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Assessing concrete strength variability in existing structures based on the results of NDTs

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HIGHLIGHTS

- Correlation between the variability of RN and concrete strength data is analysed.
- Correlation between the variability of UPV and concrete strength data is analysed.
- Expressions estimating in situ concrete strength variability using UPV are proposed.
- Expressions estimating in situ concrete strength variability using RN are proposed.

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ABSTRACT

One of the main factors affecting the survey of concrete strength in existing structures is the inherent material variability, which can only be fully characterized when destructive tests are performed, especially in older structures. Therefore, having a preliminary estimate of the concrete strength variability facilitates the planning of destructive testing campaigns. In light of this, the proposed study presents the development of general empirical expressions estimating the in situ concrete strength variability using non-destructive test (NDT) results. These expressions are defined by examining the correlation between statistical parameters of datasets of concrete core strength, rebound hammer and ultrasonic pulse velocity test results using several correlation models that are based on common conversion models and on a generalization of the bi-objective approach. Based on these analyses, empirical models that are able to provide a reliable estimate of concrete strength variability using NDT results are proposed.

1. Introduction

Over the past few years, repairing and upgrading existing reinforced concrete (RC) structures has been recognized as an important priority ([1,2]). A crucial part of assessing the conservation state and the structural performance of these structures involves evaluating their actual mechanical properties [3]. Among these, evaluating the concrete compressive strength (f_c) is particularly important given its impact in the structural performance and the known issues associated with its assessment (e.g. see [4]).

Characterizing f_c in existing buildings usually involves determining two specific parameters: a location parameter, often the mean value of concrete strength μ, and a variability parameter, usually either the standard deviation σ or the coefficient of variation (*CoV*) of the data [5]. Given the properties of these parameters, the uncertainty associated with estimating μ can be seen to be related with the uncertainty associated with estimating the variability ([6]). Thus, estimating μ requires a reliable estimate of the inherent variability (i.e. σ or *CoV*) of concrete strength, which can attain very large values (e.g. see [7]) due to the effect of workmanship ([8,9]) among other factors. Other authors (e.g. [10,11]) highlighted the importance of the uncertainty associated with core testing and within-member variability when assessing in-situ concrete strength. Furthermore, previous research [5] has also shown the effect of sampling uncertainty (mainly focusing on member-to-member variability) associated with the use of samples of small size. The authors highlighted that even when adopting a finite population strategy to control the statistical uncertainty, large size samples of concrete core strength test results are required to get a reliable estimate of the variability.

The need for a large number of concrete core strength test results to accurately estimate concrete strength variability has led to the use of alternative methods involving additional sources of information. Bayesian methods have been proposed as possible approaches to incorporate the information of different sources

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when estimating the σ or *CoV* of concrete strength ([1,2,12]) or to quantify material safety factors ([13,14]). In some cases, prior information can also be established using data about σ or *CoV* based on past studies. For example, Caspeele and Taerwe [1] proposed a set of informative priors for different concrete classes based on concrete production data from Germany. Although their strategy can be adapted to different countries, its applicability to older RC structures for which there is no information regarding the expected concrete class may be difficult without preliminary in situ testing to estimate the concrete variability. In another case, Jalayer et al. [12] used a prior concrete strength distribution defined by a lognormal distribution with a median of 16.18 MPa and a *CoV* of 0.15 to represent typical values found in post-world war II construction in Italy. Alternatively, prior information can account for the results provided by non-destructive test (NDT) results. Giannini et al. [2] proposed a systematic framework combining concrete core and NDT results that requires a given number of cores to develop a case-specific regression model to convert NDT results into f_c estimates.

It has been shown that NDTs can be used to reduce the epistemic uncertainty, despite having as a main drawback the fact that they require the use of a conversion model [2]. Recently, Alwash et al. [15] analysed the uncertainties associated with destructive tests, NDT results and with the models that are used to convert NDT results into concrete strength estimates. In terms of conversion models, these authors analysed the efficiency of specific regressions, calibrating prior models (such as those in [16]) and the bi-objective approach [5]. They concluded that all the approaches can efficiently (i.e. using a low number of core strength test results) provide adequate estimates for the mean, but only the bi-objective approach was seen as a reliable method to estimate the variability. The bi-objective approach is a method proposed by Alwash et al. [5] where the first and second statistical moments of the in situ distribution of f_c are directly related to those obtained from the sample of NDT results. Therefore, this method provides an alternative estimate of the conversion model parameters based on aggregated data instead of using the classical approach based on individual test results.

Despite the significance of NDTs towards reducing the uncertainty in the concrete strength assessment process and reducing the number of destructive tests that need to be performed, no universal conversion model can be defined between the test results of a certain type of NDT and f_c, [17,20]. However, the possibility of developing empirical expressions that are able to provide estimates of the in situ concrete strength variability using NDT results has not been analysed so far. Therefore, the present paper addresses this issue by combining the main rationale behind the prior distributions proposed in [12] and the principles of the bi-objective approach. In particular, this paper analyses if empirical models correlating the statistical parameters of a population of concrete core strength test results and those of a population of rebound hammer test results (*RN*) or ultrasonic pulse velocity test results (*UPV*) can be used to establish initial estimates for the variability of the in situ concrete strength. Furthermore, the results of the study also provide information that can be used to improve the selection of conversion models for the bi-objective approach or for specific regression methods.

2. Determining the statistical parameters of the concrete strength distribution based on NDTs

2.1. Brief review of existing conversion models

The variability of concrete strength in existing RC structures, particularly in older RC buildings, can be associated with multiple factors. Some of the factors affect not only the concrete strength but also the NDT results ([15,17]). As such, the conversion models that are established between NDT results and f_c are also significantly affected by those factors. Therefore, as referred by Breysse et al. [18], an adequate conversion model can only be developed when based on data collected in situ. Among others, [19,20] present a thorough review of different types of conversion models that are available to correlate *RN* test results or *UPV* test results with f_c. Fig. 1 shows the distribution of the type of conversion models adopted in past studies based on the surveys in [17] and [20].

As shown in Fig. 1, linear models correlating f_c with *RN* or *UPV* are often adopted. These models usually establish a linear conversion function between the NDT results (T_i) and the core strength test results $f_{c,i}$ similar to:

$$f_{c,i} = a \cdot T_i + b. \quad (1)$$

According to the data presented in Fig. 1, the number of studies using linear conversion models is approximately the same as the number of cases that consider a power model instead. The performance of this type of model was analysed by Breysse & Fernández-Martinez [20] who considered the use of a power correlation model between *RN* and f_c with regression coefficients *c* and *d* such as:

$$f_{c,i} = c \cdot RN_i^d, \quad (2)$$

which is equivalent to the following linear correlation model on a log-log space:

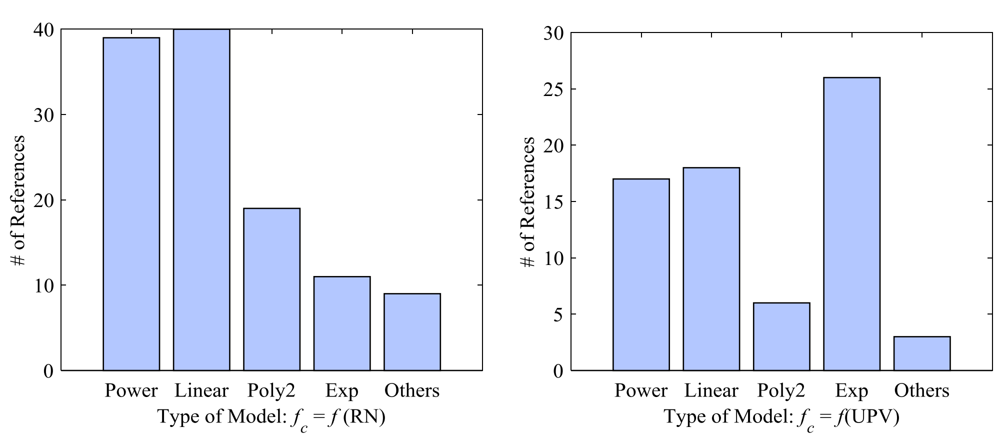

Fig. 1. Variety of models adopted to correlate f_c with *RN* or *UPV* based on the surveys in [17] and [20] (Power, Linear, Poly2 and Exp stand for power, linear, polynomial and exponential model, respectively).