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Evaluation of statistical parameters of concrete strength from secondary experimental test data

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HIGHLIGHTS

- An innovative method for the evaluation of statistical parameters of material mechanical properties is presented.
- Knowledge of statistical parameters is essential in the reliability assessment of existing structures.
- The method is based on cluster analysis of secondary databases.
- The method allows to identify concrete strength classes.

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ABSTRACT

The results of material acceptance tests or in-situ tests are a valuable source of information for reliability assessment of existing structures. Huge secondary databases of test results are usually available, coming from different sources, but individual results are often not associated to a given population, so their statistical analysis is a complicated process. In order to solve this problem, the paper presents a methodology that allows to identify homogeneous populations (or material classes), together with their statistical parameters, when mixed in arbitrary and unknown percentages in a secondary database. The methodology is based on the cluster analysis of data applying the Expectation-Maximization algorithm, which allows to figure out individual classes and their characterizing statistical parameters by fitting a Gaussian Mixture Model. The proposed methodology has been applied to a relevant case study, investigating the cubic concrete strength of the Italian production during the 1960s, also using different approaches. The study demonstrates that approximately six concrete classes can be identified, characterized by an almost constant standard deviation of about 4.0–4.5 MPa, in agreement with the results obtained by previous research. As the results obtained with different approaches agree satisfactorily, it can be concluded that, if enough experimental data are available, the proposed procedure is not only suitable for the intended applications, but it is also "robust" enough.

1. Introduction

In the reliability assessment of existing structures the estimate of the mechanical properties of the building materials and the evaluation of their most relevant statistical parameters is a crucial issue of the analysis. In some cases, useful information about this topic can be derived, when available, from standard acceptance test results or by in-situ investigation.

Standard acceptance tests are devoted to assess the mechanical properties of the material and to determine whether a production lot of the material itself is fulfilling the design requirements or not. This important quality control technique has become more and more common in the engineering practice starting from the second half of the 19th century, with different emphasis depending on the building material. Usually material samples are collected at the building site, to assess whether the material can be accepted or not, or on factory, in the framework of conformity control; the

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concrete strength distribution can be then filtered due to the rejection or acceptance of certain batches, resulting in a positive influence on the structural reliability of concrete structures [1]. Moreover, often in-situ investigation is frequently needed to supplement or to substitute laboratory tests, that are usually classified into destructive [2,3], minor destructive [4], or non destructive [5–11] tests.

As soon as the process for sampling and testing specimens has been codified in relevant Codes and Standards, test results have been stored in laboratory archives and databases; therefore in most of the cases they can be easily retrieved and consulted, regardless of whether they pertain to laboratory or in-situ tests.

In a very general context, the statistical parameters of the mechanical properties can be obtained by:

(a) analyzing sets of destructive or semi-destructive in-situ test results; or
(b) analyzing non-destructive in-situ test results; or
(c) prior evidence; or
(d) suitable combination of the above mentioned information.

Nevertheless, the practical application of these approaches could be subjected to strong restrictions, and the dependability of their outcomes could be frustrated by several factors:

- destructive or semi-destructive tests are, in most cases, incompatible with the statics and the needs of safeguarding the structure [12,13] or of preserving its cultural value and that, even in cases when semi-destructive tests can be really carried out, their number is normally so limited that appropriate statistical interpretation is very difficult.
- non-destructive tests are broadly correlated with the actual resistance: their use can be useful to support the identification of reference values of a mechanical property and to assess the homogeneity of the material, but commonly they give no direct information about statistical parameters;
- prior evidence can be derived directly from specific acceptance tests performed on the structure, provided that enough sound and reliable experimental results are available, but this is a very unusual case; or by suitable elaboration of large amounts of secondary data, derived from experimental test results obtained elsewhere;
- the best way to estimate statistical parameters of material properties is to combine prior evidence, when available, with semi-destructive or non-destructive investigations; by using spot-check results essentially to support the identification of material properties based on prior evidence or, when possible, as basis for application of Bayesian updating [14,15].

In the last decades, several studies have focused the attention on approaches (a), (b) and (d), proposing less invasive and more precise testing techniques as well as advanced procedures for combining different type of information [16,17]. Despite several progresses, the proposed approaches are not always workable in practice. On the other hand, the digitizing process has made secondary test results increasingly available, but a proper methodology for the statistical analysis and interpretation of secondary data is still lacking.

The statistical analysis of secondary material properties databases is often hindered by the difficulty of identifying in them different resistance classes and then their statistical parameters, since each individual experimental result belonging to the database cannot be referred to a specific resistance class of the material. This observation, which is quite obvious when in-situ tests are the exclusive source of information, is valid in a much wider sense, because, even in case standard test results are available, the resistance classes are often not correctly declared or not declared at all; for instance, use of downgraded material to meet the requirements of a lower resistance class is an emblematic example of incorrect declaration. On the contrary, taking into account that frequently the material properties depend on the composition of the material itself and on the workmanship, and that these aspects are nearly constant in a homogenous geographical area, it seems reasonable to group the data on the base of regional criteria.

The evaluation of the statistical parameters of the compressive strength class of the concrete is a key issue in reliability assessment of existing reinforced concrete structures. The concrete strength, whether it is produced on site or ready mix, is a random variable, whose statistical parameters can vary over the time, even in a single structure. According to [18,19], several factors can affect the variation of concrete properties, like the size of the job and the duration of the contract, the supervision, workmanship and plant used, the making, curing and testing of the specimens, the variation in successive batches, and the variation in the constituent materials. Above all, and especially on site, a relevant source of the variability is due to the fluctuations of water/cement ratio (w/c), caused by the continuous adjustment of the quantity of water added at the mixer in attempting to maintain a good level of workability and the variation in moisture of the aggregates, as well as the climatic conditions during the preparation and pouring of concrete.

Since the execution of standard acceptance or quality control tests on cubic or cylindrical specimens aimed at assessing the material compressive strength is a common practice in reinforced concrete structures, huge amounts of test results are available, often further supplemented by test results on cylindrical specimens obtained by in-situ core sampling.

The statistical analysis of these secondary data could shed a light on the statistics of the mechanical properties of the existing concrete structures.

An attempt to perform some kind of statistical elaboration of massive test results can be found in literature [20], but it was unsuccessful, as proven by the unrealistically high values of the coefficient of variation (COV) generally resulting from the analysis.

As better discussed in the following, there have been several attempts to perform some kind of statistical elaboration of massive sets of available test results, but they were unsuccessful, as proven by the unrealistically high values of the COV generally resulting from the analysis. Actually, since a broad secondary database of compressive strength tests contains results pertaining to different concrete classes, which are different statistical populations, the identification of distinct concrete classes, representing homogenous statistical populations, is a precondition for a suitable statistical analysis. In performing the analysis it must be duly taken into account that preliminary manipulations of the recorded data, like "a priori" assignment of some specimen to a given class on the base of information recorded on the test report or on the base of engineering judgments, should be avoided as this kind of information is often unreliable or incomplete and anyhow extremely subjective.

It must be underlined that existence of a certain number of distinct material classes in general, and of concrete classes in particular, can be interpreted as an intrinsic feature of the material making process, independently on its codification; the unique difference is that in Codes and Standards notional resistance classes are defined, to which reference is made both for commercial or design purposes.

In effect, also in a first stage and in absence of any standardization, building materials are produced fulfilling some mechanical requirements, suitably adapting the production and the mix design on the base of the past experience and of the raw materials locally available, according to the know-how developed in limited con-