Application of ultrasonic methods for determination location and sizes of granite blocks of the monument pedestal

Andrey Korgin, Laith Zeyd Kilani and Valentine Ermakov

Moscow State University of Civil Engineering, Yaroslavskoye Shosse, 26, Moscow, 129337, Russia

E-mail: Lostprojekt@gmail.com

Abstract: This article presents study based on ultrasonic nondestructive method in structural inspection of monument pedestal that is made of several granite blocks. The goal of the study is to define the sizes, shapes, location of granite blocks and determining the actual scheme. Ultrasonic nondestructive methods are frequently used for thickness determination, so the ultrasonic tomography MIRA A1040 that consists of 48 low-frequency broadband transverse wave was used in this study. The article contains device settings (ultrasonic wave speed and ultrasonic wave frequency) determined for usage with construction made of granite. As the results of pedestal inspection a tomograms and drawing based on ultrasonic testing are presented. The drawing accurately shows the dimension, shapes and location of granite blocks also it shows the results of tomography and the post processing of the obtained data. The analysis of the collected data is made.

1. Introduction

One of the main tasks of the structural inspection [1, 2] is to define the real structures of the inspected constructions, and comparison it with the project documentation. In addition, procedures of visual control, measurements, strength tests determination of the composition of structures including opening up works are required. However, in some cases, an opening up works cannot be done, or it's realization and subsequent recovery requires significant labor and time costs, according to this instead of conducting opening up works, methods of nondestructive testing [3] is usually used

The objective of the current study was the granite pedestal of the monument with the size of 2.1 × 2.1 m in plan and 2m height. The inspection goal was determining the composition of the pedestal, relative location of the blocks, their sizes and defining defects in the construction.

The actual construction scheme of the pedestal is one of two variants:
- Pedestal consisting only of granite blocks (figure 1a);
- Pedestal consisting of blocks and a core within (figure 1b).
Nowadays, ultrasonic thickness measurements [4, 5, 6, 7] are widely used for thickness testing. In this case, both classical instruments that measure the sounding time, and modern devices that have flexible settings of the speed and frequency of sound are used.

Weather conditions during the inspection (air temperature -25°) and work at an altitude of 7-8 meters above ground level using an aerial platform required usage of a device that allows you to work as quickly as possible without compromising the quality of the inspection.

2. Methodology
In this work low frequency, ultrasonic tomography MIRA A1040 [8,9,10] was used (figure 2), which has a high performance. The matrix antenna [11], that consist of 48 (12 blocks with 4 elements in each) low-frequency broadband transverse wave transducers with dry dot contact [12], allows coverage of inspection area of 130 \( \times \) 380 mm in one measurement, While a classical instrument will measure the propagation time of ultrasound at one point. Also significantly accelerates the process of measuring the absence of the need for contact fluid using ceramic wear-resistant tips.

![Figure 2. Tomography MIRA A1040](image)

The device works in two modes: single scan and map. Single scanning is carried out for the purpose of fitting tests and more accurate adjustment of ultrasonic parameters, and if it is necessary to analyze a small surface area. The map mode allows you to combine several single scans, but you must specify in advance, with which horizontal and vertical steps the scanning is performed.

The most qualitative processing of results is carried out in special software, which allows you to visualize the results of sounding in the form of a 3D model, and also to represent individual cross-sections in three mutually perpendicular planes (B, C, D scans, figure 3).
Figure 3. Orientation of B, C, D scans

For high-quality work of the scanner, it is necessary to establish as accurate as possible the value of frequencies and the ultrasonic wave speed.

The frequency can be selected depending on:

Thickets of the inspected object: The higher the frequency, the faster it decays, and, consequently, it becomes impossible to inspect structures with a large thickness.

The assumed size of the defect: the higher the frequency, the smaller the wavelength as in equation (1), and therefore the smaller defect is possible to determine.

\[ \lambda = \frac{v}{f} \]  

(1)

\( \lambda \) – wavelength;
\( v \) – ultrasonic wave propagation velocity;
\( f \) – ultrasonic wave frequency.

Experience with the instrument and various building materials.

Incorrect assignment of the frequency of ultrasonic wave leads to mistakes in the interpretation of the results of the inspection. The correct selection of ultrasonic wave frequency is determining during a series of single scans. In this case, the ultrasonic wave frequency was determined to be 35 kHz.

The ultrasound velocity can be determined as follows:

With the experienced assignment of the ultrasonic wave propagation velocity at various building materials. At the same time, it is necessary to take into account that the velocity of ultrasonic wave in the materials accepted by the average value can differ from the actual speed

Using the automatic ultrasonic velocity detection function (figure 4). The speed in this case is determined by one measurement, and optimally, perform a series of measurements and take the average result.
Figure 4. Setting menu. Using the measured velocity

Calibration of the sound velocity through the thickness of the structure. In some cases, to implement this method, partially weakening of the structures (drilling holes) is required. The thickness of the element measured by the tape measure is iteratively compared with the results of the device operation. In this case, the erroneous assignment of velocity is possible because of the local inhomogeneity of the building material, if there is any.

Incorrect assignment of ultrasonic wave velocity also affects the final result of determining the thickness and depth of foreign bodies as in equation (2). In this inspection, the ultrasonic velocity was 3600 m/s, which was compared to the measured distance to the crack (there were cracks in the pedestal) in the block.

\[ v = \frac{l}{t} \]  

\( v \) – ultrasonic wave propagation velocity  
\( l \) – ultrasonic wave traveled distance  
\( t \) – ultrasonic wave traveling time

3. Results and discussion

In this investigation, 16 tomogram maps were collected - 8 maps on the upper and lower level of the pedestal. Each map was created from 3-5 steps of 20 and 5 cm horizontally and vertically, respectively. The schemes of the pedestal with the indication of the location of maps scans are shown in figure 5, 6.
The result of scanning is isofield illustration of the cross section of the sounding object, where the colors (from blue to red) show the reflectivity (degree of heterogeneity) of points in the coordinate system of the section.

Adjusting the intensity of the reflectivity in the software allows increasing accuracy of the geometric location of the defect.

Figures 7 and 8 show B-scans of maps No. 16 and 7, which clearly illustrate the results of ultrasonic inspection, on which the signal at the end of the structure is clearly visible, which corresponds to the thickness of the structure in one or another place.
Analysis of Map No. 16 shows two interfaces that occur at a depth of 530 and 880 mm of a granite block, analysing map No. 7, two interfaces were also found at depths of 500 and 830 mm.

As a result of a sequential analysis of all the maps, the cross sections of the pedestal in two levels with the sizes of the blocks were obtained (figure 9).

![Figure 9](image)

**Figure 9.** Identified sizes and locations of the blocks of the pedestal: (a) lower level; (b) upper level

4. Conclusions

Analysis of the depths of the boundaries interfaces in a granite blocks clearly showed that the pedestal have a core inside. The detected volume inside the pedestal can be filled either with air, or with a concrete core, or with a granite block; therefore, an opening up works are necessary for a more complete evaluation of the constructive scheme.

The efficiency of using the ultrasonic testing method as a nondestructive method for determining the composition and dimensions of structures has been confirmed.

The frequency and ultrasonic velocity settings (35 kHz and 3600 m/sec) of the instrument are obtained, which should be used for this type of structural inspection.

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References

[1] Kunin U and Kotov V 2011 comprehensive survey of historical buildings with purpose to develop project of restoration Vestnik MGSU [Proceedings of the Moscow State University of Civil Engineering]. 1 209-215

[2] Erdly J and Vaalentino E 2007 Valentino investigation of masonry failure of a granite and limestone clad historic church in eastern Pennsylvania journal of ASTM International 4 1-9

[3] Hussain A. and Akhtar 2017 S review of non-destructive tests for evaluation of historic masonry and concrete structures Arabian journal for science and engineering 42 925-940

[4] Choia P, Kimb D, Lee c B and Won M 2016 Application of ultrasonic shear-wave tomography to identify horizontal crack or delamination in concrete pavement and bridge Constr. Build. Mater. 121 81–91
[5] Wiggenhauser H, Samokrutov A, Mayer K, Krause M, Alekhin S. and Elkin V
2017 Large-Aperture Ultrasonic System for Testing Thick Concrete Structures
J. infrastruct. Syst., 12 1-9

[6] Mannin E, Ramos I and Fernandes F 2014 Direct sonic and ultrasonic wave velocity
in masonry under compressive stress 9th international masonry conference 2014
in guimaraes 1-11

[7] Cannas B, Carcanqiu S., Concì G, Fanni A and Usai M 2011 Numerical simulation
of ultrasonic nondestructive techniques of masonry buildings proceeding of the
2011 COMSOL conference in Stuttgart 1-7

[8] Delahaza A, Samokrutov A and Samokrutov P 2013 Assessment of concrete structures
using the Mira and Eyecon ultrasonic shear wave devices and the SAFT-C
image reconstruction technique Constr. Build. Mater. 38 1276–91

[9] Schabowicz K 2014 Ultrasonic tomography – The latest nondestructive technique
for testing concrete members – Description, test methodology, application example
ACME 14 Issue 2 295–303

[10] Kashif Ur Rehmana S, Ibrahima Z, Ali Memonb S and Jameela M 2016 Nondestructive
methods for concrete bridges: A review Constr. Build. Mater. 107 58–86

[11] Bishko A., Samokrutov A and Shevaldykin V 2008 Ultrasonic echo-pulse
tomography of concrete using shear waves low-frequency phased antenna
arrays 17th World Conf. on Nondest. Test. Shanghai, China 1–9

[12] Samokrutov A, Kozlov V and Shevaldykin V 2006 Ultrasonic testing of concrete
objects using dry acoustic contact. Methods, instruments and possibilities
The Proc. 5th Int. Conf. Nondestr. Test. Techn. Diagn. Ind Moscow 152