In situ evaluation of concrete compressive strength: reliability of non destructive techniques

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ABSTRACT: In the field of non destructive testing of concrete structures, several regulations propose correlations between cubic compressive strength and ultrasonic pulse velocity or pull out extraction force respectively. These correlations are expressed by means of coefficients derived from calibration through destructive tests carried out on cores.
Aiming at evaluating the reliability of correlations in predicting concrete compressive strength, an experimental campaign has been started. Several concrete cubic specimens of different strength classes have been prepared and non destructive tested. Moreover, 16 cores have been extracted from the cubic specimens and ultrasonic and compressive tests have been carried out on them. Ultrasonic testing has been performed on both cubic specimens and cores in order to assess the influence of specimen form and dimension on the ultrasonic waves propagation.
In this paper results of the experimental campaign are presented and discussed.

1 INTRODUCTION

In situ assessment of concrete mechanical properties is generally realized by sampling the structure for obtaining cores in order to perform destructive test – e.g. compressive test. This approach not always provides decisive data because cores provide local information not representative of the condition of the building in the whole. In the bargain, structure surface has to be repaired after the test.

Non Destructive Testing (NDT) is a very useful tool for evaluating materials and structural mechanical parameters without affecting buildings functionality and serviceability.

In the case of the estimation of concrete compressive strength, a combination of two or more NDT is generally recommended in order to reduce errors dependent on materials, concrete mix proportions and environmental parameters. Thus, the use of more than one NDT can provide useful information and can improve the accuracy when assessing in situ concrete compressive strength.

Several regulations propose various correlations between cubic compressive strength and ultrasonic pulse velocity or pull out extraction force respectively. These correlations are expressed by means of coefficient that should be derived from calibration through destructive tests carried out on cored samples.

In order to determine these coefficients and to evaluate the reliability of the proposed correlations in predicting concrete compressive strength, an experimental campaign has been started. For this purpose several concrete cubic specimens of different strength classes have been prepared and tested.

Ultrasonic Testing (UT) and Pull Out Testing have been carried out in order to measure ultrasonic pulse velocity (V) and pull out force (F).

In addition, several cores have been extracted from the cubic specimens and then tested by means of ultrasonic and compressive test. Ultrasonic testing has been repeated also in cored samples in order to assess the influence of specimens form and dimension on the ultrasonic waves parameters.

2 SPECIMENS

The experimental campaign has been carried out on 16 concrete cubic specimens with a side length of 300 mm. Specimens have been sorted into four groups and have been casted by using concrete of different strength classes [UNI EN 206] (Table 1).

The strength class is defined by both characteristic cylinder strength f_{ck} and characteristic cubic strength R_{ck}, evaluated at 28 days of curing on cylindrical and cubic specimens respectively. In Table 1 the notation system gives the cylinder strength first and then the cubic strength.

Table 1. Strength Classes of concrete

Number of specimens	**Strength concrete classes**
4	C16/20
4	C25/30
4	C32/40
4	C40/50

Compressive tests have been carried out on cores extracted from the cubic specimens. From each cubic specimen 4 cores have been obtained according to UNI EN 12504-1. Specimens have been measured, marked and tested according to UNI EN 12390-3(Table 2).

Table 2. Cored specimens dimensions

Number of specimens	Strength concrete classes	Diameter* [mm]	Height* [mm]	Mass [kg]
4	16/20	93.7	188.9	3.0
4	25/30	93.7	188.2	2.9
4	32/40	93.8	188.3	3.0
4	40/50	93.6	188.5	3.0

* Mean values

3 METHODS

3.1 Ultrasonic testing

Non-destructive techniques based on ultrasonic wave propagation are often used in structural diagnosis. They are applied directly in the field for investigations of a wide range of structures and infrastructures, and in laboratory for the characterization of materials [De Nicolo, 2005]. UT method is based on measuring the travel time, over a known path length, of a pulse of ultrasonic waves. The pulses are introduced into the concrete by a piezoelectric transducer, and a similar transducer acts as receiver to monitor the surface vibration caused by the arrival of the pulse [Nawy, 2008]. A grease or gel is applied to the faces of the transducers to ensure good coupling with the surfaces and to reduce signal energy dissipation due to acoustic impedance difference between material in contact. A timing circuit is used to measure the time it takes for the pulse to travel from the transmitter to the receiver.

UT is preferentially carried out applying the Direct Transmission Technique (DTT), in which the wave is transmitted by a transducer (Emitter) through the test object and received by a second transducer (Receiver) on the opposite side. The wave velocity V is obtained from the ratio L/T, where L is the length of path and T is the travel time. V is directly related to structures parameters, e.g. density and elastic modulus [Concu, 2006]. The DTT is very effective, since the broad direction of wave propagation is perpendicular to the source surface and the signal travels through the entire thickness of the item. Standards concerning the determination of waves velocity in structures – e.g. European UNI EN 12504-4 - suggest, therefore, the application of this kind of signals transmission.

In the UT tests DTT have been applied.

The testing equipment, developed and assembled by the Department of Civil and Environmental Engineering, and Architecture of University of Cagliari, included:

- a Vellemann Instruments arbitrary waveform generator;
- a pair of piezoelectric transducer (54 kHz resonant frequency);
- a Vellemann Instruments digital oscilloscope for signal visualization and preliminary analysis;
- a PC for data storage and signal processing.

For each specimen, ultrasonic signals travel time has been measured and then propagation velocity has been calculated.

The measurement set-up and the operative procedure are shown in Figure 1.

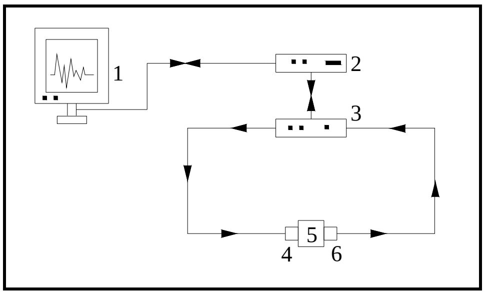

Figure 1. UT measurement set-up. 1) PC. 2) Signal generator. 3) Oscilloscope. 4,6) Transducers. 5) Specimen.

3.2 Pull out testing

Pull out testing is a standardized partially-destructive testing method to estimate a mean value of concrete compressive strength. It is typically adopted on decayed structures for which the actual static conditions are being assessed. Similarly, it is used on buildings located in “riskful areas” according to classification of national seismic hazard mapping. It is also applied for the evaluation of the materials mechanical characteristics in case of consolidation or restoration of historical buildings.

Pull out test measures the force required to extract a steel insert with an enlarged head from a hardened concrete structures. Due to its shape, the steel anchor is pulled out with a cone of concrete whose surface slope is approximately 45 degrees respect to the vertical.

European Standard UNI EN 12504-3 provides a procedure for the determination of the pull out force. The force required for pullout the embedded metal insert is related to the compressive strength of the concrete, so that an estimation of in situ concrete compressive strength can be provided by using suitable correlations.

Pull out equipment consists in:

- an aluminum hydraulic jack with a central hole;
- a special steel anchor;
- a hydraulic hand pump with a maximum pressure pointer manometer;
- a drill and under-reaming equipment for installation of the anchor into the hardened concrete.

A scheme of pull out test is shown in figure 2.

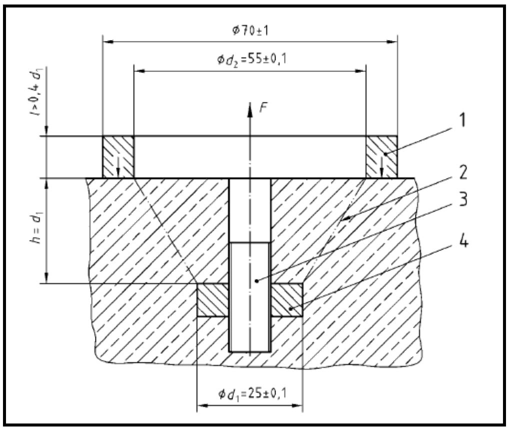

Figure 2. Scheme of pull out test: 1) Bearing ring; 2) Assumed conic fracture; 3) Pull out insert rod; 4) Pull out insert disc.

3.3 Compressive test

Compressive tests have been carried out on cylinder according to UNI EN 12390-3.

Figure 3. Compressive testing machine.

4 RESULTS

Results of Ultrasonic test and Pull out test carried out on cubic specimens are shown in Table 3.

Table 3. NDT parameters on cubic specimens.

NDT Parameters		Strength concrete classes			
		C16/20	C25/30	C32/40	C40/50
Ultrasonic	Mean Velocity [m/s]	2890	3000	2930	3075
	Standard deviation [m/s]	75.30	89.20	52.00	35.20
	COV [%]	2.60	3.00	1.80	1.15
Pull out	Mean Pull out Force [kN]	26.00	31.35	33.40	38.70
	Standard deviation [kN]	3.05	2.80	2.25	2.25
	COV* [%]	11.65	9.00	6.75	5.80

* COV = Coefficient of Variation

Ultrasonic mean velocity does not show a large variation through the different strength classes of concrete, while pull out force appears more sensitive. At the same time COV values of pull out force are more scattered than ultrasonic ones.

Table 4 shows the results of ultrasonic and compressive tests carried out on cored specimens.

Table 4. Parameters on cored specimens

Parameters		Strength concrete classes			
		C16/20	C25/30	C32/40	C40/50
Ultrasonic Test	Mean Velocity [m/s]	2375	2535	2530	2485
	Standard deviation [m/s]	70.70	72.00	51.10	92.75
	COV* [%]	3.00	2.85	2.00	3.75
Compressive Test	Mean Strength f_{cm} [N/mm^2]	25.2	35.5	45.2	53.1
	Standard deviation [N/mm^2]	0.55	0.40	0.90	1.40
	COV* [%]	2.20	1.20	2.00	2.60

* COV = Coefficient of Variation

It can be noted that pulse velocity of cores is lower than that of cubic specimens and there is no difference in values between the different strength classes of concrete, both for cores and cubic specimens.

5 CORRELATIONS AND DISCUSSION

In order to predict in situ compressive strength of concrete by means of NDT parameters, a regression analysis has been performed.

Figure 4 shows the correlation between compressive strength and pulse velocity for cubic specimens.

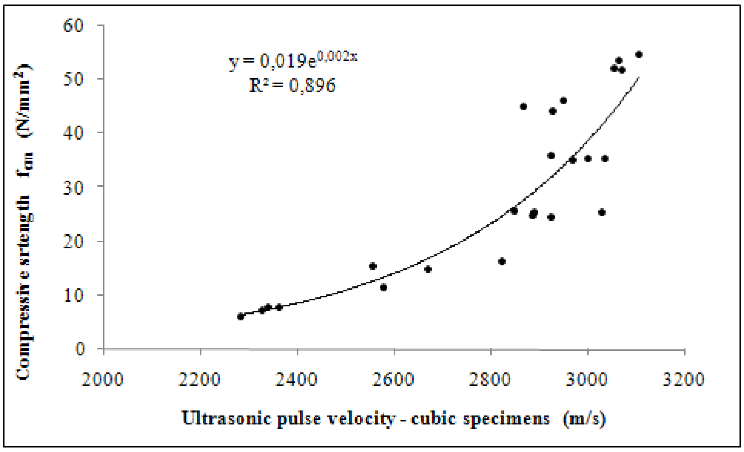

Figure 4. Correlation between Ultrasonic pulse velocity and Compressive strength for cubic specimens.

The best correlation between ultrasonic pulse velocity and compressive strength for cubic specimens is represented by an exponential curve characterized by a R^2 = 0.896.

In the same way Figure 5 shows the correlation between compressive strength and pulse velocity for cored samples.

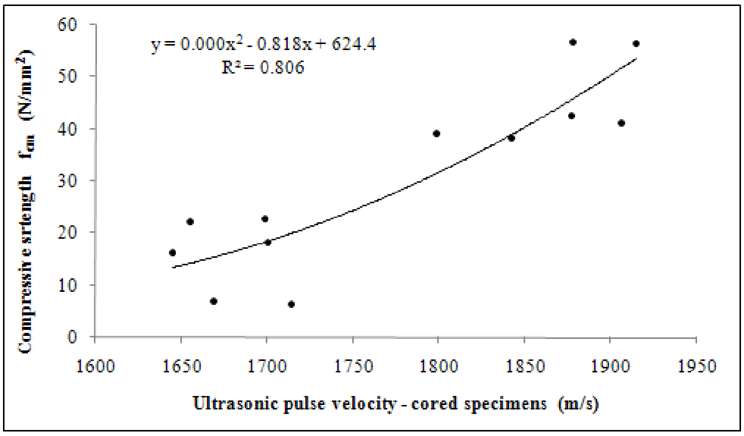

Figure 5. Correlation between Ultrasonic pulse velocity and Compressive strength for cored specimens.

The best correlation for cored specimens is represented by a quadratic polynomial curve characterized by a R^2 = 0.806.

Figure 6 shows the best correlation between compressive strength and pull out force.

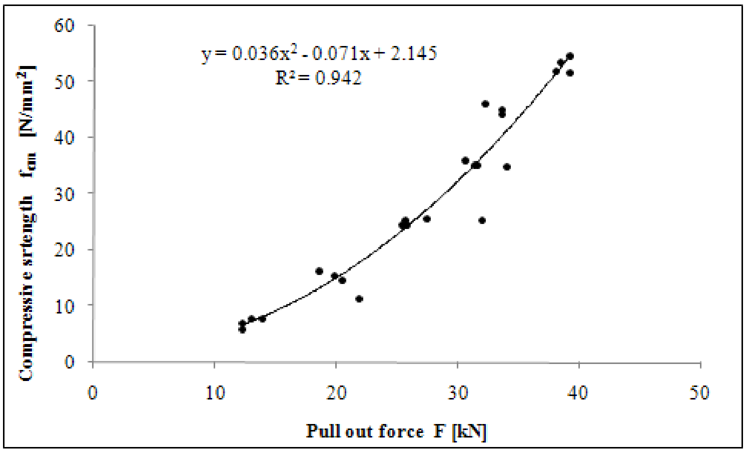

Figure 6. Correlation between Compressive strength and Pull Out Force for cubic specimens.

In this case the best correlation is represented by a quadratic polynomial curve with a R^2 = 0.942.

In order to obtain a more suitable indicator of the compressive strength a correlation between ultrasonic pulse velocity and pull out force has been studied. The analytical correlation has the following form:

$$f_c = e \cdot F^f \text{ x } V^g \tag{1}$$

where f_c is the theoretical compressive strength, F is the pull out force, V is the ultrasonic pulse velocity, while e, f and g (Table 5) are coefficients determined in order to minimize the sum of the squares difference between the theoretical and experimental compressive strength of concrete.

Table 5. Correlation coefficients for compressive strength of concrete estimation

e	f	g
0.00098	1.88489	0.51168

A R^2 = 0.943 has been obtained by using equation (1).

6 CONCLUSION

An experimental campaign has been started with the aim of evaluating the reliability of UT and Pull out test in predicting concrete compressive strength. Several concrete cubic specimens of different strength classes have been prepared and tested. In addition, 16 cores have been extracted from the cubic specimens and ultrasonic and compressive test have been carried out on them.

Throughout the achieved results several conclusions can be drawn as follows:

- Pull out force allows a better estimation of the in situ compressive strength than ultrasonic velocity, both in cubic and cored specimens;
- Ultrasonic velocities are deeply dependent on the form and size of specimens and values do not fit well with the compressive strength of concrete;

- Pull out force standard deviation and coefficient of variation are more scattered than those of ultrasonic pulse velocity.
- The best correlation between in situ compressive strength and pull out force is represented by a quadratic polynomial curve, while the best correlation between in situ compressive strength and ultrasonic pulse velocity is represented by an exponential curve, as suggested by some European regulation (e.g. Italian Guideline for structural concrete laying and for the evaluation of hardened concrete mechanical characteristics by means of non destructive testing).

It can be noted that the limited number of test specimens makes assessment difficult. Particular attention must be paid to use the correlation when velocities between sets cannot be really distinguished. In this case the correlation should be considered as mathematical more than in a practical sense.

In order to obtain a more suitable indicator of the compressive strength of concrete, a correlation between the two non destructive parameters, ultrasonic pulse velocity and pull out force, has been presented.

Further research is ongoing, aimed at deepen NDT reliability in compressive strength estimation by increasing specimens number and analyzing different non destructive testing.

7 REFERENCES

UNI EN 206-1. 2006. Concrete. Part 1: Specification, performance, production and conformity.

UNI EN 12504-1. 2009. Testing concrete in structures. Part 1: Cored specimens. Taking, examining and testing in compression.

UNI EN 12390-3. 2009.– Testing hardened concrete. Part 3: Compressive strength of test specimens.

De Nicolo, B, Mistretta, F, Concu, G. 2005. *NDT ultrasonic evaluation of early compressive strength in SCC*. 9th International Conference on Inspection Appraisal Repairs & Maintenance of Structures – Fuzhou, China, October 19-21, 2005. ISBN 981-05-3548-1.

Nawy, E. G. 2008. *Concrete Construction Engineering Handbook*, CRC Press.

Concu, G,. De Nicolo, B,. Mistretta, F, Pani, L. 2006. *Ultrasonic test methods for assessment of concrete strength during construction*. 10th International Conference on Inspection Appraisal Repairs & Maintenance of Structures – Hong Kong, October 24-26, 2006. ISBN 981-05-5562-8.

UNI EN 12504-4. 2005. Testing concrete. Part 4: Determination of ultrasonic pulse velocity.

UNI EN 12504-3. 2005. Testing concrete in structures. Part 3: Determination of pull-out force.

C.S.LL.PP. 2008. Guidelines for structural concrete laying and for the evaluation of hardened concrete mechanical characteristics by means of non destructive testing.