Study of regularities of changes in stress-strain state of coal–rock mass in fractured zones

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Abstract. The regularities of changes in the stress-strain state of coal in rock mass depending on the main mining geological and engineering factors are identified. Using these factors, it is possible to find the optimal support parameters in specific conditions to increase the stability of preparatory mine workings. The degree of influence of mining and engineering conditions of exploitation on displacements in marginal rocks with various types of support in excavation workings is investigated.

1. Introduction
The non-pillar mining technology (aka “advance and relieve mining”), which is currently gaining traction, requires searching for adequate protection of the preparatory, or advance, workings (drifts), primarily those adjacent to the excavation workings. The critical technological factors are determined by the mining depth, direction and advancement of the advance workings faces, driving and maintenance method, as well as by types and scheme of rock support or lining systems.

Effectiveness of the application of a support system in the preparatory workings depends on the strength of the surrounding rocks, extent of the hazardous deformation zones around them, the amount of displacement of roof and sidewall rocks during its operational life.

Success of any system supporting the workings is influenced by geomechanical and technological (direct) factors, as well as indirect factors—those stemming from the mining operation impacts on the geomechanical state of the rock mass. The geomechanical factors include primarily inherent parameters of the rock mass: strength, volume weight, jointing, depth, dipping angle, etc.; the technological factors are: configuration and cross-section of the mine opening, lining parameters (compliance and load-bearing capacity). The indirect factors are represented by the abutment pressure around the working face and the mining-induced fractures within surrounding rock mass and coal seams.

2. Features of numerical modeling and the results
Analysis of the stress-strain state characteristics of the rock mass near the workings was largely based on the numerical simulation using the finite element method and the ANSYS software [1]. A typical rectangular mine opening sized 3.5 m (height) x 5.0 m (width), which formed during driving operations through a coal seam at a depth of 650 m and was used as initial opening for the geomechanical model. The overburden is composed of siltstones overlain by sandstones whose thicknesses are 6 m and 10 m, and uniaxial compressive strengths (UCS) are 32 MPa and 60 MPa,
respectively. The mudstones representing the footwall rocks are 6.5 m in thickness, their UCS is 24 MPa. These are underlain by a 15 m thick horizon of siltstones.

Analysis of the distributions of conventional zones of nonelastic deformations of rock mass, or “inelastic regions” (i.e. regions surrounding the workings in which rocks under growing stresses at some point fail to deform in a purely elastic way) showed that the largest deformations are observed in the floor rocks at a depth of 4 m, while in the sidewalls deformations tend to expand into the rock mass to a depth of 2 m. In the roof, the rock failure process develops as far as the layer of siltstones which is interpreted as almost completely free of non-elastic deformations, except its lower part which is only partly (0.3 m of its thickness) involved in such process developments. The roof stability of the opening and its safety are secured with one bolt (2.4 m in length) installed in each of the side walls.

Non-encapsulated natural faults are usually filled up with methane ascending from deep sources. At this, the non-hydrostatic pressure develops in the rock mass, and the lateral earth pressure coefficient will be $\lambda < 1$. The marginal rock mass is characterized by non-uniform loading, which results in the formation of zones experiencing compressive and tensile stresses leading thereby to rock deformations and micro-and macro-fracturing.

The presence of gas pressure in the natural fault zones coupled with a $5^\circ$ deviation (from vertical) of the line of action of the principal stresses will significantly affect the development of conventional zones of nonelastic deformations (“inelastic regions”) near the mine workings at $\lambda = 0.7$. Extending perpendicular to the natural fault both in the roof (by 6 m) and in the floor (by 7 m), the distribution pattern of “inelastic regions” thereby loses its symmetry (Figure 1a) [2–8]. As a result of up to 45° increase in the inclination angle of the line of principal stresses, the zone of rock failures eventually decreases (Figure 1b). At this, the extent of “inelastic regions” measures 5.3 m in the roof and up to 7.1 m in the floor. Remarkably, such region is 0.5 m larger in the left-sided part of the drift, than in the right-sided one and measures 4.2 m.

Figure 1 demonstrates that within the natural fault area at $\lambda \neq 1$ the deformations in the sidewalls are not symmetrical, with their maximum localized to form the zone of deformations on the side opposite to the orientation of the fault, where the presence of gas pressure is found to have little effect on this zone distribution in the vicinity of the mining area. When approaching to the natural fault, which is free from gas pressure at $\lambda = 0.7$, “inelastic regions” develop more intensely in the sidewalls than in the roof.

**Figure 1.** Conventional zone of nonelastic deformations (“inelastic region”) at $\lambda = 0.7$ and with different inclination angle of the line of action of principal stresses, deg: (a) 5; (b) 45.

Results of the investigations have shown that impact from the presence of gas pressure on the formation of “inelastic regions” near the mine workings within a natural fault is significant. Such factors as gas pressure existing at $\lambda = 0.7$ and decreasing distance between the natural fault and the investigated drifts largely contribute to distortion of the picture of the distribution of “inelastic
regions”, which become elongated vertically, and their extent reaches 6 m in the roof, and 7 m in the floor, albeit slightly decreases in the sidewalls.

Results of the numerical modeling to determine the dependence of the “inelastic regions” extent $h$ on the mining depth $H$ which varied from 300 to 1000 m showed that it obeys the logarithmic law [4] (Figure 2):

$$h = a \ln(H) - b,$$

where $a$, $b$ are empirical coefficients that take into account the rock mass strength, the opening dimensions, and other parameters controlling the cavity stability (for the discussed example: $a = 2.9$, $b = 16.1$).

Figure 2. Dependence of the extent of a conventional zone of nonelastic deformations (“inelastic region”) on the mining depth.

The development of “inelastic regions” near the workings is largely influenced by the strength of rocks and degree of their jointing. Stability of the rock mass surrounding the workings along the drift depends on the size of these zones, strength $f$ of rocks and obeys the exponential law [9–10]:

$$h = ae^{bf}.$$

The calculation results have shown that the variations in the extent of a conventional “inelastic region” caused by the strength characteristics of rocks with increasing mining depth are characterized by nonlinear behavior (Figure 3).

Figure 3. Dependence parameters of the “inelastic regions” advancement deeper into the rock mass.

3. Conclusions
The variations in the stress-strain state of rock masses (displacements, stresses, jointing zones) arising from major mining geological and technical factors have been established. These allow defining optimal parameters for supporting systems of the preparatory workings (drifts) during the mining operations, as well as developing novel and improving the existing technologies for effective and safe reinforcement of the marginal rock masses.

The extent of the influence of mining-geological and technical conditions on the displacement of roof rocks during installation of the support systems is investigated. Utilization of the revealed
relationships between the extent of conventional zones of nonelastic deformation (“inelastic regions”) and mining depth enables detection of the manifestations of anomalously high rock pressure in the workings caused by deformations of the rock mass.

References

[1] Nurguzhin MR., Katsaga TYa and Danenova GT 2000 Laboratory Workshop on Modeling Design Objects at the Macro and Micro Levels: Tutorial Karaganda: KarGTU (in Russian)

[2] Timoshenko SP and Goodier J 1970 Theory of Elasticity McGraw Hill

[3] Sinkevich NI 2008 Patterns of changes in the parameters of stress-strain state of rocks in the zones of faults at different depths of development Bezop. Truda v Prom. No 11 pp 39–41

[4] Demin VF, Baimuldin MK and Baimuldin MM 2013 Assessment of Stability of Contour on Mine Opening wirt a Booundary Integral Equation Method Barcelona: Akademy of Science Engineering and Technology Issue 74 pp 717–720

[5] Reuter M, Krach M, Kissling U and Veksler Ju 2017 Geomechanical state of production faces in Polysaevskaya Coal Mine in Kuzbass Journal of Mining Science Vol 53 No 1 pp 43–48

[6] Prikhodko VV and Ulanova NP  2018 Modeling of stress-strain state of fractured rock mass nearby of conjugated workings Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu No 1 pp 5–11

[7] Demin VF, Nemova NA, Demina TV and Zeytinova ShB  2016 Control over geomechanical processes intended to improve a coal-and-rock massif stability Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu No 2 pp 5–10

[8] Vereshchagin VS 2012 To the assessment of the stability of the rock mass in the vicinity of an extensive mine work, fixed by anchors Mining Informational and Analytical Bulletin No 10 pp 352–354 (in Russian)

[9] Pham Van Thuong 2012 Studies determining the size of the zone of inelastic deformation around the mine workings Mining Informational and Analytical Bulletin No 10 pp 409–412 (in Russian)

[10] Bulich YuYu and Golovko SA 2005 Determination of the size of the zone of inelastic deformations near workings with the free destruction of rocks Geotekh. Mekh. No 59 pp 68–73