ROCK MECHANICS

STUDY OF CAVING FEATURES FOR UNDERGROUND WORKINGS IN A ROCK MASS OF BLOCK STRUCTURE WITH DYNAMIC ACTION.

PART III. ANALYSIS OF THE STABILITY OF AN INDIVIDUAL ROCK BLOCK IN THE ROOF OF A WORKING

G. G. Kocharyan

Intersecting discontinuities of a different scale govern the block structure of a rock mass. As analysis of experimental data for the fracture mechanics of actual rock masses shows [1], both the strength properties of structures in which there is local deformation and their geometry, i.e., block dimensions and shape, have an important effect on the stability of an underground construction. For this the latter may be divided conveniently into three classes [2].

1. 'Key' blocks 1 in Fig. 1. These are the most critical potentially unstable rock blocks whose shape and size makes it possible for them to drop out or 'slip' within a working under the action of the force of gravity or an external effect. Collapse of key blocks may involve caving of neighboring areas. Such blocks should be especially carefully secured.

2. Blocks of 'finite dimensions' 2 in Fig. 1, i.e., blocks whose size permits collapse within a construction after caving of key blocks.

3. The dimensions of 'infinite' blocks 3 in Fig. 1 include caving of them within a structure.

In an actual rock mass containing discontinuities in order to increase the reliability of predicting the stability of an underground construction it is necessary to analyze the small-block structure around the worked-out space. If the level of cracking of the rock mass is quite low and the existing system of discontinuities is arranged such that the greater part of blocks is 'infinite,' then it is apparently entirely permissible to approximate such workings as 'solid' material, i.e., use of some continuum models. In contrast, at the intersection of the main crack and fault systems, should a considerable number of key blocks form, then the stability of the working will be governed by the geometry and strength properties of the interblock gaps.

Since it is difficult to develop a universal method for evaluating the stability of a block structure due to the infinite variety of the possible specific realizations, it is desirable to consider the solution of a quite simple problem of a procedural nature about the stability of an individual block in the roof of a working which will make it possible to evaluate the level of the effect of different parameters on the dynamic stability of a working and make it possible to determine the most important directions for diagnosing the situation around the worked-out space.

We consider as a similar problem conditions for the stability of a block in the form of a right rectangular pyramid placed in the roof of a cylinder working.

We assume that cracks which form the block structure close to the working are quite thin in order to ignore their effect on the stress field. In view of this in determining stresses at the boundaries of a block we use an approximation of a solid. Here the block is assumed to be undeformable.

Thus a block in the form of a right rectangular pyramid with the long side of the base 2L and slope of the face f is placed in the roof of a horizontal cylindrical working of radius R so that (Fig. 2) the height of the pyramid is vertical and the sides of the base are correspondingly parallel and perpendicular to the cylinder generating line. The directions of principal stresses in the rock mass are vertical for $\sigma_3$, and horizontal along and perpendicular to the working axis for $\sigma_1$ and $\sigma_2$. The elastic properties of the rock mass are known. Thus, normal and tangential stresses at each point of the block surface in the
initial instant may be calculated by relationships of elasticity theory. The balance of forces at the surface of the pyramid faces are:

\[ \Sigma F = (T_1 + T_2) \cdot \sin \phi - (N_1 + N_2) \cdot \cos \phi - W, \]  

where \( T_1 = \tilde{\tau}_1(2S_1), T_2 = \tilde{\tau}_2(2S_2), N_1 = \tilde{n}_1(2S_1), N_2 = \tilde{n}_2(2S_2), S_1 \) is the area of face 1, \( S_2 \) is the area of face 2; \( \tilde{\tau} \) and \( \tilde{n} \) are average tangential stresses over the faces, but \( \tilde{n}_1 \) and \( \tilde{n}_2 \) are normal stresses, \( W \) is block weight.

If \( \Sigma F > 0 \) the block is stable, and if \( \Sigma F < 0 \) it is unstable. The properties of cracks bounding the blocks are assumed to be uniform and they are described within the scope of the model for deformation of a rock crack suggested in [3]. Considering that the rate of reduction in shear strength with post-limit deformation for unhealed rock contacts is small [3], for simplicity we assume that after reaching the strength limit for a crack in shear tangential stresses equal the strength time, i.e.

\[ \begin{aligned} 
\tau &= \begin{cases} 
\tau_0 + k_s \cdot d, & \tau < \tau_p, \\
\tau_p, & \tau \geq \tau_p,
\end{cases} 
\end{aligned} \]  

where \( \tau_0 \) are initial (from elasticity) tangential stresses. \( k_s \) is crack shear stiffness, \( \tau_p \) is strength of a crack in shear, \( d \) is amount of shear over a crack. As a measure of block stability it is convenient to introduce a stability factor [4]

\[ FS = \frac{W - T \cdot \sin \phi + N \cdot \cos \phi}{W} = 1 - \frac{T \cdot \sin \phi - N \cdot \cos \phi}{W}, \]  

Thus if \( FS > 0 \), then the block is unstable and it moves vertically downwards. If the stability factor becomes negative, then the position of the block is stabilized. In the case of final loss of stability the block separates from the roof, \( T = N = 0 \), i.e., \( FS = 1 \). If in the initial instant (after instantaneous creation of the working) the block is unstable, then after some small displacement \( dS \) there is a change in crack width due to opening

\[ dV = dS \cdot \cos \phi, \]  

and displacement over the crack

\[ d = dS \cdot \sin \phi. \]  

The magnitude of effective normal stresses at the boundary of the blocks \( \sigma_{ne} \) on one hand decreases as a result of crack opening, and on the other hand it may increase due to crack dilation during shear under constrained conditions. The value of \( \sigma_{ne} \) may be determined numerically from equations for normal deformation of a rock crack (relationships (4) and (11) in [3]) and crack dilation with shear may be determined ((19-(20) in [3]) taking account of (4) and (5). After calculating \( \sigma_{ne} \) by means of (2) the magnitude of tangential stresses is determined in each face. In order to determine the shear stiffness of a