Revista ALCONPAT
www.revistaalconpat.org
eISSN 2007-6835
Revista de la Asociación Latinoamericana de Control de Calidad, Patología y Recuperación de la Construcción

Evaluation of concrete flaw detection capability by means of ultrasonic tests

A. Lorenzi[1]*, J. A. Chies[1], D. S. Adamatti[1], L. C. P. Silva Filho[1]
* Corresponding author: alexandre.lorenzi@ufrgs.br
DOI: http://dx.doi.org/10.21041/ra.v7i3.127

Received: 03/01/2017 | Accepted: 09/08/2017 | Publicated: 29/09/2017

ABSTRACT
Ultrasonic Pulse Velocity (UPV) tests are being increasingly used to detect flaws in concrete. This work is part of a large experimental program aimed at studying the influence of key technological variables on detection capacity using UPV in real size elements. For this investigation two large concrete elements were cast, with some objects introduced in one to simulate possible concrete flaws due to inadequate casting. Furthermore, to check the capacity of detecting unseen voids with UPV tests, gradual perforations with different depths were made from the unmonitored face. The results confirm that UPV analysis is a very good tool to detect concrete faults, up to some depth.
Keywords: concrete; ultrasonic pulse velocity; structural defects.

Citation: A. Lorenzi, J. A. Chies, D. S. Adamatti, L. C. P. Silva Filho (2017), "*Evaluation of concrete flaw detection capability by means of ultrasonic tests*", Revista ALCONPAT, 7 (3), pp. 286-301, DOI: http://dx.doi.org/10.21041/ra.v7i3.127

[1] Laboratório de Ensaios e Modelos Estruturais (LEME), Postgraduate Program in Civil Engineering, Federal University of Rio Grande do Sul (UFRGS). Bento Gonçalves avenue, 9500 - Building 43436 - Campus do Vale. Porto Alegre RS, Brazil.

Legal Information
Revista ALCONPAT is a quarterly publication of the Latinamerican Association of quality control, pathology and recovery of construction- International, A.C.; Km. 6, Antigua carretera a Progreso, Mérida, Yucatán, México, C.P. 97310, Tel.5219997385893. E-mail: revistaalconpat@gmail.com, Website: www.revistaalconpat.org.
Editor: Dr. Pedro Castro Borges. Reservation of rights to exclusive use No.04-2013-011717330300-203, eISSN 2007-6835, both awarded by the National Institute of Copyright. Responsible for the latest update on this number, ALCONPAT Informatics Unit, Eng. Elizabeth Maldonado Sabido, Km. 6, Antigua carretera a Progreso, Mérida Yucatán, México, C.P. 97310.
The views expressed by the authors do not necessarily reflect the views of the publisher.

Any discussion, including authors reply, will be published on the second number of 2018 if received before closing the first number of 2018.

Avaliação da capacidade de detecção de falhas de concreto por meio de testes ultrassônicos

RESUMO

Ensaios de Velocidade de Propagação de Pulso Ultrassônico (VPU) são cada vez mais usados para detectar falhas em concreto. Este trabalho é parte de um programa experimental amplo que buscou estudar a influência de variáveis-chave na capacidade de detecção usando ensaios de VPU em elementos de escala natural. Para essa investigação foram moldados dois elementos de concreto de larga escala, com vários objetos introduzidos em um deles para simular possíveis falhas de concretagem. Ademais, para verificar a capacidade de identificação de vazios não-aparentes com a técnica de VPU, perfurações graduais em diferentes profundidades foram feitas a partir da face não monitorada. Os resultados confirmam que o ensaio de VPU é uma ferramenta adequada para detecção de falhas no concreto, até certa profundidade.

Palavras-chave: concreto; velocidade de propagação do pulso ultrassônico; defeitos estruturais.

Evaluación de la capacidad de detección de fallas en concreto través del ensayo ultrasónico

RESUMEN

Los ensayos de Velocidad de Propagación del Pulso Ultrasónico (VPU) vienen siendo cada vez más empleados para detectar fallas in hormigón. Este trabajo es parte de una amplia investigación experimental que tiene el objetivo de estudiar la influencia de variables tecnológicas claves en la capacidad de detección del VPU in elementos de tamaño real. Para esa pesquisa dos elementos largos de concreto fueran moldeados, con objetos introducidos para simular fallas en el hormigón. Además, para chequear la capacidad de detección de vacíos no visibles de la técnica de VPU, se realizaron perforaciones graduales hasta diferentes profundidades, empezando en la cara no monitoreada. Los resultados confirman que el ensayo de VPU es una herramienta muy buena para detección de fallas, hasta cierta profundidad.

Palabras clave: concreto; velocidad de propagación del pulso ultrasónico; defectos estructurales.

1.INTRODUCTION

In the current scenario where the quality requirements are consolidating, it is vitally important to develop alternatives that allow an effective evaluation of the quality of buildings. Within this scenario, there is a growing interest in the use of Non-Destructive Testing (NDT) to assist in the inspection and monitoring of reinforced concrete structures. Beutel et al. (2006) emphasize that the use of NDT in civil engineering depends on the reliability of application of the methods.

Following the worldwide trend, in Brazil the application of NDT has been growing in several sectors. The expectation is that in civil engineering the use of NDT methods is still significantly increased, and they have become consolidated as vital tools to assist the professionals involved in the management of performance of these works, in all stages of their life cycle.

NDTs can play an important role in detecting and evaluating the severity of defects and anomalies resulting from design failures, using incorrect dosages, using inappropriate processes of mixing, transporting, launch, densification, curing and deformation, as well as incorrect use of concrete structures. This may have significant repercussions on the quality and useful life of the construction stock, as these problems have led to the appearance of pathological manifestations, often early and with high repair costs, as Figueiredo (2005) emphasizes.

A relevant aspect is that, in general, the use of NDT helps to make feasible the detailed inspection and evaluation of the state of conservation of civil constructions in an economical and efficient way. Most NDT methods allow detection of anomalies without causing material damage. From its use, it is possible to inspect an affected structure without interruption of service, providing savings in terms of time and costs (Grabowski; Padaratz; Pinto, 2008).
The challenge, however, is to understand how to properly use NDTs and how best to interpret their results for reliable diagnoses. The use of NDT techniques to detect cracks, faults, imperfections and damages is efficient in homogeneous materials, but when the same methods are applied to reinforced concrete, a complex and temporally and spatially variable material, it is often difficult to diagnose, since the heterogeneity and the dynamic nature of the composition and structure of this material can cause diverse interferences in the results.
Fortunately, the continuous technological advancement in the area has generated increasingly robust and appropriate NDT methods to accompany the development of new materials. However, to build confidence in these approaches, it is critical to develop experimental programs designed to assess the ability of each method to provide reliable diagnostics, and understand their limitations in test situations, especially under field conditions, where control of several variables can not be performed (humidity, surface roughness, presence of reinforcement, surface carbonation, variations in concrete strength, etc.).
Unfortunately, the process of studying and incorporating new and more advanced NDT methods into civil engineering has been slow. As emphasized by Mehta and Monteiro (2008), the development of NDT methods for concrete compared to other structural materials has been slow.
Recognizing the potential of these techniques and the demand for structured studies of them, the LEME Research Group of the Federal University of Rio Grande do Sul decided, in the 90's, to establish a research line dedicated to the study and evaluation of NDT methods, which has been generating several relevant works in the area. The most studied method in the LEME-UFRGS was the Ultrasonic Pulse Velocity Test (UMP), one of the most simple and popular NDT methods for assessing the compactness and homogeneity of concrete. In the last 25 years, only a few innovative researches on different aspects of the test and its applications have been carried out, such as: mapping of microstructural damages after exposure to high temperatures (Lima, 2005); investigation of fault detection capability (Chies, 2014); and development of advanced resistance estimation models from UPV data using neural networks (Lorenzi, 2009), among others. Recent advances in computerized data acquisition, digital imaging, and the development of complex theories for heterogeneous media have contributed to the improvement of the UPV assays, and studies on the use of so-called ultrasound tomography are underway.
This work is part of a larger program designed in the LEME with the objective of evaluating the ability of the method to detect concrete failures in laboratory fabricated elements, but with dimensions and characteristics similar to those found in real structures.
The research aims to contribute to a better understanding of the potentialities and limitations of the diagnoses carried out on the basis of portable ultrasound readings, by collecting data on how many non-controllable variables in the field interfere with the results and, eventually, make it difficult to detect internal faults of the concrete. This character of the differential investigation, in relation to the majority of studies, that analyzes with small scale test specimens in a laboratory environment, is one of the main aspects that justified the study.

2. STUDY RELEVANCE

In the present work we work with a subset of data from a broad experimental program of research on the use of UPV for analysis of real structures, whose results are published more fully in the works of Adamatti (2013) and Chies (2014).

The subset of data analyzed in this article was collected with the objective of evaluating the capacity of detecting voids and hidden faults (subsurface), under conditions similar to those of actual works.
The central issue of this part of the investigation was to investigate to what depth an adequate diagnosis can be made about the presence of voids, using the mapping strategy based on indirect readings of UPV, often adopted in real cases. Therefore, as described in item 4, defects were induced and perforations were performed in blocks of natural size of concrete.
The knowledge of the critical depth limit for detection can be a fundamental information in the evaluation of real structures with this method. Although there are theoretical formulations about what this depth would be, the data collection under conditions similar to those found in real works, with the disturbances often found in practice (variations of surface roughness, presence of reinforcement, variations in concrete, change of operator, among others) is fundamental to evaluate the robustness and reliability of eventual field diagnoses.
There are practically no studies with this approach in Latin America. Thus, it is considered that the presented results represent an important contribution for users and researchers in the area.

3. ANALYSIS OF CONCRETE STRUCTURES THROUGH ULTRASONIC TESTS

The UPV method is based on determining the propagation of an ultrasonic pulse through a material. The same is a method widely used for evaluating the concrete, due to its effectiveness, simplicity of application and also by its cost.
The use of the UPV test reveals the ability to detect faults inside concrete structures, allowing a complete and adequate sweep of the concrete, as indicated by, for example, studies carried out to evaluate the degradation of mechanical properties of concrete and mortar (Nogueira, 2009); the influence of the presence of armatures in the estimation of the depth of surface cracks (Medeiros et al., 2009), and the monitoring capacity of reinforced concrete structures (Lorenzi et al., 2009).
According to BS 1881-203 - Recommendations for measurement of velocity of ultrasonic pulses in concrete (BSI, 1996), pulse velocity measurements made on concrete structures can be used for quality control of the material.
Compared to mechanical tests on control samples, such as cubes or cylinders, UPV measurements have the advantage that they relate directly to the concrete structure rather than samples that do not always represent "*in situ*" concrete.
The UPV must be related to the results of tests on structural components and, if a correlation is established with the resistance or other necessary properties of these components, it is appropriate to make use of it.
Despite the large number of studies on the UPV, there is a difficulty in relating the UPV and the compressive strength of the concrete. In order to solve this problem, Lorenzi (2009) used Artificial Neural Networks (ANNs) to efficiently correlate the UPV and concrete strength.
Several factors influence the propagation of the ultrasonic pulse in the concrete. The amount and position of the reinforcement in the concrete exert an influence on the UPV, since in steel the velocity is approximately 40% greater than in concrete, especially when the bars are oriented parallel to the direction of the pulse propagation. Other factors, such as the presence of cracks and voids along the path of the pulse propagation, the amount and type of aggregate and the moisture content of the concrete, also exert significant influence on the results, as explained in ACI 228.1R-03 (2003).
According to Naik and Malhotra (1991), the perfect contact between the transducers and the concrete of the element under study constitutes a critical point of this method. If this contact is not reached, it creates an air pocket between the transducer and the element, which causes an

error in determining the wave travel time. This error occurs due to the fact that only a negligible portion of the pulse can be transmitted through the air. In order to ensure perfect contact, it is recommended to use products such as grease and gel, which should be applied in thin layers.

The values of the UPV are in a restricted range, making accurate measurement (accuracy of ± 1%), both of the length of the route and of the time spent by the wave. In addition, measurements of UPV values can be influenced by several factors, such as: surface texture, moisture content, temperature, sample size, presence of reinforcement and the level of stress. Also according to this standard, the correlations between the UPV value and the compressive strength are difficult to obtain because they are influenced considerably by the properties and proportions of the constituent materials, as well as by the maturity of the concrete (BS 1881: Part 201, 1986).

Despite all these difficulties, the use of the UPV is increasingly widespread in the civil engineering area. The same has been used in inspection and monitoring of concrete structures, since it allows to measure and control a series of fundamental parameters to determine the quality of the concrete, both in the laboratory and in field tests.

The UPV test is now an important tool for analyzing the characteristics of the works. Through its use, it is possible to correlate the ultrasonic velocity with the homogeneity of the concrete that is the object of analysis. Therefore, it is necessary to establish statistical models for each case to consider the effect of different variables that affect the propagation of ultrasonic waves in concrete. However, the correlation between these quantities depends on several factors and is subject to certain limitations. These difficulties are, however, minimized when following the same structure over time. In this case, the UPV allows it to be possible to evaluate how the healing process will intervene in the structure.

Another alternative is the generation of neural models, according to Lorenzi (2009), that allow to perform a non-linear analysis of the relationship between concrete strength and UPV, taking into account parameters such as cement type, cure temperature, the water / cement ratio (w / c) and the concrete age. Through the application of ANNs, it is expected to generate nonlinear relationship models that allow the estimation of concrete resistance based on the knowledge of this basic information and the results of UPV tests, in order to produce robust and flexible numerical methods to estimate the compressive strength from UPV data.

According to the Brazilian standard NBR 8802 (ABNT, 2013), there are three possibilities of accommodation of the transducers: (a) direct transmission - is the most recommended arrangement in determining the propagation velocity of waves through a material; (B) indirect transmission - used when there is access to only one side of the body-specimens or component to be inspected; (c) semi-direct transmission - arrangement only used when there is no possibility of using the direct or semi-direct system. In this situation the transducers are positioned on two perpendicular faces.

The present research was used in the indirect transmission mode, which is used when only one face of the specimen or component to be inspected is accessed, allowing the transducer to traverse the face to be analyzed, keeping the transducer fixed. This arrangement is not as efficient as the direct system, in that it suffers the interference of a large area of the analyzed component or test body, reaching UPV values up to 50% lower than those obtained with the direct transmission mode. Whenever possible, direct and indirect measurement systems should be used to obtain correlation factors for the propagation time of the ultrasonic wave. For Ramirez (2015) this method is more prone to errors and is less satisfactory because the amplitude of the signal received is significantly lower than that obtained by the direct transmission method. However, the direct method requires a significantly larger number of readings for the evaluation of the same surface.

4. EXPERIMENTAL CONCEPTION

With the objective of identifying and quantifying the influence of certain variables on the NDT results using UPV, the experimental program sought to investigate how this method behaves when diagnosing faults and concrete failures in natural scale concrete elements.
In order to make this research feasible, two large concrete blocks (1,7m faces and 0.60m wide, totaling 1,734 m3) were generated, with and without the presence of reinforcement, in one of which Styrofoam spheres were introduced to simulate the presence of concrete failures, at different depths.
The blocks were mapped by the rougher face (top of shape during concrete pouring) and by the smoother face (shape bottom), using indirect measurements with more than one operator, with and without the use of coupling gel, using variable measurement grids, in order to simulate conditions that could eventually be found in real structures under analysis. As already discussed, the detailed report of the trials and their results can be found in Adamatti (2013) and Chies (2014).
Additionally, in a second moment, a perforation was generated in one of the blocks, from the smooth face, whose presence was monitored through the UPV tests performed from the rough face. The drilling had a diameter of 5 cm and its depth was gradually increased so that the distance from the hole to the monitoring face was decreasing. The idea was to verify from what depth drilling would be captured in the mappings. In this way, it was sought to ascertain the potential diagnostic capacity of a defect not visible in terms of depth.

5. MATERIALS AND METHODS

For the preparation of the test elements were generated molds using plasticised plywood and frame in eucalyptus wood, trying to approach the way of making a real concrete structure. The shapes were assembled in such a way as to obtain two square faces with a 1.70 m edge, with distinct roughnesses, one smooth (bottom of mold) and one rough (top of the mold - non - contact with the plywood). Figure 1 shows one of the molds used to make the walls.

Figure 1. Molds for the concrete pouring of the wall

The overall dimensions of the concrete elements were 1.70m x 1.70m x 0.60m. The 1.70m value was chosen so that a measurement cell with the maximum possible dimension could be used for the largest measuring grid so that an operator could carry out the measurements alone with a minimum of ergonomic comfort and generate data reasonably usable.
From previous experiments in field studies and studies developed by the team of LEME / UFRGS, the maximum cell of the measurement grid considered suitable for both consists of a

square with 75cm of edge. In this way, it was intended to generate a measuring quadrant of 1.50m x 1.50m in the block, covering 4 cells.
In order to avoid measurements near the edges, which can generate effects that interfere with the measured UPV values, 10 cm bands were added around the reading grid, totalizing the total surface of 1.70m x 1.70m defined for the element .
The molds were produced with a depth of 60cm in order to simulate robust elements, making it possible to evaluate the ability of the UPV test to locate concrete pouring faults inserted at different depths.
In the construction of the walls was used concrete, dosed in concrete central and transported by means of truck mixer to the laboratory, being thrown directly into the molds. A characteristic compressive strength at 28 days of age (fck) of 30 MPa was required, using a pre-established trace known to the concrete metering unit for this resistance level. Throughout the whole process, it was sought to approach the processes used to concretize real works.
To represent the existence of concrete failure in one of the molds were fixed, with the help of nylon wire, solid Styrofoam spheres with diameters varying between 2.5cm and 15cm, in different predefined positions. Styrofoam beads with a diameter of 2.5cm and 5cm were intended to represent small faults, such as air bubbles or unwanted materials. On the other hand, the Styrofoam spheres with a diameter of 10cm and 15cm were used to represent larger faults, due to segregation of concrete, problems in concrete pouring joints and voids due to the concentration of reinforcement.
The positioning and the depth of the voids were thought in a way that could have equal combinations for both faces. Thus, it was possible to evaluate the capacity of detecting voids with diameters of 2.5cm, 5cm and 10cm at depths between 5cm and 50cm for both a rough and smooth surface (Figure 2).
Due to the dimension of the void of 15cm in diameter being relatively large in comparison to the others, its positioning was limited to the center of the wall, to a depth of 30cm of both faces.

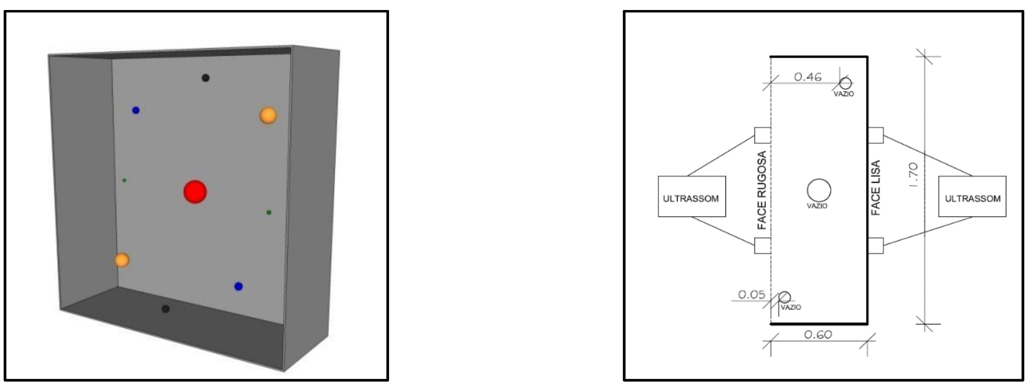


Figure 2. Positioning and depth of voids.

In order to initiate the UPV readings, the minimum time of 28 days of the concrete pouring was expected, in order to minimize the influence of the variation of the resistance of the concrete in the readings.
The variables involved in the assays of determination of the UPV were: distance between the points of transmission and reception of ultrasonic pulses, surface conditions and depth of voids, and for these definitions the equipment specifications were used.
The effective reading areas were identified and marked, corresponding to 1.50 m x 1.50 m from the total wall 1.70 m x 170 m. Then the transducer positioning points were marked for the grid mesh 25 cm x 25 cm, and from the other mesh less refined, (50 cm x 50 cm and 75 cm x 75 cm).

Once this point marking step is completed, the element is ready to be analyzed through UPV measurements. The readings were divided into two phases, the first with an operator with the longest experience with NDT using an ultrasound device, where the NDT performed measurements on both the smooth and rough face and the respective grids specified above.
Figures 3 and 4 show the sequence and reading mode within a segment of the wall. With the values of UPV obtained, the velocity variations were mapped graphically. The results of the first stage provided good indications that the parameters armature, roughness, grid size and operator experience were shown to have greater potential in relation to the quality of interpretation and execution of the test. However, the applied methodology could not accurately define the ability to detect defects at different depths.

Figure 3. Sequence of readings

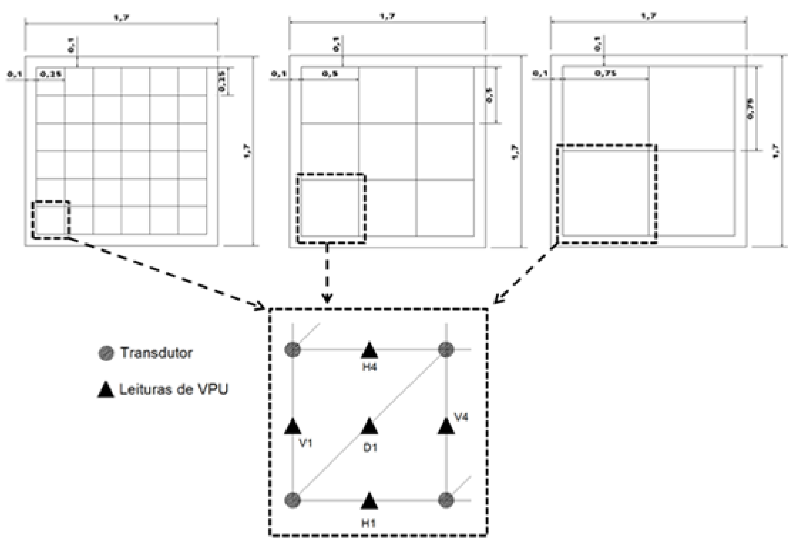


Figure 4. Reading design for each grid

Figure 5 shows the image obtained through the combination of parameters that presented greater capacity of detection of voids. The image presented is the result of the analysis of a wall without armature, tested by an experienced operator, in a grid of 25cmx25cm on the smooth face of the element. As can be seen in the figure, even with the best combination of parameters, no artificially introduced voids could be accurately located.

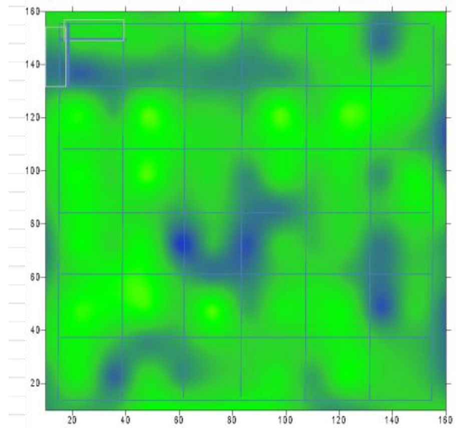


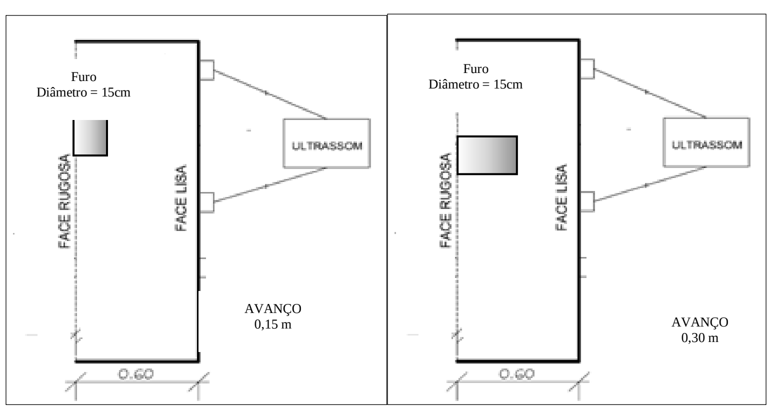
Figure 5. Image generated from the combination of parameters to identify gaps

Apparently, the natural variability of the readings along a real-scale concrete piece had similar or greater magnitude to the reading deviations caused by the presence of the induced defects (with the dimensions and materials used, and positioned at the depths of that test). It is believed that the presence of the defects was not significant due to their small size in relation to the grid, associated with the compactness of the material used to simulate them (Styrofoam).

Other tests carried out in LEME-UFRGS had already indicated that in large-scale test specimens, contrary to what is often recorded in smaller specimens, the simulation of Styrofoam defects does not generate as much disturbance as the use of wood segments or air capsules (in the shape of ping pong balls or the like). The trials of this program have confirmed this trend.

The second investigation was then carried out to complement the results obtained so far. For the accomplishment of this step a research strategy was drawn up that was based on perforations in the face opposite to the face in analysis, enabling the execution of UPV measurements after successive perforations. For this, it was limited the execution of the tests by the operator that obtained the best results in the previous stage, being these realized in the wall without armature and readings executed in the smooth face.

This step was intended to accurately identify to what depth an artificially triggered fault could be located through the test. Figure 6 shows the sequence of some successive perforations and readings that were performed. For this step a region of the block without artificial defects was chosen so as not to interfere with the results.



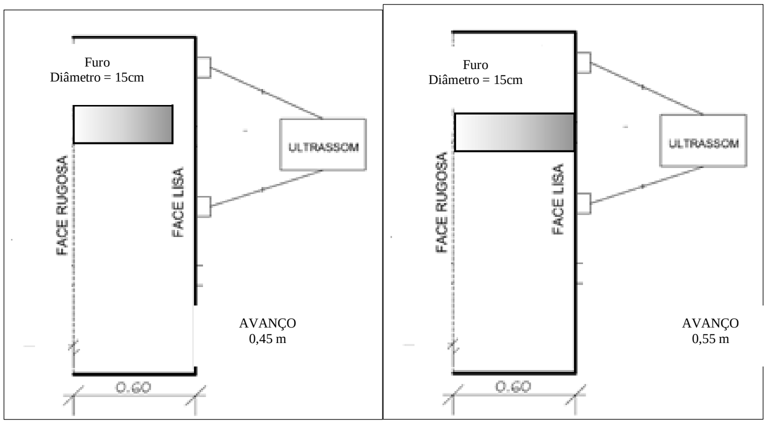


Figure 6. Drill advance diagram

As can be seen in Figure 6, the drilling was performed in several steps. A velocity reading was performed just before the first drilling. With the use of a 150mm inner diameter diamond drilling machine, 15cm was drilled from the rough face towards the smooth face (read face), where the internal material was removed from the hole, avoiding any interference that this could cause in the results. Then, readings of UPV were made on the opposite side.

This procedure was identical and strictly respected in the depths of advance of 15cm, 20cm, 25cm, 30cm, 35cm, 40cm, 50cm, 55cm and 60cm. Figure 7 shows the drilling equipment positioned and starting the job. After the closure of the perforations, UPV measurements were again made, even with the hole already apparent on the test face. As a last procedure, the hole was filled with mortar with a compressive strength of 4 MPa, which corresponds to approximately 10% of the compressive strength of the concrete used, simulating alternatively a void of concrete or non-resistant material trapped inside the structure. As in the other stages, UPV readings were acquired after 28 days of filling the hole with the mortar. Figure 8 shows one of the readings acquired at 60cm depth.


Figure 7. Drill advancement steps


Figure 8. Measurements performed at 60 cm depth

4. RESULTS

In order to perform the tests, we made use of some choices to facilitate the interpretation of the results. In addition to the choice of grid parameters 25x25 cm and smooth face, drilling operations were performed on the wall without reinforcement in order to join the best configurations in an element that did not have interferences such as the presence of steel. Previously of any drilling, a calibration reading was performed on every element, for comparison with the readings obtained after the drilling.

Figure 9 shows the generated image. After the validation of the measurements, the procedures described above were started with the drilling of a section, UPV measurements, image generation, new drilling and so on until the other side of the element was reached.

In this phase an area for the UPV measurements corresponding to ¼ of the total surface was delimited. This decision was made by covering only the region of possible interference that the hole could cause, thus allowing a greater number of successive readings. Figure 10 shows the section of the wall used in the measurements of UPV and respective segment of image generated.

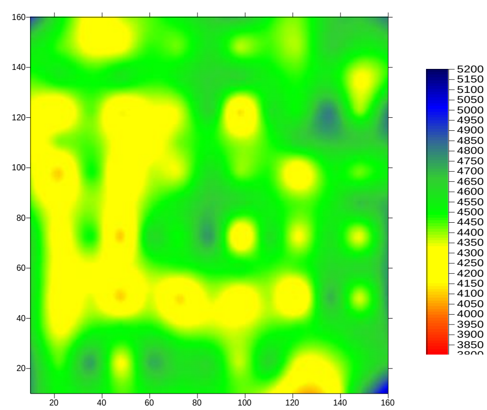


Figure 9. Measurements made for calibration

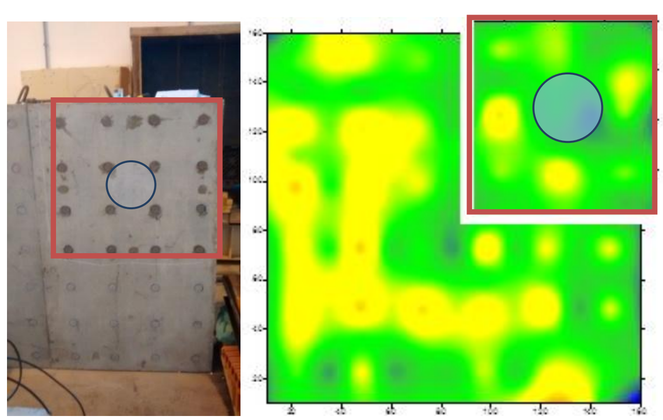
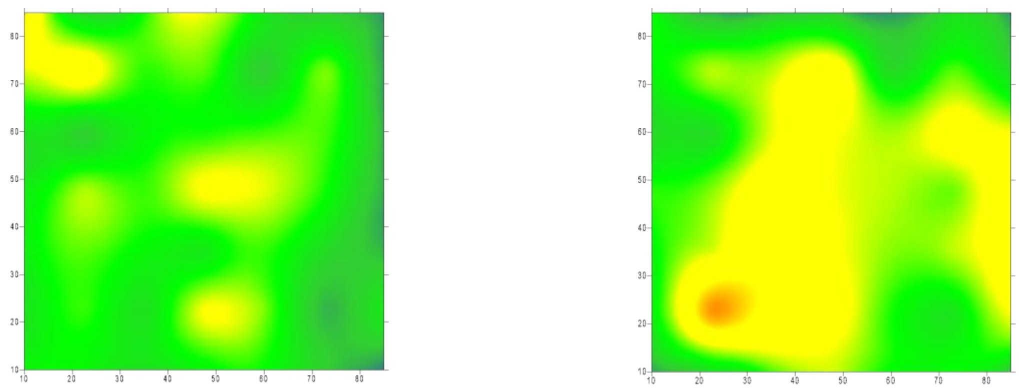


Figure 10. Delimited region and respective image generated.

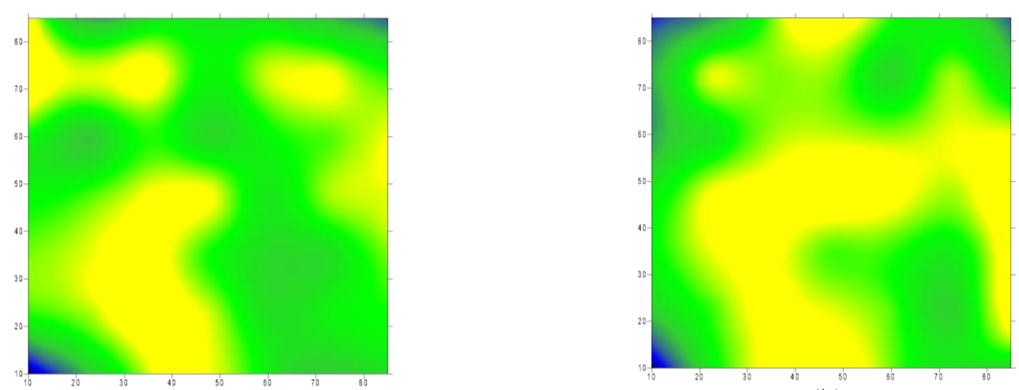
The images presented from this moment on are always relative to the area delimited in red. Initial tests were conducted to decide which region to limit without any harmful effects to a correct interpretation. For a comparison, a minimum speed of 3800 m / s representing regions under suspicion and a maximum speed of 5200 m / s were used for all images, symbolizing

homogeneous regions. Figures 11 to 13 show the sequence of images obtained and the respective depth of the hole for depths between 0 and 35cm.
We can observe in the images that up to the depth of advance of 35cm no significant changes occur in the analyzed region. We can conclude that for the study situation, it was not possible to detect signs of the presence of the hole. The differences observed are only derived from small variations and test noise.
Figure 14 shows the sequence of images obtained and the respective depth of the hole for depths between 40 and 50 cm. Based on the results obtained in the images, a significant reduction in velocity averages was observed, especially in the central region, exactly in the area where the hole is located. From the analysis of these results it is possible to visualize evidence of the presence of the defect.



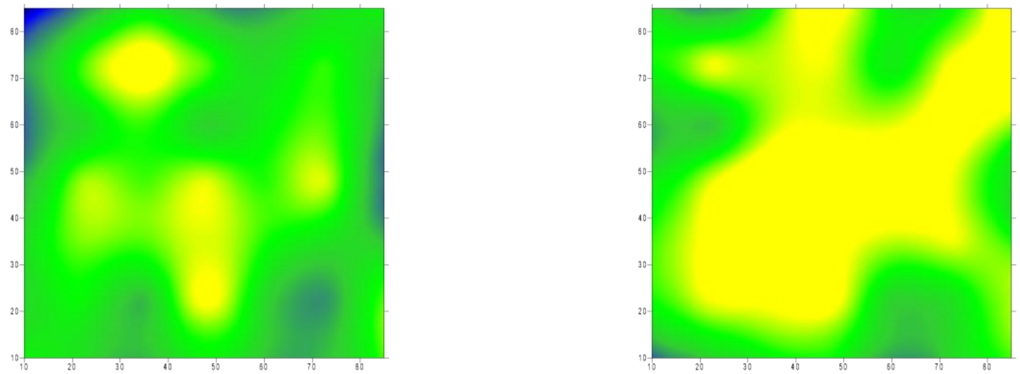
(a) (b)

Figure 11. Image corresponding to the depth of: (a) 0,0 m and (b) 0,15 m



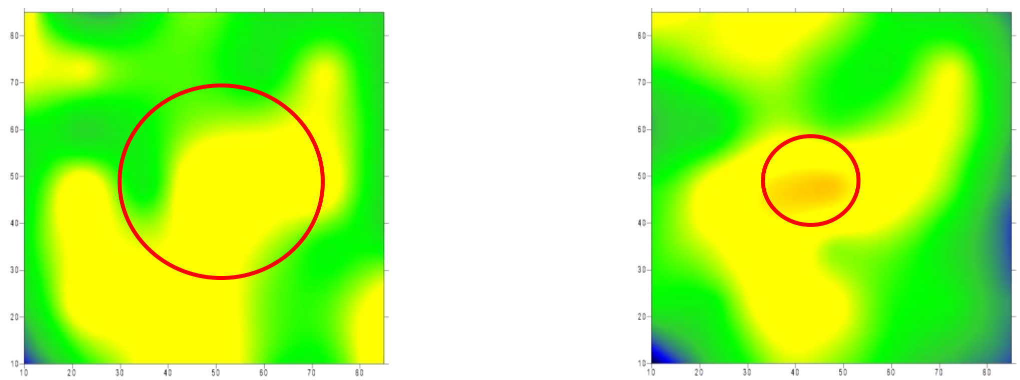
(a) (b)

Figure 12. Image corresponding to the depth of: (a) 0,20 m and (b) 0,25 m



(a) (b)

Figure 13. Image corresponding to the depth of: (a) 0,30 m and (b) 0,35 m

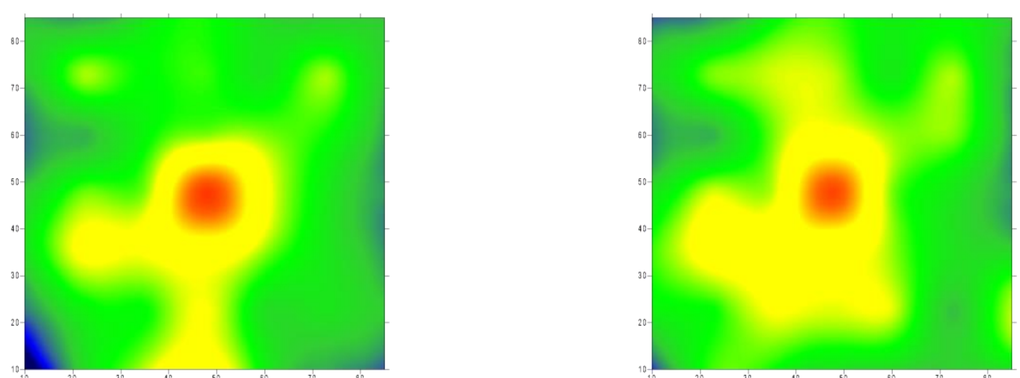


(a) (b)

Figure 14. Image corresponding to the depth of: (a) 0,40 m and (b) 0,50 m

Figure 15 shows the obtained images and the respective depth of the hole for depths between 55 and 60cm. From the images generated for the last 10cm of advance, it is clearly observed the presence of the hole, which demonstrates the ability to detect defects to a depth of approximately 10cm.

As can be seen, the generated image was also able to represent with relative precision the size of this void. After completing the drilling step, a complete reading of the wall was again performed, thus verifying if the behavior presented in the specific images of the perforated region would also be verified in a global interpolation of the element.



(a) (b)

Figure 15. Image corresponding to the depth of: (a) 0.55 m and (b) 0.60 m

Figure 16 shows the result of this interpolation and generation of the respective image. Analyzing the generated image can be observed with ease the connection between the actual position of the hole with a considerably lower speed region shown in the image.

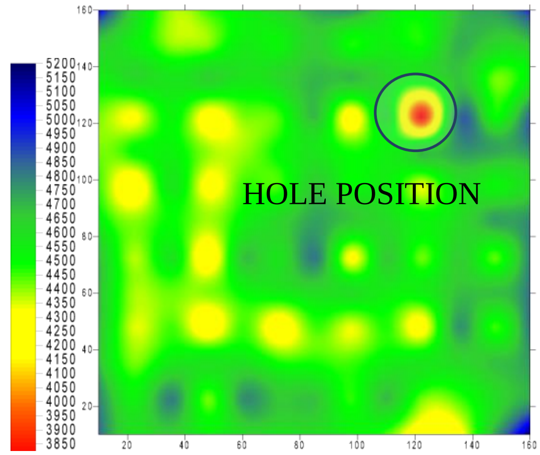


Figure 16. Image corresponding to the depth of 60 cm - full face

5. DISCUSSION

This work had as objective to analyze the influences of the parameters that were object of this study entail in the results of the UPV test. By analyzing and comparing the results obtained through the tests carried out, it can be concluded that the choice of the reading grid will depend on the size of the element and the dimension of the defect in its interior.
The careful choice of test parameters enables a complete interpretation of the quality of concrete structures. From the successive drillings performed it can be concluded that it was not possible to detect by ultrasonic pulse waves with a grid of 25cm for defects of the order of 15cm in diameter at depths greater than 30cm.
The operator's experience proved to be the most important and significant variable in the analyzes, since the lack of training of the operator can lead to erroneous interpretations, also considering that the operator is indispensable to carry out the tests.
Defects existing at a depth of 10 to 30 cm affect the average velocities of the regions close to it, which can lead to confusion in the localization with regions without defects. As well as present faults at depths of up to 10cm do not have their location and dimension clearly pointed out by the graphic images provided by the software.

6. CONCLUSIONS

The use of UPV assays is increasingly disseminated in the area of Civil Engineering. The study shows how the UPV assay can be used for the analysis of structures, since the data obtained allow to verify, for example, the presence of foreign bodies and voids. The UPV assay is highly sensitive to variations in homogeneity and density. An important advantage of the UPV assays is that they can be applied harmlessly to structures in use, an extremely important aspect for diagnostics and the definition of intervention strategies.
The application of the UPV test is in the phase of popularization of its use in concrete structures because it presents several advantages for the evaluation of the structures, however needing a knowledge in its use and operation proportional to that use by the technical means.

The study indicates that UPV assays are sensitive to variations in homogeneity and density and can therefore provide important data for decision making regarding the condition of concrete structures. That is, it can be concluded that, through the execution of UPV tests, it is possible to contribute to the quality control of concrete structures.
From the results obtained in the successive perforations it can be concluded that:

(a) It was not possible to detect by ultrasonic pulse waves with a grid of 25cm for defects of the order of 15cm in diameter at depths greater than 30cm;
(b) Defects existing at a depth of 10 to 30cm affect the average velocities of the regions close to it, which can lead to confusion in the localization with regions without defects;
(c) Faults present at depths of up to 10cm do not have their location and size clearly indicated by the graphic images provided by the software and
(d) The choice of the test parameters is a determining factor for a correct and unambiguous interpretation.

Thus, the studies confirm the hypothesis that the UPV assays have great potential of use in the cases of inspection of structures. Its use allows to obtain important indications for the characterization of the concrete, as well as data on the homogeneity and the quality of the structure. UPV trials can be useful in decision making and intervention strategies, since lack of information can increase the scope and complexity of planned interventions, increasing costs or generating additional inconvenience for users.

7. REFERENCES

Adamatti, D. S. (2013), *“Propagación da velocidad de pulso ultrasónico na análisis de estructuras de concreto armado: Estudios de parámetros tecnológicos intervenientes”*, Trabajo de Conclusao de Curso de Especializaçao em Ingeniería Civil, Universidade do Vale do Rio dos Sinos, Sao Leopoldo.
American Concrete Institute (1998), ‘*Nondestructive test Methods for Evaluation of Concrete in Structures*’, ACI 228, 2R-98. American Concrete Institute, EUA.
Associaçao Brasileira de Normas Técnicas (2013), ‘*Concreto Endurecido – Determinación da Velocidad de Propagación da Onda Ultra-sonica: Método de Ensayo*’, NBR 8802. ABNT, Rio de Janeiro, Brasil.
Beutel, R., Reinhardt, H., Grosse, C. U., Glaubitt, A., Krause, M., Maierhofer, C., Algernon, D., Wiggenhauser, H., Schickert, M. (2006), “*Performance Demuestration of Non-Destructive Testing Methods*” in: European NDT Conference (ECNDT 2006), 9, 2006, Berlin: The German Society for Non-Destructive Testing.
BRITISH STANDARDS INSTITUTION, BSI 1881 - Part 203, *Recommendations for measurement of velocity of ultrasonic pulses in concrete*, (London, UK: BSI, 1986), 20 p.
Chies, J. A. (2014), “*Ensayos no destructivos em concreto: detección de fallas no interior de estructuras de concreto com o uso de ultrasonido”*, Dissertaçao de Mestrado, Programa de Pós-Graduaçao em Ingeniería Civil, Universidade Federal do Rio Grande do Sul, Porto Alegre, 133p.
Figueiredo, E. P. (2005), Inspección e Diagnóstico de Estructuras de Concreto com Problemas de Resistencia, Fisuras e Deformações, in: G. C. Isaia (Editor), “*Concreto: Ensino, Investigación e Realizações*” (Sao Paulo, Brasil: IBRACON), cap.33, vol.2, p.985-1015.
Grabowski, S. L., Padaratz, I. J., Pinto, R.C.A. (2008), “*Evaluación de Placas de Concreto com o Método No Destrutivo do Eco-impacto*” in 50º Congressso Brasileiro do Concreto, Instituto Brasileiro do Concreto, Salvador: (Brasil), 12p.

Lima, R. A. (2005), *"Investigación do comportamento de concretos em temperaturas elevadas"*, Tese de Doutorado, Programa de Pós-Graduaçao em Ingeniería Civil, Universidade Federal do Rio Grande do Sul, Porto Alegre, 241p.
Lorenzi, A. (2009), "*Aplicación de redes neuronales artificiales para estimación da resistencia à compresión do concreto a partir da velocidad de propagación do pulso ultra-sonico*", Tese de Doutorado, Programa de Pós-Graduaçao em Ingeniería Civil, Universidade Federal do Rio Grande do Sul, Porto Alegre, 196p.
Lorenzi, A., Silva Filho, L. C. P., Caetano, L. F., Lorenzi, L. S. (2009), "*Monitoreo de Estructuras de Concreto a través de Ensayos de Velocidad de Propagación do Pulso Ultra-sonico*" in 51º Congressso Brasileiro do Concreto, Instituto Brasileiro do Concreto, Curitiba (Brasil), 13p.
Medeiros, A., Padaratz, I. J., Pinto, R. C. A. (2009), "*Influencia da Presencia de Armaduras na Estimación da Profundidad de Fisuras Superficiales em Concreto Armado a través do Ultra-som*" in 51º Congressso Brasileiro do Concreto, Instituto Brasileiro do Concreto, Curitiba (Brasil), 14p.
Mehta, P. K., Monteiro, P. J. M. (2008), "*Concreto: Estructura, Propiedades e Materiales*" (Sao Paulo, Brasil: PINI), 573p.
Naik, T. R., Malhotra, V. M. (1991), "*The Ultrasonic Pulse Velocity Method*" in: V. M. Malhotra, N. J. Carino (Eds), Handbook on Nondestructive Testing of Concrete, (Boca Raton, Florida, USA: CRC Press), 343 p.
Nogueira, C. L. (2009), "*Evaluación Ultrasónica de Dano Termo-mecanico em Concreto e Mortero*" in 51º Congressso Brasileiro do Concreto, Instituto Brasileiro do Concreto, Curitiba (Brasil), 10p.
Ramirez, F. C. (2002), "*Detección de daños em Estructuras de Concreto por meio de Tomografia Ultrasónica*", Tesis de Maestria, Universidade Federal do Rio de Janeiro, Rio de Janeiro, 167p.