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STRESS-STRAIN ANALYSIS IN COAL AND ROCK MASS UNDER TRADITIONAL MINING WITH FULL CAVING AND IN TECHNOLOGY WITH BACKFILLING

Underground mining of coal deposits has a significant impact on the host geology. Wednesday. In many respects, the zone of influence of underground developments on the geo-environment is determined by the technology of managing the roof of the coal seam. At the moment, on the absolute majority of coal mines, the technology of roof management is completely collapsed. However, the use of roof collapse technology leads to a significant change in the stress state of the coal-bearing massif. In this article, using the methods of mathematical modeling, an evaluation of the stress state of a coal-bearing massif was carried out using the technology of roof management complete collapse and laying of the worked out space.

The stress state comparison was realized by the finite element method, in accordance with the classical methods of the theory of elasticity used in geomechanics. The calculation model is a section along the minefield. The object of analysis is the area of interaction of the worked out space with an array of rocks by the subterranean underground mining of coal.

It was found out that for the spent cleaning lavas filled with collapsed rocks, in the geological environment of the unloading zone in the work-in and work-out massif, as well as the reference pressure zones falling on the parts of the pillars, is much larger than when laying the worked-out space.

Key words: *stress-strain state; SSS, modeling, roof management, roof caving, stowing*
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Introduction

Underground coal mining is distinctive of severe impact on all elements of environment, which is mostly conditioned by the traditional mining with full caving [1]. A governing factor is the size of the influence zone of mined-out void in enclosing rock mass. After generalization, the zones of full caving, stress relaxation, abutment pressure and surface subsidence are identified. By rough estimate, the sizes of these zones depending on the coal seam thickness (m) and mining depth (H) [2]: are:

- Caving zone is 3–6 m;
- Stress relaxation zone is 25–70 m;
- Abutment pressure zone adjoins the stress relaxation zone and is 0.1H–0.3H in the seam plane;
- Surface subsidence zone is beyond the stress relaxation zone, not always means ground surface deformation and is 40–125 m.

Apparently, the principal geological and geotechnical factors that affect geometry and initiation of the influence zones are the physical and mechanical properties of rocks, rock mass structure, mining depth, coal seam thickness, volume of mined-out void, applied system of mining, etc. [1, 2].

Using the mathematical modeling, the authors perform stress–strain analysis for the conditions of Boldyrev coal seam, Kirov Mines, in order to determine relative change in the influence zones under mining with full caving and in technology with backfilling.

Stress–strain modeling

2D stress–strain modeling was carried out using the finite element method in accordance with the principles set in [3, 4]. The geo-medium inside the model is assumed as isotropic–elastic. The stresses and strains are related by a generalized Hooke's law:

$$\sigma_{ij} = D_{ij}\,\varepsilon_{ij}, \qquad (1)$$

where σ_{ij} are the stress tensor components:

$$\sigma_{ij} = \begin{Bmatrix} \sigma_{xx} & \tau_{xy} \\ \tau_{xy} & \sigma_{yy} \end{Bmatrix}; \qquad (2)$$

ε_{ij} are the elastic strain tensor components:

$$\varepsilon_{ij} = \begin{Bmatrix} \varepsilon_{xx} & 0.5\varepsilon_{xy} \\ 0.5\varepsilon_{xy} & \varepsilon_{yy} \end{Bmatrix}; \qquad (3)$$

D is the matrix of elastic coefficient given for the isotropic material by:

$$\frac{E}{(1+\mu)(1-2\mu)} = \\ = \begin{Bmatrix} (1-\mu) & 0 & 0 & 0 & 0 & 0 \\ 0 & (1-\mu) & 0 & 0 & 0 & 0 \\ 0 & 0 & (1-\mu) & 0 & 0 & 0 \\ 0 & 0 & 0 & (1-2\mu)/2 & 0 & 0 \\ 0 & 0 & 0 & 0 & (1-2\mu)/2 & 0 \\ 0 & 0 & 0 & 0 & 0 & (1-2\mu)/2 \end{Bmatrix} \qquad (4)$$

μ — Poisson's ratio; *E* — Young's modulus, Pa.

The lateral stress is assumed in accordance with Dinnik as:

$$\sigma_{yy} = \sigma_{xx} \cdot \frac{\mu}{1-\mu}. \qquad (5)$$

The gravity stress is governed by the overlying rock weight:

$$\sigma_{yy} = \rho g H, \qquad (6)$$

where ρ — the density of rocks, kg/m^3; *g* is the gravitational acceleration, m/s^2; *H* is the depth below ground surface, m.

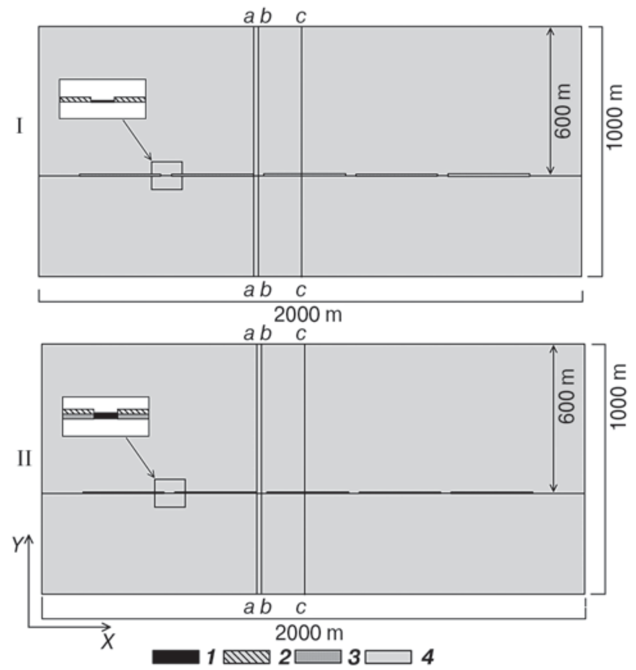

Fig. 1. Analytical model for estimation of stresses and strains during longwalling:
I — technology with full caving; II — technology with backfilling; *1* — coal seam; *2* — caved rocks; *3* — backfill; *4* — enclosing rock mass; sections a–a, b–b and c–c are profiles for the stress and strain estimation

The stress intensity is calculated from the formula:

$$\sigma_i = \left(\sigma_{xx}^2 + \sigma_{yy}^2 - \sigma_{xx} \cdot \sigma_{yy} + 3\tau_{xy}^2\right)^{1/2}. \quad (7)$$

The physical and mechanical properties of the model are described in **Table 1**.

The analytical model shows a section of mine field across the mined-out void (**Fig. 1**) for the analysis of stresses and strains in rock mass under technology with full caving and in technology with backfilling. The section is 2000 m long, the depth beneath ground surface is 1000 m, and the coal seam occurrence depth is 600 m. A longwall has a length of 300 m, the pillar between longwalls is 40 m. The coal seam is 2 m thick. Inasmuch as it is impossible to simulate the process of rock failure in the framework of an elastic model, it is assumed that the thickness of caving zone above the coal seam is 4 m = 4×2 = 8 m and the rock mass in this zone is represented by a fractured material with the reduced physical and mechanical characteristics. In the model with backfilling, the mined-out void is filled with cemented paste materials with the contraction factor 0.8 while the zone 0.4×4 = 1.6 m is also represented by a fractured material with the reduced physical and mechanical characteristics. For the backfill, the physical and mechanical characteristics were assumed as per Construction Norms and Regulations SNIP 2.03.01–84: Concrete and reinforced concrete structures [7]; concrete was grade V25. All physical and mechanical characteristics involved in the model are compiled in Table 1.

Table 1. Physical and mechanical properties of the model according to [5, 6]

Parameter	Dimension	Value
Young's modulus of caved geo-material	Pa	$8 \cdot 10^7$
Young's modulus of backfill	Pa	$3 \cdot 10^{10}$
Young's modulus of enclosing rock mass	Pa	$8 \cdot 10^9$
Young's modulus of coal	Pa	$5\ 10^9$
Poisson's ratio of caved geo-material	—	0.18
Poisson's ratio of backfill	—	0.2
Poisson's ratio of enclosing rock mass	—	0.25
Poisson's ratio of coal	—	0.15
Averaged density of caved geo-material	kg/m^3	2400
Averaged density of backfill	kg/m^3	2300
Averaged density of enclosing rock mass	kg/m^3	2500
Averaged density of coal	kg/m^3	1280

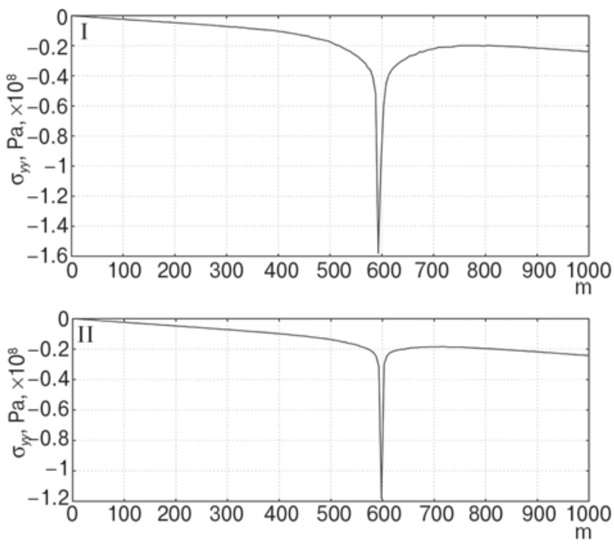

Fig. 2. Curves of vertical stresses σ_{yy} (Pa) and mining depth in section a–a:
I — technology with full caving; II — technology with backfilling

The object of the analysis is the domain of interaction between the mined-out void (later on filled with caved rocks or backfill) and adjacent undermined rock mass. The subject of the analysis are the stress tensor components (σ_{xx}, σ_{yy}) in the domain specified.

Conclusion

Fig. 2 and **Fig. 3** present the curves of the vertical stresses σ_{yy} and model depth. In section a–a (see Fig. 2) drawn along the boundary of the coal pillar and mined-out void and being the highest abutment pressure zone, higher stress concentration areas are observed. In plot I, the influence zone interval (to 200 m) is larger than in plot II (to 100 m). Alongside with the larger influence zone, the technology with full caving induces higher magnitude stresses.

In section b–b (see Fig. 3) drawn in the center of the coal pillar, it is seen that the vertical stress grows closer to the pillar. This is connected with the re-distribution of stresses due to formation of a rock cavity and subsequent weakening of rocks so that the pillars take a part of the re-distributed load. Furthermore, as before, the technology with full caving results in higher magnitude stresses to 15–20 MPa at nearly the same influence zone (round 300 m).

In section c–c (see **Fig. 4**) drawn in the center of the mined-out longwall, it is seen that a weakening zone appears due formation of a rock cavity under roof caving. In application

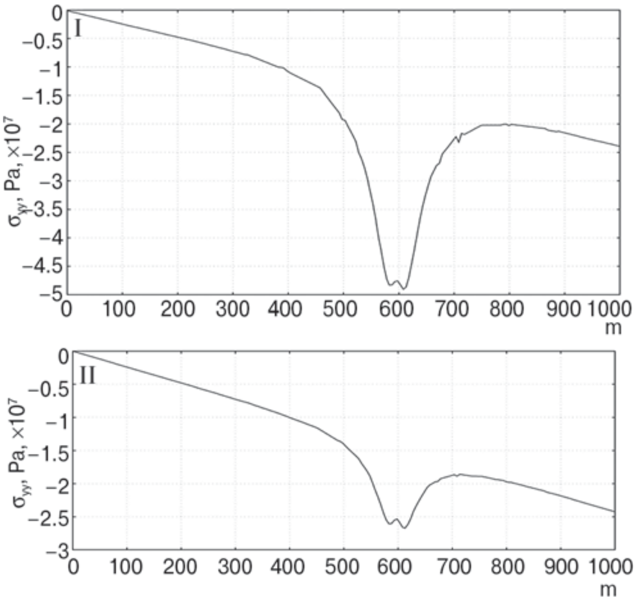

Fig. 3. Curves of vertical stresses σ_{yy} (Pa) and mining depth in section b–b:
I — technology with full caving; II — technology with backfilling

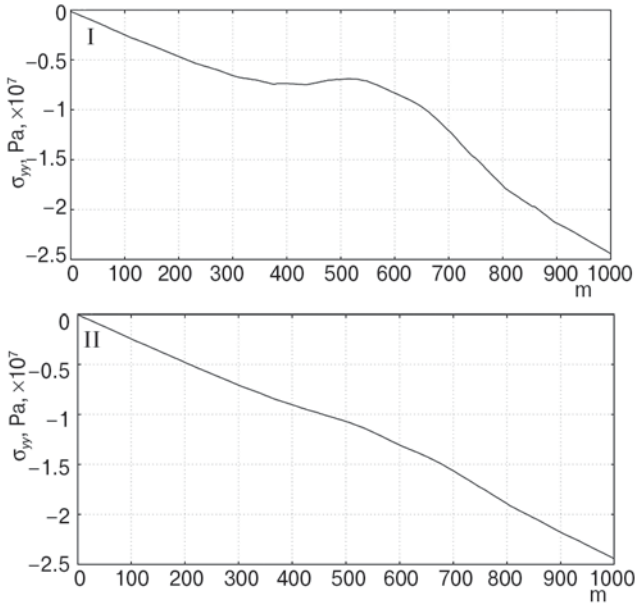

Fig. 4. Curves of vertical stresses σ_{yy} (Pa) and mining depth in section c–c:
I — technology with full caving; II — technology with backfilling

of the technology with backfilling, no considerable re-distribution of stresses is observed in enclosing rock mass and the reduced stresses differ from the background trend stresses by 0.2–0.3 MPa. In case of the modeled technology with full caving, the stress relaxation zone is clearly observable in the depth range of 250–300 m and stresses differ from the background trend by 2–3 MPa.

The general behavior of stresses is connected with the increased rock pressure zones in undermined and overmined rock mass. When mined-out longwalls are filled either with caved rocks or backfill, characteristic stress relaxation zones appear in undermined and overmined rock mass, and zones of abutment pressure arise in the pillar parts adjoining longwalls. The change in the stress state of a geo-medium can induce violation of hydrological regime, increase gas emission from enclosing rocks mass and gas-dynamic events [6–13]. It can be concluded that the choice of the ground control technique as the geotechnical control of a nature-and-technology system governs the ecological efficiency and safety of coal mining.

It follows from the modeling data that application of the technology with backfilling creates conditions for the minimization of impact on coal and rock mass by way of diminishing influence zones of mining, which entails reduction in gas emission, water inflow and dirt volume to be lifted to ground surface.

References

1. Pytel W., Świtoń J., Wójcik A. The effect of mining face's direction on the observed seismic activity. *International Journal of Coal Science & Technology*. 2016. Vol. 3. No. 3. pp. 322–329. DOI: 10.1007/s40789-016-0122-5.
2. Cheng Y., Jiang H., Zhang X., Cui J., Song C., Li X. Effects of coal rank on physicochemical properties of coal and on methane adsorption. *International Journal of Coal Science & Technology*. 2017. Vol. 4. No. 2. pp. 129–146. DOI: 10.1007/s40789-017-0161-6.
3. Baklashov I. V. Geomechanics. Higher Education Textbook. Fundamentals of Geomechanics. Moscow : MGGU. 2005. 208 p.
4. Landau L. D., Lifshits E. M. Theoretical Physics. Theory of Elasticity. 4th ed. Moscow : Nauka. 1987. 248 p.
5. Zhang P., Yang T., Yu O., Xu T., Shi W., Li S., Study of a seepage channel formation using the combination of microseismic monitoring technique and numerical method in Zhangmatun Iron Mine. *Rock Mechanics and Rock Engineering*. 2016. Vol. 49, No. 9. pp. 3699–3708.
6. Construction Norms and Regulations SNiP 2.03.01-84: Concrete and Reinforced Concrete Structures.
7. Conte E., Troncone A., Vena M., A method for the design of embedded cantilever retaining walls under static and seismic loading. *Géotechnique*. 2017. Vol. 67, No. 12. pp. 1081–1089.
8. Kurlenya M. V., Serdyukov S. V., Shilova T. V., Patutin A. V. Procedure and equipment for sealing coal bed methane drainage holes by barrier shielding. *Journal of Mining Science*. 2014. Vol. 50, No. 5. pp. 994–1000.
9. Azarov A. V., Kurlenya M. V., Patutin A. V., Serdyukov S. V. Mathematical modeling of stress state of surrounding rocks around the well subjected to shearing and normal load in hydraulic fracturing zone. *Journal of Mining Science*. 2015. Vol. 51, No. 6. pp. 1063–1069.
10. Kolikov K. S., Nikitin S. G., Manevich A. I. Analytical evaluation of methane emission prediction in accord with the regulatory documents. *Bezopasnost truda v promyshlennosti.* 2016. No. 8 pp. 34–39.
11. Tatarinov V. N., Morozov V. N., Kagan A. I. Modeling stress and filtration of groundwater by selecting sites for underground disposal of radioactive waste. *Gornyy informatsionno-analiticheskii byulleten.* 2014. No. 6. pp. 243–249.
12. Morozov V. N., Kolesnikov I. Yu., Tatarinov V. N. Modeling the hazard levels of stress-strain state in structural blocks in Nizhnekanskii granitoid massif for selecting nuclear waste disposal sites. *Water Resources*. 2012. Vol. 39, No. 7. pp. 756–769. DOI:10.1134/S009780781207007X.
13. Aimbetov M. M., Ananin A. I., Chirkov V. N., Otarbaev O. M. Design choices and production decisions in mining with backfilling at Pervomaiskoe deposit. *Gornyy Zhurnal*. 2018. No. 5. pp. 27–33. DOI: 10.17580/gzh.2018.05.03.