Influence of Geographic Location in Concrete Structures

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
UA. University of Alicante
School of Engineering
Carretera de San Vicente del Raspeig
03690, San Vicente del Raspeig (Alicante)
Spain

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

Abstract

It is very important to consider the geographical location of a building at the time of making their structural test. To do this, in this study we used the known technique of structural test based on the correlation of results between Ultrasonic Velocity (V) and Pressure Resistance (R), obtained from the samples extracted in reinforced concrete structural elements. To analyze the influence of the geographical location of the structure, this paper has classified the buildings studied in terms of their distance from the coast and following the Spanish Code on Structural Concrete, is using a reference distance of 500 meters that allows ordering the cases studied according to the aforementioned distance. As a conclusion, it is safe to say that the structures closest to the coast are more influenced by the environment, which greatly influences the quality of concrete structures.

Keywords: Concrete structures, Durability, Geographic Location, Pressure Resistance

1. Introduction

To estimate the pressure resistance of concrete, to date, different techniques had been explored and many correlations had been raised among its most significant outcomes. Most of these investigations were conducted in a laboratory environment, and especially with the removal of testing cores, comparing the results with values of tests performed as a result of sampling fresh concrete (Gomez and Vidal, 2006). Other, taking into account the type of aggregate with different dosages, with variation in temperature, etc. (Vera et al., 2009).

This paper, however, discusses various test results and the relationship between the resistance (R) of the testing cores cured in laboratory and ultrasonic velocities (V) in reinforced concrete structural elements, in real building structures.

Therefore these are not samples run in laboratory, these were extracted from reinforced concrete elements in already executed structures and later tested in simple compression test, to obtain the actual resistance of the concrete in the tested piece.

The application of the ultrasonic method is based on the correlation between the properties of concrete and the velocity of propagation of longitudinal waves. We have studied the relationship between the propagation velocity and concrete resistance in cores in order to obtain the best correlation between the two measurements.

The results sometimes do not have the desired consistency, given the influence of several factors such as core diameter, height and direction of extraction, concrete curing conditions, type of aggregates, presence of reinforcement, surface conditions, temperature, etc. To reduce this lack of uniformity and achieve greater reliability in the results, some mathematical expressions and correlation – rectes curves that facilitate decision-making to technicians, the users of these structural testing tools, to use them in the evaluation of structural security- reports.

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 handled are exclusively obtained from actual concrete structures from sites located in the Mediterranean Arch.
- 185 concrete testing cores and more than two thousand readings ultrasonic velocity values have been used.
- The necessary tools – statistical techniques were implemented to process the results.
- The results have been discussed and compared with other results from other trials processes in existing structures.
- Different structured has been used and studied, identified as:

L1: Less than 500 meters from the coast (L1).
L2: More than 500 meters from the coast (L2).

3. Results and Discussion

This section presents, analyzes and discusses the results obtained in the research process, including:

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

These results are "real" only for the analyzed parts, and therefore are not applicable to the rest of the population not analyzed. Therefore the more appropriate R-V correlation model are proposed for each of the subpopulations studied and that are discussed below.

b. These values analyzed for the 180 elements studied - selected, are obtained after the elimination or the different values "outlier" or ends. This does not affect the original sample of the data available, obtaining high reliability in the result to be discussed (Murphy and Lau, 2008).

c. As shown in the above table, in the exploratory analyse a series of values for Resistance (R) and Velocity (V) are obtained, of which it is interpreted that:

- The average values of resistance for subgroups of localization- situation 2 (R = 20.10 N / mm^2)' are the highest, above the global average (R = 16.93 N / mm^2).
- The same values of the subgroups Localization 1 (R = 15.96 N / mm^2) are below the mentioned global average (R = 16.93 N / mm^2).
- The same situations are reproduced in the velocity values (V).
- Regarding the median (quartiles 2 - 50% of cases - values), the situation is repeated mimetically.
- Regarding the typical deviation obtained, in all cases are found near values both in resistance and velocity, which confirms the poor dispersion of the values obtained.

From these results, some ideas may arise for discussion:

- The lower resistance with respect to the existing regulations, in all cases studied, is justified because the data refer to buildings "with structural problems" of one kind or another, which require testing - structural monitoring.
- Resistance values found in buildings on the coast are justified because they are affected by the environmental presence.

d. Moreover, both in the resistance values (R) such as in velocity (V), the normality hypothesis is met, given that the "p-value" (0.125 for R and 0.296 for V) is higher than 0.05, so it is accepted the null hypothesis of normality of the variable, which means that the differences between the observed frequencies in the data and in theory, under the assumption of normality, are small and may be due to the randomness of the sample. It is therefore considered, a sample that reflects a normal profile in the Gauss curve (Hempel, 1988).

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

Given the "p-value" (0.000) in all cases, the existence of a positive and meaningful correlation (more velocity, more strength) is confirmed, so it is no due to events just from chance (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 the correlation of R and V in buildings of location 2 (L2), corresponding to buildings away from the coast. And the confidence is lower in buildings with a concrete structure located closer to the coast (Location 1), therefore more affected by its environmental situation related to the durability of reinforced concrete structures.

f. Analyzing the available data and applying the Technique ANOVA (Massart et al., 1997) to the values of the variables resistance (R) and velocity (V), for the two factors of localization (L1 and L2) of the concrete structures to be analyzed, the significant difference between the mean values velocity (V) and resistance (R) is confirmed, between structures more and less than 500 meters from the coast (with a signification or "p-value" 0.000).

g. Once made the regression curves and lines and the corresponding mathematical expressions (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 analysis 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 (Belsey et al., 1980).

h. Some other considerations and discussions are exposed, with respect to the analysis of data, issuing the following comments:

- In case of equality of R^2 (explanatory power), we recommend the use of the more simple model (principle of parsimony), therefore, a linear regression will be used. This is not the case, so the quadratic regression would be used.
- Regarding the situation- localization of the structure, this model best fits the buildings located further from the coast ($R^2 = 0.630$), less affected by the environment (L2).

i. As discussion of results, considering the exposed in the bibliography consulted, different alternatives have been put forward based on the results of this research. In this respect, as it has been shown, in the national (EHD, 2008) and international bibliography (IAEA, 2002), a table appears with the standard values of correlation of results, for the " classification of concrete quality" on the basis of the parameters of Ultrasonic Propagation Velocity (as it is shown, values of resistance to compression are not covered) which introduces a clear factor "subjectivity", totally inappropriate in this type of research work.

As a contribution of this research, and facing a future building code proposal, it is complemented and enhanced the content of Table 3, with a broader spectrum of "concrete quality levels" and including the estimated values of mean resistance (R) which can be obtained, depending on the given ultrasonic velocities (V), for each type of structure to be tested, with the location variables 1 and 2 (L1 and L2). Table 4.

It is a fact that the "more accurate" correlations are those corresponding to structures located more than 500 meters from the coast (L2).

With this statistical analysis, later interpretation of data, its 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 for the normal application of expert opinion or structural assessment is available.

4. Conclusions

At this point, some of the aspects of greater interest are set out, following the investigation carried out, whose final result can be used as a basis for structural diagnosis, expert investigations and important decisions, with a great burden of responsibility, since from there, the designer will pose the most appropriate solutions to solve the problem of the reinforced concrete structure subject to action: repair, reinforcement or other intervention, and even if it were the case, the very demolition of the building.

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

A. From the initial data of the research process.
B. In terms of localization (L1 and L2).
C. Summary: definitive correlation tables, proposed normative.

Each of these aspects is developed, as final conclusion:

4.1 From the Initial Data of the Research Process

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

- Deep knowledge of the testing process, of intermediate results, mathematical calculations, statistical analysis and final result.
- Traceability of results (from prior inspection of the structure, data collection, auscultation and test assignment until the reception of the Act of Results and later interpretation).
- Perform a thorough comparative analysis of the results obtained, under different circumstances, typology, age, etc of the structure being studied.
- Globally analyze all the results obtained in the same test campaign, on the same reinforced concrete structure.
- Perform a thorough and justified interpretation of the results, based on adequate documentary management and bibliographic consultation.

All 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), since there, significant decisions will be taken for the future structural behaviour of the whole.

4.2 In Terms of Geographical Location of the Building (L1 and L2)

After thorough research with the exclusive data of two of the above techniques (ultrasonic velocity (V) / pressure resistance (R), in concrete samples and the relevant correlation between both sets of results) and analyzing their behaviour, statistical studies, interpretation of results, for the variables L1, L2, independent, implementation of mathematical expressions and applying different techniques of interpretation, the following conclusions are issued:

- The findings from previous research work conducted by one of the authors of this article are confirmed, with esclerometry/ ultrasonic methods and now, with regard only to the correlation or Result of Resistance (R) in samples with ultrasonic Velocity (V).
- The availability of large amounts of data for the study is also confirmed, which reaches 95% confidence in the results obtained with the lines and especially with the regression curves given and the so-called "confidence interval", that appear in the graph exposed.
- The correlation system that has been reached in the process of investigation is proved to be totally reliable for reinforced concrete structures, in any state of conservation with the localization variables L1 and L2.
- The general proved conclusion is that there is a clear difference between the values of resistance (R) and velocity (V) in nearshore structures, with respect to inland structures, becoming evident the higher impact on concrete quality of structures in coastal areas, with respect to concrete structures offshore (L1 and L2 respectively).

In structures that are near the coast, lower concrete resistance are found, with average values of 15.98 N / mm ^{2}, below the average value obtained in the most remote structures, of 20.10 N / mm $^{2.}$ This situation guarantees the condition of improved durability referred to in the current Spanish

Building Code on Structural Concrete where specifications are more restrictive due to the condition of aggressive environment.

- The following mathematical formulas are proposed for the correlation models proposed between the two variables, Resistance (R) and Velocity (V) for all structures analyzed, for the two subgroups of situation-localization (More or less than 500 m from the coast). Table 5.
- These expressions have been calculated through the above statistical methods, using the software mentioned and then verified or tested, with a mathematical analysis of the results.
- All this confirms their reliability and especially quadratic correlations, for the different circumstances studied and can be directly applied, depending on the case, for any structural testing.
- Graphic – quadratic regression curves are shown, for the different models studied, where average resistance values of compression of a concrete element can be graphically obtained, depending on ultrasonic velocity, for the different models analyzed. In addition, we find the curves that generated the so called "confidence intervals", where in all cases, the more likely resistance values of the reinforced concrete tested are found, with 95% confidence. From all these graphs it was confirmed that the regression curve – line agree with those previously obtained and submitted and respond to the mathematical expression of the proposed model, for each of the subpopulations (L1 - L2).

The following are the quadratic regression- correlation graphs, for the different models of structure analyzed, where average resistance values (R) of a concrete element may be graphically obtained, according to the ultrasonic velocity (V). All these graphs show that he regression curves-lines coincide with those previously obtained and submitted and respond to the mathematical expression of the proposed model for each of the subpopulations. (L1 and L2 type structures), to facilitate its application on any analysis - examination of any structure element, in any of the four factors tested, for any of the four subpopulations investigated.

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

In conclusion, with regard to other considerations, in order 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 than 10 N / mm ^{2,} to ensure proper adhesion to the support (Bresson, 1971). The statistical data from the total sample of this research shows that in the 25th percentile, the resistance value of 10.83 N / mm ^{2} is found. This indicates that 25% of the sample values are below this resistance, so we can say that 25% of the pillars tested could not be repaired using these special products, so that other alternative repair systems should be used, based on reinforcements with metal elements or other materials, without special adhesion to the support.

4.3 Summary: Definitive Correlation Tables, Proposed Normative

And finally some ideas that confirm the above and that should serve to reflect the professional user of the mentioned research techniques in structural testing:

- In every process of research in structural testing, it is necessary that to take into account the need to ensure total reliability, traceability in data and, no doubt, credibility, for the future user of the results, for the structural analysis-diagnosis.
- As a basis for reflection, the interpretation of the results obtained and the conclusions drawn in each case shall be considered, prior to the application of any of the analyzed structural testing methods and the subsequent application in structure evaluation, in future cases.
- It should not be forgotten either that the results obtained from structural testing processes, provide the basis for making diagnostic decisions and structure evaluations with the important responsibilities, as already stressed, this may imply.

- The technician or specialist will have with all this a number of tools and research methods, very suitable for testing the current status of the conventional concrete reinforced structures.
- Highlight the important information provided by the Table 4, for the independent variables of Locations (L1 and L2). See the different levels of classification for concrete quality.

This work has defined a clear scientific procedure for analyzing the two test methods and the tools necessary to do a full structural testing, to obtain the necessary data and its proper interpretation, facilitating enough information to make a critical analysis of how they work, their scope and reliability mainly - confidence level, since its results will involve the basic support for the future analysis - diagnosis - security assessment - and finally to draft Structural Intervention Project (strengthening, repair, demolition, etc.), with the responsibility that entails.

This final document intentionally has a practical nature, based on a theoretical framework, experienced enough, to provide the structural technicians - specialists - experts from the sector, the deeper understanding of the two aforementioned auscultation methods - research in structural testing, on items - pieces of reinforced concrete, implementation, reliability and the final interpretation of the results and to draft a basic document, suitable for dissemination, as an activity required to reach the professional - technical end user, directly and clearly, facilitating knowledge and dissemination, also in the University area.

The aim, in conclusion, is to carry out a scientific research work, for direct practical application. In short, to realize a transfer of knowledge and results to society.

References

Belsey, D.A., Kuh, E., and Welsch, R.E. (1980). Regression diagnostics. New York: John Wiley & Sons.

Bresson, J. (1971). Nouvelles recherches collages dans les structures. Institut Technique du Batiment et des Travaux Publics. France.

Chambers, J.M., Cleveland, W.S., Kleiner, B. and Tukey, P.A. (1983). Graphical Methods for Data Analysis, Belmont, CA: Wadsworth International Group.

ESPAÑA (2008). “Real Decreto 1247/2008, de 18 de julio, por el que se aprueba la Instrucción de Hormigón Estructural (EHE-08)”. Boletín Oficial del Estado, 18 de Julio de 2008, 203, 35176-35178.

Gómez, M.S. y Vidal, S. (2006). “Influencia en la Resistencia a Compresión de Hormigones por Efecto de la Temperatura Ambiente”, Revista de la Construcción, 5 (1), 56-61.

Hempel, C.G. (1988). “Provisoes: A Problem concerning the Inferential Function of Scientific Theories”. Erkenntnis, 28 (2), 147-164.

IAEA (2002). Guidebook on Non-destructive Testing of Concrete Structures, International Atomic Energy Agency, Vienna.

Massart, D.L., Vandeginste, B.M.G., Buydens, L.M.C., de Jong, S., Lewi, P.J. y Smeyers-Verbeke, J. (1997). Handbook of Chemometrics and Qualimetrics: Part A. Amsterdam: Elsevier.

Murphy, T. y Lau, A.T. (2008). “Dealing with Outliers”, ASTM Standardization News, Nov/Dec 2008, 22-23.

Vera, R., Villarroel, M., Carvajal, A.M., De Barbieri, F. y Troconis, O. (2009). “DURACON: Influencia de la Acción del Medio Ambiente en la Durabilidad del Concreto. Parte 2. Resultados de Chile después de 5 años de Exposición”, Revista de la Construcción, 8 (1), 13-23.

Figure 1: Ultrasonic Velocity Test, with an “Ultrasonic Tester”,on a Concrete Reinforced Element Under Investigation

Figure 2: Process of Extraction of a Concrete Testing Core, After The Ultrasonic Test. See The Diamond Bit Drill and the Hole Made

Table 1: Descriptive Values Obtained

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
Localization 1 (L1)	138	15,96	3387	14,80	3466	7,11	519
Localization 2 (L2)	42	20,10	3619	22,20	3747	9,57	603

Table 2: Correlations Reliability

Sample	r	p-value
Global (All structures)	0,677	0.0000
Localization 1 (L1)	0,616	0.0000
Localization 2 (L2)	0,773	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

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)**	
		Localization	
		L1	**L2**
> 4.500	EXCELLENT	> 21	> 36
4.000 – 4.500	VERY GOOD	13 -21	26 - 36
3.500 – 4.000	GOOD	8 - 13	19 - 26
3.000 – 3.500	ACCEPTABLE	6 - 8	13 - 19
2.500 – 3.000	DUBIOUS	(*)	9 - 13
2.000 – 2.500	DEFICIENT	(*)	8 - 9
< 2.000	VERY DEFICIENT	(*)	< 8

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

Table 5: Correlation Model Proposal

For all structures: Estimated average resistance= 50,529 – 0,032 * Velocity + 0,000006286 * $(\text{Velocity})^2$
Situation- Localization 1 (L1): Estimated average resistance = 56,519 – 0,035 * Velocity + 0,000006 * $(\text{Velocity})^2$ **Situation – Localization 2 (L2):** Estimated average resistance = 21,207 – 0,015 * Velocity + 0,000004076 * $(\text{Velocity})^2$

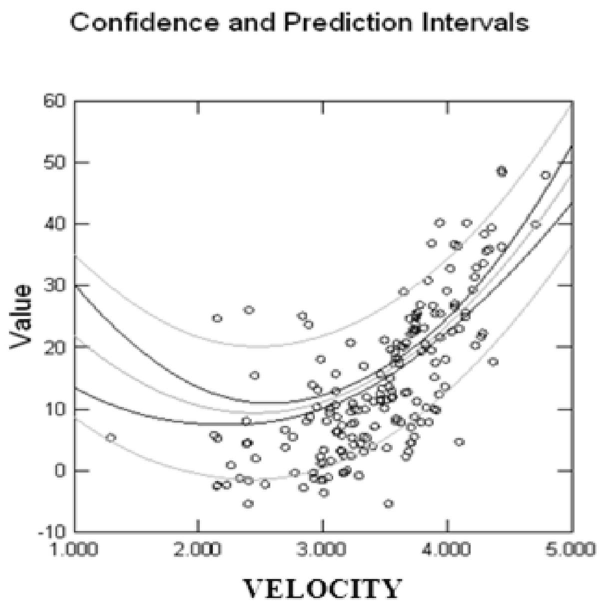

Figure 3: For All Structures

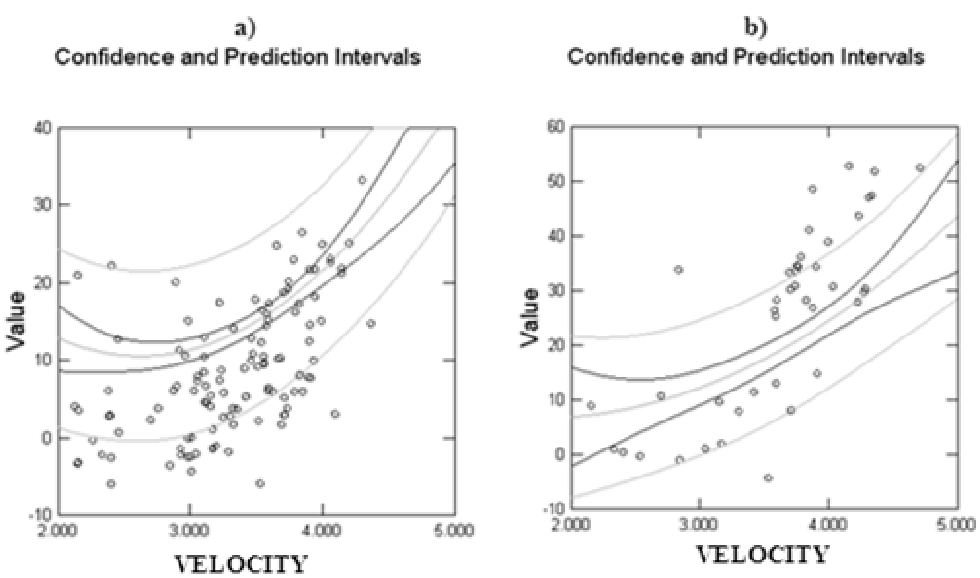

Figure 4: For Stuctures Type L1 (a), for Structures Type L2 (b)