NUMERICAL MODELLING OF MULTIPLE-SEAM COAL MINING AT THE TALDINSKAYA-ZAPADNAYA-2 MINE

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ABSTRACT

The study aimed to increase the productivity and safety of longwall mining operations at the Taldinskaya-Zapadnaya-2 multiple-seam coal mine which is located in the Kuznetsk Basin (Russia). In order to study the impact of the mined-out coal seam № 70 on stress distribution in the underlying coal seam № 69 taking into account the mine layout adopted at the Taldinskaya-Zapadnaya-2 mine, numerical models were developed using the finite element method (FEM). Numerical models showing how the seams interact with each other were developed based on 3D models representing the rock mass containing the two coal seams, mine workings, and mining voids. To describe rock behaviour under stress, the Mohr-Coulomb model was used. Developing three rock mass models made it possible to describe both independently and jointly the impact of the high-stress zone created by the pillars and that of the abutment pressure zone in the panel being mined. As a result of the study, hazardous areas in the mine workings located under the edges of coal seam № 70 were identified and recommendations for changing the parameters of the mine layout of coal seam № 69 were given. The novelty of the study lies in developing a scientifically grounded approach to conducting studies of the interaction between multiple coal seams, which implies developing numerical models of how the zones of high stress and abutment pressure both independently and jointly influence the most hazardous areas identified in each longwall panel.

Keywords: underground coal mining, multiple seams, longwall panel, pillar, high-stress zone, abutment pressure, stress and strain, entry stability.

1. INTRODUCTION

The issues of productivity and safety in the underground mining of flat-lying coal seams continue to be relevant to all the top coal-mining countries (China, the USA, Australia, Russia, etc.) [1-8]. The main cause of problems is the widespread use of longwall panels in underground mining and the necessity to leave pillars of coal between the mined-out areas which create zones of high stress spreading over considerable distances around the roof and the floor. High-stress zones can have a significant impact on the development of overlying or underlying coal seams. Most often, the top-down mining method is used, which means that the upper seam is mined out first. It is also possible to work on two seams simultaneously provided that one of the faces advances faster. This helps to minimize the interaction between the seams. It should be noted that interburden thickness - the distance between the seams - is important. An analysis of a considerable amount of data on more than 344 cases of the interaction between multiple coal seams in the United States [1-3] allowed us to draw conclusions about the determining influence of interburden thickness. It was established that at a distance of more than 60 m between the seams, no hazardous interaction between the seams was observed in the USA. At a distance of less than 60 m, the influence of one seam on the other can lead to mine collapses and rock bursts. The main reason for mine collapses is the joint impact of high-stress zones formed by coal pillars and abutment pressure zones in front and to the side of the longwall panel. The parameters of high-stress zones depend on the mining depth, the deformation properties of the interburden and the seam being mined, the pillar width, and the dimensions of the mined-out areas [1-3, 7-13]. The parameters of the abutment pressure zone depend on the thickness of the seam being mined, the stress-strain characteristics of the overburden and the seam being developed, and the longwall panel width. The mine workings located in the zones of high stress and abutment pressure are affected by the stress-strain properties of the enclosing rocks, the type and the parameters of roof support, the presence and the parameters of the coal pillars, as well as the location of the mine working relative to the edges and the pillars left after mining out the previous seam, and interburden thickness. The use of state-of-the-art and high-performance equipment made it possible to significantly increase coal panel lengths and widths [13-16]. An increase in panel length led to an increase in the variability of mining depth and the stress-strain properties of rocks and it also caused a significant change in mining conditions as the panel face advances. In our opinion, the current situation requires that a differentiated approach to determining the parameters of roof support should be taken, which should imply the identification of zones within the working area that are characterized by conditions that differ significantly from the rest of the area. First of all, the most hazardous zones with the biggest mining depth and the influence of several complicating factors should be identified. In addition, to select the best mine layout taking into account the impact of both underlying and overlying seams, the influence of the zones of high stress and abutment pressure should be assessed both jointly and independently. As an effective method for assessing the interaction between multiple seams, numerical modelling can be used as this method makes it possible to analyze all rational options for mine development at a minimum time and cost. The aim of this study is to develop a numerical model of the stress-strain state of seam № 69 which is being developed at the

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Taldinskaya-Zapadnaya-2 mine after the overlying seam № 70 has been mined out. It should be noted that mining seams № 69 and 70 is complicated by the fact that roof and floor rocks are unstable; as a result, when seam № 70 was being mined at depths exceeding 400 m, floor heaving was observed, which could reach values of 2 to 3 m. Taking into consideration the additional impact of the mined-out seam, it is important to solve the problem of how to ensure efficient mine planning for seam № 69.

2. MATERIALS AND METHODS

The Taldinskaya-Zapadnaya-2 mine is developing a group of flat-lying coal seams in the Kuznetsk Basin (Russia). Seam № 70 (with an average thickness of 5.2 m) has been mined out and entry development is carried out in seam № 69 (with an average thickness of 5.1 m) which lies 51 m below seam № 70 (Figure-1). The seams have complex structures and consist of alternate layers of coal and rock. Coal in seams № 69 and 70 is prone to spontaneous combustion. Roof and floor conditions are very unstable. Within the area being mined, seams № 69 and 70 create an oval syncline. The angle of dip varies from 3 degrees in the lower part to 30 degrees near the surface.

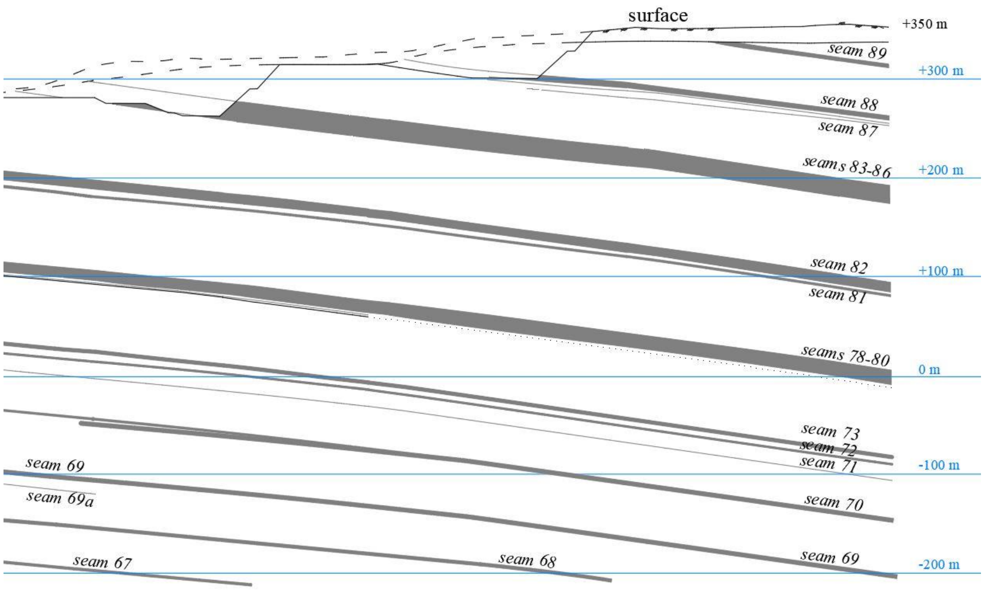

Figure-1. A geological cross-section of the area.

When seam № 70 was mined, panels had widths of 200-300 m and lengths of 1750-2670 m, with barrier pillar widths ranging from 20 to 30 m. Longwall panels in seam № 69 are directed parallel to those in seam № 70 (Figure-2) and are slightly shorter. In order to work on seam № 69, panel width was increased up to 400 m and barrier pillar width was increased up to 50 m. Most mine workings in seam № 69 are located under the mined-out areas of seam № 70. The exception is the lowest workings that are located under the edge of the area. Such a layout in which mine workings of seam № 69 are located at a distance from the pillars or the edges of seam № 70 is the most effective way to ensure their stability in multiple-seam mining [2, 10]. Since the panels are directed along the dip and are mined bottom-up (to minimize water inflow), setup rooms are located at the biggest depth. As longwall panel № 69-08 is gradually mined out, the mining depth will decrease from 580 to 260 m. Experience in multiple-seam mining shows that mines start collapsing at depths exceeding 370 m and the bigger the mining depth, the more difficult it is to ensure mine stability [1, 10]. This is the reason why numerical models were developed for the deepest part of panel № 69-08, which is where the setup room is located. However, since abutment pressure will develop along with moving away from the setup room and reach its maximum only after an advance of more than 70-100 m and roof collapse, an advance of 200 m was adopted in modelling the dimensions of the mined-out area in order to take into account the maximum influence of abutment pressure. After an advance of 100 m from the setup room, the mining depth for seam № 69 will be 570 m.

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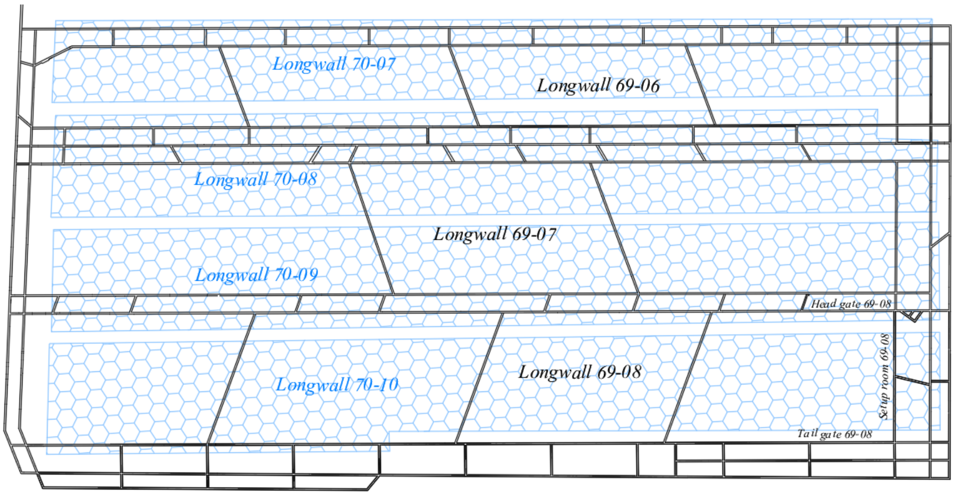

Figure-2. A mine layout for seam № 69 and the boundaries of longwall panels in seam № 70.

In order to carry out numerical modelling, three versions of a 3D model of the area were developed (Figure-3). The model covers an area with dimensions of 1200x750x500 m. The model includes coal seams № 69 and 70, enclosing rocks, mine workings in seam № 69, and mined-out areas in seams № 69 and 70. To describe rock behaviour under stress, the Mohr-Coulomb model was used. The mined-out areas were defined by lowering the deformation characteristics of the rocks in the gob area and lowering rock density from 2.7 to 2.2 t/m^3. The parameters of the model corresponded to the initial stage of mining operations in panel № 69-08 (the first panel in seam № 69 to be mined) conducted under panels № 70-09 and 70-10 in seam № 70 (Figure-2). The first version of the model (Figure-3, A) is meant for modelling the stress-strain state of the rock mass taking into account the overlying mined-out areas before the coal in seam № 69 is extracted. In this case, there are only developing entries in seam № 69. This version of the model makes it possible to assess the influence of the mined-out areas and pillars left from mining seam № 70. The second version of the model (Figure-3, B) corresponds to the beginning of developing panel № 69-08 and makes it possible to assess the joint impact of high-stress and abutment pressure zones. The third version of the model (Figure-3, C) considers a situation where seam 70 has not been mined out. This is an unrealistic situation but this approach makes it possible to assess only the influence of front and side abutment pressure in the panel being mined in seam № 69.

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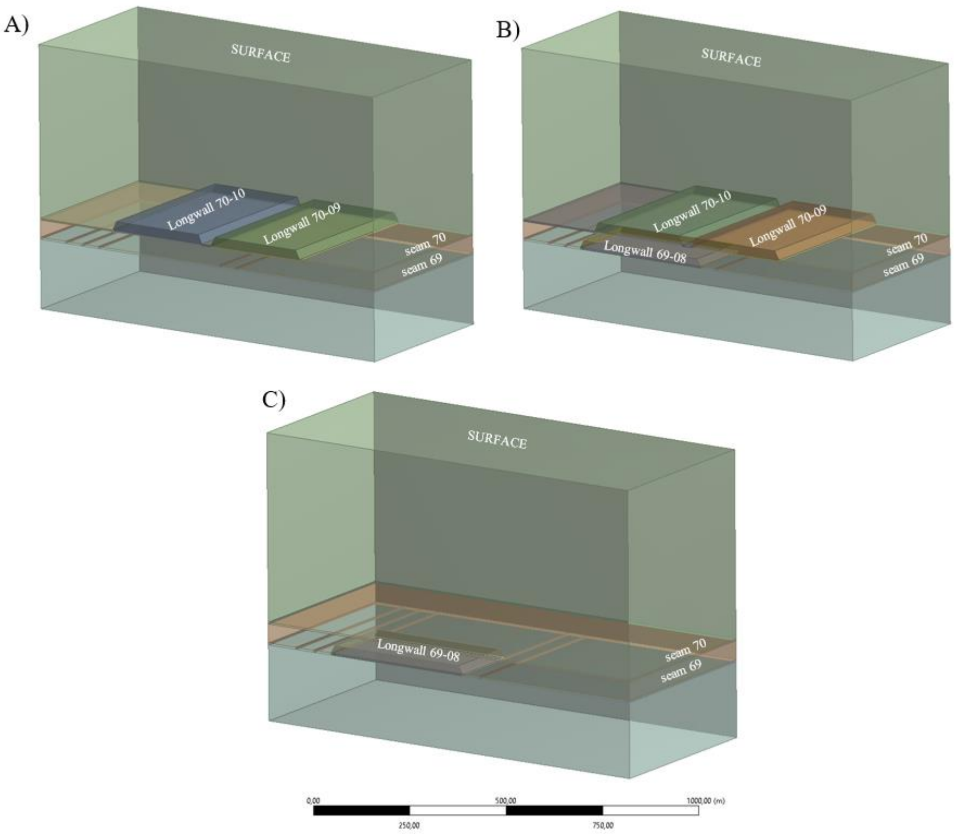

Figure-3. Rock mass models.

3. RESULTS AND DISCUSSIONS

Figure-4 shows stress fields and diagrams for seam № 69 which correspond with the results of numerical tests using the third version of the model (Figure-3, C). Figure-4 makes it possible to evaluate the parameters of the abutment pressure zone which would be formed in seam № 69 if seam № 70 had not been mined out. As can be seen from Figure-4, abutment pressure zones are formed around the panel being mined and stress levels rise from 15 to 35-40 MPa. In this situation, the middle sections of the longwall face and panel are characterized by the greatest stresses, while the corners of the panel are subjected to the lowest stress. An increase in pillar width minimizes the influence of abutment pressure on mine workings № 1, 4, and 5 protected by the pillars, and stress levels in their vicinity do not exceed 20 MPa. In mine workings № 2 and 3, which are adjacent to the panel and abandoned after the panel has been mined out, stress levels reach 25 MPa. At a considerable distance from the panel face, stress levels around mine workings are lower and do not exceed 17.5 MPa.

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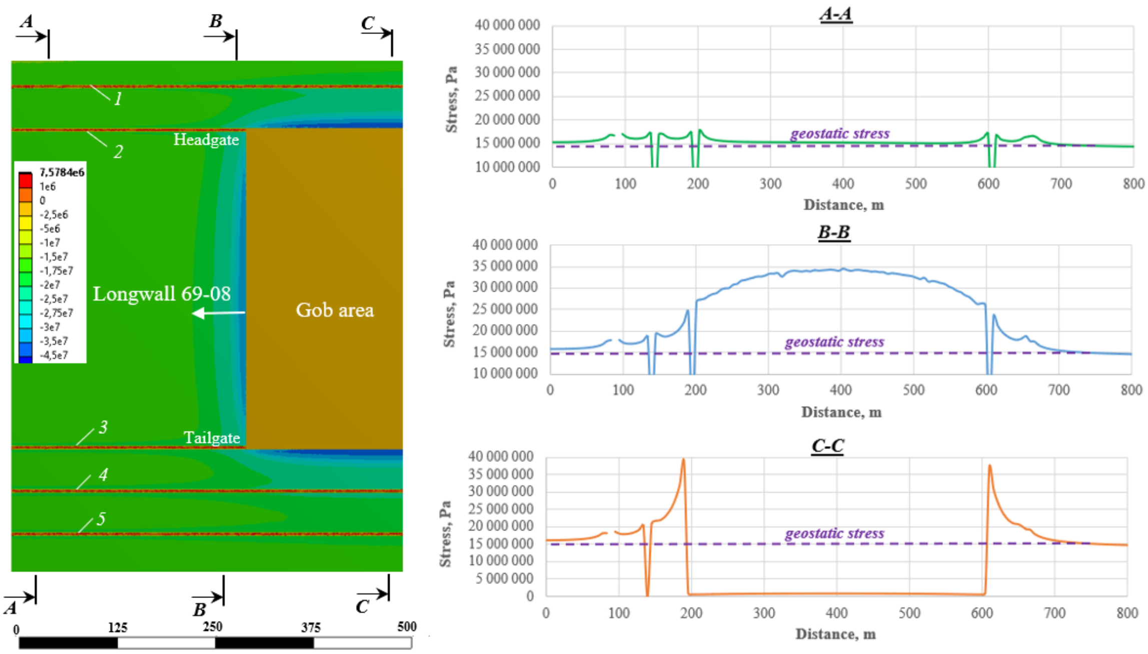

Figure-4. Stress distribution in the area of seam № 69 (without the influence of overlying mined-out areas).

Figure-5 shows the results of modelling the stress-strain state of seam № 69 before coal extraction which were obtained using the first model (Figure-3, A). As can be seen from Figure-5, the overlying mined-out areas significantly change the stress-strain state of the seam. Even before the extraction process, there are zones of low stress, which are located under the mined-out areas in seam № 70, and zones of high stress, which are located under the edges of the area and the entire seam № 70. In the zones of low stress, stress levels are about 2.5 MPa, i.e. 0.15 of the geostatic stress level; in the zones of high stress, they reach 27 MPa, i.e. they are 1.8 times higher than the initial stress level. This means that even before coal extraction in seam № 69 begins, there will be an issue of supporting those mine workings which are located under the edges of the area due to an increased level of stress.

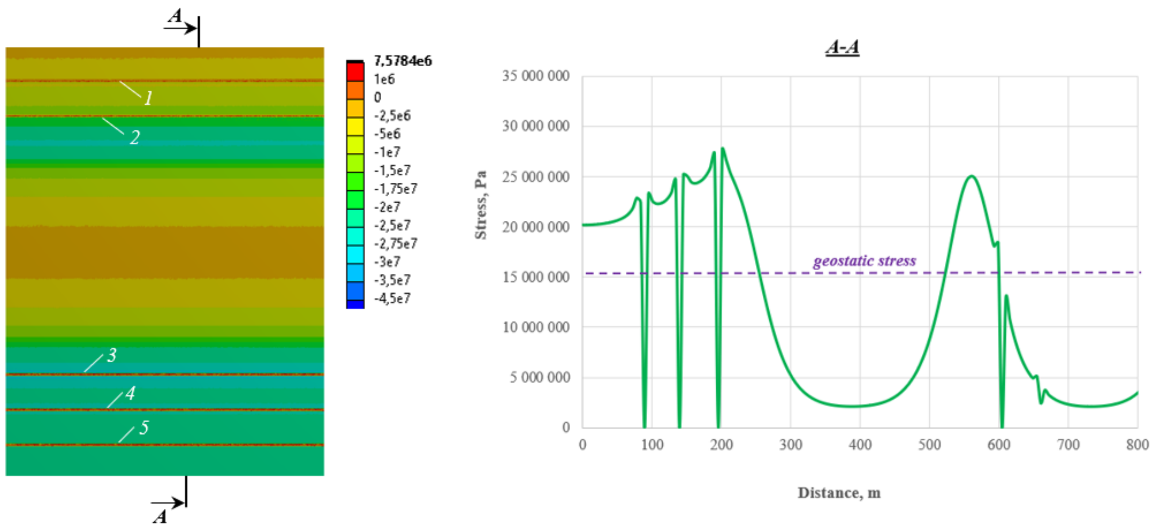

Figure-5. Stress distribution in the area of seam № 69 before coal excavation in panel № 69-08.

The simultaneous influence of the zones of high stress and abutment pressure is shown in Figure-6. At a considerable distance from the panel face, the influence of only the zones of high stress arising from the pillars in seam № 70 is observed (Figure-6, profile A-A). However, at a distance of 80-100 m, abutment pressure starts playing its role and stresses around the panel face begin to increase, reaching 40-50 MPa in front of the face. The highest levels (up to 40 MPa) are observed under the edges of seam № 70, i.e. around mine working № 3

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(Figure-6). Mine workings № 1 and 2, which are located under the mined-out areas in seam № 70, are in favourable conditions in terms of their stability.

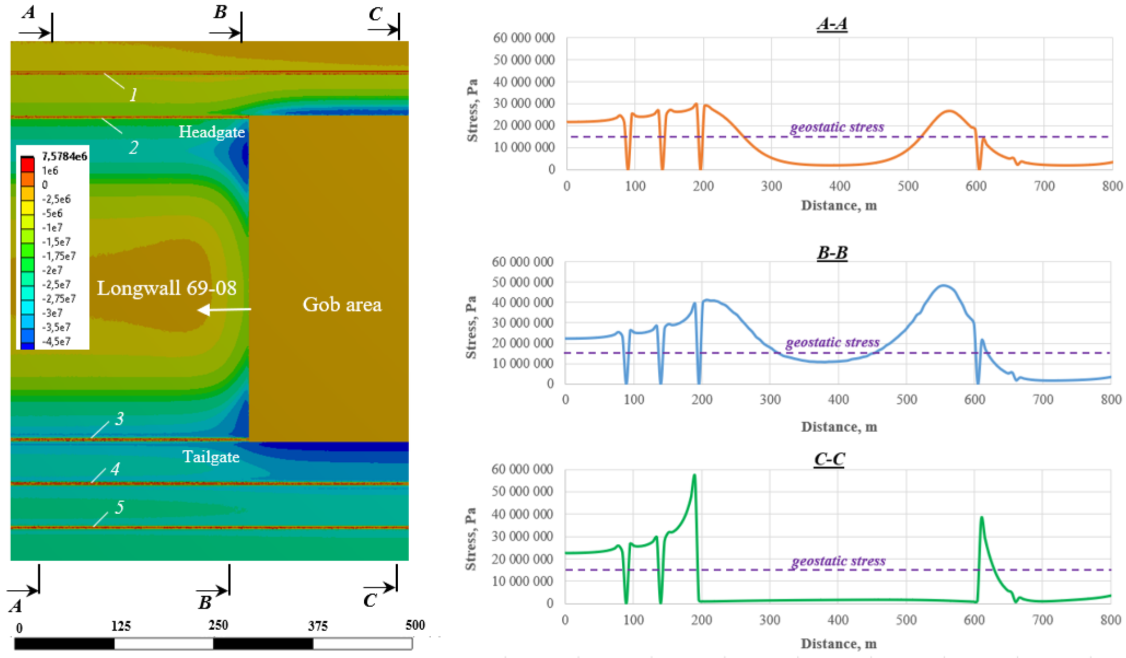

Figure-6. Stress distribution in the area of seam № 69 taking into account the simultaneous influence of high-stress and abutment pressure zones.

4. CONCLUSIONS

The results of the study, which included developing numerical models of how high-stress and abutment pressure zones influence rock mass both independently and jointly, let us conclude that it is possible to use this approach to identify the degree of influence of mined-out areas on multiple coal seams. When studying how such coal seams interact with each other, it is necessary to identify the most hazardous zones in mine workings, which are characterized by both the biggest mining depth and the joint impact of several complicating factors. The results confirm that it is possible to reduce stresses around mine workings by locating them under the mined-out areas and show that the mine layout adopted for developing seam № 69 (Figure-2) minimizes the influence of the pillars left from mining seam № 70 but leads to a high risk that working № 3 located under the edge of the area may collapse (Figure-6). To mitigate this risk, it is possible to locate such workings under the mined-out area. However, such a layout will result in leaving a wide (about 200 m) coal strip behind and a decrease in the width of panel № 69-08. As a possible solution, it can be suggested that one more panel № 69-09 with a width of 200 m should be used to mine this coal strip and that the width of panel № 69-08 should be reduced to 250 m in order to accommodate workings № 3, 4, and 5 under the mined-out area of panel № 70-10. The disadvantage of the proposed solution is the need to reduce panel widths and use two additional mine workings. If this solution is not adopted and the initial mine layout of seam № 69 is used, it is necessary to reinforce mine support in workings № 3 (Figure-6) with cable bolts and prepare equipment for removing rocks resulting from floor heaving. It should be noted that the current trend towards increasing panel widths and lengths in underground mining makes it more difficult to plan layouts for mining multiple coal seams and necessitates conducting advanced studies. However, ignoring the influence of multiple coal seams on each other can lead to massive mine collapses and economic damage reaching tens of millions of dollars [6, 10]. The research results can also be useful for assessing the influence of overmining and undermining on methane emission from adjacent seams into the gob of the longwall panel [17].

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