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Numerical simulation of geomechanical state of coal massif in the vicinity of underground workings in the superimposed seams

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Abstract. The results of numerical modeling of stresses distribution in the formation of coal seams, mined successively in a descending order are presented. The variant is considered, in which the working of the upper seam is carried out in advance and the selvages of the mine workings in the tapped and overworked seam are located in zones of increased rock pressure and unloading, which creates dangerous conditions for mining operations. A mathematical model of stress-strain state of the geomassif in the form of a boundary-value problem, which was solved by the finite element method. Computational experiments were carried out to assess the mutual influence of excavations in the superimposed seams. The zones of increased rock pressure are determined within which the most dangerous geomechanical situation arises. The evaluation of the conformity of the numerical simulation results with the requirements of normative documents is performed. The proposed approach is recommended for the development of project documentation.

1. Introduction

The principles of controlling geomechanical processes in rock massifs are based on the use of the revealed regularities in the distribution of geomassif stress-strain state parameters in the process of mining coal seams lying in different mining and geological conditions.

Coal mining technologies and technical capabilities of mine equipment allow the face advancing speed to be increased up to 20 m per day. However, intensive technogenic impact on the geomassif leads to the formation of geodynamic phenomena in the of coal seam selvages and zones of increased rock pressure such as rock bumps, sudden coal, rock and gas burstings, cavings and dynamic sediments of roof rocks with the release of hazardous gases in the form shock air waves [1 - 3]. These phenomena limit the productivity of mechanized faces equipped with expensive equipment.

To ensure the safety of coal mining and the prevention of these dangerous phenomena, it is necessary to prevent pre-emergency situations by system analysis of mathematical and numerical modeling results of geomassif stress-strain state, the stress field of which is formed under the influence of natural and technogenic factors [4 - 6].

When mining the formation of seams, the presence of workings in the superimposed seams leads to stresses redistribution in the zone of influence of both workings as a result of their mutual underworking or overworking [7]. Such anthropogenic impact can lead to the formation of zones of increased rock pressure and unloading in the geomassif. Therefore, in order to justify the order and sequence of mining of seams in the formation, it is necessary to establish the parameters of these zones.

2. Methods of research

When carrying out computational experiments the mathematical model of the geomassif stress-strain state was used [8] that takes into account the effects of gravitational forces $\vec{F}$, formulated in the form of a boundary value problem in a general formulation: find the displacement vector *U=(u,v)*, *u=u(x,y)*, *v=v(x,y)*, which satisfies the system of differential equations within the computational domain

$$\mu \Delta \vec{u} + (\lambda + \mu) grad\ div \vec{u} = \vec{F} \tag{1}$$

and the boundary conditions shown in figure 1, where *u* and *v* are horizontal and vertical displacements; σ_y – vertical stresses; λ, μ are lame parameters.

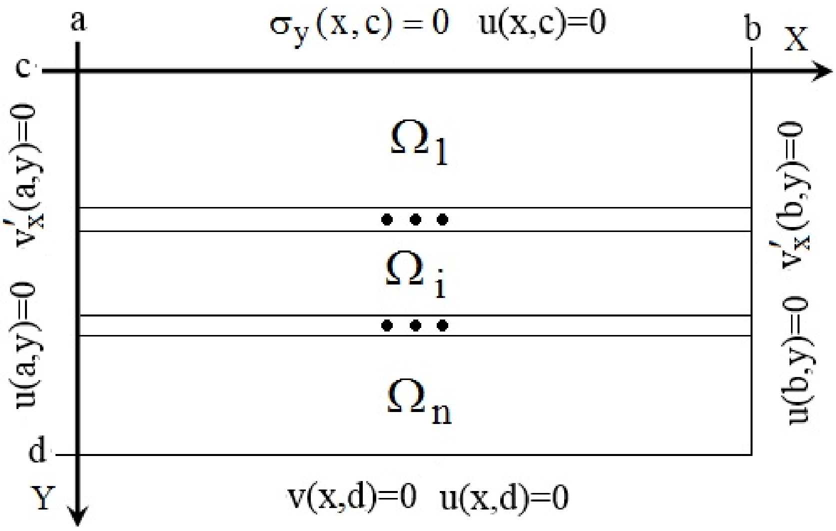

Figure 1. Boundary conditions accepted for mathematical model of the investigated geomassif section.

The conditions on the vertical and horizontal boundaries of mathematical model were determined as follows:

- horizontal displacements *u(a,y)=0*, *u(b,y)=0*, *u(x,c)=0*, *u(x,d)=0* are given on the vertical and horizontal boundaries of computational domain at *x=a*, *x=b*, *y=c* и *y=d*;
- on the vertical boundaries of computational domain at *x=a*, *x=b* the following derivatives are given: $v'_x(a,y)=0$, $v'_x(b,y)=0$;
- vertical stresses are set on the upper base $\sigma_y(x,c)=0$;
- vertical displacements *v(x,d)=0* are set on the bottom base.

The boundary problem was solved under the condition that the mass forces are directed along the vertical axis and were created by the intrinsic weight of the rocks.

The calculated domain of the investigated section of geomassif Ω (figure 2) is represented by argillites (Ω1, Ω3), siltstones (Ω5) and contains formation of coal seams (Ω2, Ω4). In the underworked seam (Ω2) the working boundaries in figure 2 are denoted by points B1 and B2, and in the mined seam (Ω4) – by points B3 and B4. Under the basic conditions of computational experiment mining is carried out on the upper seam of the formation.

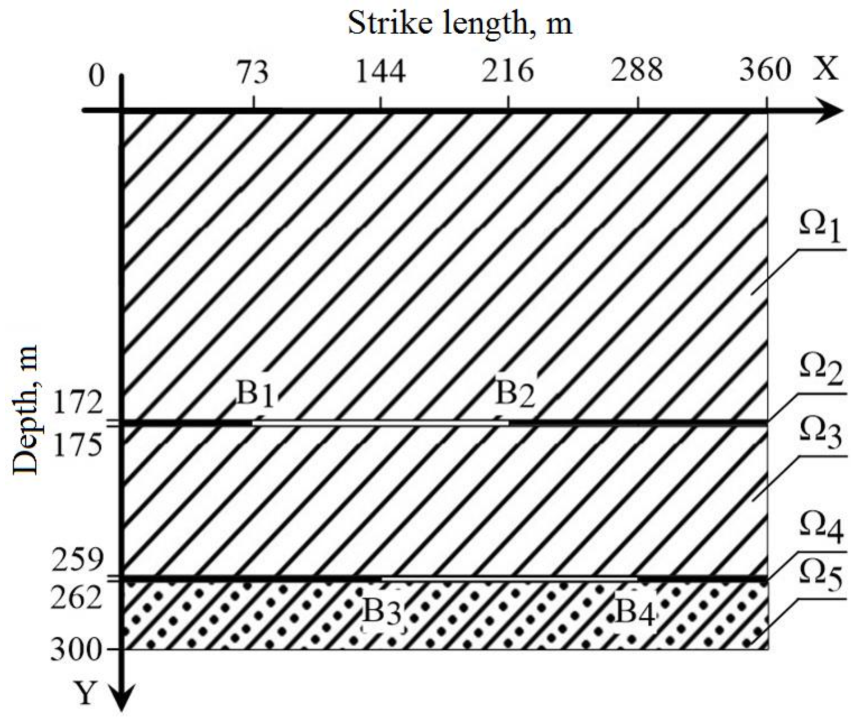

Figure 2. Estimated area of the geomassif section which includes workings in the superimposed coal seams.

Physical and mechanical properties of coal and rock are specified in table 1. The mathematical model was studied by the finite element method [10 - 12]. For carrying out computational experiments the authorial complex of problem-oriented programs NDSolverV1.0, developed in the Mathematica system in Wolfram Language [13], was used.

Table 1. Physical and mechanical properties of rocks [9].

Rock	Density ρ, kg/m^3	Elastic modulus E, MPa	Poisson coefficient, ν	Legend
Argillite	2600	26000	0.28	
Aleurolite	2700	28000	0.27	
Coal	1380	3000	0.34	

3. Results and discussion

The estimation of mutual influence of workings in the superimposed seams of formation was made on the basis of study results of stresses distribution obtained for two mining variants of the investigated section in the mining massif:

- mining of the coal seam in the formation by a single face without taking into account the influence of workings in the superimposed seams;
- simultaneous mining of two layers by mechanized faces taking into account their mutual influence in the form of underworking and overworking of seam selvages (figure 2).

Figure 3 shows the isolines of vertical stresses distribution (the minus sign corresponds to compressive stresses). The dotted isoline -4.47 MPa, corresponding to the position of vertical stresses equal to the stresses in the unmined massif for the upper seam, is distinguished. The presence of the working led to the unloading of the roof rocks and seam soil, which is confirmed by the change in the values of the vertical stresses in the zone of influence of gob relative to the gravitational stress field. In the roof of the seam tensile stresses are observed, which can lead to the rock destruction, the formation of caving and cracking zones. The height of arches of these zones can be approximately half the length of the working.

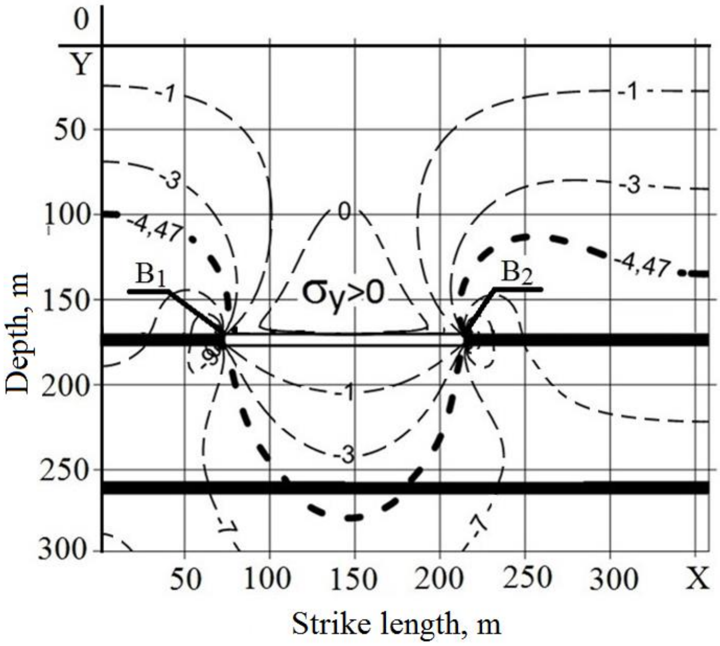

Figure 3. Isolines of vertical stresses distribution during mining in the upper seam of formation, MPa.

In the selvages of the coal seam a bearing pressure zone is formed, the presence of which was proved by the results of a mine experiment, physical and numerical modeling [14 - 17]. According to figure 3, the maximal compressive stresses are 9 MPa, i.e. the coefficient of vertical stresses concentration is equal to 2. Since the maximal compressive stresses do not exceed the coal strength limit of 11 MPa, coal spall in the selvage of the seam does not occur.

Figure 4 shows the stresses distribution in the presence of mutual influence of two faces in the superimposed seams 1 and 2. Vertical stresses in the unmined massif for the upper seam 1 at a depth of H=172 m make -4.47 MPa, and for the lower seam 2 at H=259 the stresses reach the value of -6.73 MPa.

In order to compare the results of numerical modeling of vertical stresses under mutual influence of two faces with the base variant, in figure 3 the isoline from figure 4 is dotted, corresponding to the values of vertical stresses equal to -4.47 MPa. Due to the extra underworking of the upper seam 1 by works in seam 2 in the selvage of the mine in the vicinity of point B_2, the unloading took place that confirms the isoline displacement towards the unmined massif corresponding to the vertical compressive stresses of -4.47 MPa in figure 4. In the vicinity of point B_1 there is an increase in vertical stresses by 1.4 times in comparison with the corresponding values of stresses in figure 3.

As a result of overworking of lower seam 2 in its selvage (in the vicinity of point B_4) the zone of increased rock pressure is formed, within which the coefficient of stress concentration reaches 1.93.

The selvage of the lower seam 2 (in the vicinity of point B_3) underwent partial unloading under the influence of gob in the upper seam; the coefficient of vertical stress concentration is 1.34.

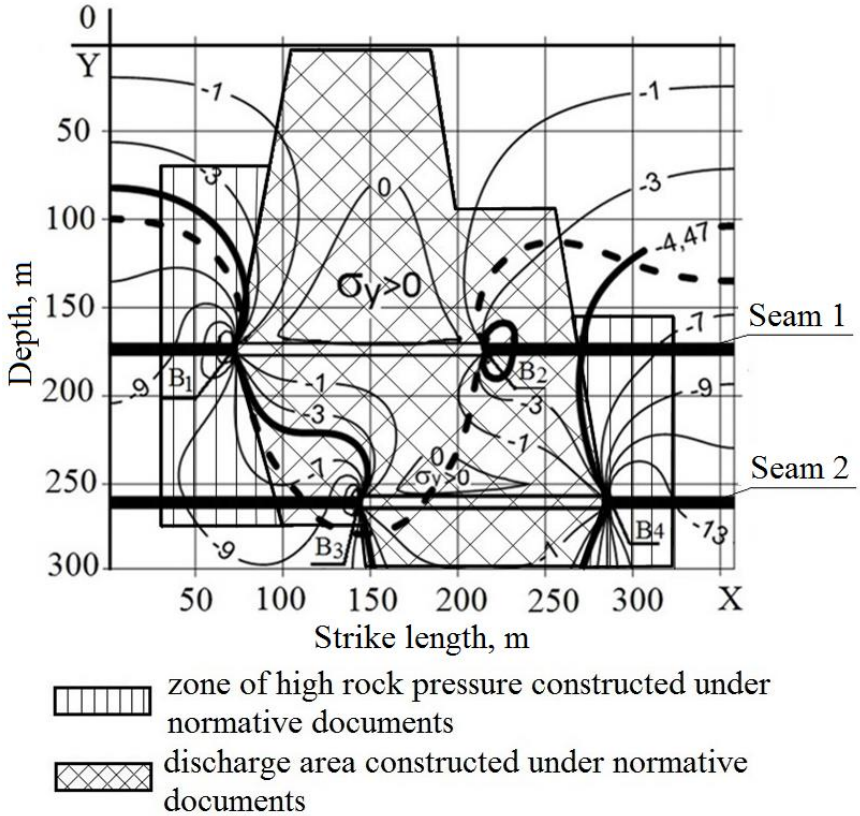

Figure 4. Isolines of vertical stresses distribution under mutual influence of two faces in the superimposed seams, MPa.

The maximal coefficient of stress concentration is revealed in the vicinity of point B_4, in which the vertical stresses of two bearing pressure zones in the selvages of the overworking face of the upper seam 1 and the inferior lower seam 2 are superimposed. The zones of caving and gradual descent are clearly delineated by the boundaries of zones of partial unloading, where the values of vertical stresses are essentially less than the stresses in the unmined massif.

To determine the correspondence between the distribution of calculated stresses and the recommendations of normative documents [18], zones of increased rock pressure and unloading are constructed in figure 4, the boundaries of which are qualitatively coincide with the areas of vertical stress distributions obtained from the results of computational experiments.

4. Conclusions

It is substantiated that under mutual influence of gobs in the superimposed seams, the stress fields are superimposed with the formation of unloading zones and increased rock pressure. Based on the results of numerical modeling of geomechanical state of massif, which includes mutual impacts of workings in the superimposed seams, the shapes and sizes of zones of increased rock pressure and unloading were determined.

It was established that the most dangerous situation in terms of geomechanical conditions occurs when the zones of reference pressure of the upper and lower seams are superimposed. The suggested approach is recommended for the prediction of quantitative parameters of the stressed-deformed state of geomassif at the stage of development of project documentation and justification of spatial position of faces and development workings in the formation of superimposed seams.

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