Calculation of stresses in a rock mass and lining in stagewise face drivage

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Abstract. Using the method of calculating mechanical state of a rock mass for the conditions of stagewise drivage of a production face in large cross-section excavations, the specific features of stress redistribution in lining of excavations are found. The zones of tensile stresses in the lining are detected. The authors discuss the influence of the initial stress state of rocks on the tension stress zones induced in the lining in course of the heading advance.

Mine workings of sizable cross-sections are driven in stages [1]. In every stage a face of small cross-section is driven and its profile is lined. This process for drivage of large cross-section mine workings implies specific approaches to calculation of stress state of a periphery rock mass and successively mounted lining segments. Investigation and analysis of strain in a rock mass and the lining enable to conclude, that heading of a small-profile face increases load on earlier mounted lining and running rocks in the periphery of a large cross-section mine working excavated by the moment. The older is the lining segment, the greater load it experiences at the present moment. Conventional methods for stress calculation in the lining and a periphery rock mass do not work under these conditions. The statement and solution to the problem under consideration should consider a stagewise principle of drivage and lining of mine workings. Thus, when evaluating the stress–strain state of a rock mass and lining units it is necessary to consider a mining sequence of face formation and to develop respective methods and softwares for computation of mechanical state of rocks.

One of respective approaches is proposed in [2, 3]. The authors employ superposition of analytical solutions obtained for a single face with lined profile [4, 5]. Empirical coefficients used to consider the stagewise character of excavation of large cross-section faces. These coefficients evaluate a contribution of each single face to the final solution.

In another approach, based on the numerical solution to the problems, the mathematical statements are used to evaluate extra stress fields arising in a rock mass and lining units as a consequence of mining operations [6]. To consider stress redistribution in rocks and lining members under elastic deformation is feasible through summing of solutions to problems of the elasticity theory for additional fields of stresses induced by excavation of each face [7]. The direct realization of this approach encounters large problems with setting boundary conditions for successively excavated faces.
The said problems can be solved by methods and algorithms developed at IM SB RAS to model the stress redistribution process in a rock mass and lining units with account for progressive mining operations [10]. The methods and algorithms are based on the use of the initial stress and deformation methods implying application of a calculation rigidity matrix which does not undergo changes in finding non-linear solutions [11, 12]. The compliance of used relations with the single-curve hypothesis underpinning solutions to many non-linear problems on mechanics of deformed solid body and rocks is justified.

In the present paper the novel algorithms and softwares are used to evaluate a character of stress redistribution in lining units under conditions of stagewise cross-sectional face drivage. Mining sequence is shown in Figure 1. Computation is made for plain-deformation conditions. In the first computation series the researchers preset zero values of the horizontal component of displacement vector $u$ and the tangential component of stress tensor $\tau_{xy}$ in vertical boundaries of the calculation domain. These terms correspond to the initial stress state of a rock mass at stress tensor components: $\sigma_y^0 = -\varrho H; \sigma_x^0 = -v\varrho H / (1-v); \tau_{xy}^0 = 0$ and are realized in regions where tectonics is not a problem [14]. Here $\sigma_x^0, \sigma_y^0, \tau_{xy}^0$ are normal and tangential components of stress tensor; $\varrho$ is volume density of rocks; $v$ is Poisson ratio of a rock mass; $H$ is distance to Earth surface. Axis $Ox$ is oriented horizontally, $Oy$ is oriented vertically. The upper boundary of the calculation domain is free of external load. In the lower boundary the zero vertical component of displacement vector $v$ and zero tangential component of stress tensor $\tau_{xy}$ are assumed. Mechanical properties of a rock mass are suggested: Young modulus $E = 50000$ MPa; $v = 0.25$. For the lining material $E = 100000$ MPa; $v = 0.2$. Volume density of rocks and lining material is 0.03 MN/m$^3$.

Figure 2 demonstrates lines of equal-in-value principal stresses $\sigma_1, \sigma_2$ in lining and periphery rock mass after execution of 4 stages of the face cross-section opening. A complex pattern of stress distribution is formed in the lining. In the stagewise drivage and lining of mine workings the appreciable fragment of the lining is under tension stresses (Figure 2a). Tension stresses are small, less than 0.5 MPa in more than a half of the finished lining, but in some sections tension stress exceeds 5MPa.

These sections locate in under-roof lining units in the vicinity of its contact with vertical members, mounted in the second and third stages of mining operations. The maximum tension stresses...
in zones of its concentration reach 12 MPa. Compression stresses in the lining are not high and do not exceed 3–4 MPa (Figure 2b).

![Figure 2. Distribution of principal stresses (a) $\sigma_1$, (b) $\sigma_2$, MPa, in the lining and surrounding rock mass after four stages of the face cross-section opening.](image)

In Figure 3 the final distribution of principal stresses $\sigma_1$ and $\sigma_2$ in a rock mass and lining units corresponds to the seventh opening stage. Mining advance leads to redistribution of stress fields in the lining. New areas of tension stress concentration are formed along with reduction in tension in earlier formed tension concentration zones (Figure 3a). All the zones of tension stress concentration locate nearby contacts of lining members formed in different mining stages. Values of tension stress exceed 5 MPa in three zones from four zones of detected tension stress concentration. Distribution of compression stresses $\sigma_2$ in the lining does not undergo sensible variations. The distribution of stresses in a rock mass surrounding the lining complies with the earlier established pattern of stress distribution in the vicinity of mine workings [7].

![Figure 3. Distribution of principal stresses (a) $\sigma_1$ and (b) $\sigma_2$, MPa in the lining and surrounding rock mass after mining operations on opening of face cross-section are completed.](image)
The second series of calculations was performed for the hydrostatic initial stress field. The same mining sequence on the opening of the face cross-section was considered. The main aim of modeling was to evaluate the effect of initial stress state of a rock mass in formation of tension stress zones in the face lining. The conclusions obtained after the analysis of calculated results on redistribution of stresses in the course of mining advance are illustrated in Figure 4 where isolines of principal stresses after the complete opening of the face cross-section are shown.

![Figure 4](image)

**Figure 4.** Distribution of principal stresses (a) $\sigma_1$ and (b) $\sigma_2$, MPa in the lining and surrounding rock mass after mining operations on opening of face cross-section are completed in the case of hydrostatic distribution of the initial stress field.

It is important to emphasize the qualitative and quantitative effect of the initial stress field on formation of tension stress zones in the face lining, namely, their locations, number, and level of acting stresses tend to vary. In some lining sections the tension stress values exceed 10 MPa (Figure 4a). Zones of appreciable compression stress concentration are not observed, though compression stress can increase more than twofold in some lining sections as compared to the initial gravity stress field (Figure 4b).

**Conclusion**
1. The new-proposed method for calculation of the mechanical state of a rock mass and lining enables to evaluate a character of the stress field redistribution in a stagewise drivage of mine workings of large cross-sections.
2. Increase in the horizontal component of the initial stress field leads to growth of a number of tension stress concentration zones in the lining members and stress values acting in them.

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