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DISCONTINUITY ZONES IN THE JUNCTION REGION OF TWO MINE TUNNELS

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The boundary integral equation method was used to solve the problem of the stress sate at the junction of two mine tunnels. The regions of rock breaking are obtained using the Mohr strength criterion.

Key words: *stress sate, mine tunnels, junction, surfaces of weakness, rock strength, discontinuity zone.*

An analysis of the stress–strain states of rock outcrops is necessary for designing and constructing mine tunnels, and it becomes even more urgent if there is a junction of mine tunnels. At the junction of mine tunnels, the rock are in a three-dimensional stress, which makes the problem more complicated than the problem of a single extended mine tunnel.

Let us consider the stress sate around the junction of two horizontal mutually perpendicular mine tunnels of square cross-section (Fig. 1). We formulate the problem of the stress sate around the mine tunnels as follows [1]. Along the x_3 coordinate axis, an infinite elastic massif is subjected to stresses $\sigma_{33}^\infty = \gamma H$, where γ is the volumetric weight of the rocks of the massif and H is the depth of the massif. In the horizontal x_1 and x_2 directions, the massif is acted upon by stresses $\sigma_{11}^\infty = \sigma_{22}^\infty = \lambda\gamma H$, where λ is the lateral pressure coefficient. Inside the massif there is a cavity which models the given junction. The entire surface of the massif or its part are acted upon by forces F, which can be produced, for example, by the response of the support. It is required to find the stress sate at any point of the massif around the junction.

This problem was solved using the boundary integral equation method, which consists of the following [2–4]. A compensating load of intensity a is applied to the surface of the cavity. The total stresses from the action of the external and compensating loads at each point of the cavity should satisfy the conditions on the surface. The stresses from the compensating load are determined by integration over the Kelvin solution within the cavity surface [3]. As a result, the surface conditions are described by the integral equation (see [3])

$$\frac{1}{2}\,a_q(Q_0) - \iint\limits_O \Phi_{qm}(Q_0, M_0)a_m(M_0)\,dO_{M_0} = n_q(Q_0)\sigma_{qq}^\infty - F_q(Q_0), \qquad (1)$$

where $\Phi_{qm}(Q_0, M_0)$ is Green's tensor defined as (see [2–5])

$$\Phi_{qm}(Q_0, M_0) = \frac{1}{8\pi(1-\nu)R^2}\Big\{(1-2\nu)\Big(\frac{x_q n_m}{R} - \frac{n_q x_m}{R}\Big) + \Big[(1-2\nu)\delta_{qm} + 3\,\frac{x_q x_m}{R^2}\Big]\frac{n_t x_t}{R}\Big\}.$$

Here ν is Poisson's constant, R is the distance between the points Q_0 and M_0, δ_{qm} is the Kronecker delta, σ_{qq}^∞ is the stress tensor at infinity, O is the surface area of the cavity, n_q and n_m are the unit outward normal vectors to the cavity surface at the points Q_0 and M_0, respectively; the subscripts q, m, and t are the coordinate axis numbers, which take values 1, 2, and 3.

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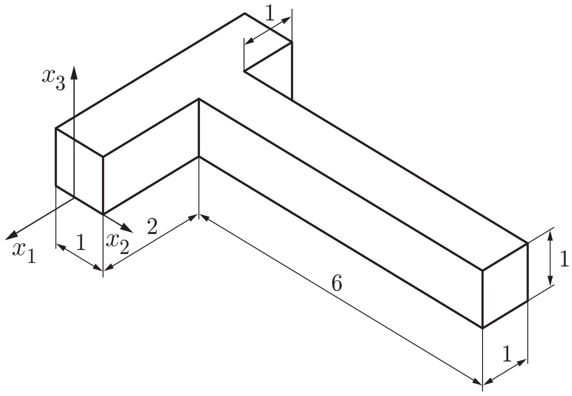

Fig. 1. Junction of two mine tunnels of square cross-section.

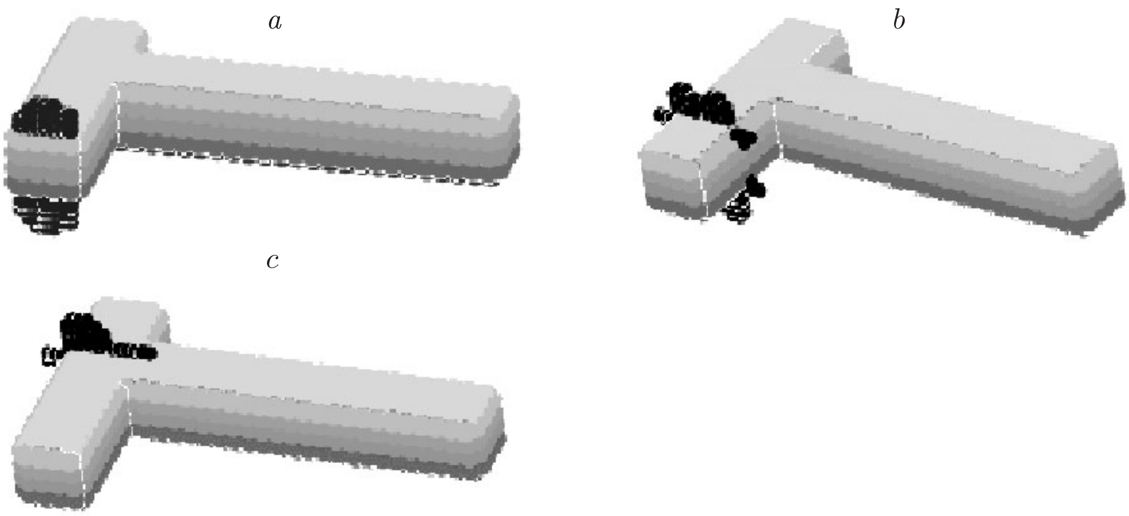

Fig. 2. Discontinuity zone at the end section of the main mine tunnel (a), in the middle cross-section (b), and in the section of the main mine tunnel at the junction with the lateral mine tunnel (c).

Equation (1) is solved numerically. The cavity surface is first replaced by a finite number of plane elements (N) and the integral is replaced by the sum [6]. Then, integration over each element is performed under the assumption that within an element, the intensities a and F are constant. As a result, the integral equation (1) is replaced by the following N vector equations:

$$\frac{1}{2}\, a^*_{q.i} - \sum_{\substack{j=1\\ j\neq i}}^{N} \Phi_{qm.ij} a^*_{m.j}\, \Delta O_i = n_{q.i} t^{\infty}_{qq.i} - F^*_{q.i}. \tag{2}$$

Here i is the number of the point on the cavity surface at which the boundary conditions are formulated, j is the current point number on the cavity surface; summation is performed over all points except for $j = i$. In Eqs. (2) (and below), the subscripts of the tensors are separated by a point from the subscripts of the points of the cavity.

Solving Eqs. (2) for $a^*_{q.j}$, one obtains the stress tensor σ_{qm} at any point i of the massif using the superposition principle:

$$\sigma_{qm.i} = \sigma_{qmt.ij} a^*_{t.j} + \sigma^{\infty}_{qq.i}.$$

Here σ_{qmt} is the stress tensor due to unit load (the Kelvin tensor), defined as (see [2, 4, 5])

$$\sigma_{qmt} = \frac{1}{8\pi(1-\nu)R^3}\Big[(1-2\nu)(\delta_{mt}x_q + \delta_{qt}x_m - \delta_{qm}x_t) + \frac{3x_q x_m x_t}{R^2}\Big].$$

The broken regions or discontinuity zones around the mine tunnel are found as the set of points at which the rock has broken by the Mohr strength criterion:

$$\tau_\nu = \sigma_\nu \tan\varphi + K, \tag{3}$$

where K is the rock jointing factor. In the present study, it is assumed that the massif produces a hydrostatic stress field ($\lambda = 1$) and has horizontal surfaces of weakness, in which the jointing coefficient is $K = 0$, and the angle of internal friction is $\varphi = 20°$.

The problem is solved using the MATHCAD mathematical software. The stresses are calculated in dimensionless form, i.e., are normalized by γH. The dimensions of the mine tunnels are also dimensionless. After determination of the stresses and formulation of strength conditions for points at which the stresses were calculated, discontinuity zones are constructed in some sections around the main mine tunnels, which are shown in Fig. 2 as shaded regions.

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