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On the dispersion of data collected by in situ diagnostic of the existing concrete

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HIGHLIGHTS

- Assessment of concrete adopted in the safety assessment of existing building.
- Numerical processing of data referred to DTs and NDTs of RC existing schools.
- Evaluation of statistical dispersion of the concrete compressive strengths.
- Comparison between several samplings and CV threshold value of the FEMA rules.

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ABSTRACT

The compressive strength of in-place concrete is a crucial mechanical parameter which influences the performance level and the safety assessment of existing RC structures both under seismic loads and under dead loads. Italian NTC and Eurocode 8 [1,2] have established that the fundamental basis of the safety assessment is the "Knowledge Level (KL)", which shall be defined according to the procedures adopted for in situ inspection and materials testing (destructive and non-destructive). Within this framework – in the case of RC constructions – a major requirement is the explicit identification of the reference values for the strength of in situ concrete. The afore mentioned building codes, however, do not include any consideration about the uncertainty level affecting the results of in situ tests, which can indeed invalidate the reliability of the mechanical parameters. This problem is instead well addressed by FEMA 356 [3], which prescribes a limit value (14%) to the statistical dispersion of the measures performed on a set of concrete specimens. In this paper, after presenting and discussing a procedure applied for processing experimental data provided by in situ tests in a number of real case studies (school buildings in the Province of Foggia, Italy), the attention will be focused on the problem of the data scattering in the case of in situ concrete strength. It is shown that the variance is a crucial parameter, which should always be considered when performing the safety assessment, even if FEMA requirements, in this respect, are too much restrictive.

1. Introduction

The sustainable urban development is one of the future strategic priorities in Europe, and this implies that the "cementification" and consumption of the territory should be held down in favour of the revitalization of existing spaces and constructions. The extensive and effective re-use of the existing buildings is thence a priority option that will allow to save the urban and natural landscape; optimize the natural, energetic and economic resources – while exploiting already existing facilities. The option of reusing existing buildings (is also raising the attention of the building enterprises) is inhibited by a number of technical and operational difficulties, mainly driven by the strict requirements of the modern technical seismic standards and by the complexity of the matter. An existing building, in fact, reflects the degree of technical knowledge of its times, and any procedure aimed at assessing the structural performance level after many years will be able to provide only a partial reconstruction of the actual conditions.

Contemporary building codes [1–5] devote a great attention to the question of the safety of existing buildings and, besides specifying criteria and methods of analysis, they precisely define the procedures to be followed in order to obtain an adequate "Knowledge Level", based on specific preliminary surveys and investigations.

With regard to RC buildings, a crucial part of the preliminary knowledge process is represented by the investigation about the actual mechanical properties of the materials. In particular, the main mechanical parameter that should be provided is the compressive strength of concrete. The appraisal of compressive

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strength of in situ concrete is affected by several factors such as: compaction, curing quality and age of concrete, type of structural element on which the test is performed, and position of the sample. The significant deviations induced by these parameters actually characterize the strength of in situ concrete as a random variable [6]. It should also be considered that the techniques used for in situ diagnostics – as any kind of instrumental measurement – involve additional sources of uncertainty.

The Italian Building Code [1] prescribes that, in existing RC structures, the mechanical parameters must be derived by specific experimental tests. In particular, it is clearly stated that the mechanical properties of concrete should be evaluated by resorting to specific destructive tests, consisting in the "*extraction of concrete cores from the structural elements and execution of laboratory compression tests on the obtained samples*". These tests can be supplemented with non-destructive testing (NDT), provided that they are calibrated by using the results of the destructive laboratory tests [4]. In fact, it is widely acknowledged that NDT (which provide an indirect estimate of the mechanical parameters, based on the measurement of some physical parameters empirically correlated to the mechanical ones) cannot completely replace destructive ones, but could only be used to complement them, after properly calibrating specific correlation functions on the basis of the actual results of the destructive laboratory tests. On the other side, the usefulness of NDT is nowadays widely recognized, and there are several studies that propose the simultaneous use of destructive and non-destructive methods in order to provide a wide database about the properties of materials, which could not be realistically obtained only with a destructive approach [7–9].

In Italy, after the Umbria–Marche earthquake and the subsequent issuing of OPCM 3274 [10], a systematic process of assessment has been initiated for all relevant and strategic existing buildings, and is actually still going on. For current buildings, instead, the safety assessment is compulsory only under particular circumstances, like for example the clear evidence of degradation and/or decay of the mechanical properties of materials. Anyway, within the safety assessment procedure, a critical point is represented by the verification under non-seismic loads: if it is negative, the Italian Building Code [4] prescribes the adoption of urgent measures aimed at guaranteeing a performance level compliant to the technical standards. In this respect, it is specified that possible provisions include: reduction of live loads; limitation in the use of the structure; execution of suitable retrofitting interventions. It is evident, thence that the characterization of in situ materials is crucial, and a too low Level of Knowledge can involve unacceptably consequences: in some cases, if the mechanical strength provided by the investigations is lower than a minimum threshold, materials might not be accepted at all, and the building could even be declared out of service. The whole protocol related to the assessment of in situ concrete strength, thence, requires a great care both in the execution phases and in the interpretation of data. It is also important to mention that the technical standards, when defining the reference value for in place concrete usually disregard any information about the numerical dispersion of the data provided by experimental tests.

The paper presents a statistical analysis of data about in situ concrete strength collected in the occasion of the seismic vulnerability assessment of some school buildings in the Province of Foggia (Italy), in which a wide experimental campaign (including both destructive and non-destructive tests) was carried out. The investigation is part of a scientific cooperation between *Politecnico di Bari* and *Autorità di Bacino of Puglia* aimed at the seismic vulnerability assessment of school buildings [11] and bridges [12] in the Province of Foggia.

The paper is organized as follows: after some preliminary considerations about the main indications proposed in this field by different building codes and about the relevant aspects of the adopted methodology (Section 2), the numerical processing of the data relative to all the schools is presented (Section 3). In Section 4, a sub-sampling (referred to the results of DTs and NDTs of a single building) is specifically analyzed. The comparison between the complete sampling and the sub-sampling is then showed, deriving some significant observations about the correct identification of the representative strength values, the scatter of data, and the combination of non-destructive and destructive methods.

2. Appraisal of in situ concrete strength

2.1. Preliminary remarks

With regard to existing buildings, European standards [2] define three possible *Knowledge Levels*, according to the number of experimental tests performed on materials: KL1 – Limited Knowledge; KL2 – Normal Knowledge; and KL3 – Full Knowledge. The choice of the method of analysis and of the value of the *Partial Safety Factor* for materials depends on the specific knowledge level obtained. In this way, the accuracy or limitedness of the knowledge about the structure (historical information, geometric survey, mechanical characterization, etc.) is taken into account. At the end, the design value of the concrete strength used in the verification depends on the number of data gathered by in situ tests, and is calculated as a function of the mean value of the cylindrical compressive strength $f_{c,mean}$, after applying the *Partial Safety Factor* and the material safety factor (γ_m).

It has to be remarked that, in all this procedure, the issue of the scattering of the measurements, which is a very typical problem of the of in situ properties of structural materials, is not considered at all. Indeed, the mean values which are adopted as design parameters could be poorly significant in those cases in which the data set is characterized by a high *coefficient of variation CV* (usually called *Relative Standard Deviation RSV*). The CV is a non-dimensional index of the numerical dispersion which quantifies, for a generic sampling, the scattering around the mean value. It is defined as the ratio between the standard deviation σ and the absolute value of the mean value (μ).

FEMA 356 Standards [3] explicitly take into account the data variation in the measurement of in situ concrete properties, restricting the possibility of using the mean strength value obtained by experimental data according to the value assumed by the coefficient of variation CV. More precisely, it is allowed to use the mean value $f_{c,mean}$ as a design value only if CV $\leqslant$ 14%, otherwise one of the following actions should be taken:

- The sampling must be enlarged, by performing additional experimental tests until the new value of CV is lower than 14%.
- The mean value must be corrected by subtracting the standard deviation: $f_{c,mean} - \sigma$, in order to obtain the design value.

It should be noticed that the above mentioned corrections are not always easy to apply. From a theoretical point of view, when the scatter of data is relevant, increasing the number of samples is surely a way to cluster the numerical results in a smaller range. However, when dealing with very old buildings (in which materials are strongly degraded) the actual risk is that by increasing the number of tests the results will be even more scattered. Thence, besides the additional economic cost, this kind of strategy could actually provide a greater heterogeneity of the sampling. The second option, after all, is a conventional assumption, that is often too conservative. Instead, in the presence of an excessive scatter of experimental data, it has to be considered the possibility that the