A STATISTICAL STUDY FOR THE CORRELATION OF NON DESTRUCTIVE TESTING AND DESTRUCTIVE TESTING ON STRUCTURES IN CONCRETE

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ABSTRACT

There is often a need to evaluate the in place strength of concrete in existing structures for an accurate assessment of their structural capacities.
A study was carried out on a building in concrete (Punta Perotti in Bari, Italy) before its demolition. Punta Perotti, exposed for more than ten years to aggressive environmental conditions (near the sea and in a windy area), was selected to study the life cycle of the materials. About 180 cores (10 cm diameter) were taken from the pillars at five different floors after a previous non destructive testing campaign (mainly ultrasonic and rebound hammer tests) made on the same stations. European (EN 13791) standard and USA (ACI 228) guide lines were followed for in situ measurements and data analysis. The possible correlations between non destructive testing (NDT) and compressive strength (DT) of cores are analysed with an exhaustive statistical approach and a new method to improve correlation results is proposed.

INTRODUCTION

For the seismic reliability, following the European standard [CEN (2004)], the Italian Guide Linee [OPCM 3274/2003] and its successive modification [OPCM 3431/2005] predicts a founded quantitative process on following phases: structural knowledge, definition of the required performances, evaluation of the existing structure in accord to the actualised performing level, plan of adaptation and at last, evaluation of the adequate structure.
The interventions of seismic reliability imply the necessity to elaborate in opportune way the data concerned the material properties.
In the verification of structural reliability, methods of analyses compatible with the acquaintance of the building must be chosen. It is necessary to redefine a complete and reliable model of the structure and the total outlay for the intervention of the structural reliability must be reduced.
About the concrete structure to analyse, it must be necessary to know the technical norms utilized in phase of planning. It is necessary to know the constructive practice at the age of the building and the original function. The characteristic strength of the concrete in the existing buildings is obtained from the results of in situ tests divided the "Factor of confidence". This last one depends on the level of the knowledge of the all structure. To obtain the appropriate type of analyses and the relative levels of "confidence", three different types of knowledge must be defined:

- LC1: Limited knowledge
- LC2: Adequate knowledge;
- LC3: Accurate knowledge.

The aspects that define the levels of knowledge are: geometry (the geometric characteristics of the structural elements), structural details (the numbers and disposition of the armours, the consistency of the not structural elements), materials (the mechanical properties of the materials). The acquired level of knowledge determines the method of analysis, and the values of the factors of confidence to apply to the property of the materials.
For the knowledge of the characteristic compression strength of the concrete, the mentioned Guide Line makes possible to substitute (not more than 50%), with a large number (at least three times) of non destructive tests.
The same Guide Line indicates in the surface of plan of 300 m^2 the minimum number of cores to extract, variable from three to nine in accord to the plan of investigation (limited, extensive or

exhaustive).
Apart from these general indications for the evaluation of the strength of the concrete in situ, do not exist consolidates procedures of combined investigations (destructive tests and non-destructive tests).
As shown in literature [G. Fabbrocino et al., 2005], the relationship between concrete compressive strength measured by means of mechanical testing and the measurements obtained by means of in situ non destructing testing results to be disperse and does not easily correlated.
The main object of this work is to try to validate the use of non destructive testing (ultrasonic measurements and rebound number) through the identification of reliable correlation curves reducing the cores number to extract from the studied structure.
It is necessary to identify a good practice to select the eligible test stations of the same structural element on which to do the cores to minimize the errors in the technical evaluation.
To reach this goal a consistent number of experimental data (mainly ultrasonic measurements, rebound number and mechanical compressive test) was raised in order to lead statistical studies. ENEA has identified the Punta Perotti structure in Bari (Fig. 1) as a suitable case of study. Punta Perotti was a building (14 levels high, about 1560 m^2 for level) exposed for more than 10 years to particular aggressive environmental conditions (near the sea and in a windy area), of which are well known the technical schedules of original materials and was selected in order to study the life cycle of the materials and structures, until the demolition process.

Figure 1: Punta Perotti building

EXPERIMENTAL

A wide campaign of DT and NDT on the compound of Punta Perotti has been carried out (table 1). In particular the tests used for the data analysis reported in the present report are:

- ultrasound and rebound Hammer tests were carried out in situ on 90 pillars at three different heights (test stations) on five different floors of the building (-1, 0, 1, 2, 3) and were extracted cores and microcores from the same places of the test stations.
- ultrasound velocity measurements obtained in laboratory on 180 cores and 290 microcores and on which have been executed relative strength measurements.

The used instrumentations for the tests in situ are:

- Schmidt Concrete Test Hammer for normal concrete structures. Impact energy 2,207 N/m.
- Digital CM42 CoverMaster Concrete Pachometers (microprocessor COVERMASTER CM9) equipped with an standard probe from 7 to 90 mm
- Low frequency Ultrasonic Instrument RP5000 SIRIO equipped with a microcomputer and two probes of 50Hz frequency and crystal of 1’’

- Professional hydraulic core drill for manual use with endowed column of sliding of diamond crowns of diameter 3,5 cm and 10 cm, for perforation to water on all the superficial ones of armed concrete

The used instrumentations for the laboratory tests are:

- Low Frequency RP5000 SIRIO Ultrasound instrument endowed of microcomputer and two probes of 50 KHz frequency, crystal from 1"½
- Low Frequency KrautKramer 23 LF Ultrasound instrument, computer laptop inside acquisition board A/D converter and two probes of 50 KHz frequency, crystal from 1"
- Low Frequency Boviar Ultrasound instrument endowed of palm computer and two probes of 50 KHz frequency, crystal from 1"½
- Low Frequency Numeric Ultrasound instrument and two probes of 50 KHz frequency, crystal from 1"
- 250 KN CONTROLS Press for automatic compression tests equipped with computer for data acquisition.

Studied pillars	*Pachometric tests*		87
	Rebound hammer		68
	Ultrasonic tests		64
	Thermographic analysis		3
Non destructive testing	*Pachometric tests*		365
	Rebound hammer		298
	Ultrasonic tests		152
	Thermographic analysis		3
	Carbonation tests		180
Destructive testing	*Cores*	*micro*	293
		standard	180

Table 1: Analysis done in situ on the Punta Perotti building.

DATA ANALYSIS

All the acquired data were used to try to establish a quantitative assessment of the strength for the concrete in the existing structures of Punta Perotti. In order to develop the strength relationship, it is generally necessary to correlate the in place tests parameter with the compressive strength of cores extracted from the structure. Furthermore by combining results from more than one in place test (for example ultrasonic test and rebound hammer), a multivariable correlation can be established to estimate strength. Combined methods are reported to increase the reliability of estimated strength. For example an increase in moisture content increases pulse velocity but decrease the rebound number, so their combined use results in a cancelling effect that improves the accuracy of the estimated strength [ACI 228 1R -03].

For this reason it was decided to evaluate the in situ experimental results both with the strength versus the ultrasonic velocity variable

$$R\_ac = a \times V^{c} \text{ (Eq. 1)}$$

and versus the ultrasonic velocity and rebound variables

$$R\_abc = a \times IR^{b} \times V^{c} \text{ (Eq.2).}$$

The result of the comparison between the multivariable and single variable correlation, Fig. 2, shows that the calculated values are quite similar. For this reason it was decided to work on the curve correlation obtained only versus the ultrasonic velocity.

A further interpretation of the data is carried out in order to try to define the homogenous groups of data with the aim to define a wide statistical sample to obtain the best correlation curves.

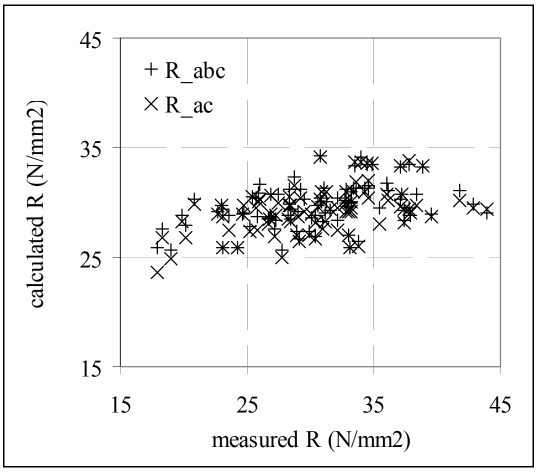

Figure 2: Comparison between multivariable (R_abc) and single (R_ac) correlation.

For this purpose it was used the software Analyse-it [Analyse-it for Microsoft Excel] in order to use methodology ANOVA (ANalysis Of VAriance) that is an instrument of statistics developed in order to verify the significance of the differences between the arithmetic means of two or more similar statistics populations.
ANOVA allows to decompose and to measure the incidence of the various variation sources on the values observed of two or more groups of data.
The concrete for its nature it is a material that has strongly variable physical characteristics if measured in punctual way.
ANOVA is, in our opinion, a good statistical instrument to deal the data obtained from this type of experimental campaigns. ANOVA is more suitable of the t of Student, commonly used for this type of analysis.
The base hypotheses of this methodology are that the data must be between independent each other, normally distributed and that the variances of several the groups must be homogenous. These hypotheses turn out satisfied on the measures that we carried out on the structure of Punta Perotti.
The totality of the data has been decomposed in various groups in which a single parameter varied (i.e.: the floor, the test stand, the instrument of measure etc.).
Through the elaboration of the data, there were defined the groups of different specimens for physical causes, and those with similar behaviour have been joined, with the aim to carry out a statistical study on the maximum number of data between homogenous samples.
The results can be therefore synthesized:

- there are not meaningful differences between the values of velocity and strength of the same pillar of the same floor taken at different height whereas there are significant variations of the compressive strength and of the ultrasonic velocity in the concrete versus the analysed floors.
- there is not a meaningful difference between the measurements of ultrasound velocity carried out in situ on the pillars and the ultrasound measurements carried out in laboratory on the cores with same ultrasound instrument.
- the application of the correlation methods to evaluate the compressive strength in function of the ultrasonic pulse velocity or both ultrasonic pulse velocity and rebound number has suggested, for this situation, to use the correlation in function solely of the ultrasonic pulse velocity.

STATISTICAL ANALYSIS

Starting from these considerations, the statistical analysis has been set by considering for each individual floor all the possible combinations of 10 test stations measurements (decuples) selected on 10 different pillars. The number of the possible combinations for each floor is reported in Table 2.

Floor	Number of cores	Number of cored pillars	Number of decuples
-1	47	18	269.034.631
0	14	10	16
1	18	10	256
2	56	20	3.348.291.335
3	19	11	1.792

Table 2: Data distribution on different floors

It was decided to work with ten cores because it is the number of the cores suggested by the Italian Guide Lines [OPCM 3274, 2003], [OPCM 3431, 2005] for a structure as Punta Perotti to obtain an adequate knowledge of the building for each floor.

This study was carried out to understand the possible implications in the measurements of concrete strength of the structure due to the arbitrary choice of the test station from the technician. The number of the possible combinations is reported in Table 2 for each floor.
A computing code was written in Fortran to elaborate the statistical analysis.

First of all the strength class for all samples of each floor according to [EN 13791:2007] standard was studied. The results are reported in Table 3, whereas the same calculation repeated on all possible decuples of each floor leads to a distribution of the compressive strength class as reported in Table 4 .

floor	Compressive Strength class (EN 206-1)
-1	C25/30
0	C30/37
1	C30/37
2	C25/30
3	C25/30

Table 3: Compressive strength class calculated on all data for each floor

	Strength class according to EN 206-1			
floor	C20/25	C25/30	C30/37	C35/45
-1	0,00 %	**40,22 %**	53,50 %	6,28 %
0	0,00 %	0,00 %	**100,00 %**	0,00 %
1	0,00 %	0,39 %	**99,61 %**	0,00 %
2	0,62 %	**98,77 %**	0,61 %	0,00 %
3	0,00 %	**99,61 %**	0,39 %	0,00 %

Table 4: Distribution of the compressive strength class calculated on all the possible decuples for each floor

Tables 3 and 4 show that, with except of the -1 floor, the probability to obtain the same strength class of all the data population is very high. Instead for the floor -1 almost the 60% of the decuples bring to a higher strength class with respect the value calculated (bold number in Table 4) on all the data of the floor.
It is important to note that to estimate the strength class it is necessary to calculate the in-situ characteristic value f_{ck}.

It is clear that, in the case of the -1 floor, a technician has a high probability to obtain different strength classes depending on the choice of the ten points of coring.

CORRELATION CURVES ANALYSIS

In order to develop the strength relationship, it is necessary to correlate the in-place tests parameter with the compressive strength of cores.
The ad hoc correlation curve between the compressive strength measured by means of mechanical testing and the ultrasonic velocity measurements for the floors -1 and 2 was built up following the eq.1 using all the data available for each floor.
The correlation curves obtained following the standards [EN 13791:2007] and [ACI 228.1R-03] for all the samples available on the floors -1 and 2 are reported in Fig. 3 and Fig. 4 .

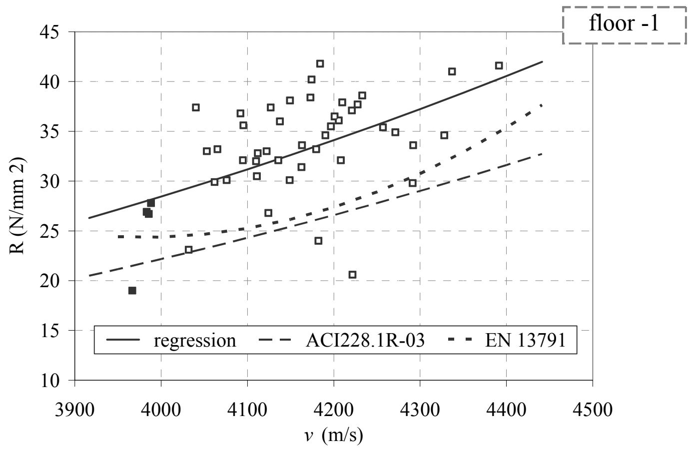

Figure 3: Comparison between ad hoc regression curve, EN 13791:2007 and ACI 228.1R-03, for the floor -1

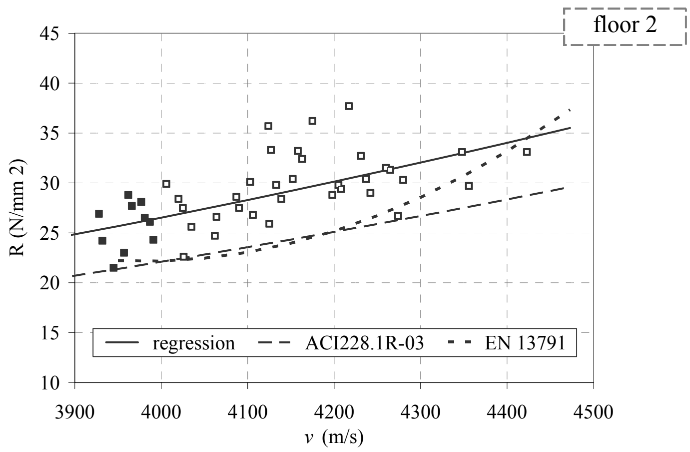

Figure 4: Comparison between ad hoc regression curve, EN 13791:2007 and ACI 228.1R-03, for the floor 2

In both cases the curves undervalue the ad hoc correlation curves to reach safety condition in the evaluation of the strength value of the structure. Our main goal was to try to be closer as possible to the ad hoc correlation of the entire population with the identification of decuples more significant through the use of non-destructive tests carried out previously.
An exhaustive analysis of all the possible decuples of cores (Table 2) was carried out in order to verify the hypotheses of pre-selected zones on which to carry out the cores. In this way it was evaluated the behaviour of the regression curves – compressive strength versus ultrasonic pulse velocity – on all the available decuples of cores with respect to the regression curve on all the data of the floor. It was supposed to take into account the decuples with a distribution of the ultrasonic velocity measurements similar to the one calculated on all the data of the floor, in order to test a

new method to identify the structural elements from which collect the cores for the mechanical tests and obtain data with a higher probability of being representative of the correlation curve of the floor [V. Luprano, V. Pfister, A. Tundo (2009)].

The results of the analysis demonstrate that, with a previous campaign of non destructive testing and an accurate statistical analysis of the results, it is possible to improve of 3 % the probability to obtain correlation curves representative with the selected decuples.
Moreover following this new method and analysing the data using the technique of the statistical similarity of the ultrasonic velocity distribution, the risk to have cases of regression curves not representative of the state of the concrete structure under consideration can be reduced.

CONCLUSION

A wide campaign of non destructive and destructive tests on the same structure (Punta Perotti, Italy) was carried out in order to study a methodology to built up a better correlation curve to define the mechanical strength of the concrete.
The main goal of this research work is to support the designer to assess the reliability of an existing structure, without having a complete knowledge of its condition, in the choice of the best position in which to extract the cores. To reach this goal a statistical approach was used.

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