3D Ultrasonic Tomography Technique as a tool to Evaluate Concrete Structures

Alexandre LORENZI [1], Lucas Alexandre REGINATO [1], Rafael Burin FÁVERO [1], Luiz Carlos Pinto da SILVA FILHO [1]

[1] Laboratorio de Ensaios e Modelos Estruturais, Programa de Pós-graduação em Engenharia Civil, Universidade Federal do Rio Grande do Sul; Porto Alegre, Brasil
Phone: +55 51 33089547, e-mail: alexandre.lorenzi@ufrgs.br

Abstract

Nondestructive testing methods are important components of inspection procedures for infrastructure facilities, such as bridges, highways and tunnels. The use of these methods provides means to control important characteristics of concrete structures that compose a large part of the infrastructure of several countries. Therefore, the development of control methods to determine the state condition of these concrete structures is critical and very important. The increasing number of early deterioration symptoms found in relatively new concrete structures provides a strong argument for the development and validation of techniques to monitor the condition state of concrete elements and to provide data about its potential service life. The evolution of sensor and information technology has induced the proposition of new and improved NDT techniques. It is necessary, nonetheless, to test these enhanced tools under various conditions to check their capacity of detecting signs of deterioration or map variations in homogeneity. To this end, the current work proposes to evaluate the usefulness and precision of 3D Ultrasonic Tomography (UT) for concrete analysis. Furthermore, it tests various data interpretation strategies. UT tests provide more information than traditional UPV tests and may potentially serve as a useful tool to support the analysis of concrete bridges and other complex structures. The results indicate that tests have a high accuracy and enable operators to make a successful detection of internal defects of small dimensions in large concrete structures.

Keywords: Nondestructive Testing, Concrete, Ultrasonic Tomography

1. Introduction

The evolution of technology in various fields of knowledge, such as physics and electronics, has fueled the creation of new techniques for nondestructive testing (NDT), broadening the scope of research applicable to concrete structures tools. Most of these methods allows the detection of abnormalities without causing damage to the material, and after their use, it is possible to carry out an inspection of an affected uninterrupted service structure, providing a saving in terms of time and cost [1].

Accurate measurements of structures durability are difficult tasks, as well as the data interpretation from these analyzes. This is due to the inherent heterogeneity of concrete. The NDT methods of cementitious materials are a fundamental area of research which allows obtaining the quality and the degradation state of building materials. Ultrasonic NDT techniques can be used to provide information regarding to the microstructure of composite materials [2].

The application of NDT methods for quality assurance of concrete structures has made considerable progress recently. Driven by technology and knowledge transfer from other areas of materials testing and medicine a versatile toolbox of methods for the investigation of concrete structures has emerged from research [3].

The condition assessment of building material is a key point when one wants to reassess existing structures whose material ageing can have resulted in some performance loss and

some deterioration of the safety level. Progressive decay of performance also induces important maintenance costs, such as to prevent future deterioration and ultimate failure [4].
NDT is widely used in civil engineering for controlling new structures (quality control) as well as for assessing the level of damage of old structures and buildings whose behavior is under question.
The purposes of NDT can be classified as follows: (a) to detect a defect or a variation of properties, (b) to build a hierarchy, regarding a given property, between several areas in a structure or between several structures, (c) to quantify these properties, e.g. compare them to allowable thresholds.
This paper presents the results of a case study that seeks to determine the accuracy of Ultrasonic Pulse Velocity (UPV) and Ultrasonic Tomography (UT) in the detection of internal defects in concrete structures.

2. Ultrasonic Pulse Velocity

The Ultrasonic Pulse Velocity method is based on determining the longitudinal propagation characteristics of an ultrasonic pulse through a material. UPV is the method most commonly used in the assessment of concrete structures. This method is widely used for evaluation of concrete due to its effectiveness, ease of implementation and low cost.
The UPV tests are characterized by an NDT method that aims to detect defects or internal discontinuities present in various types of materials. The UPV in a solid material will depend on the density and elastic properties of material. In concrete the test provides three different parameters (velocity, range and dispersion) of ultrasonic pulses [5].
More complex equipment allows analysis the extent and dispersion of pulses. Most portable devices, however, records only the pulse velocity. Ultrasonic methods have the characteristic of being applied quickly and provide the appropriate level of confidence and security tools to provide quantitative information about concrete and on-site assessment conditions [6]. The ultrasonic tests has been increasingly employed in the diagnosis of structures because it allows to material characterization, assess its integrity and measure important physical properties by monitoring the velocity of propagation of high frequency waves at material [7].
Naik e Malhotra [8] told that almost 50 years UPV has been successfully used to assess the concrete quality. Using the method it is possible detect structural changes in mortar and concrete, which allows to monitor how the deterioration process of concrete results in cracks and changes in microstructure of the material. Through the UPV is possible to demonstrate that differences in the results are proportional to the pores structure and micro cracks of concrete [9]. UPV test offers the opportunity to establish a total control of structure elements. The analysis results can be used for quality prediction of the technological process [10].
According International Atomic Energy Agency [11] measurements of changes in pulse velocity are usually indicative of changes in strength and have the advantage that they can be made over progressive periods of time on the same test piece throughout the investigation. Since the quality of concrete is usually specified in terms of strength; it is, therefore, sometimes helpful to use ultrasonic pulse velocity measurements to give an estimate of strength. The relationship between ultrasonic pulse velocity and strength is affected by a number of factors including age, curing conditions, moisture condition, mix proportions, type of aggregate and type of cement.

UPV technique can be used in defect detection, measurement of thicknesses of the constituent materials or characterization of an object [12]. NBR 8802 [13] prescribes that UPV can be used for check the concrete uniformity, monitor the concrete characteristics during the lifetime, evaluate the depth of cracks, evaluate the modulus of deformation and even to estimate the compressive strength of the concrete.
BSI-1881: Part 201[14] considers that the main applications of this method are:

a) determining the uniformity of concrete;
b) determination of cracks;
c) estimation of compressive strength of concrete;
d) monitoring the concrete strength;
e) evaluation of concrete deterioration.

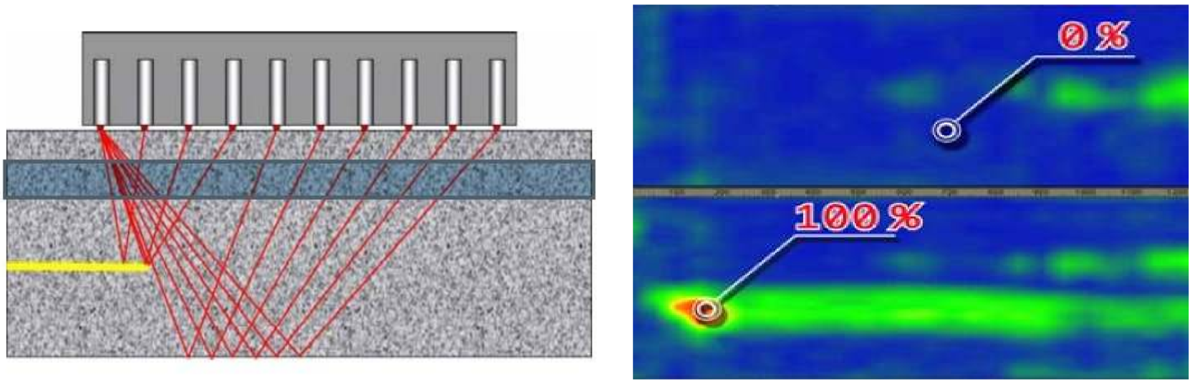
However, it is possible use UPV for specific purposes, such as evaluate the presence of concreting failures or detected damage caused by fire. The relatively low cost of the equipment have stimulated many researchers to seek new purposes to use [15]. An important factor is that the UPV allows doing multiple tests in the same location, in order to monitor changes associated with time. With increasing the early deterioration in concrete structures, it is interesting to perform this type of continuous monitoring of buildings conditions. Through constant monitoring of structures it is possible anticipate maintenance demands and collaborate to increase the structures life-time.

3. Ultrasonic Tomography

Ultrasonic tomography (UT) is an emerging method of NDT that assays concrete diagnostics which can be used for improved quality assurance/quality control during concrete structures construction and assist in rehabilitation decision making. Detection of flaws using ultrasonic tomography requires significant effort and user expertise [16].
UT is assigned to control concrete structures, ferroconcrete and stone with one side access in order to determine the integrity of the material in the structure, search of foreign insertions, cavities, not grouted areas, exfoliations and cracks, and also measuring the thickness of the controlled object. It is possible to control thicknesses up to 2 meters [17].
The ultrasonic tomograph uses shear waves and a system is capable of generating 3D tomographic images of concrete elements, which enables the detection of flaws in concrete structures.
The ultrasonic tomograph device contains 40 “touch and go” transmitting and receiving DPC transducers (see Figure 1). The probes are firmly fixed in an array with 10 channels of 4 transducers resulting in a scanning aperture of 400 mm by 50 mm. Each of the probes can act as either receiver or transmitter with a default operation ultrasonic frequency of 55 kHz [17].

Figure 1 – Ultrasonic Tomograph A1040 - MIRA.

The device measures time of signal propagation between the transducers at fixed distances for material velocity calibration, and uses the synthetic aperture focusing technique for analysis in scan mode to reconstruct the medium below the measurement based on the shear wave reflections. SAFT has been found to be a feasible algorithm for use with the ultrasonic pitch-catch technology as well as other applications [18].
Applicable for concrete inspection allowing imaging of the internal structure of objects from concrete, reinforced concrete, different stones. The operation applies pulse-echo technique at one-side access to the object. The instrument is feasible for concrete inspection for searching conduct ducts, conduits, detection of foreign inclusions, holes, honeycombing, cracks and other defects inside the concrete objects and to assess the condition of reinforcement in concrete. Due to tomographic data processing the more informative imaging of structure is provided [17].
Figure 2 illustrates the operation of MIRA devices and represent the results of an ultrasonic tomography, showing the detection zones with 0% of voids (blue) and 100% of voids (red). The other colors are the result of interpolation between the two extremes and the reflection effects of waves emitted by the device.



(a) (b)
Figure 2 – (a) data acquisition and (b) results representation of the tests [17].

4. Practical Application

Practical application of tests was performed in three different case studies. The first case was the application in a segment of concrete pole. The second case shows the application of the technique on a slab consisting of precast cellular elements.

4.1. Case Study 1
This study was based on the application of MIRA tomograph to detect internal defects in concrete poles commonly used by electric power distribution companies. The scan was made along the length of a double T pole, as can be seen in figure 3 segment. For this scan a grid reading by 10 cm x 25 cm (vertical x horizontal) was used, the frequency used was 30 kHz and pulse ratio by 2400 m/s.
Once acquired the data, the results were entered into the software to generate a 3D image of the reflected element interfaces. At the images generated by the software is possible see the different interfaces present at post segment. Figures 4 and 5 illustrate the results.
Figure 4 shows the stirrups presents in the pole segment analysed as well as their spacing. In Figure 5 is possible visualize the results of longitudinal direction readings of the pole,

where it is possible to identify the longitudinal reinforcement element and a pipe embedded in concrete for receiving the electrical wiring.

(a) (b)

Figure 3 – Pole segment analyzed (a), MIRA readings (b).

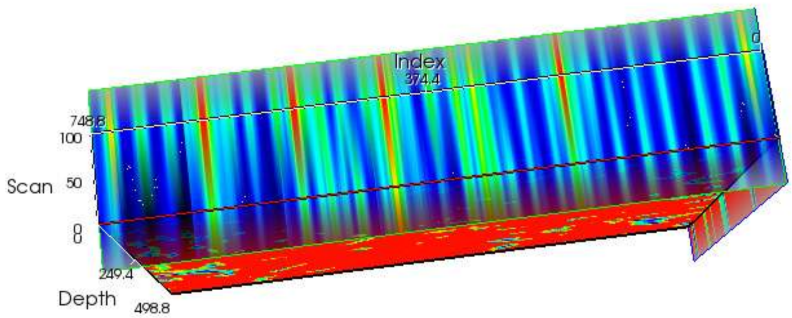


Figure 4 – MIRA view of the stirrups.

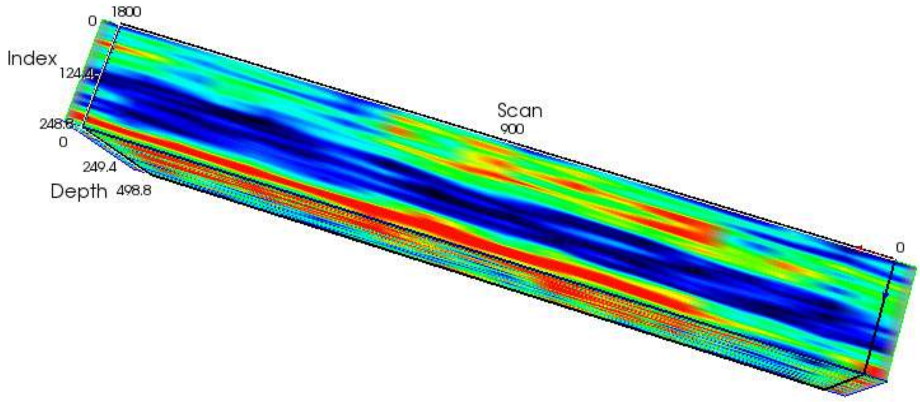


Figure 5 – MIRA results at longitudinal directions.

4.2. Case Study 2

The second study case is based on the application of MIRA to detect the location of precasted hollow core slabs used in a building structure. In this case, a frequency of 70 kHz and pulse velocity of 3040 m/s was used.

At this study, the objective was to analyze the level of detail captured by 3D tomography by varying the used grid. The maximum grid recommended by the manufacturer was used (10 x 25 cm), and a finer grid of 5 x 10 cm. The second grid allows overlapping the data readings for interpolation. Moreover, they also reads with a higher than recommended grid were made.

Figure 6 shows the top view of 3D tomography of the slab obtained with the 5 x 10 cm grid. It`s clearly to observe the hollow cores location. At Figure 7, there is a cross-section of the slab. The image allows observing the hollow cores, their spacing, shapes and distance to the top.

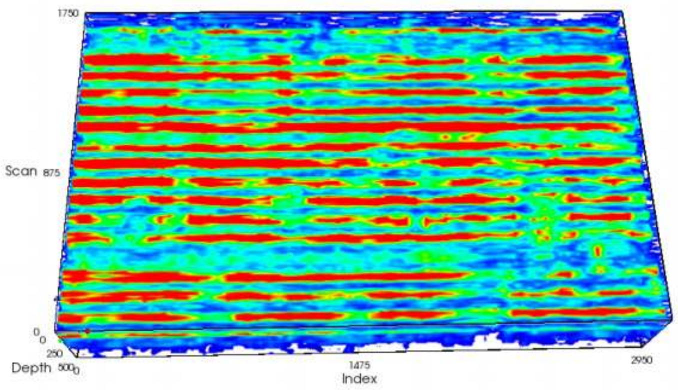


Figure 6 – Results of ultrasonic tomography with 5x10 cm grid.

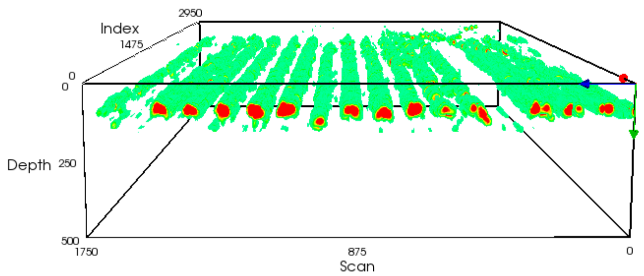


Figure 7 – Identification of hollow cores in sectional, using the 5x10 cm grid.

However, when a spacing greater grid (10 x 25 cm) was used, it is possible to see a reduction at the detail level captured by the 3D scan, which is shown in Figure 8.

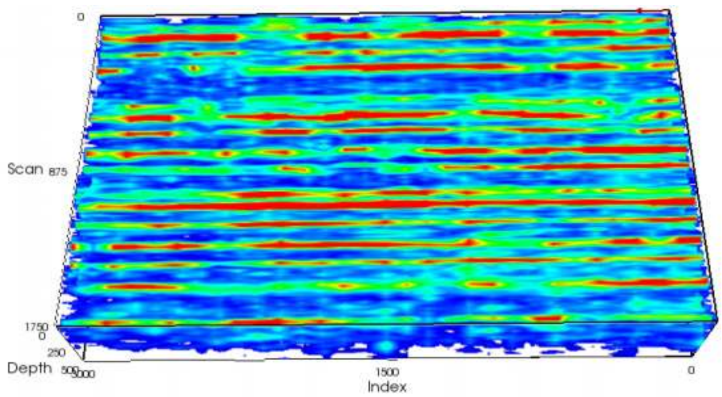


Figure 8 – Results of ultrasonic tomography with 10x25 cm grid.

Although the hollow cores are still perceptible, the image loses the quality and more refined analysis may be compromised. In the case of using larger grids than those recommended by the manufacturer (greater than 10 x 25 cm), the equipment do not interpolate the data between the readings. The results are shown in Figure 9.

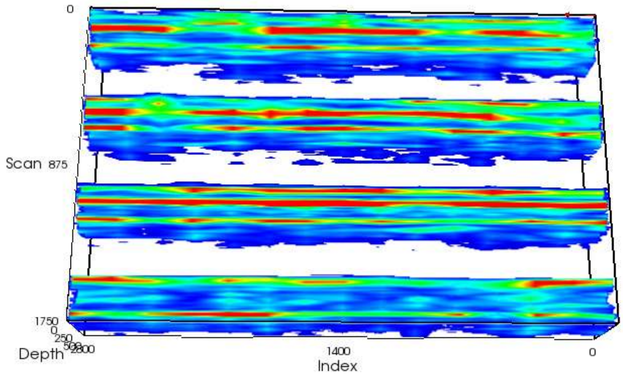


Figure 9 – Results of ultrasonic tomography with 25x50 cm grid.

The software allows viewing the location area where there are voids. In this case it’s possible to observe the internal surface of the hollow cores, where is clearly the continuity and shape of these voids, as shown in Figure 10.

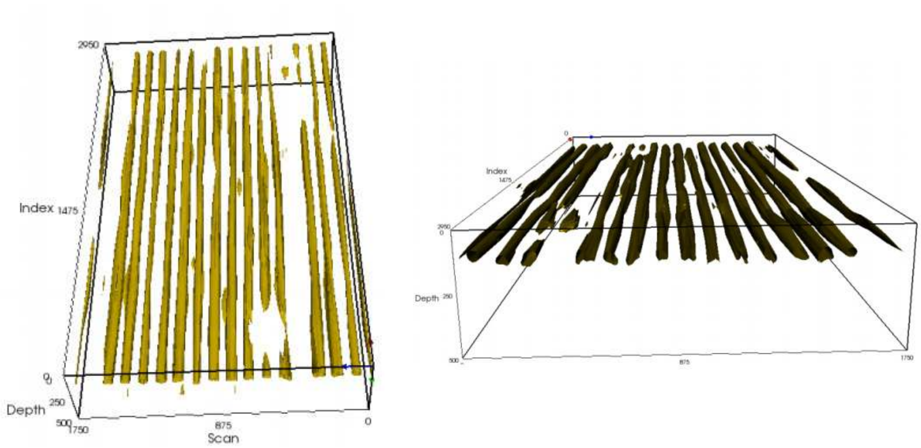


Figure 10 – Top and front view of the slab with the internal hollow cores surface.

5. Conclusions

The tests have proved that ultrasound technology are useful to analyze differences in homogeneity and to detect patterns of cracks in concrete structures. In this context, the application of 3D ultrasound tomography begins to gain importance. UT is a very promising technique in the field of NDT.

This tool is an efficient way to create a three dimensional representation of internal defects that may be present in a particular element and provides a fairly comprehensive analysis of images generated been quite useful in the evaluation of concrete elements.

This is an ideal way to create a three dimensional representation of internal defects that may be present in a particular element and provides a fairly comprehensive analysis of images generated, been quite useful in the evaluation of delicate elements tool.
This paper shows the application of 3D ultrasonic tomography for detection of hollow core slabs in order to show the possibilities for the use as well as the interference of the grid used in the quality of the images obtained.
At the concrete pole 3D images of the tested element reflected interfaces were generated, showing the presence of different elements in the post. On the other hand, the slab analysis allowed to accurately determining the position, number and size of the hollow cores of precast elements. The data analysis allowed exploring the surfaces and making cuts in the structure, showing the versatility of the software.
In general way, it can be assert that the application of UT is an important tool in the assessment of concrete structures, allowing generate three-dimensional tomographic images of the concrete analyzed elements very faithful and permit an accurate diagnosis through the data collected.

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