Computation of Seismic Fragility Curves Using Artificial Neural Network Metamodels

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Abstract:

In seismic probabilistic risk assessment, fragility curves are used to evaluate the risk of failure of civil structures under seismic excitations. The fragility curve is defined as the conditional probability of failure of a structure, or its critical components, for given values of earthquake intensity measures (IM), such as the peak ground acceleration (PGA). For simulation-based fragility curve estimation methods, the conditional probability of failure for an intensity measure level α is usually computed assuming a lognormal distribution [6]:

$$P_f(\alpha) = \Phi(\frac{\ln \alpha - \ln A_m}{\beta}) \tag{1}$$

Although with this assumption only two parameters (the median A_m and the logarithmic standard deviation β) need to be determined, the computational cost remains still considerable, especially when the soil-structure interaction (SSI) simulations are performed.

Another way to improve the computational efficiency consists in building a metamodel to calibrate the statistical relation between seismic intensity measures and structural damage measures (DM). Metamodels have been widely used in structural reliability, but have started to be applied to seismic fragility curve estimation only very recently [5, 8]. This is mainly because the simplification of the continuous stochastic ground motion process by a small set of representative IMs cannot provide a satisfactory description of the randomness of the ground motion, and therefore cannot ensure the performance of the metamodels [10]. The simplest metamodel for seismic IM-DM relation is the power law function [3]. Other more complicated functional models were later proposed in [7, 9]. Considering these works, a non-linear regression metamodel seems more suitable to adequately compute the non-linearity in the IM-DM relation.

In this study, we focus on the application of an artificial neural network (ANN) for the computation of fragility curves. The main technical problems to solve in the computation of fragility curves with ANN are:

1. Feature selection. Before the training of the ANN, it is important to select the IMs that are the most relevant to the structural damage measure. This step, named feature selection, is crucial in the metamodel construction phase, because the redundant information carried by the IMs reduces the accuracy of the ANN model [1]. In addition, a large input size increases the number of weights in the ANN structure, which requires more training examples to prevent the overfitting of the network.

2. Integration of ANN prediction uncertainties. Given large number of simulation results provided by ANN, both parametric and non-parametric methods can be applied for the computation of the fragility curves. It is important to take into account the ANN prediction

uncertainty because the regression of the ANN surrogate model reduces the variability of the DMs, and thus β of the fragility curves. The prediction uncertainty of the ANN should be integrated additionally in order to obtain a correct β.

This methodology for ANN-based fragility curve estimation is applied to evaluate the risk of failure of an electrical cabinet in the Kashiwazaki-Kariwa nuclear power plant, studied in the context of the KARISMA benchmark.

The applicability of an adaptive learning algorithm based on ANN is further studied in seismic fragility analysis. The objective of such application is to select in the design of experiment more samples in the neighborhood of the failure threshold, which are more critical for the computation of fragility curves. Based on the works of [2, 4], an adaptive learning algorithm is proposed for the construction of ANN metamodels. This allows improving the quality of the training data set, while requiring less finite element simulations to obtain an ANN with accuracy. The proposed algorithm is applied to a non-linear Takeda oscillator for the computation of fragility curves.

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Short biography – Zhiyi Wang is graduated from Ecole Polytechnique, with a double degree with Technical University of Munich in solid and computational mechanics, and is currently a CIFRE PhD candidate at EDF Lab Saclay and Centralesupélec to develop advanced statistical methods for the computation of seismic fragility curves, to estimate the probability of failure of nuclear power plant structures under seismic conditions.