Structural reliability and stochastic finite element methods

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This paper aims to provide a comprehensive review of uncertainty quantification methods supported by evidence-based comparison studies. Uncertainties are widely encountered in engineering practice, arising from such diverse sources as heterogeneity of materials, variability in measurement, lack of data and ambiguity in knowledge. Academia and industries have long been researching for uncertainty quantification (UQ) methods to quantitatively account for the effects of various input uncertainties on the system response. Despite the rich literature of relevant research, UQ is not an easy subject for novice researchers/practitioners, where many different methods and techniques coexist with inconsistent input/output requirements and analysis schemes. Design/methodology/approach. This confusing status significantly hampers the research progress and practical application of UQ methods in engineering. In the context of engineering analysis, the research efforts of UQ are most focused in two largely separate research fields: structural reliability analysis (SRA) and stochastic finite element method (SFEM). This paper provides a state-of-the-art review of SRA and SFEM, covering both technology and application aspects.

Moreover, unlike standard survey papers that focus primarily on description and explanation, a thorough and rigorous comparative study is performed to test all UQ methods reviewed in the paper on a common set of reprehensive examples. Findings Over 20 uncertainty quantification methods in the fields of structural reliability analysis and stochastic finite element methods are reviewed and rigorously tested on carefully designed numerical examples. They include FORM/SORM, importance sampling, subset simulation, response surface method, surrogate methods, polynomial chaos expansion, perturbation method, stochastic collocation method, etc. The review and comparison tests comment and conclude not only on accuracy and efficiency of each method but also their applicability in different types of uncertainty propagation problems. Originality/value. The research fields of structural reliability analysis and stochastic finite element methods have largely been developed separately, although both tackle uncertainty quantification in engineering problems. For the first time, all major uncertainty quantification methods in both fields are reviewed and rigorously tested on a common set of examples. Critical opinions and concluding remarks are drawn from the rigorous comparative study, providing objective evidence-based information for further research and practical applications.