An expert-opinion survey of structural construction details in existing buildings

L. Elefante, F. Jalayer, I. Iervolino, G. Manfredi

Department of Structural Engineering, University of Naples Federico II, Via Claudio 21, 80100 Napoli.

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ABSTRACT

The performance assessment of structures is subjected to various sources of uncertainties. One of the most challenging aspects of the seismic assessment of existing buildings is the characterization of structural modeling uncertainties since it measures the incomplete knowledge of the structural properties in as-built conditions. It is possible to distinguish between two different sources of structural modeling uncertainties in the assessment of existing buildings: uncertainty in the mechanical properties of materials used in construction and the uncertainty in construction details that affect the component capacities. It is important to take into account the uncertainties in the construction details since the variations in structural detailing parameters (a.k.a. *structural defects*) can be quite significant; to the extent that they may change the eventual structural collapse mechanism. The focus of this work is to provide a basis for the characterization of the uncertainties related to the construction details attributed to the as-built conditions of the structure. This is achieved by interpreting and quantifying the common pool of knowledge created by professional experience into prior probability distributions. These prior probability distributions can be used in a Bayesian framework in order to take into account the uncertainties in the construction details before implementing the data provided by the tests and inspections. An expert-opinion survey addressed to practicing engineers has been conducted. The preliminary results obtained by interviewing a group of practicing structural engineers are presented. It is demonstrated how the results of such survey can be processed in order to construct prior probability distributions for selected structural detailing parameters.

1 INTRODUCTION

The seismic performance evaluation of existing buildings is characterized by the large amount of uncertainty in the structural modeling parameters. These modeling uncertainties can be classified into two groups; the uncertainty in the mechanical properties of the construction materials and the uncertainty in the structural detailing or *defects*. The uncertainties in construction details can be mainly attributed to the incomplete knowledge of: (a) the structural original design, and/or (b) the as-built conditions of the structure.

In the structural reliability assessment, the uncertainties are propagated in order to assess the structural performance in terms of the probability of exceeding a specified limit state. The Bayesian framework seems to be particularly suitable for reliability assessment of existing RC structures (Jalayer et al. 2010).

It allows for adaptive updating of both the structural reliability and the uncertainties based on the results of tests and inspections available.

The application of the Bayesian framework for the performance assessment of existing buildings requires the characterization of the uncertainties (including structural modeling uncertainties) by prescribing prior probability distributions, before taking into account the output of the tests and inspections (Jalayer et al. 2011). These prior probability distributions should reflect the amount of information available on the structural modelling parameters. For instance, when little or no information is available, the non-informative prior distributions are employed. Considerable care should be taken when characterizing the prior probability distributions; especially when there is little information available from tests and inspections.

The objective of this work is to provide a basis for the characterization of the uncertainties related to the construction details attributed to the as-built conditions of the structure. The basic idea was to identify and to characterize the most dominant types of construction defects which may be found in the existing RC buildings built after the second world war in Campania, Italy.

A survey for professional engineers was prepared in order to be able to characterize these prior distributions in relation to expert opinion (Elefante, 2009).

Thanks to ReLUIS (Rete Laboratori Universitari di Ingegneria Sismica), the survey was presented on its website and a number of professional engineers answered to the questions. In this work, the preliminary results of the survey are presented and are used in order to.characterize the uncertainties in the structural detailing parameters.

2 THE SURVEY

In order to develop a survey for professional engineers on the uncertainty in structural details, the first step was to identify a set of possible detailing parameters which may affect the structural response. In the next step, a representative quantifiable parameter was assigned to each structural detailing parameter.

For each detailing parameter, a query related to its relevancy in the professional practice was introduced in the survey. Moreover, to each structural detailing parameter, a set of various plausible values were assigned. Compiling the survey, the professional engineer indicates the most plausible value of the detailing parameter, based on his/her professional experience. Moreover, for each type of detailing uncertainty, a query is added in order to inquire about possible correlations within the structure. Three different limiting possibilities are considered: (a) systematic within the building; (b) systematic within the construction zone (e.g., floor); and (c) uncorrelated with other elements.

The survey consists of 34 questions divided in seven different categories. Each category regards a specific structural detailing parameter:

1. Concrete cover
2. Anchorage
3. Stirrups
4. Reinforcing bars
5. Overlap length
6. Reinforcement position
7. Geometric dimensions of structural elements

The survey has been complied anonymously; however, two queries are included in order to have some information about the engineer's professional experience. First, the engineer is asked to indicate the reference province in which she/he operates. The engineer is then asked to provide the number of RC structures that she/he has designed, supervisioned and/or assessed before and after the year 1976. The choice of 1976 as reference year is because the first Italian code with the national seismic zonation dates back to 1976. This additional information could be used in more advanced implementations in order to weight the results of each compiled survey in relation to the professional experience of the surveyee. The results presented in this paper are based on the modules compiled by 72 professional engineers.

3 METHODOLOGY

The Bayesian updating framework is used in order to characterize the result of the survey in terms of probability distributions. These probability distributions can be later employed in a fully-probabilistic methodology for assessing the structural performance of an existing building taking into account the uncertainties in structural construction details.

In this context, the information provided by the survey is going to be treated as data denoted generically by D. Moreover, it is assumed that the pre-survey information is limited to knowledge of the intervals in which the detailing parameters' value is going to vary. In other words, departing from uniform prior probability distributions, the Bayesian inference is adopted in order to update the prior distributions based on the information provided by expert judgment.

Following the Bayes theorem, the updated probability distribution (or posterior distribution) can be expressed as:

$$f\left(p|D\right)=c^{-1}f\left(D|p\right)\cdot f\left(p\right) \tag{1}$$

where p is the structural detailing parameter in question, $f(p)$ is the prior probability distribution for p, D represents the survey results related to parameter p, $f(D|p)$ is the likelihood function and c is a normalization constant. In the next section, it is described in detail how the likelihood function is calculated for different structural detailing categories.

3.1 *Processing the queries with a simple YES/NO answer*

As mentioned in the previous section, for certain types of construction defects a query has been provided in order to inquire about its relevancy with a simple yes/no answer. This information can be used in order to construct a probability distribution for the frequency of encountering the specific construction defect in practice. The Bayesian formula in Equation 1 has been used in order to obtain such probability distribution as a posterior probability distribution. The Binomial distribution is then used in order to calculate the likelihood function based on the data (i.e., the number of k positive answers in a total of n surveys compiled):

$$f(D|p) = \binom{n}{k} p^k (1-p)^{n-k} \tag{2}$$

where p is the probability that the considered defect is encountered in practice, n is the number of professional engineers that answered to the question and k is the number of positive answers (yes). Assuming that no information is available about the probability of encountering a defect p, a uniform priori distribution is used in order to construct $f(p)$. Substituting the likelihood function in Equation 2 and the uniform prior distribution in Equation 1, the (updated) probability distribution for the probability of encountering a particular defect denoted by $f(p)$is obtained. It should be noted that probability of encountering the defect can be estimated as the expected value or the maximum likelihood value of the updated probability distribution.

3.2 *Processing the queries related to the frequency of encountering a defect*

For certain types of construction defects, a query is provided which inquires about the frequency with which the engineer has encountered (or expects to encounter) the proposed structural defect in practice. The generic form of the question is *"Among N inspection how many times do you expect to find the proposed defect?*", where a few options are proposed as possible answers. The likelihood function is calculated, based on the information provided by the survey, as the product of binomial probability distributions measuring the probability of encountering k_i times the specific defect out of N inspections based on the experience of i^{th} engineer:

$$P(D|p) = \prod_{i=1}^{n} \binom{N}{k_i} p^{k_i} (1-p)^{N-k_i} \tag{3}$$

where p is the probability of encountering the defect and n is the number of professional engineers that answered to the query. Similar to previous section, the prior probability distribution for p denoted by $f(p)$ is a uniform distribution, assuming that no information (besides the fact that it varies between 0 and 1) was available about p before conducting the survey. The proposed value for the frequency/probability of encountering the defect can be estimated as the expected value or the maximum likelihood value for the updated probability distribution for p calculated from Equation 1 after substituting the likelihood function from Equation 3 and uniform prior $f(p)$.

3.3 *Processing the queries related to the value of the structural detailing (defect) parameter*

For certain types of construction defects, multi-optional queries are provided which directly inquire about the numerical value of the structural detailing parameter. In such cases, the probability theory is used in order to obtain the probability distributions of the median η_p and fractional standard deviation σ_p (i.e., standard deviation of the logarithm) of the defect parameter based on the survey data D. Survey data D is consisted of the numerical values indicated by each engineer who compiles the survey. The expected values of η_p and σ_p can be evaluated as

$$E(\eta_p|D) = \int_\eta \eta_p \int_\sigma P(\eta_p, \sigma_p|D) \cdot d\sigma \cdot d\eta \tag{4}$$

$$E(\sigma_p|D) = \int_\sigma \sigma_p \int_\eta P(\eta_p, \sigma_p|D) \cdot d\eta \cdot d\sigma \tag{5}$$

where $P(\eta_p,\sigma_p|D)$ is the posterior joint probability distribution for median and standard deviation based on data D. Similar to previous sections, $P(\eta_p,\sigma_p|D)$ is calculated using the Bayesian approach outlined in Equation 1 and has the analytical form of a multi-variable Normal distribution (Box and Tiao, 1992):

$$P(\log(\eta_p), \sigma_p|D) = k\sigma_p^{-(n+1)} \exp\left(\frac{\nu s^2 + n\left(\log\eta_p - \overline{\log D}\right)^2}{-2\sigma_p^2} \right)$$

$$k = \sqrt{\frac{n}{2\pi}} \left(\frac{\Gamma(\nu/2)}{2} \right)^{-1} \left(\frac{\nu s^2}{2} \right)^{\nu/2} \tag{6}$$

where n is the number of engineers that answered to the question, k is a normalizing constant, $\Gamma(\cdot)$ is the gamma function, $\nu=n-1$, $\overline{\log D}$ is the sample mean value for $\log D$ and νs^2 is sum of the squares of the deviations from the sample mean value.

4 RESULTS

In this section selected results of the survey for professional engineers are presented. Moreover, it is demonstrated how the results are post-processed by employing the Bayesian methodology discussed in the previous section.

It should be noted that, due to space limitations, only some significative implementations and results of the conducted survey are presented in this paper. The results are grouped based on the type of construction defect.

4.1 Concrete cover

In order to investigate on the construction defects related to the concrete cover, the following query has been included in the survey:

- *If the original documents indicate a value of the concrete cover δ* (Figure 1) *equal, to cm 3, what is the concrete cover that you expect to find in the existing structure?*

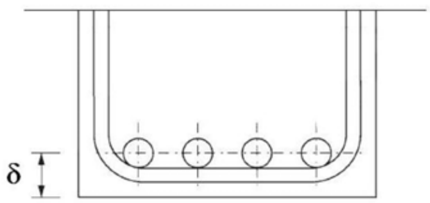

Figure 1. Schematic figure illustrating the concrete cover

Figure 2 illustrates the histogram of the query results.

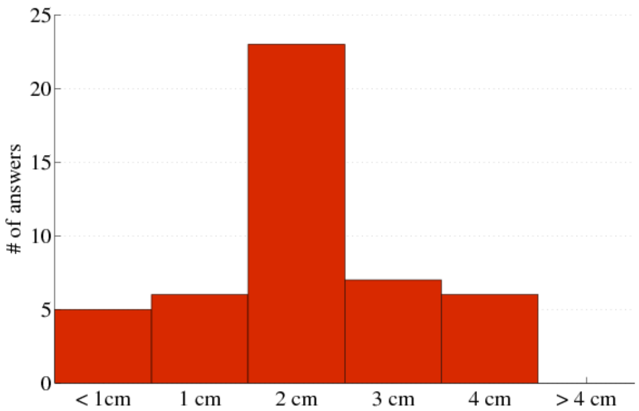

Figure 2. Histogram of the survey results on concrete cover

This data is post-processed using the procedure described in Section 3.3 in order to obtain the joint probability distribution for the median and fractional standard deviation of the concrete cover. Figure 3 illustrates the contours of the resulting joint probability distribution in Equation 6. The expected values for the median and the fractional standard deviation calculated from Equations 4 and 5, respectively, are also reported on the figure.

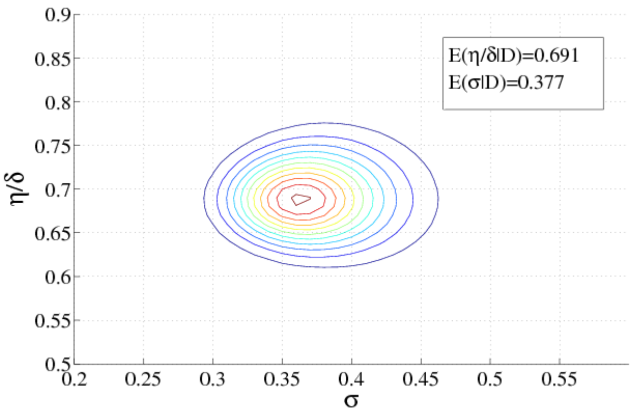

Figure 3. Contours of the joint multi-variate Normal probability distribution for (normalized) median and fractional standard deviation of concrete cover

It should be noted that the median value (η/δ) reported on the Y axis in Figure 3 is normalized with respect to the nominal value of concrete cover indicated in the query (i.e., 3 cm)..Thus, the survey results indicate that around 50% of the surveyees expect to find a concrete cover that is less than around 2.10 cm (i.e., 70% of the nominal value of 3cm). It should be noted that the reported best-estimate values for median and fractional standard deviation of the concrete cover can be potentially employed in a fully probabilistic approach to performance assessment of existing structures. In such an approach the median and standard deviation of the concrete cover can be used for building a prior probability distribution for concrete cover (e.g., a lognormal probability distribution) before implementing the results of in-situ tests and inspections.

Moreover, the survey includes a query that aims to collect consensus on the systematic nature of construction defect related to concrete cover.

- *Do you believe that the concrete cover would be equal throughout the entire structure or its evaluation should be repeated for different areas within the building (e.g., those made with the same cast of concrete) or for each single structural component?*

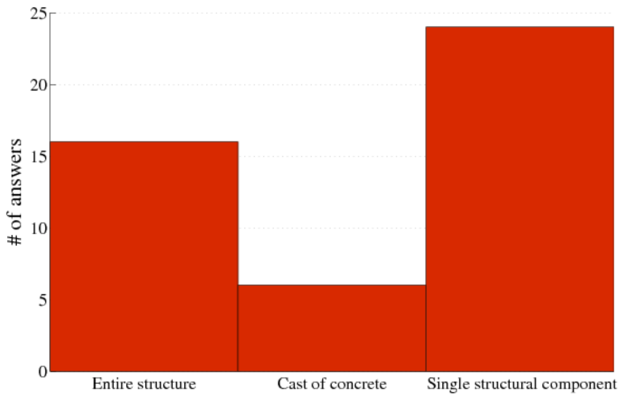

Figure 4. Histogram of the answers on the systematic nature of the value of cover concrete.

The survey results are reported in Figure 4. It can be observed that most of the surveyees believe that the concrete cover may vary from one structural component to another. It should be emphasized that in order to draw meaningful conclusions from this query one should conduct the survey on a larger population.

4.2 Anchorage

The use of hooks for anchoring the ends of reinforcing bars is common in existing RC buildings built after the second world war. The effectiveness of such anchorage system depends to a large extent on the angle of the hook.

In order to investigate on the construction defect related to the use of hooks as anchorage, the following query has been included in the survey:

- *Suppose that the original documents indicate the use of hooks as anchorage. Among 100 hooks, how many of them are bent properly? That is, how many of them are bent with an angle γ larger than 150 °* (Figure 5, A) *?*

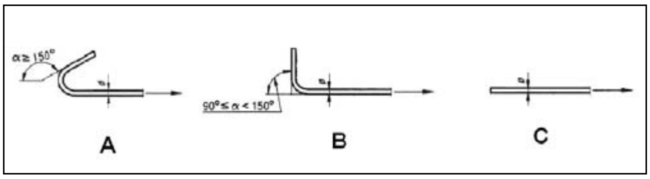

Figure 5. Illustrative figure included in the survey for anchorage quality.

Figure 6 illustrates the histogram of the surveyees answers to the query.

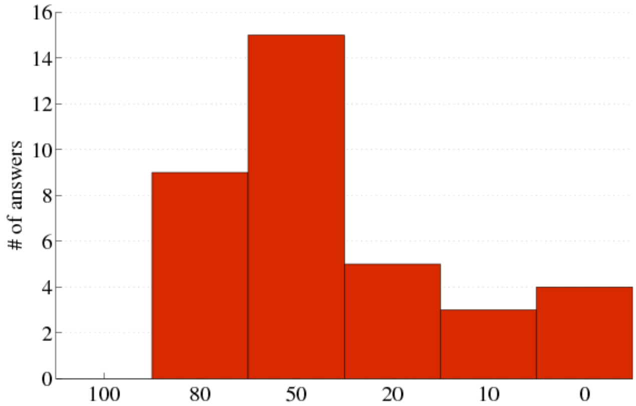

Figure 6. Histogram of the surveyee answers on the frequency of finding properly-bent anchorage hooks

This information is post-processed by employing the procedure described in Section 3.2 in order to find the probability distribution for the percentage of the hooks that are bent properly. In this procedure, the likelihood of obtaining the survey results reported in Figure 6 is calculated as the product of a sequence of binomial probability distributions (one for each surveyee) from Equation 3. The probability distribution for the percentage/probability of having a properly-bent anchorage hook is then calculated from Equation 1 employing the likelihood function and a uniform prior distribution.

Figure 7 illustrates the prior uniform probability distribution (continuous line) and the posterior probability distribution obtained by implementing the survey results (dashed line).

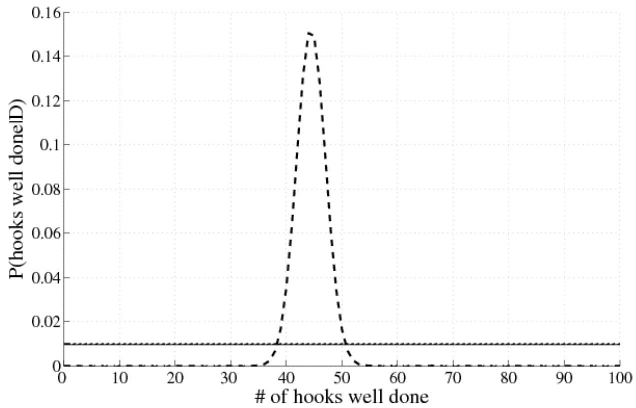

Figure 7. Prior and posterior probability distribution for the percentage/probability of finding hooks that are bent properly

The figure indicates that the surveyees expect to find about 45% of hooks properly bent. This information can also be interpreted in probabilistic terms, that is, the survey results indicate that on average with 45% probability the hooks used in an existing building are properly bent.

The next query investigates further the theme of hook anchorage:

– *Among ten hooks that are not properly bent, how many are bent with an angle γ between 90° and 150°* (Figure 5, B)*?*

In this case, the objective is to evaluate the probability that the hook is bent with an angle γ between 90° and 150° given the information that the hook is not well done (not closed with an angle larger than 150°).

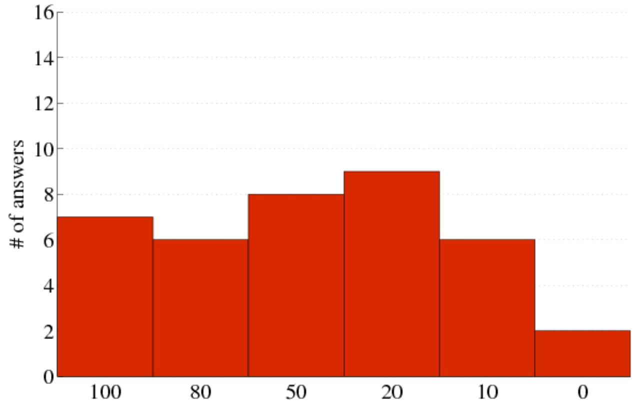

Figure 8. Histogram of the surveyee answers on the percentage of hooks with $90° \leq \gamma < 150°$, given $\gamma < 150°$ (not properly bent).

Figure 8 illustrates the histogram of the surveyee answers to the query. Using probability theory one can expand the probability that the hooks are bent with an angle $90° \leq \gamma < 150°$ and denoted by $P(90° \leq \gamma < 150° | D)$ as following:

$$P(90° \leq \gamma < 150° | D) = P(90° \leq \gamma < 150° | D, \gamma < 150°) \cdot P(\gamma < 150° | D) \qquad (7)$$

Where D denotes the data provided by the survey answers. Thus, implementing the same Bayesian procedure employed in the previous query and described in Section 3.2, the probability that the hooks are bent with $90° \leq \gamma < 150°$ given that they are not bent properly ($\gamma < 150°$) and denoted by $P(90° \leq \gamma < 150° | D, \gamma < 150)$ can be calculated. The probability that the hooks are not bent properly denoted by $P(\gamma < 150° | D)$ is calculated as $1 - P(\gamma \geq 150° | D)$, being the two condition mutually exclusive. $P(\gamma \geq 150° | D)$ or the probability that the hooks are bent properly is the value estimated by processing the previous query (i.e., 45%) .

Figure 9 illustrates the prior uniform probability distribution (continuous line) $P(90° \leq \gamma < 150° | \gamma < 150)$ and the posterior probability distribution $P(90° \leq \gamma < 150° | D, \gamma < 150)$ obtained as mentioned above (dashed line).

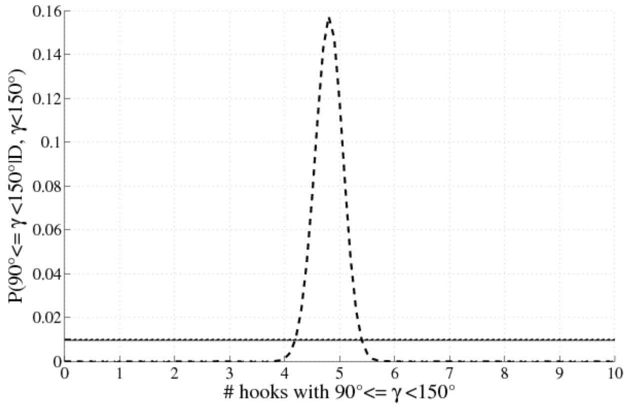

Figure 9. Prior and posterior probability distribution for the number of hooks (out of a total of ten) bent with an angle γ between 90° and 150° given the hook is not bent properly.

Based on the posterior probability distribution in Figure 9, the best estimate for $P(90° \leq \gamma < 150° | D, \gamma < 150)$ is taken as the maximum likelihood estimate; that is around 50% (5 out of 10). Finally the probability $P(90° \leq \gamma < 150° | D)$ that the hooks are bent with an angle $90° \leq \gamma < 150°$ can be calculated from Equation 7 as 0.50(1-0.45)=0.2750. This means that, the surveyees evaluate that with around 28% probability the hooks are bent with an angle between $90° \leq \gamma < 150°$. This also means that the probability that the hooks are done with an angle less than 90° is estimated to be equal to (1-0.50)(1-0.45)=0.275.

The next query inquires about the systematic nature of the construction defect related to the hook anchorage quality.

– *Do you believe that the hook anchorage quality is homogenous throughout the entire structure, to a single cast of concrete or to each single structural component?*

The histogram in Figure 10 illustrates the results of this query. In this case, the majority of surveyees is of the opinion that the uncertainty related to the hook closure is systematic for the entire structure.

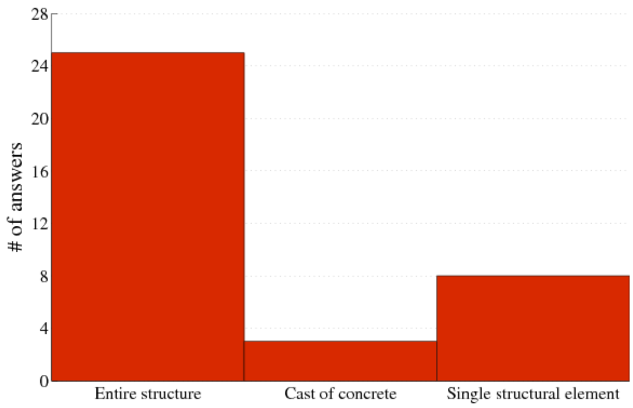

Figure 10. Histogram of the surveyee answers on the systematic nature of the hook closure.

The next query on the quality of rebar anchorage is related to the anchorage length.

– *In the original documents an anchorage length of L=25cm is indicated. What is the value of the anchorage length you expect to find in the existing structure?*

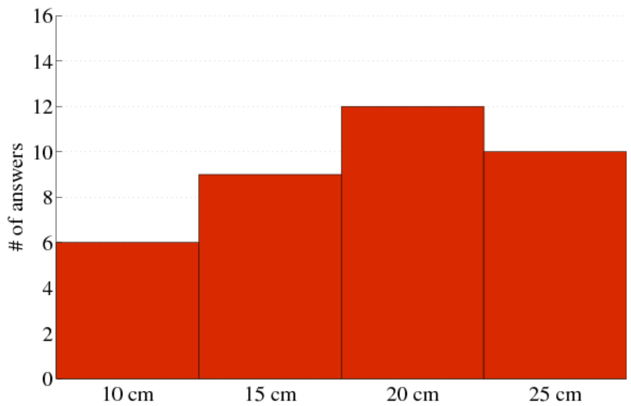

Figure 11. Histogram of the surveyee answers on the anchorage length.

Four different options were proposed as the answer, each indicating a value of the anchorage length less or at least equal to L=25 cm. Figure 11 shows the histogram of the surveyee answers to the query.

The survey data is post-processed by following the Bayesian procedure described in Section 3.3 in order to calculate the joint probability distribution (Equation 6) for the (normalized) median denoted by (η/L) and the fractional standard deviation σ of the anchorage length. Figure 12 illustrates the contours of the joint distribution. The expected values for the normalized median and the fractional standard deviation are calculated from Equation 4 and 5 respectively and reported on the figure.

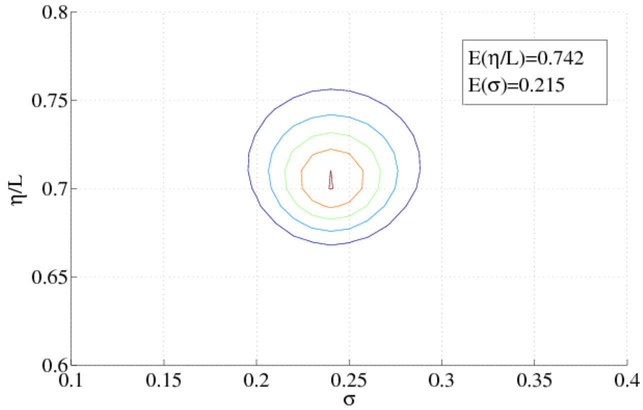

Figure 12. Contours of the joint probability distribution for normalized median and fractional standard deviation of the anchorage length

The best estimate value for the normalized median can be taken as the expected value of the posterior distribution illustrated in Figure 12, that is, E(η/L)=0.742. This can be interpreted in the following manner: around 50% of the surveyees expect to find anchorage length less than around 18.50 cm (i.e., 74% of the nominal value of 25cm). As mentioned before for the case of concrete cover, the best-estimate values for (normalized) median and fractional standard deviation of the anchorage length can be employed in order to construct a prior probability distribution for anchorage length.

The next query on this theme explores the systematic nature of the defect related to anchorage length. The results are reported in Figure 13.

– *Do you believe that the anchorage length is homogenous throughout the entire structure or the evaluation should be repeated for different areas of the building (e.g., those made with the same cast of concrete) or for each single structural component?*

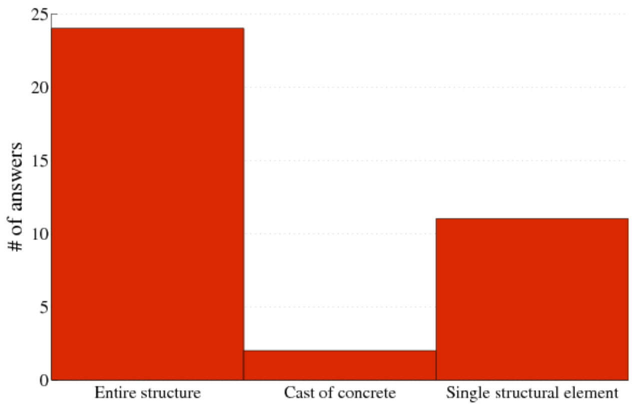

Figure 13. Histogram of the surveyee answers on the systematic nature of the anchorage length.

Also in this case the majority of the surveyees believe that the anchorage length is homogenous throughout the entire structure.

4.3 Stirrups

In the conducted survey, particular attention has been given to the stirrups and the possible structural defects related to them. In fact, ten queries were included in the survey related to this theme.

Existing RC buildings, in particular those constructed after the second world war, often present a construction defect related to inadequate stirrup spacing which poses a serious problem in terms of component shear capacity. Moreover, a significant percentage of the stirrups placed in these buildings might not be properly tied and therefore could result ineffective.

The following survey query regards the construction defect related to stirrup tie.

- *Among 100 stirrups inspected in an existing RC structure, how many, in your experience, have not been tied properly?* (Figure 14)

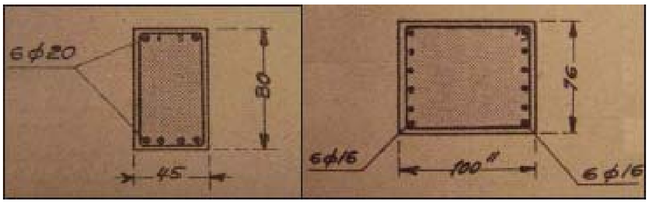

Figure 14. Illustrative figure included in the survey for stirrup tie (Santarella, 1926).

Figure 15 illustrates the histogram of the surveyee answers to the query.

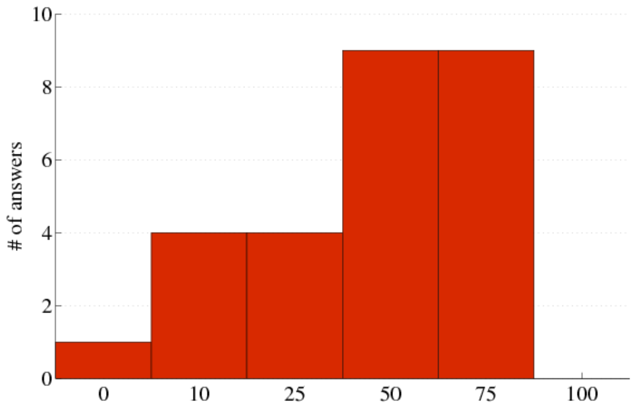

Figure 15. Histogram of the survey results on the percentage of stirrups not tied properly.

The survey results are post-processed by employing the procedure described in Section 3.2 in order to find the probability distribution for the percentage of the stirrups that are not tied properly. In this procedure, similar to the quality of hook anchorage, the likelihood of obtaining the survey results reported in Figure 15 is calculated as the product of a sequence of binomial probability distributions from Equation 3. The probability distribution for the percentage/probability of stirrups not tied properly is then calculated from Equation 1 employing the likelihood function and a uniform prior distribution.

Figure 16 illustrates the prior uniform probability distribution (continuous line) and the posterior probability distribution obtained by implementing the survey results (dashed line).

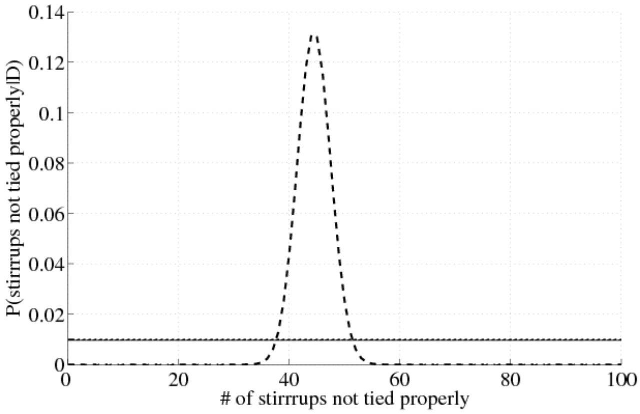

Figure 16. Prior and posterior probability distribution of stirrups not tied properly.

This means that in an existing RC building, the surveyees expect to find about 45% of stirrups not tied properly. In other words, they estimate the probability that the stirrups are not tied properly to be around 45%.

In order to investigate about stirrup spacing, the following query was included in the survey.

- *It is indicated, in the original documents for an existing structure, that in a beam of length equal to 4 m a number of stirrups* (N) *equal to 26 have been installed. In your experience, how many stirrups are actually present in this beam?*

Six options were proposed as potentials answers to the surveyees.

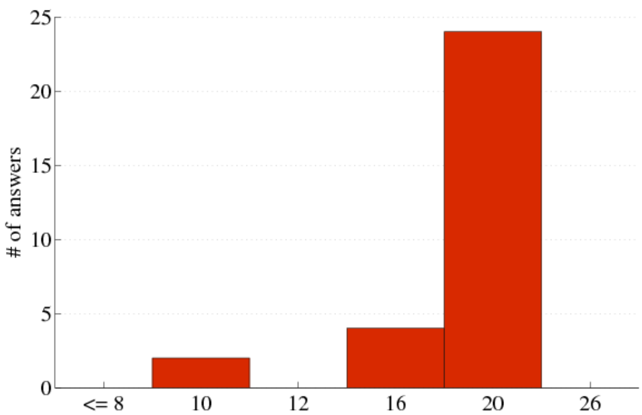

Figure 17. Histogram of the answers on the number of stirrups actually present in the considered beam.

Figure 17 illustrates the histogram of the answers to this query.

The survey data is post-processed by following the Bayesian procedure described in Section 3.3 in order to calculate the joint distribution (Equation 6) for the (normalized) median denoted by (η/N) and the fractional standard deviation σ of the number of stirrups. Figure 18 illustrates the contours of the joint distribution. The expected values for the normalized median and the fractional standard deviation are calculated from Equation 4 and 5 respectively and reported on the figure.

Figure 18 illustrates the contours of the resulting joint Normal distribution and the expected values for the normalized median and the fractional standard deviation. Considering a constant stirrups spacing in the beam indicated in the question, the nominal number of N=26 stirrups corresponds to a stirrup spacing equal to 16 cm.

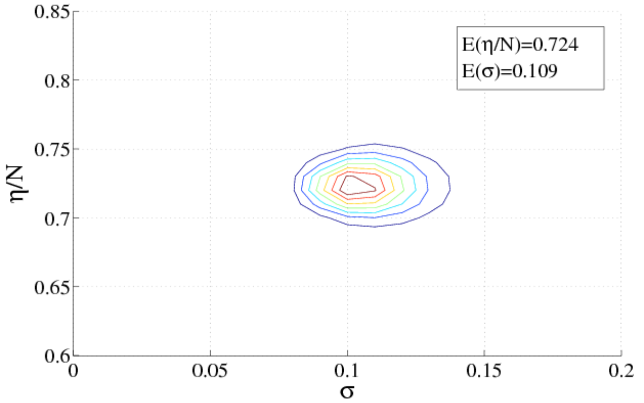

Figure 18. Contours of the joint probability distribution for normalized median and (fractional) standard deviation of the number of stirrups actually present in the beam

The expected value for the normalized median of the number of stirrups number is equal to %72 of the nominal value, that is, about 19 stirrups. This corresponds to stirrup spacing approximately equal to 21 cm. The reported best-estimates for normalized median and fractional standard deviation might be used in the context of a fully probabilistic approach for building a prior (e.g., Lognormal) probability distribution for the number of stirrups present in the beam.

The next query evaluates the hypothesis of constant stirrup spacing in the considered beam:

- *With reference to the previous question, do you expect to find the stirrups placed with constant spacing?*

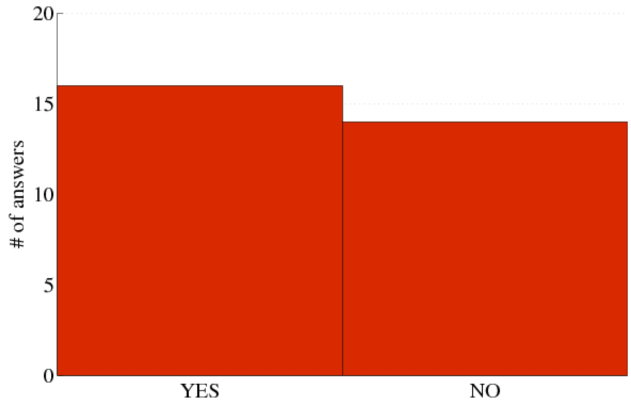

Figure 19. Histogram of the surveyee answers on constant stirrup spacing.

The response to this query consists of a simple YES/NO answer, the results are illustrated in Figure 19. It can be observed that the obtained results are not particularly in favour of either YES or NO. However, the survey data are used in order to calculate the distribution for the probability (percentage) of finding stirrups arranged with constant spacing in a given beam in an existing building. The procedure described in Section 3.1 is used in order to calculate the likelihood function for the survey results illustrated in Figure 19 as a Binomial distribution from Equation 2. Assuming a uniform prior distribution, the Bayesian formula in Equation 1 is then used to calculate the posterior probability of observing constant stirrup spacing based on the survey results. Figure 20 illustrates the posterior probability distribution obtained based on the survey results (dashed line).

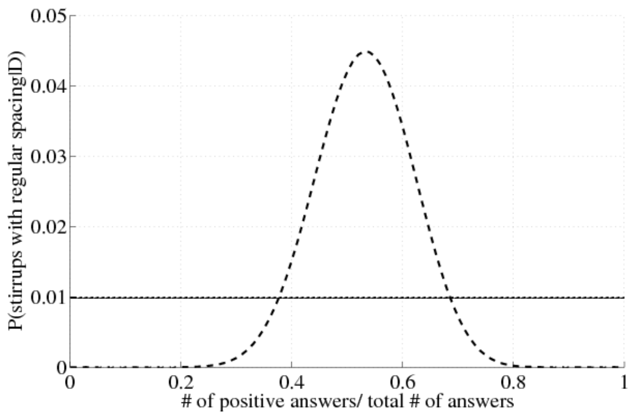

Figure 20. Prior and posterior probability distributions of observing constant stirrup spacing in a beam in an existing building

Taking the maximum likelihood estimate as the best-estimate value, it can be observed from Figure 20 that around 55% of the surveyees expect to find beam stirrups arranged with constant spacing. Note that the wide dispersion observed in the posterior probability distribution in Figure 20 reflects the significant dispersion in estimating the probability of finding constant stirrup spacing. Also in this case, increasing the population of surveyees will be quite helpful in obtaining more meaningful results.

Two additional queries were included on the subject of stirrup spacing, considering the same structural element of the previous questions (a beam 4 m long with 26 stirrups) but focusing on support areas and beam span.

– *The original documents indicate that in a beam of length equal to 4m 26 stirrups have been installed. How many stirrups do you expect to find in 50 cm of the beam near the supports?*

Figure 21 illustrates the histogram of the answers to the query.

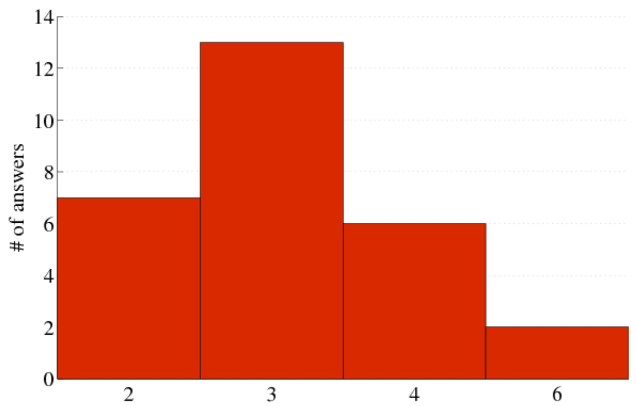

Figure 21. Histogram of the answers on the number of stirrups near the beam support.

If the stirrup spacing in the beam is constant, it is expected to find 4 stirrups (n=4) in a length of 50 cm. Therefore, the query results have been normalized to n=4. Using the procedure described in Section 3.3, the joint probability distribution of normalized median (η/n) and fractional standard deviation σ of the number of stirrups near the beam support is obtained. Figure 22 illustrates the contours of the joint distribution and the expected values for the normalized median and the fractional standard deviation.

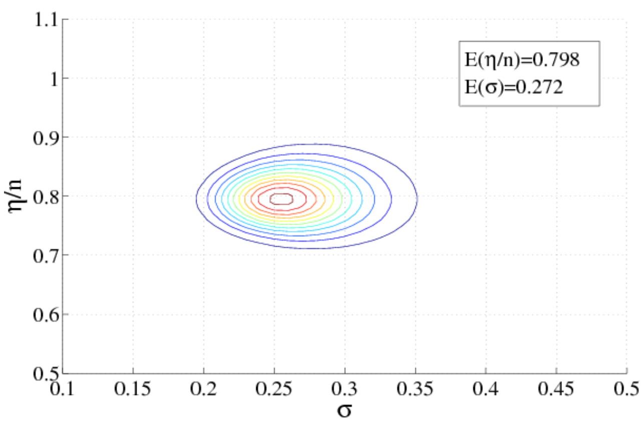

Figure 22. Contours of the joint probability distribution of mean and standard deviation for the value of stirrup spacing near beam support

The expected value for the joint probability distribution plotted in Figure 22 is adopted as the best-estimate for the median number of stirrups near the support. Therefore, it can be concluded that 50% of the surveyees expect to find less than 3 stirrups (80% of the nominal value, corresponding to a value of stirrup spacing approximately equal to 16 cm) in the 50 cm support area.

The second part to this query focuses on the stirrup spacing in the span area:

– *and how many stirrups in a meter of beam span?*

Figure 23 illustrates the histogram of the answers to the query. The query results are processed in the same manner described for the first part of the query above in order to obtain the joint probability distribution for the normalized median and the fractional standard deviation of the number of stirrups in the beam span.

In this case, if the stirrup spacing in the beam is assumed to be constant, in a span length of 1 m it is expected to find 7 stirrups (m=7). Hence, the query results have been normalized to this number.

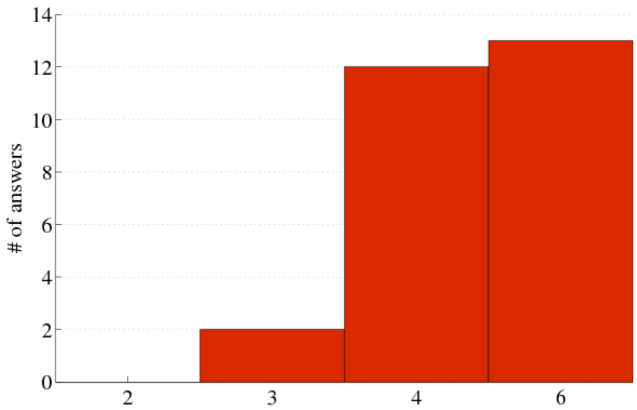

Figure 23. Histogram of the survey results on the number of stirrups in the beam span.

Figure 24 illustrates the contours of the obtained joint distribution and the expected values for the normalized median (η/m) and the fractional standard deviation σ.

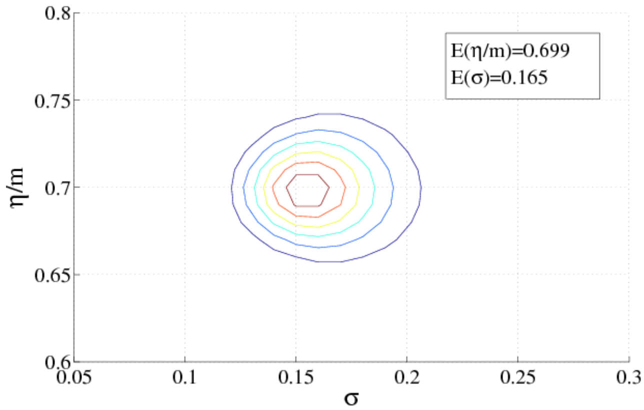

Figure 24. Contours of the joint probability distribution for normalized median and fractional standard deviation for the number of stirrups in the beam span

Interpreting the results reported in Figure 24 in the same manner as the first part of the query, it can be inferred that 50% of the surveyees expect to find less than 5 stirrups (70% of m=7, corresponding to a stirrup spacing around 20 cm) in one meter of the beam span (away from the supports).

5 CONCLUSIONS

The characterization of structural modeling uncertainties, which affect mechanical properties of building materials and construction details, is one of the most challenging aspects of the seismic assessment of existing buildings.

The focus of this work is to provide a basis for the characterization of the uncertainties related to the construction details attributed to the as-built conditions of the structure. This is achieved by interpreting and quantifying the results of a survey for professional engineers into parameters for prior probability distributions.

The paper presents a selection of the survey results for some significant categories of structural construction detailing parameters referred to as the construction *defects*. In particular, construction defects related to concrete cover, reinforcement anchorage and stirrups have been presented.

For each type of the construction defect considered, the results of the survey are processed using a Bayesian methodology in order to make a probabilistic estimation of the parameters characterizing the defect. These parameters could eventually be used in order to construct prior probability distributions (prior to in-situ tests and inspections) for representing the uncertainties in the structural modeling. The prior probability distributions are of fundamental importance when Bayesian methods are used in order to make probabilistic performance-based assessment of buildings.

It should be emphasized that this work presents the preliminary survey results. In order to be in the position of drawing more general conclusions from the survey results, it is essential that the survey be conducted by a large number of professional engineers. These preliminary results are going to be employed in refining the queries and facilitating the compiling process. In particular, the survey queries are going to be categorized in terms of the year of the construction of the existing building having in mind the evolution of Italian Code. It is clear that a survey on expert opinion would benefit immensely from the expert opinion of the researchers on improving its quality and broadening the scope of its application.

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