Computationally efficient uncertainty propagation for seismic vulnerability assessment through surrogate or reduced-order modeling

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Seismic vulnerability assessment involves the quantification and propagation of the different courses of uncertainty impacting structural performance. For engineering demand parameters (EDPs) the relevant uncertainties pertain to the seismic hazard and/or to the structural model characteristics, while the detailed characterization of structural vulnerability is typically performed using nonlinear response-history analysis (NLRHA). Despite recent advances in computational science, the adoption of computationally intensive, high-fidelity finite element models (FEMs) for performing NLRHA remains a challenge for many seismic risk assessment applications, forcing some sort of simplification of the uncertainty characterization. This presentation will investigate two alternative computational statistics approaches for improving computational efficiency in such settings. The first approach will be the use of reduced order models (ROMs), coupled, if needed, with a Multi-Fidelity Monte Carlo (MFMC) implementation. ROMs simplify the physics-based description of the original FEM through some form of condensation of the degrees of freedom and equations of motion, coupled with an approximation of the nonlinear (hysteretic) response characteristics. In order to accommodate any potential bias from the ROM approximation, a MFMC setting is additionally examined. In the latter setting, the ROM serves as a means to accelerate the Monte Carlo convergence, relying ultimately on the FEM to establish unbiased predictions. The second approach will be the use of surrogate models, offering an entirely data-driven mathematical approximation of the input/output relationships of the high-fidelity model. For addressing aleatoric uncertainties in the hazard description (i.e., the so-called ground-motion to ground-motion variability), a stochastic Gaussian Process (GP) formulation is adopted to directly approximate the EDP distribution (considering influence of aleatoric uncertainties). Improvements in computational efficiency are further established by considering partial replications for the stochastic GP implementation.

Biography: Dr. Alexandros Taflanidis is Professor in the Department of Civil and Environmental Engineering and Earth Sciences at the University of Notre Dame. He holds a concurrent position at the Department of Aerospace and Mechanical Engineering. He received his Bachelors (2002) and Masters (2003) in Civil Engineering from Aristotle University of Thessaloniki, Greece. He got his PhD in Civil Engineering with minor in Control and Dynamical Systems from the California Institute of Technology (2008). His research focuses on uncertainty quantification and uncertainty-conscious analysis/design, with applications to dynamical system analysis, natural hazard risk mitigation and sustainability/resilience of civil infrastructure systems. A special area of interest for his group is the integration of computational statistics techniques in risk assessment/design and real-time emergency response management. He received the 2021 ASCE Walter L. Huber Civil Engineering Research Prize for applications of machine learning and computational statistics in the domain of natural hazards engineering.