# Influence of Age in Concrete Structures by Means of Core Testing

**Jesús Herminio Alcañiz Martínez**
Professor
UCAM. Saint Anthony Catholic University
School of Engineering
Laboratory of materials
Campus de los Jerónimos, 137, Guadalupe
30107, Murcia. Spain

**Miguel Louis Cereceda**
Professor
School of Engineering
University of Alicante, Spain

**Ana Lasheras Estrella**
UCAM. Saint Anthony Catholic University
School of Engineering
Laboratory of materials
Campus de los Jerónimos, 137, Guadalupe
30107, Murcia. Spain

## Abstract

The structural test based on the correlation of results between Ultrasonic Velocity (V) and Pressure Resistance *(R), obtained from samples extracted in structural elements of reinforced concrete serves as a tool for understanding the quality of the concretes. To analyze the influence of age, it has been used this method of correlation, confirming the better performance of structures aged less than 20 years. For older ages, it is statistically justified the need for intervention, repair – reinforcing based on the results of the test and results of the correlation ultrasonic velocity- compression on concrete testing cores.*

**Keywords:** Concrete Structures, Durability, Age, Testing

## *1. Introduction*

Concrete undergoes deterioration over time, and in extreme cases, this can lead to degradation of the structure. Performing detailed evaluation of the characteristics of these concretes are considered extremely valuable in terms of providing empirical data on the deterioration of concrete over time (Sawaki et al, 2009).

Until now, in order to estimate the compressive strength of concrete, it has been investigated about different techniques and planned several correlations between their results (Atahan et al, 2011). Most of these investigations have been taken up in a laboratory environment and specially, with the extraction of testing cores, comparing these results with other results obtained as a result of fresh concrete samples taken.

This paper analyzes different test results found on the relationship among the resistance of concrete testing cores cured in laboratory (R) and the ultrasonic pulse velocity (V) on structural elements of reinforced concrete, in cases of real building structures. It does not deal with testing cores made at the laboratory, but taken from real elements made of the stressed concrete.

The extraction of testing cores has been taken in real structures elements and it has been proceeded to use a uniaxial compression test in order to obtain the real resistance of the concrete in the tested piece. Besides, it has been applied the ultrasonic pulse method, based on the correlation between elastic properties (concrete strength) and the propagation velocity of a pulse of ultrasonic longitudinal waves.

It has been studied the correlation between pulse velocity and compressive strength from cores test to obtain the graphical correlation between both results.

Sometime, results does not present the uniformity that we are looking for, because of various factors like core diameter, length – diameter relation, height and direction of extraction, curing condition, aggregates qualities, armed localisation – reinforcing bars, surface condition, ambient temperature, etc (Uva et al., 2013). To reduce this not uniformity and to obtain a more reliable in the results, it has been found several mathematics expressions law and correlation - rectes curves, in order to help the technician to make the best decision for the structural security evaluation – expertise.

The studied variable has been the structure age, more or less of 20 years, because it is a critical age for a building, in order to determine possible specific conservation solutions, and repairmen performances.

## *2. Methodology*

The work has been developed based on an extensive research program, which has been performed taking into account the following aspects:

- The data used were obtained exclusively from actual reinforced concrete structures, from sites located in the Mediterranean Arc. Figure 1.
- 185 concrete testing cores and more than two thousand readings of ultrasonic velocity values were used. Figure 2.
- The necessary tools have been applied- technical statistics, to address the results.
- The results obtained have been discussed and cross-checked with other results from other trials processes in existing structures.
- Structures of different characteristics structures were used, being identified as:

E1: Less than 20 years of age (E1).
E2: over 20 years of age (E2).

## *3. Results and Discussion*

In this section, the results obtained in the research process are raised, discussed and analyzed, including:

From the statistical treatment carried out, different "descriptive values" are obtained for the selected final total sample (180 concrete cores), which are summarized in Table 1.

These results are "real" only for the analyzed parts, not transferable to the rest of the population, not analyzed. For that, most appropriate correlation models R - V are proposed, for each of the subpopulations that are discussed below.

These values analyzed for 180 elements studied - selected, are obtained after removal of the different values "outlier" or ends. This way, the original sample of the data available is not affected, achieving great reliability in the result to be discussed (Murphy and Lau, 2008).

In the exploratory analysis, as shown in the summary table above (Table 1), a series of resistance values (R) and velocity (V) are obtained, of which can be interpreted that:

- The mean values of resistance for subgroups of age 1 (R = 20.58 N/mm$^2$) are the highest above the global average (R = 16.93 N/mm$^2$).
- The same values of the subgroups of Age 2 (R = 15.01 N/mm$^2$) are below the abovementioned global average (R = 16.93 N/mm$^2$).
- The same situations are reproduced in the velocity values (V).
- Regarding the median (second quartile - 50 % of cases - values), the situation is repeated mimetically.
- Regarding the standard deviation obtained, in all cases values are very close, both in strength and speed, which confirms the low dispersion of the values obtained.
- The average values of resistance for Age 1 (R = 20.58 N/mm$^2$) are below current normative constraints, minimal in HA-25 (Spanish Structural Concrete Instruction, 2008), but above the minimum normative minimum values set at 175 Kp/cm$^2$ (17.5 N/mm$^2$) above Spanish Regulation for Structural Concrete.

- The average values of resistance for Age 2 (R = 15.01 N/mm$^2$) are well below current regulatory requirements and under the above provisions of R = 17.5 N/mm$^2$ (minimum in reinforced concrete structures).
- These results can raise some ideas for discussion:
- The less resistance regarding existing regulations, in all cases studied it is justified because the obtained data correspond to buildings with "structural problems" of one kind or another, which require the testing - structural monitoring.
- Resistance values in older buildings are justified because they are more affected by fatigue of concrete itself over time.
- Moreover, both the values of Resistance (R) such as the Velocity (V), met the hypothesis of normality, since the "p-value" (0.125 to 0.296 for R and V) is higher to 0.05, so that the null hypothesis of normality of the variable, which means that the differences between the frequencies observed in data and in theoretical ones, under the assumption of normality, they are small and may be due to randomness of the sample. It is therefore considered, a sample that reflects a normal profile in the Gauss curve (Hempel, 1988).

Correlations (r) between the values of resistance (R) and velocity (V) are obtained, which are identified in Table 2.

Given the "p-value" (0.000) in all cases, the existence of a positive correlation is confirmed (the more speed, the more strength) and significant, so that does not correspond to random phenomena (Chambers et al, 1983).

Since the higher the r value, the better the fit of the correlation, it is confirmed that it is more reliable a correlation of R and V in buildings of Age 1 (E1), corresponding to younger buildings. And it is lower the confidence in building with an older concrete structure (Age 2), therefore more affected by age.

Analyzing the available data and applying the ANOVA technique (Analisys of Variance) to the values of the variable resistance (R) and velocity (V), for the factor Age (E1 and E2) of concrete structures to be analyzed, we have:

- The significant difference between the average values of resistance and velocity is confirmed, between the structures of more and less than twenty years old (with a significance or "p-value" of 0.000).
- The estimated value for the average velocity of the youngest buildings is 3.656 m/s, and the resistance of 20.58 N/mm$^2$, while in older buildings is 3,329 m/sec and 15.96 N/mm$^2$.

Once the curves and regression lines and corresponding mathematical expressions are made (quadratic regression and linear regression, respectively), different models are obtained, one for each sub-population, with the explanatory power of each model.

In all cases, it is evident that the quadratic regression is more reliable than the linear regression, since the coefficient of "explanatory power" ($R^2$) is higher in all cases, compared to the linear regression for each of the sub-populations studied (Belsley et al., 1980).

Some other considerations and discussions are exposed below regarding the analysis of the data, issuing the following comments:

- In case of equality of $R^2$ (explanatory power), the use of the simplest model is recommended (principle of parsimony), therefore, linear regression is used. This is not the case, so the quadratic regression would be used.
- The model that works best is the one obtained for the younger buildings (E1) with almost 70 % ($R^2$ = 0.693) confidence of the resistance value, depending on the velocity. However, in older buildings (E2) these values do not fit with that precision. ($R^2$ = 0.370).

As discussion of results, in view of the literature consulted, other alternatives are raised, depending on the results of this research. In this regard, as it has been shown in the national bibliography (Spanish Structural Concrete Instruction, 2008) and in international bibliography (International Atomic Energy Agency, 2002), a table of standard values of correlation results appears, for the "concrete quality classification" in terms of the values of Ultrasonic Propagation Velocity (as noted, compression strength values are not covered), which introduces a clear factor of "subjectivity" that is totally inappropriate in this type of research.

As a contribution of this research and for a future legislative proposal, the content of Table 3 has been complemented and enhanced, with a broader spectrum of "concrete quality levels", and incorporating the estimated values of mean strengths (R) that can be obtained, depending on the given ultrasonic velocities (V), for each type of structure to be tested, with the old variable Age 1 and 2 (E1 and E2). Table 4

The "more accurate" the correlations are those for younger structures, with less than 20 years old (E1) and also with very similar values.

In this way, this summary table can be used to access with ultrasonic velocity values, depending on the type of building - structure that is being analyzed at each time.

With this statistical analysis, later interpretation of data, the practical application, application of the mathematical expressions and graphical representation for each of the proposed models for the different sub-populations that have been studied, a powerful tool is available for the normal application of expert opinion - structural assessment.

## *4. Conclusions*

At this point, the exposition of those aspects of greatest interest are set out below, after the research carried out, whose final result can be used as a basis for structural diagnosis, expert investigations and for important decisions-making processes, with a big responsibility, since from there, the designer will pose the most appropriate solutions to solve the problem of reinforced concrete structure subject to action: repair, reinforcement or any other intervention, and even if it were the case, the demolition of the building.

Therefore these are the findings of this study, with the following scheme:

A. Initial data of the research process.
B. As to the age of the building (E1 and E2).
C. Summary: Definite correlation tables, proposed normative.

Then each of these aspects is developed, as final conclusions:

### 4.1. Initial Data of the Research Process

For the interpretation and discussion of the results of the work of structural testing, as the beginning of a structural expert opinion-evaluation, it is necessary to take into account, among other, the following circumstances:

- Deep knowledge of the testing process, of its intermediate results, mathematical calculations, statistical analysis and final outcome.
- Traceability of results (from the previous inspection of the structure, data collection, auscultation and custom essay, pending the results protocols and its subsequent interpretation).
- Perform a thorough comparative analysis of the results obtained, under different circumstances, type, age, etc. of the structure being studied.
- Globally analyze all the results obtained in one test campaign on the same reinforced concrete structure.
- Perform a thorough and justified interpretation of the results, based on adequate document management and bibliographical consultation.

All this, with a great deal of rigor, which will provide sufficient reliability and credibility, when issuing a Technical Report - Expert Report (official documentation with exposure of conclusions and recommendations), for it is from there that highly significant decisions will be taken, for the future structural behaviour of the whole.

### 4.2. Age of the building (E1 and E2)

After a thorough research on the exclusive data of two of the above techniques (ultrasonic velocity (V) / Simple Compressive Strength (R), in testing cores and relevant correlation between both sets of results) and on the behaviour analysis, statistical studies, interpretation of results, for E1 and E2 variables, mathematical expressions implementing and applying different techniques of interpretation, the following conclusions are issued:

- It is confirmed the finding from previous research conducted by one of the authors of this article, with esclerometry/ultrasonic techniques and now, with regard only to the simple compressive strength result correlation (R) in concrete cores with ultrasonic velocities (V).

- It is confirmed the availability of large amounts of data for the study - research, which reaches 95 % confidence in the results obtained with the lines and especially with given linear regression curves and with the so-called "confidence intervals" appearing in the graphics display.
- It is confirmed that the correlation system that has been reached in this research process is completely reliable for reinforced concrete structures, in any condition and with the age variables E1 and E2.
- It is confirmed the existence of a clear difference between the values of resistance (R) and Velocity (V) in building structures under and over 20 years of age (E1 and E2 respectively), being demonstrated the higher concrete quality and more reliable correlations in the structures of the youngest buildings.
- It is proposed the following mathematical formulae to the correlation models proposed between the two variables, Resistance (R) and Velocity (V) for all the structures analyzed, for both age subgroups (under or over twenty years). Table 5.
- These expressions have been calculated by the cited statistical methods, using the software mentioned and then verified or tested, with a mathematical analysis of the results.
- With all it is confirmed their reliability and especially the quadratic correlations, for different circumstances studied and can be directly applied, as appropriate, for any structural testing.
- The quadratic regression curves graphs are exposed, Figures 3 and 4 for the various models studied, where graphically average compressive strength values of a concrete element can be obtained, depending on the ultrasonic pulse velocity, for the different models analyzed. Besides the arcs from which the highest reliable bars are generated are also appreciated, called "confidence intervals" where in all cases, the most probable values of resistance are found, of the parts of the reinforced concrete being tested, with 95% confidence. From all these graphs it is confirmed that the linear regression curve agrees with those previously obtained and submitted and respond to the mathematical expression of the proposed model, for each of the subpopulations (E1 - E2).

This will justify the performance of the general and specific objectives of the present research , which may be considered fully achieved, as the information sought and its interpretation is successfully obtained, facilitating decision-making in the evaluation of the structural security of the concrete element, since these results demonstrate that structural testing technique and the correlation systems of posed data can be regarded as a totally reliable tool in structural evaluation, since results of the correlations confirm its suitability for their intended use and can provide excellent results in an assessment - structural expert opinion for any reinforced concrete structure.

It can also be concluded that, with regard to other considerations, to repair a reinforced concrete structure, using special materials like Epoxy resin or similar, it is necessary that the element to be repaired presents a concrete strength higher that 10 N/mm2, to ensure proper adhesion to the support material (Bresson, 1971). Analysing the statistical data from the total sample of this research, it is noted that in the 25th percentile, the resistance value of 10.83 N/mm2 is found. This indicates that 25% of the sample values are below this strength, so that 25 % of the pillars tested can not be repaired using these special products, so other alternative repair systems should be posed, based primarily on reinforcements with metal elements or other materials without special adhesion to the support material.

### 4.3. Summary: Definite Correlation Tables, Proposed Normative

And finally, as a summary of all this work, these are some of the ideas that confirm the above and that should lead the professional to reflection - the technical user of the above research techniques in structural testing:

- In every process of research in structural testing, it is necessary to take into account the need to ensure total reliability, traceability in data and certainly credibility, for the future user of the results for the analysis - structural diagnosis.
- The interpretation of the results obtained and the conclusions drawn in each case need to be taken into account, as a basis for reflection, prior to the implementation of any of the analyzed structural testing methods and subsequent implementation in structural assessment in future cases.
- It is also important to note that the results obtained from structural testing, provide the basis for the decision making of structural diagnosis and examination, with the important responsibilities all this entails, as already emphasized.
- The technician will have available with this, a number of research tools and methods very suitable for testing the current status of the conventional reinforced concrete structures.

- It is to be noted the important information the final table provides for each model (Table 4) presented earlier, to the independent variables Age (E1 and E2). See the various levels of classification for the concrete quality.

We can say that with this research, we have defined a clear scientific procedure for analyzing the two test methods and the necessary tools to do a full structural testing, to obtain the necessary data and its proper interpretation, facilitating sufficient information to make a critical analysis of how they perform, their scope and reliability mainly - confidence level, since its results will involve the basic support for the future analysis - diagnosis - security assessment - structural expert opinion and finally, the drafting of the relevant Structural Intervention Project (strengthening, repair, demolition, etc..), with the responsibility that entails. This final research paper has been made, with a practical nature, based on a theoretical framework, experienced enough, to provide the technicians - specialists - experts of the structural construction sector, the deeper understanding of the two aforementioned auscultation methods - research in structural testings, on items - pieces of reinforced concrete, implementation, reliability and the final interpretation of the results and generate a basic document, suitable for dissemination, as an activity required to reach the professional - technical final user, directly and clearly, facilitating knowledge and dissemination, also in the University area.

In sum, the intention has been to perform a scientific research work, for direct practical application. In short, a transfer of knowledge and results to society. This shows the importance of age in the behavior of structures and their influence on the final quality of the concrete.

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**Figure 1: Extraction Process of a Concrete Testing Core After the Completion of the Ultrasonic Test. See the Diamond for the Extraction and the Hole this Action Leaves**


**Figure 2: Process of Realization of the Ultrasonic Velocity Testing, Using a "Ultrasonic Tester", in a Piece of Reinforced Concrete under Investigation**

**Table 1: Descriptive Values after the First Treatment of the Data**

| DESCRIPTIVE VALUES | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| **Sample (Subpopulations) measured** | **Values** | **Average** | | **Median (Quartile 2)** | | **Deviation** | | |
| | | **R** | **V** | **R** | **V** | **R** | **V** | |
| Global (Total) | 180 | 16,93 | 3441 | 15,40 | 3535 | 7,92 | 548 | |
| Age 1 (E1) | 62 | 20,58 | 3656 | 21,55 | 3729 | 8,84 | 510 | |
| Age 2 (E2) | 118 | 15,01 | 3329 | 14,00 | 3416 | 6,69 | 535 | |

**Table 2: Correlations Reliability**

| Sample | r | p-value |
|---|---|---|
| Global (All structures) | 0,677 | 0.0000 |
| Age 1 (E1) | 0,833 | 0.0000 |
| Age 2 (E2) | 0,608 | 0.0000 |

**Table 3: Classification of Concrete Quality (IAEA, 2002)**

| PROPAGATION VELOCITY (m/s) | CONCRETE QUALITY |
|---|---|
| > 4.500 | EXCELLENT |
| 3.500 a 4.500 | GOOD |
| 3.000 a 3.500 | ACCEPTABLE |
| 2.000 a 3.000 | DEFICIENT |
| < 2.000 | VERY DEFICIENT |

**Table 4: Proposal of Concrete Classification (Contribution of the Authors)**

| PROPOSAL OF CLASSIFICATION OF CONCRETE QUALITY TABLE OF CORRELATION RESULTS (WithVelocity and Resistence) | | | |
|---|---|---|---|
| **ULTRASONIC VELOCITY (m/s)** | **CONCRETE QUALITY (**)** | **AVERAGE RESISTENCES ($N/mm^2$) (Expected value)** | |
| | | **Age** | |
| | | **E1** | **E2** |
| > 4.500 | EXCELLENT | > 36 | > 31 |
| 4.000 – 4.500 | VERY GOOD | 26 - 36 | 22-31 |
| 3.500 – 4.000 | GOOD | 18-26 | 15-22 |
| 3.000 – 3.500 | ACCEPTABLE | 12-18 | 11-15 |
| 2.500 – 3.000 | DUBIOUS | 7-12 | (*) |
| 2.000 – 2.500 | DEFICIENT | 4-7 | (*) |
| < 2.000 | VERY DEFICIENT | <4 | (*) |

(*) Non congruent values obtained from the Quadratic Regression formula.
(**) Denomination of Concrete Quality.

**Table 5: Correlation Model Proposal**

| |
|---|
| **For all structures:**<br>Estimated average resistance= 50,529 – 0,032 * Velocity + 0,000006286 * $(\text{Velocity})^2$ |
| **Age 1 (E1):**<br>Estimated average resistance = 7,350 – 0,008 * Velocity + 0.000003172 * $(\text{Velocity})^2$ |
| **Age 2 (E2):**<br>Estimated average resistance = 48,138 – 0,029 * Velocity + 0.000005595 * $(\text{Velocity})^2$ |

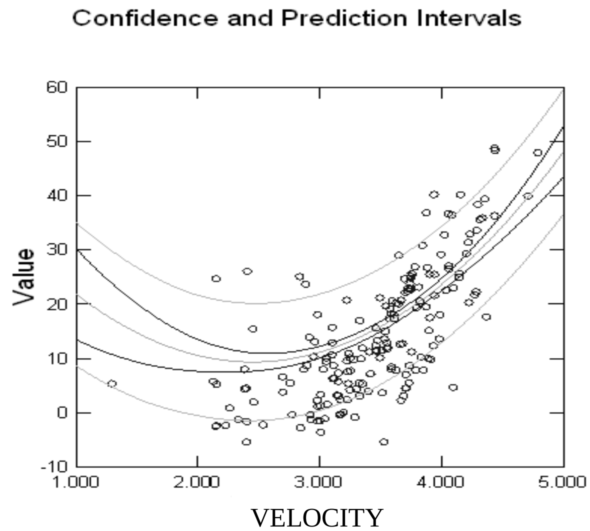


**Figure 3: Quadratic Regression Curves Graph (All Concrete Testing Cores)**

**a)** **b)**

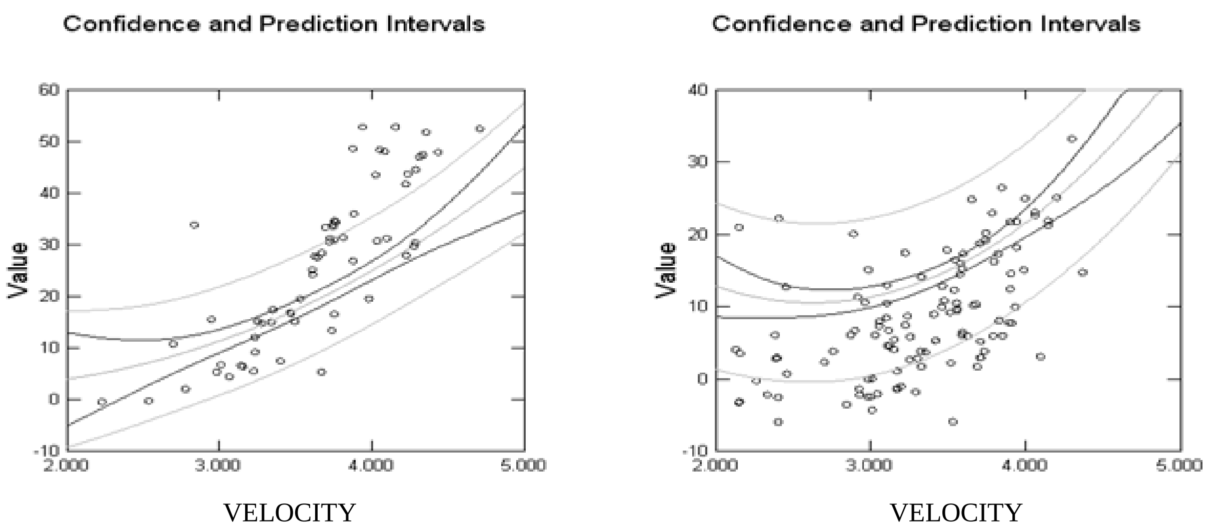


**Figure 4: Quadratic Regression Curves Graph. For stuctures type E1 (a), for structures type E2 (b)**