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Features of stress state of support under varying displacement of free contour of underground excavation

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Abstract. The scope of the discussion covers the issues of stress state assessment in support and rock mass surrounding an underground mined-out void, considering partial relaxation of rocks from initial stresses prior to contact interaction between the underground excavation contour and the support elements. The dedicated methods and algorithms are used to determine stress field distribution in elements of support in an arched underground excavation under varying pre-contact displacements of the excavation contour.

Stability assessment in mining with reinforcement and support includes estimation of stresses both in surrounding rock mass and in support units [1]. These issues are sufficiently studied, with formulation of boundary value problems on mechanical condition of rocks and support, and with analytical calculations and numerical procedures meant to determine behavior and features of stresses in rocks and support under varied loading conditions [1–5]. On the other hand, some assumptions on rocks–support system deformation not to the full describe conditions in a real mine and need refinement in view of increasingly complicating ground conditions in deeper level mining [5].

It is important that a rock–support interaction model correctly describes mechanics of this contact interaction [1–5]. One of the common formulations of the problem on stress state of surrounding rock mass and support units considers deformation of discontinuous rock mass at rigid contact with support when the back surface of the support is subjected to the action of forces equivalent to in situ stresses. Mechanically, such formulation means that support is installed “instantaneously” and no elastic unloading of rock mass and in situ stress relief takes place [6, 7]. Technically, “instantaneous” installation of mine support immediately after drivage is infeasible. There is always a time gap between drivage and support installation, and surrounding rock mass undergoes displacement and unloading of in situ stresses during this time.

Depending on support installation technology, destressing of surrounding rocks can be partial or complete. Under partial unloading, exposed surface displaces a little inwards the mined-out void and surrounding rocks undergo unloading of elastic stresses. After support installation, stress relief continues in rocks, but in this case, both surrounding rocks and support units are subjected to deformation. Apparently, if surrounding rocks less displace inwards an underground excavation, support units will be subjected to lower loading later on. Applied problems use simpler formulations, as a rule. First, a problem on deformation of surrounding rock mass and unsupported excavation is solved. Then, support with its back surface subjected to the action of normal compressive stresses is considered. Solutions of the two problems with an additional condition of equal displacement of the back surface of the support and the exposed surface of surrounding rock mass are assumed a final solution [2, 3]. It is difficult to assess the degree of approximation due to consideration of unrelated deformation of surrounding rocks and support units.

Some formulations, accounting for support installation after partial relief of in situ stresses in surrounding rocks, determine displacement of back surface of support using relations: $u–u_0 = u_p$; $v–v_0 = v_p$, where u, v—projections of displacement vectors of unsupported exposure in the Ox and Oy axes (in 2D problem); u_0, v_0—projections of displacement vectors of exposed surface before support installation; u_p, v_p—displacements of back surface of support after installation [8]. In such formulation, displacement of surrounding rocks in combination with deformation of support has the same values as in case of an unsupported excavation. In other words, support has no influence on total displacement of surrounding rocks. In order to assess the effect of such approximation on the results of stress calculation in surrounding rocks and support units, it is required to formulate problems that account for rock–support contact interaction.

The Institute of Mining, SB RAS, offers developed methods and algorithms to model stress distribution in rocks and support, considering sequence of mining operations [9, 10]. The algorithms use initial stress and initial strain methods with a stiffness matrix that is unchanged in solving nonlinear problems of deformable solid mechanics [11, 12]. Thereupon, a method to calculate stresses and strains in support units and surrounding rock mass with regard to free displacement of rocks until the contact with back surface of support has been proposed and approved. Modeling the process of formation of an underground excavation using the initial stress method and equaling all stress components in finite elements representing the mined-out void zero enables splitting the problem into two sub-problems. The first sub-problem determines mechanical condition of rocks in the course of free deformation and displacement inwards the excavation; the problem is assumed solved when displacements reach a certain value governed by the support installation technology. The second sub-problem describes joint deformation of surrounding rocks and support using the initial stress method, as well.

The applicability of the method to calculation of stresses and strains in surrounding rocks and support with regard to support installation conditions was illustrated in [9, 10], with the assessment of stress behavior in surrounding rocks depending on the value of free displacement of exposed surface inwards a mine excavation until the contact with the support, and with the discussion of the method application when rocks and support posses essentially different physical properties.

This article presents the results of using the mentioned algorithms to estimate stresses in arch support in case of different free displacements of surrounding rocks until the contact with the support. Figure 1 shows the configuration of underground excavation and support. The calculations are performed for plane strain conditions. At the vertical boundaries of the computational domain, the horizontal displacement vector component u and the shear stress tensor component τ_{xy} are set zero. Such boundary conditions conform with the in situ stress state of rock mass with the stress tensor composed of $\sigma_y^0 = -\wp H;\ \sigma_x^0 = -\nu\wp H/(1-\nu);\ \tau_{xy}^0 = 0$ and are observed in the regions where there is no tectonics [11]. Here, $\sigma_x^0,\ \sigma_y^0,\ \tau_{xy}^0$—normal and shear components of the stress tensor; $\wp$—bulk density of rocks; ν—Poisson's ratio of rocks; H—depth below the ground surface. The Ox axis is oriented horizontally and Oy—vertically. The upper boundary of the computational domain is free from external load. At the lower boundary, the vertical displacement vector component v and the shear stress tensor component τ_{xy} are assumed zero. The physical properties of rock mass are: $E = 50000$ MPa; $\nu = 0.25$. For support, it is assumed that $E = 150000$ MPa; $\nu = 0.25$. The bulk density of rocks and support is 0.03 MN/m^3.

Figure 1 shows the isolines of the principal stresses σ_1 and σ_2 in support and in a small area of rock mass surrounding an arch excavation in the case when rocks are not unloaded from in situ stresses before support installation. Compression concentration zones of σ_2 are observed in support at the sidewall bottom, starting from the contact with the excavation floor. The highest compressive stresses are observed on the back surface of the support. In the arch of the excavation, σ_2 are lower. The stresses σ_1 are not higher than –5 MPa in modulus in the support and are lower than –30 MPa in the concentration zones (in modulus). In the arch of the excavation, small areas of tensile stresses not higher than 1 MPa appear in the support. This stress pattern is in the whole in conformity with the known mechanical behavior of support installed in arch excavations [2, 3].

(a) (b)

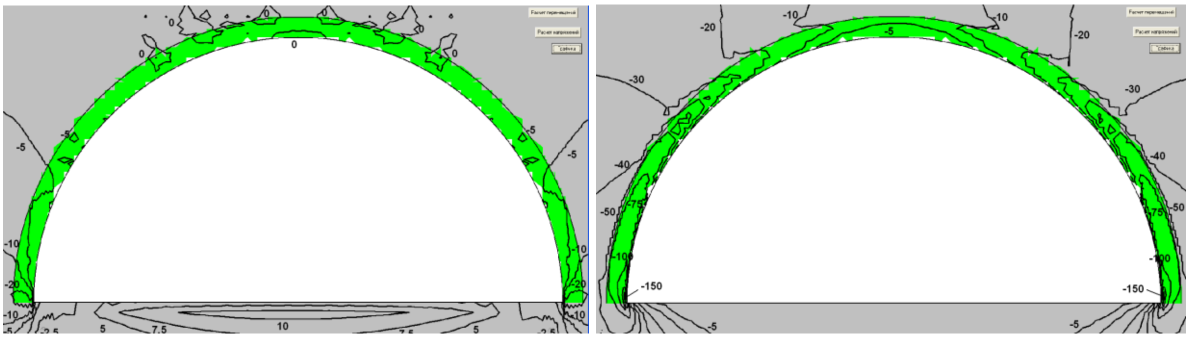

Figure 1. Principal stresses (a) σ_1 and (b) σ_2 (MPa) in support in case of its "instantaneous" installation.

Qualitatively, the stress pattern in the support in case of the partial unloading of rocks during free displacement inwards the mined-out void until the contact with the support remains the same (see Figure 2). Displacement of surrounding rocks in this case is half the displacement of surrounding rocks without support. The concentration zones of the compressive stresses σ_1 and σ_2 diminish as the compression reduces. The concentration zone of σ_2 shifts to the back surface of the support and the stresses here are not higher than 100 MPa (in modulus). Almost entire support is unloaded from the compressive stresses σ_1 not higher than –5 MPa (in modulus).

(a) (b)

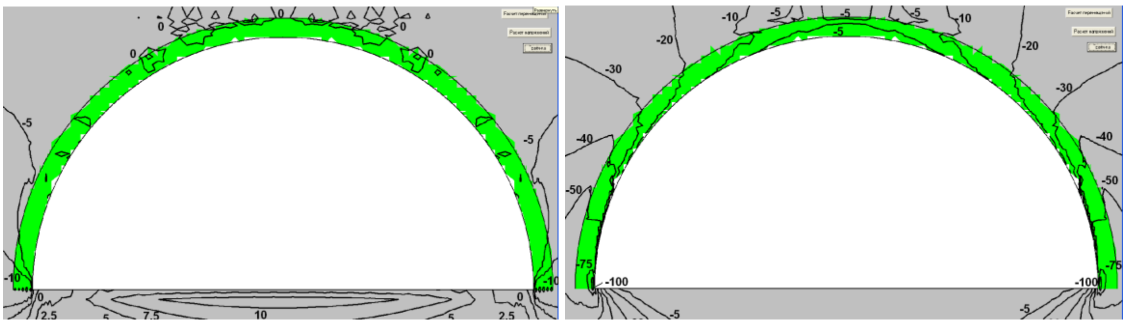

Figure 2. Principal stresses (a) σ_1 and (b) σ_2 (MPa) in support in case of surrounding rock displacement making the half of displacement of unsupported exposure.

This change in the stress pattern in the support even deepens with an increase in stress relief in surrounding rocks before the support installation. Figure 3 depicts stress patternt in support in case of 95% displacement of surrounding rock mass until its contact with the support, which is conformable with deformation of unsupported excavation. In this case, the support is stress-free. At the same time, there is a small and low-stress concentration zone of σ_2 at the junction of the support and the excavation floor. Thus, the compression concentration zone in an arch excavation with support at different displacements of surrounding rock mass until its joint deformation with the support is at the floor of the excavation.

(a) (b)

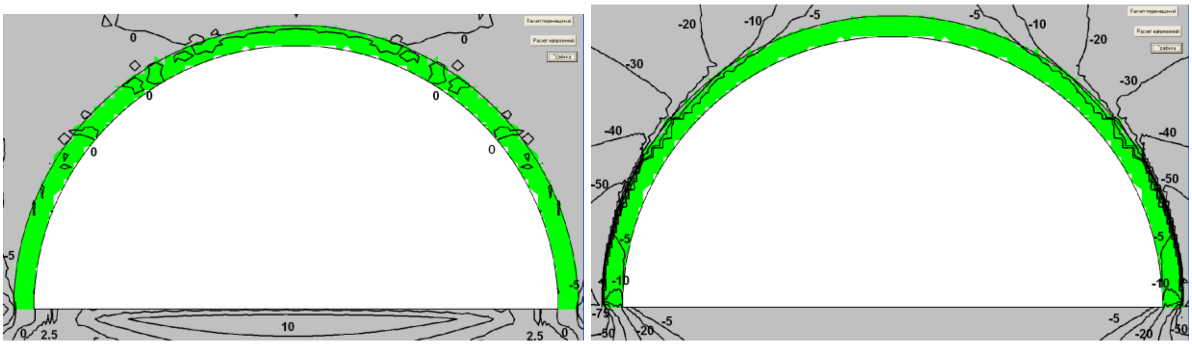

Figure 3. Principal stresses (a) σ_1 and (b) σ_2 (MPa) in support in case of surrounding rock displacements equaling 95% displacement of rocks in unsupported excavation.

Conclusion

The discussed method to assess stress state in the rock mass–support system under deformation makes it possible to determine loading on the support and to analyze its stress state in case of different displacements of adjoining rock mass.

Under gravitational in situ stresses, the highest compression zone in a support installed in an arch excavation is at the juncture of the sidewalls and the floor of the excavation. The concentration of the compressive stresses in this zone is preserved under further increase in displacements of surrounding rock mass.

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