

# Numerical analysis of inter-panel pillars in the bump prone conditionals of the Alardinskaya mine

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**Abstract.** The purpose of the paper is to substantiate the width of the barrier and yield pillars for the application of a new seam development scheme in the conditions of the Alardinskaya mine (Russia). The Alardinskaya mine develops gas-bearing coal seams that are prone to spontaneous combustion and are hazardous due to rock bumps, which leads to frequent accidents. The analysis of the world experience of mining seams being hazardous to rock bumps showed that safe mining with longwalls can be provided by a system of inter-panel pillars: very wide barrier pillar and two yield pillars. Numerical modeling using the finite element method was carried out to assess the possibility of reducing the barrier pillar width in order to decrease the volume of coal losses in the subsoil. The model of rock massif was created in Ansys mechanical software. Numerical modeling of the longwall panel development with longwalls was carried out at various widths of broad and yield pillars. The analysis outcomes of the vertical stresses diagrams in the seams are presented for different parts of the longwall panel. The rational parameters of the pillar system, ensuring the minimization of the reference pressure influence from the previously worked-out column and the reference pressure of the operating longwall, are determined as a result of numerical analysis. The conclusion is made about the expediency of the technological scheme application proposed by the authors in the conditions of the Alardinskaya mine to reduce the endogenous fire hazard and the danger of rock bumps.

## 1 Introduction

The efficiency of underground mining of coal seams depends on the correct choice of the applied mining technology. The main method of coal mining at present is the development by longwalls [1-3], the work of which is to conduct mine workings along the contour of large rectangular blocks of coal (longwall panels). The overlying rocks lose their support during coal extraction, and some of these rocks fall down. However, most of the rocks hover and transfer their weight to the massif edges formed by coal mining. Thus, increased stresses or reference pressure arises in the edge parts of the massif. Primarily, the length of the reference pressure zone depends on the depth of mining and is several tens of meters (30-120 m), and the stress level is computed by the overlying rock properties of the main roof and can exceed the geostatic level by 2-3 times. The maximum stress in the reference pressure zone is located at a distance approximately equal to the extracted seam thickness. Inter-panel coal pillars (with a width of 30 m and more) are left to exclude the reference pressure influence between the longwall panels; they reduce the effect of the reference pressure on the adjacent longwall panel. Generally, longwall mining at relatively shallow depths (less than 400 m) is very efficient and safe [4-6]. However, the danger of dynamic phenomena, namely rock bumps and sudden emissions of coal and methane, increases when working at depths over 400 m [7-10].

The main cause of rock bumps is the ability of some coals to elastically deform under load and accumulate significant energy, which is sufficient at great depths to instantly destroy the edge of the pillar or massif and eject the destroyed coal into the mine workings [11-12]. Development of seams in conditions of dynamic hazard is carried out with the application of yield pillars of coal [13-15], which have a small width and are destroyed even at minor loads excluding the possibility of accumulating energy required for a rock bump. Anyway, there are conditions prohibiting the use of narrow inter-panel coal pillars. For instance, it is necessary to exclude the air ingress into the previously worked longwall panels during the development of seams prone to spontaneous combustion, which is achieved by leaving wide barrier pillars (more than 30 m), not cut by workings between the longwall panels. Therefore, there is a contradiction in the requirements for ensuring safe conditions during the development of seams prone to spontaneous combustion and hazardous to rock bumps.

Currently, considerable experience in fighting endogenous fires [16-20] and rock bumps has been accumulated [21-23]. However, solving the problem of safe development of seams that are both hazardous due to rock bumps and endogenous fires is an extremely complicated task. For example, a series of gas-bearing coal seams, which are prone to spontaneous combustion and rock bumps, are mined in the Alardinskaya mine (Kuznetsk coal basin, Russia). Coal pillars were not left between the longwall panels, or narrow yield pillars

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were left to exclude rock bumps at the Alardinskaya mine. Thus, dynamic safety was ensured, but endogenous fires and methane explosions in worked areas began to occur due to air leaks into the mined-out spaces of previously worked areas. The technological scheme with retention of a coal barrier pillar with a width of more than 30 m was used to solve the problem of coal spontaneous combustion at the Alardinskaya mine. The first longwall panel was successfully completed. Nevertheless, a rock bump or dynamic destruction of the pillar edge occurred during the development of the second longwall panel; the working was filled with destroyed coal for more than 80 m. Another rock bump took place after the working restoration and coal mining continuation [24].

The fundamental cause of rock bumps is a high concentration of stresses created by the overlapping of reference pressure zones from the side of the previously worked and developed panel. Besides, the presence of a strong sandstone layer in the main roof leads to a stress increase in the reference pressure zone. It is worth leaving the pillar with a width greater than the length of the reference pressure zone to minimize the effect of the reference pressure of the adjacent panel. A pillar with a width equal to two lengths of the reference pressure zone should be left to completely exclude the mutual influence of the reference pressure. Therefore, it is possible to create conditions with wide pillars retention to minimize the risk of rock bumps and endogenous fires. The opportunity of applying wide coal pillars is confirmed by the experience of mining seams in the conditions of mines in the state of Utah (USA) [25-28]. However, retention of very wide pillars leads to considerable losses of coal, the value of which reaches 50% of all reserves. Such level of losses during thick seams mining is unacceptable.

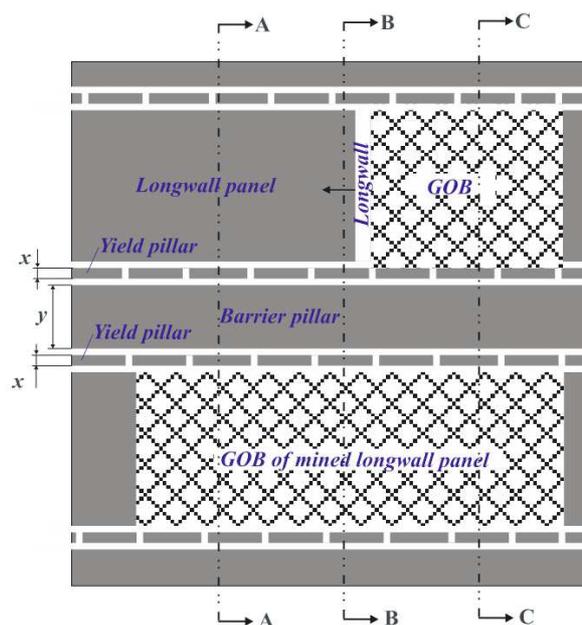
It is advisable to consider the possibility of reducing the width of the barrier pillars when applying the technological scheme that has been used in US mines to

decrease coal losses. In our opinion, the barrier pillar width can be significantly declined with a minimal effect of previously worked longwall panels. It is required to assess the distribution of stresses, which are directly related to the ability of energy accumulation for dynamic phenomena to assess the potential of implementing such a scheme.

The research purpose, which outcomes are presented in the paper, is to analyze the stress state of the rock massif when using wide and yield pillars of various widths; and to evaluate the possibility of reducing the width of the inter-pillar pillars for coal losses decline.

## 2 Methods

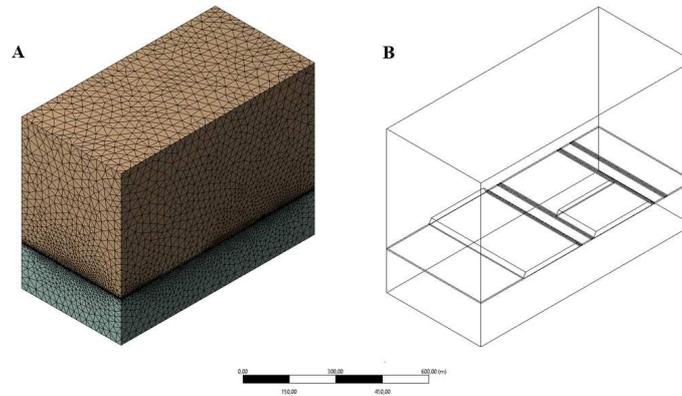
The finite element method, which is widely applied to solve various problems of mining geomechanics, was used in research [29-31]. The studies were carried out by dint of the Ansys mechanical software. The research computational scheme is shown in Figure 1. It represents the location of mine workings, longwalls and pillars within the developed seam. Two longwall panels were under consideration: one had already been worked out, and the other was in the process of being developed. The basic parameters of the computational scheme were: the width of yield pillars -  $x$  and the barrier pillar -  $y$  (Figure 1). Three primary sections, differing in terms of the conditions in the inter-panel pillar, were highlighted. Section A-A (Figure 1) was outside the influence of the longwall reference pressure (at a distance of 200 m from the longwall), section B-B passed through the zone of longwall reference pressure, and section C-C was at a distance of 200 m from the longwall. The longwall panel width was taken equal to 300 m, the depth of mining - 600 m. The modeling was carried out with a change in the width of stable pillars from 40 to 100 m (with a step of 10 m) and yield pillars - from 6 to 10 m (with a step of 2 m).



**Figure 1.** Computational scheme for determining the width of inter-panel pillars

The three-dimensional numerical model (Figure 2) is a part of the rock massif around two longwall panels - being developed and previously worked out. Figure 2A shows the finite element breakdown of the model, and Figure 2B represents the model frame with a rock workings system. The worked spaces were modeled as a continuous medium with

low deformation and strength characteristics and high Poisson's ratio. The coal and host rocks density and the effect of gravity were taken into account, which formed the stress level in the rock massif. The Mohr-Coulomb model and the rock strength passport were used to consider the non-linearity of rock deformation under load.

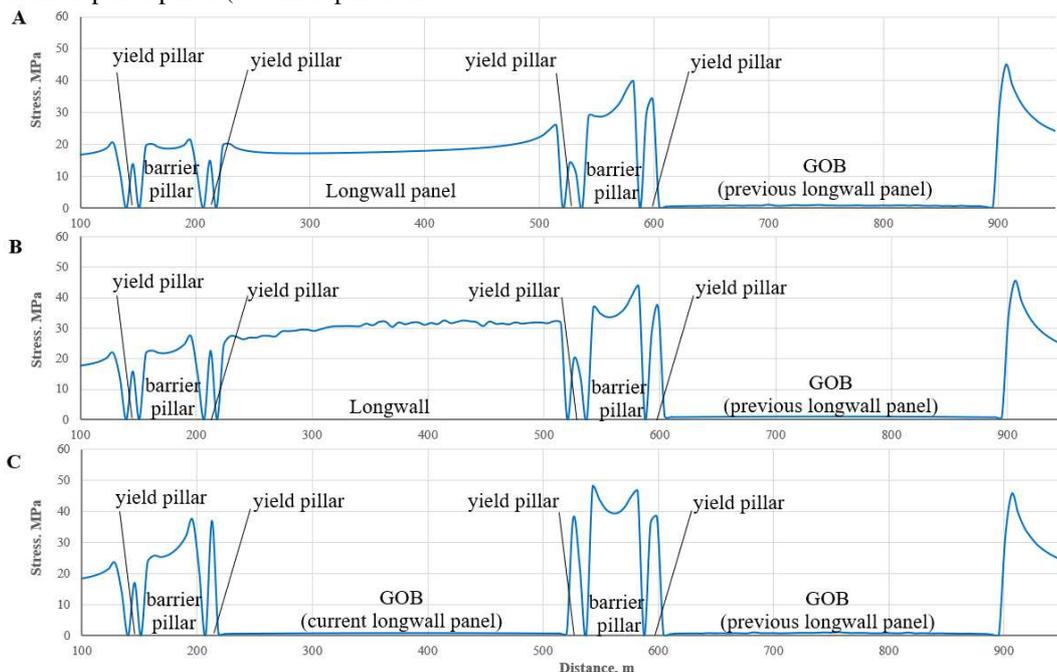


**Figure 2.** Rock massif model

### 3 Results and Discussion

The stress distribution in the three-dimensional model of the rock massif was obtained and the stress diagrams along the line passing through the seam for sections A-A, B-B and C-C shown in the computational scheme were plotted by means of the numerical analysis (Figure 1). As an example of the obtained outcomes, Figure 3 presents the stress distribution for pillars with recommended parameters: the width of the barrier pillars is 60 m, the yield pillars are 8 m. Figure 3A demonstrates the use of pillar systems with various yielding as an inter-panel pillar (a barrier pillar and two

yield pillars located around it) and allows reducing the stress level even after the first longwall panel has been worked out. Stresses reach 45 MPa (Figure 3A) in the right part of the worked panel (the absence of a system of pillars), and in the left side (in the inter-panel pillar) - 40 MPa. Figure 3B allows assessing the impact of the reference pressure zone formed in front of the active longwall. The stress level in the pillar increases up to 44 MPa as the reference pressure zones overlap. Besides, the stresses increase from 21 to 27 MPa on the other side of the longwall, namely, at the border with the next mining section. The maximum stress level (48 MPa) in the inter-panel pillar is observed behind the longwall (Figure 3B).



**Figure 3.** Distribution of vertical stresses when using the recommended variant of the technological scheme

It should be noted that the stress level in the barrier pillar reached 40 and 29 MPa when the longwall approached at modeling wide pillars (130 m), from the side of the previously worked and being worked pillar, respectively. The level was 44 and 37 MPa with the proposed pillar width of 60 m. Consequently, reduction of the pillar width by more than 2 times leads to an increase in the stress level by 10-20%. However, a further decrease in the pillar width to 40 m leads to a sharp rise of the stress concentration in the pillar up to 52 MPa. The outcomes of the performed studies made it possible to recommend the use of barrier pillars with a width of 60 m and yield pillars with a width of 8 m to reduce the coal loss in the barrier pillar. The reduction will allow eliminating the loss of up to 1 million tons of coal in each inter-panel pillar during powerful seams mining in the conditions of the Alardinskaya mine.

## 4 Conclusion

An increase in the depth of mining leads to a deterioration in conditions due to rock pressure rise and the methane content growth of coal seams in coal mines. Mines that develop gas-bearing seams prone to spontaneous combustion and rock bumps are distinguished by the most complicated development conditions [32-33]. The technology of seams development hazardous to rock bumps with the retention of barrier pillars 30-45 m wide, used at the Alardinskaya mine, does not allow excluding dynamic phenomena due to overlapping reference pressure zones and an increase in the inter-panel pillar stress. Besides, the application of diagonal workings leads to an increase in the risk of rock bumps during their transition with the longwall. The system of wide barrier and yield pillars with four workings in each longwall panel used in the state of Utah (USA), completely eliminates the reference pressure influence from the previously worked pillar, and is characterized by the lowest stress level, which completely eliminates the risk of rock bumps. However, such technological scheme is designated by an exceedingly high level of coal losses in the inter-panel pillar. The authors propose to reduce the width of the inter-panel pillar for declining the coal loss in the barrier pillar. The studies have led to the conclusion that the pillar width can be reduced to 60 m with the width of yield pillars of 8 m for the conditions of the Alardinskaya mine at 600 m deep, which will minimize the reference pressure effect from the previously worked adjacent longwall panel. At the same time, the reference pressure influence remains, but is minimal (an increase in the stress level by 10-20%), and the pillar width is reduced from 130 m to 60 m making it possible to decrease coal losses by almost 1 million tons for each longwall panel. Directions for further research will concern the substantiation of ventilation schemes for excavation areas to ensure a high load on longwalls and with the interconnection of mining operations in adjacent seams developed at the Alardinskaya mine.

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