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Neural Network Predictions in Computational Mechanics: To Trust or Not to Trust

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Structural analysis methods were traditionally based on rigorous scientific procedures that are formed on mathematical methods and the principles of theoretical mechanics and are solved with the implementation of numerical simulation methods based on discretized continua. However, three decades ago new families of computational methods, denoted as soft computing (SC) methods, have been proposed. These methods are based on heuristic approaches rather than on rigorous mathematics. Despite the fact that these methods were initially received with suspicion, their use in various areas of engineering science is continuously growing. Artificial Neural Networks (ANN), Genetic Algorithms and Fuzzy Logic, are the most popular approaches of SC. An ANN can store experimental knowledge and make it available for later use. It features adaptive learning, self-organizing capability during training and fault imprecision during applications. The main advantage of using ANN is that it can deal with problems that do not have an algorithmic solution or for which an algorithmic solution is too complex to be found.

Over the last ten years ANN have emerged as a powerful alternate tool for replacing time consuming numerical procedures in many engineering applications. Among others, ANN have been used for the identification of nonlinear dynamic systems and damage assessment [1,2]. Predictions of the structural behaviour by neural networks have been employed in the context of design optimization [3,4] and structural reliability analysis [5,6]. Furthermore, ANN have been applied for the prediction of the structural response under static or dynamic loading conditions [7,8].

Performance-Based Design (PBD) is the current trend for the design of structural systems where the structural performance is assessed for multiple hazard levels. PBD framework is performed by means of either Nonlinear Static Analysis (NSA) or Nonlinear Dynamic Analysis (NDA); in the later case multiple NDA have to be performed for every hazard level requiring significant computational effort. In seismic design the structural nonlinear behaviour has to be predicted for earthquake actions of increased severity.

Structural reliability analysis can be performed either with simulation methods, such as the Monte Carlo Simulation (MCS) method, or with other approximation methods. Although the major advantage of MCS is that accurate solutions can be obtained for almost every problem, yet it requires excessive computational effort in many cases. Variance reduction techniques, such as Importance Sampling, Directional Simulation, Antithetic Variates or Adaptive Sampling, have been proposed in order to reduce the computational effort of MCS. However, recent results [9] reveal that variance reduction techniques still require significant number of the system response evaluations in order to estimate failure probabilities of low order.

In this work the capabilities and limitations of ANN are investigated in a number of applications of Structural Mechanics, such as design optimization, reliability analysis and nonlinear structural

dynamics. Adaptive neurocomputing schemes are proposed in order to predict the nonlinear structural behavior and drastically reduce the excessive computational cost.

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