# Evaluation of the concrete characteristics by measurements of sonic wave velocity

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**ABSTRACT: (10 pt)**
The seismic vulnerability of the existing RC buildings and their retrofit are two important topics in modern seismic engineering (both search and professional practice). The related problems with assessment of material and structural characteristics have been extensively studied in last years and then incorporated in seismic codes. In particular, in order to define new effective methodologies and techniques many studies have been performed. Moreover, economic problems regarding these techniques must to be considered. Commonly, in situ tests on RC buildings are subdivided in Non Destructive Test (NDT) and Destructive Tests (DT). The advantage of NDTs tests is that no damage is caused to the structural elements and moreover provide a large amount of data with relatively low cost. In this paper we propose a fast NDT methodology based on the measure of the sonic wave velocity within the RC structural elements. This technique has been developed by means of a wide experimental campaign (carried out in Laboratory of University of Basilicata) on RC elements extract by existing RC buildings. An impulse is generated by a hammer on the surface of the considered elements. Then the average velocity of the sonic waves was estimated. Finally, the results were compared with those obtained by the classical ultrasonic method. From the analysis of the preliminary applications, the proposed technique seems to be able to describe the concrete characteristics with few economic costs due to unexisting damage on non structural components.

*Keywords: RC Buildings, Concrete characteristics, Non Destructive Tests*

## 1. INTRODUCTION

The evaluation of the strength of an existing structure requires the knowledge of mechanical characteristics of building material. For RC building the most important feature is the strength of concrete. The test to be performed are grouped according to the level of damage caused to the structure. Among the destructive test, the most used and efficient method is coring. This method can be applied only on a limited set of points on the structure, and the cost of drilling and core analysis is quite high (Masi et al 2009).
The non-destructive tests (NDT, as Ultrasonic, Scelometric and combined SonReb methods) offer the advantage of preserving the structural integrity and can be applied on a large set of test points at a reduced cost. However, since the estimate of concrete compressional strength is indirect, the obtained informations have to be taken more carefully. Finally, the execution of tests causes damage to non-structural component such as plaster and finishing with non-negligible repair costs.
Among the various studies and experimental campaigns aimed to set up a reliable and non-invasive methodology for in-situ testing of concrete degradation and strength, we mention for the ultrasonic technique Vary, 1988, Rose J.L., 1999, Philippidis and Aggelis, 2003, Schubert et al., 2004, Liang M.T. for the dispersion of surface waves Krstulovic-Opara et al., 1996, Gudra and Stawinski, 2000, for the pulse progation Lin and Sansalone 1992, Sansalone et al., 1997, Schubert, 2004, Malhotra, 1984, for the neural networks Hola et al., 2005 and for the combined methods Masi et al., 2008, Masi and Vona, 2009.
This work reports the result of a new non-destructive test giving the advantage of a very limited damage also on non-structural components, thus with reduced cost and execution time. The theoretical base is

the propagation of P-waves in the frequency range from 100 to 300 Hz, and the novel approach is in the fixing of the three sensors required to the RC element under test.
To validate the proposed procedure we performed a series of tests on RC structural elements extracted by a demolished building comparing the results with those obtained from standard ultrasonic tests.

## 2. DESCRIPTION AND CHARACTERIZATION OF ELEMENTS

The experimental campaign was performed mainly on beams and columns extracted by an Italian existing RC building. These building located in Fivizzano, (Italy) were partially demolished. The structures of Fantoni school building, of Fivizzano (Italy), were designed for only gravity loads. As a result to in situ and in laboratory investigations, between 2000 and 2002, the vulnerability has been assessed and the partial demolition of the building was accorded.
Ten structural elements have been extracted from the last storey (realized in 1975) for the laboratory activities. As described in previous studies (Masi & Vona, 2007), the concrete strength shows a significant variability, inside and between the structural elements.
In this paper, we compared our results of classic NDTs method (standard ultrasonic test) with the results obtained by the new proposed test. Moreover, we evaluate the predictive ability of the new non-destructive test with regard to the concrete strength obtained by coring. To achieve these aims, the results provided by destructive and non-destructive experimental tests on the structural elements have been analyzed. In the experimental campaign we considered two different groups of columns based on their characteristic and deterioration of the concrete surface.
As regard the first group columns the first step of the experimental campaign (NDTs and DTs performed in accordance to UNI EN 2001, 2002, 2005) has been designed. Then, NDTs have been previously performed on the columns (standard ultrasonic and rebound number tests). Subsequently, we have carried out the new non-destructive test. Finally, the core test on each column has been carried out. On the second group columns have been carried out three core tests finalized to define the variability of the concrete strength along the elements. Dimension, reinforced details and layers of the NDTs and DTs are reported in Figure 1.

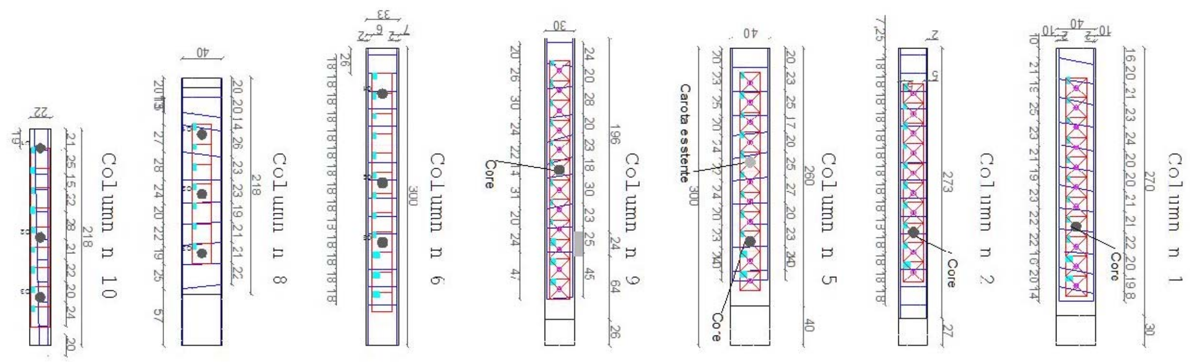

**Figure** 1. Dimensional characteristics of studied columns.

The results are shown in Figure 2, regarding the ultrasonic tests and coring, too. The results prove the ability of standard ultrasonic test with a good accuracy to represent the variability of the concrete characteristics along the development of each element. Indeed, the results reported in Figure 2 highlight, particularly for columns 6, 8, 9, 10, a substantial homogeneity of the concrete characteristics as also provided by the cores. Based on these results we performed the comparisons with the proposed procedure.

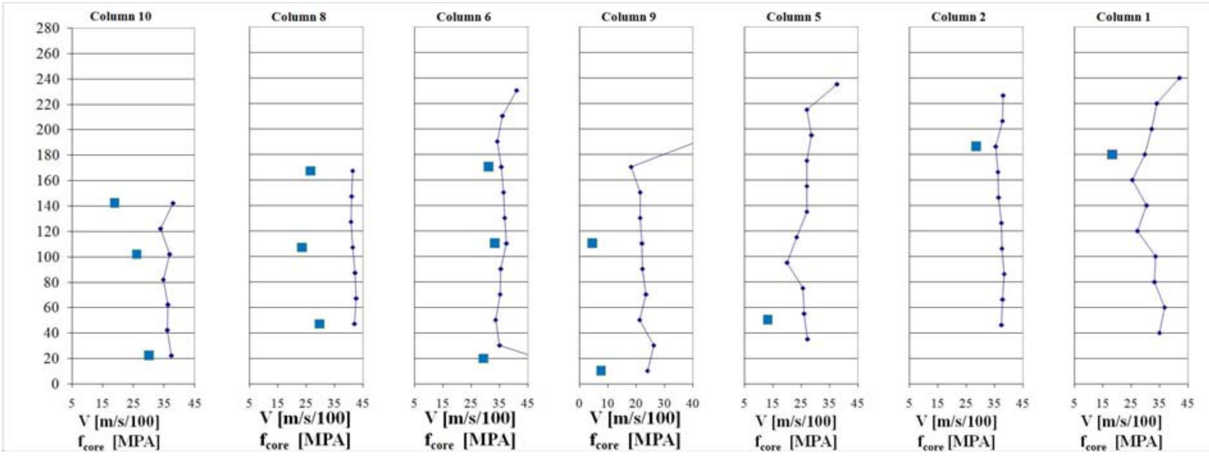

**Figure 2**. Ultrasonic (blu line) and core tests (blu square) results.

## 3. NEW NON-DESTRUCTIVE TEST

In order to better explain our approach to the problem, some details about the theoretical approach will be provided in this section. Obviously, all the future considerations will be referred to an idealistic and elastic medium. Perturbing with an impulsive action a medium having the characteristics mentioned above, the perturbation will be extended by mean of a wave-field composed by elastic waves. The velocity of wave-field depends from both the mechanical characteristics of the medium and the dynamic characteristics of the perturbation. The wave-field could be composed from body-waves and surface-waves. Generally, the former could be composed by P-waves and S-waves while the latter could be composed by Rayleigh-waves and Love-waves. In any case, it is worth noting that P-waves are faster than S-waves. Furthermore, surface waves have a velocity of propagation around 95% of S-waves (this approximation is valid for a condition of Poisson solid) and their energy content is less than body-waves energy content for near-source conditions. On the contrary, for far-field conditions the energy content of surface-waves is greater than the energy content of body-waves. For this study, an approach based on the ray theory has been used. In fact, considering a propagating wave in a layered medium, it is know that for each separating interface will be generated two different waves: a reflected wave and a refraction wave following the Snell's law. The methodology used for this experiment belongs to the refraction seismic prospection methods. It is important to note that for this methodology the refracted P-waves are used. A simple hammer was used as energizer.

For this experiment a system composed by two receiving sensors was prepared. These sensors provide to send to the acquisition system the signals recorded during tests. Generally, for normal condition, recorded signals are composed by noise and signal generated by the hammer. It is considerable to observe that for the sensor located closer to the impact point the time-delay is less than time-delay evaluated for far-sensor. As above mentioned, the wave-field propagation will be influenced from both the mechanical medium characteristics and the geometric characteristics of the specimen.

An important consideration regards the experiment set-up. In fact, considering the tests conditions it is important the choice of the instrumentation and the sampling frequency. This latter parameter is strongly dependent from specimen geometry and wave-field velocity.

Considering all the variables mentioned above several test were carried out. From the analyses performed on recorded signals it was possible to observe that for distance less than 50 cm the evaluated propagation velocities were very low. For these cases the direct wave was the faster, then signal was propagated only through the surface (for the elements considered in our tests the surface were composed by a very degraded concrete).

For distance enclosed in 1-1.5 m distance (between the two receiving sensors) the estimated velocities were greater that those obtained for a previous configuration. Following the Fermat's principle it is clear that using this configuration it is possible to evaluate the kernel velocity and then the kernel characteristics. Finally, also tests using 2m distance (and greater) between the sensors were carried out. But in these cases velocity values are not so clear. Probably this is due from complex phenomena occurred close to the element border.

The instrumentation adopted for the experiments were composed by:

- Acquisition unit (Geode 24 bit);
- Two velocimetric sensors;
- One laptop with storage unit.

For the acquisition we used a sampling interval equal to 0.02 ms and the velocimetric sensors were fixed to the specimen by mean anchors.
Considering the recorded signals, the distance and the time-delay between the two sensors it is possible to estimate the wave velocity for the tested element. Obviously, at this scope the first arrivals were considered.
For preliminary phase we focused our study on the anchoring system. After several tests a solution with two expansion steel anchors (10 cm length) has been adopted. For an optimal test condition it is necessary that the anchor diameter should be comparable to the hole diameter.

## 4. VALIDATION

In this section the results of the tests and processing are discusses. The tests were conducted on the elements horizontally positioned then without axial stress. For each element were considered different test configurations defined by different distances of the velocimeter and positions of the source (different impact points of the hammer). Moreover, two perpendicular sides of each element are considered. For each test we are carried out 15 to 20 repetitions.
Starting from a quiet condition the pulse generated by the hammer perturbs the specimen. In these conditions a wave-field is generated and using the velocimetric sensors, fixed on the specimen, it is possible to record the propagating wave and performing a signal analysis it is possible to evaluated the pulse velocity. As example, in Figure 3 two recorded signals are depicted. The green line represents the signal recorded at the sensors closer to the impact point while the blue line represents that one recorded at the furthest sensor.

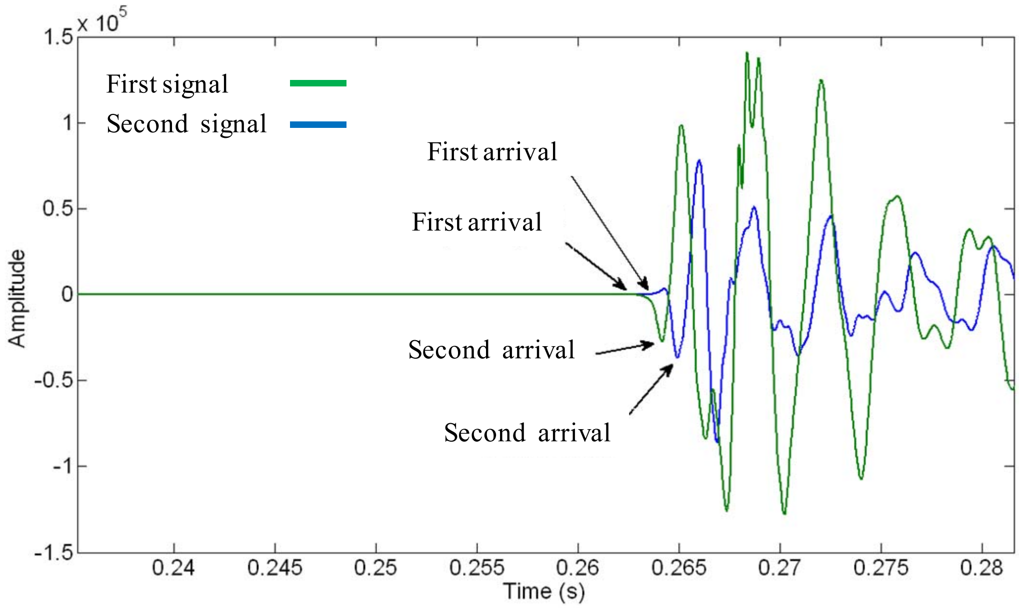


**Figure** 3. First arrivals of the signal.

It is possible to note that the first arrivals are easily identifiable from the recorded signals. Moreover, knowing the distance between the sensors it is easy to evaluate the wave velocity starting from the time-delay evaluated directly from the graph. The wave propagation velocity is equal to:

$$v = \frac{\Delta L}{\Delta t} \tag{4.1}$$

In any case the proposed procedure is easily standardizable. In fact, it is possible to obtain the same wave velocity by using a cross-correlation analysis between the two recorded signals. Generally, for two signals x(t) and y(t), the cross-correlation is defined as:

$$\varepsilon_{xy}(\tau) = \int_{-\infty}^{+\infty} x(t) \cdot y(t+\tau) d\tau \tag{4.2}$$

But for our case it is necessary to use the discrete formulation defined as:

$$R_{xy}(k) = \sum_{i=-\infty}^{\infty} x_{i+1} \cdot y_i \tag{4.3}$$

Cross-correlation analysis provides information about signals time-delay. It is necessary that the time-series have the same length. If x(t) and y(t) are the same signal we are talking about autocorrelation analysis. In general to evaluate the time-delay for the considered signals we are referred to the maximum of the cross-correlation function. Then, knowing the distance between the two sensors it is possible to estimate the wave velocity. This procedure was implemented using MatLab. As example in Figure 4 the velocity distribution, evaluated varying the distance between the sensors, for a structural element were depicted. From the figure it is possible to note that the velocity wave is growing up from 1000 m/s, evaluated for the surface, to 2400 m/s, obtained positioning the sensors with a distance equal to 1.50 m. As mentioned above, the latter estimated wave velocity represents that occurred for the internal kernel where the concrete characteristics are better than those estimated for the superficial concrete.

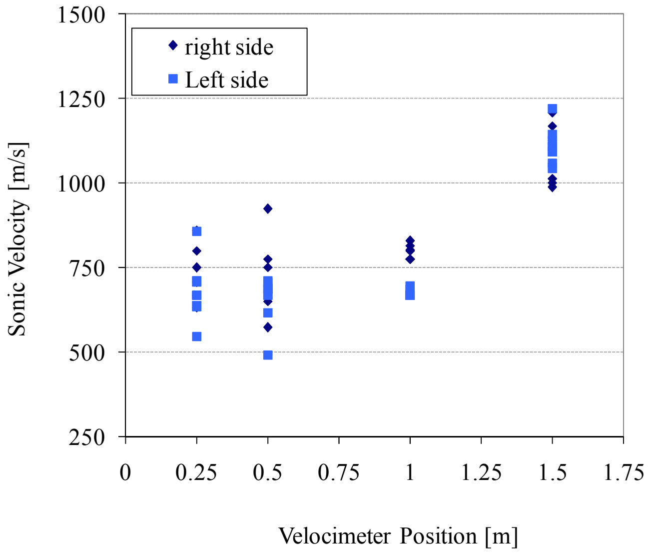


**Figure 4.** Velocity distribution in column 9.

Finally, maximum wave velocity values obtained from the test were reported. Obviously all values are representative of internal kernel of each tested element. These values are compared with those obtained using the classical ultrasonic method (Figure 5).

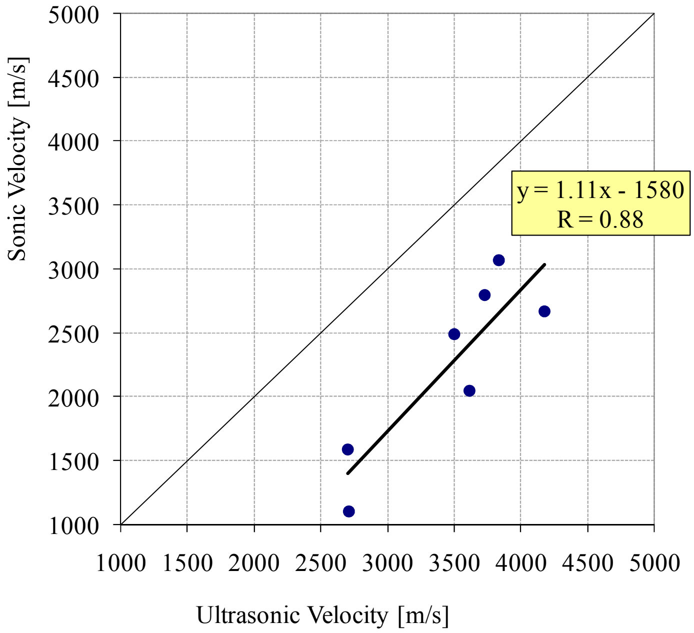


**Figure 5.** Comparison between ultrasonic velocity and sonic velocity.

The difference among absolute values could be easily explained considering the ultrasonic method uses functioning frequencies around 50 kHz while greater that those used for our experimentation (around 250Hz). Considering the equation obtained for a linear standard solid (equation 4.4), that allows to evaluate how change the estimated wave velocity changing the frequency. It is worth noting that wave velocity increases with frequency (Figure 6).

$$v(\omega) = v_0\left[1 - \frac{\ln(1/\omega)}{\pi}\left(LQ_\mu^{-1} + (1-L)Q_k^{-1}\right)\right] \tag{4.4}$$

In any case, it is evident from Figure 5 that the two different methodologies provide different values for waves velocities, but for considered elements the trend is exactly the same.

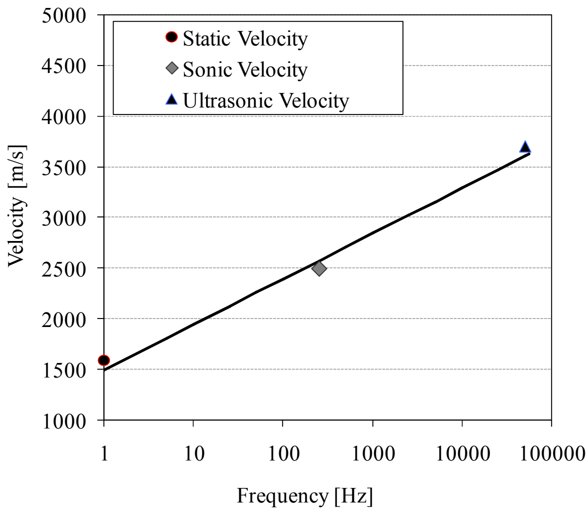


**Figure 6.** Comparison between theoretical line and experimental velocity values.

## 5. CONCLUSION

NDTs, contrary to the DTs methods, are advanced methods since, no damages to the structural elements are required and also provide several information with relatively low cost. However, NDTs are affected by many factors and their exclusive use (unreliable by the current code) not permitted to estimate the mechanical properties of concrete. By combining of NDTs and DTs it is possible to reduce the disadvantages associated with the use of the individual methodologies. The objective of this study was to present a new non-destructive test based on measurements propagation of P-waves (in the frequency range from 100 to 300 Hz) in reinforced concrete elements. This new test type is characterised by great simplicity executive. The principally advantages are: low cost, short execution time, simple data processing procedure, and especially no-structural damage. By experimental results (obtained on structural elements extracted by existing RC buildings), we have been observed a higher variability of the P-waves velocity of propagation by a simple impulse. In particular, a velocity increase has been observed with the increasing of the distance between the velocimeter on the surface of the element. This difference is due to the presence of layers with different mechanical properties. In particular, we have been noted the presence of a degraded surface layer (velocity about 1000 m/s) and an inside layer (velocity about 2500 to 3000 m/s). The results of the experimental campaign show that the velocity values obtained with the standard ultrasonic test are generally higher than those obtained by the proposed test. This difference could be due to the different set up test. It was noted that the relationship between the obtained data set shows a good correlation. Further, experimental tests are in progress in order to improve the executive procedure (type and size of the fixing, sensors, data processing procedures). Moreover, we will test the new non-destructive test directly in existing RC buildings considering the influence of the axial stress.

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