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HYDRODYNAMIC STRATIFICATION OF PETROLOGICALLY UNIFORM STRONG ROCKS AS A MEANS OF CONTROLLING INTRANSIGENT ROOFS

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Intransigent (difficult-to-demolish) roofs are a serious complicating factor during cleaning-up operations in mining galleries. While such roofs are still hanging, there is an increased load on the supports and an increase in the stresses in the marginal parts of the coal seam. Settling of the main roof, especially if it does not take place smoothly, but in the form of an inpact load, may be accompanied by rapid deformation of the supports, caving in of its "face," rupture and outbursts from the system of supports and equipment (including expensive digging machines), collapse of the working face, the working area, and a significant decrease in coal output and production work. During coal extraction from strata prone to rock detonations and sudden outbursts of coal and gas, the suspension of intransigent roofs increases the stresses in the marginal part of the seam, which produces and causes dynamic and gasdynamic phenomena. Their occurrence may, in turn, contribute to rapid settlement of the roof and lead to serious consequences. Consequently, the development of methods of effective control of intransigent roofs during cleaning operations is one of the important objectives to be achieved in increasing the technicoeconomic indices and safety factors for various systems of operation.

At present, there are two means of controlling intransigent roofs in working areas equipped with mechanized supports. The first consists of creating mechanized supports with increased strength. In [1], which is an industrial experiment and in which the results of studies have been generalized, it has been correctly stated that the creation and application of such supports can reduce the number of cases where the support sections are stressed, but cannot exclude similar and other difficulties in oil coal seams with intransigent roofs. In this work it has been stated that "about 60% of such coal seams have weak seat-earths and unstable lower roof strata, in the presence of which, mechanized supports with increased strength will break into the rocks, will disrupt them, will not develop nominal strengths, and will not prevent falls in the working face. In some other seams with intransigent roofs with high contact strength in the lateral rocks in individual sectors, expecially during primary falls, the external active loads may exceed 250-300 tons/m^2. The creation of mechanized supports with such high strength is extraordinarily complex" [1]. To this we may add that such supports will be costly and when improperly adapted, will not be able to fulfill the function if reliable control of intransigent roofs, especially under the complex conditions and at the great depth at

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TABLE 1. Maximum Stresses σ_m (kgf/cm^2) in End Portion of Joint with σ = 100 kgf/cm^2 and Different Values of a and r

a, cm	r, cm				
	1	0,5	0,2	0,1	0,05
2	280	400	630	890	1300
5	450	630	1000	1400	2000
10	630	890	1400	2000	2800

which cleaning-up operations in galleries are carried out. The scientific grounds for adapting mechanized supports have been considered in Frolov's work [2].

The second method of controlling intransigent roofs amounts to weakening the rocks en masse. It must be taken into account that this method could not be set off against the necessity to create and use more modern mechanized supports, since under the most complex conditions, the essential effect will possibly be obtained only with concurrent combination of both methods.

Various methods of weakening rocks for controlling intransigent roofs are known [1, 3-6]. Some of these methods are based on drilling boreholes or blastholes in the roof, the dispersal of explosive material and the explosion of charges through them, including shooting of strong rocks. In another group of methods, injection of water through drillholes is provided for in regimes of moistening or hydraulic rupture of uniform strong rocks. Combined methods have also been suggested, including explosion and hydraulic pressure on the rocks [1]. Although distinguished in the mechanism of the effect on the natural properties of the rocks and on the technology employed, all the current methods have a common approach, which involves a decrease in the strength and stability of the rock mass. However, these changes are not uniform, and this deficiency is more or less typical of all the existing methods of affecting the roof rocks. For example, near drillhole or blasthole charges VV, the rocks of the roof are finely pulverized, whereas at a distance from them, the rock mass may be affected by disintegration. When using the method of moistening uniform rocks, possessing extraordinarily low values of porosity and permeability, it is not in general possible to create an even field of moisture. Hydraulic rupture in the form recommended for weakening intransigent rocks may be developed only on the basis of individual, randomly oriented endogenic and exogenic joints, which also ensures even treatment of the roof. It is doubtful whether the combination of explosion and moistening can improve the position as compared with the separate use of each method of weakening the rocks. It must be kept in mind that with the mechanical properties of the rocks varying with the strike and dip of the sedimentary sequence, corresponding irregular changes in the stress—strain state inevitably arise in the vicinity of mining operations both in the rock and in the coal, and this, as is well known, contributes to rock bursts, rock and coal falls, sudden outbursts of coal and gas, and other forms of dynamic and gasdynamic phenomena in shafts.

On what basis, then, may we develop a method of controlling intransigent roofs?

If we compare intransigent and readily demolished roofs, the main difference between them amounts to the fact that the former consist of uniform rocks, whereas the latter clearly possess well-defined bedding and a capacity to split readily along the stratification planes. Without altering the material, mineralogical, or petrographic composition of the rocks, it is possible in advance to alter a uniform rock mass, creating in it artificial joints, oriented, for example, parallel to the stratification (bedding). In carrying out such operations, an intransigent roof can be transferred to the category of easily- (medium-) demolished form, since with decrease in thickness of the roof layers, its capacity towards deformation is increased. This may be illustrated by the following approximate estimate using elementary strength-of-materials data.

Let us assume that the main roof is a plate in the form of a cantilever, bending under its own weight. Its free end will sag by an amount

$$f = ql^4/8EI, \tag{1}$$

where q is the intensity of distribution of the load (weight of the plate) in kgf/cm; l, length of the cantilever, cm; E, modulus of elasticity of the rock, kgf/cm^2; and I, axial moment of inertia, cm^4.

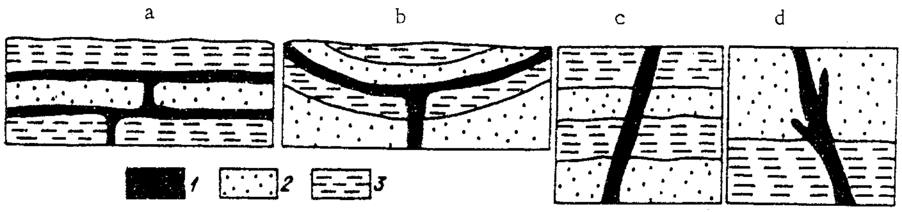

Fig. 1. Sills (a), lopolith (b), dike (c), and vein with blind leads (d): 1) magnetic intrusive rocks; 2, 3) older rocks of different composition and origin (sedimentary, magnetic, and metamorphic).

In its turn

$$I = bh^3/12, \tag{2}$$

where b and h are, respectively, the width and thickness of the plate in cm.

If two plates have a thickness h_0 and h, then the relative intensity of the load will be

$$q_0/q = h_0/h. \tag{3}$$

With constant values for l, b, q, and E, we have, on the basis of (1), (2), and (3), the relationship

$$f_0/f = h^2/h_0^2, \tag{4}$$

which denotes that the value of the sag in the main roof is proportional to the square of its thickness. If, for example, the thickness of the roof decreases threefold, then the magnitude of the sag (bend) increases ninefold.

The bending (shearing) stresses in the plate at the site of fixture, as compared with other parts of the plate, are maximum. They are determined from the formula

$$\sigma = M/W = \left(\frac{1}{2}\, ql^2\right)\Big/\left(\frac{1}{6}\, bh^2\right) = 3ql^2/bh^2, \tag{5}$$

where M is the moment of the force inkgf/cm; and W is the moment of resistance, cm^3.

For the plates with thicknesses h_0 and h at constant values of l and b, and allowing for condition (3), we obtain

$$\sigma_0/\sigma = h/h_0. \tag{6}$$

This signifies that as the plate bends under its own weight, the stresses acting at the point of support are inversely proportional to the thickness of the plate. A plate of half thickness undergoes double the stress. For this reason, the layers of the roof of lesser thickness, bending under their own weight, crumble first.

If we now assume that two plates of thickness h_0 and h and length l_0^* and l^* at the point of support undergo critical breaking stresses σ_0^* and σ^*, of equal magnitude ($\sigma_0^*/\sigma^* = 1$), then from (5), with allowance for (3), we obtain

$$l_0^*/l^* = (h_0/h)^{0,5}. \tag{7}$$

This equation reflects the relative relationship between the thickness of the bending roof and the critical length of its span, at which crumbling of a bending strong roof of thickness 9 m takes place with a length of span of 30 m; with a roof 1 m thick, the limiting length of the span, according to (7), is 10 m.

The relationship between the roof thickness and the magnitude of the critical span will first of all be substantially more complicated (it is necessary to take account of the pressure of the upper layers on the lower layer, the friction between the layers, the inelasticity, the deformation in the rocks allowing for the time factor, the presence of defects in the rock sequence in the form of natural joints, etc.), and second, this relationship will be more significant, as emphasized by the results of comparing the behavior of uniform and bedded roofs in coal mines.

We shall now illustrate the essentials of the method now being developed in IGD (Siberian Branch of Academy of Sciences of the USSR) for controlling intransigent roofs, the coauthors of which are Bobrov and Posokhov [7].

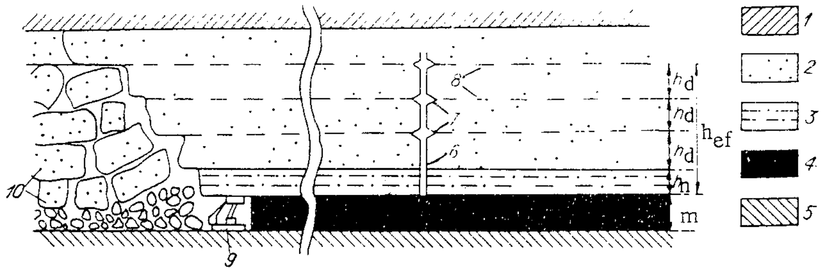

Fig. 2. Rock lying above main roof (1); main roof (2); immediate roof(3); coal (4); seat-earth (5); drillhole (6); annulus (concentrator of stresses) (7); artificial joints (8); support assemblage (or pillar) (9); worked-out space (10).

From the theory of jointing, it is known that in a solid, elastic, and stressed body in the restricted region of the end part of a joint, high stresses develop, under whose influence rupture may occur (extension of joints). To a greater degree qualitatively and diagrammatically than quantitatively, the magnitude of the stresses in the "tip" of the joint can be estimated from the formula

$$\sigma_m = 2\sigma(a/r)^{0.5}, \tag{8}$$

where 2σ is the stress at the circular notch; a, half-length of the joint; and r, radius of curvature of the joint in the end portion.

With values of a/r = 5, 10, 50, and 100, the coefficient of concentration of stress σ_m/σ will be respectively 4.5, 6.3, 14, and 20. In order to create high stresses in front of the joint, it is necessary to increase its length and decrease the radius of curvature in the end portion. This is seen from the table, the results of which have been calculated from formula (8).

For the stable propagation of a joint in a rock mass in a prescribed direction, it is necessary at the outset to create in it a concentrator of stresses in the form of an artificial macroembryonic joint with as great extent as possible and with a maximally pointed end portion, and to conduct a fluid (liquid or gaseous) into this structure under pressure, the elastic energy of which will "terminate" in the mass and create a tensional stress in it, under the influence of which an oriented fluid-rupture will take place in the necessary direction with the formation of an extended joint.

An analysis of geological data shows that in nature, intrusive bodies of layer- and platelike form exist, which have been formed during the process of fluid rupture of the rocks of the magma moving up from the depths (Fig. 1). The thickness of such bodies varies from a centimeter up to several tens of meters, and their extent, up to tens and even hundreds of kilometers. These geological bodies have been formed either by layer-by-layer fluid rupture (sills and lopoliths) or have been injected vertically or at an angle to the sequences and geological horizons (dikes and sills). It is significant that during geological fluid rupture, the layer- and platelike bodies under consideration intersect a large number of previously existing endogenic and tectonic joints. From an analysis of the geological data, it follows that oriented fluid rupture of the rocks can take place not only during the injection of magma, but also hydrothermal solutions, gases, and solid bodies, being in a plastic or quasiplastic state.

Whereas in inorganic nature, where vital activity is lacking and where extremely extensive geological bodies have been and are currently being formed under the influence of fluid rupture, the resolution of similar problems by technical means (e.g., the creation of extended joints) can also be considered achievable. We note that the breakdown of a rock mass as a result of tensional stresses is just as feasible energywise as other means of activity on the mass (compression, wrenching, bending, and buckling).

Figure 2 is a sketch of the workings of an intransigent roof. This represents a sector not affected by mining work, distant from cleaning-up operations, in the rocks of which drillholes have been sited perpendicular to the stratification. Several narrow openings (annuli) have been made in them as stress concentrators. In order to create such concentrators in the Mining Institute of the Siberian Branch of the Academy of Sciences of the USSR, several types of mechanisms have been developed, which have been tested on rocks. Each of these

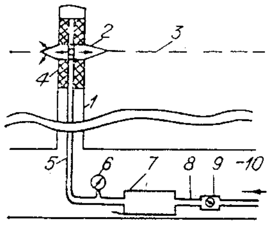

Fig. 3. Drillhole (1); annulus (stress concentrator) (2); joint formed during fluid rupture (3); packing (4); high-pressure pipe (5); manometer (6); pump with motor (7); low-pressure pipe (8); liquid flowmeter (9); preliminary generation (10).

mechanisms enables us to create an annulus in the rock mass with a diameter D_a of about $1.8 \cdot D_{dh}$, where D_{dh} is the diameter of the drillhole. Using different mechanical constructions, we can significantly increase the ratio D_a/D_{dh}. The annulus created is covered on both sides with packing, and liquid is injected under pressure into the space between. The scheme of technology of fluid rupture, shown in Fig. 3, should lead to the formation of artificial layered joints in the rock mass of the main roof. When using this method of hydrodynamic stratification for an intransigent roof, it is possible to improve the behavior of such a roof substantially, converting it into an easily or medium-demolishable form.

The length of the drillhole l_{dh} and the thickness of the rock affected, h_{ef}, may in the general case be determined according to the formula

$$l_d = h_{ef} = \{[m - h_n(k_n - 1)]/(k_0 - 1)\} + h_n, \tag{9}$$

where m and h_n are, respectively, the thicknesses of the coal seam and the immediate roof, and k_n and k_0 are the coefficients of disintegration of the rocks respectively of the immediate and the main roof.

The number of annuli, n, in the drillhole, or in other words, the number of extended joints within the main roof, is obtained from the expression

$$n = [m - h_n(k_n - 1)]/h_d(k_0 - 1), \tag{10}$$

where h_d is the distance between the annuli (artificial joints).

Since it is difficult to calculate the value of h_d in advance, it can be determined from measuring the thickness of the layers (distance between layering joints) in easily or medium-demolishable roofs. It is possible that such a method may turn out to be most worthwhile and effective, since it may be expected that after using the method of hydrostatic stratification of the rocks, the intransigent roof will react in the same manner for which the characteristic h_d has been determined.

The possibility of fluid rupture by the initiation of an oriented process of propagating joints by preliminary creation in a drillhole of a circular (annular) concentrator of stresses in the form of an annulus, oriented normal to the axis of the drillhole, has been considered. These and other forms of gaps, which may ascribe a different direction of propagation to the joint of fluid rupture, are shown in Fig. 4. Using different combinations of drillholes and annuli of a particular form with respect to the attitude of the main roof and the plane of the cleaning face, it is perhaps also possible to create a joint of fluid rupture not only in the direction of the stratification, but also to any angle to the plane of the roof. This also makes it possible to resolve other problems, for example, to break up strong rocks along an earlier-formed joint, oriented transversely to the plane of the roof, conforming with the line of the cleaning face, and in this way forming the necessary step toward lowering an intransigent roof.

If it is not necessary to have joints tens of meters long, then creating stress concentrators through drillholes in the rock mass, and operating along a directed rupture of strong rocks may be produced, not with hydraulic energy, but with explosion energy. The

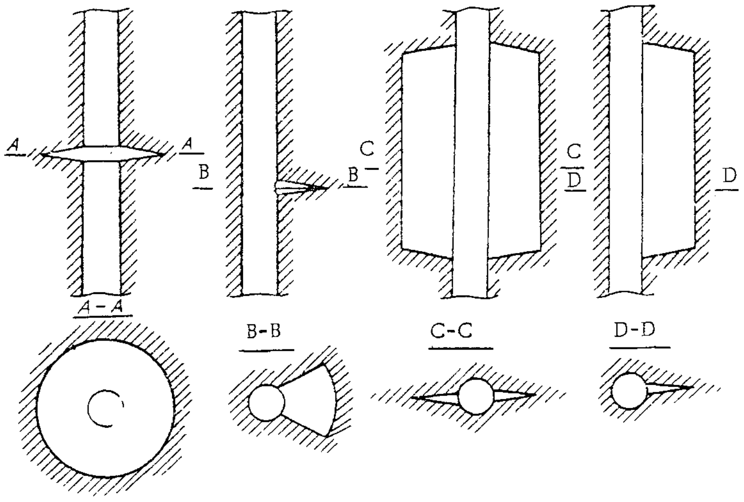

Fig. 4

choice of the method of operating on the rock mass must be determined, with allowance for the prescribed objective and the local conditions.

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