Research Project Highlight

Bayesian Inference for Mechanics-Based Digital Twinning of Bridges

PEER-Bridge TO2

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Abstract
California's bridges are critical arteries in the national economy and integral components of the regional, state, and local ecosystem. Therefore, it is important to enable accurate prediction of their seismic response for pre-event probabilistic performance-based assessment and post-event damage identification. Despite substantial advancements in numerical modeling techniques, our forward models inherently encompass sources of uncertainty and error, including model parameter uncertainties, boundary condition uncertainties, and modeling errors arising from mathematical idealizations and simplifications. The uncertainties are especially pronounced in the presence of Soil-Foundation-Structure Interaction (SFSI), where the soil properties and the foundation input motions (FIMs) are uncertain and hardly measurable. To address these issues, we propose developing a Bayesian inference framework for nonlinear finite element (FE) model updating/training in time domain. The framework integrates mechanics-based models of bridge structures with historic and online data as they become available. Through the model updating/training, we estimate the unknown/uncertain model parameters, the spatial variability in FIMs, and their associated uncertainties. The updated model, referred to as the mechanics-based digital twin, serves as a digital representation of the real asset with quantified uncertainties. With the recent advancements in the infrastructure instrumentation and the growing number of instrumented bridges, we envision a computational platform where measurement data is continuously collected and seamlessly integrated with numerical models, to train the mechanics-based digital twins. The trained digital twins can offer a live digital inventory of bridge assets that is particularly useful for rapid post-earthquake assessment and damage diagnosis.

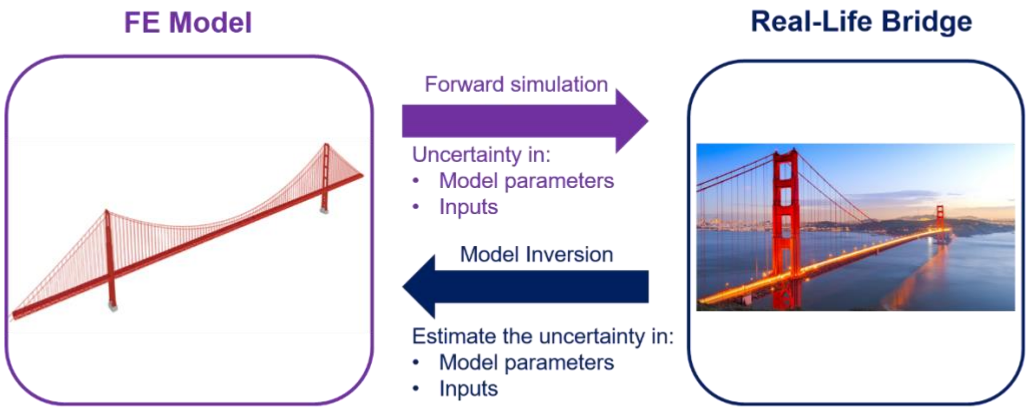
Deliverables
The project deliverables include a new code package compatible with OpenSees for input-output and output-only Bayesian linear/nonlinear FE model updating for joint input-parameter estimation and uncertainty quantification of large-scale FE models. The code package will be open-source and will be made publicly available. Moreover, educational materials, including technical tutorial, application tutorial,

and written documentation will be developed to enable new users. The code will be shared with NHERI SimCenter and BRACE2 project for potential integration and adoption. Other deliverables include presentations at PEER meetings and other conferences, as well as journal publications.

Research Impact

The PEER's Performance-Based Engineering (PBE) methodology is now accepted in the engineering community and used in practice for design of new structures or assessment of existing ones. Dynamic nonlinear time-history analysis is at the center of this methodology, so any improvement in the numerical modeling of the structures reduces overall uncertainties of the final outcomes. Damping energy dissipation, nonlinear material behavior, and SFSI effects are among sources of uncertainties, which can only be addressed through model inversion using real-life data. This project can potentially impact the state-of-practice through validation of design models, potential development of guidelines for more accurate forward modeling, and development of digital inventory of bridge infrastructures across California to be continuously trained with data.

Project Image



A) Forward simulation vs. model inversion

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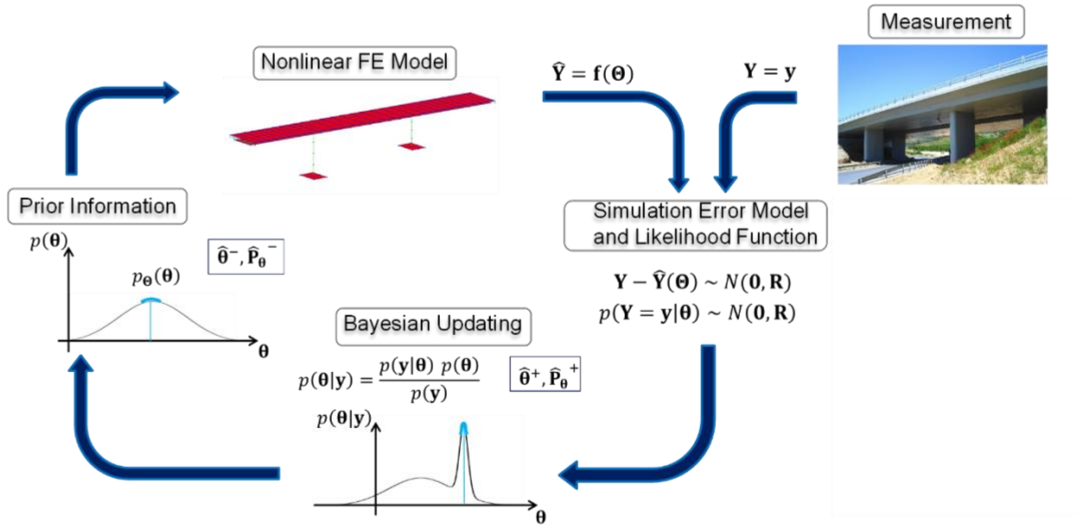

B) Model inversion framework using sequential Bayesian inference

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