Construction and Building Materials 38 (2013) 72–83

Contents lists available at SciVerse ScienceDirect

Construction and Building Materials

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

Proposal of a methodology for assessing the reliability of *in situ* concrete tests and improving the estimate of the compressive strength

Giuseppina Uva, Francesco Porco, Andrea Fiore *, Mauro Mezzina

DICATECh, Politecnico di Bari, Via Orabona 4, 70126 Bari, Italy

HIGHLIGHTS

- The use of coring for estimating the *in situ* strength of concrete is discussed.
- Proposal for a methodology aimed at the definition of the parameter called "C_{DD}".
- C_{DD} evaluates the degradation of material and the damage of the drilled core.
- Validation of $R_{c,situ}$ based on the compaction degree (g_c) of the concrete.
- Two case studies have been considered: an existing and a new RC building.

ARTICLE INFO

Article history:
Received 14 November 2011
Received in revised form 25 July 2012
Accepted 11 August 2012
Available online 21 September 2012

Keywords:
Existing RC buildings
In situ tests
Concrete strength
Seismic assessment
Core drilling
Compaction degree
Concrete

ABSTRACT

For the seismic assessment of existing RC buildings an important question is the reliable appraisal of the *in situ* concrete strength. This parameter can be performed by resorting to destructive tests (concrete core drilling) properly combined with qualitative information provided by Non-Destructive tests (NDTs). However, there are many factors that influence the results of the experimental tests, and it is difficult to establish whether the value obtained is really representative of the material *in situ* and if there are alterations which have arisen in time. In the paper, a methodology aimed at the definition of a coefficient called "C_{DD}" is proposed. This coefficient takes into account the effects of the deterioration and alteration of the drilled core, and provides an ideal percentage decrease of the mechanical strength (ΔR) of the concrete core (with respect to the original one), as a function of the compaction degree g_c. The proposed methodology was applied to 2 set of samples, including drilled concrete cores and cubic specimens, respectively coming from an existing and a brand new building. The method allows to appraise and critically compare the difference between the strength obtained from drilling tests and the one measured on the specimens sampled during the casting.

1. Introduction

The possibility of performing a reliable appraisal of the compressive strength of *in situ* concrete is a crucial question for the seismic assessment of existing RC buildings. In current European and Italian standards [1–4], it is clearly stated that the seismic assessment of existing buildings should be based on an adequate preliminary knowledge of the structure, of the mechanical properties and condition of materials. These data shall be collected both from available information and from *in situ* and/or laboratory tests. In the case of RC structures, the main mechanical parameter that should be provided is the compressive strength of concrete.

The most widespread method for determining the *in situ* strength of concrete is to drill cores from the structural elements [5,6]. About this issue, the Italian Technical Standards, issued in 2008 (see Section C8A.1.B.3 of [3]), basically contain the same provisions of Eurocode (see Section 3 of [4]), with some additional specifications. In particular, it is clearly stated that the mechanical properties should be evaluated by resorting to specific destructive tests, consisting in extraction of concrete cores from the structural elements and execution of laboratory compression tests on the obtained samples. These tests can be supplemented with Non-Destructive methods (NDT), provided that they are calibrated by using the actual results of the destructive laboratory tests [3]. In fact, it is widely acknowledged that non-destructive methods cannot completely replace destructive ones, but can be effectively used to support them in view of the extensive inspection of the structure, that could not be realistically performed with a destructive approach. In the literature, there are several studies that propose procedures based on the simultaneous use of destructive and non-destructive methods in order to extend the results of DT [7–12].

* Corresponding author. Tel.: +39 080 5963832; fax: +39 080 5963823.
E-mail address: andrea.fiore@poliba.it (A. Fiore).

0950-0618/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.conbuildmat.2012.08.025

When discussing about the appraisal of the compressive strength of *in situ* concrete, it should be remembered that the measurements performed on drilled concrete cores are affected by several factors (such as consolidation, curing quality and age of concrete; type of structural element from which the sample is extracted; and position of the sample) that could induce significant deviations, and actually characterize the actual strength of the *in situ* concrete as a "*random variable*" [13]. Moreover, it should also be considered that the same operation of extraction of the concrete samples (aspect ratio and diameter of the core, presence of embedded reinforcements, disturbance due to drilling) induces a significant alteration. Considering the presence of all these "disturbing" factors, and, on the other side, keeping in mind the possible implications involved by the judgment about the efficiency of the materials, the whole protocol related to the assessment of *in situ* concrete strength requires a great care both in the operational phases and in the interpretations of data. In fact, according to Italian and European Standards [2,14], when the *in situ* strength is significantly different from the design value (suggesting that a relevant decay and degradation of the materials has occurred), it is mandatory to perform a complete safety assessment of the structure also under non seismic loads (see NTC2008 – Section 8.3). Moreover, if the *in situ* mechanical strength is lower than a minimum threshold, materials cannot be accepted at all, and the building could even be declared out of service.

After all, the safety of existing buildings is strictly related to the actual conditions of the materials and, in this sense, both Eurocode 8 and Italian NTC define the "Knowledge Level (*KL*)" of the structure as the fundamental basis for the assessment, which affects, in particular, the design values of the mechanical parameters to be used in the verification.

More specifically, three Levels of Knowledge are defined: *KL*1 – Limited Knowledge; *KL*2 – Normal Knowledge; *KL*3 – Full Knowledge. According to the knowledge level, the allowable method of analysis is chosen, together with the value of the Partial Safety Factor that could eventually be more severe than the one used in the original design. At the end, the value of the concrete strength used in the verification will depend on the mean value calculated after *in situ* testing (that is usually lower than the design one) reduced by the Partial Safety Factor. Thence, a positive outcome of the verification is not obvious.

In Italy, after the issuing of OPCM 3274 [1], a wide process of assessment of the seismic vulnerability was initiated for relevant and strategic existing buildings, and is actually still going on. In this framework, many Italian Regions have promoted research programs in coordination with the competent boards and universities, in order to draft specific guidelines [15–17]. Some of these documents, published after the issuing of NTC2008, underline the obligation of performing a full safety assessment, both under seismic and non seismic loads, if some specific circumstances occur: a typical case, for example, is the presence of a clear evidence of degradation and/or decay of the mechanical properties of the materials. If under non seismic loads the safety verification is negative, urgent measures aimed at restoring the required performance level must be immediately adopted, otherwise the structure should be dismissed, as remarked by the Ministerial Circular n. 617 of 2 February 2009.

It is thence evident, within this framework, that the question of the appraisal of the materials' mechanical properties on the base of *in situ* investigations assumes a crucial importance, and should be considered with particular attention, critically comparing the results provided by the different correlations available in the literature. With regard to the above mentioned issue, the present paper is focused on the use of coring for estimating the *in situ* compressive strength of concrete. First of all, it is presented a wide overview of the main formulations available in the literature for deriving the actual compressive strength ($R_{c,situ}$) of *in situ* concrete by core tests (f_{core}). Afterwards, two case studies are presented, for which both experimental and numerical elaborations have been performed. The objective is the definition of a coefficient C_{DD} that could be used to evaluate the loss of the mechanical strength of the *in situ* concrete due to the combined effects of the degradation of the material and of the damage suffered by the samples during the extraction.

2. State of the art

2.1. Variability of core strength measurements

Concrete core testing is essential in order to calibrate the results provided by non-destructive methods that are extensively used to achieve the structural information about existing constructions.

These tests, if correctly executed by following the European Standards (UNI EN 12390-1 [18] and UNI EN 12504-1 [19]), represent the most established method for appraising the *in situ* concrete strength, whereas ND methods such as rebound-hammer, ultrasonic test; pull-out test do not guaranty the same level of reliability. On the other hand, the drilling of concrete is surely more time consuming, invasive and expensive, also because it requires the repair of the structural element. In Fig. 1, the theoretical procedure for deriving *in situ* concrete strength starting from a core test specimen is schematically shown.

With regard to the test procedure and to the numerical elaboration of the results, a fundamental reference is represented by the American Standards ACI 214.4R-03 [20], ASTM C42-90 [21], and by the British Standards BS n. 1881 [22]. In these documents, it is defined the "reference" value for the core strength, which should be measured on a standard specimen characterized by the following slenderness:

$$\lambda = \frac{H}{D} = \frac{200\ \text{mm}}{100\ \text{mm}} = 2 \quad (1)$$

where H and D respectively are the height and the diameter of the cylindrical core.

Actually, it is also possible to use specimens having a non standard slenderness, provided that the corresponding strength ($f_{c,nst}$) is properly corrected, deriving the strength of the "equivalent" standard specimen ($f_{c,st}$), as follows:

$$f_{c,st} = F_{H/D} F_{dia} F_r f_{c,nst} \quad (2)$$

The coefficients $F_{H/D}$, F_{dia} and F_r are introduced in order to correct the strength value, respectively, with regard to the variation of λ, D and to the presence of embedded reinforcements.

It has long been known (see for example ASTM-1927) that the parameter λ has a significant influence on the ultimate strength of a core specimen. Actually, in the presence of a slenderness close to 1, the collapse load is very high, thanks to the reduced lateral dilation occurring during the test [23], whereas for standard slen-

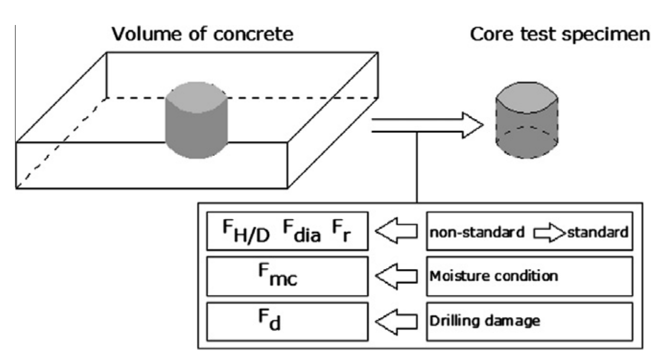

Fig. 1. Relationship between *in situ* strength and core strength.