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EFFECT OF BEARING PRESSURE ON THE STRENGTH OF A ROCK MASS CONTAINING CYLINDRICAL CUTS

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The three-dimensional problem of stress distribution in a rock mass in the vicinity of two cylindrical holes located in the zone of elevated mountain pressure is solved using the boundary-element method. The technogenic disturbance of the mass with regular strength anisotropy was estimated quantitatively using specially introduced parameters.

Key words: *bulk stress state, strength anisotropy, surfaces of weakness, discontinuity zone, technogenic disturbance of rock mass, elevated mountain pressure.*

Accounting for the effect of elevated mountain pressure on the stress-strain state of a mine working is an important practical and scientific problem. Elevated mountain pressure, as a rule, is caused by the so-called bearing pressure resulting from the formation of a worked-out area in a mass, for example, in mining coal or other minerals. Bearing pressure considerably increases rock failure areas in the vicinity of the working, leading to additional loads on the support and to increased release of methane if the working is driven in gas-bearing beds.

It is known that methane release from a coal seam begins when the seam fails with the formation of additional free surfaces: cracks, cleavage, etc. In the case of bearing pressure acting ahead of the working face, a methane drainage borehole drilled in the coal seam disrupts its continuity. As a result, part of methane from the seam that has not reached the working face passes into the borehole and then to the surface. This allows one to considerable reduce the supply of methane to the working face and to reduce the probability of sudden emissions of coal and gas.

To effectively use the system of methane drainage boreholes in a seam, it is necessary to determine their parameters (diameters, distances between boreholes, and borehole inclination) that provide the greatest disturbance of continuity of the coal mass in the vicinity of the boreholes in the bearing pressure zone.

In the formulation of the problem, it is necessary to take into account that a sedimentary rock mass as a continuous medium has regular systems of surfaces of weakness, whose strength characteristics are much lower than the strength characteristics of the rock located between them and called the basic rock [1]. Therefore, failure in the mass occurs primarily along the surfaces of weakness at stresses much lower than the elastic limit of the basic rock. Hence, to estimate the strength of a mass containing surfaces of weakness, it is sufficient to determine the stress field in the elastic mass. The degree of disturbance of an anisotropic (in strength) mass near natural or man-made underground cavities used for various purposes is predicted using the following computation scheme [2]. An infinite elastic rock mass with free boundaries containing a system of holes (or one hole) is penetrated by surfaces of weakness and is loaded near them by gravitational stresses. A certain region of this mass is subjected to the additional stresses caused by bearing pressure and modeled by a quadratic dependence (Fig. 1).

In the formulation of strength conditions on regular surfaces of weakness, it is necessary that the stress field be continuous. The most effective and, probably, single method that determines this field with the additional stress acting only in the vicinity of the system of holes is the boundary-element method (BEM) [2, 3]. Normal and tangential stresses on the surfaces of weakness whose orientation in space is specified by the angle α between the normal $\boldsymbol{\nu}$ to the surface and the vertical axis of the cross section z and the angle β between the projection of the

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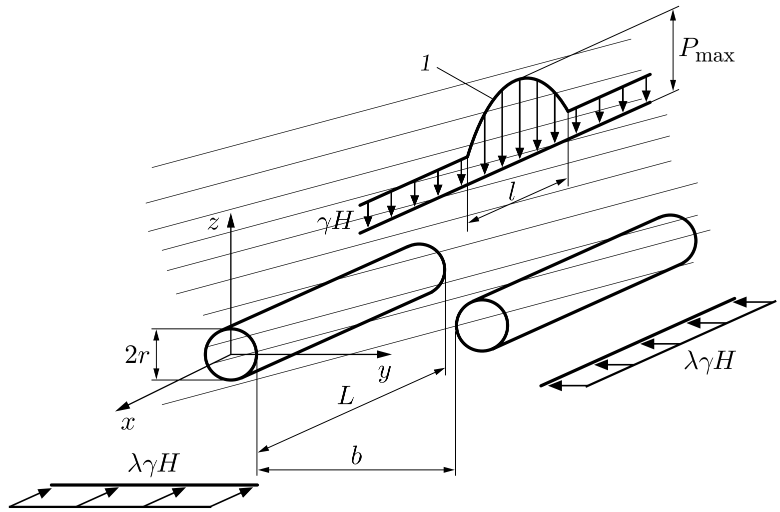

Fig. 1. Computation scheme of the problem: the bearing-pressure distribution is marked by 1; inclined lines shows surfaces of weakness.

normal onto the horizontal plane xy and the axis of the working x are linked to the stress tensor field components by well-known relations [2]. The failure condition for the rock mass material is performed along the surfaces of weakness using the Mohr–Kuznetsov strength criterion in which the key strength parameters are the internal friction angle φ and the coefficient K of rock jointing on these surfaces. The set of points of failure according to the Mohr–Kuznetsov condition forms zones of mass disturbance — discontinuity zones (DZs) [1].

In [4], the bulk stress in the vicinity of conjugate mine workings of square cross section was calculated using the BEM and the DZs were constructed without estimating the disturbance of a rock mass containing holes. Quantitative estimates of the disturbance of a rock mass containing holes are required to choose a reasonable shape of the hole cross section and to establish the degree of disturbance of the coal seam in the vicinity of slot holes during partial or complete gas drainage from the coal seam. In [5, 6], quantitative estimates of disturbance were obtained for a mass with plane strains in the vicinity of long slot holes with rectangular and cross-shaped cross sections and near holes with cross sections of typical and atypical shapes. The proposed computation for the geomechanical state of the mass in the vicinity of voluminous structures is implemented in the MATHCAD software package.

The degree of disturbance of the mass is defined by the disturbance coefficient k_n and disturbance intensity I:

$$k_n = \frac{S_n(x)}{S}, \qquad I = \frac{1}{l}\int\limits_0^l k_n(x)\,dx$$

[S is the cross-sectional area of the holes, $S_n(x)$ is the area of the discontinuity zone, and x is the abscissa reckoned along the axes of the holes].

A numerical experiment was performed for a system of two identical cylindrical holes modeling a fragment of a system of methane drainage boreholes. The arrangement of the holes is specified by the angle θ between the axis connecting their centers and the horizon. The bearing-pressure distribution is given by a parabolic curve (curve 1 in Fig. 1). As shown by the results of the experiment, the maximum disturbance of a mass with the orientation of surfaces of weakness specified by the angles $\alpha = 25°$ and $\beta = 90°$ is reached for $\theta = 50°$. The initial data for the calculation were the following parameter values (see Fig. 1): $K = 0.2\gamma H$, $L = 12$, $r = 1$, $b = 4$, $1 \leqslant f = P_{\max}/(\gamma H) \leqslant 7$, $1 \leqslant l \leqslant 6$, $\varphi = 20°$, and $\lambda = 1$ (γ is the bulk mass of rock, H is the depth of the mine working, λ is the lateral pressure coefficient, L is the length of the cylindrical hole, r is the radius of the hole cross section, b is the distance between the contours of the cylindrical holes, and $P_{\max}$ is the maximum bearing pressure; the linear dimensions are normalized by the radius of the cylinders $r = 1$).

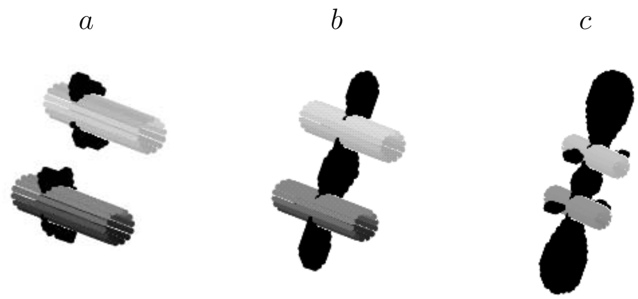

Fig. 2. Mass disturbance zones near cylindrical holes outside the bearing pressure zone (a) and in the zone of the maximum bearing pressure (b and c): $l = 4$ and $f = 5$ (a and b); $l = 6$ and $f = 7$ (c).

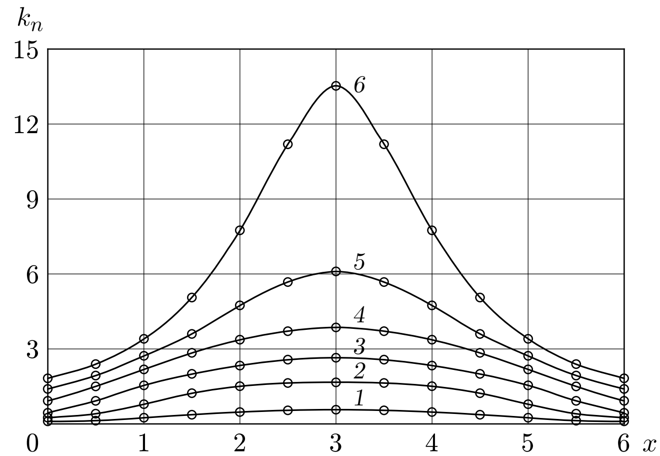

Fig. 3. Disturbance coefficient k_n versus coordinate x in the bearing pressure zone for $l = 6$ and $f = 2$ (1), 3 (2), 4 (3), 5 (4), 6 (5), and 7 (6).

Figure 2a and b shows the DZs in the vicinity of sections of two holes outside the bearing pressure zone and in the bearing pressure zone for $l = 4$ and $f = 5$. It is evident that in the second section, which is acted upon by the maximum bearing pressure (see Fig. 2b), the DZs are much larger than that in the first section (see Fig. 2a). In Fig. 2, the DZs are constructed in the section with the maximum bearing pressure $P_{\max} = 7\gamma H$ at $l = 6$, and $f = 7$. It is evident that as the bearing pressure increases, the DZs are united in a single zone called the instability zone.

Figure 3 shows a curve of the disturbance coefficient k_n versus coordinate x in the bearing pressure zone for $l = 6$ and various values of f. In Fig. 3 it is evident that, for f increasing in the range $2 \leqslant f \leqslant 5$, the dependence $k_n(x)$ is almost linear, and for $f = 6$ and 7 the dependence $k_n(x)$ ceases to be linear. This is due to the fact that, at $P_{\max} = 7\gamma H$ and $b = 4$, the following phenomena take place. First, the DZs of two holes adjoin or even overlap each other throughout and beyond the bearing pressure zone. Second, in the maximum bearing pressure zone, the length of the DZs increases considerably, reaching a value equal to two hole diameters at a distance equal to $b/2$. Third, there is a considerable increase in the disturbance zones from the opposite sides of the holes; the area of each of the zones is several times larger than the area of the joining zone, as can be seen in Fig. 2c. We note that the behavior of curves on Fig. 3 is similar to the behavior of Gaussian type curves and is described by the expression $k_n = (f - c)\exp\left(-d(x - l/2)^{1.5}\right) + c$, where the coefficients d and c are determined for each curve of the family.

Figure 4 shows curves of the disturbance intensity I versus the area under the curve of the elevated pressure $Q = 2l(f - 1)/3$. From Fig. 4, one can determine the effect of the parameters of the bearing pressure zone (the maximum value and length of the zone) on the disturbance intensity. It is evident that an increase in the length of the bearing pressure zone l for a fixed value of f leads to a decrease in the growth rate of the curves, and an increase in the maximum bearing pressure f for fixed values of l leads to an increase in the growth rate of the curves. This indicates that the disturbance intensity is more greatly affected by the maximum bearing pressure than by the

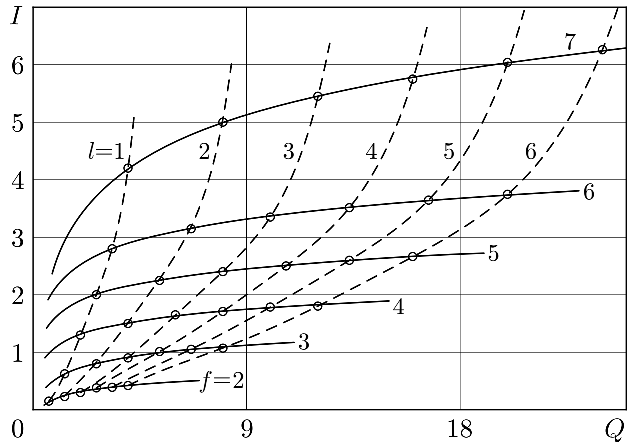

Fig. 4. Disturbance intensity I versus the area of bearing pressure distribution Q for fixed values of f and various values of l (solid curves) and for fixed values of l and various values of f (dashed curves).

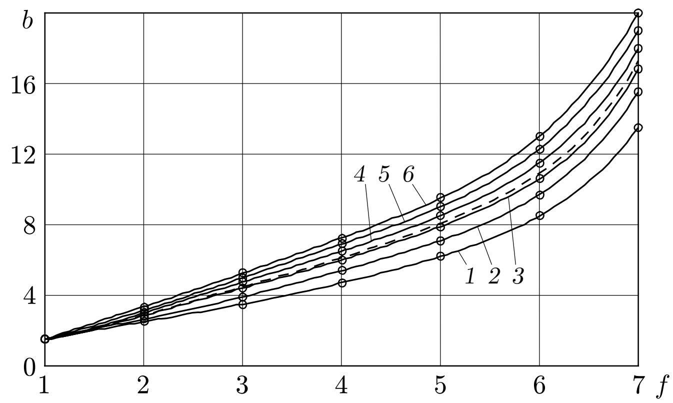

Fig. 5. Distance b between the holes at which there is joining of DZs versus maximum bearing pressure f for $l = 1$ (1), 2 (2), 3 (3), 4 (4), 5 (5), and 6 (6); the dashed curve corresponds to average values.

length of the bearing pressure zone. Furthermore, for any pair of curves in Fig. 4, there are regions $0 \leqslant Q \leqslant Q_0$ (Q_0 is the abscissa of the points of intersection of the curves) in which the length of the bearing pressure zone has a more significant effect than the maximum bearing pressure. For example, for the pair of curves $f = 3$ and $l = 3$ before the point $Q = 4$, the length of the curve has a more significant effect than its maximum. By the reasonable distance between the boreholes we shall mean the distance at which there is joining of the DZs in the vicinity of these boreholes in the section acted upon by the pressure $P_{\max}$. This is due to the fact that, during movement of the working face, the bearing pressure half-wave moves synchronously into the depth of the seam, providing the joining of the DZs of the pair of holes and gradual movement of this joined zone along the extraction pillar at the velocity of movement of the working face. Figure 5 shows a curve of the distance b between holes versus the maxima of the curve of f obtained using this approach for various lengths of the bearing pressure zone l.

The analysis of the results leads to the following conclusions.

The index of planar disturbance of a mass — the disturbance coefficient — allows one to analyze the distribution of this disturbance along the axis of the holes.

As the maximum bearing pressure increases, the disturbance zone is concentrated in its vicinity, reaching a value of $0.4l$, and accelerated accumulation of disturbance occurs in this zone.

A criterion of the reasonable arrangement of boreholes was established and used to determine the reasonable distances between boreholes as functions of the maximum and length of the bearing pressure curve for the medium considered.

The proposed procedure can be applied to media with other parameters.

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