TWO PROBLEMS IN ROCK MECHANICS ARISING OUT OF
THE WORKING OF DEEP ORE OR COAL DEPOSITS

E. I. Shemyakin

Research of the stress-strain state of extensive rock masses, including that in the neighborhood of systems of underground workings, is becoming important as deep coal and ore deposits are being opened up, deep mines being planned and constructed, and systems for mining at great depths being created. This research is being done by geophysicists, mechanical engineers, and mining engineers, both in order to refine our basic ideas on the state of stress of the earth's crust and for practical purposes associated with mining at great depths. Depths have already been reached at which the stresses in the undisturbed rock are comparable with its strength (we arbitrarily call such depths "great"). At these depths such dangerous phenomena as shock bumps are more frequent and more hazardous; here we must reexamine the question of the "optimim" technology (e.g., work with continuous stowing). We can distinguish two main groups of problems in rock mechanics, the first of which involves assessing the initial state of the rock (before disturbance by human agency), estimating its stresses and principal displacements; the second involves strength calculations on the structural elements of systems of workings (development and main workings and the influence of extraction operations).

1.1. The first group of problems requires for its solution a further development of methods of estimating rock pressure in the "undisturbed" rock. Over the last 10-15 years this work has been extensively developed in the USSR, including the Siberian Division of the Academy of Sciences.

In recent years our general ideas concerning the need to develop methods of measurement have had the result that under the sponsorship of the Siberian Division there has been convened an All-Union seminar on the Measurement of Stresses and Deformations in the Solid Rock, and the first standardized issue of commercial instruments (about 50 items) has been made to research groups. The Commission of the Council for Mutual Economic Aid (SEv) for Mining Geophysics Instruments has created the first integrated set of load relief methods, and a second set is now being prepared.

The last decade has seen a number of important results. The concept of rock pressure has been refined: the pressure at any depth (the state of stress of the rock with three magnitudes of principal stresses and three principal directions of the stress tensor) is composed, for a given stratified and jointed structure, not only of the weight of the superincumbent rocks, but also of tectonic forces which differ from one region to another (Kola peninsula, Urals, Gornaya Shoriya, etc.). A second result, which has not yet been realized as it should be, is the introduction of these initial data into the practice of planning calculations, and the influence of the data on rock pressure and its variation during the course of mining operations on the selection of the principal types of systems of mining.

* The Seminar meets once in two years. In July 1975 the 5th All-Union Seminar was convened, including scientists from Leningrad, Moscow, Kiev, the Academies of Sciences of the republics of the Union, and important branch institutes.


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The introduction of these results is one of the most important present-day problems in mining science.

Methods of estimating rock pressure, mainly experimental ones, in turn require sound application of physical knowledge to mining science. This involves development of devices and experimental techniques and theoretical analysis of the behavior of rocks under pressure and at elevated temperatures (with allowance for irreversible deformations) — a combination necessary for the study of a complex and unusual object like rocks which are jointed and very varied in their mechanical and thermal properties.

1.2. To calculate the state of stress of the rock in the vicinity of a working, wide use is made of the mechanics of continuous media and mathematical models of the processes of deformation and breakage (elasticity, plasticity, creep, and brittle and tough fracture). Bulychev et al. [1] surveyed this branch of science as it is applied to the construction of underground workings.

In this article we will consider some new ideas on the strength standards of rocks and shall give practical conclusions for illustrative problems based on data found recently at the Institute of Mining of the Siberian Branch of the Academy of Sciences of the USSR [2, 3].

Professor M. M. Protod'yakonov introduced as the principal characteristic of rock hardness a quantity associated with the compressive strength. This characteristic proved to be very stable, has permeated all planning calculations, and is genuinely comparable between rock samples and the rock in situ.

The next important step involves the work of Professor G. N. Kuznetsov and his school, who put on a firm footing the information concerning the strength standards of rocks, reflecting two "strengths" — cohesion and friction [4-6].

Many authors [5-7] have discussed the strength of rocks on the basis of Coulomb-Mohr-Prandtl diagrams; this has led to the establishment of a relation for the envelopes of the Mohr circles in the form

$$T = f(\sigma_n). \tag{1.1}$$

Here $T$ is the maximum tangential stress, $2T = \sigma_1 - \sigma_3$, as a function of $\sigma_n$, the normal stress on the same area, $2\sigma_n = \sigma_1 + \sigma_3$; a uniform state of stress of a rock element is characterized by the values of the principal normal stresses,

$$\sigma_1 \geq \sigma_2 \geq \sigma_3^* \tag{1.2}$$

and the three principal directions.

Relation (1.1) reflects the main features of the behavior of rocks loaded to breaking point:

a) The difference between the strengths in uniaxial tests under compression ($\sigma_c$) and tension ($\sigma_t$); for rocks, unlike many solids, it is characteristic that $\sigma_t \neq \sigma_c$ and

$$\sigma_c \approx (2 - 10) \sigma_t \tag{1.3}$$

b) As the normal stresses $\sigma_n$ increase, on the slip area we observe an increase in the limiting value of the shear strength $T$; there is a section where $T$ is nearly proportional to $\sigma_n$. This reflects the manifestation of friction which prevents breakage (division into parts) of a rock specimen [8-10], and after fracture prevents relative movements between the parts.

c) For high and superhigh values of $\sigma_n$ the value of $T$ tends to a limit, which may possibly depend on the rate of loading [11, 12].

Bearing in mind (a) and (b) as the principal properties, for an approximate description of the strength standard we introduce two numerical characteristics of the arbitrary strength, the angle of internal friction $\varphi_\theta$ and the cohesion in kg/cm²; if property (c) is used in a problem it is necessary to take account of the angle of internal friction $\varphi_\theta$ and the limiting value of $T_\theta$.

Relation (1.1) is established only after construction of large Mohr circles and their

*In strength theory the following convention is commonly employed: compressive stresses are considered negative, while the critical values $\sigma_c$, $\sigma_t$, and $T_\theta$ are positive. 633