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ANDREJ KOS*, JOŽE KORTNIK**#

ULTRASONIC QUALITY INSPECTION OF DIMENSION STONE BLOCKS COMPACTNESS

METODY ULTRASONOGRAFICZNE W JAKOŚCIOWEJ KONTROLI ZWIĘZŁOŚCI WYMIAROWYCH BLOKÓW SKALNYCH

The compactness of dimension stone blocks was previously controlled through various methods that were partially based on personal experiences, acoustic and visual observance of materials. With the development of technology, the ultrasonic pulse method is frequently used for the examination of stone test pieces and with an analysis of acquired data through the tomography method, the compactness is determined. The monolith stone blocks that are found at a site contain hidden discontinuities. The technique of data acquisition and the use of various instruments enable a good overview of the block interior. With an increased number of measurements, a suitable classification is prepared that helps reduce modification costs and increases the quality of stone blocks. The control methodology of compactness is based on the passage of longitudinal waves through the stone block without damaging the block during control. High differences in speed show irregularities in the material. With the observation system, we can prepare a tomography of the measured profiles that show us the locations of irregularities that should be observed more closely. During in situ measurements, the data for comparison with measured results are acquired. Determination of critical locations is of extreme importance before the processing of the block into smaller stone products or during the reconstruction of older stone elements or sculptures. The purpose of "in situ" measurements is to prepare a simple and fast method for the evaluation of materials compactness and for production work.

Keywords: dimension stone, ultrasonic method, stone blocks, compactness classification

W przeszłości, zwięzłość wymiarowych bloków skalnych badano w oparciu o różnorodne metody, w głównej mierze wykorzystujące doświadczenie osób przeprowadzających badanie oraz obserwacje wizualne i metody akustyczne. Postęp technologiczny zrodził nowe metody, obecnie jedną z metod często używanych do badania zwięzłości wymiarowych bloków skalnych jest metoda impulsów ultradźwiękowych, połączona z analizą danych wykorzystującą tomografię komputerową. Monolitowe bloki skalne

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w miejscu ich występowania zawierają zazwyczaj ukryte nieciągłości. Odpowiednia technika akwizycji danych i wykorzystanie odpowiednich instrumentów umożliwiają obserwację wnętrza bloku skalnego. Po uzyskaniu odpowiednio dużej liczby danych pomiarowych, przygotowano odpowiednia klasyfikację umożliwiającą obniżenie kosztów dodatkowej obróbki (modyfikacji) bloków skalnych i poprawę ich jakości. Metoda kontroli zwięzłości wymiarowych bloków skalnych polega na przepuszczeniu przez bloki fal wzdłużnych, które nie powodują ich uszkodzenia. Znaczne różnice prędkości rozchodzenia się fali wskazują na nierówności w materiale, przeprowadzić można także dodatkowe badanie tomograficzne analizowanych profilów skalnych w celu dokładnego zlokalizowania nieciągłości, które następnie zbadać można szczegółowo. W trakcie pomiarów in situ zbierane są dane do analizy porównawczej. Niezmiernie ważne jest określenie lokalizacji krytycznych nieciągłości przed podziałem bloków skalnych na mniejsze fragmenty, a także w trakcie rekonstrukcji starych elementów kamiennych lub rzeźb. Celem badania prowadzonego in situ jest opracowanie szybkiej i prostej metody oceny zwięzłości materiału i wspomagania prac wydobywczych.

Słowa kluczowe: blok skalny wymiarowy, metoda ultradźwiękowa, bloki skalne, klasyfikacji zwięzłości skal

Introduction

Diverse tectonics, cracked and crushed parts are transferred from the mineral raw material site into smaller units – stone blocks. The sizes of stone blocks or monoliths are between 1.5 to 8 m^3. The quantity of acquired material at natural stone sites is between 8 and 15%. The stone blocks are monoliths with a parallelepiped form and are processed from all six sides (Kos & Kortnik, 2015). Discontinuities and errors on the outer surfaces are quickly noticed; the core of the block represents a greater problem. The inner structure is hard to determine with such a great volume, thus the older methods, e.g. visual observance, wetting of the surface and listening to the echo, are unreliable and should be amended. With the recent development of technology, the use of non-destructive methods for material examination is on the rise. In Slovenia, we established the speed of sound propagation in natural stone according to the standard SIST EN 14579:2004. Testing is performed on stone prisms with dimensions 300×75×50 (mm) and a tolerance of ±2 mm (SIST, 2014). Our task was to perform more tests on natural stone blocks with a gauge up to 7 m^3; visual examination of blocks, the use of measurements by ultrasonic pulse method for checking the inner structure on certain profiles and results analysis. During the examination, certain gross measurement errors may occur, thus it is necessary to use skilled workers, suitable tests for instrument calibration and suitable lubricants.

Tomography is also used for the examination of smaller blocks or elements for restoration. The example was made using two tomographic programs: TOMO Tools and Pundit. Due to large block volumes, it is difficult to perform a tomography of the whole block, because it is extremely time consuming and the errors in relation to dimension preparation and precise data entry represent a significant risk (Boviar, 2018). Data analysis is performed with computer programs for the creation of a tomographic profile, even though such a method of data processing is frequently used for restoration.

Demands of investors for larger dimensions of slabs, even better utilisation of the block and faster production mean that it is necessary to evaluate a monolith not only visually but also by determining its inner structure. The classification of stone block has not yet been done. Only the old classification according to block length and height and structure directions is used. The new classification also gives data on the inner structure of the block based on the average speed of the passage of longitudinal waves. The density of observed profiles is determined on the basis of the block size. With a higher density of observed profiles, the data are used for profile analysis with the computer program TOMO Tools and the tomography of the observed profile (Boviar, 2018). The method is useful for an overview of the sculptures and for restoration.

The course of irregularities (cracks) can be visually determined only superficially, but we cannot foresee how deep into the block they extend. Sometimes, discontinuity may appear only a few centimetres under the block surface and go through most of the block. In such cases, production often becomes a waste of time, because the production time is extremely limited and a false selection causes increased costs and lack of competitiveness on the market.

A detailed overview and determination of the quality contribute to more economic use of materials, because there may be, due to lack of knowledge of the material quality for preparation and processing of blocks, wrong decisions regarding the cut. The inner block structure was previously determined intuitively and by visual surface cracks, but now the quality is determined by ultrasonic pulse method. The measurements are performed on predefined profiles, where the speeds of wave passage through the block are measured. On the basis of acquired data, we determine the inner block structure. We also use the computer programs DataSonic and TOMO Tools, with which we can determine the block quality. The results are then compared, because the block is cut into slabs, and we thus acquire empirical data that are used for a new categorisation.

Development of ultrasonic research

Acoustic methods are based on generating, expanding and reflection of mechanical sound waves in solid materials, which depends on the density and elastic properties of the examined material, the frequency of the used wave motion and the method of generating and receiving the sound waves (Špeglič, 2013). Transmitters and receivers are piezoelectric devices that transmit and receive waves. Ultrasonic frequencies are higher than 20 kHz (Wiberg, 1994). Ultrasonic methods are designed based on the passage and reflection of ultrasonic wave motion that is generated by the transmitter and detected by the receiver. The transmitters generate longitudinal, transversal waves, whose expansion depends on the mechanical properties of the material (Bodare, 2005). Material measurements of the ultrasonic pulse speed may be performed in three ways: directly, semi-directly and indirectly (Kahraman et al., 2008; Meola et al., 2005). For quality measurements, the surface of the measured material must be smooth so that transmitters and receivers have good contact. We also use gel for better contact.

According to authors Lemoni and Christaras (1999), a direct method is the most satisfactory, because the wave direction is parallel to converters, as shown in the Figure 1. If the converters are on the opposite side of the material, the spreading of waves is faster and the pulse speed will be higher than with the indirect method. The statistical analysis of concrete, performed according to Turgut & Kucuk (2006), reveals that the average value of the direct ultrasonic pulse speed is 9% and 4% higher than the average indirect ultrasonic pulse speed in the selected direction and the indirect ultrasonic pulse speed in the horizontal direction. The indirect method is used for determining the weathering depth and consolidation degree and for detecting cracks near the surface (Lemoni & Christaras, 1999; Akevren, 2010).

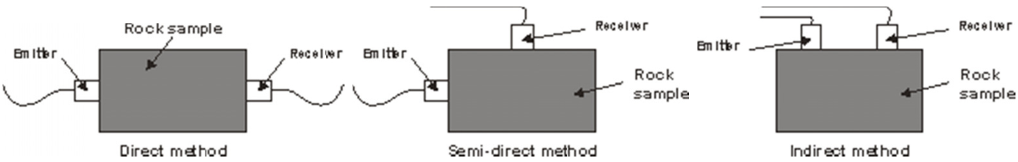


Fig. 1. Display of data collection method according to direct, semi-direct, and indirect method (Kahraman et al., 2008)

Ultrasonic instruments

Ultrasonic instruments generate short-term voltage pulses, due to which the piezoelectric converter in the ultrasonic probe oscillates and then stops oscillating. Materials possess various elastic properties that cause various sound speeds that are characteristic for a certain material. The sound speed for a certain material is thus constant and depends on the elastic material property and material density. These mechanical vibrations are a basis for the formation of ultrasonic waves (frequencies >20 kHz, outside of the audible sound field) (Medveščček, 2015). The oscillation propagates through the test piece in the form of waves that are reflected from the border areas and can be inversely detected. The incoming wave energy mechanically deforms the piezoelectric receiver, which causes electric charge and voltage that are shown on the instrument display. With the help of suitable settings, the sound path length to an individual reflector is defined on the basis of time or distance on the display between the emitted pulse and received signal from the reflector. With the help of formulas and other accessories for locating, it is possible to determine the position of the reflector in the examined test piece. On the basis of the wave length, it is possible to estimate the detection limits of the smallest, still recognisable reflector size, whose size is approximately one half of the wave length (1/2 λ). Figure 2 shows an ultrasonic instrument Boviar with technical data.

Transmitter	**Hammer**
Frequency	55 kHz ÷ 20 kHz
Voltage	1,6 kV
Energy	0.05 J ÷ 0.02 J
Width	770 g
Dimensions	50 mm × 75 mm
Receiver:	
Frequency span	1 ÷ 70 kHz
Sensitivity	1 kHz = 4 840 mV/g
Highest sensitivity	6 kHz = 30 V/g
Receiver power	20 dB
Weight	760 g
Dimensions	50 mm × 75 mm

Fig. 2. Ultrasonic instrument Boviar with technical data

The speed of ultrasonic wave passage c_i from the transmitter to the receiver is calculated with the equation 1.

$$c_i = \frac{l}{t} \quad \left(\frac{m}{s}\right) \tag{1}$$

where l is the length of the measured profile and t is the time of passage of longitudinal waves.

Method of collecting in situ data on stone blocks

While cutting, cracks larger than 0.5 m represent a problem because the cutting force opens them during sawing. Cracks in the range 0.20 ÷ 0.30 m, depending on the type/orientation/number of cracks, do not cause significant problems (if there are not parallel). A gangsaw with rated power 95 kW creates 90 strokes per minute. Cutting speed is 0.25 m/h. At such speed and strokes, the cracks that are partially or fully open are opened during cutting as shown in the Figure 3.

Fig. 3. Opening a block during sawing on the gangsaw

Limestones Lipica Unito, Lipica Fiorito, Repen, and Kopriva contained all kinds of discontinuities that affect on compactness of blocks. Profile measurements “in situ” were performed before cutting. The used measurement mesh was divided into profiles sized 400×400 mm as the smallest plate size. With a precise analysis, we do the visual examination with a minimum of four profiles (Fig. 4) that were directed to all directions in the middle and thus got three different longitudinal speeds. In case of larger surface errors, these can be followed in the interior of the block. The classification is amended with an average speed of the longitudinal waves on profiles as shown in the Figure 4.

The profile density depends on the visual overview of the blocks. It was determined that it is possible to evaluate a healthy block with a mesh of four profiles in length and three line profiles in width.

In case of discontinuities, the profile density is enlarged to a scheme as shown in Figure 4. In width, observance profiles in three lines profile should be made, namely on the 1/4 (c) of the width and height. In length, observance profiles in two lines should be made at the interval of 1/6 (a) of the block length and in height in two lines at the interval of 1/3 (b) of the block height.

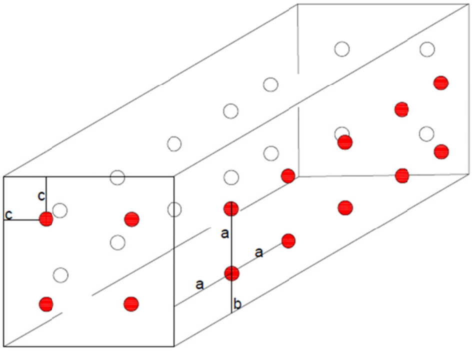


Fig. 4. Position of profiles on the stone block in width on the 1/4 (c) of the width and height.
In length, observance profiles in two lines should be made at the interval of 1/6 (a) of the block length and in height in two lines at the interval of 1/3 (b) of the block height

The results of measurements were different due to the influence of surface, material discontinuities and material structure. After the data processing, we established deviations of speed on profiles that arise due to material structure. The discontinuity of smaller dimensions is announced by a speed decrease of 20%. If the speed decreases by 50%, the test piece contains several crack systems or a crack of several tenths of a mm. A block with this average speed is dangerous for further processing with a multi-blade gangsaw. A multi-blade gangsaw with cutting power 95 kW causes opening of cracks, and the material could fall apart and thus damage the machine and workers in the immediate proximity.

While examining blocks with an ultrasound, we established various wave passage speeds. The differences in wave passage speeds showed that there are different errors hidden in the block that affect the quality of cut plates. These are mainly various cracks that decreased speed; open cracks from 0.1 mm to 0.3 mm; if there was only one, the speed was decreased by 10%. In case of larger cracks, the speed decrease was more than 25%. At the open crack wider than 0.5 mm, the result was negative or the waves did not reach the transmitter. Minor speed changes 1-9% arise due to content of fossil shells in the rock that contain smaller openings. In case of larger consecutive cracks, the speed was decreased by 50%. Smaller calcite veins have no larger influence on speed decrease, because these cracks are closed and only a few tenths of a millimetre wide. A larger calcite vein decreases speed by up to 10%. In case of a crack filled with earth, it acts like a silencer and decreases speed by 30% (depends on the thickness of the discontinuity).

During examination with an ultrasound, ultrasonic probes or hammers may be used. The ultrasonic probe has a frequency of 55 kHz, and the hammer emits a frequency of 20 kHz. A hammer with a smaller frequency and higher energy is used for materials with smaller wave propagation characteristics. In certain cases, the signal may be too weak and cannot be properly analysed, thus it is difficult to estimate the arrival of the first wave. While using both methods on blocks, there were no larger deviations between the probe and the hammer. Speed deviation range was between 1-3%.

The measured data were processed with the computer program DataSonic, where the average speed and arrival time of waves are calculated together with a standard deviation on measured profiles. The measurements were made before the foreseen cutting, so that result comparison on individual slabs after cutting (visual) could be performed. The first pick of waves from the transmitter to the receiver was measured, which is shown with the blue line, and it is continued with a damped oscillation. The arrival time of the first wave to the receiver is measured. The accuracy of measurements must be ensured through a good contact between the instrument and rock, so gel or plastic mass is used.

Equations (2) and (3) are used in figure 5 and figure 6 for calculation of average speed and standard deviation.

With a larger number of performed measurements, the middle value is calculated that gives us the quality estimation of the block.

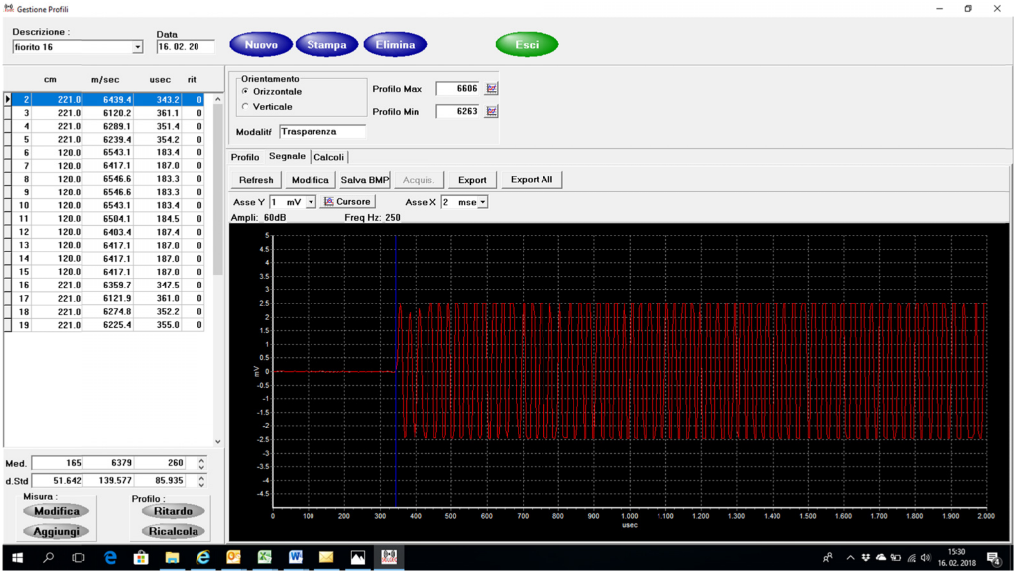
$$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i = \frac{1}{n}\cdot\left(x_1 + \ldots + x_n\right) \tag{2}$$

Standard deviation may be calculated as σ (sigma), namely as a deviation of the whole population or a random variable, or as s, namely as a deviation of an individual sample of the statistical population.

$$\bar{s}_x = \sqrt{\frac{\sum_{i=1}^{N}\left(x_i - \bar{x}\right)^2}{N-1}} \tag{3}$$

where x_i is an i-th unit in the statistical population, $\bar{x}$ is the arithmetic mean of the population and N is the number of all units.

Figure 5 shows us methodology of ultrasonic measurements with probe from profile 2 till profile 15. Figure 6 shows are methodology of measuring with hammer from profile 16 till profile 19. Analysis shows us small differences of ultrasonic velocities. The program has used equation 2 and 3 for calculate average velocity and standard deviation. Profiles 2, 3 and 4 have

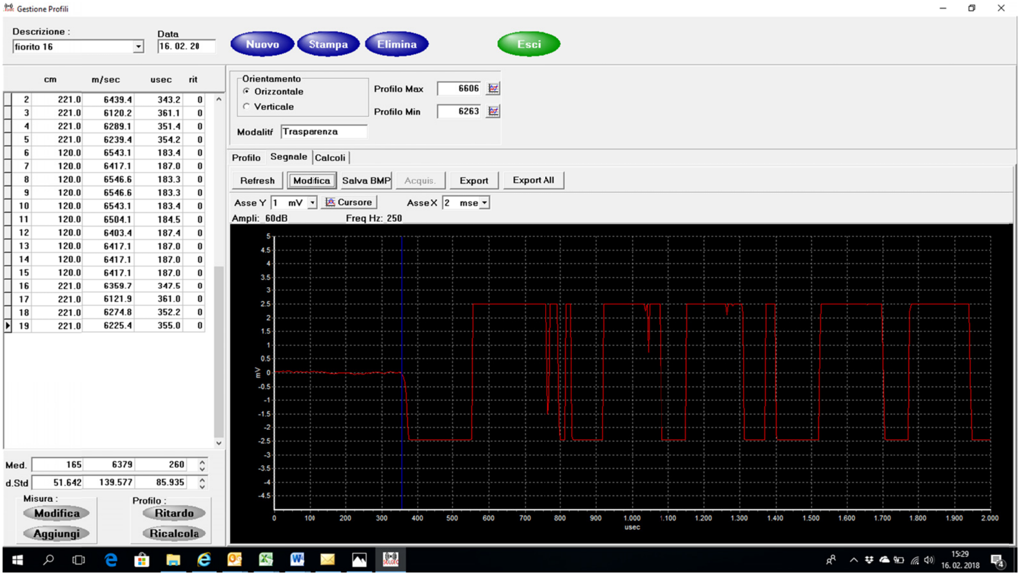


Descrizione : fiorito 16
Data 16. 02. 20

	cm	m/sec	usec	rit
2	221.0	6439.4	343.2	0
3	221.0	6120.2	361.1	0
4	221.0	6289.1	351.4	0
5	221.0	6239.4	354.2	0
6	120.0	6543.1	183.4	0
7	120.0	6417.1	187.0	0
8	120.0	6546.6	183.3	0
9	120.0	6546.6	183.3	0
10	120.0	6543.1	183.4	0
11	120.0	6504.1	184.5	0
12	120.0	6403.4	187.4	0
13	120.0	6417.1	187.0	0
14	120.0	6417.1	187.0	0
15	120.0	6417.1	187.0	0
16	221.0	6359.7	347.5	0
17	221.0	6121.9	361.0	0
18	221.0	6274.8	352.2	0
19	221.0	6225.4	355.0	0
Med.	165	6379	260	
d.Std	51.642	139.577	85.935	

Orientamento
● Orizzontale
○ Verticale
Profilo Max 6606
Profilo Min 6263
Modalitť Trasparenza
Asse Y 1 mV
Asse X 2 mse
Ampli: 60dB
Freq Hz: 250

Fig. 5. Display of the measurement diagram with the ultrasonic probe



Descrizione : fiorito 16

Data 16. 02. 20

	cm	m/sec	usec	rit
2	221.0	6439.4	343.2	0
3	221.0	6120.2	361.1	0
4	221.0	6289.1	351.4	0
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Orientamento
● Orizzontale
○ Verticale

Profilo Max 6606

Profilo Min 6263

Modalitŕ Trasparenza

Asse Y 1 mV

AsseX 2 mse

Ampli: 60dB Freq Hz: 250

Fig. 6. Display of the measurement diagram with the ultrasonic hammer

detected two white calcite veins, on figure 7 are marked with black lines. Ultrasonic velocity was dropped around 3% of average velocity, but on profile 1 the veins weren`t detected neither with a probe nor with a hammer.

As a part of the research, 780 profiles on 127 stone blocks were measured, an average of 4.24 profiles per block. The measurements were performed according to the direct method with an ultrasonic probe and a hammer. The difference is in the wave emission frequency, because the

Fig. 7. Methodology of block measurement, black line shows white calcite vein

hammer creates waves of 20 kHz that are suitable for determining smaller cracks. After several performed measurements, we updated the method, because a larger number of measurements represent a greater loss of time.

In the results unit only data of Lipca Unito rocks will be presented as an example which describes the analyzed method.

Tomography on natural stone blocks

The ultrasonic tomography uses ultrasonic waves for the creation of pictures. An elastic interruption that travels between two points of a certain material spends a certain amount of time t and travels with an average speed v. If the distance between two points is decreased to 0, we can determine a point speed v_p and point delay $s = 1/v_p$, which is defined as a reverse value of point speed. The behaviour of the material area can be determined when the “delay” s is considered as a function of the position $s = s(x,y)$ and is valid for any point (x,y) of this area. The function $s(x,y)$ can be approximated if the area is divided into N rectangular cells in which the speed and also the delay are presumably constant. The cell size defines the tomography resolution and thus the minimum error size the method is able to detect.

The reconstruction of the delay allocation in N cells derived from known M-times of wave propagation along different paths between origin points and data collection at the area border represents a tomographic problem.

The wave path area depends on the speed allocation. Nevertheless, we decided, due to the indeterminacy of the actual path the wave propagate between origin points and data collection site, to use linear topography and thus consider straight wave paths as you can see in Figure 8.

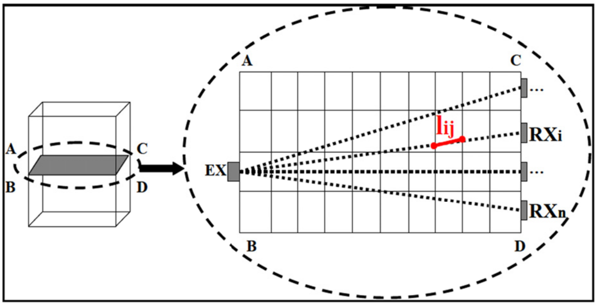

Fig. 8. Graphic display of the tomography (l_{ij} is the wave length i in the cell j) (Boviar, 2015)

In linear tomography, the values of slowness in N cells, in which the area was defined (see mesh in Figure 2), are acquired with the following equation system

$$\begin{aligned}
&\{l_{11}s_1 + l_{12}s_2 + \dots + l_{1M}s_N = t_1\}\\
&\{l_{21}s_1 + l_{22}s_2 + \dots + l_{2M}s_N = t_2\}\\
&\dots\\
&\{l_{N1}s_1 + l_{N2}s_2 + \dots + l_{NM}s_N = t_M\}
\end{aligned} \tag{4}$$

where the element l_{ij} represents the length of the i-th wave path inside the j-th cell, s_j is the delay (reverse speed value) of the j-th cell and t_i is the propagation time of the i-th wave path measured with the device. In the system, the lengths l_{ij} are known when the area geometry and a certain resolution are known; times t_i are known and are acquired through measurements, and slowness s_j is an unknown quantity. In the matrix form, the system is defined as,

$$[L] * \overline{s} = \overline{t} \tag{5}$$

where $\overline{s}$ is a length vector, $[L]$ a length matrix and $\overline{t}$ a wave propagation vector.

Thus, the solution is tomography, calculation of the delay vector

$$\overline{s} = [L]^{-1} * \overline{t} \tag{6}$$

Generally, the smallest size of the detectable error cannot be a converter diameter. The tomography resolution is thus conditioned by the definition of the section: the denser the mesh is, the higher is the resolution and smaller errors may be detected and shown. In praxis, the size of the cell is the same as the smallest error size that can still be detected by the tomography. One would expect that very thick mesh for the increase of resolution would be used, but while the number of cells also means a number of unknown quantities, we need a certain number of equations at the end of the solution of the linear tomography system, i.e. measurement of the travel time that is larger than the number of unknown quantities. This is why increasing the resolution necessarily means a disproportionate increase in number of measurements.

Generally, the matrix L is not square, badly conditioned and deficient, thus it is not possible to directly calculate a reverse value. Thus, the problem must be solved with allocation coefficients that are suitable for the processing of badly conditioned inverse problems (Boviar, 2015).

Results display on the block case Lipica Unito limestone

For each, a profile and tomography geometry must be determined according to the block state. Each block contains a different structure and direction of discontinuities, which means that for each block a special geometry must be created but with no less than four points if it is an overview of compactness.

In case it is a review of the entire profile for the needs of tomogram creation, for which the selection of geometry is needed, number of cells, their size and allocation can be tricky because the activity of the allocation coefficient (inverse algorithm) of the linear system may cause tomography problems in the equation that are directly connected to this selection, and we must also consider the number of measurements that can be performed or that we are prepared to perform.

The program demands that the user enters a desired resolution and the function of a presumable error according to the typology of the considered structure element. Depending on the resolution value, the algorithm suggests setting the sources and receivers with which we can reach the desired resolution and creates instructions for the performance of measurements and data collection.

If the profile geometry is very unfavourable, e.g. on very long profiles where only the short sides are accessible, it can happen that the linear system becomes insolvable, because it is impossible to set sources and receivers in such a way that more measurements can be performed than there are cells.

The program analyses speed on the measured profile on the basis of the used algorithms. It can also show them graphically as a speed map reconstructed in two dimensions, where the speed gradients are connected with a certain colour, on the basis of which it is easy to determine anomalies in material and thus interpret data.

Example of a tomogram on the block Lipica Unito limestone

The Lipica Unito stone is a Cretaceous limestone deposited in the open parts of the shelf of the Dinaric carbonate platform. The area was later subjected to many tectonic phases but two basic groups of structures are present. The first one comprises deformations that resulted from regional compression in the northeast-southwest direction during Cretaceous and Paleogene, and the second group in deformations that resulted from regional compression in the general direction north-south during Neogene and Quaternary (Jurkovšek et al., 1996). Therefore 6 different systems of discontinuities can be observed in the Lipica quarry.

The tomographic overview was performed on a piece of Lipica Unito limestone with dimensions 1550×1670×1390 mm. The profiles A-A' and B-B' were produced through the stone block centre in a cross system. The distance between points was 10 cm, which is the minimum distance for a qualitative profile measurement and creation of a tomogram. Figure 9 shows the measurement paths that were used to calculate the profile tomogram. The measurements were performed according to the direct method.

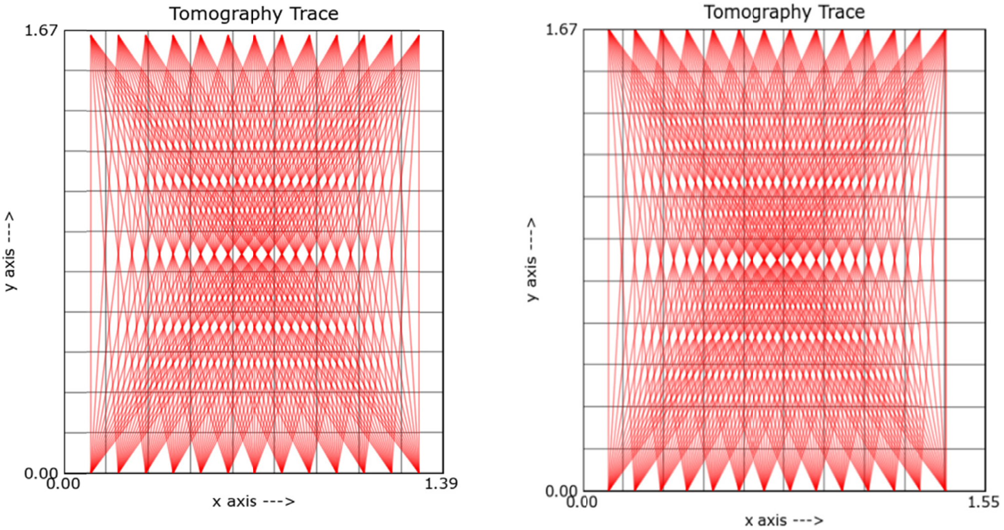

Fig. 9. Display of a sample collection on the profile of the Lipica Unito limestone

Data processing includes coordinates of the transmitter and receiver on the profile. Coordinates (Tx_i ; Ty_i); (Rx_i ; Ry_i); arrival time in ms must be processed. The step for sample collection was 0.1 m in this case; the shorter the leg, the more accurate the resolution of the profile display will be. At steps from 0.1 m to 0.5 m, the program does not calculate the profile tomography.

Before measurement, an instrument calibration was performed. It is of extreme importance to accurately define the lengths between individual points. Data processing according to the program DataSonic on 169 measured points showed an average speed of 5,620 m/s and an average time of the measurement between points of 52 µs. Visual, one could see that a corner with an open crack 0.2 mm wide was damaged. The results of the calculation are shown on the profile in Figure 10. The problematic sections of the rock are marked in black. Different shades of other colours are not critical, and they show deviations due to material structure.

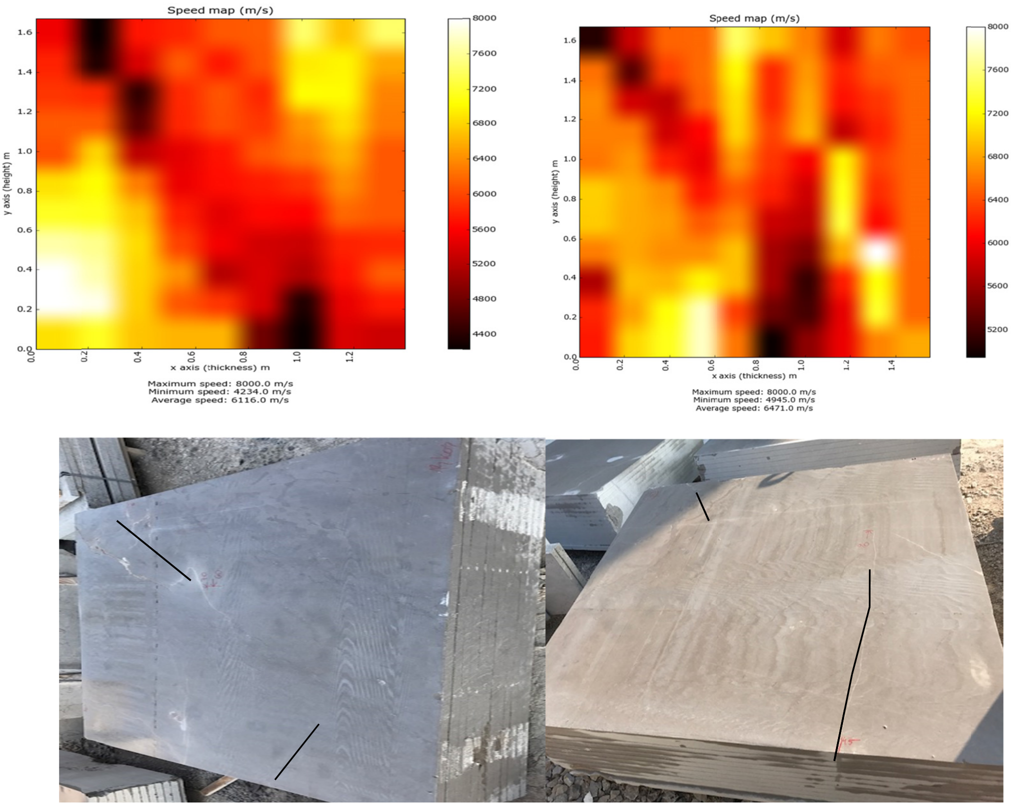

Fig. 10. The colours show changes in the material structure, for example in the case of the stone Lipica Unito limestone

The block Lipica Unito limestone was cut into 30 mm thick plates. According to the average speed of the measured profiles of 6,120 m/s, according to the classification, it was assigned for the production of slabs of 20 or 30 mm. Figure 6 shows a black field where speeds under 5,200 m/s were measured. The picture below shows that on the upper right side, there is an open discontinuity that continues 0.65 m towards the block centre, where it ends. The discontinuity does not travel to the other side of the block, thus there is no danger of opening during cutting.

The other colours show changes in the material structure. The block has different structures, for example a change in graininess that minimally affects the passage speed of waves. Speeds higher than 8,000 m/s also appear, but that is an error in element measurements. It starts closing after 0.70 m and does not represent a risk for opening during cutting.

Conclusions

Classification of natural stone blocks was performed on the basis of visual parameters and measurements. It was impossible to examine the interior of the block and it was false many times. For the evaluation of the stone block, a non-destructive method is most useful, because there is no affect or damage to the material during examination.

During examination of a large number of blocks with an ultrasonic test, we gained many qualitative data and methods that facilitate and accelerate the evaluation of natural stone block. The examination method is based on longitudinal waves that travel from the transmitter to the receiver, and on the basis of wave arrival time, we determine the cutting method. Different discontinuities are transferred from the site into stone blocks and have different effects on the measurement. The profile density depends on the cracks that are indicated on the visual side of the block and can be followed to see how deep they penetrate. The blocks must be made according to stone-cutting rules and shaped in the form of a parallelepiped. A smooth surface of the processed block is extremely important for an accurate measurement, because a suitable contact must be made between the instrument and the block. The compactness can be determined on the basis of minimum four measured longitudinal profiles. While performing measurements, there are system errors we should be aware of and that have a significant influence on the measurement quality. Table 1 shows a categorisation on the basis of average speeds for the wave passage and block usability for a certain plate thickness. The plates are often sawed without net reinforcement, which means that the material must be well evaluated and examined.

TABLE 1

Example of categorisation of monoliths

Category	**Velocity (m/s)**	**Usability**
I.	≥6,200	Material is useful for all thicknesses and does not require further reinforcements.
II.	5,500 ÷ 6,190	Natural stone block that contains small cracks and structural changes and is useful for all thicknesses without reinforcement
III.	4,500 ÷ 5,490	The block contains larger cracks and holes and is useful for sawing plates with 30 mm thickness without reinforcement.
IV.	3,500 ÷ 4,490	A block with bad quality with irregularities in the structure and contains many open cracks; it is useful for 40 mm plates without reinforcement
V.	≤3,490	Bad quality material; the piece needs to be reinforced before sawing

One of the methods for insight into the interior of a stone block is the creation of profiles and the creation of a tomogram from the data. Blocks with larger dimensions require a lot of time, which was not our goal in evaluating the blocks. The creation of a tomogram is ideal for reconstruction work or for restoration, where on the basis of a small number of profiles we get a quality picture of the damage in the element. It also supports better material use where the price is extremely high; in case we are dealing with expensive materials, it is necessary to examine the block in detail and then decide how and for what purpose the material shall be used. For deciding, the ultrasonic method of stone examination is of great help and also saves time and money and minimises risks.

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