Construction and Building Materials 61 (2014) 278–284

Contents lists available at ScienceDirect

Construction and Building Materials

journal homepage: www.elsevier.com/locate/conbuildmat

Evaluation of concrete strength by means of ultrasonic waves: A method for the selection of coring position

Valerio Pfister [a], Antonella Tundo [b], Vincenza A.M. Luprano [a,*]

[a] ENEA, Brindisi Research Center, SS. 7 'Appia' km 706, 72100 Brindisi, Italy
[b] ENEA, Ufficio Territoriale di Bari, Viale Japigia 188, 70126 Bari, Italy

HIGHLIGHTS

- We propose a new method to select the eligible positions where to extract the cores.
- We compare the implications of a random choice and the proposed guided choice.
- The risk to have cases of correlation curves not representative is reduced.

ARTICLE INFO

Article history:
Received 30 August 2013
Received in revised form 11 March 2014
Accepted 12 March 2014
Available online 4 April 2014

Keywords:
Non-Destructive Testing (NDT)
Coring point selection
Concrete strength
Ultrasonic pulse velocity

ABSTRACT

The evaluation of the concrete properties in a structure has a fundamental importance for safety and structural integrity assessments. An adequate knowledge of the structural concrete performances can be obtained from a large number of cores where performing destructive tests. Non-destructive ultrasonic waves test can be performed before other kind of tests, allowing to improve the assessment of the structural concrete performances and to extend the results to the same kind of elements of the structure, not directly investigated by destructive tests. The aim of this work is to test a new method to identify a good practice to select the position of testing points on which extract the cores starting from an analysis of a preliminary campaign of non-destructive measurements. In this way it is possible to reduce risk of errors of the compressive strength evaluation by a different approach from those used nowadays. The data obtained from an experimental campaign with both non-destructive and destructive tests on 75 concrete columns were considered to validate the new method. The implications of a completely random choice and the guided choice, using the method proposed, were analysed with an iterative and exhaustive approach. European Standard (EN 13791) was followed for in situ measurements and preliminary data analysis.

1. Introduction

In recent years, innovative Non-Destructive Testing (NDT), which can be used for the assessment of existing structures [1] such as bridges [2], dams [3,4], has become available for in situ measurements on concrete, also by means of imaging [5,6]. This kind of test is not yet adopted for routine inspections. In the last years a considerable effort in the normative field has been done to achieve an evaluation of in situ compressive strength in structures and precast concrete components [7,8], using traditional non-destructive and semi destructive methods such as ultrasonic pulse velocity (UPV), rebound hammer test, penetration resistance, pull-out test. The use of ultrasonic techniques, recommended by International Standards, has been evaluated in the paper of Komlos et al. [9] and Breysse [10] for the assessment of concrete properties.

The Italian Guideline (IGL) for the seismic reliability, [11,12], makes possible to substitute part of the destructive measurements (not more than 50%) with a larger number of non-destructive tests (at least three times).

Fabbrocino showed [13] that the relationship between concrete compressive strength, measured by mechanical testing, and the measurements obtained by in situ non-destructive testing results to be disperse and not easily correlated.

This means that it is difficult to completely define a relationships between NDT measurements and concrete strength [14] or that an universal law simply does not exist [10].

* Corresponding author. Tel.: +39 0831 201452; fax: +39 0831 201453.
E-mail address: vincenza.luprano@enea.it (V.A.M. Luprano).

http://dx.doi.org/10.1016/j.conbuildmat.2014.03.017
0950-0618/

This study was carried out to understand the possible implications, due to the arbitrary choice of the testing points, in the measurements of concrete strength of the structure.

The aim of this work is to validate a new method to select the position of the testing points where to extract the cores. In fact, although NDT measurements are largely codified, such kind of control is not yet widespread because there are some elements depending on the operation carried out by a technician, such as the definition of the measuring points to achieve the analysis with a small number of measurements.

A consistent number of experimental data [15] (mainly ultrasonic measurements, rebound hammer test and compressive test, see Table 1) was used in order to lead exhaustive studies with the aim to evaluate the effects of a certain choice of coring points.

Preliminary considerations were obtained by applying the European Standard (EN 13791) [7] to better establish the criteria of data analysis reported in the present work.

A new method, within a more general procedure, has been studied in order to select the coring positions.

The procedure can be summarized with the following steps: (i) definition of the number of needed cores (depending on Standards or Guidelines); (ii) execution of a large preliminary NDT measurement campaign; (iii) analysis of the NDT measurements and definition of the coring positions; (iv) execution of the destructive test in the indicated positions and (v) strength assessments.

The definition of the coring positions is based on the similarity of the statistical distributions of preliminary non-destructive measurements. This method, first of all, divides the values of the NDT measurements into subsets. For each subset the method provides information on the number of cores to extract in that range of measurements. The method itself provides information on the minimum and maximum number of cores to be taken. The position where to extract the cores can be chosen among the structural elements which have the same range of NDT measurements.

The implications of a completely random choice and the guided choice, using the method proposed, were analysed.

2. Experimental

A large campaign of destructive and non-destructive testings on the building of Punta Perotti (in Bari, Italy, Fig. 1) has been carried out [15]. Punta Perotti was a building (14 floors high, about 1560 m^2 for floor) exposed for more than 10 years to aggressive environmental conditions (near the sea and in a windy area). It was possible to extract several cores (diameter of 10 cm and height of 20 cm) without caution from this building since it was considered a damage for the environment and in fact it was demolished one month after the experimental campaign.

Due to the constrains imposed by the terms of shipbuilding safety and accessibility to the various floors of the building, there were limited possibilities to select the columns from which to extract the cores. Mainly the internal columns have been cored. Fig. 2 reports a plan of the columns studied for the floor −1: the columns have rectangular section with shorter side varying between 30 cm up to 90 cm and longer side varying between 79 cm up to 305 cm. The aspect ratio of the section (ratio between longer side and shorter side) varies from 1 up to 10.

Table 1
Number of studied columns, of the in situ and laboratory NDT measurements on Punta Perotti (compressive strength was measured on each core).

Floor	Columns	Measurements (V, R) in situ on the testing positions before the extraction of the cores	Measurements (V) in laboratory on the cores
−1	18	24	47
0	10	14	14
1	10	18	18
2	20	8	56
3	11	18	19
6	6	4	7
Total	75	86	161

Fig. 1. Building of Punta Perotti.

The measurements, from 6 different floors of the building, used for research purposes were:

- In situ, 86 ultrasonic velocity measurements and rebound hammer tests at different heights of the same column (the number of the testing points per column was up to 3) according respectively to EN 12504-4:2004 [16] and EN 12504-2:2001 [17] Standards (Table 1, column 3).
- In laboratory, 161 ultrasonic pulse velocity measurements obtained on cores (86 from the above test positions and 75 from test positions with no in situ UPV or rebound hammer measurements) and strength measurements according to EN 12504-4:2004 [16] and EN 12390-3:2001 [18] Standard (Table 1, column 4).

The following instrumentations have been used for the tests:

- Schmidt Concrete Test Hammer for ordinary concretes, impact energy 2.207 N/m.
- Digital CM42 CoverMaster Concrete Pachometers (microprocessor COVERMASTER CM9) equipped with a standard probe from 7 to 90 mm to detect reinforcement rods before UPV measurements and rebound hammer tests.
- Low frequency Ultrasonic Instrument RP5000 SIRIO equipped with a microcomputer and 2 transducers of 50 kHz frequency.
- Hydraulic core drill for manual use with endowed column of sliding of diamond crowns of 10 cm.
- 250 kN CONTROLS Press for automatic compressive tests equipped with computer for data acquisition.

3. Preliminary data analysis

3.1. Definition of the correlation law

Two different power law models have been considered to correlate the compressive strength (f) to the in situ NDT measurements depending on the ultrasonic velocity (V) variable (Eq. (1)) and depending on both the ultrasonic velocity and rebound number (R) variables (Eq. (2)):

$$f = a \times V^c \tag{1}$$

$$f = a \times R^b \times V^c \tag{2}$$

The use of a combined method (Eq. (2)) has been considered in order to evaluate the possibility of an improvement of the estimated strength. The underlying concept is that if two variables