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In-situ tests and inspections for reliability assessment of RC buildings: how accurate?

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ABSTRACT
Measuring the incomplete knowledge of the structural properties in as-built conditions is a formidable challenge in the performance-based seismic assessment of existing reinforced concrete (RC) buildings. Two basic sources of structural modeling uncertainties, which can directly affect the component demand and capacities and even influence the eventual structural collapse mechanism, are related to the mechanical properties of materials and the construction details. Recent European codes propose to consider the uncertainty in the knowledge of structural properties for an existing building by introducing an adjustment factor applied to the mean material strength, called Confidence Factor, whose value depends on the level of knowledge (KL) of structural properties. The latter (KL) is established as a function of number of in-situ tests and inspections available. The implementation of the code-based approach inevitably brings up several questions to be answered ranging from the implementation of the result of tests and inspections, and their relative measurement error. This work aims to introduce a Bayesian framework to quantify the relative error associated to the compressive concrete strength's non-destructive ultrasonic tests. The proposed framework is applied to the test data available for an existing frame belonging to a pre-seismic code RC school building in Avellino (Campania), located in southern Italy. The framework also provides means of quantifying the relative weights of the concrete strength based on non-destructive test results for assessment of existing RC buildings.

1 INTRODUCTION

Eurocode 8 Part 3 (EC8-3) and NTC 2018 propose to consider the overall uncertainty in the structural properties by introducing the so-called Confidence Factor. It is an adjustment factor applied to the mean material strength depending on the level of knowledge (KL) obtained through test and inspections on the existing structure. The intension to apply this factor to mean value of material resistances will to some degree take into account the uncertainties in the engineering estimates. Guaranteeing a specific level of reliability by means of confidence factor is the main question that arises out of this code-based approach. This task should ideally be addressed through a fully probabilistic approach (e.g., Monti and Alessandri 2008, 2009; Jalayer et al. 2010 and 2011, Franchin et al. 2010,). This is while the code procedure seems to provide a deterministic way of looking into an inherently probabilistic problem. The code-based procedure for calculating the confidence factor for an existing RC building is based on the percentage of the inspected reinforcement details and the number of tests on materials per each floor of the building; nevertheless, the type and spatial configurations of the test are not fully specified. The Bayesian inference can be used as a tool to be applied to the results of tests and inspections that can provide updated structural modelling parameters (and consequently updated reliability estimation of the building) as a function of the data available (Jalayer et al. 2010, 2011).

Regarding the seismic assessment of an existing RC structure, in-situ compressive concrete strength is one of the key parameters to be estimated. The most common in-situ tests for concrete mechanical properties are core testing (destructive) and ultrasonic pulse velocity (non-destructive) tests. In this context, characterizing the compressive concrete strength based on both in-situ destructive and non-destructive tests presents a challenge (see e.g., Del Monte 2004, Masi, 2005; Masi and Vona 2007, just to name a few works done in Italy; see also Miano et al. 2019 for a more complete literature search on this issue).

By proposing a fully probabilistic methodology and with the help of Bayesian inference, this works attempt to characterize the compressive concrete strength by combining both in-situ destructive and non-destructive test results. The proposed framework is applied to a pre-seismic code 4-story RC school building in Avellino (Campania), located in southern Italy. The data of the (destructive) core tests and ultrasonic pulse measurements (non-destructive) tests done on the case-study building has been employed in order to provide the distribution of the concrete strength within different floors together with their correlations. The Bayesian inference framework presented herein manages to quantify the relative error of the non-destructive tests with respect to the destructive core tests. As the final outcome of the procedure, the relative weights associated with the non-destructive tests are estimated for the compressive concrete strength calculation. These relative weights for ultrasonic tests are compared with the code-based provisions (NTC 2018) in which the relative weights are considered to be of 1 and 1/3 for destructive and non-destructive tests, respectively.

2 METHODOLOGY

In this section, we are going to describe the proposed methodology in a stepwise manner as follows. It is to note that f_{core} denotes the equivalent in-situ value of the strength data related to the core specimen; f_{ultr} is the estimated strength based on the ultrasonic test; V is the measured velocity of the ultrasonic waves.

2.1 Calculating f_{core} based on the strength data of the core specimen

The value of strength obtained from the original core specimen, denoted herein as $f_{core,original}$ should be adjusted in order to reflect the actual in-situ strength, f_{core}. This is due to the differences in size and geometry of the core specimen (defined with the correction factors $C_{H/D}$ and C_{dia} with D as diameter and H as height), damages due to drilling (defined with C_d), and the presence of reinforcing bars (defined with C_a). Thus, we employed the following expression (see Dolce et al., 2006):

$$f_{core} = (C_{H|D} \cdot C_{dia} \cdot C_a \cdot C_d) \cdot f_{core,original} \tag{1}$$

$$C_{H|D} = \frac{2}{1.50 + D/H}$$

$$C_{dia} = \begin{cases} 1 + 0.0012 \cdot (100 - D) & D \le 100\,\text{mm} \\ 1 - 0.0004 \cdot (D - 100) & D > 100\,\text{mm} \end{cases}$$

$$C_d = \begin{cases} 1.20 & f_{core,original} < 20\,\text{MPa} \\ 1.10 & f_{core,original} \ge 20\,\text{MPa} \end{cases}$$

It is to note that C_a=1 for no bars, and varying between 1.03 for small diameter bars (Ø10) and 1.13 for large diameter bars (Ø20).

2.2 A regression-based probabilistic model for predicting f_{core} given the ultrasonic velocity V

Herein, a regression-based probability model is employed to describe the f_{core} for a given V level. Let $f_{core}=\{f_{core,i},\ i=1:N_{cu}\}$ be the set of equivalent in-situ value of the strength data related to the N_{cu} core specimen, and $V=\{V_i,\ i=1:N_{cu}\}$ be the set of ultrasonic velocity data extracted exactly at the N_{cu} points where the core tests are also extracted (it is to note that this regression can be performed on that partition of the test data, whose number is denoted as N_{cu}, in which the destructive and non-destructive tests are performed at the same position). The regression probabilistic model can be described as a linear regression between the logarithm of f_{core} and logarithm of the ultrasonic velocity V. This is equivalent to fitting a power-law curve to the V-f_{core} response in the arithmetic scale. Thus,:

$$\ln \eta_{f_{core}|V} = \ln(a_v) + b_v \cdot \ln(V) = \ln\left(a_v \cdot V^{b_v}\right) \tag{2}$$

$$\beta_{f_{core}|V} = \sqrt{\frac{\sum_{i=1}^{N_{cu}} \left(\ln f_{core,i} - \ln \eta_{f_{core}|V,i}\right)^2}{(N_{cu} - 2)}}$$

where $\ln(a_v)$ and b_v are the parameters of the linear regression; $\eta_{fcore|V}$ is the median for f_{core} given V; $\beta_{fcore|V}$ is the logarithmic standard deviation (dispersion) for f_{core} given V, which is a constant value over the entire range of V.

2.3 The conditional probability model for predicting f_{ultr} given the ultrasonic strength f_{core}

By employing Eq. (3), one can obtain an estimate of the f_{ultr} given a level of ultrasonic velocity; i.e.:

$$f_{ultr} = a_v \cdot V^{b_v} \tag{3}$$

We again have exploited the logarithmic regression in order to construct a conditional probability model for predicting f_{ultr} as a function of f_{core} (in order to quantify the relative error). A linear regression model between the logarithm of f_{ultr} and logarithm of f_{core} can be defined as follows:

$$\begin{aligned} \ln \eta_{f_{ultr}|f_{core}} &= \ln\left(a_f\right) + b_f \cdot \ln\left(f_{core}\right) \\ &= \ln\left(a_f \cdot f_{core}{}^{b_f}\right) \end{aligned} \tag{4}$$

$$\beta_{f_{ultr}|f_{core}} = \sqrt{\frac{\sum_{i=1}^{N_{cu}}\left(\ln f_{ultr,i} - \ln \eta_{f_{ultr}|f_{core},i}\right)^2}{\left(N_{cu}-2\right)}}$$
$$= \sqrt{\frac{\sum_{i=1}^{N_{cu}}\left(\ln\left(a_v \cdot V_i^{b_v}\right) - \ln \eta_{f_{ultr}|f_{core},i}\right)^2}{\left(N_{cu}-2\right)}}$$

where $\ln(a_f)$ and b_f are the parameters of the linear regression; $\eta_{fultr|\ fcore}$ is the median for f_{ultr} given f_{core}; $\beta_{fultr|fcore}$ is the logarithmic standard deviation (dispersion) for f_{ultr} given f_{core}. It should be noted that an early version of this relationship (a proportional one) was proposed in the work of Petruzzelli et al. 2010. Herein, the early version proposed by Petruzzelli et al. (2010) is evolved into a powerlaw relationship in the arithmetic scale.

2.4 Characterizing the uncertainty in the concrete strength considering both destructive and non-destructive test results

The procedure for updating the probability distribution for concrete strength is outlined herein. Let **D** defines the set of available test data consisting of the core test data (destructive, denotes as $\mathbf{D}_{\mathrm{core}}$) and ultrasonic test data (non-destructive, denoted as $\mathbf{D}_{\mathrm{ultr}}$); thus, $\mathbf{D} = \{\mathbf{D}_{\mathrm{core}}, \mathbf{D}_{\mathrm{ultr}}\}$. By employing the Bayes theorem, the updated joint probability distribution of the median η and logarithmic standard deviation β of the concrete strength given **D**, $p(\eta,\beta|\mathbf{D})$, can be expressed as follows:

$$p\left(\eta,\beta \mid \mathbf{D}\right) = c^{-1} p\left(\mathbf{D} \mid \eta,\beta\right) p\left(\eta,\beta\right) \tag{5}$$

where $p(\mathbf{D}|\eta,\beta)$ is the likelihood of our data **D**; $p(\eta,\beta)$ is the prior joint distribution of the concrete strength parameters; c^{-1} is the normalizing constant. Eq. (5) can be re-written as:

$$\begin{aligned} &p\left(\eta,\beta \mid \mathbf{D}\right) = \\ &c^{-1} p\left(\mathbf{D}_{\mathrm{core}} \mid \eta,\beta\right) p\left(\mathbf{D}_{\mathrm{ults}} \mid \mathbf{D}_{\mathrm{core}},\eta,\beta\right) p\left(\eta\right) p\left(\beta\right) \end{aligned} \tag{6}$$

where $p(\mathbf{D}_{\mathrm{core}}|\eta,\beta)$ and $p(\mathbf{D}_{\mathrm{ults}}|\ \mathbf{D}_{\mathrm{core}},\eta,\beta)$ are the likelihoods of the two sets $\mathbf{D}_{\mathrm{core}}$ and $\mathbf{D}_{\mathrm{ultr}}$, respectively. Note that the likelihood of the ultrasonic test is conditioned on the $\mathbf{D}_{\mathrm{core}}$ data. Assuming independence between core test measurements (which not true in general), the likelihood of observing the core test measurements can be can be written as:

$$\begin{aligned} &p\left(\mathbf{D}_{\mathrm{core}} \mid \eta,\beta\right) = \\ &\prod_i p\left(D_{\mathrm{core},i} \mid \eta,\beta\right) = \prod_i \phi\left(\frac{\ln\left(D_{\mathrm{core},i}/\eta\right)}{\beta}\right) \end{aligned} \tag{7}$$

where $\phi(\cdot)$ is the standard Normal probability density function; $\mathbf{D}_{\mathrm{core}}=\{D_{\mathrm{core},i},\ i=1:N_{core}\}$ where N_{core} defines the total number of core test data. On the other hand, the likelihood $p(\mathbf{D}_{\mathrm{ults}}|\ \mathbf{D}_{\mathrm{core}},\eta,\beta)$ can be written by employing the total probability theorem as follows:

$$\begin{aligned} p\left(\mathbf{D}_{\mathrm{ults}} \mid \mathbf{D}_{\mathrm{core}},\eta,\beta\right) &= \prod_k p\left(D_{\mathrm{ults},k} \mid \mathbf{D}_{\mathrm{core}},\eta,\beta\right) \\ &= \prod_k \left(\int_{\mathbf{\Omega}_{f_{\mathrm{core}}}} p\left(D_{\mathrm{ults},k} \mid f_{\mathrm{core}}\right) p\left(f_{\mathrm{core}} \mid \eta,\beta\right) \mathrm{d}f_{\mathrm{core}} \right) \end{aligned} \tag{8}$$

where $\mathbf{D}_{\mathrm{ults}}=\{D_{\mathrm{ults},k},\ k=1:N_{ults}\}$; N_{ults} defines the total number of ultrasonic test data. In Eq. (8), the probability of observing the kth ultrasonic data $p(D_{\mathrm{ults},k}|\eta,\beta)$ can be expanded with respect to the vector of the core values f_{core} where $\mathbf{\Omega}_{f\mathrm{core}}$ is its domain. Note that the conditioning on $\mathbf{D}_{\mathrm{core}}$ manfests itself in the conditional probability

$p(D_{\text{ults},k}|f_{\text{core}})$, which is is a lognormal distribution with the median and logarithmic standard deviation derived in Eq. (4). Hence, it can be expressed as:

$$p\left(D_{\text{ults},k} \mid f_{\text{core}}\right) = \phi\left(\frac{\ln\left(D_{\text{ults},k} \big/ (a_f\, f_{\text{core}}{}^{b_f})\right)}{\beta_{f_{ultr}|f_{core}}}\right) \tag{9}$$

Substituting Eq. (9) into Eq. (8), we have:

$$p\left(\mathbf{D}_{\text{ults}} \mid \eta, \beta\right) = \prod_k \left(\int_{\Omega f_{\text{core}}} \phi\left(\frac{\ln\left(D_{\text{ults},k} \big/ (a_f\, f_{\text{core}}{}^{b_f})\right)}{\beta_{f_{ultr}|f_{core}}}\right) \phi\left(\frac{\ln\left(f_{\text{core}}/\eta\right)}{\beta}\right) \mathrm{d}f_{\text{core}} \right) \tag{10}$$

Finally, the likelihoods estimated in Eq. (7) and Eq. (10) are combined through Eq. (6) in order to derive an estimation for the updated joint probability distribution $p(\eta,\beta|\text{D})$ of the median η of the concrete strength. It should be noted that the derivation herein are implicitly assuming perfectly correlated concrete mechanical properties across a given floor. Therefore, the mechanical property of interest herein is the spatial average of concrete strength across a given floor (i.e., a constant value of concrete strength is going to be used for structural analysis, performance assessment, .. etc.). This means that we are going to be specifically interested in the probability distribution for concrete median strength values across a given floor.

The marginal distribution of the median η, $p(\eta|\text{D})$, can be calculated directly from the updated joint probability distribution by integrating the joint probability distribution over the domain of dispersion parameter β. This marginal probability distribution of η takes into account both destructive and non-destructive test results. The parameters of this distribution. The maximum likelihood of the median η, denoted herein as f_c, can directly be estimated from of the joint distribution $p(\eta,\beta|\text{D})$. The coefficient of variation (COV) of the median η, denoted as COV_{fc}, is estimated as follows:

$$\text{COV}_{f_c} = \frac{\sqrt{\mathbb{E}\left(\eta^2\right) - \mathbb{E}\left(\eta\right)^2}}{\mathbb{E}\left(\eta\right)} \tag{11}$$

$$\mathbb{E}\left(\eta\right) = \int_{\Omega_\eta} \eta \cdot p\left(\eta|\mathbf{D}\right) \mathrm{d}\eta$$

$$\mathbb{E}\left(\eta^2\right) = \int_{\Omega_\eta} \eta^2 \cdot p\left(\eta|\mathbf{D}\right) \mathrm{d}\eta$$

As a result, the parameters f_c and COV_{fc} can directly be used as the median and logarithmic standard deviation of an equivalent Lognormal probability density function for the concrete strength.

2.5 Estimating the relative weights associated with each ultrasonic non-destructive test data

In order to have an estimate of the relative weight of the kth ultrasonic test given the measurements of the core test $\mathbf{D}_{\text{core}}$, we start with the probability of observing the kth ultrasonic data given the maximum likelihood estimates of the joint distribution $p(\eta,\beta|\text{D})$ that can be shown as $p(D_{\text{ults},k}|\ \eta_{\text{ML}}=f_c,\ \beta_{\text{ML}})$ (note that we have dropped the conditioning on $\mathbf{D}_{\text{core}}$ since it is already embedded in the estimated maximum likelihood parameters η_{ML} and β_{ML}). With reference to Eq. (8) up to Eq. (10), this probability can be written as:

$$\begin{aligned} & p\left(D_{\text{ults},k} \mid \eta_{\text{ML}}, \beta_{\text{ML}}\right) \\ &= \int_{\Omega f_{\text{core}}} p\left(D_{\text{ults},k} \mid f_{\text{core}}\right) p\left(f_{\text{core}} \mid \eta_{\text{ML}}, \beta_{\text{ML}}\right) \mathrm{d}f_{\text{core}} \\ &= \int_{\Omega f_{\text{core}}} \phi\left(\frac{\ln\left(D_{\text{ults},k} \big/ (a_f\, f_{\text{core}}{}^{b_f})\right)}{\beta_{f_{ultr}|f_{core}}}\right) \phi\left(\frac{\ln\left(f_{\text{core}}/\eta_{\text{ML}}\right)}{\beta_{\text{ML}}}\right) \mathrm{d}f_{\text{core}} \end{aligned} \tag{12}$$

Eq. (12) can be interpreted as the “exact” probability content of $p(D_{\text{ults},k}|\eta_{\text{ML}},\beta_{\text{ML}})$ (in the sense of if one wants to account for the relative measurement error explicitly). Alternatively, this probability content can be approximated as a standard Normal distribution; i.e., $p(D_{\text{ults},k}|\eta_{\text{ML}},\beta_{\text{ML}})= \phi(\ln(D_{\text{ults},k}/\eta_{\text{ML}})/\beta_{\text{ML}})$. In this context, the relative weight of the kth ultrasonic test, w_k, can be interpreted as the adjustment factor that should be multiplied to $\phi(\cdot)$ to have the same probability content as $p(D_{\text{ults},k}|\eta_{\text{ML}},\beta_{\text{ML}})$ in Eq. (12). Thus, By re-arranging Eq. (12), we have:

$$w_k = \frac{\int_{\Omega_{f_{\text{core}}}} \phi\left(\frac{\ln\left(D_{\text{ults},k}/(a_f\, f_{\text{core}}^{\,b_f})\right)}{\beta_{f_{ultr}|f_{core}}}\right)\phi\left(\frac{\ln\left(f_{\text{core}}/\eta_{\text{ML}}\right)}{\beta_{\text{ML}}}\right)\mathrm{d}f_{\text{core}}}{\phi\left(\frac{\ln\left(D_{\text{ults},k}/\eta_{\text{ML}}\right)}{\beta_{\text{ML}}}\right)} \quad (13))$$

3 APPLICATION

3.1 *The Test data*

The database used herein are the destructive and non-destructive tests performed on an existing 4 story (three floors plus one mezzanine) reinforced concrete (RC) school building located in the Avellino (southern Italy). The building was constructed in 1960s and originally was designed only for gravity loads (frequent design-style for the post-second world war constructions in Italy). Fig. 1 shows the core test data $\mathbf{D}_{\text{core}}$ associated with each of the three main floors. Note that the core data, $\mathbf{D}_{\text{core}}$, have already been adjusted based on the Eq. (1).

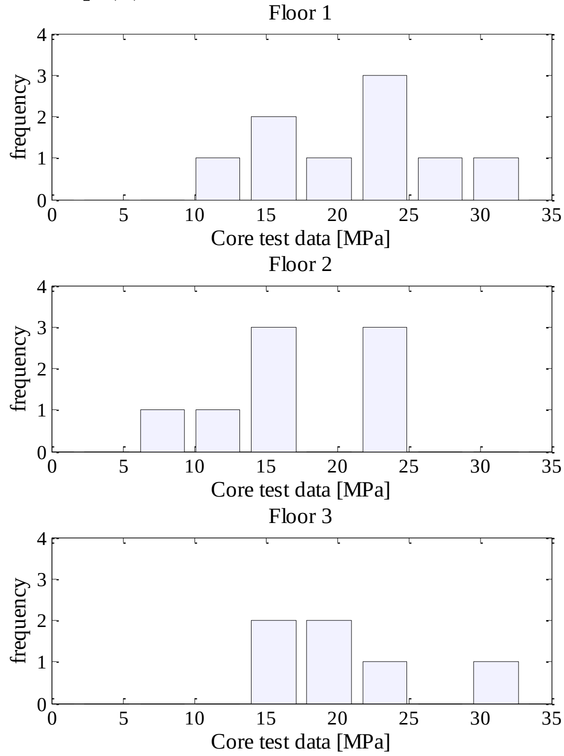

Figure 1: The core test data, $\mathbf{D}_{\text{core}}$, associated with each of the three main floors of the case-study building

Among the 23 core tests performed on the building, the contribution of floors 1 to 3 are 9, 8, and 6 tests, respectively. Fig. (2) illustrates the 63 ultrasonic test results (in terms of velocity, [m/sec]), for which the contribution of floors 1 to 3 are 23, 24, and 16 tests, respectively.

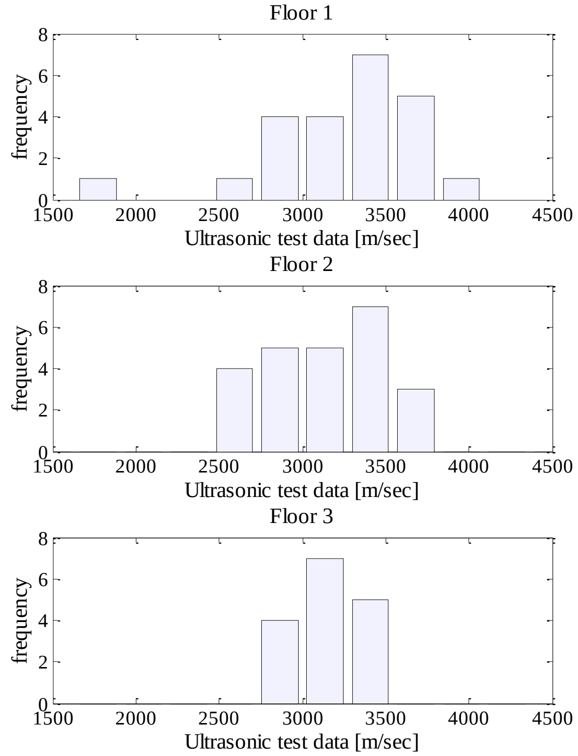

Figure 2: The ultrasonic wave velocity measurements associated with each of the three main floors of the case-study building

3.2 *Estimating a regression-based probabilistic model for predicting f_{core} given V and f_{ultr} given f_{core}*

The direct implementation of the regression-based probabilistic model proposed in Section 2.2 (and Eq. 2) to describe the f_{core} for a given ultrasonic velocity level, V, is shown in Fig. 3. It is to note that N_{cu}=18; that is, the number of cases in which the destructive and non-destructive tests are performed at the same position in the building. The regression parameters derived in Eq. (2) are shown on Fig. (3). According to the results derived through the probabilistic model in Fig. (3), one can directly estimate the distribution of f_{ultr} given a level of f_{core} by employing Eq. (4) in Section 2.3. Fig. (4) shows the regression-based probabilistic model parameters for f_{ultr} given f_{core}.

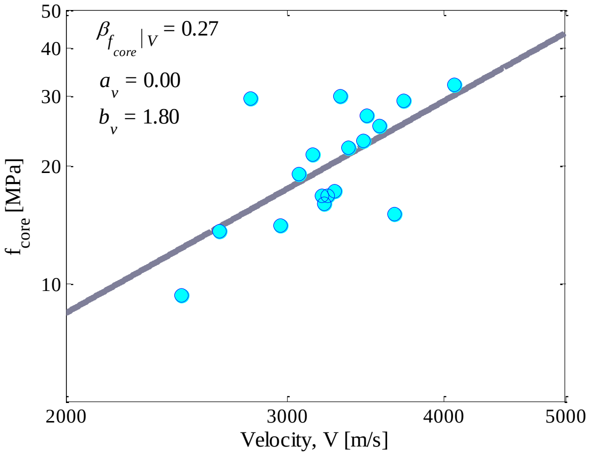

Figure 3: The regression-based probabilistic model (see Section 2.2 and Eq. 2) to describe the f_{core} given ultrasonic velocity V

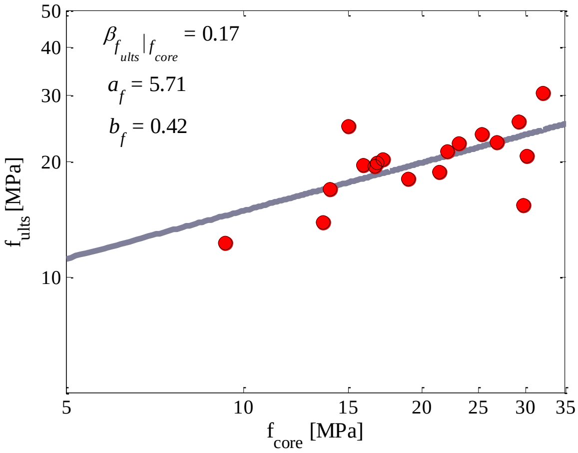

Figure 4: The regression-based probabilistic model (see Section 2.3 and Eq. 4) to describe the f_{ultr} given f_{core}.

3.3 Uncertainty characterization in the concrete strength taking into account both core and ultrasonic test results

Following the Bayesian updating procedure proposed in Section 2.4, the marginal distribution of the median of the concrete strength η, denoted as $p(\eta|\mathbf{D})$, can be calculated directly. The error in both destructive and non-destructive tests are incorporated within this distribution. It can be directly employed for uncertainty propagation within the framework of performance-based design and assessment of structures. Fig. (5) illustrates the posterior distribution of the median of the concrete strength, $p(\eta|\mathbf{D})$, for each of the three floors of the building with thick black line. The prior probability distribution of the median η, denoted as $p(\eta)$ in Eq. (6), is assumed to have the distribution proposed by Verderame et al. (2001a, b), which is based on the typical values of the post-world-war II constructions in Italy. It is a Lognormal distribution with the median equal to 16.5 MPa and a COV equal to 0.15. This prior is shown in Fig. (5) with a thin grey line. Moreover, we have assigned a non-informative prior to $p(\beta)$. Fig. (5) also shows the maximum likelihood estimate of the median η, denoted as f_c in Section 2.4, with red-dotted line. It is directly extracted by marginalizing with respect to β the joint distribution $p(\eta,\beta|\mathbf{D})$. Moreover, the coefficient of variation (COV) of the median η, denoted as COV_{fc}, calculated through Eq. (11) is reported on this figure for each floor.

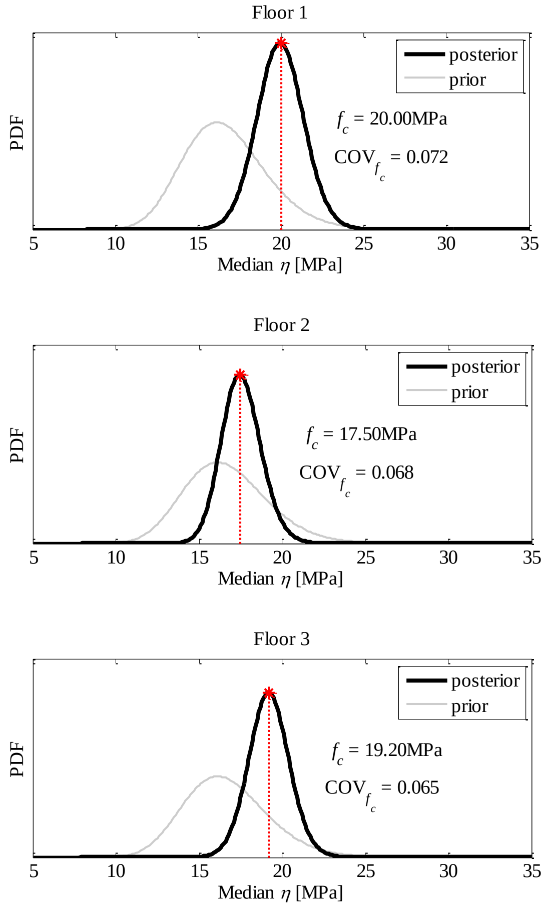

Figure 5: The posterior and prior distribution of the median of the concrete strength for each of the three floors of the building considering both core and ultrasonic test results according to the Bayesian framework proposed in Section 2.4 (note that the value of f_c is the maximum likelihood estimate).

3.4 Estimating the relative weights associated with ultrasonic non-destructive test data

By directly employing Eq. (13), we can have an estimate of the relative weight associated with each ultrasonic test. Fig. (6) shows the distribution of the relative weights of the ultrasonic tests per floor of the case-study building. In order to have an estimate of the final concrete strength obtained through these weights, the statistics of the weights of ultrasonic tests associated with each floor are shown in Fig. 6 as well. The (weighted) mean of the weights of ultrasonic resistance (denotes as E_w) is shown with red-dash-dotted line and calculated as:

$$E_w = \frac{\sum_k w_k \cdot f_{ults,k}}{\sum_k f_{ults,k}} \tag{14}$$

The weighted mean plus/minus weighted one standard deviation ($E_w \pm \sigma_w$) is illustrated with red-dotted line, where σ_w is estimated as follows:

$$E\left(w^2\right) = \frac{\sum_k w_k^{\,2} \cdot f_{ults,k}}{\sum_k f_{ults,k}} \tag{15}$$

$$\sigma_w = \sqrt{E\left(w^2\right) - \left(E_w\right)^2}$$

It is to note that the code-based (NTC 2018) relative target weight of ultrasonic test equal to 1/3 is also shown with a purple-dashed line.

A systematic difference can be detected based on the equivalent weights obtained by employing the fully-probabilistic method and the code-based weight. Table 1 synthesises the final concrete strength obtained through these weights and compare it with the fully probabilistic approach proposed herein. Considering the second row of Table 1 (which is the mean value obtained by Bayesian Updating approach in Eq. 10) as a sort of "*golden truth*", it is revealed that the calculated weights proposed in this study are generally more close to the golden value compared to the code-based approach; the exception proves to be in 2nd floor where the code-based approach is closer to the Bayesian-derived value. The last column shows the strength

Clearly, the influence of a case-specific quantification of the relative weights on the final resistance to be adopted in the analyses needs to be further investigated.

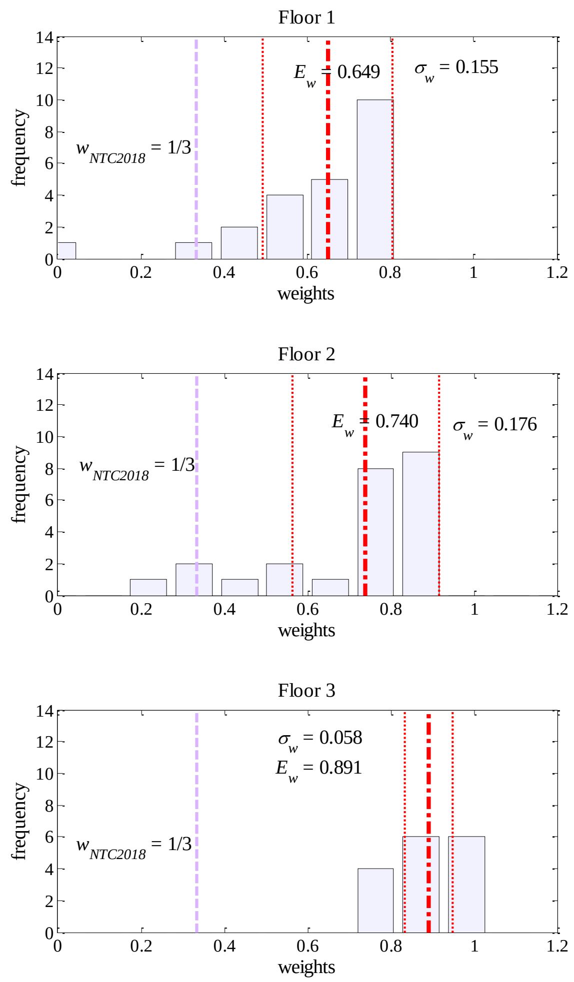

Figure 6: The distribution of the relative weights of the ultrasonic test for each floor of the case-study building based on the proposed method in Section 2.5

Table 1: Concrete strength obtained at the different floors based on different approaches

Method	Floor		
	1	2	3
Mean value using Bayesian updating in Eq. 10 (MPa)	19.98	17.57	19.22
Using weights of this study by Eq. 13 (MPa)	20.52	18.23	19.12
Using the code-based weight 1/3 (MPa)	20.59	18.02	19.54
Using simple averaging (MPa)	20.47	18.30	19.08

CONCLUSIONS

The objective of this work is to derive a methodology to incorporate the relative error of different concrete strength measurements (destructive and non-destructive) within the performance-based seismic assessment framework. A Bayesian updating framework is proposed to account in an integrated manner for core and ultrasonic test measurements. The methodology is described in an step-wise manner in order to be applicable to the destructive and non-destructive tests gathered for a single building or an ensemble of buildings. There are several advantages associated to the proposed method:

- ❖ The proposed framework is capable of taking into account all the test information available including the core and ultrasonic data in order to define the distribution of the concrete strength.
- ❖ It can be directly used for uncertainty propagation purposes within the framework of performance-based design and assessment of the buildings.
- ❖ The probabilistic methodology can also lead to an estimate of the relative weight of each ultrasonic non-destructive test compared to the core test results. These weights are systematically higher than the target code-based (NTC 2018) relative weight of 1/3 recommended for ultrasonic tests.
- ❖ The concrete strength estimated by these relative weights are more close to the values obtained through the fully Bayesian approach as opposed to those estimated by code-based weights.

It should be kept in mind that, for the proposed methodology to work quite properly, we should have a reasonable number of test data for which the destructive and non-destructive tests are performed at the same position.

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