Computing seismic fragility curves of nonlinear structural systems with polynomial chaos-based autoregressive with exogenous input models

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Abstract:

In the field of civil engineering, the framework of seismic risk assessment has been of particular interest in the last decade. A fundamental component of this framework is the computation of seismic fragility curves. In practice, due to the prohibitive computational cost of non-linear transient analysis of structures, only a limited number of analysis is used. Thus, the computation of fragility curves is done by parametric methods that are based on simplified assumptions (e.g. use of a lognormal shape), which are often crude.

In this context, metamodelling appears as the solution that allows one to overcome the problem related to the prohibitive cost of structural analysis. Using metamodel as a substitute of the actual numerical (e.g. finite element) model, one can afford a large number of analysis at a reasonable computational expense. This allows the computation of fragility curves by means of non-parametric methods. Among different metamodelling techniques, polynomial chaos expansions are proved effective in various applications.

However, it is well known that PCE (as well as other metamodelling techniques) fail to represent the non-linear dynamics of structures, i.e. the time dependent response quantities. Recently, Spiridonakos and Chatzi [1] proposed the use of autoregressive with exogenous input (ARX) model together with PCE to represent non-linear response time history of structures. ARX is used to capture the dynamics, whereas PCE is used to propagate uncertainties. This original approach allows one to take into account uncertainties from seismic excitations and structural properties. However, its performance depends strongly on the appropriate selection of ARX and PC terms, which was done with the heuristic genetic algorithm. In this paper, we propose the use of least-angle-regression (LARS) [2] as an alternative for the effective selection of the mentioned terms. LARS proves reliable and fast to detect the relevant ARX terms from the experimental analysis. The representation of ARX coefficients as a function of uncertain parameters also relies upon the LARS-based sparse adaptive PCE scheme [3]. The applicability of the LARS-based ARX PCE model is illustrated with engineering applications and validated with Monte Carlo simulation. For instance, Figure 1 depicts the displacements of a Bouc-Wen oscillator subject to synthetic ground motions predicted by ARX PCE and computed by the numerical model. The metamodel allows one to predict the responses of the structure under stochastic seismic excitations. Figure 2 represents the maximal responses of the oscillator for a validation set of size 10^4. The results are then used for computing non-parametric seismic fragility curves and compare with those obtained under the simplifying lognormal assumption.

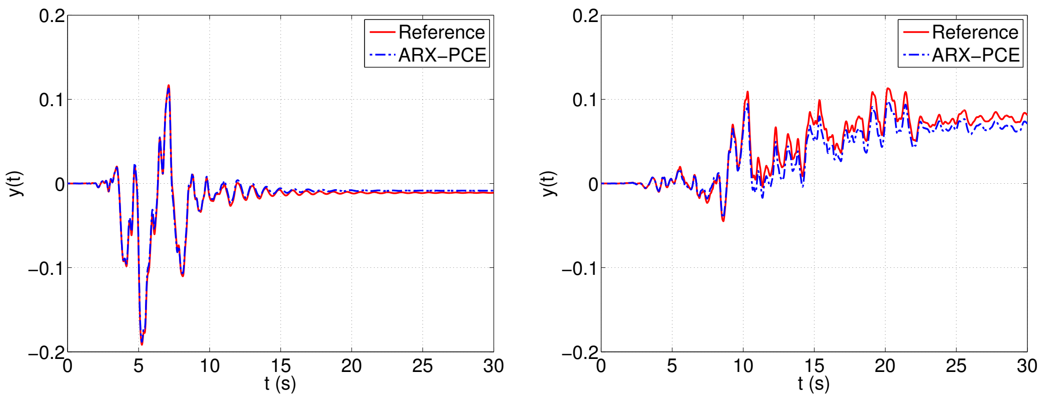
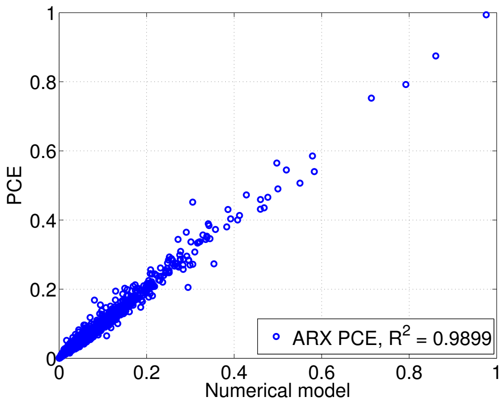
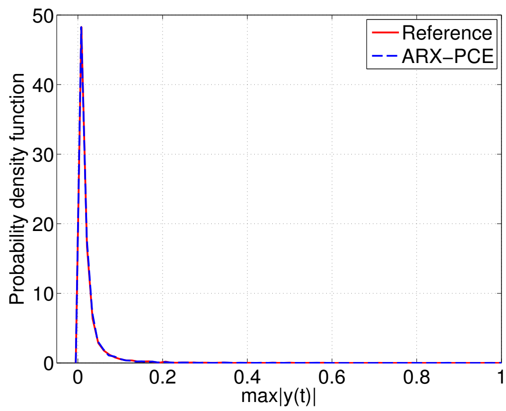


Figure 1: Bouc Wen oscillator – Two particular trajectories of displacement $y(t)$ and their prediction by means of ARX PCEs



(a) Maximal values of displacement



(b) Probability density function of maximal values of displacement

Figure 2: Bouc Wen oscillator – Maximal responses.

References

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[3] G Blatman and B Sudret. Adaptive sparse polynomial chaos expansion based on Least Angle Regression. *J. Comput. Phys*, 230:2345–2367, 2011.

Short biography – Chu V. Mai received his bachelor in civil engineering at National University of Civil Engineering in Hanoi, Vietnam in 2011. He obtained a Master degree in Materials and Structures from the Paris-Est University in 2012. His PhD topic focuses on the use of sparse polynomial chaos expansions in structural dynamics with applications to earthquake engineering. His research interests also include reliability and global sensitivity analyses.