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Factors affecting the reliability of assessing the concrete strength by rebound hammer and cores

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HIGHLIGHTS

- Selecting core locations based on rebound measurements improves the assessment reliability.
- Reducing repeatability of rebound measurements improves the assessment reliability.
- Increasing the number of cores improves the assessment reliability.
- Concrete intrinsic variability plays an important role on the assessment reliability.

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ABSTRACT

To assess concrete strength in a structure, nondestructive technique (NDT) like rebound hammer is combined with destructive technique (coring tests) in order to implement a relationship "conversion model" between the compressive strength and, NDT measurements. The conversion model is used to estimate the local strength value at each test location using the corresponding NDT value. Then the estimated mean strength and/or estimated strength standard deviation (concrete strength variability) values are calculated. However, the reliability of these estimated values is always a questionable issue because of the uncertainties associated with the strength predictions based upon NDT measurements. To improve the reliability, the uncertainties must be reduced by specifying and controlling their influencing factors. The objective of this paper is to study the reliability of assessment by analyzing the effects of several influencing factors: number of test locations used to identify a conversion model between strength and rebound measurement *NC* (number of cores), true value of concrete strength variability, within-test variability of rebound measurements, accepted uncertainty level, quantity to be assessed (mean strength, strength variability), model identification approach (like regression) and the way of selection core locations (random or conditional i.e. selection based on NDT measurements from preliminary investigation). To this end, a large campaign of laboratory studies datasets (1700 test results) was considered for the analysis in the present study.

Results show that *NC*, within-test variability of rebound measurements and true concrete strength variability have significant effects on the assessment reliability. Conditional selection of cores has also an important effect on improving the reliability so it is strongly recommended.

Abbreviations: Superscript –, mean value of the variable under consideration; *s*( ), standard deviation of the variable under consideration; *CV*( ), coefficient of variation of the variable under consideration; Test location, limited area selected for measurements used to provide one test result; f_c, core (or cube) compressive strength corresponding to one test location; f_{cest}, estimated strength of concrete corresponding to one test location; *R*, Rebound number, test result, it is the mean of rebound hammer readings corresponding to one test location; CV_R, within-test variability of rebound measurements (in terms of the coefficient of variation); *NC*, represents the number of cores (or cube) used to identify the model, in present study, one core is considered to be provided by each test location, consequently *NC* also refers to number of test locations for cores; *NI*, number of repetitions; *NR*, number of test locations for rebound hammer measurements; *NT*, total number of test locations of the reduced dataset; *U*, accepted level of uncertainty, relative value %; *T*, true reference value; *U*×*T*, accepted level of uncertainty, absolute value.

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1. Introduction

Assessment of in-situ concrete strength in structures is always a challenge for engineers. In the current methodology, nondestructive techniques (NDT) are combined with destructive techniques (coring tests) in order to implement a relationship "conversion model" between the compressive strength and NDT measurements. Regression approach is the most popular approach that is used to identify the conversion model [1–5]. However, in real practice, engineers also use "calibration approach" as a model identification approach [5–7]. This approach is based on calibrating a prior model or basic curve (from literature or standards) according to the measured core strengths. Alwash et al. [7] have recently proposed a new model identification approach so-called "bi-objective approach" which is devoted to capture the concrete strength variability in addition to mean strength, Appendix A provides the principle of this approach.

Thereafter, the conversion model, whatever the model identification approach, is used to estimate the local strength value at each test location using the corresponding NDT value. Then the estimated mean strength and the estimated strength standard deviation (concrete strength variability) values are calculated. However, the reliability of these estimated values is always a questionable issue because repeating an investigation program (i.e. same number of measurements, same techniques for the same building) several times will produce different estimated values.

For decades, studying the reliability of assessing the concrete strength by rebound hammer measurements has been the objective of many scientific researches. However, this issue is quite controversial [8–9]. Some researchers [10–12] are pessimistic considering that rebound hammer is unable to give a reliable estimate of the concrete strength. However, the combination of rebound hammer with the ultrasonic pulse velocity may improve the reliability of assessment [13–14]. On contrast, other researchers like [15] consider that the accuracy of estimation of compressive strength of test specimens cast, cured, and tested under laboratory conditions by a properly calibrated hammer lies between ±15 and ±20%. Furthermore, the probable accuracy of estimation of concrete strength in a structure is ±25% [15–16]. Szilágyi and Borosnyói [17] indicate that the expected error of the strength estimation by the Schmidt rebound hammer under general service circumstances is about ±30%. FHWA [18] states that the accuracy of in-situ strength assessment with rebound hammer is between ±30 and 40%.

Many sources of uncertainty exist and affect the global concrete strength prediction process and the final reliability of the assessment: measurement uncertainties [2,19], true strength variability [20], model uncertainties [20], statistical uncertainties of sampling [21], and influence of uncontrolled factors such as concrete degree of saturation and carbonation [1,22–24].

Moreover, it is necessary to indicate here that the effects of the sources of uncertainty in old structure can differ from that in newly-built structure due to the age effects (i.e. cracks, local damage, steel reinforcement corrosion, etc.). Because of the age effects, more uncertainty is expected in the case of old structure and consequently less reliable assessment.

To improve the reliability, the uncertainties must be reduced by controlling their influencing factors. The objective of this paper is to study the reliability of assessment by analyzing the effects of several influencing factors: number of test locations used to identify a conversion model between strength and rebound measurement *NC* (number of cores), true value of concrete strength variability, within-test variability of rebound measurements, accepted uncertainty level, quantity to be assessed (mean strength, strength variability), model identification approach (regression, bi-objective) and the way of selection core locations (random or conditional i.e. NDT based selection). To this end, a large campaign of laboratory studies datasets was considered for the analysis in the present study.

2. Datasets

In order to study the assessment reliability, datasets are required to perform the analysis. Seventeen datasets that belong to different laboratory studies presented in [25] were considered in this paper. Each dataset resulted from one specific laboratory study and specific testing conditions, but the specific study can include one or several mixes with variety of concrete characteristics (mix properties, age, curing, and admixture). The size of datasets varies from 100 to 216 test result pairs (rebound number *R*, cube strength f_c), i.e. in total more than 2500 test result pairs. For comparison purposes and avoiding statistical biases due to the effect of sampling uncertainty [21], we reduce the size of each dataset by selecting only 100 test result pairs from its original results. Consequently we have a fixed size for all datasets ($NT = 100$). For each dataset, the selection was carried out by ranking *R* values from minimum to maximum then subdivided them into 100 groups and the median value of each group was selected to be in the reduced dataset. This process of selection ensures that the reduced datasets (each have $NT = 100$) well represented their original datasets.

Table 1 gives the necessary information about these datasets. They cover a wide range of concrete mean strength $\bar{f}_c$ (36–77 MPa) and concrete variability (in terms of strength standard deviation $s(f_c)$ from 6.4 to 17.4 MPa or in terms of strength coefficient of variation $CV(f_c)$ from 11 to 33%). Regarding the rebound number values *R* (test results), the range of *R* corresponding to each dataset is also shown in Table 1. Moreover, each *R* test result value represents the average value of 10 replicates (10 rebound hammer readings on the same surface of a concrete specimen during the laboratory tests). Therefore, within-test variability (or repeatability) of rebound measurements (in terms of the coefficient of variation, CV_R) is known for each test result and the average values of CV_R for each dataset is given in Table 1. Through this study each dataset is represented by the letter D followed by the mean strength value then the value of strength coefficient of variation. The mean strength and concrete variability values given in Table 1 will be called "true or reference" values and used as a reference: estimated strengths will be compared to these true strengths.

3. Research methodology

The methodology adopted in this research was subdivided into three main steps:

- assessing mean strength and strength standard deviation and plotting the cumulative distribution function (CDF) curves,
- Assessing the quality of these estimates by developing risk curves
- Studying the effect of the way of selection the *NC* test locations on the reliability of assessment.

3.1. Assessing the values of $\bar{f}_{cest}$ and $s(f_{cest})$ for all datasets and plotting the CDF curves

In real practice, to assess the concrete strength in a structure, the engineer establishes an investigation program: he carries out NDT measurements (rebound hammer in this study) at a number of test locations (*NR*) and from some of these test locations (*NC*)