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Utilization of Artificial Neural Network Based Response Surface Method for Reliability Analysis of Structures

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Abstract: The key step of the reliability and lifetime assessment of structures is the determination of reliability level, described by failure probability or reliability index. Some of the simulation or approximation techniques can be used for this purpose. In case of large structures analyzed using the nonlinear finite element method, it is necessary to develop more efficient procedures, reducing the number of evaluations of original limit state function to a minimum. Here, artificial neural network based response surface method in combination with small-sample simulation technique Latin Hypercube Sampling is utilized for the approximation of a limit state function. Thanks to ability of artificial neural network to generalize it is efficient to fit limit state function with a sufficiently small number of simulations.

Introduction

A utilization of the response surface method (RSM) can be a suitable solution if time-consuming nonlinear finite element method (FEM) analysis of structures is applied and the crude Monte Carlo (MC) simulation method can not be used because of millions of simulations needed. In polynomial RSM, the limit state function (LSF) is approximated using a suitable polynomial function in most cases of first or second order. Parameters of surrogate function are adjusted with regard to several discrete points obtained from evaluations of original LSF and failure probability is then calculated by utilization of classical simulation methods or first-order reliability method (FORM). In case of large structures, artificial neural network based response surface method (ANN-RSM) in combination with small-sample simulation technique Latin Hypercube Sampling (LHS) can be utilized as a powerful parallel computational system, reducing the number of evaluations of original LSF to a minimum.

In proposed ANN-RSM a feed-forward multi-layer network type is used [1]. Artificial neurons are organized into several layers and the signal moves from the input nodes through the nodes in hidden layers (if any) to the output node. Feed-forward network is trained using "supervised" learning, where a set of example pairs (p, y), $p \in \mathbf{P}$, $y \in \mathbf{Y}$ is introduced to the network and the aim is to find a function in the allowed class of functions that matches the examples best. The stratified simulation LHS method is used for selection of artificial neural network training set elements to emphasize the efficiency.

Application

The ANN-RSM was applied for reliability calculation of a single-span post-tensioned composite bridge in the Czech Republic (see Fig. 1 left). Normal load bearing capacity of the bridge was assessed using computational tools of advanced nonlinear mechanics based on FEM and fully probabilistic approach. Numerical model was created in ATENA 2D software [2]. Stochastic parameters of random input variables were defined using FReET software [3] according to appropriate recommendations.

At first, sensitivity analysis was performed to capture the most important variables. The repetitious deterministic FEM analyses with random realizations generated by LHS were performed and the sets

of structural responses and corresponding vectors of input random variables serve as a training set for ANN training using appropriate optimization technique. Trained ANN was used as a surrogate LSF for consequent reliability analysis where failure probability or reliability index were calculated by utilization of classical simulation methods or FORM method. In case of simulation methods millions of simulations can be used thanks to very fast evaluation of surrogate LSF compared to original one.

By reason of time-consuming nonlinear analyses, only serviceability limit states (SLS, the limit state of decompression and limit state of cracking) were investigated. The value of normal load bearing capacity was assessed considering the common bridge type. It was assumed $\beta = 0$ $(p_f = 0.5)$ for both SLS. Results are summarized in Fig. 1 right as a comparison of proposed ANN-RSM method with classical simulation method LHS in combination with Cornell reliability index, approximation method FORM, and first order response surface method (RSM-linear).

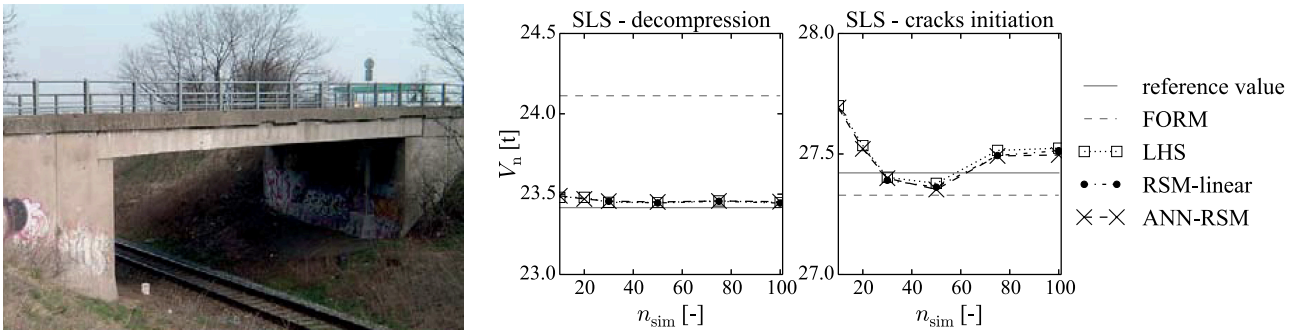

Fig. 1: Side view of the analyzed bridge (left); Comparison of normal load bearing capacity V_n obtained by various methods and using different number of simulations n_{sim} (right)

Summary

Artificial neural network based response surface method in combination with small-sample simulation technique Latin Hypercube Sampling has been proposed. The method was applied to a single-span post-tensioned composite bridge in the Czech Republic to assess the normal load bearing capacity and reliability of the structure within the framework of fully probabilistic nonlinear analysis. Results of ANN-RSM were compared with those obtained by other reliability methods.

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