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Neural network-based reliability analysis using subset simulation: application in random fields

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ABSTRACT

In the framework of reliability analysis methods, Au and Beck (2001) proposed Subset Simulation (SS) method to calculate small failure probabilities in high dimensions. Although the computational cost of the method in the estimation of the failure probability, compared to crude Monte Carlo simulation, is significant smaller there is still the need for further reduction. For this reason, Artificial Neural Networks (ANN) have been recently implemented in the framework of subset simulation with success, leading to cost-efficient but approximate predictions of the probability of failure [1]. The method developed in [1] enhanced the efficiency of classical SS in the estimation of small failure probabilities encountered in engineering reliability analysis, reaching the same accuracy, both in terms of mean and coefficient of variation (COV) of the estimation, with one order of magnitude less computational effort.

In this work, an improved version of the method presented in [1], extended to problems where the theory of random fields is used for the quantification of the uncertainty of the systems under consideration is described. For the description of the random fields the Karhunen-Loève (KL) expansion is used. The link between subset simulation, KL and ANN are the normal random variables ξi, i = 1,..M of the KL expansion [3]. The method utilizes the Latin hypercube sampling technique (LHS) for generating the training samples for the ANN, based on the distribution of the conditional Markov chain samples generated in each subset; This version of the method offers greater flexibility for incorporating information to the training process of the ANN while the demand that the ANN samples must be inside the failure region is provided by a acceptance/rejection criterion during the training process. After properly trained, the ANN is used as a robust meta-model in order to increase the SS efficiency by significantly enriching the sample space at each SS level with a minimum additional computational cost.

This application is illustrated by considering a statically determinate cantilever subjected to a uniformly distributed load. A probability of failure which corresponds to a failure criterion obtained with brute force Monte Carlo simulation is estimated with both classic SS and the proposed approach. A relatively high correlated random field is used to describe the spatial distribution of the Young's modulus. ANN is incorporated in the framework of SS after finding the first failure region which corresponds to a predefined conditional probability.

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