MODELING FIBRE CONCRETE: FROM EXPERIMENT TO RELIABILITY ASSESSMENT

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Abstract

This paper describes a complex methodology for statistical and reliability analyses of fibre concrete structures. It describes a virtual simulation to be used all the way from the assessment of experimental results to reliability analysis. The approach is based on a randomization of nonlinear fracture mechanics finite element analysis of concrete structures. Theoretical as well as practical application aspects are presented emphasizing the conceptual framework and key points of the solution. Efficient techniques using both nonlinear numerical analysis of concrete structures and stochastic simulation methods of the Monte Carlo type have been combined in order to offer an advanced tool for assessment of the realistic behaviour of concrete structures from the statistical and reliability points of views. In order to use appropriate parameters of material laws in the computational model, an inverse analysis based on experimental results has to be performed.

Keywords: statistical simulation; nonlinear fracture mechanics; inverse analysis; artificial neural networks; sensitivity, reliability.

1 Introduction

The transparent and easily understandable concept of reliability assessment of structures including those made of fibre concrete, is that the analyst obtains a stochastic structural resistance and considers a stochastic load distribution. The stochastic response requires repeated analyses of the structure with stochastic input parameters which reflect randomness and uncertainties in the input values. The concept presented here uses a nonlinear computer simulation for realistic prediction of a structural response and its resistance. As nonlinear structural analysis is computationally very intensive, a suitable technique of statistical sampling technique should be utilized, which allows a relatively small number of simulations (which are an expensive evaluation of the structural response). The final results are: statistical characteristics of the response (stresses, deflections, crack width etc.), information on dominant and non-dominant variables (sensitivity analysis) and an estimation of reliability using a reliability index and theoretical failure probability.

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In order to use appropriate parameters of material laws in the computational model, an inverse analysis based on experiments in a laboratory or in situ has to be performed. A suitable technique for the inverse analysis is the stratified sampling scheme for the modeling of uncertain model parameters combined with artificial neural networks.

In this paper, a logically complex and systematic treatment of fibre concrete structures is presented. A statistical simulation of the Monte Carlo type is utilized twice in our approach: (i) at the stage of preparation of the training set for the artificial neural network and, once the model parameters are identified, (ii) to obtain the statistics of the response and for reliability calculations. The procedure can be outlined as follows:
- experiment (laboratory, in situ)
- development of a deterministic computational model to capture the experiment
- inverse analysis to obtain parameters of the computational model
- deterministic computational model of a structure
- stochastic model of a structure
- statistical, sensitivity and reliability analyses of a structure.

This paper represents a comprehensive description of methodology with an application published in details, Novák et al. (2007), Keršner et al. (2007).

2 Experiment

The key basic part of the complex methodology is a suitable and correctly performed and evaluated experiment. Laboratory experiments are planned and performed in order to obtain material parameters of fibre concrete, such as compressive strength, modulus of elasticity, etc. Fracture-mechanical parameters such as tensile strength or fracture energy are not always tested, in spite of the fact they are essential for the failure modeling of concrete. The recommended "almost classical" experiment to obtain fracture energy is the three-point bending test of a notched specimen, see Fig. 1. The test has to provide an accurate representation of the load-deflection (l-d) curve in both pre-peak and post-peak branches.

Fig. 1 A laboratory experiment

3 Virtual simulation of experiment

The next logical step in the methodology is the development of a virtual numerical model of the experiment. Such a model should be able to simulate experimental results very well. Only nonlinear models based on nonlinear fracture mechanics principles can provide satisfactory results given the failure load, the simulation of crack propagation and the post-peak branch, Fig. 2 and Fig. 3.

Such a nonlinear numerical analysis requires the use of an appropriate and realistic material model. Generally, the more sophisticated the model, the more model parameters that are needed. Basic parameters such as compressive strength, modulus of elasticity, etc. are usually known. Typically, some other parameters can be estimated using the recommended formulas from previously-published literature, but in most cases these formulas can be used only as a first approximation of the parameters. The objective is very often to find such a set of material parameters as gives the best agreement between the simulated and experimental (if available) load-deflection curves. The calculated l-d curve is not in agreement with the experimental one (see Fig. 3 with a purposely emphasized difference) – and in many cases this is not possible to achieve easily via a trial and error approach. An advanced identification technique is needed.

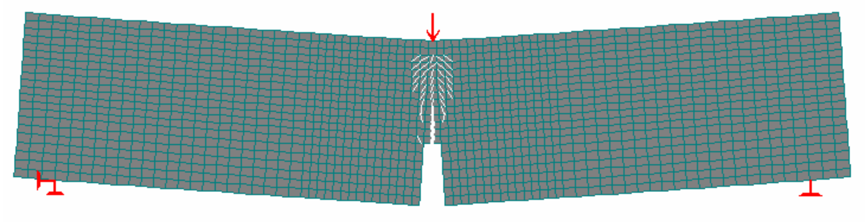

Fig. 2 A Virtual nonlinear FEM computational model

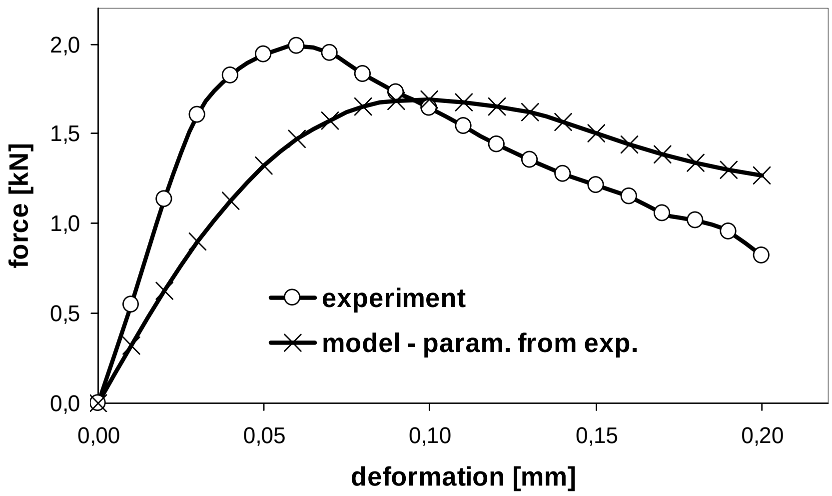

Fig. 3 Load-deflection curves – experiment and initial numerical simulation

4 Inverse analysis

The next step is the solution of the inverse problem: "Which material model parameters should be used to capture the experiment well?" This is illustrated by the curves in Fig. 3: the computed curve should be as close as possible to the experimental one. The recently proposed identification strategy is based on a coupling of the stratified sampling in the nonlinear fracture mechanics analysis and in the artificial neural network (Novák & Lehký

2006). The fundamental scheme of the approach is shown in Fig. 4; the neural network is trained by the values of the load-deflection curve and the values of identified parameters (considered to be random variables) in a repeated stochastic way – the preparation of a training set for a neural network uses stratified simulation. The example of an identification result is shown in Fig. 5 – notched specimen for fracture energy testing were simulated by ATENA 2D software and identification procedure was applied. The result of this step was identified fracture-mechanical parameters of a particular fibre concrete.

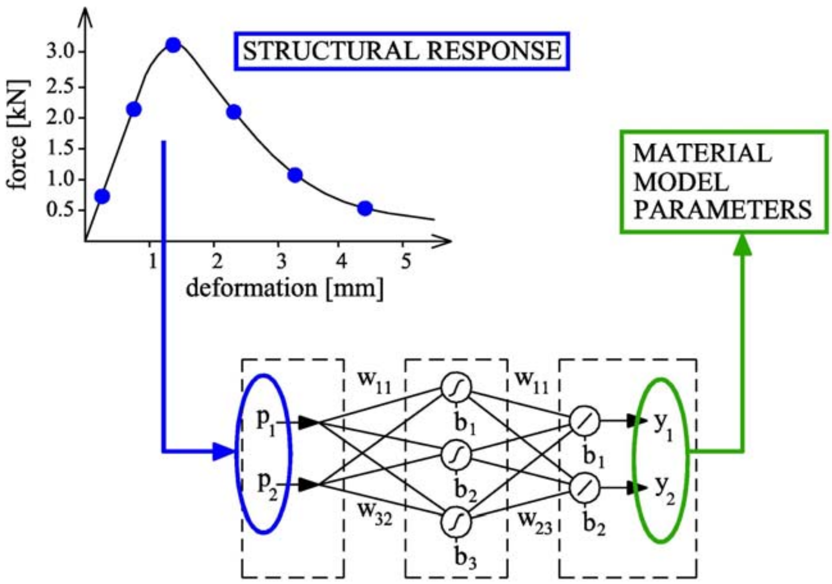

Fig. 4 Scheme of inverse analysis

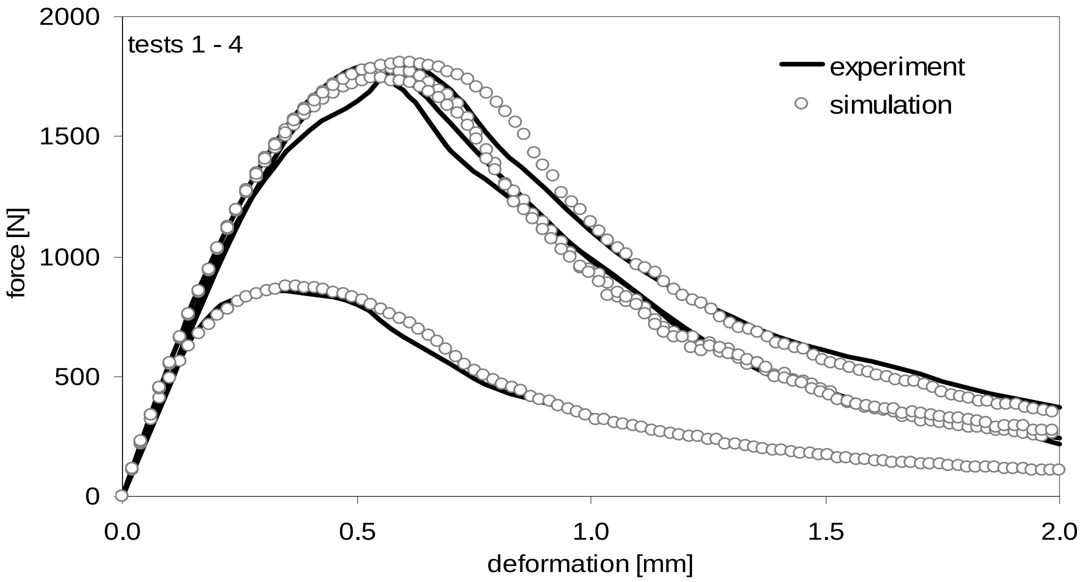

Fig. 5 Experimantal and simulated (with identified parameters) load deflection curves from three-point bending of notched specimens

5 Deterministic computational model of a structure

After constitutive model parameter identification based on experiment, a computational model of a real structure can be developed. We provide here an illustrative example: The production of facade panels made of alternative FRC-material has been initiated by VUSTAH research institute and they are under development. As it represents a new facade system utilizing new composite material which exhibits a large variability, a computational analysis is desirable – addressing reliability issues of this special structure.
3D FEM computational model has been developed using ATENA 3D nonlinear fracture mechanics software, Fig. 6. Wind intake was simulated by continuous loading. Newton-Raphson solution method with the loading increment step of 1 kN/m^2 provided non-linear solution. Deflection in the middle of the panel was monitored and compared with experiment. 3D cementitious material model has been used with material parameters identified by procedures described above. Note, that the deterministic numerical model was partially calibrated using measured and also estimated (by inverse analysis) mechanical/fracture parameters of composite and partially using the results of vacuum-treated experiment of the panels.

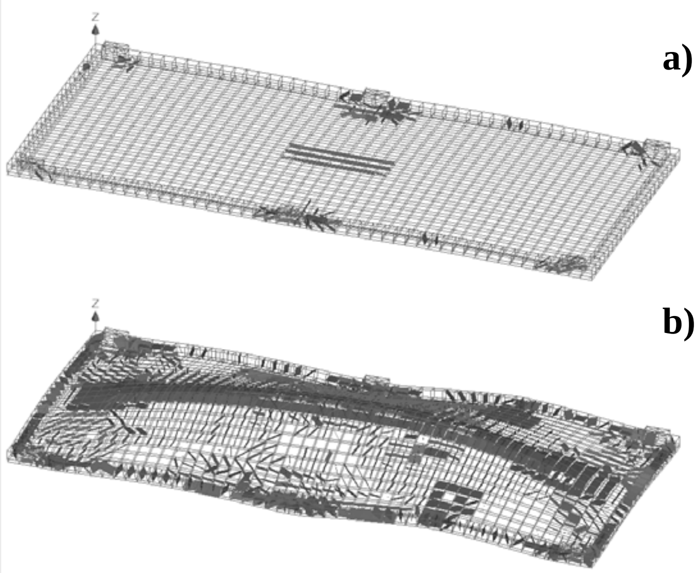

Fig. 6 Cracks in panel – formation of fracture process zone; a) initiation; b) final stage at failure

6 Stochastic computational model and reliability

In order to calculate the reliability of a structure, input parameters have to be considered as basic random variables (from identification) and Monte Carlo type simulation can be performed. Statistical analysis can be efficiently performed using the Latin hypercube sampling method by SARA/ATENA/FREET software. 32 simulations were performed for facade panels - resulting bundles of *l–d* curves are in Fig. 7. A simplified reliability analysis can be then performed based on the results of statistical analysis – PDF´s of ultimate capacities of panels.

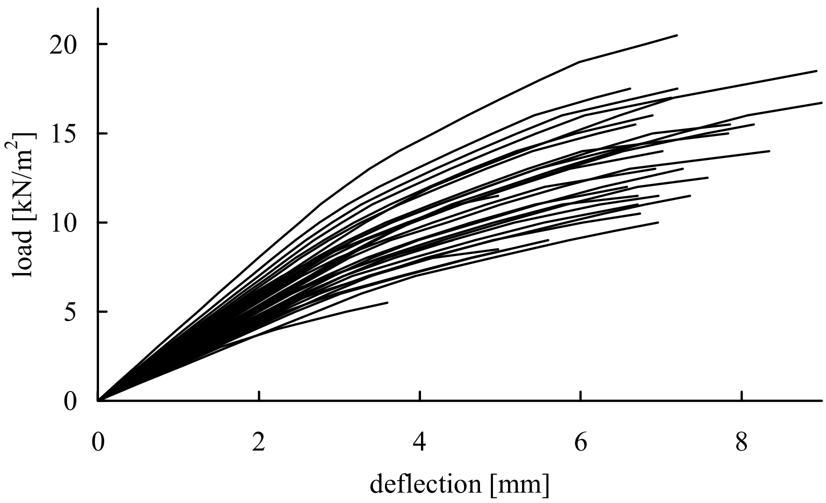

Fig. 7 Random *l–d* curves – the reference facade panel

7 Conclusion

The paper shows a complex methodology for statistical and reliability analyses of fibre concrete structures. It describes a virtual simulation to be used all the way from the assessment of experimental results to reliability analysis. The example of fiber- reinforced facade panels illustrates key steps of the methodology.

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