The method for determining the rock resistance to brittle fracture

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Abstract. In the paper the most common and rapid methods of determining the strength properties of rocks in domestic and foreign practice are considered. The authors proposed a fundamentally new way of assessing the rock resistance to brittle fracture. The developed method can be successfully used to determine the properties of rocks both on samples and outcrop of the massif, as well as in the wells drilled in the massif.

1. Introduction

Strength characteristics of rocks are one of the main factors that determine the rationale for making certain decisions in the mining industry and machine building. The most important among them are the coefficient of rock strength on the scale of Professor M.M. Protodyakonov and the tensile strength in uniaxial compression. The first indicator is used mainly in domestic practice and in the CIS countries, the second – abroad.

Rapid methods are of particular relevance when determining the strength properties of rocks, ensuring the prompt receipt of information in the conditions of mining. This article is devoted to the analysis of standard rapid methods for determining the mechanical properties of rocks used in domestic and foreign practice. In the paper the authors also propose a fundamentally new way of assessing the rock resistance to brittle fracture.

2. Standard rapid methods for determining the strength properties of rocks

Coefficient of rock strength and its tensile strength in uniaxial compression are used for calculation of the parameters of mine workings support, performance of drilling and blasting operations, and also for determining the required technological measures in mines that develop coal seams prone to rock bumps and sudden coal outbursts.

The considerable labor content and low efficiency of laboratory methods used for determining the physical and mechanical properties of rocks contributed to the development and application of rapid methods that allow the research to be performed in the conditions of in-situ rock.

The main features of such methods are:
- the possibility of carrying out studies on samples of irregular shape;
- rapidness of analysis;
- simple implementation in the conditions of mining;
- obtaining of acceptable result with a small number of measurements.

In foreign practice, the rapid methods for determining the strength properties are used: method for determination of the Schmidt Hammer rebound hardness [1,2], method for determination of the Shore scleroscope hardness [2,3], method for the needle penetration test [4], method for determination of the

point load strength index of rock [5]. These methods are generally recognized and recommended by the International Society for Rock Mechanics (ISRM).

These methods are based on the determination of indirect indices (Schmidt hardness, Shore hardness, needle penetration index, rock strength index) characterizing the strength properties of the rock, with further switching to standard strength characteristics or technological parameters of the mining equipment operation [6].

The method of measurement by the Schmidt hammer (figure 1) is based on the determination of the shock pulse that appears after the impact by the striker on the rock with a given force. The strength properties of the rock under study are determined by the height of the striker rebound according to the established calibration curve.

The Shore scleroscope (figure 2) is based on a similar principle of action with the only difference that the impact of the striker is carried out by free fall from a constant height. The value of hardness is estimated according to the height of the striker rebound.
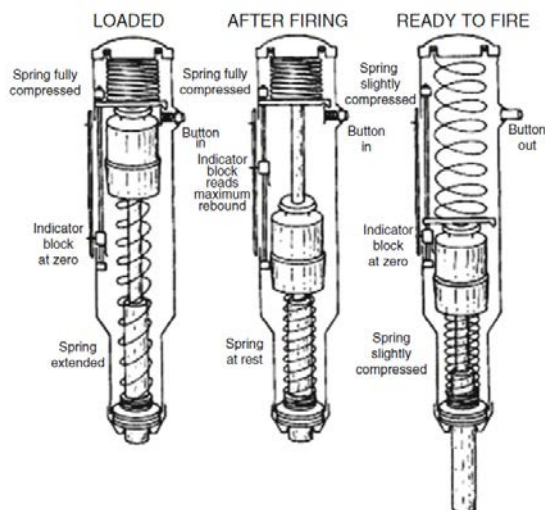

**Figure 1.** Working principle of a Schmidt hammer [1].
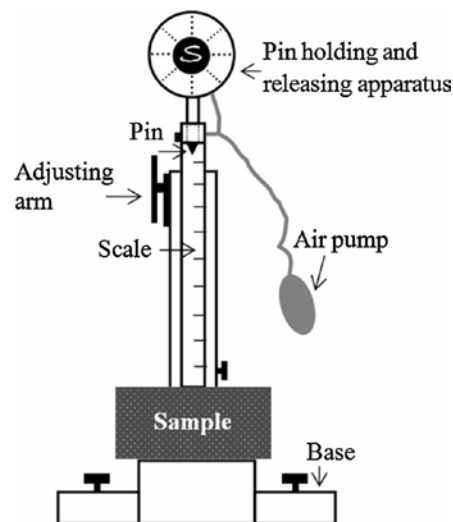
Figure 2. Schematic view of a Shore scleroscope instrument [6].

The properties of the rock using the penetrometer (figure 3) are determined according to the needle indentation index, which is defined by the impact of a special needle on the rock and is calculated depending on the its penetration depth and the load required for it. The needle is made of hardened steel and is a rod 0.84 mm in diameter, ending with a conical tip (figure 4). This sewing needle, designated as JIS S 3008 (No. 2)
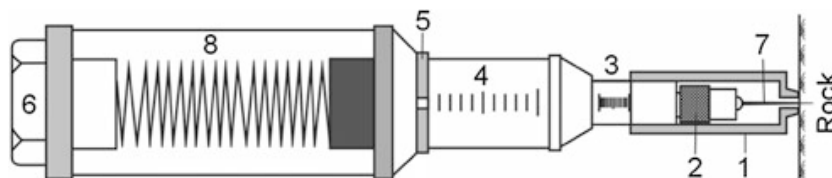

Figure 3. Needle penetrometer and its parts: 1 – presser, 2 – chuck, 3 – penetration scale, 4 – load scale, 5 – load indicating ring, 6 – cap, 7 – penetration needle and 8 – spring [4].
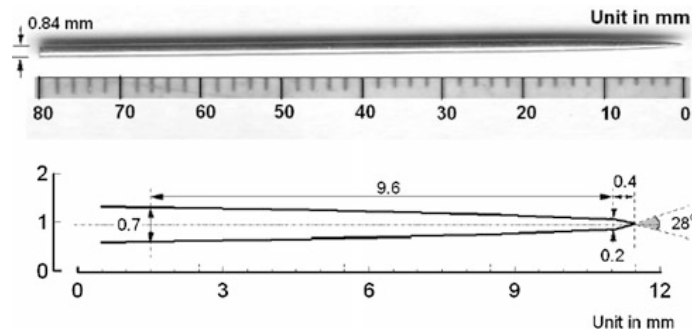
Figure 4. Sewing needle designated as JIS S 3008 (No. 2) and its geometry [4].

The point load method is realized by crushing the samples between conical punches (figure 5) with the fixation of the force necessary for their destruction. In accordance with the recommendations of the International Society of Rock Mechanics, the method can be used for core tests with diametrical or axial load applications, as well as for testing block or lumpy samples. The result of the tests is the rock strength index, on the basis of which it becomes possible to calculate the ultimate strength for uniaxial compression according to the correlation dependence.

(a)	(b)
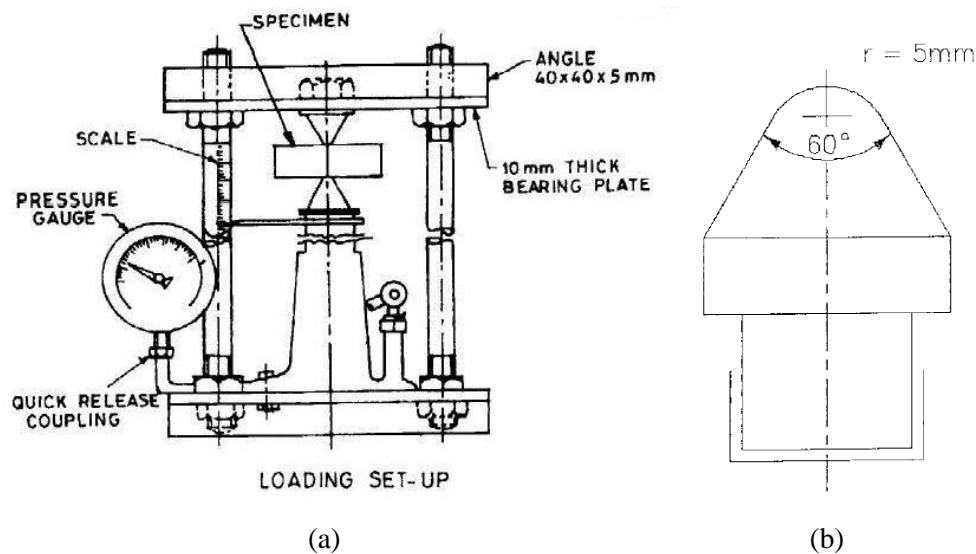
Figure 5. Schematic view of a Point Load Testing Machine (a), platen shape (b) [5].

Such rapid methods as the method of determining the hardness coefficient on Protodyakonov scale Russian National Standard (GOST) 21153.1-75 and the method for determining the contact strength (GOST R 50834-95) are used among numerous standard methods in Russia.

Determination of the hardness coefficient in accordance with GOST 21153.1-75 is carried out on samples of irregular shape by dropping the load with the help of a special device POK-1 (figure 6). The device POK-1 consists of a cup – 1, with inserted in it a tubular impactor – 2, balance weight – 3 of 2.4 kg with a handle – 4, to which the twine is tied. The tubular impactor has in the upper part a limiter of the weights lifting – 5 to a height of 0.6 m. The device kit includes a volumeter, consisting of a cup – 6 and a plunger – 7 with a measuring scale, and a sieve with a hole size of 0.5 mm for screening the crushed pieces of rock samples. Determination of the strength is carried out on the basis of the fraction volume of the crushed rock after screening.
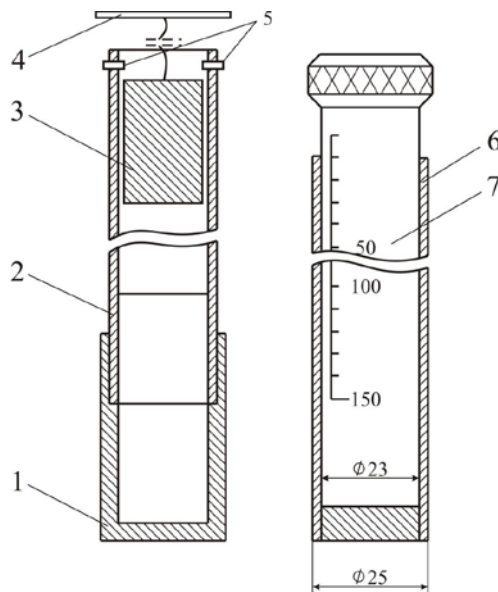
Figure 6. Scheme of the device POK-1 for determining the rock strength by the method of grinding in accordance with GOST 21153.1-75.

Determination of contact strength in accordance with GOST R 50834-95 is carried out by pressing indenters from a hard alloy with flat round bases $d_1 = 1.0 \pm 0.1$ mm and $d_2 = 3.0 \pm 0.1$ in diameters, having the form of a truncated cone with an angle at the apex 60° (figure 7). The contact strength is determined based on the values of the destructive force obtained by pressing indenters with smaller and larger bases. The advantage of this method is the ability to perform measurements by pressing the indenter into the borehole wall.

(a)   (b)
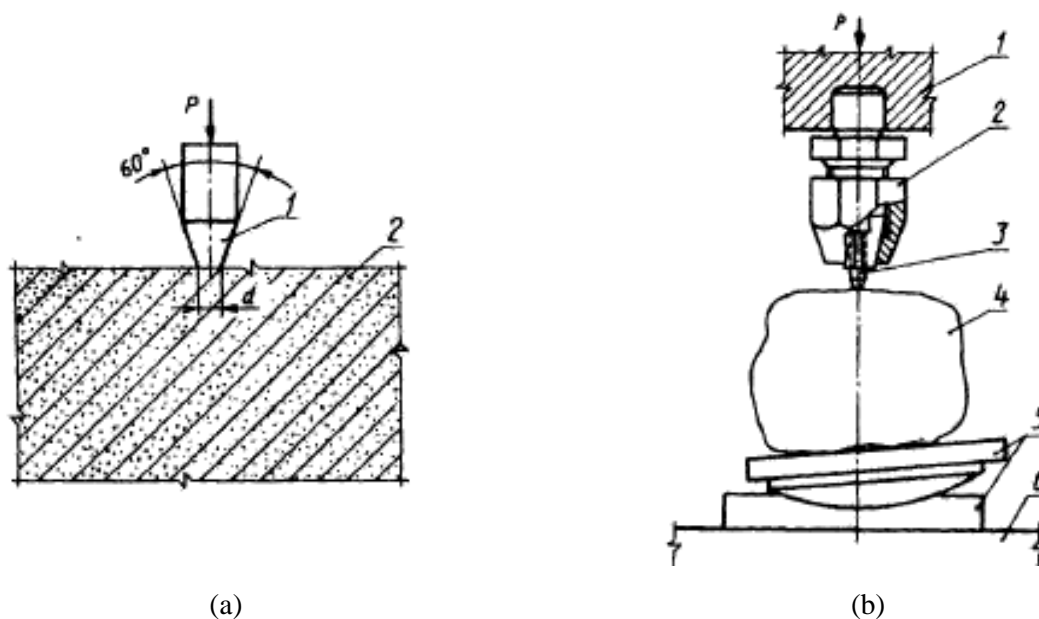
Figure 7. Determination of the contact strength according to GOST R 50834-95 (a) the rock loading scheme (1 – indenter, 2 – rock, d – indentor diameter, P – applied force), (b) load device diagram (1 – upper press plate , 2 – clamping chuck, 3 – indenter, 4 – sample, 5 – spherical joint, 6 – lower press plate, P – applied force).

3. Results and discussion

Existing standard express methods, with the exception of the method for determining the contact strength according to GOST R 50834-95, can be used only in the study of rock samples and outcrops of the massif. However, mining practice has shown that for the implementation of various technological tasks, the information on the properties of rocks in different sites of the massif is often required.

Performance of cores examination by the above given methods is rather labor-consuming and takes long time, as in this case the core drilling is required. The use of the method for determining the contact strength in the well according to the recommendations of GOST R 50834-95 does not provide with the objective data for a number of reasons.

First, in accordance with this method pressing of indenters in the form of a truncated cone into the cylindrical surface of the borehole wall leads to the formation of a stress concentrator and the destruction of the rock with less effort, which distorts the measurement results.

Second, the small contact surface of the indenters used in the method does not allow reliable information to be obtained about the rock resistance to brittle fracture.

Third, the method lacks the analytically justified mechanism for interpretation of the massif properties by the fixed indicators.

In addition, in accordance with the method the use of two indenters with different diameters of the contact surface complicates the research and makes it last longer in time.

Taking this into account, the authors have developed a method to determine the rock resistance to brittle fracture [7], which can be successfully used for studying the properties of rocks both in samples and massif outcrops and in wells drilled in the massif. In accordance with this method, the strength properties of rocks are determined by the magnitude of the effort required for brittle fracture of the rock by the indenter of a special shape.

The indenter used in the method is shown in figure 8, where: 1 – the body of the indenter made in the form of a straight circular cylinder with diameter D, equal to its length L; 2 – ends of the indenter having roundings with radius R equal to the radius of the straight circular cylinder forming the body 1 of the indenter, 3 – the rock under test, P – the force applied to the indenter. The action of the indenter on the rock 3 to be destroyed is carried out along the generatrix of the quadric cylinder forming the body 1 of the indenter. When measuring in wells, the indenter is positioned in such a way that the generatrix of the cylinder constituting its body is directed parallel to the generatrix of the cylindrical surface of the well.
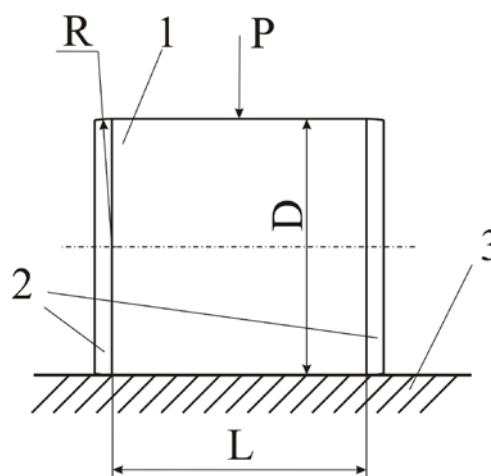
Figure 8. The indenter used in the proposed method [7].

Taken into account the ideas of K.V. Ruppeneyt considered in [8] for the simulation of rotary drilling, the minimum volume of rock that retains its properties can be represented in the form of a cube, on each facet of which there must be at least 30 rock-forming grains. In this case, the length τ of the edge of such cube can be related to the average grain diameter d by the dependence:

$$\tau = 6.7d \tag{1}$$

Taking real dimensions of the grains of homogeneous rock within 0.1 ... 1.0 mm, it can be determined that the length of the edge of the cube of minimum volume should be not less than 6.7 mm. Thus, the length L of the indenter body in the developed method is assumed to be not less than this value.

4. Conclusion

The feature of the proposed method is the use of the indenter with rounded ends, which makes it possible to exclude the presence of a stress concentrator. As a result, it becomes possible to obtain acceptable measurement results without thoroughly ensuring the parallelism of the cylinder generatrix and the rock.

An advantage of the method is also the possibility of achieving the indenter penetration into the rock under the study with a slight effort. This effect is due to the fact that at the initial stage of the measurement the interaction of the indenter with the rock takes place only along the thin line of contact, which is the generatrix of a quadric cylinder forming the indenter body. This feature, on the one hand, ensures the coverage of the required amount of rock grains to achieve an acceptable measurement accuracy (in comparison with the cylindrical and conical indenters), and, on the other hand, the possibility for conducting studies in wells where the use of indenters with a flat contact surface does not allow reliable results to be obtained.

Determination of the rocks properties of samples in accordance with the developed method is supposed to be carried out on a manual hydraulic press. To perform the research in the well conditions, the authors proposed a special device Strength Tester PSSh-1 ("PSSh-1") [9].

Determination of rocks strength properties by the developed method is supposed to be carried out with the help of empirical dependencies involving the known analytical equations of the theory of contact problems. A detailed description of the theory of contact problems can be found in the works of I.Ya. Shtayerman, A.I. Lurye, S.D. Ponomarev et al. [10-12].

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