STOCHASTIC NONLINEAR ANALYSIS OF FACADE PANELS MADE OF FIBRE-REINFORCED CEMENT BASED COMPOSITE

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Abstract

The paper presents the complex approach to the design and evaluation of structures/structural members made of advanced cement based composites and outlines the reasons why it is important to use that approach. The approach is based on randomization of nonlinear fracture mechanics finite element analysis of quasi-brittle structures. Chosen aspects and results of the analysis of nonlinear stochastic model of glass fibre-reinforced composite facade panel's check test are presented. Special attention is given to the results of probability analysis (incl. influence of material degradation). Their use in design and evaluation of structures/structural members is discussed. The paper also deals with fracture parameters determination, incl. their statistics and influence of material degradation.

Keywords: Stochastic analysis; (glass) fibre-reinforced cement based composite; fracture parameters; degradation; facade panel.

1 Introduction

The appropriate model of the real behaviour (response to applied load) of structures/structural members made of advanced fibre-reinforced cement based composites is necessary for the structural designing/evaluating. Under the term "real behaviour" we mean the complex behaviour including fracture, randomness character of load response (which is due to the heterogeneity of the material and fibre content much higher than in the case of "normal" concrete) and also other influences, e.g. degradation of used material. The stochastic model of facade panel's behaviour including all mentioned factors and the results including the reliability of structures calculated from the stochastically obtained structural resistance and expected load distribution are presented in the paper.

2 The role of fracture-mechanical parameters in modelling of the real cement based composite's behaviour

The behaviour of cement based composites after reaching the ultimate tensile capacity (or more precisely after leaving the linear part of load-deflection/deformation graph due to microcracking) can be described using fracture-mechanical parameters. Some of these

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parameters play important role in nonlinear fracture models, which can be implemented into FEM codes. The knowledge of fracture energy is necessary when using cohesive crack models (e.g. classical Bažant's crack band model implemented also in software ATENA 3D (Červenka et al. 2005) which was used for the deterministic nonlinear numerical model of studied facade panel). Note that certain problems are still involved in the fracture energy determination (e.g. Trunk et al. 2001, Veselý et al. 2007). Two basic approaches were applied to determine mechanical/fracture parameters from experimental results (three-point bending test of central notched specimens (40×40×200 mm, notch depth 15 mm, span 180 mm) made of referenced and degraded composites, each set included 40 specimens): (i) effective crack model / work-of-fracture method (e.g. Karihaloo 1995, Stibor 2004), (ii) inverse FEM analysis using nonlinear fracture mechanics (Lehký, Novák 2004). The study of the influence of material degradation on the fracture-mechanical parameters was also carried out. The synthesis of the results of mentioned approaches resulted in parameters summarized in Table 1.

Variable	Unit	Mean value		COV [–]	PDF
Modulus of elasticity	GPa	10.1	R	0.195	Rayleigh
		7.8	D	0.199	Weibull min (3 par)
Compressive strength	MPa	53.5	R	0.250	Log-normal (2 par)
		31.5	D	0.250	Log-normal (2 par)
Tensile strength	MPa	6.50	R	0.250	Weibull min (2 par)
		3.81	D	0.250	Weibull min (2 par)
Fracture energy	J/m^2	816.2	R	0.383	Weibull max (3 par)
		195.8	D	0.418	Log-normal (2 par)

Tab. 1 Basic random variables of material parameters of fibre-reinforced cement based composite

3 Stochastic model

The presented stochastic model deals with experimental test of facade panels (2050×1050×13,5mm). The loading action caused by wind intake was simulated by vacuum-treated laboratory experiment (Melcher et al. 2006). The model combines deterministic nonlinear numerical model in ATENA 3D (Podroužek, Novák 2006) and Latin Hypercube Sampling Method (Novák et al. 2006) used for generating of 2×30 sets (reference and degraded) of random input parameters. The most important material input parameters (modulus of elasticity, fracture energy, tensile and compressive strength) are considered as random variables and their decrease due to material degradation is taken into account. Statistical correlation among random input variables was also considered.

The stochastic model was evaluated using statistical, sensitivity and probability analysis. The histograms and PDF of ultimate capacities of the referenced and degraded panel were determined. The total decrease of the mean value of ultimate load due to degradation comes to 50.7% (from 13.23 kN/m^2 to 6.52 kN/m^2).

A simplified reliability analysis was performed based on the results of the statistical analysis – PDF´s of ultimate capacities of panels (basic and degraded). Action of load – wind intake was considered deterministic at several levels until 18 kN/m^2. The theoretical failure probability – the probability that the panel will not resist the load (wind intake) was calculated using mathematical model of PDF. The result of the reliability study is shown in Fig. 1, 2.

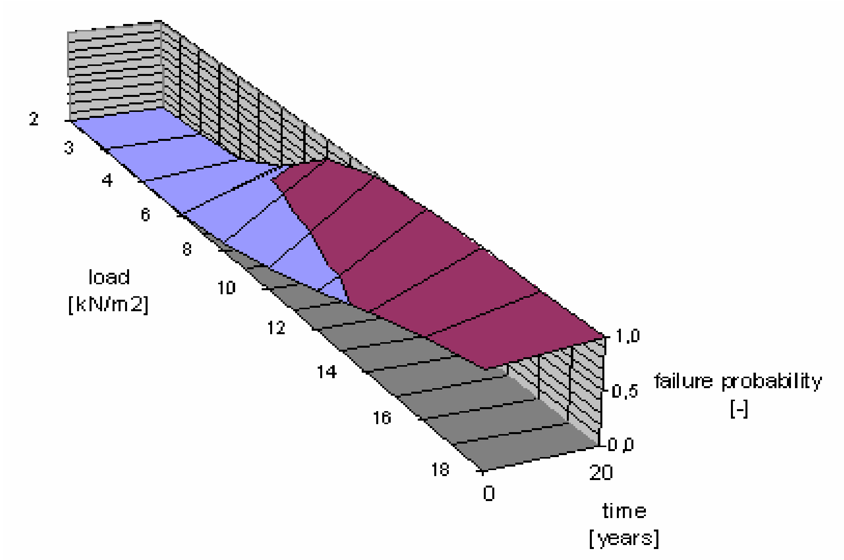

Fig. 1 Graph of theoretical failure probability vs. applied load (wind intake) and time

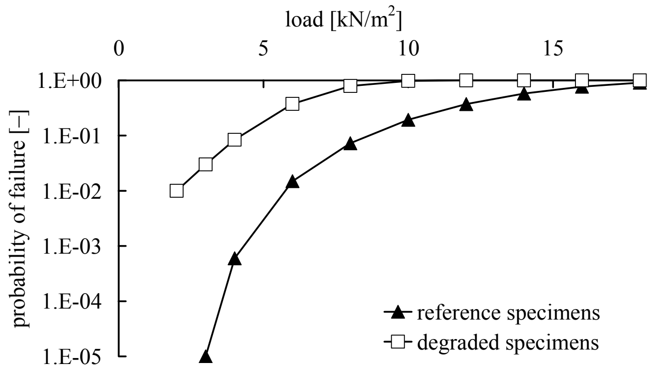

Fig. 2 Theoretical failure probabilities for different levels of load

According to Fig. 1 we can estimate the theoretical probability failure of facade panel with respect to the time of degradation. We can see that this probability increases essentially due to degradation (Fig. 2). Of course it will be necessary to confirm this study with other experiments focused on the influence of degradation process to material parameters and with experiments investigating the response of composite structural members/structures to applied load. Simultaneously other effects (e.g. variability of wind intake and the influence of geometrical imperfections or material inhomogeneity on ultimate capacity of panels) should be taken into account. In Fig. 1 the function between theoretical probability of failure at the beginning of degradation and in the time of twenty years is considered as a linear function. This assumption should also be validated by experiments. The specified graph can then present the useful tool for design and evaluation of structural members/structures or for maintenance planning.

4 Conclusions

The paper presents the necessity of the complex approach to the design and evaluation of structures/structural members made of advanced cement based composites. The quasi brittle character of the composite's behaviour calls for the implementation of nonlinear fracture mechanical principles to the nonlinear numerical model. The variability of material parameters has to be taken into account using statistical and probability theories and advanced simulation methods. It is also necessary to evaluate the influence of degradation during the life cycle of structures/structural members and other mentioned effects. The application of this approach – stochastic model of the facade panel's response to applied load (wind intake) – is presented. Some difficulties of (fracture) input parameter's determination are outlined and also the results and other chosen aspects are discussed.

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References

[1] Červenka, V., Pukl, R.: *ATENA Program Documentation*, Cervenka Consulting, Prague, 2005
[2] Karihaloo, B.L.: *Fracture mechanics of concrete*. New York: Longman Scientific & Technical, 1995
[3] Lehký, D., Novák, D.: Identification of material model parameters using stochastic training of neural network, In: *Proc. of 5th PhD Symposium*, Delft, Netherlands, 535–542, 2004
[4] Melcher, J., Karmazínová, M., Knězek, J., Lederer, L.: Experimental verifikation of glass fibre-reinforced facade panels member, In: *Proc. of Ecology and New Building Materials, X. Conference*, Telč, Czech Republic. (in Czech), 2006
[5] Novák, D., Vořechovský, M., Rusina, R.: *FREET – Program Documentation, Theory and User's Manual*, Brno, 2006
[6] Podroužek, J., Novák, D.: Analysis of facade panels made of fibre-reinforced composite I: Nonlinear 3D modelling, In: *Ecology and new buildings materials and products,* Telč, Czech Republic (in Czech), 2006
[7] Stibor, M.: *Fracture-mechanical parameters of quasi-brittle materials and the methods for its determination*. Ph.D. thesis, Institute of Structural Mechanics, Faculty of Civil Engineering, Brno University of Technology, Brno, Czech Republic (in Czech), 2004
[8] Trunk, B., Wittmann, F. H.: Influence of size on fracture energy of concrete, In: *Materials and Structures*, Vol. 36, 260–265, 2001
[9] Veselý, V., Řoutil, L., Keršner, Z.: Structural geometry, fracture process zone and fracture energy, In: *FraMCoS*, Catania (Italy), 2007; in print