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Reinforced concrete structure: Non destructive in situ strength assessment of concrete

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HIGHLIGHTS

- Destructive and non-destructive testing were carried out on an historical building.
- Rebound Hammer, ultrasonic pulse velocity and combined method (SonReb) were employed.
- These methods supplement the destructive method, containing the costs.
- Their combination allows to obtain a higher level of knowledge and accuracy.

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ABSTRACT

When a study of the seismic damageability assessment of reinforced concrete (RC) structures is conducted, the characterization of the concrete used during the construction is of fundamental importance. According to the most recent seismic codes, the evaluation of concrete compressive strength is a fundamental step in the assessment of existing RC buildings. In fact in the assessment of seismic vulnerability of structures or in the evaluation of their seismic damage, we cannot ignore the correct evaluation of the materials' mechanical properties. Recent innovations in codes provide clear rules for assessing the safety and conduct of static strengthening on existing buildings. The type and number of in situ tests depend on the level of knowledge: Limited, Normal and Full. The knowledge level defines adoptable methods of analysis as well as the values of the Partial Safety Factors.

A series of destructive and non-destructive tests were carried out on an important historic building in Reggio Calabria: the National Museum of "Magna Grecia". This paper outlines the structure which was tested and the principal results of the testing campaign. The results show the variation of the mechanical properties of the in-situ concrete, the reliability of the combined methods, the need to calibrate the strength obtained by non-destructive methods with the strength of cylindrical specimens (cores) which were extracted from the same structural elements in the proximity of the non-destructive test.

1. Introduction

The assessment of existing buildings is an important issue that involves researchers and engineers in many countries. The assessment of in situ compressive strength of a reinforced concrete structure plays a key role in the evaluation of its safety. The study of an 'ancient' structure is interesting because it provides information about both the materials and technologies available at the time of its construction and the knowledge of the main physical properties of concrete and its state of conservation. An estimation of concrete strength in existing structures becomes necessary when evaluating their seismic capacity and designing seismic strengthening. This estimation is usually performed by compressive tests carried out on cylindrical specimens extracted from structural elements. Destructive tests can be supplemented by non-destructive tests with the objective to improving information and contain quality control costs.

Recent innovations of codes [1–3] provide clear rules for assessing the safety and conduct of static strengthening on existing buildings. The type and number of in situ tests depend on the level of knowledge: Limited (KL1), Normal (KL2) and Full (KL3). The knowledge level defines adoptable methods of analysis, as well as the values of the Partial Safety Factors.

The Italian code [2,3] suggests estimating the mechanical properties of materials on specimens extracted, by coring, from structural elements. Both European and Italian codes allow the use of non-destructive test methods (e.g. Schmidt hammer test (Rebound), Ultrasonic Pulse Velocity test (UPV), SonReb, etc.): these

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tests must always be used in conjunction with destructive tests [4]. The NDT test can be used after the construction of a specific calibration curve; i.e. when a specific relationship is established between the in-situ compressive strength and the result obtained from the indirect method for the concrete taken under consideration.

Hence, the importance of a correct estimation of the in-situ compressive strength of concrete by compression tests conducted on cores extracted from structural elements is clear.

In this respect, a series of destructive laboratory tests on 359 cores were performed with the purpose of estimating the characteristic strength of in-situ concrete [5]. An analytical expression was introduced in order to estimate the characteristic in-situ compressive strength of concrete. The results of these applications were compared with those obtained by other equations available in technical literature demonstrating that the proposed formulation was capable of providing a good estimate of the in-situ characteristic concrete compressive strength.

The characterization of the materials utilized during the construction of "ancient" or historical structures is of fundamental importance when the structural resistance or the seismic damageability assessment are conducted in a reinforced concrete building (RC), where the ranges of time do not allow a correct evaluation of the mechanical characteristics of the materials. Moreover, these buildings often have great historical importance, therefore it is convenient to limit the number of destructive tests (cores).

The use of non-destructive methods is generally justifiable only if a direct correlation is performed between the NDT test results and the compressive strength of cores taken from the structure.

A significant database of both destructive and non-destructive tests conducted on existing RC buildings located in the Italian Region of Tuscany and built between the 50's and 80's was used to perform statistical analyses [6,10]. The paper details the need to conduct a wide campaign of on-site tests, which are useful in defining the compressive concrete strength with suitable reliability.

It is, in fact, well known [7–9] that a proper evaluation of concrete strength is essential to correctly determine the seismic performance of existing buildings. It has been found that formulations available in technical literature provide different results from the actual values. Conversely, the results of the SonReb method, calibrated with the strength of cylindrical specimens (cores) extracted from a single building, are close to the actual ones.

The coefficients of variation for a significant number of existing buildings located in Tuscany by Cristofaro et al. [10] were evaluated; the application demonstrated a frequent high value for existing RC buildings. Moreover, the dispersion of compressive strength obtained by the SonReb method, using correlation curves calibrated ad hoc on a single building, shows how increasing the quantity of data does not always correspond to a significant reduction of the coefficient of variation.

Breysse analyzes why and how non-destructive testing (NDT) measurements can be used in order to assess on-site strength of concrete [11]. The paper was based on both an in-depth critical review of existing models and an analysis of experimental data gathered by many authors in laboratory studies as well as on site. The key factors influencing the quality of strength estimate were identified.

Two NDT techniques (UPV and Rebound) were specifically prioritized whilst a large number of empirical strength-NDT models were analyzed. The measurement error was shown to have a much larger influence on the quality of estimate than the model error. The Author proposed a strategy for concrete assessment in which the number of unknown parameters were drastically reduced. The key issue of calibration was addressed and a proposal was made in the case of the SonReb combined approach based on the use of a prior double power law model, identifying a single parameter. The Author shows that the number of calibration cores can be significantly reduced without reducing the quality of assessment. In fact, the Author, in accordance with the EN 13791 [12], considers the following two different approaches:

- Approach A: consists of looking for a multivariate regression function between the (I and V) values measured on the concrete specimens (either directly on the structure, on cores taken from the structure or on cubes cast with the same concrete) and $f_{c,car}$ values measured on cores:

$$\ln f_{c,car} = \ln a + b \ln V + c \ln I \tag{1}$$

which corresponds to:

$$f_{c,car} = aV^b I^c \tag{2}$$

- Approach B: consists in using a prior model, e.g. a ($f_{c,est} = aV^bI^c$) model, where b and c are given, and to calibrate the a value. Calibration can be done by calculating the mean value of estimated strength $f_{c,est,mean}$ and the mean value of experimental strength $f_{c,car,mean}$:

$$k = f_{c,est,mean} / f_{c,car,mean} \tag{3}$$

Thus the calibrated model can be written as:

$$f_{c,car} = (a/k)V^b I^c \tag{4}$$

Moreover, the Author provides a synthesis of the errors to: (i) prevent searching for a universal NDT-strength relationship that simply does not exist; (ii) avoid meaningless comparisons and check the statistical validity of the model; (iii) be careful with any extension of the domain of validity (i.e. extrapolation); (iv) think how the model can be used [11].

A technique based on Bayesian inference was suggested by Giannini et al. [19] to rationally combine the results of direct and indirect measurements (the ultrasonic pulse velocity) providing the probabilistic distribution of the concrete strength and some significant properties such as the median and characteristic value.

The proposed method was validated by experimental data.

It is also convenient to remember that there are three commonly used techniques to predict the in-situ compressive strength of concrete based on the SonReb measurements. These are: computational modelling, artificial intelligence and parametric multi-variable regression models [20].

Computational modelling, based on the modelling of complex physical phenomena, is often impractical due to the complexity of the model. Artificial intelligence includes the artificial neural network and the fuzzy logic method. It is a nonparametric statistical tool that does not require priori assumptions about the characteristics of the samples (i.e. a parameter); however, the assumptions are less restrictive than those in the usual statistical parametric.

Parametric multi-variable regression models, are easily implementable and used in technical practice. In particular, the model can provide insights on how each variable in the model influences the prediction.

Huang et al. [20] used a probabilistic multi-variable linear regression model to predict the in situ compressive strength of concrete using SonReb measurements and additional concrete properties. The Bayesian updating rule and the all possible subsets model selection were used to develop a model based on the collected data with a wide range of concrete properties. The Bayesian updating rule and the all possible subsets model selection were used to develop a model based on the collected data with a wide range of concrete properties. The model was compared with other available regression models.