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Substantiation of pillar parameters in mining of inclined coal seams in Quang Ninh Province, Vietnam

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Abstract

Design and operation of auxiliary underground workings in coal mines involves substantiation of parameters of coal pillars and requires development of new approaches to substantiate their geometrics. On the one hand, sufficient stability of a “rock mass – working – coal pillar” system should be ensured. On the other hand, the parameters of “frozen” coal reserves in the pillars should be justified. The joint solution of these two problems requires accurate forecasting based on modern digital models of a rock mass. In this study, a model of rock mass and mine workings with different dimensions of a coal pillar is presented with the use of Flac3D software. The simulation findings showed that when developing sloping coal seams, the volume of coal extraction in a longwall has an effect on the stress-strain state of the enclosing rock mass. During the study different factors having effect on geometrics of a coal pillar were analyzed, and their influence on the field of stresses and shear of inclined layers in a rock mass was studied, and the size of the plastic deformation zone around an auxiliary mine working was also determined. The study findings are also of practical importance in terms of substantiating the parameters of a working support design. The size of coal pillar is also connected with the support type. It should be taken into account that bolts should be of sufficient length to ensure firm fixing and located in the zone of intact rocks. The research showed that a coal pillar should be 10 to 15 m wide in order to ensure optimal mining conditions and safety.

Keywords

Mining, coal mining, coal pillar, rock mass, working, rock mass stress, stability, numerical model, Quang Ninh, Vietnam, Flac3D

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РАЗРАБОТКА МЕСТОРОЖДЕНИЙ ПОЛЕЗНЫХ ИСКОПАЕМЫХ

Научная статья

Обоснование параметров целиков при отработке наклонных угольных пластов в условиях шахт провинции Куангнинь Вьетнама

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Аннотация

Проектирование и эксплуатация вспомогательных подземных выработок при разработке угольных месторождений предполагают обоснование параметров целиков угля и требуют разработки новых подходов для обоснования их геометрических параметров. С одной стороны, необходимо обеспечить достаточную устойчивость системы «массив горных пород – выработка – угольный целик», с другой –

обосновать параметры «замороженных» в целиках запасов угля. Совместное решение этих двух задач требует точного прогнозирования на основе современных цифровых моделей массива горных пород. В настоящем исследовании авторы публикации, используя программное обеспечение Flac3D, представили модель массива горных пород и выработок с различными размерами угольного целика. Результаты моделирования показали, что в условиях наклонного залегания угольных пластов и массива горных пород объём добычи угля в забое влияет на напряженно-деформированное состояние массива горных пород. В ходе исследования были проанализированы различные факторы, влияющие на геометрические параметры угольного целика, изучено их влияние на поле напряжений и смещений горных пород, происходящих в условиях их наклонного залегания в массиве, а также определена величина зоны пластической деформации вокруг вспомогательной выработки. Результаты исследования имеют практическое значение и в части обоснования параметров конструкции крепи выработки. Размер угольного целика также связан с типом крепи выработки. Следует учитывать, что анкер должен иметь достаточную для прочного крепления длину и располагаться в зоне ненарушенных горных пород. Исследования показали, что для обеспечения оптимальных условий ведения горных работ и безопасности ширина угольного целика должна составлять от 10 до 15 м.

Ключевые слова
горное дело, добыча угля, угольный целик, массив горных пород, выработка, напряжения в массиве горных пород, устойчивость, цифровая модель, провинция Куангнинь, Вьетнам, Flac3D

Финансирование
Это исследование было поддержано проектом «Исследование применения численного метода для прогнозирования стабильности горных выработок в условиях динамических нагрузок при глубокой разработке, а также для обоснования конструкции горных выработок», код 191/HĐ-KHCN-KC.01.DD03-18/16-20.

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Introduction

The Vietnamese coal industry aims to improve the methods of underground coal mining while improving the technical and economic level of mine development and mining safety. Quang Ninh Province has significant reserves of coal for underground mining. By 2025, the underground mining volume is expected to reach 63.1 mln t of coal. Although the underground coal mining is the most difficult technologically, underground mining of the most valuable coal grades for the industry is quite justified.

For several decades, coal industry has been conceptually developing using "mine – longwall" process principle, which ensures high productivity and competitiveness of mining enterprises. Such solutions are successfully applied at advanced coal mines in Russia, China, India, USA, Australia, and many other countries. The greatest effect of this approach is achieved while developing extraction panels of more than 1000 m long at longwall length of not less than 250–400 m. For the conditions of inclined coal seams typical for Quang Ninh Province, the implementation of high-productivity solutions on the basis of the previously voiced principles is complicated to a great extent. However, since more than 24 % of the total coal balance reserves occur under these conditions, it is necessary to solve the whole set of problems to provide effective operation of mines. One of the key problems to be solved when justifying mining processes and parameters is substantiating the size of pillars, ensuring the stability of mine workings. The search for process solutions in this field for the conditions of Vietnam's coal mining is described in [1–4]. Although safety pillars became widely used in underground coal mining in Quang Ninh Province of Vietnam, no clear techniques for calculating and substantiating their parameters are available. In most cases, assessment of pillar parameters was based on empirical dependencies, which led to overestimation of pillar widths and, consequently, reduced the efficiency of coal extraction. In some cases, at the design stage, decisions were made without preliminary calculations, based on analogies, which also provided overstated values of pillar parameters. In conditions of longwall (mechanized) coal extraction from inclined coal seams, the task becomes even more complicated [5]. The approaches described in [6, 7] allowed to make calculations of safety pillars in conditions of Khe mine [6], where the pillar width of 6 m was substantiated, but the criteria related to ensuring stability of an auxiliary mine working, as well as a longwall parameters and characteristics were not taken into account [6]. The main idea of the present study is to determine the parameters of safety pillars by the criteria of stability of an auxiliary working [8], as well as taking into account the characteristics of a longwall in the conditions of inclined coal seams. The methods of numerical simulation of stress-strain state of rock mass on the basis of finite-difference models [9, 10] were used as a toolkit in the study. Flac3D was used as a software environment.

1. Simulation model parameters

Geometrics: length, 220 m; width, 120 m; height, 150 m.

The rock mass model includes 14 different rock layers with different properties. The rocks mechanical properties are presented in five categories (Table 1).

A force simulating the mass rock pressure acts on the top of the model. The formalized boundary conditions of the model are shown in Fig. 1.

When creating a model of the coal mining area, the following was taken into account: rock layer sloping occurrence; dimensions of coal pillars, including coal seam thickness; parameters and characteristics of rocks (consisting of sandstone, siltstone, and coal) occurring between coal seams (see Table 1) [11]. Numerical parameters of the model take into account a coal seam dip angle of 20°, thickness of 3.5 m, and the rock mass thickness (from a working bottom) of 300 m. The mine working support is presented by СВП-27 steel arched support, spaced at intervals of 0.7 m in a working.

The workings are shaped as a rectilinear semicircular arch 5.0 m wide and 3.5 m high (a working parameters are also relevant for solving the task [12]). The model includes two longwalls, LC1 and LC2, 190 m long, two ventilation drifts 01, 03, and a haulage roadway 02. The model coordinate center is located in the center of the lower ventilation drift. The simulation grid becomes denser while approaching the workings that allows more accurate studying stress-strain state of the rock mass, having effect on the workings stability (Fig. 2).

2. The main stages of model development

Based on actual tunneling data and processing results obtained by experimental method of observation, an algorithm for conducting the study was derived:

Step 1: Model development: establishing the values of stress at the measurement points in the rock mass and running the model until the equilibrium state is reached.

Step 2: Workings #1 and #2 tunneling up to the boundary of the mine field. Running the model until equilibrium state is reached.

Step 3: LC1 longwall operation. Running the model until equilibrium state is reached.

Step 4: Working #3 tunneling. Running the model until equilibrium state is reached.

Step 5: Collecting parametric modeling data. Determination of the stress-strain state of a rock mass

Table 1

Mechanical properties of rock layers

Layer	Compressive Strength σ, MPa	*E*, GPa	Density γ, *t/m*³	Bedding angle φ, degrees	Rock deformability *C*, MPa
Sandstone (*f* = 6–8)	96.64	20	2.67	34	33.6
Siltstone (*f* = 4–6)	47.79	18	2.73	32	14.6
Gritstone (*f* = 8–10)	138.13	22	2.59	34	47.2
Coal (*f* = 1–2)	15	5	1.50	20	2.2

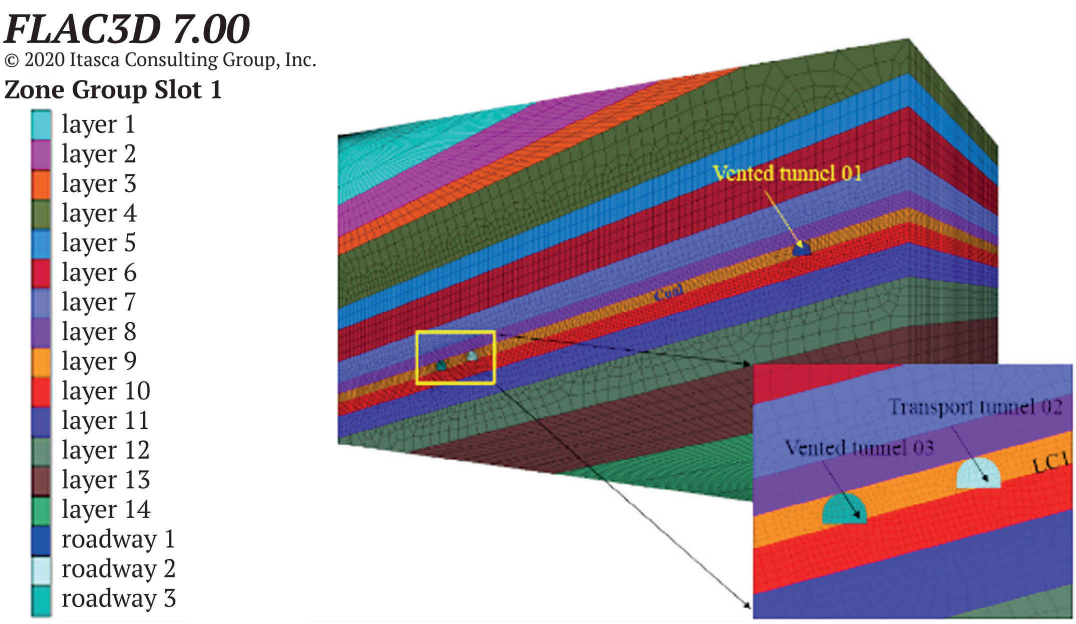

Fig. 1. Boundary conditions and model of force distribution

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for subsequent analysis and determination of mine workings stability.

Calculation of stress-strain state models of rock mass was carried out at different widths of coal pillars: 5, 8, 10, 15, 20, 30 m. Stability of mine working No. 3 was assessed.

3. Analysis of modeling findings

Distribution of stresses in a rock mass represented in Fig. 3 shows that coal extraction in LC1 longwall has a significant effect on distribution of vertical stress components in the rock mass around LC2 longwall. In this case, the maximum stress in the rock mass, about 25 MPa, is achieved in the coal seam within the longwall contour. The zone of maximum support pressure in the vicinity of LC2 longwall is located at a distance of about 7.5 m from the edge of coal pillar.

Distribution of stresses in a rock mass at a working roof is shown in Fig. 3. The stresses distribution in rock mass is asymmetrical in relation to the working. Thus the size of coal pillar has a significant effect on geotechnical conditions in LC2 vicinity.

The results of mathematical simulation data processing showed that when coal pillar width increases, the maximum compressive stress in the rock mass to the left of a working tends to shift towards the mined-out space of LC1 longwall. Decrease in coal pillar size results in gradual decreasing its carrying capacity that leads to shifting the maximum compressive stress towards the zone below LC1 longwall.

Fig. 5 shows the positions of rock mass plastic fracture zone around auxiliary working #3. This was used for analyzing these zones distribution. The data were also obtained on the basis of the above model.

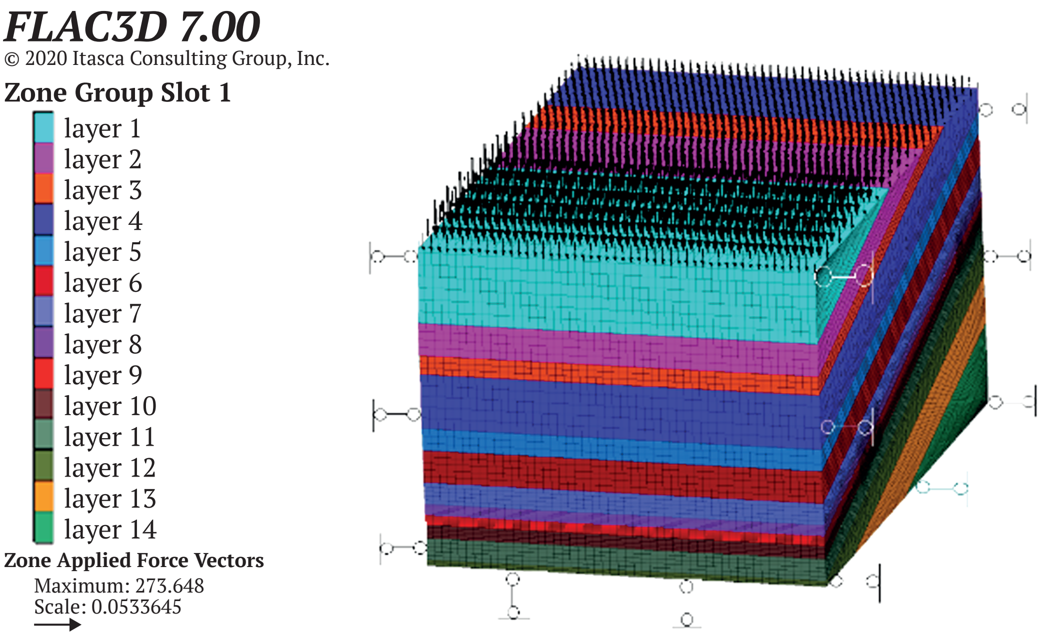

Fig. 2. Model in Flac3D

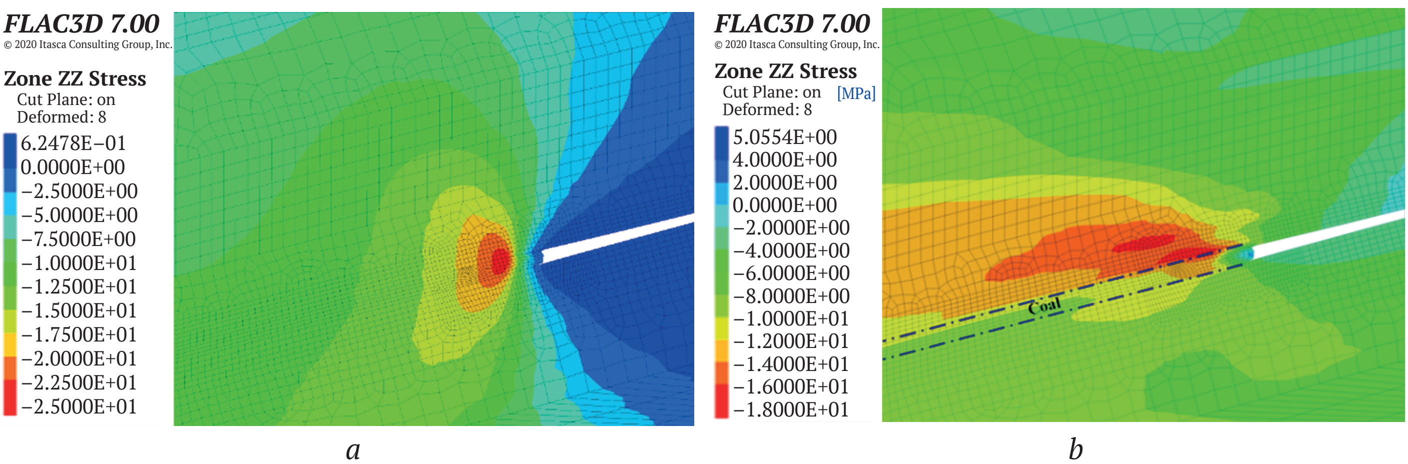

Fig. 3. Distribution of vertical (*a*) and horizontal (*b*) stresses in rock mass

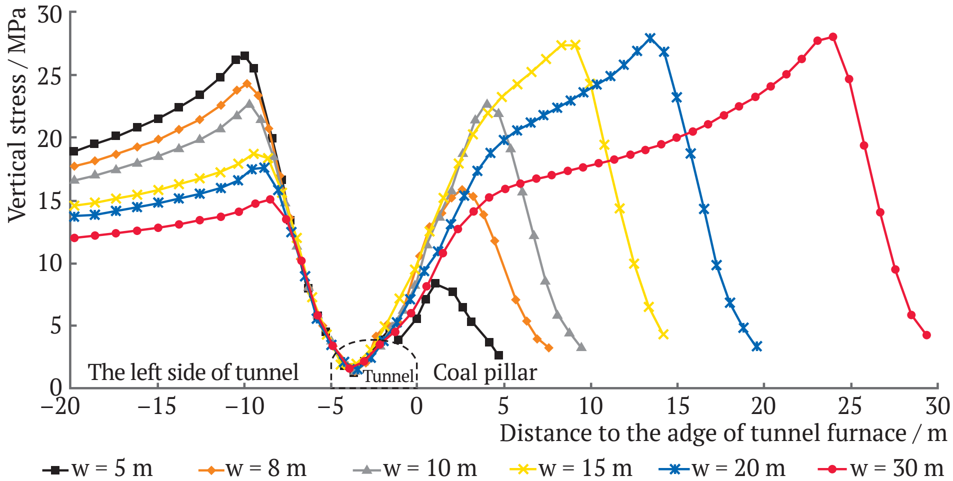

Fig. 4. Distribution of stresses at a working roof at different sizes of coal pillar

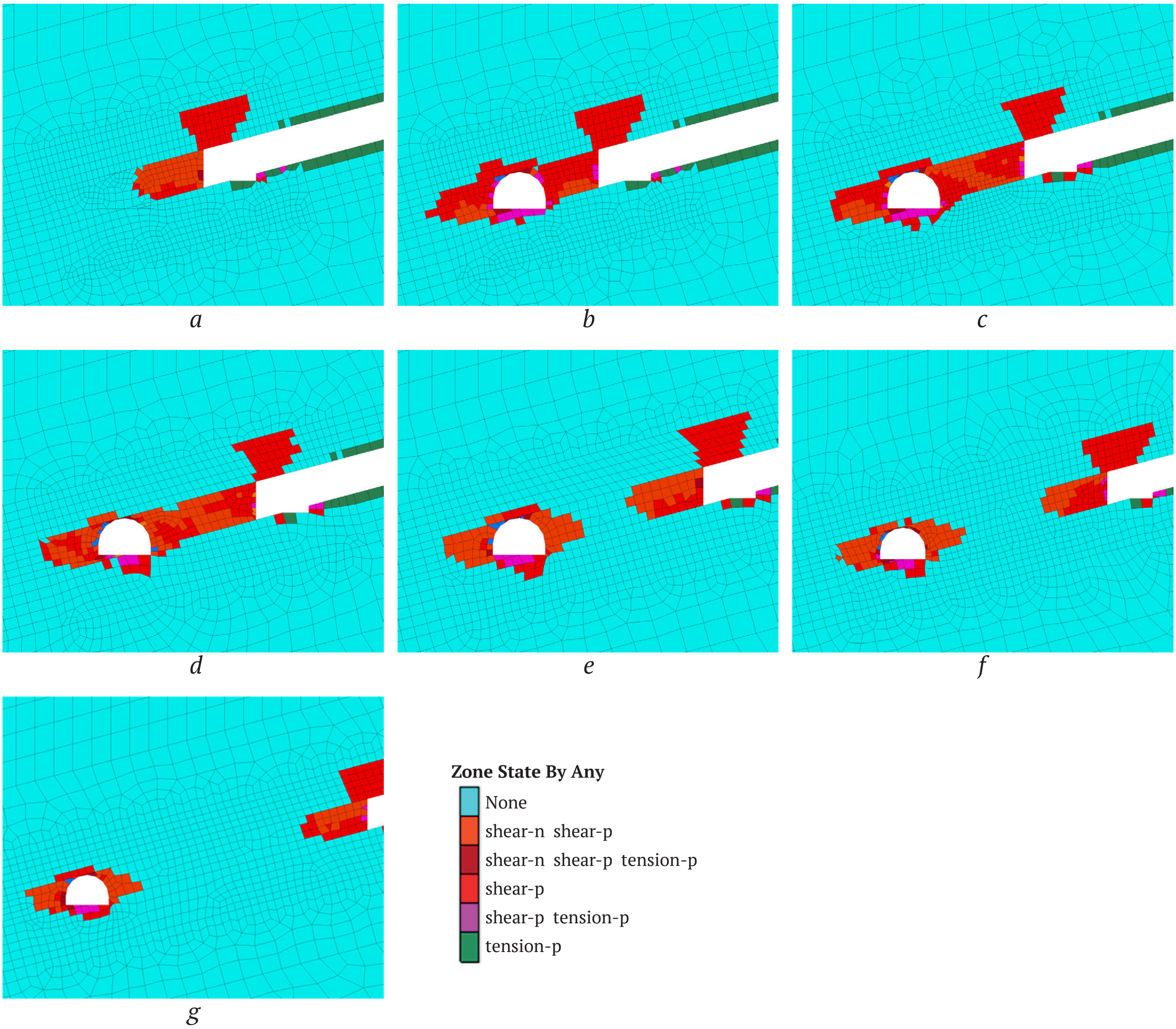

Fig. 5. Characteristics of rock mass shift around auxiliary working #3 at different sizes of coal pillar:
a – 5 m; *b* – 8 m; *c* – 10 m; *d* – 15 m; *e* – 20 m; *f* – 25 m; *g* – 30 m

The simulation findings showed that mining operations in LC1 longwall resulted in fracturing the rock mass around working #2. As the size of the simulated coal pillar gradually increased, the linear dimensions of the zone of the coal pillar plastic deformation changed ("continuous zone" — "discontinuous zone") (Fig. 5, *a*–*d*) and reached 7 m.

It is known that when using working bolting, a bolt rests on intact rock mass [13–15], so the size of coal pillar must be sufficient to install and fix a bolt in intact stable rock. Taking into account this requirement, width of a coal pillar should be at least 2.5 m. If the auxiliary tunnel is placed in the zone of decreasing stresses, the tunnel support stability and the coal pillar stability will be ensured.

When driving an auxiliary working based on bolting support, geotechnical conditions of a coal pillar must provide sufficient strength for bolting. If coal pillar stability (rock strength) is too low (increased fracturing or deformation of the rock mass), it is incapable to provide reliable operation of bolting support. Therefore, bolts should be positioned outside the fracture zone, potentially caused by the influence of LC1 longwall. Consequently, the decision to select the size of a coal pillar should ensure not only the stability of a working, but also its effective operation.

Conclusions

1. For the conditions of inclined coal seams extraction, rock mass pressure on a working roof and stresses distribution on both sides of a working are asymmetrical.

2. As the size of coal pillar increases, the position of maximum vertical stress shifts to the side of coal pillar. This phenomenon demonstrates in fact a transition of the system from one steady state to another one.

3. If the rock mass is insufficiently stable, a special attention should be paid to strengthening support to increase the corresponding stability.

4. The selection of a coal pillar size should be based not only on the analysis of the rock mass deformation behavior, stress distribution, and the interval of plastic fracture zone, but also on the need to maximize coal reserve extraction.

5. The size of coal pillar is also connected with the support type. While supporting a working by bolting, one should take into account that bolts should be of sufficient length to ensure firm fixing and be located in the zone of intact rocks.

6. The research showed that a coal pillar should be 10 to 15 m wide (in the conditions of the presented model) in order to ensure optimal mining conditions and safety.

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