Stochastic simulator-based uncertainty quantification for seismic responses of bridges

TSRP Project #: NCTRZW

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Start-End Dates:
08/01/2023 - 07/31/2024

Abstract
This research project will develop an efficient stochastic simulator-based approach for probabilistic seismic analysis of bridges. The technical aims involve (i) developing stochastic surrogate models for the stochastic simulator to efficiently estimate performance measures such as first-passage probabilities and fragility curves, and (ii) developing sensitivity analysis methods leveraging stochastic surrogate models. A stochastic simulator builds on a stochastic ground motion model and a structural model with model uncertainties; it maps parameters of the ground motion and the structure into a quantity of interest. This mapping is stochastic due to the presence of aleatory variabilities in the stochastic ground motion. An explicit definition of a stochastic simulator enables a separation of the high-dimensional aleatory uncertainties of the ground motion from other uncertainties. This separation can be leveraged to significantly reduce the dimensionality of the probabilistic seismic analysis problem. Stochastic simulators are an emerging topic in the field of uncertainty quantification (UQ) and have many applications in engineering. In earthquake engineering, stochastic simulator-based UQ is still in its early stages, but it has significant potential as it provides the missing link for the efficient use of stochastic ground motion models. Moreover, this project will prioritize the analysis of real bridges, with the aim of providing practical and efficient computational tools for forward UQ and sensitivity analysis that can benefit the community of bridge engineers. The integration and comparison of the proposed approach with ground motion selection-based seismic risk analysis approaches will provide new insights into the influence of aleatory uncertainties from ground motions.

Deliverables
A PEER report documenting the project contributions, and two research papers describing the forward uncertainty quantification and sensitivity analysis methods using the stochastic simulator.

Research Impact
This proposed research is instrumental in complementing current approaches of seismic risk analysis of bridges. Stochastic simulators are an emerging topic in the field of UQ and have many applications in engineering. In earthquake engineering, stochastic simulator-based UQ is still in its early stages, but it has significant potential as it provides the missing link for the efficient use of stochastic ground motion models. Moreover, this study will prioritize the analysis of real

bridges, with the aim of providing practical and efficient computational tools for forward UQ and sensitivity analysis that can benefit the community of bridge engineers. The integration and comparison of the proposed approach with ground motion selection-based seismic risk analysis approaches will provide new insights into the influence of aleatory uncertainties from ground motions. Finally, although the application of this proposal focuses on bridges, the methodology can be applied to other critical structure/infrastructure systems such as high-rises, water supply, and oil and gas pipelines.

Project Image

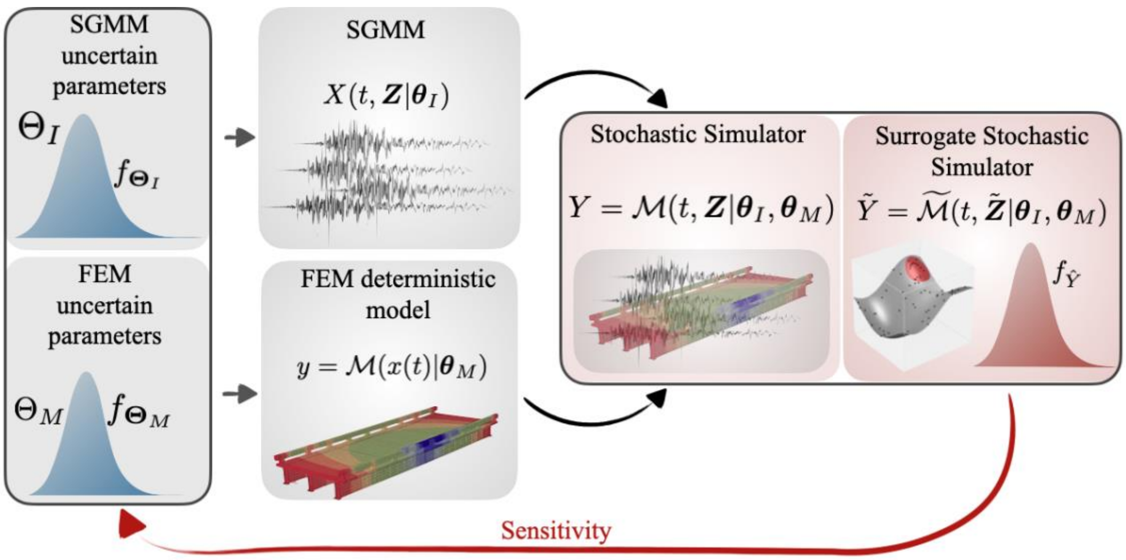

Figure 1. Framework of the proposed approach. *The stochastic simulator consists of (i) a stochastic ground motion model with aleatory uncertainties $\boldsymbol{Z}$ and epistemic uncertainties $\boldsymbol{\Theta}_I$, and (ii) a finite element model with model uncertainties $\boldsymbol{\Theta}_M$. The stochastic surrogate model for the stochastic simulator takes realizations of $\boldsymbol{\Theta}_I$ and $\boldsymbol{\Theta}_M$, i.e., $\boldsymbol{\theta}_I$ and $\boldsymbol{\theta}_M$, respectively, as input, and the stochasticity comes from the low-dimensional $\widetilde{\boldsymbol{Z}}$ that captures the effect (with respect to response quantity Y) of the high-dimensional aleatory vector $\boldsymbol{Z}$. Simulations of the stochastic surrogate model yield the probability distribution of the response quantity of interest. Performing sensitivity analysis on the stochastic surrogate model helps to understand the influence of uncertainties from different sources.*