Geomechanical justification based on the results of numerical modeling of combined technology parameters of working areas development with the use of robotized means of underground mining

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Abstract. Based on the results of numerical modeling the assessment of the options for selective and sequential development of the working areas and coal mine blocks by fully-mechanized longwalls with a complete collapse of the roof and short faces with the roof controlled by rib pillars. As the criteria for assessing the effectiveness of geotechnological options, the coefficients of vertical stress concentrations in the selvedge of the coal seam in the vicinity of extraction galleries and the height of the unloading zone of the roof rocks over the gob are adopted. Factors that limit the use of longwall faces are the presence of disjunctive disturbances within the mine field, which leads to coal losses and irrational use of subsoil. It was established that successive development of excavation sites with long and short faces results in a more even distribution of the vertical stress concentration coefficients, reduces the probability of zones with increased rock pressure and gas dynamic phenomena, and also provides an opportunity to increase the coal extraction factor.

1. Introduction

The modern technology of underground mining of flat coal seams is characterized by a daily load of 5-30 thousand tonnes for the mining face, which is achieved by selective development of coal seams, as a rule, sections of a rectangular shape with a length of an extraction pillar up to 3 km and a face up to 400 m. Factors that complicate the use of high-performance complex mechanized longwalls (CML) are geological disturbances of discontinuous type, zones of increased rock pressure and threatened by gas-dynamic phenomena, areas of coal seams with increased fracturing and the tendency for roof fall, variable thickness and seam inclination, high gas content of the coal-methane seam within the extraction pillar.

These factors, taking into account the complex shape of the boundaries of the mining allotment, the variability of mining and geological parameters and the need to reduce production costs due to the high competition of coal products on the market, lead to the selective mining of coal seams. At the same time, separate seam development is carried out at the first stage by high-performance CML, and at the second stage the residual reserves are mined with special technologies. Accordingly, all the balance reserves of coal within the mine field fall into two categories: technological for the use of long mechanized faces and residual, temporarily conserved and designed to be developed in future periods by new technologies.
In this paper we propose an option of simultaneous combined development of rectangular working areas by longwall mining (LM) and oblique areas with limited coal reserves by shortwall mining (SM).

Based on the analysis results of mining layouts, preparation and development of the coal layers of the mines “Antonovskaya”, “Polosukhinskaya”, “Yubileynaya”, “Alardinskaya” and others in Kuzbass, the most typical mining situation was reconstructed with the arrangement of high-performance long mechanized faces (extraction pillars 4 and 7 in figure 1) and blocks of limited sizes or in the form of oblique figures (blocks 1-3,5,6 in figure 1). According to the tectonics of Kuzbass, disjunctive disturbances are revealed within the mining allotment of the mine (in figure 1 are shown by square hatching), which regulate the spatial position of extraction pillars 4 and 7 for their development by LM and blocks with coal extraction in short faces.

It is obvious that after selective mining of coal reserves in extraction pillars 4, 7 by long complex mechanized faces, the following options for the development of mining operations are possible (figure 1):

- cleaning-up of residual coal reserves in blocks 1-3, 5, 6 by peripheral technologies, for example, short faces;
- conservation of mining operations in the seam.

When cleaning-up the residual coal reserves, the following complicating factors are possible:

- limited access to reserves, since when developing the seam with long mechanized faces in sections LM 4, LM 7, the ventilation roads 4, 7 that square them up and the belt roads 4, 7 will be gobbed, so there will be a need for new workings;
- lack of progressive technological solutions for mining seam sections of limited dimensions or in the form of oblique figures;
- location of areas with residual coal reserves in the zones of bearing pressure, which occurs under the influence of the suspended underworked roof rocks in extraction pillars 4, 7, which can lead to the emergence of concentrators of elastic energy and bumps;
- the need to ensure the level of technical and economic indicators, not lower than those achieved at the initial stage of seam mining by long mechanized faces.

Thus, the separate sequential development of a seam at the first stage by high-capacity CMLs, and the development of residual reserves by special technology at the second stage are associated with both an increased risk of hazardous industrial situations and a decrease in technical and economic indicators at the second stage.

However, the combined option of simultaneous mining of coal seams reserves in complex mining and geological conditions is also possible. The essence of the method consists in the simultaneous preparation and mining the rectangular-shaped sites by long mechanized faces and oblique sites with limited coal reserves by short faces.

Advantages of such organization of mining operations in accordance with the combined technology are as follows:

- increase in the extraction factor of balance reserves in the coal seam due to partial excavation of coal in sites with an oblique form and limited coal reserves;
- reduction in the specific volume of workings due to their use in development of technological and non-technological coal reserves for long mechanized faces;
- compensation for reduction in the mine production level during the re-installation of the purification equipment due to a periodic increase in the production simultaneously in several oblique sites with limited coal reserves;
- reduction of risks of gas dynamic phenomena occurrence through forecasting the parameters of geomechanical processes, rational spatial and temporal location of long and short faces and the order of mining operations within the mine field.
Having regard to the above, scientific research providing rational spatio-temporal location of mining excavations with a simultaneous combined mining of rectangular-shaped sites by long mechanized faces and oblique areas with limited coal reserves by short faces is currently relevant. As an alternative geotechnology for mining the oblique sites with limited coal reserves, special methods can be used, with elements of automation and robotization of technological processes [8 - 11].

2. Methods of research
For the geomechanical substantiation of the parameters and the choice of the rational spatial and temporal location of the mine workings with the simultaneous combined mining of sites within the mine field, the following methods were used: analysis and generalization of the experience of mining the sections of coal seams in accordance with a sequential scheme, numerical modeling on the basis of the finite element method for quantitative prediction of geomechanical parameters under the mutual influence of long and short cleaning faces, scientific generalization of the research results.

3. Results and discussion
To solve the task, the following research program was developed and implemented: the formation of a geomechanical model of the rock massif with different options of mine workings location, numerical modeling of geomechanical processes; identification of regularities in the distribution of geomechanical parameters of coal bed development systems, the choice of a rational option of a simultaneous combined scheme for mining rectangular shaped sections by long mechanized faces and oblique blocks with limited coal reserves by short faces.

The geomechanical model of the rock massif with different options of location of mine workings included vertical sections along the line of incidence of the seam (I-I in figure 1).

The rock massif in the model is assumed to be layered with an isotropic distribution of layers in each layer, the number of layers is 100. The thicknesses of layers and the physical and mechanical properties of the rocks are accepted for the conditions of Yerunakovskiy district in Kuzbass. The field of investigation is limited from above by the earth’s surface, from below by the boundary of the zone of overwork, adopted according to [1, 2]. At the lateral boundaries of the model vertical displacements were determined in the gravitational stress field according to the Dinnik theory [3]. On the bottom of the model, the vertical displacements are assumed to be zero. The dip angle of the seam is equal to 0°, the extractable seam thickness is 3.00 m. The model dimensions for seam dip, according to figure 1, are equal to 2400 m, the maximum depth of the bed is 400 m. In the zones of disjunctive disturbances, the increased fracture and fall zone was taken into account by the coefficient of structural weakening according to [2].

A quantitative forecast of geomechanical processes was carried out by the finite element method in a plane-deformed two-dimensional formulation of the problem using the author's package of problem-oriented programs [4-8].

Based on the results of numerical modeling, vertical, horizontal and principal stresses, as well as vertical and horizontal displacements and deformations of rocks within the entire model were determined. The calculations were carried out in stages by solving the following tasks:

1) elastic without taking into account the influence of mine workings;
2) elastic, taking into account the influence of mine workings and disjunctive disturbances;
3) elastic-plastic by changing the modulus of elasticity in the “stress-strain” diagram by the secant deformation module with a preliminary estimate of the out-of-limit state of the rocks according to the Mohr-Coulomb strength and strength energy theory.

In the process of numerical simulation several options of the location of workings and mined sites are considered (table 1). Considering the large amount of information for comparing the geomechanical parameters of the rock massif, one integral indicator is taken – the coefficient of vertical stresses concentration.

| Option No. | Layout of workings | Maximum coefficient of vertical stresses concentration at the short face | at the long face |
|------------|--------------------|---------------------------------------------------------------|-----------------|
| 1          | Worked extraction pillars LM 4, LM 7 | 2.48 | ----------- |
| 2          | Worked blocks RPM 1-3 | - | 1.77 |
| 3          | Worked blocks RPM 1-3, pillar RPM 4 | 2.82 | 2.44 |
| 4          | Worked blocks RPM 1-3, pillar RPM 4, blocks RPM 5-6 | 3.02 | 2.48 |
| 5          | Worked blocks RPM 1-3, pillar RPM 4, blocks RPM 5-6, pillar RPM 7 | 3.61 | 2.62 |

Figure 2 shows the isolines of the distribution of the vertical stress concentration factor in the rock massif after selective excavation by long faces (figure 2a) and sequential mining by short and long faces (figure 2b).
Figure 2. Distribution of the coefficient of vertical stresses concentration in the rock massif: a – after selective mining of working areas RPM-4 and RPM-7 (option 1 in table 1); b – after subsequent mining of working areas SM 1-3, RPM-4, SM 5-6 and RPM-7 (option 5 in table 1).

Based on the comparison results of five options for placement of mining blocks and pillars, the following dependencies are established:

- the coefficient of vertical stresses concentration during mining of a single block by short faces is 1.4 less than the corresponding coefficient for mining the seam by long faces;
- the height of the zone of tensile vertical stresses (unloading zones) over the gob is 100-120 m, that is, approximately 30% of the length of the gob;
- sequential mining of blocks by short faces and pillars by long faces leads to redistribution of vertical stresses with a gradual increase in the concentration coefficient over the coal pillars between the gobs up to 3.61;
- disjunctive disturbances are concentrates of increased stresses and are the centers of probable occurrence of gasdynamic phenomena.

Features of the distribution coefficient of vertical stresses concentration in the vicinity of blocks mined by short faces are shown in figure 3. The parameters of the zone of bearing rock pressure at the marginal sections of the seam taking into consideration the influence of the disjunctive disturbance are compared. It is established that in the zone of influence of the disjunctive (to the left from block RPM 1-3 in figure 3) the width of the zone of bearing rock pressure reaches 200 m, and in the absence of violation – 130 m. Therefore, when choosing the spatial position of the development workings and the width of the pillars, disjunctive violation as a source of occurrence of gas-dynamic processes should be taken into account.

The distribution isolines of the coefficient of vertical stresses concentration with the mutual influence of the gobs after mining the seam by short and long faces in the presence of disjunctive disturbances are shown in figure 4.

According to figure 4 the distribution of the vertical stress concentration coefficient in the roofs mined by long as well as short faces is identical. The most dangerous by geomechanical criteria is the coal pillar between the pillar LM 4 and blocks 1-3, since the contouring preparatory workings will be located in the dangerous zone in the vicinity of disjunctive disturbances. Especially it should be noted that in this zone there is a high probability of occurrence of gas dynamic phenomena in the form of mountain bumps or sudden outbursts.
Figure 3. Distribution of the coefficient of concentration of vertical stresses in the rock massif after mining the extraction blocks RPM 1-3 (option 2 in table 1).

Figure 4. Distribution of the coefficient of vertical stresses concentration in the rock massif after mining the extraction blocks RPM 1-3 and LM 4 (option 3 in table 1).

On the basis of the forecast of geomechanical situation, it follows that the technology of preparatory workings and the extraction of coal in the faces must include robotic elements ensuring the performance of basic operations without the presence of people. To reduce the dangerous consequences of the occurrence of dynamic phenomena in the form of a rock outbursts or a sudden release of coal, rock and gas in the vicinity of blocks mined by short faces, it is also necessary to use the means of robot stoping of the coal seam.

4. Conclusion

Thus, the sequential mining of a coal seam within the mine field by combined technology is possible by geomechanical conditions and can be recommended for use in combination with the application of robotic means of coal extraction and transportation of rock mass.

The proposed approach will ensure an increase in the coal mining factor, reduce the probability of accidents and incidents and increase production efficiency by reducing the specific capital costs and the repeated use of development workings for combined mining by short and long faces.
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