The long-term behaviour of civil engineering structures is influenced by a multiplicity of environmental actions, which result in time-dependent structural responses (e.g. displacements and stresses). In general, all time-dependent structural actions and responses are uncertain structural processes. Non-traditional uncertainty models [7] can be used to consider uncertain structural processes in numerical analyses of engineering structures.

Structural parameters can be identified by structural monitoring. In the conventional meaning, parameters representing the structural behaviour are obtained with the aid of experimental investigations. However, mainly due to the increase in computational power, the numerical monitoring becomes important and provides insight into the behaviour of structures or structural members, see e.g. [4]. Thereby, the time-dependent structural behaviour is numerically simulated utilizing nonlinear computational models. Repeated numerical simulations with varying input parameters may be also interpreted as numerical experiments. The input parameters of the computational model may be determined by means of experiments with test specimens as well as parameter identification based on the results of in-situ monitoring. In so far, numerical monitoring can be understood as an extension of the conventional monitoring and not as a substitute.

Measured results of experimental investigations are generally characterized by uncertainty because of physically originated variations and imprecision. The description of the observed structural behaviour close to reality requires the consideration of uncertainty. The observation and estimation of physically originated variations requires a lot of experimental investigations with identical boundary conditions (i.i.d. paradigm). This is not the case in most of the civil engineering applications. That is, imprecision dominates the results obtained from experimental investigations. The imprecision may be adequately modelled by means of the uncertainty model fuzziness, which is a special case of the generalized uncertainty model fuzzy randomness [6]. Time-dependent structural parameters are quantified by fuzzy processes.

Engineering tasks (e.g. reliability analysis, robust design, lifetime prediction, etc.) can be solved with time-dependent structural analyses. The nonlinear finite element analysis is a powerful tool to compute time-dependent structural responses. Thereby, uncertain time-dependent material behaviour, observed in experimental investigations of test specimens, can be modelled by fractional rheological bodies with uncertain parameters, see e.g. [2].

As an alternative, a novel method for the numerical prediction of time-dependent structural responses under consideration of uncertain action processes is proposed, which combines neural computing (artificial neural networks, see e.g. [5]) and mapping of fuzzy data (fuzzy analysis, see [8]). Artificial neural networks are utilized for the approximation and prediction of time-dependent structural behaviour. Uncertain structural action processes are mapped onto time-dependent structural responses with neural networks. Training and validation sequences are obtained by experiments or numerical analyses as results.
of structural monitoring. In order to capture time-dependent structural behaviour, the neural networks require a temporal signal processing. Suitable network types for this purpose are recurrent neural networks. The treatment of fuzzy data with recurrent neural networks requires an extension of the signal processing of precise data presented e.g. in [9]. In [3] recurrent neural networks for fuzzy data are introduced. They are trained with uncertain values obtained by time-discretization of fuzzy processes. That is, the input and output training data sets contain fuzzy values. However, also intervals and deterministic numbers may be processed as special cases beside fuzzy intervals and fuzzy numbers. In general, two ways of computation with recurrent neural networks for fuzzy data are possible:

1. The neural network is used as deterministic fundamental solution of a fuzzy analysis. The prediction of fuzzy structural responses is realized by means of the $\alpha$-level optimization [8] for each $\alpha$-cut. This leads to a deterministic signal processing of the recurrent neural network.

2. The prediction is carried out by fuzzy arithmetic, which is an extension of interval arithmetic. Thereby, fuzzy signals are processed in the recurrent neural network.

The approach presented here is based on fuzzy arithmetic and aims at the prediction of fuzzy structural response processes caused by fuzzy structural action processes. Different types of mapping with recurrent neural networks for fuzzy data are introduced in [1]. For the uncertain mapping of fuzzy structural action processes to fuzzy structural response processes fuzzy network parameters are required.

The developed neural network approach is verified with a fuzzy fractional rheological material model in [1]. Thereby, uncertain stress-strain-time-dependencies obtained by numerical monitoring are used to train recurrent neural networks for fuzzy data which are utilized for the prediction of further stress-strain-time-dependencies. The new neural network approach can be applied for the prediction of the long-term behaviour of textile strengthened reinforced concrete structures.

References


