For calculating the additional loading from formulas (2) and (4), a universal Fortran program has been written; the initial data are coordinates of the joints, the values of $\Delta x_i$ for each tubing, and joint moments $m_i$.

As an illustration, we will describe the calculation of the characteristics of a support system developed by the Institute of Mining as it responds to the action of a compression waves arriving vertically. The calculation of the main loading was performed at the Tula Polytechnic by a program written by N. N. Fotieva. The curves of bending moments $M^0$ and normal forces $N^0$ are shown in Fig. 4a. Additional loading was calculated by means of the above program. The data are given in Table 1.

From (1), we computed the force curves of Fig. 4b. The distribution of forces (internal fibers are compressed, the intensity is greater in the arch than in the wall) matches the results of measurements of stresses by photoelastic sensors.

The stresses in the support system measured in the static operation conditions are lower than calculated values by a factor of 1.5-2, as was expected.

The method proposed above is suitable for calculating the multijoint characteristics of a support system in mines.

LITERATURE CITED

OPTIMAL GEOMETRIC PARAMETERS OF ORE DISCHARGE

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Some versions of the system of underground workings with rock collapse include well-known technical processes such as the discharge of the blasted ore mass under the overlying collapsed rock. The emission of loose material from the discharge apertures occurring here is associated with the formation of disintegration figures in the loose material: discharges bounded by closed convex surfaces resembling ellipsoidal surfaces. These topics were discussed in detail in [1-3], for example.

The mass prepared for explosion is in contact at its surfaces with collapsed rock - loose material with a lower content of useful components than the mass itself. Therefore, after explosion, the contact surfaces are surfaces of discontinuity in the content of useful components in the loose material. In connection with this, it is of interest to seek relations of the geometric parameters of the discharge figures and the contact surfaces such as might ensure the best ore-extraction indices. In the case where $R = 0$ ($R$ is the coefficient of volume depletion), an optimal relation of sufficiently obvious form was obtained in [2]: the discharge figures, as they develop, must be inscribed in a volume bounded by the contact surfaces. This relation is called the inscription principle.

At the same time, the experimental data of [4] indicate that decrease in thickness of the discharged section by 0.5-1.0 m (in comparison with the thickness maintained according to the inscription principle) permits improvement in the discharge indices.
In the present work, the optimal geometric parameters of the discharge are investigated on a mathematical model.

**Principles of Modeling and Optimization.** Using the well-known definitions of the volume-loss coefficient \( P \) and the depletion coefficient, two equations may be written

\[
VR - V_s = 0, \tag{1}
\]
\[
P - 1 + (1 - R)V/V_s = 0. \tag{2}
\]

where \( V \) is the volume of the discharge figure; \( V_s \) is the volume of the added collapsed rock; \( V_s \) is the volume of the exploded section of the ore.

The quantities \( V \) and \( V_s \) depend on the time (duration) of discharge \( t \in [0, \infty) \). It is readily evident that its role in Eqs. (1) and (2) is played by the parameter \( R \in [0, t) \) since there is bijection between \([0, 1)\) and \([0, \infty)\).

Assuming the well-known equation of the surface of the discharge figure and its law of development (with increase in \( R \)), as well as the equation of the exploded-section surface, all the volumes in Eqs. (1) and (2) may be calculated. The equation of the discharge-figure surface is determined by the mechanics of emission of the loose material and, in some coordinate system of three-dimensional space, by the set of geometric parameters \( \psi_i, i = 1, \ldots, m \). The equations of the exploded-section surface, however, are assumed to be technically specified and to depend in the same coordinate system on the geometric parameters \( x_k, k = 1, \ldots, n \); then

\[
V = V(\psi_1, \ldots, \psi_m), \quad V_s = V_s(x_1, \ldots, x_n),
\]
\[
V_s = V_s(\psi_1, \ldots, \psi_m, x_1, \ldots, x_n). \tag{3}
\]

The parameters \( x_k \) are now optimized, choosing the loss coefficient

\[
P = 1 - \frac{(1 - R)V}{V_s}, \tag{4}
\]

which is easy to determine from Eq. (2), as the target function; i.e., the parameters \( x_k \) are said to be optimal if they permit a minimum of the function in Eq. (4) under the constraint in Eq. (1).

Note that Eqs. (4) and (1) in the space of parameters \( P, R, x_k \) form a family of functions, each member of which corresponds to a particular value of \( R \).

Generally speaking, the given problem is a problem of convex programming in finite-dimensional space. However, a more modest aim is formulated and realized here: in the simplest extremal problems permitting the use of the classical method of solution [5], the possibility of optimization — for the convexity in Eq. (4) — and the difference of the results from the inscription principle is shown.

Taking account of Eq. (1), it becomes obvious that Eq. (1) implicitly relates the parameters \( \psi_i \) and \( x_k \). Then, the use of the classical method reduces the minimization problem to the solution of a system including Eq. (1) and the equations

\[
\frac{\partial(V/V_s)}{\partial x_k} = 0, \quad k = 1, \ldots, n, \tag{5}
\]
\[
\frac{\partial(VR - V_s)}{\partial x_k} = 0, \quad k = 1, \ldots, n. \tag{6}
\]

the latter of which appears in differentiation precisely because of the implicit dependence of \( \psi_i, i = 1, \ldots, m \) on \( x_k, k = 1, \ldots, n \). The use of the classical method is expedient in the case where the derivatives \( \partial \psi_i/\partial x_k \) can be excluded from Eq. (1), (5), and (6).

The systems in Eqs. (1) and (2) and Eqs. (1), (5), and (6) do not impose any specific requirements on the surface of the discharge figures. However, in the specific optimization problems considered below, the discharge figure is an ellipsoid of revolution. There are two reasons for this: first, all the necessary volumes are easy to calculate in this case; second, and more significantly, a discharge ellipsoid has become, despite its shortcomings, the primary "unit of measurement" in technical disciplines.

**Optimal Thickness of Discharge Section.** The problem is formulated so that the calculation of the volumes \( V, V_s, V_s \) does not pose any difficulties; therefore, Eqs. (1) and (4) are given at once in their final form. It will simply be noted that \( V_s \) is the volume cut off from the volume of the discharge figure by the contact surfaces of the section and is zero when \( R = 0 \).