Detection of regularities in variation in geomechanical behavior of rock mass during multi-roadway preparation and mining of an extraction panel

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Abstract. The results of numerical simulation of the stress–strain state in a rock block and surrounding mass under multi-roadway preparation to mining are presented. The numerical solutions obtained by the nonlinear modeling and using the constitutive relations of the theory of elasticity are compared. The regularities of the stress distribution in the vicinity of the pillars located in the zone of the abutment pressure of are found.

Geological and geotechnical conditions of coal occurrence, as well as coal mining methods have an effect on various events due to rock pressure. One of such influences is the process flowsheet of preparation and extraction of coal reserves in the limits of a bed or a bed series.

Currently a promising flowsheet is multi-roadway preparation of extraction panels as it allows better ventilation, haulage and evacuation of people in case of emergency. There are a number of multi-roadway preparation scenarios [1]. Considering the international experience of coal mining and with regard to coal ignitability, two or entries are driven in actual practice in mines in Kuzbass.

Aimed to find regularities in variation in geomechanical behavior of coal and rock mass during multi-roadway coal bed preparation, a two-dimensional model of coal and rock mass has been developed. The computational domain was constructed based on the data on an extraction panel in coal bed 26a having a thickness of 2.1 m and occurring at a depth of 363 m at Baiday deposit in Kuzbass. The coal bed is overlaid with a layer of unstable coaly siltstone (false roof) 0.40 m thick; this layer is caved simultaneously with coal. Accordingly, the extractable thickness in modeling was assumed as 2.50 m. the false roof is overlaid with alternating siltstone, sandstone and coal beds of unworkable thickness. The dirt beds have compression strength of 28–31 MPa and are 1.0–14.0 m thick. The longwall length is 200 m, the auxiliary and ventilation roadways are 6 m thick each. The fragment of the analytical model is shown in Figure 1.

The stress state of coal and rock mass was determined using classical equations of the continuum mechanics and the resulting equations of the finite element method within a variational problem.

In the framework of the developed nonlinear mathematical model, constitutive equations are selected to determine deformation conditions in the zones of displacements, and the internal boundary conditions are coordinated upon transition of rocks to elastoplastic, limiting and post-limiting states [2, 3]. The relations approximating the experimental stress–strain curves take into account different resilience of rocks under alternating stresses in the zones of compression and tension [4].

The natural gravity stress field is assumed to be given by [5]:

$$\sigma_y = \rho g H ;$$  \hspace{1cm} (1)
\sigma_x = \lambda/(\lambda + 2\mu) \rho g H, \hspace{1cm} (2)

where \(\sigma_x, \sigma_y\) — horizontal and vertical stresses in intact field of gravity; \(\rho\) — density of rocks; \(g\) — gravitation constant; \(H\) — depth of mining; \(\lambda, \mu\) — Lamé parameters.

**Figure 1.** Fragment of analytical model of extraction panel.

Numerical calculations used a developed package of problem-oriented programs with the built-in constitutive relations from the both mathematical models, which enabled comparing the results (Figs. 2–4, the negative and positive signs correspond to compressive and tensile stresses, respectively).

The distribution of vertical stresses resultant from the solution of the nonlinear problem and boundary value problem of elasticity is presented in Figure 2.

From the analysis of the stress distribution, it follows that the highest compressive stresses are observed at the edge of the coal bed in the section 300–303 m. The compressive stresses decrease in the roof rock of the roadways and increase above the pillars. Inclusion of the nonlinear dependence between the stresses and strains leads to the reduction in deformation characteristics of rocks surrounding mined-out area, roadways and pillars. The values of the compressive vertical stresses in the influence zones of mined-out area and the auxiliary and ventilation roadways are lower in the nonlinear problem than in the problem of elasticity.

**Figure 2.** Isolines of vertical stresses in surrounding rock mass around mined-out area.

Figure 3 shows the epures of vertical stresses in coal bed. The ratio of peak compressive stresses resultant from the elastic problem and nonlinear problem solved for the pillar between the conveyor
and auxiliary roadways is 1.2 and for the pillar between the auxiliary and ventilation roadways is 1.1. It is typical for the both solutions that the influence of the excavation weakens in the line of the conveyor roadway into the depth of coal bed and reaches the value of stress field induced by gravity in the intact rock mass at a distance of \( \approx 0.2H \) from the ventilation roadway.

The analysis of the epures of stresses yields that the excavation induces nonuniform stress distribution in the coal bed. The concentration factors of the compressive stresses caused by mining assume maximum values at the boundary of the pillar at the conveyor roadway and make up more than 3\( \rho gH \) in the solution of the boundary value elastic problem and more than 2.5\( \rho gH \) in the nonlinear problem solution.

![Figure 3. Epure of vertical stresses in coal bed: 1—mined-out area in excavation; 2—conveyor roadway; 3—auxiliary roadway; 4—ventilation roadway.](image)

In the elastic problem solving, the ratio of the maximum vertical stresses is 1.5 for the edge area of the pillar between the conveyor and auxiliary roadways and 1.2 for the pillar between the auxiliary and ventilation roadways. In the nonlinear problem, these ratios are 1.4 and 1.1, respectively.

The increase in the stress concentration above the pillar adjoining the conveyor roadway is conditioned by the intensive mining-induced effect as compared with the pillar between the auxiliary and ventilation roadway.

The obtained regularities point at the pillar between the conveyor and auxiliary roadways as at the raisor of potential energy. Since the values of the vertical displacements, calculated with regard for the nonlinear relation of stresses and strains above the excavation, exceed the vertical displacements resultant from the boundary value elastic problem solution, by 2.5 times, then at the boundary of the pillar adjoining the conveyor roadway, it is highly probable that the intensive mining impact will result in disintegration and fracturing of rock mass, which will end with the support failure in the conveyor roadway.

The graphs of distribution of the compressive vertical stresses above the roof of roadways and pillars in Figure 4 feature maximum values in the coal bed and gradual attenuation of secondary vertical stresses induced by excavation at a distance from it, which is confirmed by the decrease in the difference between the stresses of plots 1–4 and the intact rock mass stresses \( \rho gH \). The vertical stress in the roof after solution of the nonlinear problems are 10–15% less in value than the stresses calculated from the problem of elasticity (plots 1, 2 and 3, 4, respectively, in Figure 4).

In the stress relaxation zones above the roadways (plots 5–8, Figure 4), the vertical stresses are lower than in the intact rock mass. In the roof of the auxiliary roadway, the area of the stress relaxation zone is 2 times less than the same zone area in the roof of the ventilation roadway. The values of the vertical stresses above the roadways, calculated by solving the nonlinear problem, are lower than the vertical stresses obtained from the solution of the problem of elasticity (plots 5, 6 and 7, 8, respectively, in Figure 4). However, in the stress relaxation zone above the auxiliary roadway, directly at the roof, the nonlinear problem stresses exceed the elasticity problem stresses. The point of equality of the stresses lies in the roof at the distance making the half-width of the excavation (Figure 4).
Figure 4. Plots of distribution of vertical stresses in the roof of roadways and pillars: 1, 2—pillar adjoining conveyor roadway; 3, 4—pillar between auxiliary and ventilation roadways; 5, 6—auxiliary roadway; 7, 8—ventilation roadway.

The proposed approach to numerical modeling allows finding the regularities in variation in geomechanical behavior of coal and rock mass in case of multi-roadway preparation and extraction of coal, such as:
— in the pillar remote from the mined-out area, compressive vertical stresses are lower than in the pillar at the boundary of the excavation;
— stress razor is the pillar lying in the zone of abatement pressure of the excavation;
— stress distribution at a distance from the excavation behaves as G-field;
— the maximum difference between the stresses calculated by solving the nonlinear problem and the problem of elasticity is observed in the zones of the highest stress concentration;
— the area of stress relaxation zone in the roof of the roadways is larger in the results of the nonlinear problem solution than in the problem of elasticity.

These found regularities can help substantiating engineering solutions on preparation and mining of extraction panels at the ensured stability of roadways and coal pillars.

Acknowledgements
The studies have been supported by the Ministry of Education and Science of the Russian Federation in the framework of the Federal Targeted Program on R&D in Priority Areas of Advancement in the Science and Technology of Russia for 2014–2020, Topic: Efficient Robotic Longwall Top Coal Caving Technology, Unique Identifier RFMEF160417X0173.

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