Special Issue on Advances in Performance-Based Design Optimization of Stochastic Dynamical Systems

Editorial

Actual dynamical engineering systems often require complex and high-dimensional models. However, no mathematical models can capture entirely the behavior of these real systems. Furthermore, system performance predictions are generally sensitive to modeling and excitation uncertainties. In this context, one of the fundamental challenges in design optimization is that such uncertainties cannot be avoided due to either irreducible aleatory uncertainty or incomplete knowledge. Thus, for an efficient robust-to-uncertainty design it is important to explicitly quantify all uncertainties arising from the modeling of the system and its environment.

Proper design procedures that explicitly treat uncertainties generally enhance the reliability and the performance of systems, allowing risk-informed decisions to be made. The task of designing a system comprises applying strategies for uncertainty quantification and optimization. This in turn demands evaluating the system's performance repeatedly, considering diverse scenarios and different design solutions. Such evaluations can be very costly and even prohibitive from the numerical viewpoint. In view of these challenges, the design of complex dynamical systems under uncertain conditions has become the subject of active research in recent years.

In the previous framework, this special issue is aimed at providing a venue for researchers in optimal design of complex dynamical engineering systems under uncertain operating conditions to present some of the latest developments in this field, with applications in different areas of engineering. The Special Issue comprises 11 papers which are briefly described and summarized below.

• Linear structures under stochastic excitation represent an important class of systems in the context of this special issue. They play a special role, e.g., when structural performance is measured in terms of serviceability conditions. In this framework, the contribution by Faes and Valdebenito introduces an operator norm-based approach for constrained reliability maximization problems involving discrete design variables. The main idea is to implement a suitable operator norm as a numerically efficient proxy for the failure probability function. As a result, a single optimization process followed by a single reliability assessment step are required. Three numerical examples are presented to illustrate the capabilities of the approach.

• Performance measures in structural design are usually conflictive in nature. To address such situations, multi-objective optimization formulations represent a sound theoretical framework. In the paper by Subgranon and Spence, a bi-objective optimization approach is proposed for the design of structures subject to stochastic wind loading. Correlations between component damages and losses are directly accounted for in the formulation. A pseudo-simulation scheme is introduced to efficiently solve a series of single-objective problems, which provides a set of Pareto optimal designs representing compromise solutions between upfront cost and expected losses. Design problems involving multistory buildings subject to stochastic wind loads are addressed to show the practicality of the approach.

• In the paper by Kim and Song, an approach based on quantile surrogates and sensitivity by adaptive Gaussian process is proposed for reliability-based design optimization. The procedure does not rely on sampling procedures. Instead, it focuses on an efficient estimation of the quantile surrogates based on both input uncertainties and model errors of surrogates. In this manner, optimal designs can be obtained in an efficient fashion. A specific aim of the proposed method is to treat effectively high-dimensional engineering applications, which is highly relevant for the performance-based design optimization of stochastic dynamical systems. This is illustrated by a variety of optimization problems featuring up to 15 design parameters.

• Dynamic load characterization is pivotal in performance-based design optimization. Often, available measurements are incomplete, corrupted or not recorded at the points of interest. In this context, the paper by Pasparakis et al. adopts a compressive sampling-based approach to address the reconstruction, extrapolation, and stochastic field statistics estimation of incomplete wind time-histories. For one-dimensional problems, an adaptive basis re-weighting scheme is integrated with an l_1-norm minimization problem. Further, a methodology based on nuclear norm minimization and low rank matrices is introduced for two spatial dimensions. To demonstrate the efficacy of the methodologies, various numerical examples are presented.

• Magnetorheological (MR) dampers, a class of semi-active control devices, are quite popular for structural performance improvement due to their inherent stability, low energy consumption, and installation flexibility. A critical implementation issue is the development of effective control laws that account for uncertain conditions. In this direction, Kuok et al. propose the novel algorithm *broad learning, robust, semi-active control* for vibration suppression by MR dampers. A nonparametric reliability-based output feedback control strategy is developed, which relies on adaptive broad learning networks and the clipped-optimal control technique. A robust failure probability formulation that incorporates both predicted failure probabilities and the underlying structure uncertainties is adopted. Two examples are presented to study the algorithm performance.

• Polyphase uncertainty approaches integrate probabilistic and non-probabilistic uncertainties. This provides more flexibility to the analyst. However, the corresponding computational efforts can be significant or even prohibitive. To address this issue, Wang et al. present an efficient approach for polyphase uncertainty analysis based on a virtual modeling technique. A kernel-based machine learning technique named Twin Extended Support Vector Regression is developed to formulate the virtual model. Sufficient statistical information can be obtained by the approach, which is shown by means of an analytical example and two practical applications. The results are promising in the context of performance-based decision-making processes involving stochastic dynamical systems.

• Practical design situations usually require to select member sizes from a list of discrete, commercially available choices. Further, the growing use of composite materials highlights the importance of treating problems in which some or all the design variables are discrete. In the paper by Jensen, Jerez and Beer, a stochastic search-based method is presented for the reliability-based optimization (RBO) of structural dynamical systems under stochastic excitation involving mixed discrete-continuous design variables. An equivalent Bayesian model updating problem is formulated, which is solved by a Markov chain Monte Carlo scheme with appropriate proposal distributions for the continuous and discrete components. Three numerical examples involving linear and nonlinear structural systems are presented to illustrate the performance of the proposed method.

• Traditional methods for stochastic optimal control are usually limited to Gaussian excitations. Therefore, their applicability is hindered in scenarios where ground excitations cannot be accurately modeled by means of Gaussian processes. To address this issue, Li et al. introduce an approach for reliability-based stochastic optimal control of building structures via the direct probability integral method. The approach is applicable to performance-based design of general control systems of linear structures under non-stationary and non-white random excitations. To verify the method effectiveness, a 10-story shear frame building controlled by active tendons under random excitations of near-fault earthquake ground motions is studied.

• Energy dissipation devices are a popular choice to improve the seismic performance of civil structures. Under uncertain conditions, stochastic optimization formulations provide an effective means to achieve optimal seismic performance of structures equipped with these devices. In this setting, the paper by Xian and Su proposes a stochastic optimization framework for nonlinear viscous dampers of large-scale structures under random seismic excitations and uncertain damper parameters. The approach relies on the integration of Monte Carlo simulation, a dimension-reduced explicit time domain method, and the method of moving asymptotes. To demonstrate the feasibility of the method, a large-scale suspension bridge equipped with nonlinear viscous dampers is analyzed.

• Computational aspects play a key role in the RBO of structural dynamical systems under stochastic excitation. Hence, several methods have been developed to address this class of optimization problems. In the paper by Jerez, Jensen and Beer, a brief survey on some of the latest developments in this area is presented. The different approaches are categorized, described and summarized. Additionally, remarks are provided about their scope of applications, capabilities, limitations, and potential research directions. In general, the overview suggests that methods for optimal design of stochastic structural dynamics are no longer restricted to academic-type of problems but they can be used as tools in a class of practical engineering design problems as well.

• Vibrational energy harvesters at the infrastructure level convert ambient vibration response kinetic energy into electrical energy. This, in turn, can be beneficial for structural performance. In this framework, the paper by Fernandez and Wojtkiewicz addresses the analysis and design of electromagnetic vibrational energy harvesters for large-scale buildings. By exploiting the locality of the harvester with respect to large structural models, the complexity of the system can be reduced to perform design optimization, uncertainty and sensitivity analyses in a computationally efficient manner. The efficiency of the approach is studied for two high-rise building models equipped with different harvester configurations.

In conclusion, the different contributions of the SI suggest that computational aspects play a critical role in designing stochastic dynamical systems. In this regard, future efforts may be focused on making approaches even more efficient an effective. Devising improved theoretical algorithms and appropriate tools needed for applying such procedures could lead to additional advancements in this area.

Finally, the guest editors would like to thank all the authors for their contributions, the reviewers for their quality and timely reports, the Editor-in-Chief for his continuous support, and the Elsevier Editorial team for their efforts and technical support with the submission system that helped with

the realization of this Special Issue.

Guest Editors: Hector Jensen, Michael Beer, Jianbing Chen, Seymour Spence