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Using Markov Chain Monte Carlo Simulation for Robust Reliability Assessment of Existing Structures Based on the Inspection Results

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ABSTRACT

Determining the material properties and structural detailing in existing structures is subject to a significant level of uncertainty. Therefore, instead of a unique structural model, a set of plausible structural models can be identified. A robust assessment of structural reliability takes into account a whole set of possible structural models that are weighted by their corresponding plausibility. Moreover, performing in-situ tests and inspections can improve the state of knowledge about the structure. A bayesian updating framework can be implemented in order to update both the structural modeling properties and the reliability based on test results (Beck and Katafigiotis, 1998).

The present study is aiming at addressing the issue of modeling uncertainty in existing structures, in the context of the European and Italian seismic guidelines (e.g., reference number 4). These guidelines synthesize the effect of modeling uncertainties in the so-called confidence factors which are applied to the mean material properties. Evaluation of these confidence factors is rather qualitative and depends on the acquired level of knowledge about the structure. These guidelines define three increasing levels of knowledge, for each of which, they prescribe a certain set of verifying tests and inspections to be performed. The objective of the present study is to take into account the structural modeling uncertainties in a Bayesian framework where the results of tests and inspections can be implemented in order to update the structural modeling parameters' probability distribution and to calculate the robust reliability.

Methodology: Let D denote some test data and consider that the set of possible structural models can be defined by M. The plausibility of a model is quantified by a probability distribution over the model parameters $\theta = [\theta_1, \theta_2, ..., \theta_n]$ that define a model within the set of possible models. The updated probability distribution can be defined using the Bayes Theorem:

$$p_D(\theta) = p(\theta|D, M) = \frac{p(D|\theta, M)p(\theta|M)}{p(D|M)} \tag{1}$$

where $p(\theta|M)$ is the prior probability distribution for θ specified by M and $p(D|M)$ is the probability distribution for data D specified by M. Updated response predictions can be made implementing data D through $p_D(\theta)$ given by Equation 1. For example, if the probability of a failure event F based on

modeling parameters θ is denoted by $P(F|\theta, M)$, the robust failure probability can be calculated from the following:

$$P(F|D,M) = \int P(F|\theta, M)p(\theta|D,M)d\theta \quad (2)$$

where $P(F|\theta, M)$, the failure probability for the structural model defined by θ can be calculated as (Au and Beck 2001):

$$P(F|\theta, M) = \int I_{F|\theta,M}(\theta')p(\theta'|\theta, M)d\theta' \quad (3)$$

where θ' is the set of uncertain parameters and $I_{F|\theta,M}$ is the failure index function that is equal to one in the event of failure and equal to zero otherwise.

In this work, the failure event F is defined as when structural demand exceeds structural capacity. Structural capacity is obtained using the pushover analysis as the global displacement at which the first element is in crisis (3/4th of the ultimate chord rotation in the member). The structural demand is defined as the global displacement corresponding to the intersection of the capacity curve of the equivalent SDOF system and the corresponding code-based seismic response spectra for the seismicity and the soil characteristics at the site of the project (a.k.a, capacity spectrum method, Fajfar, 1999). The failure probability $P(F|\theta, M)$ for a given structural model is calculated using the subset simulation method (Au and Beck 2001). The robust failure probability is then calculated using the Markov Chain Monte Carlo (MCMC) algorithm for generating samples from $p_D(\theta)$ (Beck and Au, 2002). The acquired data can be introduced in the form of an embedded sequence of data denoted by $D_1 \subset D_2 \subset ... \subset D_n$. In this case, the MCMC algorithm can be used to generate samples from the updated PDF's $p_i = p_{D_i}(\theta)$ according to the Bayes' theorem.

Numerical Example: The three-dimensional finite element model of an existing school built in the 1960's in Avellino Italy has been developed. The non-linear behavior in the structure is considered by employing the concentrated plasticity concept. The prior probability distribution model for the uncertain parameters is constructed based on the state of knowledge about the building before in-situ inspections and tests are conducted. The sources of uncertainty are considered to be related to structural material properties and concrete rebar detailing. The test results available for the building consist of (non-destructive) ultrasonic results and (destructive) carote tests for determining the concrete resistance. The results of the tests are used in two levels in order to update the probability distribution for concrete resistance at different storeys in the structure and to calculate the robust reliability.

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