18th International Conference
ENGINEERING MECHANICS 2012
Svratka, Czech Republic, May 14 – 17, 2012

pp. 54–55
Paper #92

LATTICE MODELING OF CONCRETE FRACTURE INCLUDING THE EFFECT OF MATERIAL SPATIAL RANDOMNESS

J. Eliáš*, **M. Vořechovský****

Abstract: *The paper presents stochastic discrete simulations of concrete fracturing. The spatial material randomness of local material properties is introduced into a discrete lattice-particle model via an autocorrelated random field generated by the Karhunen–Loève expansion method. The stochastic discrete model is employed to simulate failure of three-point-bent beams with and without a central notch notch. The effect of spatial randomness on the peak load and energy dissipation is studied.*

Keywords: ***lattice model, concrete, fracture, stochastic simulations, material randomness, fracture energy, flexural failure.***

1. Introduction

It has been widely recognized that mechanical properties of materials exhibit a spatial variability. The seminal theory of Weibull (1939) offered simple and powerful tool to determine the probabilistic distribution of structural strength. The advantage of Weibull theory comes from the fact that the mechanics of failure does not interact with the stochastic model. However, applicability of the Weibull theory is limited to brittle structures with no redistribution prior to the peak load.

Many structures are made of quasibrittle materials like concrete, ceramics, rocks or ice. These structures have the ability to partially redistribute released stresses. Also the Weibull assumption of independence stands out against the natural expectation that the local strength fluctuate rather continuously inside a structure. Sufficiently simple and robust extension of the Weibull theory that properly overcome both objections does not exists. A laborious way of quasibrittle structural strength estimation is represented by stochastic failure simulations that include proper mechanics of stress redistribution, e.g. finite element or discrete modelling. In this study, we adopt the lattice particle-model developed by G. Cusatis (Cusatis and Cedolin, 2007) for modeling of concrete fracturing. Spatial material fluctuations are introduced by assinging the material properties according to realizations of a random field. The model is used for numerical simulations of failure of notched and unnotched three-point bent beams.

2. Brief model description

The material is represented by a discrete three-dimensional assembly of rigid cells surrounding one concrete mineral grain (Fig. 2.a,b). The cells are interconnected by set of three nonlinear springs (normal and two tangential) placed at the interfaces between the cells. On the level of rigid cell connection, the cohesive crack model is used to represent cracking in the matrix between the adjacent grains. The interparticle fracturing is assumed to be of damage-mechanics type and is modeled using a single damage variable ω. To save computer time, the lattice-particle model covers only the region in which cracking was expected. Surrounding regions of the beams were assumed to remain linear elastic and were therefore modeled by standard 8-node isoparametric finite elements. The meso-level material properties (the fracture energy and strength) of each inter-particle connection are assigned according to a stationary autocorrelated random field $\boldsymbol{H}(\boldsymbol{x})$. According to recent studies by Bažant and co-workers (Bažant et al., 2009), the field distribution have a Gaussian core onto which a power-law tail is grafted from the left at a probability about 10^{-4}–10^{-3}. Two correlation lengths $d = 80$ mmm and $d = 40$ mm were considered.

*Ing. Jan Eliáš, Ph.D.: Institute of Structural Mechanics, Faculty of Civil Engineering, Brno University of Technology, Veveří 331/95; 602 00, Brno; CZ, e-mail: elias.j@fce.vutbr.cz
**Doc. Ing. Miroslav Vořechovský, Ph.D.: Institute of Structural Mechanics, Faculty of Civil Engineering, Brno University of Technology, Veveří 331/95; 602 00, Brno; CZ, e-mail: vorechovsky.m@fce.vutbr.cz

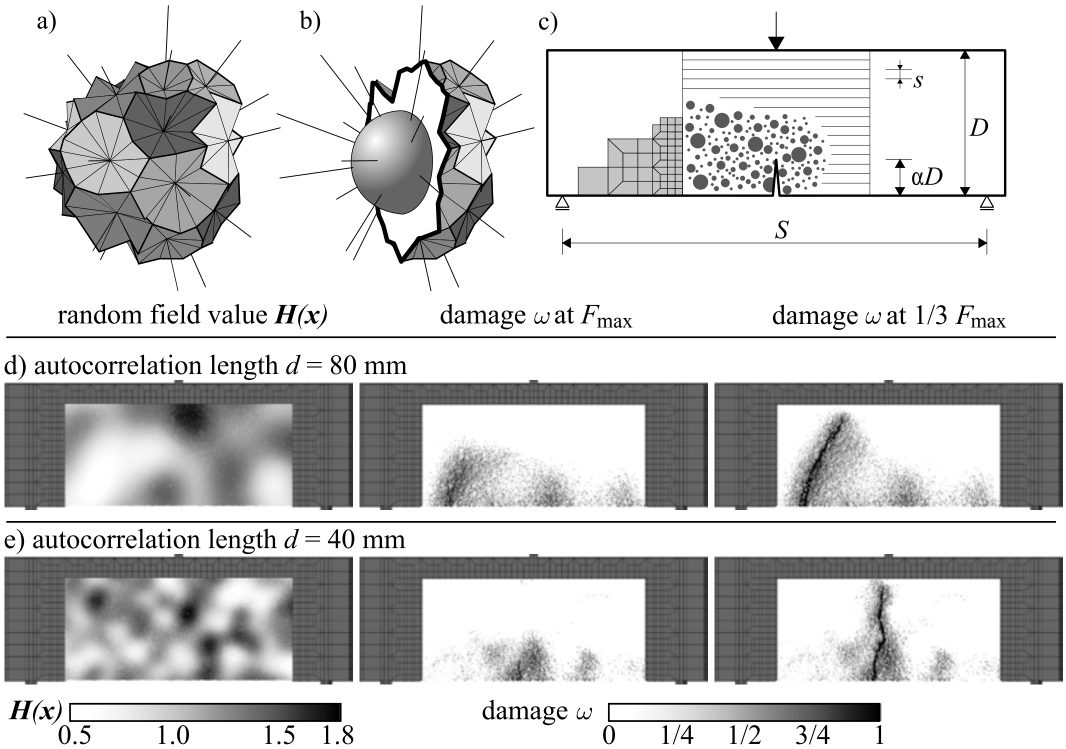

Fig. 1: a) One cell of the lattice-particle model and b) its section revealing the aggregate. c) Geometry of the beams simulated in three-point-bending. c-d) Realizations of random field $\boldsymbol{H}$ (left) and corresponding damage patterns developed in bended unnotched beams for two correlation length: c) $d = 80$ mm and d) $d = 40$ mm.

3. Results

In the simulations of notched beams, the crack is forced to start at the notch tip. Therefore, the mean value of the maximal load for notched beam simulations does not change when material spatial randomness applies. However, the standard deviation of the maximal load increases when material randomness is introduced. Also, the energy dissipation in deterministic and random media exhibit the same mean but an increasing standard deviation for the random cases.

In unnotched beams, the macrocrack initiates in a locally weaker spot. When a shorter correlation length of material properties is applied, the weaker is statistically the initiation spot and therefore the mean of the maximal load is lower. Standard deviations of the maximal load increase when randomness applied, however the shorter correlation lengths lead to a decrease of the standard deviation. Energy dissipated in unnotched beams is dependent on the randomness of the material. Two effects responsible for the dependency were identified. i) Change of the dissipated energy due to correlation of the local meso-level fracture energy and low meso-level strength of inter-particle bonds through which the macrocrack propagates. For the current settings of the model, the lower is the local meso-level strength, the lower is also the local fracture energy and the lower is the energy dissipated inside the macrocrack. ii) The pre-peak distributed cracking has a tendency to localize only in weaker areas and thus the material dissipated less energy outside the macrocrack when random field is applied.

References

Bažant, Z. P., Le, J.-L., and Bazant, M. Z. (2009). Scaling of strength and lifetime distributions of quasibrittle structures based on atomistic fracture mechanics. *Proceeding of the National Academy of Sciences, USA*, Vol. 106, No. 28, pp. 11484–11489.

Cusatis, G., and Cedolin, L. (2007). Two-scale study of concrete fracturing behaviour. *Engineering Fracture Mechanics*, Vol. 6, pp. 3–17.

Weibull, W. (1939). The phenomenon of rupture in solids. In *Royal Swedish Institute of Engineering Research*, Vol. 153, pp. 1–55, Stockholm.