe ground stress and gas pressure at the time of t before uncovering coal seams in rock crosscut, respectively. According to the catastrophe theory, the equation (14) has three real roots, thus the conditions of coal and gas outburst during uncovering coal seams in rock crosscut are obtained as follows. (1). when $q(t)+s(t)$ is equal to the elastic modulus of coal and rock mass before uncovering coal seams in rock crosscut, the rock mass conditions may change instantaneously, so coal and gas outburst may occur. (2). when $q(t)+s(t)$ is greater than the elastic modulus of coal and rock mass before uncovering coal seams in rock crosscut, coal and gas outburst will occur. (3). when $q(t)+s(t)$ is less than the elastic modulus of coal and rock mass before uncovering coal seams in rock crosscut, coal and gas outburst will not occur. However, when the reserved thickness of safe rock pillar decreases or the gas accumulation energy is more than the elastic modulus, coal and gas outburst may occur. Therefore, the horizontal stress and gas pressure must be decreased so as to prevent coal and gas outburst.

4. Result Analysis and Discussion

To verify the adaptability and feasibility of the minimum reserved thickness of safe rock pillar calculated by the deduced formula, the position, thickness, gas pressure and the physical-mechanical properties of coal seam must be acquired, and the reliability of these data must be analyzed. Besides, properties, thickness and fracture development of rock pillar must be acquired to analyze the destroy degree of geological structure, ground stress, mining action and mining pressure of the reserved safe rock pillar. Therefore, the uncovering Z_1 coal seam in rock crosscut in Mengjin coal mine was selected as the research object. In Mengjin coal mine, the elevation of uncovering coal roadway is -445.486 m, the vertical wall and semicircle arch is used in the uncovering coal roadway, the width of the roadway is 2.8 m, the height of the roadway is 2.8 m, the overall length of uncovering coal roadway is 12 m. In elevation of -445.486 m, the bottom-up distribution of coal and rock is as follows. The thickness of coal seam is 5.5 m, the thickness of mudstone is 0.6 m, the thickness of siltstone is 1.2 m, the thickness of sandy mudstone is 0.4 m - 0.5 m, and the thickness of sandstone is 7.2 m. Gas pressure is 2.1 MPa, gas content is 11.7 m^3/t, the sturdiness coefficient f of coal is 0.3227, the initial velocity of gas diffusion Δp is about 18.4. Three groups of rock samples and rock cores at the ribs of crosscut roadway are acquired. The physical and mechanical parameters of rock are tested, a series of basic parameters of the roof in Z_1 coal seam are obtained, as shown in Table. 1. A large amount of information about ground stress has been consulted and analyzed, it is found that in Z_1 coal seam, the initial velocity of gas diffusion is large, the coal is soft, gas content and gas pressure are large. The sandstone of the roof has high hardness, the region of Z_1 coal seam has high ground stress.

Table 1. Physical and mechanical parameters of rock

Items	Rock density /kg.m^{-3}	Acoustic velocity /m.s^{-1}	Tensile strength /MPa	Compressive strength /MPa	Elastic modulus /10^4MPa	Poisson ratio /μ	Friction angle /(^{o}‘)	Cohesive force /MPa
siltstone	2665	3447	2.18	84.8	2.24	0.225	$45^o42'$	8.35
mudstone	2517	2980	0.85	14.4	0.87	0.275	$26^o38'$	2.22
sandy mudstone	2652	3199	0.99	19.3	1.15	0.249	$32^o48'$	4.78

4.1. Analysis on Ground Stress

The stress distribution and deformation of coal and rock mass in the roadway is only calculated under the action of ground stress; the stability of coal and rock mass is analyzed. According to the principles of the finite element, the calculation scope should be 3-5 times of the roadway radius; therefore, the calculation height is 12 m, the upper portion of the roadway is about 4 m, the lower portion is about 5 m; the width is 18 m, the widths of both sides are 7.6 m. The mechanical parameters are shown in Table. 1.

According to the geological data in Mengjin coal mine, the minimum principal stress in the region ranging from -420 m to -500 m increases with the depth H and can be described as the equation S_h=-0.819+0.018H; while the maximum horizontal stress can be described as the equation S_H=-3.855+0.028H. In level of -450 m, S_h is 9.0 MPa, S_H is 11.4 MPa. There is a high horizontal stress zone in the rock stratum with the elevation ranging from -420 m to -500 m, the maximum horizontal principal stress and the minimum principal stress reach 21 MPa and 14 MPa, respectively. The orientation of the maximum horizontal principal stress mainly concentrates on N56°E-N88°E, the average orientation is N75°E, which is in rough agreement with the orientation of the regional tectonic stress. According to the distribution of the vertical stress, the vertical stress in -450 m is $\sigma_z=\gamma H$=13.7 MPa,γ is the volume force of the overlying rock, the vertical stress caused by the horizontal stress is $\sigma_x=\sigma_y=\lambda\sigma_z$=3.73 MPa,$\lambda$ is the pressure coefficient determined by Poisson ratio, λ is 0.27 in this engineering test.

The calculation indicates that the ratio of the maximum horizontal principal stress of actual measurement and the horizontal principal stress from the calculation is 5.63(21/3.73), the ratio of the maximum horizontal principal stress of actual measurement and the vertical stress from the calculation is 3.06(11.4/3.73); the ratio of the maximum horizontal principal stress according to regression relation and the maximum horizontal principal stress from the calculation is 3.06(11.4/ 3.73); the ratio of the maximum horizontal principal stress according to regression relation and the vertical stress from the calculation is 0.83(11.4/13.7). According to the above basic measurement of ground stress, here the horizontal principal stress is 13.7 MPa and the vertical principal stress is 21 MPa.

4.2. Analysis on Gas Pressure in Coal

Only the stress distribution of coal roadway under the action of gas pressure is considered, the horizontal calculation boundary is the same to that of ground stress calculation, the coal perpendicular to the roadway is removed, and the constraint conditions are different from above calculation. Five experimental schemes are selected, where the reserved thickness of safe rock pillar is 2.5 m, 2 m, 1.5 m, 1.3 m and 1.0 m, respectively, then calculation results of ground stress are analyzed to determine the reasonable reserved thickness of safe rock pillar. The SAP95 is used in the finite element analysis, here the results are analyzed only based on Von Mises stress. The calculation results indicate that when only ground stress works, the maximum stress appears at the base angle of roadway and the top of the semicircular arch, its value is 37.94 MPa - 44.42 MPa; the maximum Von Mises stress is 44.42 MPa. The compressive stress at the base angle of roadway is not less than 28.903 MPa, the maximum stress zone is mainly concentrated on the base angle of roadway, but the scope is rather small. The main control area is the floor. When different reserved thicknesses of safe rock pillars are adopted, Von Miser stress and the roadway floor displacement are shown in Table. 2.

Table 2. Stress value of the floor of roadway under the action of gas pressure

The thickness of coal/m	Von Mises stress/MP	Tensile stress/MPa	Floor displacement /10^{-4}m
2.5	0.851	0.717	8.537
2.0	0.938	0.854	0.854
1.5	2.059	1.209	12.090
1.3	3.982	3.548	15.496
1.0	4.510	10.898	19.470

4.3. Determination of the thickness

From Table. 2, it is indicated that the tensile stress caused by gas pressure exists in the surrounding rock of the floor. At the same time, high compressive stress caused by ground stress also exists in the surrounding rock of the floor. The tensile stress and the compressive stress cancel out each other so that the tensile stress will not appear in the rock of the floor. When the reserved thickness is more than 1.5 m, the tensile stress at the floor caused by gas pressure slowly increases with the decrease of the reserved thickness. When the reserved thickness is less than 1.5 m, the tensile stress increases dramatically; when the reserved thickness decreases to 1 m, the tensile stress reaches 10.898 MPa. Therefore, the reserved thickness cannot be less than 1.5 m.

The lithology test results show that the strength of the siltstone is highest among different kinds of rock mentioned in Table. 2, its compressive strength is 84.8 MPa. The parameters are obtained by experiment, so it cannot be completely considered as the strength index of rock mass. According to engineering experience and blasting experiments, combined with the actual mining in coal mine, here 80% of the strength of rock sample is considered as the strength of rock mass, i.e. the strength of rock is 67.84 MPa. Comparison of the above 5 schemes, the reserved thickness of safe rock pillar cannot be less than 2.0 m.

The reserved safe rock pillar with the thickness of 2 m is adopted during two consecutive uncovering coal processes in rock crosscut, uncovering coal seams takes 28 days and 32 days, respectively, which is far less than the planned project time, the direct economic benefit is about 20 million Yuan. The engineering practice shows that it decreases the engineering quantity of drilling and tunneling, accelerates pressure relief and gas drainage, and effectively relieves the danger of coal and gas outburst.

5. Conclusions

To obtain the minimum reserved thickness of safe rock pillar in different geological and mining conditions, the influencing factors on the minimum reserved thickness were analyzed theoretically, and the calculation formulas were deduced and practiced in the uncovering coal seam in rock crosscut in Mengjin coal mine. The main conclusions are as follows.

(1) The influencing factors on the minimum reserved thickness of safe rock pillar are complex and interactive, which result in the uncertainty of the reserved thickness, and bring many difficulties for determining the minimum reserved thickness.

(2) The calculation formulas of the minimum reserved thickness of safe rock pillar and its application scope are obtained.

(3) The practice results in uncovering coal seam in crosscut in Mengjin coal mine show that the minimum reserved thickness of safe rock pillar is 2.0 m, the actual time of uncovering coal seam is far less than the planned project time. During the uncovering coal seam in crosscut in Mengjin coal mine, the constructions succeed smoothly, and the mining in coal mining is safe. The direct economic benefit is about 20 million Yuan.

(4) The deduced calculation formulas for the design of the minimum reserved thickness of safe rock pillar are feasible by proving of uncovering coal seam in crosscut in Mengjin coal mine, therefore, they can provide theoretical guidance in engineering application, also provide the feasibility for amending relevant items in "*Coal Mine Safety Regulations in China*".

References

[1] T. Yang, J. W. Liu: *Study on the rules of time and spatial distribution of coal and gas outburst accidents in china during 2010-2015.* Journal of north China institute of science and technology *13* (2016), No. 6, 96–100.

[2] S. X. Tian, C. L. Jiang, L. H. Xu, D. D. Yang, J. Tang, Y. J. Chen, X. W. Li: *A study of the principles and methods of quick validation of the outburst-prevention effect in the process of coal uncovering.* Journal of natural gas science and engineering (2016), No. 30, 276–283.

[3] Z. Liu, Z. H. Li, Y. B. Yang, H. J. Ji, Y. B. Tang: *Pressure relief and outburst elimination effect of outburst prevention rock tunnel in rock cross-cut coal uncovering region.* Journal of Mining & Safety Engineering *30* (2013), No. 6, 940–945.

[4] H. L. Xue, H. Q. Cui: *Meticulous geo-exploration and scrutiny approach based on the gas drainage boring hole in rock crosscut coal uncovering.* Journal of safety and environment *14* (2014), No. 6, 60–64.

[5] J. Liu, Z. G. Liu, K. Gao, Y. K. Ma: *Simulation experiment of mechanical characteristics and acoustic emission response during outburst induced by rock cross-cut coal uncovering in tectonic belt.* Journal of China coal society *39* (2014), No. 10, 2022–2028.

[6] W. Yang, B. Q. Lin, H. J. Wu, F. W. Meng, Y. X. Zhao, C. Zhai: *Mechanism study of the "strong soft strong" structure for cross cut in uncovering a coal seam.* Journal of China university of minim & technology *40* (2011), No. 4, 517–522.

[7] M. Y. Zhang: *Application of rapid excavation technology in rock cross-cut coal uncovering in gently inclined and thick coal seam.* Safety in coal mines *48* (2017), No. 3, 76–78.

[8] Q. Ye, W. J. Wang, G. Wang, Z. Z. Jia: *Numerical Simulation on tendency mining-fracture-evolution characteristics of overlying strata and coal seams above working face with large inclination angle and mining depth.* Arabian journal of geosciences *10* (2017), No. 4, 1–15.

[9] D. Zhao, Y. S. Zhao, Z. C. Feng: *Analysis of effect of water injection on methane desorption in coal combining pore structure.* Chinese journal of rock mechanics and engineering *30* (2011), No. 4, 686–692.

[10] C. S. Zheng, Z. W. Chen, M. Kizil, S. Aminossadati, Q. L. Zou, P. P. Gao: *Characterization of mechanics and flow fields around in-seam methane gas drainage borehole for preventing ventilation air leakage: a case study.* International journal of coal geology (2016), No. 162, 123–138.

Received November 16, 2017