Structural Integrity Prediction for Complex Engineered Systems

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Abstract

A primary challenge of stochastic analysis is to discover rigorous ways to forecast the low probability of failure which is critical to reliability constraints. In this study, a new framework is proposed for the accurate estimation of the low failure probability. Combining the excellent advantages of the Polynomial Chaos Expansion (PCE), Karhunen-Loeve transform, and local regression method will result in a new simulation-based modeling technique that enables the accuracy of the structural integrity prediction. The proposed procedure can allow for realistic modeling of sophisticated statistical variations, and facilitate to achieve improved reliability by eliminating unnecessary conservative approximations. A common approach to the computationally-expensive procedure of the probabilistic methods is to approximate the system response using relatively inexpensive surrogate modeling techniques. In the approximation of the response function, the accuracy depends on the choice of the basis function and the sampling method including the choice of the sampling region and the position of the sampling points. An effective choice of the basis function for the uncertainty analysis is the direct use of stochastic expansions, i.e. PCE, since the stochastic expansions provide analytically appealing convergence properties based on the concept of a random process. The PCE can reduce computational effort of uncertainty quantification in engineering design applications where the system response is computed implicitly. To achieve a high quality surrogate model, a local regression method, namely Moving Least-Squares Method (MLSM), is integrated to a previously developed probabilistic decision support framework. The stochastic modeling process repeats and recalibrates the PCE model with the local regression scheme until sufficient model adequacies are achieved. This will allow the accurate estimation of the low probability of failure with limited sampling points. Several specific examples including a supercavitating torpedo are presented to illustrate how the method is used to provide a quantitative basis for developing robust designs associated with the low probability of failure.

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