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Use of moment independent importance measures in the framework of seismic fragility analysis

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Abstract

In the nuclear industry, the seismic probabilistic risk assessment (PRA) has become the most commonly used methodology for evaluating the seismic risk of nuclear plants. In this framework, fragility curves express the conditional probability of failure of a structure or component for a given seismic input motion parameter value. The failure probability of a component due to a seismic event is obtained by integrating the conditional probability of failure (fragility) with respect to seismic hazard curve. In this paper, we present an application of moment independent sensitivity measures as introduced by Borgonovo in order to assess the sensitivity of these curves with respect to model parameters.

Keywords: Moment independent, Importance measure, Fragility curve, Log-normal, Seismic risk

1. Some elements on fragility curves

In the nuclear industry, the seismic probabilistic risk assessment (PRA) has become the most commonly used methodology for evaluating the seismic risk of nuclear plants. In this framework, fragility curves express the conditional probability of failure of a structure or component for a given seismic input motion parameter value *a*. More precisely, the structure or component fails, if capacity is less than seismic demand, expressed by ground motion parameter *a*, yielding:

$$P_f(a) \equiv P(A \leq a) = \int_0^a p(x)\, dx.$$

When a log-normal fragility model is chosen, then [Reed et al 1994] fragility curves are entirely characterized by two parameters, namely median capacity A_m and the standard deviation β yielding:

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$$P_f(a) = \Phi\left(\frac{\ln(a / A_m)}{\beta}\right)$$

where $\Phi(\cdot)$ is the standard Gaussian cumulative distribution function. When the lognormal model is retained, then the numerical task is reduced since the parameters can be estimated by means of maximum likelihood method from the numerical experiments.

Fragility curves can be evaluated by numerical simulation, more precisely by calculating *N* structural response for different earthquake loads and taking into account uncertainty related to model parameters. However, the random variable modeling capacity *A* (in terms of seismic motion level, for example the peak ground acceleration - PGA) is not observed directly. Instead, for each model run, we can evaluate, for a given criteria, if failure has occurred or not. This allows constructing the likelihood function; see for example [Zentner et al. 2008].

2. Proposed work

Let Y be the model output and $\mathbf{X} = (X^1, \ldots X^k)$ the k the random input parameters. Then, each numerical simulation provides one realisation of this variable,

$$y_i = f(\mathbf{x}_i, \tau^i_{a_i}),$$

where $\mathbf{x}_i$ is a realization of $\mathbf{X}$ and $\tau^i_{a_i}$ denotes the i$^{\text{th}}$ ground motion time history characterized by parameter a_i.

For our application, Y is the inter-story drift (differential displacement) of a concrete building subjected to seismic loads. It is well known that the seismic load, an intrinsically random phenomena, is the most important contributor to output variability. However, engineers are interested in the influence of the model parameters on the calculated fragility curves, the latter are generally considered as rather epistemic uncertainties.

We propose to use a moment independent importance measure, recently introduced by [Borgonovo 2007], in order to evaluate the importance and rank model parameters. The use of moment independent importance indices, measuring the shift between the conditional densities (one of the parameters is known) and the unconditional density of the variable of interest, is a very promising perspective for sensitivity analysis related to fragility curves.

3. References

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