The peculiarities of structurizing enclosing rock massif while developing a coal seam

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Abstract. Different concepts of the development of geo-mechanical processes during longwall mining of a seam which are fundamentally different from the conventional ones are introduced in the article. Fundamental principles of the model for structurizing enclosing rock mass while longwall mining along the strike are described. The model was developed on the bases of non-linear geomechanical laws. According to the model, rock mass in the area of mining operation is organized as rock geomechanical layers with shifting arches. And the formation period of shifting arches in disintegrated rock mass is divisible by the length of the stope. Undulate characteristic of a massif as a peculiarity of man-made structurization of a massif is defined. It is shown that structuring the broken massif causes the formation of block-structured system and it can be detected while monitoring the ground pressure in powered support props. The results of the research allow decreasing the negative influence of a ground pressure and can be applied to specify parameters for controlling the roof, defining geometrical dimensions of a mining section and positioning of holing chute (face entry).

1. Introduction

Mining extraction leads to the change of a rock stress state and even effect on forming shift troughs on the ground surface. When the stope is moving different geomechanical processes take place in coal-gas massif in significant volumes. Resulting from the disintegration of a massif gas, which coal seams contain, evolves actively. Its intensive flows disperse in different directions: into a goaf (mine openings) and on the surface. This can explain gas outburst danger in mines and in surface buildings. Zones of its dangerous influence, volumes, character and the length of the disintegration, rock- and ground surface displacement depend on:

- thickness, angle of gradient, depth and gas-bearing capacity of working seams and their adjacent seams;
- size of stopes, stable pillars size and layout;
- ways to ground pressure control;
- face advance (movement) rate;
- presence of earlier worked out areas in the vicinity of a stope;
- physical and mechanical properties of a rock;
- rock mass structural features (thickness of the faces, geological dislocations etc.).

German research scientists when applying physical modelling method found out [1] that above the goaves (mined-out face) of long stopes not one but several arches in underworking rock mass are...
formed during the face movement. One of the reasons of arch formation is horizontal thrust in rock layers. The phenomena of formation and disappearance of the thrusts in the roof caving is in their periodical alternation. The consequences of the process manifest themselves in periodical roof-caving. Later, German research scientists [2, 3] obtained the results on measuring pressure in powered support props of a long face. It was proved that the distribution of ground pressure along the long face is periodic and undulate. However, the parameters of the results have not been identified yet.

The research of abovementioned features started in Institute of Coal of Siberian Branch of the Russian Academy of Science (now it is Institute of Coal of The Federal Research Center of Coal and Coal Chemistry of Siberian Branch of the Russian Academy of Sciences) in 2000. Nowadays this research is in its full progress [4 - 11]. The researches of man-made geomechanical processes in coal and gas-bearing rocks are being done and the ways of decreasing negative influence on mine safety are being developed [13 - 24]. The researches of gas-geomechanical process allowed us to develop a model of structuring the enclosing rock while developing the working area by longwall mining along the strike. The description of the model is published in papers [9 - 11].

2. Fundamental principles of an enclosing rock structuring model
To specify the size of the zones of a mass geostatic stress relief and dynamics of its development current knowledge about the massif disintegration while stope (working face) moving were applied. The laws of non-linear geomechanical were used for that [12]. The method of mine aero-gas-dynamics was taken as a basic method for the development of the model. The ground for it was formed on the basis of a widely-known rule that firedamp (methane) evolution in coal seams is possible only while softening the stresses, in other words outer contour of gas depletion zone for coal and gas-bearing rocks is a front of their man-made relief from natural stress.

The model is based on the rules of zonal mass disintegration ahead of a stope (radial stress relief) and on a hierarchy of non-linear block structures in a goaf (vertical stress relief). These processes develop undulatory. Geometric boundaries of this development are defined by the length of stopes (working faces), stratification depth of a working out seam and mechanical features of the massif. The rock mass is introduced as a combination of rock geomechanical layers in the area of mining activity. Their thickness is equal to arch-paraboloid heights that are forming in corresponding layers. General picture of the displacement in the rock is introduced by the system of nested undulations with the parameters divisible by a square root of two raised to the n-th power (n- level of structural hierarchy). In its turn, this undulation is a combination of imbed periodical functions which describes adequately the contour of upper half of arches displacements. That is why to make the algorithm presentation of geomechanical features more convenient sinusoidal functions are used.

3. Model application case study
Vivid confirmation of a rock pressure undulation while the stope moving is in experimental observations of the hydraulic pressure in powered support props during mining of a working area in “Aldardinskaya” coalmine in Kuzbass region (figure 1). Site features: the length of a stope is 220 m, stratification depth of a working seam – 520-650 m, extracting seam thickness – 4.5 m. with abandoning coal patches at the seam floor, moving velocity about 3 m. per sec, hard seam roof. Natural observations are made by two of the authors of the article together with the mine engineering staff. The quantitative evaluation of the results revealed the periodical change of the pressure divisible by the length of a stope (Figure 1).

Proving the adequacy of the concept about the development of geo-mechanical processes while underground mining was fulfilled in a complex environment – directly in a massif bottom-hole area, i.e. on the border transition from radial stress relief ahead of the face into vertical stress relief above the goaf (Figure 2). Assuming that the layer’s weight corresponds to the support response and average density of a roof rock is 2.5 ton per m$^3$, the values of the layers’ height that press on the bars of the powered support are taken as a pressure arch thickness.
Figure 1. $h$ height of a pressure arch on the sections of a powered support while mining a seam with a hard roof in “Aldarinskaya” coalmine.

Figure 2. Changing arch heights $h$ in bottom-hole area of a seam while moving of the stope in “Aldarinskaya” coalmine: a) along the length of the extraction panel $L$ at the interval 610–830 m; b) along the length of a stope (working face) $l$ at the distance of 548 m from installation chamber.
Calculating thickness of a pressure arch is introduced in figure 2 as a sine wave indicated by a dashed line with $T_n$ period corresponds to

$$T_n = l_0 \cdot 2^n, \text{ m},$$

(1)

where $l_0$ – base diameter of a minimal geo-environment element, m; $n$ – structural hierarchy level.

Pressure arch amplitude $A_n$ corresponds to

$$A_n = \frac{h_n - h_{n-1}}{2}, \text{ m},$$

(2)

where $h_n$ and $h_{n-1}$ are the thickness of $n$ and $n-1$ layers of geomechanical structurization of the underworking massif, respectively, m;

Arch-paraboloid parameters $l_0$ and $h_0$ in the closest to a working seam geomechanical layer are taken as the size of minimal geo-environment element:

$l_0$ – base diameter of a minimal arch is taken as the closest to the step of a secondary caving or calculated according to the formula

$$l_0 = \frac{l}{2^n} \approx \frac{n}{4} \approx r_2, \text{ m},$$

(3)

where $l$ – is the length of a stope (working face), m; $n$ – the level of structural hierarchy, is calculated according to the assumption that the relation $r_1$ to $r_2$ is about 4; $r_1$ and $r_2$ – are the steps of primary and secondary roof caving, respectively (they are calculated according to known formulas or elaborated according to geotechnological data), m; $h_0$ – minimal arch height (or the height of minimal geomechanical layer) is calculated according to a formula

$$h_0 = l_0 / 2, \text{ m}.$$  

(4)

Actual thickness of a pressure arch is indicated in figure 2 by dot-and-dash line and it is obtained according to the data of a pressure in hydro-cylinders of powered support props in the experimental area. Actual data were measured along the length of an extraction panel at the interval of 610-830 m from installation chamber (Fig. 2a). Figure 2b demonstrates the scheme of the shifting process along the stope $l$ at the distance of 548 m from the installation chamber.

Period and amplitude of a pressure arch thickness in a bottom-hole seam zone generally corresponds to the model of geo-mechanic process development in the enclosing rock [10]. Moreover, the sine curve amplitude that approximates actual values is always lower then the calculated one in about $\sqrt{2}$ times ($\sqrt{2}$ – a value of geo-environmental canonical parameter). The contrast of the period figures can be explained by roof rock anisotropy and neighboring of a working area with a goaf in an abandoned place.

4. Conclusions

Thus, the undulating character of geo-mechanic layers formation both along the length of the extracted panel (Figure 2a) and along the length of the stope (working face) (Figure 2b) is registered. The formation period for shifting arches of disintegrated massive in a goaf is divisible by the length of a stope. The following features are revealed:

- during radial stress relief ahead of a moving stope the period of forming zonal disintegration in a seam is close to divisibility by single square root of two;
during more intensive vertical stress relief the period for forming mass shifting arches in a goaf is divisible by two. The peculiarities of forming the radial stress relief are in correspondence with shifting processes in development headings when shifting covers only rock layers that are in immediate neighboring to a mine working. As for practical results it is necessary to note that while laying out of plan for a working area (block) the length of a stope \( l \) should be taken as divisible by \( h_02^{\alpha+1} \).

Following this condition helps:
- to soften negative influence of a ground pressure while geometrical measuring of a working area (block) and the position of holing chute (cроссcut);
- to specify the parameters of the main roof control such as defining the caving step;
- to measure bearing support zone made in the form of stable pillars contouring the working area (block) for sustainable process of arch-formation. As it is seen in figure 2b (shifting arches goes to negative zone along the X- axis) a part of relief arch bases is behind the belt entry and the airway;
- to provide effective ventilation and outgassing due to specifying the height of shifting arches and the areas of relieving enclosing massif which initiates gas flows from adjacent seams to the working areas (blocks).

In whole, specifying geomechanical processes in enclosing massif improves the evaluating adequacy of a massif disintegrating characteristics, forecasting precision of geomechanical parameters, basic methane release both while planning the mining and during the mining process.

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