of the rock kinematics enable us to predict rock pressure phenomena during working of coal seams with stowage.

LITERATURE CITED


CALCULATION OF THE STRESS-STRAIN STATE IN JOINTED ROCK AROUND MINE WORKINGS

A. F. Nozhin and V. G. Zoteev

The rapid development of approximate numerical methods, in particular the finite-element method [1], is now enabling us to create mathematical models for rock with allowance for jointing and stratification.

In this article we pose and solve the plane boundary-value problem for a jointed ledge rock mass in the cases of open-cut and underground mining workings of any arbitrary profile.

Formulation of Problem. Consider a heavy half plane containing a recess or hole of any configuration, representing the cross section of an open-cut or underground working. The half plane is bounded by rectilinear boundaries fairly remote from the working. According to St. Venant's principle, this permits us to neglect the influence of the working on the boundary conditions. The lower boundary and one of the sides of the rectangular region are fixed by constraints which limit the freedom of movement of the lower boundary in a vertical direction and the side boundary in a horizontal direction. On the free side we impose a distributed load simulating horizontal tectonic forces or lateral thrust. The intensity of the lateral load can vary with depth according to any arbitrary rule.

As a rule, the rock mass is divided by surfaces of several orders. Therefore, we dissect our region into structural-tectonic blocks of the first order, starting from the largest tectonic and stratigraphic surfaces of weakness. The structural-tectonic blocks surrounding the mine workings or directly containing them are dissected into separate second-order layers and blocks. This detailing of the structure of the rock permits us to include possible movements over the surfaces of second order in the zones of abutment pressure and load relief in our calculations. In turn, the structural blocks are dissected into triangular elements.

We will assume that surfaces due to stratification and schistosity are continuous. Joints of normally or obliquely intersecting systems are usually discontinuous and have a well-determined average length, so that the rock can be represented in the form of cohesive "brickwork." If the second system of joints is weakly developed, the rock is regarded as a stratified medium with determinate contact cohesion between the rock layers. Within a stratum or rock block the rock is regarded as elastic, uniform, and isotropic.

Solution of the Problem. Ngo and Scordelis [2] introduce the concept of an element of "cohesion" which models the bond between the node points lying on opposite sides of a joint (Fig. 1). We will refer to this element as an element of nodal interblock cohesion or simply

Fig. 1. Element of nodal interblock cohesion along joint. 1, 2) Nodes of finite elements lying in different blocks of rock. Here $\Delta L$ is the width of the joint, and $\alpha$ is angle of inclination of the normal to the joint relative to the $X$ axis.

an element of cohesion. It consists of a system of two rigid angle pieces and two elastic linear elements of the cylindrical spring type. The stiffness of the springs is characterized by the normal and shear rigidities of the cohesion across the joint.

The nonlinear deformation along the joints, i.e., the dependence of the rigidity of the cohesion between the blocks on the relative displacement along the joint, can be quite easily taken into account by introducing the "equivalent rigidity" [3]. The shear rigidity is determined by the value of the normal stress, by the angle of friction, by the cohesion, by the displacement, and by the limit of linear deformation along the joint.

The formation necessary for solution of the problem can be divided into two groups. The first group includes data on the strength and deformation properties of the rock within each structural block, information on the undisturbed state of stress of the rock before the mine working is cut and on the dimensions and configuration of the working, and data on the strength and deformation properties of the contacts between the blocks or rock strata, and finally, the orientation of the surfaces of weakness of each system of joints.

The second group includes data on the dissection of the region into triangular elements and information on the number of elements of nodal interblock cohesion.

The procedure for solving the problem is shown in the form of a flowchart (Fig. 2) in ALGOL to be implemented on a BESM-6 computer. To compile the algorithm we used the principles in "A Program for Static and Dynamic Analysis of Structures by the Finite Element Method for an M-220 Computer" [4].

The fourth block of the program is a loop for the successive elements of nodal interblock cohesion. In the $i$-th iteration for each cohesion element we choose the normal and shear rigidities in conformity with the normal stress and the magnitude and direction of the displacement at the joint, as found in the preceding $(i-1)$-th step. If the joints are open, $K_n$ and $K_v$ are assumed to be zero, but if the normal stresses are compressive the normal rigidity is taken as four orders of magnitude higher than the rigidity of the blocks in order to exclude their mutual interpenetration.

When the iteration is completed, we calculate the stresses and deformations in the sixth segment. The interblock movements and the widths of the joints are determined in the next segment of the program. If the signs of the normal displacement $\varepsilon_n$ for successive iteration are preserved and the difference between the preceding and current values of the shear rigidity $K_v$ does not exceed a given error value $IE$, the terminate-calculation flag is generated.

The program provides for the case of dangerous deformations at the joints causing loss of stability and supporting capacity in the rock near the periphery. If the normal or shear displacement of even one cohesion element exceeds a given critical gap (or shear), the ter-