Uncertainty quantification and global sensitivity analysis of seismic fragility curves using kriging

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Adaptation of the UQ framework to seismic probabilistic risk assessment

- Substitution of the costly mechanical computer model by a Gaussian process surrogate
- Uncertainty propagation on a goal-oriented quantity of interest, the seismic fragility curve
- Sensitivity analysis on parameters tainted by epistemic uncertainties to ensure information based design choices

Kriging of computer model output

\[ G \sim GP(0, \Sigma) \]
\[ Y(a, x) = G(a, x) + \varepsilon \]
\[ D_n = \{(a_i, x_i), y_i(a_i, x_i)\}_{i \leq n} \]

\[ G_n \sim (G | D_n) \]
\[ \sigma_n(x)^2 = \sigma(a, x)^2 + \sigma_e^2 \]

Seismic ground motion

Seismic intensity

\( A \in \mathbb{R} \)

\[ \Psi = \mathbb{E}_X \left[ \varphi(a, X) \right] \]

Aggregated Sobol indices

\[ \Psi(a, X) = \mathbb{E}_X \left[ \varphi(a, X) \right] \]

Kriging based sensitivity indices

\[ S_4 = \frac{\mathbb{E}_X \left[ \varphi(a, X) \right] \mathbb{E}_X \left[ \varphi(a, X)^2 \right]}{\mathbb{E}_X \left[ \varphi(a, X) \right]^2} \]

\[ \beta_k = \frac{\mathbb{E}_X \left[ \varphi(a, X) \right] \mathbb{E}_X \left[ \varphi(a, X)^2 \right]}{\mathbb{E}_X \left[ \varphi(a, X) \right]^2} \]

Numerical results

- Good predictivity of the kriging surrogate (\( R^2 = 86 \% \))
- The kriging surrogate provides an uncertainty on the estimated fragility curves

Fragility curve kriging estimator: \( \Psi^{(1)}(a, x) = \Phi \left( \frac{G_n(x) - \log(C)}{\sigma_e(x)} \right) \)

Fragility curve posterior distribution: \( \Psi^{(2)}(a, x) = \Phi \left( \frac{G_n(x) - \log(C)}{\sigma_e(x)} \right) \)

Application to a French pressurized reactor piping system

- Boundary conditions are relaxed on the clamped end of the mock-up in order to match the modal characteristics of the overall piping system
- Each variable is independent and follows a uniform distribution with a 15% relative variation (maximum entropy principle)
- After a screening step (HSIC based independence test), the variables 1, 2, 3, 8, 9 and 10 are considered influential.

To go further: Sequential planning of experiments

References


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