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IMPROVEMENT OF ACOUSTIC METHODS OF STUDY OF QUALITY AND RELIABILITY OF CAST-IN-SITU CONCRETE CONSTRUCTIONS IN THE CONDITIONS OF MINE OPERATIONS

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In the process of mine workings, when a top-down mining of minerals is taking place, one of the most important conditions to prevent accidents is a safe artificial roof of underground workings. The material used for roof making is the cast-in-situ cement-sand concrete of low strength. The peculiarities of the roof manufacturing technique predetermine, in a number of cases, concrete stratification leading to decrease in artificial roof's strength. This, in its turn, may cause the roof collapse and, as a result, traumatize the workers. By analyzing the physics of the process of the elastic wave interaction with a solid-state body, one can make a conclusion on a theoretical possibility to cope with the above-stated problem. Propagation of elastic waves in a solid-state body with structural inhomogeneities – material stratification, macro- and microcracks – is accompanied by the change of the acoustic wave parameters (like, for example, propagation velocity, amplitude, spectral components) depending on the acoustic wave amplitude-frequency characteristics. The problem of the development of the research technique and instrumentation for its application has been solved, taking into account physical-and-mechanical properties of cement-sand concrete, changes of the characteristics of a sounding signal as it propagates in the composite material under consideration, and dimensions of the anticipated structural concrete inhomogeneities, whose detection makes up the solution of the considered problem.

One of the most important preconditions to prevent accidents during mining operations, when a top-down mining of minerals takes place, is a safe artificial roof of underground workings. The material used for roof making is the cast-in-situ cement-sand concrete of low strength. A concrete mix, in this case, is transported by concrete haulers and delivered under pressure to the necessary place through a concrete pump. Some peculiarities of the production technique of this construction element of mine workings predetermine, for a number of cases, horizontal stratification of concrete. The dimensions of such structural rupture of concrete may amount to several square meters at undefined depth of location of a concrete stratification layer.

This effect may be caused by a long enough period of interruption in concrete supply, when covering the artificial roof with concrete. This may occur, for example, because of the processing equipment failure or violation of the technology of concrete mix preparation. In the first case, the formation of a cast-in-situ concrete stratification layer is due to appearance of an air space between the first and the second layer. In the second case, the formation of a stratification layer is caused by the difference in concrete strength in the layers. Here, a decrease in strength of the artificial roof takes place, which may lead to its collapse and, as a consequence, to industrial injuries and stop of mining operations.

The methodologies dealing with seismic studies of materials in a solid monolith and observation of seismic characteristics allow one, in principle, to tackle the problems of this type [1]. However, a practical use of these methods, if applied to the problem under consideration, comes up against a number of objective challenges, the main of which are unavailability of the necessary mobility of equipment, rather laborious preparatory works, and unsatisfactory resolution of the methods. Also, an essential disadvantage of the methods, if applied to solving the above problem, is the necessity to perform the lower-power blasting operations that involve drilling the auxiliary bore-holes as an integral part.

In addition to the above stated, recent trends are toward increased use of cast-in-situ concrete in the different fields of construction. Also, a periodic examination of the existing buildings, constructions and structures, which contain construction elements from cast-in-situ concrete, is vital.

The above statements witness that the problem of development of the technique and equipment for the study of the concrete structure in a monolith becomes more pressing.

One of the currently existing and widely used methods of non-destructive material quality control – the ultrasonic impulse method – makes it possible to solve the problem of the study and detection of concrete's structural inhomogeneities [2,3]. However, the specifics of the method does not permits one to carry out the study of the cement-sand concretes of low strength in a monolith. This is connected with the fact that, owing to its structural peculiarities, concrete is a physical filter for high frequencies. Therefore, the available technical solutions allow one to apply the ultrasonic impulse method of detecting the concrete stratification layers in the artificial roof of mine workings only in the regions bounded by the distance from the receiving to emitting transformers of no more than L= (10-20) cm. Besides, application of such solutions is characterized by insufficient reliability of the results of control and considerable labour-intensiveness, since the drilling of auxiliary bore-holes in roof's concrete is needed.

At the same time, the analysis of the physics of the process of elastic waves-solid body interaction permits one to conclude on the feasibility of solving the stated problem from a conceptual point of view [2].

Propagation of elastic waves in the solid-state body with structural inhomogeneities – material stratification, macro- and microcracks – is accompanied by the changes of wave parameters (for example, velocity of propagation, amplitude, spectral components), depending on the wave amplitude-frequency characteristics [2,3].

Based upon this fact, the formulation of the problem dealing with the development of the relevant technique and control equipment has been made. Here, the physical-and-mechanical properties of cement-sand concrete, the changes of the sounding signal characteristics as the signal propagates in the studied composite material, and dimensions of the suggested structural concrete inhomogeneities, the detection of which makes up the solution of the problem under consideration, were taken into account.

The essence of the technique consists in using a longitudinal surface profiling of the roof's concrete. Emission of the elastic wave signal takes place at certain frequency using the piezo-electric transformers. Information signals are received in a number of points distributed over the studied region of concrete of the artificial roof. A set of the measured characteristics of the received signals is processed according to a specially designed algorithm. Further analysis of the data obtained allows one to establish availability/unavailability of the concrete stratification layer and calculate its sizes, depth and location. From the obtained final results one can conclude on the degree of reliability of the studied construction element made of cast-in-situ concrete. An important element of the developed technique is the elimination of the necessity of drilling the auxiliary bore-holes to carry out measurements [4,5].

A preliminary construction of the correlation dependence "elastic wave propagation parameter – concrete strength" makes it also possible to determine the concrete compression strength in the studied regions of the artificial roof or any other object to be controlled, which is in accordance with the existing standards.

The specialized portable acoustic equipment (PAE) employs the suggested technique. It is developed with regard to the specifics of measurement performance and provides maximum simplicity of measurement, trustworthy results and operational reliability.

In Fig.1 is shown the simplified functional scheme of the equipment, and in Fig. 2 is presented the outward appearance of its outer units [6].

The specialized portable acoustic equipment is operating as follows.

At first, prior to the measurements, the emitting (1) and receiving (2) piezoelectric transformers are fastened on the surface of concrete (3) of the studied construction. The power supply is given. The automatics unit (4) generates the driving pulse which simultaneously activates the sounding impulse generator (5), oscillograph (6) and digital meter (7). Here, the piezoelectric emitter transforms the output signal of the sounding impulse generator into the elastic wave that is introduced into the concrete of the construction under consideration. The information signal arrives at the receiving transformer (2) and is amplified by the amplifier (8) up to the necessary amplitude. The information signal parameters are recorded by the oscillograph (6) and digital measuring device (7). At the next stage, the receiving transformer moves about the concrete surface with discrete mounting in the points *a, b, c…i*, where similar measurements are performed.

If there is a structural inhomogeneity (9), the received information signal parameters are subject to changes. Further processing of the received data allows one to reveal an essential concrete stratification and determine its geometrical characteristics – dimensions and depth of location.

In particular, the above development has been used for diagnostics of the artificial mine working roofs of cement-and-sand concrete with strength R_{comp} = (1 – 10) MPa .

In the course of measurement, the PAE-3 emitter was placed in some point on the surface of the studied construction, and the receiver was installed successively along the concrete profile with the step l_i = 0,5 m.

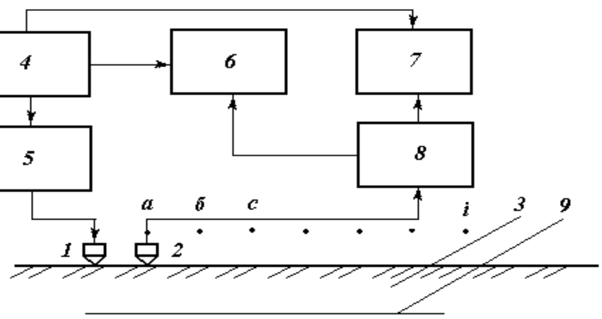

Fig.1.- Portable acoustic equipment for studying the concrete quality in a solid monolith. Functional scheme. 1 – emitting transformer; 2 – receiving transformer; 3 – studied concrete; 4 – automatics unit; 5 – sounding impulse generator; 6 – oscillograph; 7 – digital meter; 8 – amplifier; 9 – concrete defect.

The implementation of the developed technique and the relevant equipment allowed one, for example, to find that at a depth H = 0,8 m there was a stratification layer due to the difference in concrete layer strength at one of the studied locations of the artificial roof concrete.

The revealed stratification layer of the roof's concrete was probably due to stop or interruption in supply of a concrete mix used for construction making.

It is likely that this was caused either due to equipment malfunction that led to formation of the concrete stratification layer, or violation of the technology of preparation of the mix used for concreting the upper layer of the construction.

Investigation of the possibility of determining the concrete's compression strength (R_{comp}) employing the developed technique and equipment has also been specified when formulating the problem of the measurement experiment.

For this purpose, a preliminary construction of the correlative curve "elastic wave parameter – concrete's compression strength" ($V – R_{compr}$) has been carried out. A cycle of on-site measurements has taken place, which allowed one to determine some specific values of concrete's strength at the compression in the given layers.

Thus, an average strength of concrete in the roof's lower layer is R_{compr} = (0,8 - 1,2) MPa. The concrete strength of the lower layer is R_{compr} = (1,5 - 1,6) MPa [7].

The described diagnostics of concrete-sand low strength concrete, which employed the developed technique and portable acoustic equipment, has been duplicated by the measurements performed on the basis of the known ultrasonic impulse method.

In order to apply this method for the same regions of the artificial roof, several paired parallel auxiliary bore-holes have been drilled, with the emitting transformer installed in one and the receiving transformer – in the other. The measurements using the ultrasonic technique were performed to test for availability of concrete structural inhomogeneities and concrete strength value (R_{compr}), which were determined through the use of the developed technique and appropriate equipment.

The comparison between the measurement data obtained by means of the developed acoustic control technique and PAE and the data obtained by means of the ultrasonic impulse method has shown good agreement (to sufficient reliability) in values related to depth and locations of concrete stratification of an artificial roof.

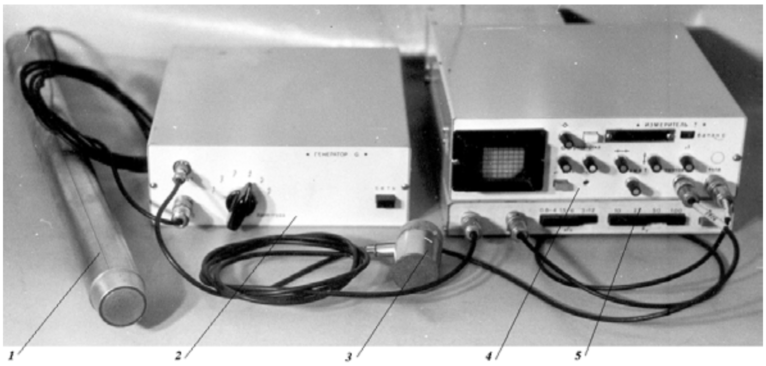

Fig.2 – Portable acoustic equipment. Outward appearance. 1 – emitting piezoelectric transformer; 2 - sounding impulse generator unit; 3 – receiving piezoelectric transformer; 4 – indication unit; 5 – amplifier unit.

The discrepancy between the values of concrete compression strength measured by the use of each of two methods is 5-8%.

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