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Stress–strain state of adjacent rock mass under slice mining of steeply dipping ore bodies

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Abstract. Under analysis is the stress state of rock mass surrounding stopes in the initial cutting layer displaced in plan relative to the above-lying extracted layer in the overcut rock mass. The authors determine the boundaries of the post-limiting deformation zones during stoping advance using the Mohr–Coulomb criterion. The sequence of stoping to ensure better support conditions is proposed.

Internatsionalnaya kimberlite pipe in the form of a subvertical ore body with an oval cross section is developed by ALROSA Company using the underground method of descending horizontal slicing with the layers 4–5 m high. The room-and-pillar system involves stopes 5–6 m wide with cemented backfilling [1]. Aimed to ensure the mine design productivity, the ore body is divided by cut layers into working sub-levels with a height of 30–45 m.

The geomechanics of the cut layers where stability of stopes is difficult to ensure though it is of crucial importance is analyzed in [1] in terms of a vertical ore body. Numerical modeling of stress state of rocks in combination with the in situ monitoring of deformation processes in surrounding rock mass around underground excavations made it possible to substantiate the cut layer flow chart from the center sideways with the separation of the layer into two or three panels.

The problems on stresses in rocks during cutting and backfilling were solved using the method of boundary integral equations [2, 3]. The initial parameters on natural stresses were assumed in accordance with the field data for Internatsionalny Mine: $\sigma_z^\infty = -\gamma H$, $\sigma_x^\infty = \sigma_y^\infty = -\lambda\gamma H$ at $\lambda = 0.7$, where σ_z^∞—vertical stress, $\sigma_x^\infty, \sigma_y^\infty$—horizontal stresses; λ—coefficient of lateral earth pressure; γ—bulk weight of rocks; H—mining depth. The calculated data interpretation involved the components of stress tensor and shear stresses σ_s which allowed using the Mohr–Coulomb criterion for the analysis [4]:

$$\sigma_s = \frac{\sigma_1 - \sigma_3}{2\cos\varphi} + \frac{\sigma_1 + \sigma_3}{2}\tan\varphi ,$$

where $\sigma_1 > \sigma_2 > \sigma_3$—principal stresses; φ—angle of internal friction.

By the visual observations and from the numerical calculation results, it was found that failure took places in adjacent rock mass in the zones where $\sigma_s > 4$ MPa [2, 5, 6]. For this reason, $\sigma_s^C = 4$ MPa was assumed as the critical value.

As mining goes to deeper levels, the morphology of the ore body changes: its inclination, shape of the cross section. Figure 1 depicts the analytical data on the geomechanical behavior of rock mass in a cut layer at a depth of 1211 m below surface (actual -811 m) where the north–south displacement relative to the previous cut layer reached 18–20 m (Figure 1a), which considerably changed stress redistribution in the pillar between the layers. Given there are no displacement of the layers in plan view, the zones of the increased stresses σ_s form in the roof in the most stopes in the center of the cut layer, while in the displaced layer the increases stresses are generated in the roof of the stopes in the southern part of the layer (Figure 1).

(a) (b)

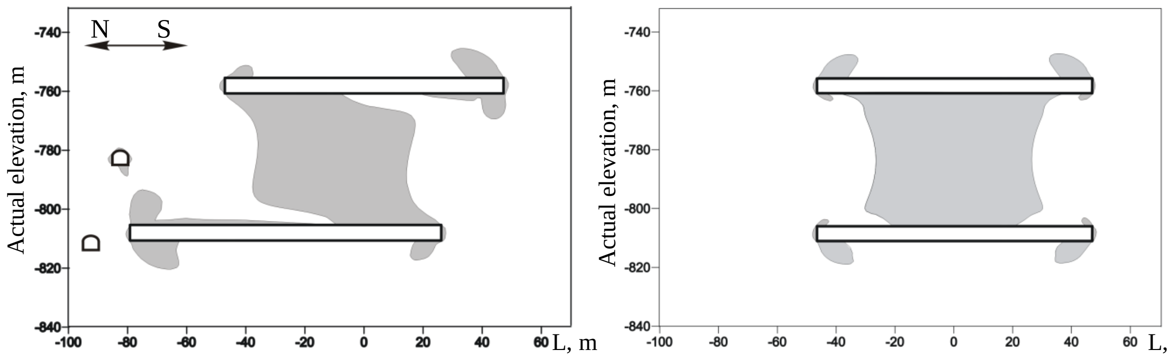

Figure 1. Distribution of σ_s (MPa) in the cut layer (elevation view): (a) actual; (b) it is assumed that the bottom layer is not displaced relative to the earlier cut top layer.

(a) (b)

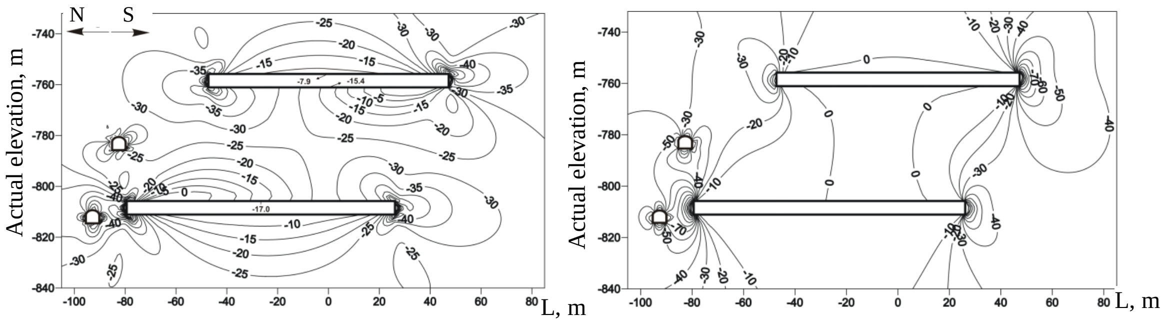

Figure 2. Distribution of horizontal (a) and vertical (b) stresses (MPa) after completion of works in the cut layer (elevation view).

Stress state in the pillar between the cut layers is characterized by concentration of horizontal stresses in the roof in the south of the cut layer and by stress relaxation in the north part; regarding the earlier cut layer, stress concentration is observed in the bottom in the north and stress relaxation takes place in the bottom in the south (Figure 2a). At the same time, the pillar is free from vertical stresses except for the ends of the layers (Figure 2b).

The analysis of the scenario of separating a cut layer into three panels similarly to [1] nearby the earlier cut and backfilled stopes (Figure 3) shows that:

—extraction of a panel in the north part (wedge-out) of the ore body will be carried out under relatively comfortable conditions in case that the first stope is cut in the near-contact zone and further mining is conducted in the directions from the center towards the extracted and backfilled chamber;

–it is indifferent whether stoping in the south part of the panel is carried out back-to-back the backfilled stopes or not: anyhow, zones of the increased stresses σ_s forms in the roof, which requires obligatory roof support;

—advance of stoping in the central panel in the line of the ore body wedge-out part induces the zone the increased stresses σ_s in the pillar in the mined-out and backfilled section of the layer, and this

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zone merges with the earlier formed zone in the bottom of the above-lying layer. In the roof of the next stopes σ_s are under the critical value.

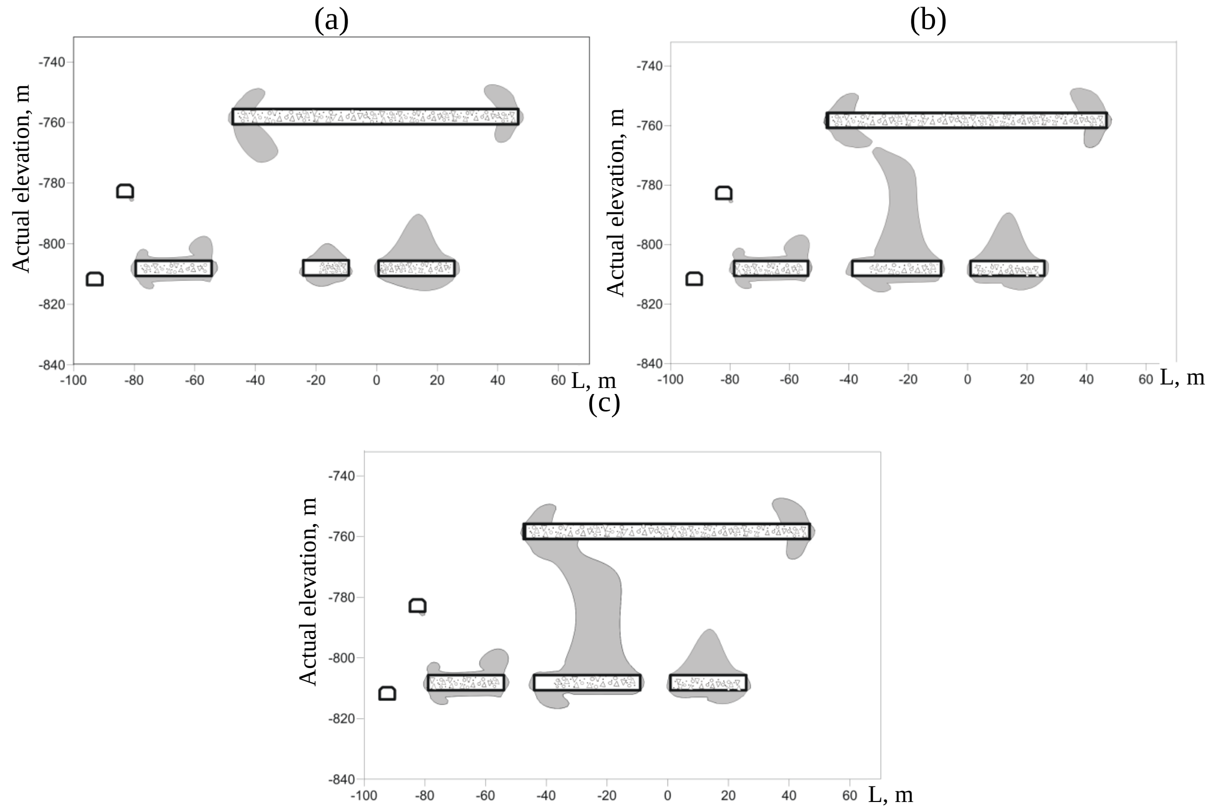

Figure 3. Inelastic strain zones during subdivision of the cut layer into three extraction panels. The end panels are mined-out, stoping in the central panel is advanced in the direction of the wedge-out part of the layer: (a)–(c)—stages of work in the central panel.

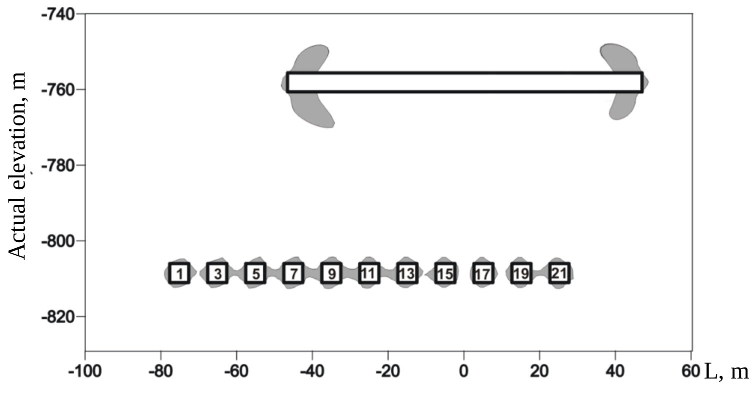

Figure 4. Post-limit deformation zones in the course of cutting the layer by stopes arranged next but one.

When the cut layer is developed by stopes arranged next but one (Figure 4), the most unfavorable conditions are in the center of the layer (5–15): σ_s higher than the critical value form in the pillars between the stopes and in their roofs at a distance to 2 m.

Conclusion

Features of stress distribution are determined in the surrounding rock mass of stopes in the cut layer made in the overmined rock mass under change in the ore body morphology. Using the Mohr–

Coulomb criterion, the authors have assessed the post-limiting deformation zones in ore body at different stages of mining operations.

When stopes in the cut layer are made back-to-back in separating the layer into three panels, it is recommended to start stoping from the ore and rock contact toward the center in the overmined (south) part of the layer and from the center toward the wedge-out end (north) in the center of the ore body.

In the two-stage stoping, for the purpose of better stability of stopes and to reduce cost of support, it is recommended to mine out ore-and-rock interface zones using the first stage stoping. Furthermore, the first stage stopes in the center of the ore body need supporting.

References

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