Unified framework of stochastic mechanics: direct probability integral method

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Abstract

Stochastic mechanics involves the topics of simulation of random field or stochastic process, stochastic structural analysis, random vibration, reliability estimation and reliability-based design optimization. However, the existing methods only focus on parts of these topics, resulting in the complicated calculation and the absence of versatility. Nevertheless, the limited scope of application of approximation methods, inaccuracy and inefficiency of numerical approaches and the expensive computational cost of stochastic sampling methods restrict the development of stochastic mechanics. In this study, the novel direct probability integral method (DPIM) as a unified framework is proposed to solve the uncertainty quantification and reliability-based design optimization problems of static and dynamic structures. This method decouples the computation of probability density integration equation (PDIE) and governing equation of structures, and can achieve the probability density functions of stochastic responses and reliabilities for linear or nonlinear structural systems. Firstly, the PDIE governing the propagation of randomness from input to output is derived based on the principle of probability conservation. The two key techniques, i.e., the partition of probability space and smoothing of Dirac delta function, are introduced to solve the PDIE. Then, the first-passage dynamic reliability based on the equivalent extreme value mapping and its sensitivity as well as reliability-based design optimization are addressed. Finally, several examples of static and dynamic structures illustrate that the DPIM is an accurate, efficient and unified methodology for uncertainty quantification and design optimization, especially for large-scale nonlinear structures under random excitation.

Keywords: Stochastic mechanics, Uncertainty quantification, Static and dynamic structures, Direct probability integration method, Stochastic responses and reliabilities, Reliability-based design optimization