Ultrasound methods and means for examination of physical and mechanical properties of rocks

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Abstract. The paper gives an overview of main ultrasound methods applied in examination of physical and mechanical properties of rock. Main types of interference arising in ultrasound examination of rock properties are considered, as well as methods for their suppression.

1. Introduction

Obtaining reliable information on stress-deformation condition of a rock mass is one of the main tasks solved in geological examination. Such information is widely used both at the design stage and during the operation of underground facilities (justification of blasting design, assessment of rigidity of rock exposed by excavations, determination of stable operating modes of extracting machines). Ultrasound examination methods have found a wide range of applications in studies of physical and mechanical properties of rocks. Ultrasound is widely applied due to the fact that the studies may be performed with practically no interference from limiting surfaces. Due to a short wave length, a beamed ultrasound radiation is possible. Ultrasound studies allow not only determining the properties of rock, but explaining the physical nature of underlying phenomena as well.

2. Methods of Ultrasound Examination

Application of ultrasound methods shall be determined by the goal of studies being performed: for laboratory measurements of examination of physical and mechanical properties of rock in a rock mass. The laboratory methods of examination may be divided into two groups: direct and indirect ones [1]. The speed of sound in direct measurements is calculated from the ratio between the sample length to the period of wave propagation through the sample, in indirect measurement it is obtained by multiplying the wavelength and a given oscillation frequency [2]. In addition, the two groups may be further classified from several other properties: signal acquisition method, acoustic contact method between the transducer and the sample, type of radiated waves. Depending on location of the ultrasound receiver and transmitter, there are echo method, longitudinal profiling method and sounding.method. In echo method studies, the transmitter and receiver are put on the same side of the sample, unlike in the sounding method, where the receiver and the transmitter are on the opposite side of the sample. In sounding and echo method, both the transmitter and the receiver are stationary, which differs them from the longitudinal profiling method. In longitudinal profiling, the receiver is moving along the straight line (observation profile), while the transmitter is stationary.

By the nature of acoustic contact between the transducer and the sample, the ultrasound examination methods are divided into contact method and immersion method [3]. In the contact

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method, a special contact substance that improves wave transition between the transducer and the sample is applied onto the surface of the sample. In case of the immersion method of measurement, the transmitter and the receiver are located at a certain distance from the sample, while transmission and acquisition of ultrasound vibrations proceeds through a liquid.

In ultrasound examination of rock properties, compression, shear and surface waves have found their application; they define selection of a certain examination method as well as selection of a piezoelectric transducer type. In laboratory studies of physical and mechanical properties of rock, shadow and time-shadow methods are used [3].

The methods for detection of stress-deformation condition of a rock mass are based on interaction of the ultrasound wave with the rock that lead to changes in parameters of the wave, which becomes a carrier of measurement data. Most often, it is the propagation speed of compression and shear waves, and attenuation rate. When determining stress values in a border zone, ultrasound sounding, ultrasound logging and reflection method are used.

3. Ultrasound sounding method

The ultrasound sounding method is one of the most common methods used to determine the stress-deformation state of a rock mass [4]. In this method, the measured area is located in between the ultrasound receiver and transmitter. Most commonly, this method is applied to studies of spacial distribution of stress in the vicinity of excavation and tracking its change over time. The method involves drilling parallel shot holes from the excavation following a circular or a triangular scheme, and placing probes in the shot holes. In one probe, its transducer is used as a receiver, in the opposite one it is used as a transmitter. Then the probes are moved into the depth of the rock mass, synchronously and with a preset approach and time increment values. One of the most important conditions is to ensure reliable acoustic contact during every movement of the probe. At each step of the movement, compression wave propagation speed is measured, its spacial distribution characterizes spacial distribution of stress values. The distance between the shot holes is usually under 0.6 m and depends on accuracy in determining the distance between the shot holes, allowable error in the compression wave propagation speed measurement and error in measuring the time of the compression wave propagation. The operating frequency of the transducers used in this method usually ranges from 60 to 100 kHz.

4. Reflection method

The ultrasound reflection method is based on radiating an ultrasound signal into the monitored space with further registration of its reflected signal [4]. This method is not as common as the sounding method, which may be explained by significant loss of signal strength between the transducer and the reflecting surface or a non-uniformity. However, in rocks with insignificant attenuation of elastic wave it gives more accurate results than the sounding method. This method involves drilling two parallel shot holes in the rock mass. One of the shot holes is the measuring one. A combined or dual-element transducer is placed into it. The second shot hole is used as a reflective surface. The information parameter obtained by measuring with this method is the ratio of amplitudes of diffracted waves, primary reflections and double reflections from the given boundary. This ratio measured at various distances from the excavation limit, characterized the spacial distribution of stress values.

The reflection method may be also used to determine the complete stress tensor in the rock mass. For that end, the measurements shall be performed in the sidewalls and the roof of the excavation. As a result of the measurements, lines will be obtained that characterize distribution of the elastic wave speed in various directions: compression wave stress-director line [1]. The stress-director lines have a form of an ellipsis or a circle. Their form allows making conclusions on the direction of the stress tensor. At the highest vertical stress in the rock mass, the stress-director lines will be elliptical or circular in the roof of the excavation, while in the side walls they will be ellipses with a prolonged vertical axis. If the form of the stress-director line in the walls of the excavation is an ellipsis with an

elongated horizontal axis, then the stress is horizontal. If the form of the stress-director lines is close to circular in both roof and side walls of the excavation, the stress in the rock mass is uniform [1].

5. Ultrasound logging method

It is an examination method based on studying the acoustic characteristics of the rock adjacent to a well. It is implemented with a single well probe that includes one transmitter and several receivers. The probe is moved along the axis of a water-filled or dry well. From the nature of distribution of the acoustic characteristics along the profile, a conclusion is made on the nature of stress distribution in the border rock mass [4].

6. Shadow and time-shadow examination methods

Attenuated amplitude of waves having passes through the monitored item serves as an evidence of a defect in the shadow method. The shadow method examination may employ an inspection instrument operating on the basis of a split scheme, that is, with functional separation of transmitting and receiving transducers. Shadow method of examination does not use contact transducers, instead it employs local immersion and slit transducers [3].

Local immersion transducers differ from immersion transducers in that the cumbersome liquid bath used in the immersion examination methods is replaced with a compact bath provided with an elastic membrane made of polyurethane with characteristic impedance close to that of water. This condition is necessary to avoid echo signal on the membrane and liquid contact surface. The transducer itself is made in the form of a roller, thus allowing the transducer's membrane to cover the irregularities of the object's surface, which results in improved productivity of examination. A local immersion transducer consists of: piezoelectric-crystal plate, a case with an elastic membrane with immersion fluid inside it.

In a slit transducer, the liquid is supplied directly onto the object of examination through a nozzle. The contact liquid fills the structural gap between the transducer and the object; the gap is usually adjustable.

A disadvantage of the shadow method is a necessity for access to two sides of the examined object. Besides, a serious disadvantage of the shadow method is a significant level of error in readings of the instrument registering the level of passed signal due to instability of acoustic contact of both transducers with the sample. Neither the shadow method provides any information on coordinates of a defect.

A time-shadow method is based on the fact that the path of ultrasound vibrations that envelope a defect is longer than the direct path through the examined object. Presence of defects in rock is determined with low frequency oscillations by delayed arrival of the pass-through signal to the receiver. Examination with this method is performed with an impulse inspection instrument provided with a strobing system that allows accurate determination of the time of arrival of the pass-through signal. An extremely short duration of the strobing impulse is determined by changes in thickness of the examined object and changes in the speed of sound in the material.

7. Interferences and methods of their suppression

In the shadow method of examination, where the presence of a defect is determined by changes in the amplitude of a signal having passed through the sample, any perturbation leading to attenuation of pass-through or back wall signal shall be deemed an interference [3]. On that basis, high requirements are put to the quality of the acoustic contact. An accidental deterioration of the acoustic contact leads to the system showing an imaginary defect. The main method to suppress this type of interference is to use slit and immersion type transducers.

The next type of interference typical for the shadow method is axial malalignment of the transducers. This problem is solved with adjustment of the transducers and provision of a design mechanism for rigid fixation of the transducers onto the object [3]. In addition, interferences in the shadow method of examination may cause resonance phenomena in the object, leading to an abrupt changes in propagation of ultrasound through the examined object. An impulse mode is employed to

suppress the interference. A duration of an impulse shall be shorter than the total travel time of the wave. This condition shall be met, so that the impulses having passed through the object and reflected in it arrive at the receiver at different time and do not interfere with each other.

When examining rocks, issues arise due to changes in absorption and scattering of ultrasound. Changes in structure of the rock may lead to increase attenuation of ultrasound in the areas of larger crystals (coarse-grain zones) and to reduced attenuation in fine-grain zones [3]. Attenuation of back echo signal due to this type of interference is often erroneously interpreted as finding a defect in the sample. An efficient method to suppress the structural interference is to employ the time-shadow method to studies of rocks. As sensitivity of the time-shadow method is practically independent of frequency, for rock types with large attenuation coefficient the frequency may be significantly lowered to obtain necessary amplitude of pass-through signal.

8. Conclusion

From analysis of ultrasound methods applied to examination of physical and mechanical properties of rocks, a conclusion is made that an important and necessary factor ensuring veracity of ultrasound examination is provision of reliable acoustic contact between the transducer and the studied sample. This issue is partially solved in immersion methods of examination, but their application is complicated by multiple reflections of the sound waves at the phase boundary. As the rock mass is non-uniform in its composition, structure and physical and mechanical properties, it rules out generation of simple analytical methods for calculation of stress-deformation state of rock masses. For the foregoing reasons, a conclusion may be made that the role of experimental ultrasound examination methods will become greater. As the depth of deposits in development steadily increases each year, and reliable data on the condition of the rock mass is necessary to ensure safety at the deposit and to make right design decisions, finding analytical descriptions of ultrasound propagation speed and attenuation coefficient as functions of pressure in the rock mass becomes a more important field in studies of stress-deformation state of rock mass.

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