Metamodeling of structural systems with parametric uncertainty subject to stochastic excitation

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ABSTRACT

The assessment of the dynamic response of structural systems subjected to extreme loading conditions, such as earthquakes, is of particular importance for the safe operation of civil structures. Nevertheless, for the vast majority of such structures, it is hardly ever possible to perform dynamic response testing on the actual structure or even realistic simulation tests on an appropriately scaled structural model. The advancements achieved in the field of Finite Element (FE) modeling methods have played a key role in overcoming this hurdle by enabling the realization of sophisticated simulation experiments emulating structural response. However, despite the rapidly growing computational power and the continuous development of increasingly efficient algorithms, the also growing complexity of FE models and the necessity for more detailed descriptions of both structural geometry and mechanical properties renders the use of highly detailed FE models almost prohibitive for complex, large structures. The problem is even more pronounced when taking into account that the structural systems are commonly characterized by parameter uncertainty to what concerns for instance the mechanical properties of the structure. Thus, the analyst is faced with the task of performing a number of simulations in order to obtain an accurate numerical model of an existing structure. Moreover, when the linearity assumption is relaxed in favour of increased modeling accuracy the structure must be tested for a number of different excitation scenarios. Thus, for the extensive experimentation required for design optimization or model updating procedures based on time history loading, a simpler representation of the FE model should be considered which should also be able to describe the behaviour of the structure for a wide range of excitations.

In this work, both structural properties and excitation uncertainties are treated by means of a time-series model with random parameters utilized for the description of uncertainty propagation through the FE model. More specifically, the random responses of a large-scale FE model are approximated by a suitably defined Polynomial Chaos Nonlinear Autoregressive with eXogenous input (PC-NARX) metamodel which is able to describe both types of uncertainties by the expansion of its random model parameters onto a finite-dimensional PC basis. Thus, the PC-NARX metamodel is described by a low number of deterministic coefficients of projection, which are estimated by a linear least squares method.

The method's effectiveness is demonstrated through the construction of a metamodel of a five-storey building with nonlinear material properties. Toward this end, a limited number of simulation experiments is conducted with the numerical model being subjected to a number of different realizations of synthesized earthquakes. Synthesized earthquakes are produced by filtering a white noise process through a non-stationary impulse response function and a non-stationary modulating function in order to simulate the time-varying characteristics for both the temporal and spectral content of a real earthquake. The non-stationary filter and the modulating functions are described by a small number of uncertain parameters, with sample observations of the latter being estimated through fitting of the model to real recorded earthquake ground motion signals.

Overall, this study introduces an efficient method for the estimation of low order stochastic metamodels that are capable of accurately approximating large-scale FE models for a wide range of excitations.

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