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Strength assessment in reinforced concrete structures: From research to improved practices

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ABSTRACT

The nondestructive assessment of concrete strength in existing structures is a real and complex challenge. Recent research advances have been done, like the idea of conditional coring or the development of a bi-objective approach for assessing concrete variability. It will be shown here how, through the use of synthetic simulations and the analysis of uncertainty propagation in the investigation and assessment process, it is possible to (a) confirm the interest of these research results, (b) develop a consistent approach for an efficient and reliable assessment of concrete strength in existing structures. This work will be based on the definition of prescribed targets in terms of uncertainty of assessment and on the concept of risk, i.e. probability of missing the targets.

1. Introduction

The nondestructive assessment of concrete strength in existing structures is a real and complex challenge. While on one hand, many studies and research programs have been carried out in order to develop tools and models for assessing this strength, on the other hand, one still lacks any validated methodology which guarantees the quality and efficiency of this process.

Several nondestructive techniques have been promoted (rebound hammer [38], ultrasonic wave velocity measurement [35], pull-out [5,30], etc.) and a large variety of conversion models (i.e. empirical relationships providing a strength estimate once the NDT result is given) have been proposed, but there is no agreement on what can be done in real situations in order: (a) to estimate concrete strength, (b) to know the quality of this assessment. Many case studies have developed an investigation methodology to an existing structure and established specific conversion models using a variety of nondestructive techniques [23,9,25,8] but they usually fail to draw more general conclusions that could be applied as general rules of good practice.

A large part of the debate consists in comparing alternative conversion models [26,21,15,39,22], but their main conclusions is that all differences remain small and that there is no way to identify an "always best" conversion model. In addition, the authors usually compare the quality of fit without analyzing the real predictive capacity of the models. Another very active field in research is the development of heuristic "black-box" conversion models, based for instance on neural networks or fuzzy logic [17,6]. Such methods could perhaps be applied in the future to develop machine learning algorithms, but they are not capable, in their present state of development, to provide reliable estimates of concrete strength for an unknown structure.

Interesting innovations have appeared but have failed until now to reach a wide diffusion, like the analysis of various scales of heterogeneity in an existing building [27,28] or the added-value than can be brought by conditional coring, which comes to choose the location of concrete cores on the basis of prior NDT results, as initially promoted by [34,2].

Strength assessment however remains a key issue when buildings have to be retrofitted or when their structural safety is questioned. It is the reason why a RILEM Technical Committee (TC-ISC 249) has been created in order to study this important issue and to propose a relevant assessment methodology. Such a proposal would account for:

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- the fact that existing Standards, while opening the possibility of nondestructive strength assessment of existing structures usually require a so large number of cores that this option is not interesting from an economical point of view [16,32],
- the fact that in most cases, the final assessment of concrete properties remains limited to a strength value (which can be a mean strength or a local strength) but that nothing is known about the uncertainty interval of this assessment,
- the need of having a consistent approach, covering all steps of the assessment, from the data collection to the strength assessment,
- the need to provide some recommendations regarding a controversial issue, that of combining several nondestructive techniques for reaching a more reliable assessment. The idea of combining several techniques, mostly rebound and ultrasonic measurements, appeared in the 1980s [24]and had been promoted by RILEM 25 years ago [19], but there is no consensus about the fact that it really works or not [20,36],
- the possibility of addressing additional issues, like the estimation of concrete variability, which plays a major role in safety analyses of existing structures.

This paper will present the most innovative issues that have been analyzed and validated during this collective work and that will be promoted by RILEM Recommendations. The interested reader is invited to get the soon to be published RILEM Recommendations and Guidelines to have a comprehensive knowledge of the process while additional information will also be available in Appendices.

2. Recent research advances and development of a consistent global approach on the basis of a collective expertise

2.1. Global view on the assessment process challenge

It is only recently that significant research efforts have been devoted to the fundamental issues of the nondestructive concrete strength assessment [14,13] and that a more systematic analysis of all degrees of freedom of the nondestructive investigation and assessment process has been carried out. The three main steps of this process can be seen on Fig. 1:

- The data collection stage, covering both nondestructive and destructive measurements, which includes the definition of the nature of tests, the number of measurements, their location, etc...
- The conversion model identification stage, which covers both the choice of the empirical model mathematical shape and the choice of the model parameters identification process,
- The strength assessment stage, which must also cover the estimation of the uncertainty of this assessment.

Since the uncertainty on the final strength assessment must be quantified, one must be aware that it results from the influences of uncertainties that can arise at all steps of the previous process, as can be seen on the flowchart of Fig. 2, which is divided in two parts. Experts agree on the fact that the strength assessment cannot be done with a conversion model that has not been adapted to the specific context and that some calibration is always required.

Firstly, the uncertainty attached to the identified conversion model (i.e. the uncertainty on the values of the model parameters) results from:

(a) The sampling uncertainties that come from the fact that the model is identified from a limited dataset (let us note N_{core} the number of cores, which is also the number of ($f_{c\ i}$, Tr_i) pairs where $f_{c\ i}$ is the i-th strength value measured on a core and Tr_i is the i-th nondestructive test result. To the classical problem of a finite size sample, which has known solutions, is added the fact that, depending on how core location has been selected, the core strength values can provide a more or less representative picture of the whole population.

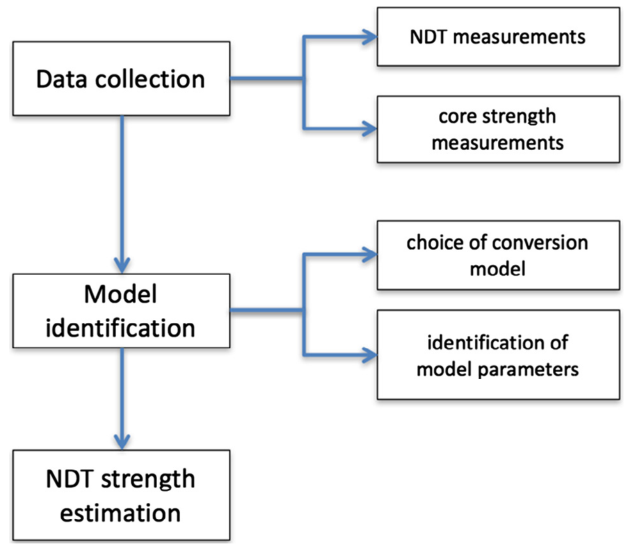

Fig. 1. The three main steps of the assessment strategy.

(b) The measurement uncertainties, since the f_{ci} and Tr_i values are obtained from experimental tests and thus do not exactly correspond to the "real" value of the same property at this location. In fact, the real value cannot be known and is only estimated by the measurement. Repeating the same measurement at the same location (which is possible with nondestructive tests but not for strength) would provide another test result.

(c) Any other influencing factor that can affect the measured value whereas they are not considered explicitly in the conversion model. Many such influencing factors are known for concrete, like the moisture content, the carbonation depth, the type of aggregates.

All these factors being known, the model parameter identification process has also a small influence. Different identification approaches can be used, like fitting a specific model through the minimization of squares, or calibrating a prior curve with a drift (like in EN13791) or a multiplying factor. These different options would lead to slightly different uncertainties.

Once the conversion model has been identified, the second step is using it to estimate strength values from new nondestructive rest results (Tr). As shown in Fig. 2, one has thus new measurement errors while additional influencing factors can increase the uncertainty, for instance if the temperature is different from what it was when the first series of measurements had been carried out.

It is also possible to classify the uncertainties into four groups, according to the fact that they can be controlled or not during the investigation and assessment process:

- statistical (sampling) uncertainty, due to the limited size of the dataset on which the model is calibrated, i.e. typically the number of cores,
- measurement uncertainty, on strength measurements as well as on NDT measurements, which mostly depend on the technique itself, but also on the device, on the expertise of who takes the measurement and on the environmental context,