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The Influence of Autocorrelation Length of Random Strength in Stochastic Discrete Simulations

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Abstract: The contribution studies an influence of the autocorrelation length of a random field of local tensile strength and fracture energy on the fracture process zone in concrete beams. Experimentally obtained data on bending of concrete specimens of four different sizes with and without notch were simulated by discrete lattice-particle model enhanced by stochastic extension. The simulations reveal an interesting and clear dependence of the peak load on the autocorrelation length in terms of the mean value and also variability. For example, when the autocorrelation length in unnotched specimens equals roughly the fracture process zone size, the average specimen strength is significantly reduced.

Introduction

Concrete and other similar cementitious composites belong among the most commonly used materials in civil engineering. Concrete is a highly heterogeneous material with quasi-brittle behavior. For the proper understanding of this behavior, a development of advanced complex numerical models is necessary. The models should allow a description and prediction of the material's strength as well as its post-critical response.

Besides models describing the material as a continuum, the meso-scale discrete models can be also employed. Classical lattice models represent the material as a system of elasto-brittle elements forming a lattice with geometry independent of the inner material structure. Nevertheless, due to their fine resolution, these models demand long computational time and therefore such a modeling strategy is not suitable for larger structural elements. A model with a less dense lattice, where the nodes correspond to individual aggregates, seems to be a suitable compromise. These models are termed as the *lattice–particle* models. The contacts between adjacent elements (large particles) generally have a nonlinear constitutive law (for example linear elastic branch followed by a nonlinear softening branch).

Discrete lattice-particle model

One advantage of meso-scale models lies in the incorporation of spatial material variability by modeling its inner meso-structure. Although here being referred to as the *deterministic model*, the response of this model varies due to the heterogeneity of the inner structure, which is constructed by generated spheres of random diameters and random positions, representing the individual mineral aggregates in concrete. Furthermore, an additional stochastic description, capturing the variability in some model parameters of material, can be considered and modeled by a random field. In the present contribution, parameters of the lattice–particle model developed by Cusatis [1] are modeled by stationary random field. Such a model was used to simulate bending experiments on concrete beams [2, 3] and is referred here to as the *stochastic model*.

Selected parameters of the contacts were considered as randomly spatially varying. They were described by a single random field with Gauss-Weibull probability distribution [4] and squared exponential autocorrelation function (with autocorrelation length l_c as an additional parameter). Parameters of the deterministic and stochastic models were identified using the response of concrete beams of four different sizes and three different notch lengths loaded in bending [3].

Deterministic and stochastic simulations

The variability of response caused by the random location and diameter of particles was evaluated with the results of deterministic model and compared with the results of stochastic simulations. In stochastic simulations, four parameters (tensile and shear strength and fracture energy in tension and in shear) were selected to be modeled as random and linearly dependent on each other. Therefore, the variability of all four parameters was represented by a single random field. The mean value of each random parameter was equal to the parameter values used in the deterministic model and the coefficient of variation was fitted on some experimental data (see [3] for more details).

Comparing both types of simulations, there is a significant increase in response variance (of strength as well as of fracture energy) of notched beams after the consideration of variability of input variables. The mean value of both quantities kept unchanged. For the unnotched beams, the decrease in the mean strength could be observed, which can be explained by a higher probability of the occurrence of weaker spots at the bottom face of the beam, where the crack can initiate. The random field helps the strain to localize into narrower zones and the numerical calculation to converge compared to deterministic simulations.

The main conclusion from the stochastic simulations of notched and unnotched bent beams with various autocorrelation lengths are as follows: In *unnotched* beams with $l_c \to \infty$ the random parameters take constant random values over the volume of the specimens and therefore the variability of nominal strength is composed of the variability measured in deterministic models plus the variability due to random local strength. The mean value is not influenced. When $l_c \to 0$, the nominal strength is virtually similar to the strength of deterministic models because the whole FPZ (fracture process zone) of relatively large size has a homogenized strength of randomly varying local strengths. When, however, l_c is approximately equal to the size of FPZ, the average nominal strength of the whole beam attains its minimum that is lower than the strength of the deterministic model.

In *notched* specimens, the ability to sample from many possible weak zones to form a decisive FPZ is limited by the stress concentration. Therefore, the effect of autocorrelation length on the mean strength vanishes. However, the autocorrelation length influences the variability in nominal strength. When l_c reaches the ca $3 \cdot d_{\max}$, the variability suddenly increases.

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