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MEASUREMENT OF THE VELOCITY OF ULTRASONIC WAVES OF DIFFERENT FREQUENCIES ON GRANITE SAMPLE (STRZEGOM, POLAND)

MĚŘENÍ RYCHLOSTI ULTRAZVUKOVÝCH VLN RŮZNÝCH FREKVENCÍ NA VZORKU ŽULY (STRZEGOM, POLSKO)

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Abstract

Recognition of the impact of cracks on the strength of the massif is necessary due to the use of the obtained results for design and engineering purposes, for example, in constructing a tunnel or studying the stability of the geological medium. The study was performed by ultrasonic tomography to visualise cracks in a granite rock sample taken from a granite quarry in Strzegom, located in southwestern Poland. Two transducers with a frequency of 54 kHz and 250 kHz were used in the measurements to test the effect of the selection of the frequency of the transducer on the size of the granite sample. The comparison of the final results showed differences in the obtained P-wave velocities. Therefore, selecting the appropriate transducer frequency for the selected sample is an important step in planning the measurements.

Abstrakt

Rozpoznání vlivu trhlin na pevnost masivu je nutné z důvodu využití získaných výsledků pro projektové a inženýrské účely např. při stavbě tunelu nebo studiu stability geologického prostředí. Studie byla provedena pomocí ultrazvukové tomografie za účelem vizualizace prasklin ve vzorku žulové horniny odebraném z žulového lomu ve Strzegomi, který se nachází v jihozápadním Polsku. Při měření byly použity dva měniče s frekvencí 54 kHz a 250 kHz pro testování vlivu výběru frekvence měniče na velikost vzorku žuly. Porovnání konečných výsledků ukázalo rozdíly v získaných rychlostech P-vlny, proto lze usoudit, že výběr vhodné frekvence měniče pro vybraný vzorek je důležitým krokem při plánování měření.

Key words

Ultrasonic method, the size of a rock sample, granite rock mass

Klíčová slova

Ultrazvuková metoda, velikost vzorku horniny, žulový horninový masiv

1. Introduction

Ultrasonic methods for non-destructive investigation have a broad spectrum of use. This method can be used to accurately describe the fracture development and strain localisation during rock deformation (Ezersky, 2017; Zhu et al., 2022) or for non-destructive evaluation of the weathering state on a marble obelisk, considering the effects of structural properties (Menningen et al., 2018) but also to evaluate the degree of weathered granite rock masses (Lednická and Kaláb, 2016), which allows for the identification of the weathering grade of the rock massif and/or cracking of the surface layers. The elastic wave velocity measured in rock allows to know its physical properties. Seismic wave velocity can be measured both in the field and in the laboratory (Barton, 2007; Mavko et al., 2009; Živor et al., 2011), but the laboratory measurements allow for recognition of the rock's internal structure. Ultrasonic transducers measure the ultrasonic velocity at both ends of the rock sample. Using many combinations of ultrasonic transducers on the rock surface and obtaining many wave transit times for different paths makes it possible to perform tomography of the sample (Zhu et al., 2022).

One of the most important things during the measurements is to select the frequency of the transducer to the size of the study object. The minimum recommended sample size depends on the transducer frequency and pulse rate. This article aims to show the impact of the selection of the transducer frequency on the sample size and to evaluate the results obtained on the example of a granite sample from a quarry in Strzegom, Poland.

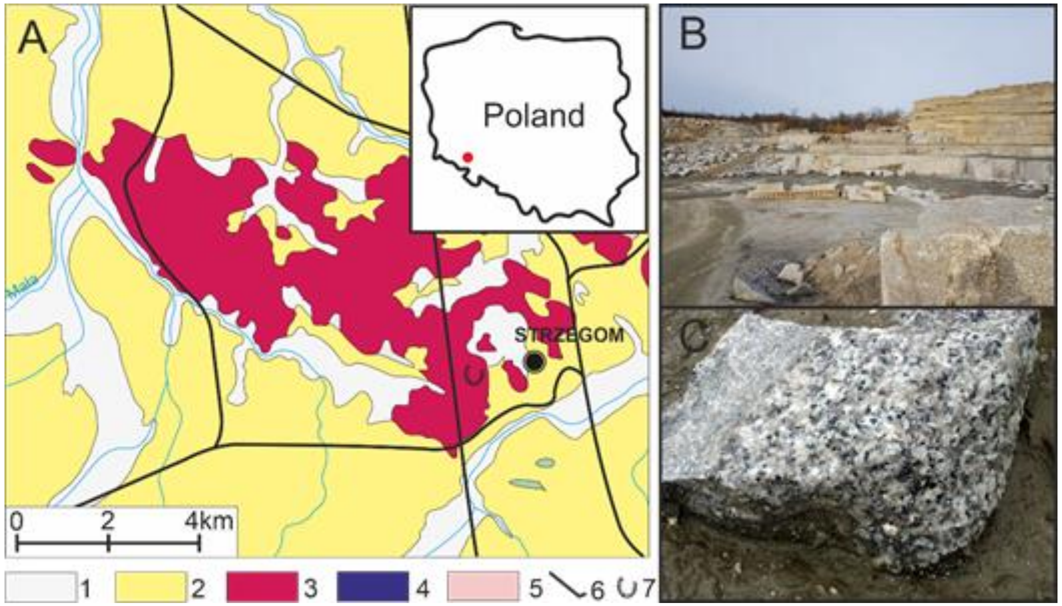

***Fig. 1** Sketch of the geological structure and location of the deposit (A) (based on Grocholski et al., 1981): 1 - Holocene, 2 – Neogene, 3 – Carboniferous – Perm (granite and granodiorite), 4 – Paleozoic, 5 – Proterozoic, 6 – faults, 7 - the quarry; (B) –view of the deposit; (C) fragment of the granite rock, (photos Stan-Kłeczek)*

2. Localisation and geological structure

The granite deposit is located in Strzegom city. The deposit is located in the northernmost part of the Sudeten Foothills within a large geological unit of the Strzegom-Sobótka granite massif (Fig. 1). The entire cover of the Strzegom massif is built of the old Paleozoic including metamorphosed Cambro-Silurian sedimentary shales (Moroz-Kopczyńska, 1962). The granite was squeezed between gneiss and shales and caused an uplift of the latter. The gneiss is stiffer and more resistant, so it was untouched in the ground. The result of this tectonic deformation is dense cracks in the granite. The shield of the massif form metamorphosed work represented by Caledonian shales changed on contact with granite into hard and compact hornfels. The investigated granite deposit is a small fragment of the Strzegom granite massif. The deposit area is on a gentle west slope of a vast hill with a height of 290 m a.s.l. The deposit is part of a granite intrusion emerging as a domed hill from under the Paleogene and Neogene formations. The deposit is biotite granite, light grey colour, usually medium-grained. This granite is made of white feldspar, grey quartz and black biotite. The thickness of this deposit ranges from 39 m to 57 m. The thickness overburden ranges from 0 m to 9,5 m (Kancler, 2004).

3. Methodology of ultrasonic measurement

A cuboid with a length of 300 mm and a section of 200 mm x 200 mm was cut out from the block of granite rock (Fig. 2). The granite from the deposit described above is medium-grained, and there is a single crack on the selected sample.

The experiments were carried out with the ultrasonic pulsing method using the ultrasonic instrument Pundit Lab+ (Proceq Company). The ultrasonic pulse velocity is used as the physical measure. The ultrasonic impulses are transmitted to the sample. The result of the

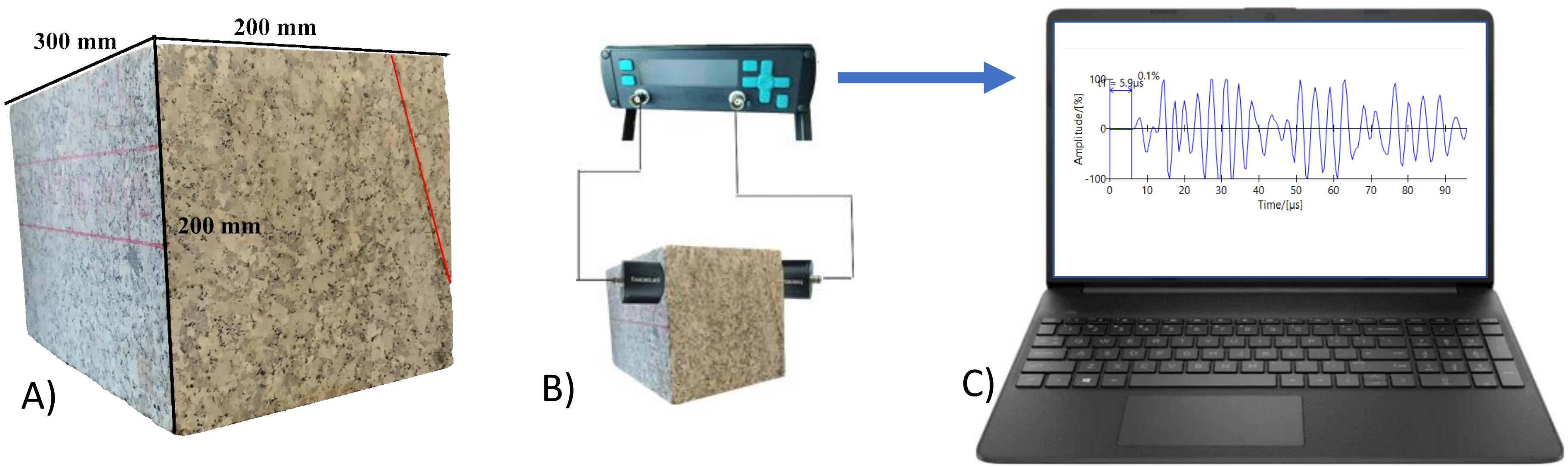

Fig. 2 A) The granite sample with marked a single crack (red line), B) performing measurements with P-wave transducers, C) signal curve read saved during measurements

ultrasound reading is the travel time (t) of the ultrasonic wave (Fig. 2 C). The length of the sample is a travel path length (s). Therefore, the ultrasound velocity is known as v=s/t. The transmitter and the receiver transducers opposed the sample in marked places. To ensure close contact between the surface of the sample and transducers, a fine layer of couplant was applied.

The first step of measurements is zeroed using a calibration rod regularly, particularly if the transducer frequency is changed. Because the PunditLab+ is equipped with one transmitter transducer and one receiver transducer, to obtain a spatial distribution of the P-wave velocity, the transmitter transducer is placed in the position T1 and the receiver transducer successively in the position from R1 to R14. Then, the position of the transmitter transducer was changed to position T2 and the measurements were repeated and so for all positions of the transmitter transducer (until T6). During the study, approximately 2500 measurements were made, and 84 paths were obtained for each pair of transducers. The measured ultrasonic times were interpreted using the aTom software (1.0.2). The software performs a tomographic analysis on the base on the geometric shape of the sample and the time of an ultrasonic wave passing through a sample. The software carries out a mathematical interpretation of the results, which are presented as velocity distribution maps (tomograms) of the P-waves along the plane of sections obtained using an iterative calculation procedure type S.I.R.T. (Simultaneous iterative reconstruction technique) (aTom manual).

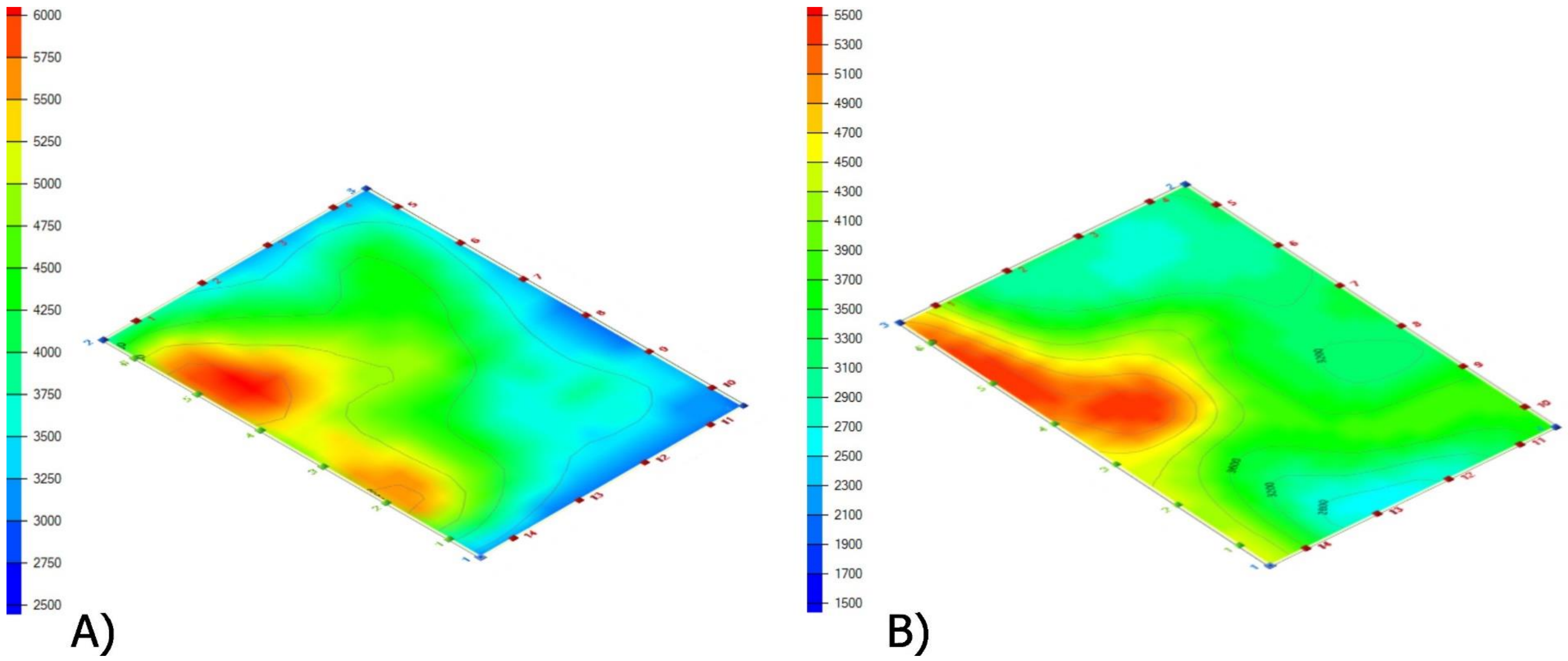

Fig. 3 Tomography results: A) for-wave transducers 54kHz, B) for P-wave transducers 250kHz

4. Results and discussion

The aTom software calculates the velocity values for each sample based on measured P-wave travel - times, the sample geometry and the location of the transmitter and receiver transducers. Figure 3 demonstrates the structure of P-wave velocity in the first layer of the study sample. For P-wave transducers 54 kHz (Fig. 3A), the lowest P-wave velocities is 2900 m/s and the highest is 6067 m/s. For P-wave transducers 250 kHz (Fig. 3B), the lowest P-wave velocities are 2555 m/s, and the highest is 6648 m/s. It is common knowledge that the seismic wave velocity is greater in the perpendicular direction than in

Tab. 1 Comparing of the P-wave velocities in the selected distance

Localisation	Distance [m]	Frequency [kHz]	Velocity [m/s]	λ [m]
6-1	0,04	54	8410	0,16
		250	5515	0,02
6-2	0,08	54	1956	0,04
		250	3026	0,01
6-5	0,2	54	4185	0,08
		250	3933	0,02
5-1	0,08	54	6259	0,12
		250	4906	0,02
4-1	0,13	54	5769	0,11
		250	4529	0,02
2-14	0,08	54	5997	0,11
		250	3991	0,02
1-4	0,33	54	4650	0,09
		250	4294	0,02
1-13	0,08	54	2340	0,04
		250	2999	0,01
1-14	0,04	54	8422	0,16
		250	6648	0,03

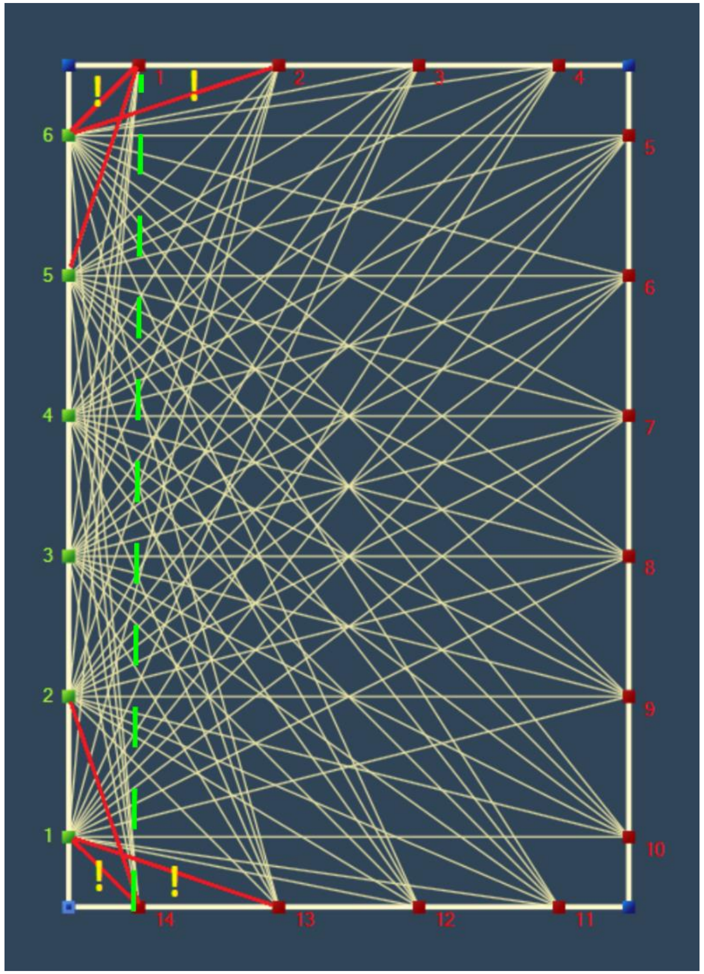

Fig. 4 Rays for the 54 kHz head. Red rays are measurements removed. Measurements with anomalous velocity values are marked with exclamation marks (values in the table in brown). The crack is marked with a dashed green line.

the parallel direction. Analysing the obtained tomography image (Fig. 3 A and B), increased velocity values can be seen in some places. This situation may be related to the contact between the sample edge and the crack. Perhaps not only does the crack occurring in the anomalous area impact the increased velocity values.

When making measurements with the 54 kHz transducers, measurements on the corners of the sample were omitted, given the lack of effective coverage of straight rays (Fig. 4). Velocity was anomalous, over 8000 m/s or about 1900 m/s. This effect was gone using the 250 kHz transducer, and all measurement results could be included in later processing (Tab. 1). This phenomenon is due to the selection of the frequency, f and the wavelength, λ, which should be twice the sample size. λ is given by $\lambda = c/f$, where c is the rock sample's pulse velocity (speed of sound).

The tomographic analysis revealed areas and trends of different velocities inside the study sample (Fig. 3). However, it was impossible to unambiguously identify the crack using ultrasonic tomography. There are several possible reasons: the relationship between the frequency used during the measurement and the velocities of the resulting rays is an aspect which has to be considered. It can be seen that many authors struggle with a similar problem. For example, LI Y., and WU R. (2023) had the same problem. These authors also had to reject the outermost elements. MENNINGEN ET AL. (2018) noticed that the higher the frequency, the lower the sample penetration. Therefore, the next measurements were made with 46 kHZ transducers (Tab. 2).

Tab. 2 Comparing the sample size to the transducer frequency in literature

Transmitters frequency	**Sample size [m]**	**Conclusion**	**Literature**
20 MHz	0,16/0,16/0,16	P-wave velocities of the outermost elements were omitted, given the lack of effective coverage of straight rays.	Li Y., Wu R., 2023
250 kHz	Monolith, 0,665 - 0,455 width, height of 5,2	They do not penetrate the obelisk.	Menningen et al., 2018
46 kHz	Monolith, 0,665 - 0,455 width, height of 5,2	To distinguish structures in a sample by ultrasonic tomography at 46kHz, the minimum structure size can be 5 cm.	Menningen et al., 2018
1 MHz	Cylinders, 0,038 in diameter, long of 0,04	With increasing frequencies, Vp increase more (~20% at 1 MHz) than Vs	Trippetta et al., 2010

The second problem could be irregular coverage of the studied plane. Maybe an irregular grid can avoid those systematic resolution problems. It is necessary to remember the shortest path of the ray passing through the sample and the tested rock's P-wave velocity values.

5. Conclusion

In the measurements made using both transducers (54 kHz and 250 kHz), the crack in the granite sample was well visualised. In the case of the 54 kHz transducers, measurements on corners must be removed because the distance was too short. The minimum path length should be equal to or greater than the transmission wavelength, or a severe reduction in the pulse velocity may be detected. Comparing measurements with two frequencies showed that the identical localisation transducers are at the same time of the ultrasonic wave entry and other velocities. Most likely, the reason is the phenomenon of longitudinal spatial resolution of the image. Higher frequencies allow better resolution in the measurements. Additionally, the shorter distance must be critically analysed due to the uncertainty caused by the frequency and beam path. It was shown that the selection of the frequency to the sample size is of great importance when looking at the results critically.

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