Modeling stress–strain state of rock mass under mining of complex-shape extraction pillar

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Abstract. Based on the results of numerical modeling of stresses and strains in rock mass, geomechanical parameters of development workings adjacent to coal face operation area are provided for multi-entry preparation and extraction of flat seams with production faces of variable length. The negative effects on the geomechanical situation during the transition from the longwall to shortwall mining in a fully mechanized extraction face are found.

1. Introduction
Efficient fully mechanized mining is possible in gently dipping coal mine fields 3–4 km in size along the dip and strike. Extraction panels should be single-wing and rectangular. In practice, in the presence of synclinal and anticlinal folds, disjunctive dislocations or different purpose coal pillars, a mine project can assume complex-shaped extraction panels. Figure 1 depicts a variant of preparation and extraction in a panel with disjunctive dislocations revealed during driving of ventilation drift 01. When a fully mechanized mining face is advanced from the flank shafts to the central shafts, longwall will have varied length.

Figure 1. Operation in complex-shaped extraction panel in the influence zone of disjunctive dislocations: I, II, III—locations of working face.
Under such conditions, it becomes necessary to support systems of parallel longwalls at a mining depth of 200–800 m by coal pillars with a width of 20–60 m. The width of pillars is chosen based on specific geological and geotechnical conditions, including the length of longwall. In the transition from shortwall to longwall fully mechanized mining and vice versa, it is required to determine parameters of stable coal pillars and support designs for entry ways. Justification of the width of stable coal pillars and reliable support design for roadways outlining an extraction panel, it is required to estimate stresses in coal and enclosing rock mass.

During fully mechanized longwalling, it is required to shorten the fully mechanized mining system by the length of cross split 20–21 by disassembling some sections of powered support. After extracting coal in a shortwall between cross splits 1 and 2, the length of the fully mechanized system is increased again, and coal development past cross split 2 is continued by a longwall [1].

The geomechanical assessment of safe mining in case of a complex shape extraction panel in Figure 1 involves a few engineering problems to be solved:

—validation of an algorithm to select support design and ensure stability of cross splits in the abatement pressure zones as the fully mechanized longwall system approaches them;

—determination of input data to calculate geometry for a safe entry of the fully mechanized mining system in cross split 1;

—determination of input data for the support design in ventilation drift 01-bis, conveyor drift 01 and ventilation drift 02.

The available practical guides ensure incomplete solution of the set problems.

So, the necessity to model stress state in coal-and-rock mass in case of complex shape of longwalls and to design support for roadway outlining mined-out area in case of bench mining is conditioned by:

—formation of stress raisors at the corner edges of the coal bed when the width of the coal pillar between the work face and cross split 1 is shortened and dynamic events due to rock pressure are possible;

—unavailability of quantitative relations for characteristics of abatement pressure in rock mass around roadways in the varied length sections of longwalls;

—difficulty of validating parameters of entry of the fully mechanized mining system to a disassembling room and ensuring its stability during removal of powered support units.

2. Model and methods

Geometrical model of extraction panel includes such characteristics of work face position (Figure 1) as:

—position I—before entry in the dissembling room (cross split 1) for the transition from longwall to shortwall fully mechanized mining;

—position II—shortwall mining;

—position III—after addition of powered support units in cross split 2 and transition to longwall mining.

The process objects where it is necessary to assess vertical stresses is the pillar between the fully mechanized longwall face and cross split 1, cross split 1, as well as ventilation and conveyor drifts (Figure 1).

The mathematical model of coal-and-rock mass stress state is based in the constitutive relations of the theory of deformation solid in the form of a boundary value problem [2, 3] and the finite element method [4, 5].

Aimed to reveal mechanisms of vertical stress distribution in coal bed and roof rocks in a complex-shaped longwall, the computational experimentation has been carried out using the authorial package of problem-oriented programs [6, 7].

The source data of modeling were: extraction panel 800 m long, work face length 300 m in the longwall and 200 m in the shortwall, development entries 5 m wide, mining depth of 600 m, coal bed
thickness 2 m, immediate roof 7 m thick, main roof thickness 30 m, coal strength 10 MPa, roof rock strength 30–60 MPa.

3. Results and discussion
In the modeling, the width of the pillar between the fully mechanized face and cross split 1 was shortened from 50 to 0 m at step of 10 m. Figure 2 shows the stress isolines in the longwall when the fully mechanized face is spaced at 10 m from cross split 1.

The analysis of the distribution of stresses, displacements and coal disintegration factor shows that:
— with the narrower pillar between the fully mechanized mining system and the cross split, the most hazardous zone is the juncture of ventilation drift 01-bis and cross split 1; the vertical stress concentration factor is 4.6 in this zone, and the vertical stresses are much higher than the coal compression strength;
— the maximum of the abatement pressure epure is at the edge of the coal bed when the coal pillar is 50 m wide and drifts to the center as the width of the pillar is reduced, which initiates concentration of energy that can release in the form of a rock burst;
— the presence of the disjunctive dislocation with high methane content between cross splits 1 and 2 an outburst of coal, rocks and gas is possible in the juncture zone of ventilation drift 01-bis and cross split 1;
— the diagrams of disintegration coefficient in coal and roof rocks show that when the coal pillar is 5 m wide, coal fails in the pillar and in the sides of cross split 1 while the roof of the cross split disintegrates into blocks under the action of the horizontal and shearing stresses.

![Figure 2. Distribution of vertical stresses on approach of longwall face to cross split 1.](image-url)

Based on the determined distribution of stresses in coal and rock mass and using the estimated probability of gas-dynamic events, ejection of coal from sidewalls and roof rock falls, the developed engineering solutions recommend making a disassembling room instead of cross split 1 as the fully mechanized mining system is advanced.

After transition the fully mechanized system from longwall to shortwall mining, the extraction situation has normalized (Figure 3).
The concentration coefficient of vertical stresses at the edge of the coal bed in the middle of the shortwall has halved as compared to the same coefficient in the longwall and made 2.2. The negative effect exerted by the bench at the juncture of cross split 1 and ventilation drift 01-bis on stability of the latter was felt as the fully mechanized mining system moved away from the bench to the extent of 0–0.2\(H\), where \(H\) — mining depth. In the shortwall the residual/initial strength ratio of coal became 0.8–1.0, which means reduction in probability of sloughing of edge coal.

The process of transition of the fully mechanized mining system from the longwall to the shortwall brought no essential complications to the geomechanical situation (Figure 4). The units of the powered support are assembled in cross split 2 and ensure stability of roof rocks is the assembling room. At the first stage of longwall mining, overhanging rocks of the bench at the juncture of driven ventilation drift 01-bis and cross split 1 induce local increase in the vertical stresses in the edge coal; however, as the face is advanced and the roof rocks are caved, the stresses become uniform longwise the face. Further longwall mining causes no geomechanical complications (Figure 4).

Based on the research findings, the concentration coefficient of vertical stresses in coal pillar between conveyor drift 01 and ventilation drift 02 is given by:
\[ k = 0.25 + 4.00 \frac{l}{H}, \]

where \( k \)—concentration coefficient of vertical stresses; \( l \)—length of longwall, m; \( H \)—depth of mining, m.

This formula is recommended for determining an estimated depth of mining, normal displacements of roof and sidewall rocks in roadways and a width of pillars in conformity with the guidelines provided by VNIMI.

4. Conclusion
The authors have found that the transition of the fully mechanized system face from longwall to shortwall mining can affect geomechanical situation in an extraction panel in the form of: increased stress zone formed at junctures of rooms when the width of the coal pillar between the working face and the disassembling room is reduced; probability of gas dynamic events in the coal pillar and at the coal bench where energy raisor is generated; failure of roof rocks and sidewalls in the disassembling room when the coal pillar width is under 5 m.

It is recommended to transit between longwall and shortwall mining within an extraction panel by means of cutting a disassembling room, roof rock support and sequential disassembling of mining equipment.

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