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Modeling geomechanical processes in underground longwall and shortwall mining of thick coal seams with elements of robotization

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Abstract. A variant of the technological scheme for thick layer mining with top coal caving and pre-destruction of coal by means of advanced parallel chambers is proposed. Based on the results of numerical modeling, the optimum dimensions are justified for chambers, interchamber coal pillars as well as crown pillar between the chambers and immediate roof rocks. It has been proved that after the advanced chambers are made, the strength roof coal is reduced by a factor of 2 to 2.5, and therefore the conditions are created for uniform coal caving without dilution. A variant of the technology of unmanned coal mining in the chambers is proposed.

1. Introduction

The problem of safe and efficient thick coal mining in the conditions of spontaneous combustion hazard and dynamic phenomena in Kuzbass has been of increasing concern for the late 50 years [1, 2]. The rate of development of technology and equipment for mining thick coal seams lags far behind the technology for medium-thick coal mining.

The fully mechanized thick coal mining technology using system KTU-3M has a number of variants with slicing, hydraulic mining and coal transport [2–7]. Recently, the fully mechanized top coal caving technology is efficiently implemented [2, 6, 7]. At the same time, due to uncontrolled pre-fracturing and destruction of top coal, the coal loss reach 0.9–4.2 t/m² of mined-out seam, or 18% in the total extraction panel [8].

In order to develop methods and means for pre-fracturing and destruction of top coal, it is necessary to determine laws of stress state formation in top coal. The complexity of the problem is constituted by the requirement to preserve stability of top coal near the face for elimination of uncontrolled coal caving in the operation zone of a cutter–loader and to create conditions for dynamic coal breakage in the zone of coal loading on conveyor.

The major constraint of pushing the limits of application of the longwall top coal caving technology is the absence of procedures and guidelines for evaluation of geomechanical parameters ensuring safe and efficient coal mining in difficult conditions.

2. The objective and program of the research

This study based on the revealed stress distribution patterns, shapes and sizes of pre-fracture zones in top coal proposes the method of preliminary weakening by means of advanced extraction of top coal by rooms and pillars using robotic equipment.



The objective of the research is to validate parameters of rooms and pillars in the upper layer to ensure stability of top coal at the face of the lower layer and destruction of coal in the zone of loading on conveyor.

The research program included stage-wise implementation of:

- analysis of stress state of rocks in the traditional LTCC technology without advanced room and pillar in the upper layer;
- finding of regular patterns of stress distribution in rock mass during partial extraction of coal in the upper layer by advanced rooms in case of varied spatial arrangement of rooms along the coal seam height, width of rooms and rib pillars;
- justification of recommendations for selecting rational parameters of rooms and pillars in the pre-set geological and geotechnical conditions.

3. Research methods

The numerical modeling assumed a geometric layout vertically along line *I-I* (Figure 1). The plain strain problem for classical elasticity–plasticity has the following boundary conditions: the top of the model is free from loading, the horizontal displacements of the side boundaries and the vertical displacements of the bottom boundary are zero.

The finite element-based modeling results are estimated using the in situ measurement data. The ratio of residual and initial strengths of coal is determined using the values of principal stresses found from the Mohr–Coulomb failure envelope.

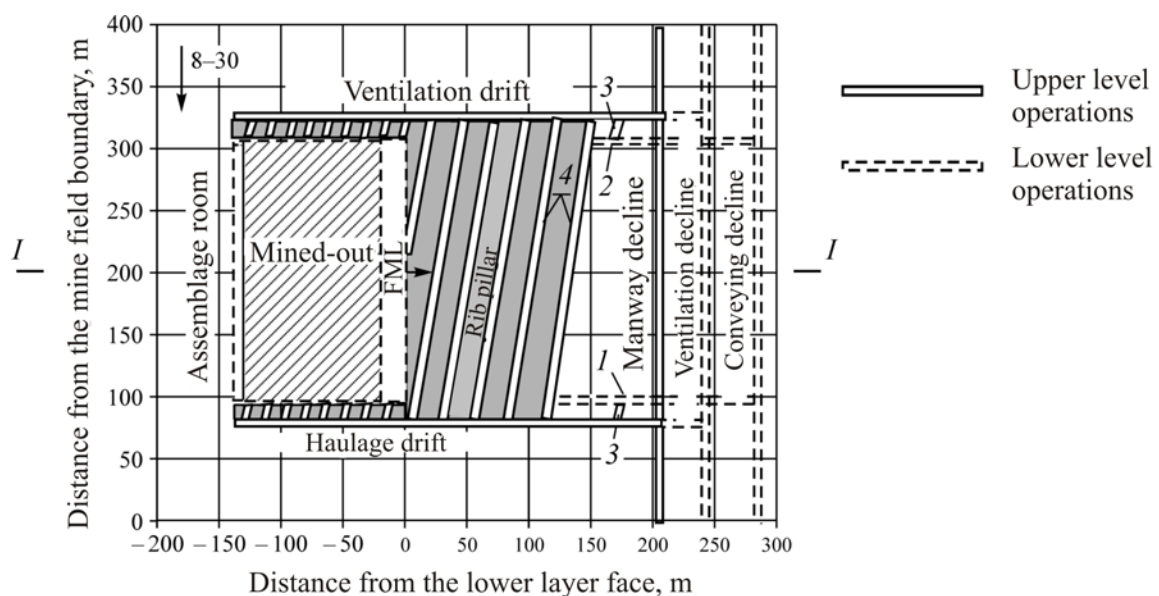


Figure 1. Process layout of thick coal seam mining with shotwall pre-fracture of upper layer and cutting of lower layer and loading of coal on armored face conveyor: 1—conveyor drift in the lower layer; 2—ventilation drift in the lower layer; 3—cross connections; 4—rooms; FML—fully mechanized longwalling in the lower layer.

4. Results and discussion

The analysis of the influence exerted by rooms in partial extraction of coal in the upper layer involved a few variants of spatial arrangement of the rooms and rib pillars relative the coal seam thickness. Figure 2 depicts the results of vertical stress distribution near the face of the lower layer before cutting rooms in the upper layer. The rational variant of room arrangement in the undercut layer in Figure 3 shows that in the coal seam 9.4 m thick, the crown pillar with a thickness of 0.9 m is left at the seam roof, and the pillar at the floor of the rooms is 3.7 m thick.

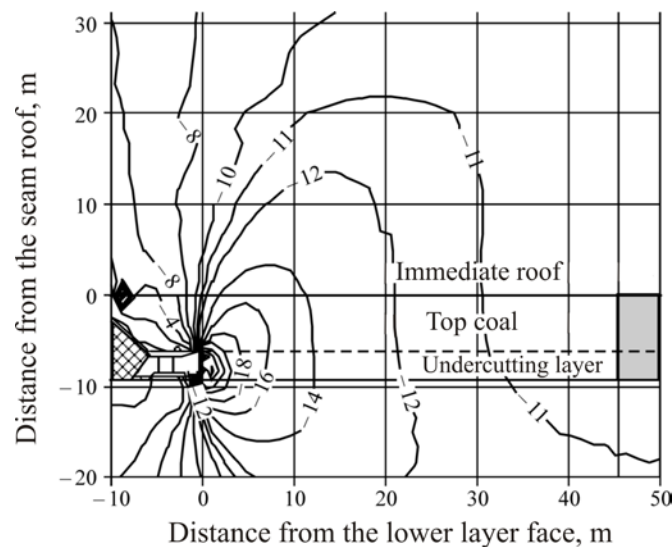


Figure 2. Contour lines of vertical stresses in rocks near the faces in the LTCC technology.

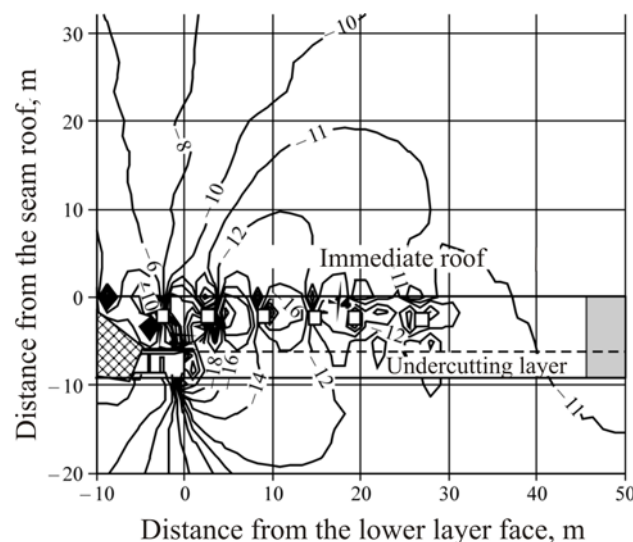


Figure 3. Contour lines of vertical stresses in rocks near the faces in the LTCC technology after advanced room and pillar in the upper layer.

The comparison of the vertical stress distributions in rocks before and after advanced room and pillar in the upper layer in Figures 2 and 3, respectively, reveals some regular patterns as follows:

- the maximum vertical stress concentration factor is observed near the fully mechanized longwall face (Figure 2) and equals 2.2; it reduces by 10% approximately after advance room and pillar (Figure 2);
- during advanced shortwall mining in the upper layer, two zones of abutment pressure arise: ahead of the fully mechanized longwall face in the lower layer and ahead of the room closest to intact rocks;
- rib pillars are the stress raisers: the vertical stress concentration factors in the pillars are by 1.2–1.3 times higher than before the preliminary cutting in the upper layer;
- the influence of advanced rooms on the vertical stresses at the face in the lower layer is much less than the pressure of overhanging undercut roof rocks, i.e., shortwalls unalter the geomechanical

situation on the whole and are the tool for handling local problems, including intensification of coal pre-fracture in the upper layer.

In the analysis of coal pre-fracture intensity in the upper layer before (Figure 4) and after advanced room and pillar (Figure 5), the ratio of residual and initial strengths of coal was determined.

In the traditional coal mining without the upper layer pre-fracture (Figure 4), the strength of coal above the roof support decreases by 40–50%. Directly above the units of roof support, under the influence of their bearing ration and triaxial stress of rocks, coal compacts and large blocks are formed. The latter fact is confirmed by coal distraction at the interface of immediate roof and the seam. The most dangerous zone at the face is the zone of operation of the cutter-loader as reduction in coal strength to 30–40% of initial strength is possible in the course of cutting in the lower layer; for this reason, the probability of loose coal rash and face slip is very high.

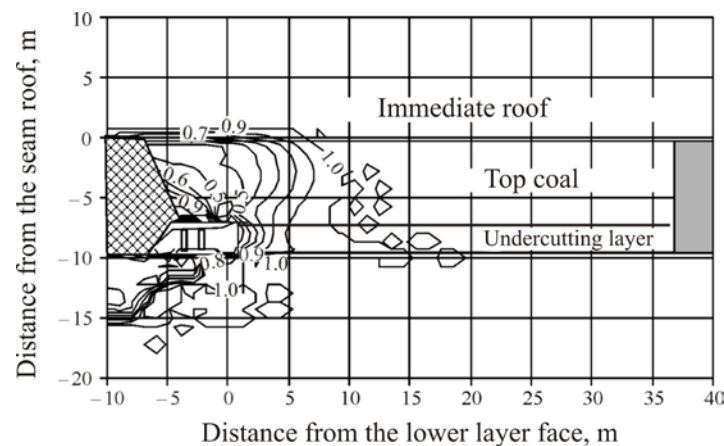


Figure 4. Contour lines of ratio of residual and initial strengths of coal in the upper layer.

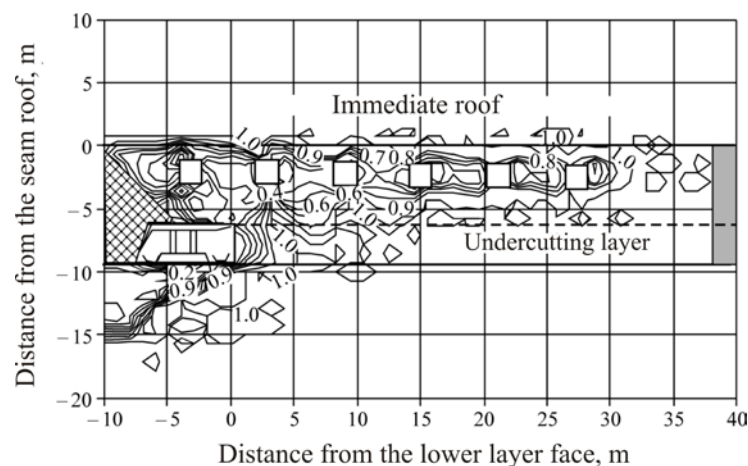


Figure 5. Contour lines of ratio of residual and initial strengths of coal after advanced room and pillar in the upper layer.

In case of shortwalling in the upper layer (Figure 5), strength of coal in the layer decreases by 40–50%. Ahead of the face in the lower layer, the ratio of residual and initial strengths of coal in Figures 4 and 5 is almost the same, i.e., the room and pillar mining in the upper layer has almost no influence on the strength of coal in the undercutting layer.

Immediate roof rocks are nondestructured; thus, rock falls and coal dilution are improbable. The advanced room and pillar in the upper layer reduces impact of secondary roof caving behind the face [9].

At the same time, in the vicinity of rooms and in the rib pillars in the upper layer, the strength of coal is reduced by 2–2.5 times, i.e., top coal caving will be uniform in the whole height of the upper layer.

For the technology of pre-fracturing of coal in upper layer by room and pillar, it is proposed to use robotic equipment with remote control by operators accommodated in safe places [10–12].

The unmanned coal cutting technology is to comply with the requirements below:

- the rooms and rib pillars should be unsupported not to violate the LTTC conditions;
- the cross section area of the rooms should be within 1–2 m² as larger areas can result in formation of roof arches and rock failure in the immediate roof;
- electric energy is prohibited in the advanced room and pillar as high rate methane drainage in this case can result in explosion of air and methane mixture.

For the room and pillar method implementation, it is suggested to use augering.

Conclusions

Based on the numerical modeling result and expert estimation, it is found that stability of immediate roof rocks requires a coal crown 1.0–1.5 thick to be left above the rooms of advanced pre-fracturing. In order to preserve top coal stability above the face in the operation zone of cutter-loader, it is recommended that the thickness of coal layer between the floor of rooms in the upper layer and the upper boundary of the undercutting layer is not less than 2 m.

The applicability and efficiency of top coal pre-fracturing without reduction of load-bearing capacity of immediate roof and coal above and beneath the advanced rooms has been proved.

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