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Keynote Paper

Fracture, Stochastic Upscaling and Size & Scale Effects

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The main goal of this work is to provide a thorough scientific understanding of the interplay between stochastics and mechanics, by classifying what can be achieved by representing mechanical system parameters in terms of deterministic values (homogenization) versus random variables or random fields (stochastic upscaling). The latter is of special interest for novel Bayesian applications capable of successfully handling the phenomena of fracture in both the quasi-static and the dynamic evolution of heterogeneous solids where no scale separation is present, which we refer to as stochastic upscaling. We seek to quantify the sensitivity of these phenomena with respect to the size-effect (changes in characteristic system dimension) and to the scale-effect (changes in characteristic time evolution). The challenge is to provide an answer as to why a system that is big does not break under quasi-static loads in the same way as a small system, even when both are built of the same material, and further extend this to inelasticity and fracture under dynamic loads. We plan to illustrate the crucial role of fine-scale heterogeneities and to develop the groundbreaking concept of stochastic upscaling that can capture their influence on instability and dynamic fracture at the system macro-scale. The stochastic upscaling is the key to size and scale laws in the proposed multi-scale approach, which can reach beyond homogenization to properly account for epistemic uncertainties of system parameters and the stochastic nature of dynamical fracture.

The methodology proposed in this work develops novel concepts in irreversible thermodynamics of nonequilibirum processes (yet referred to as nonequilibrium statistical thermodynamics, where neither space nor time scales are separated. This groundbreaking concept is here referred to as stochastic upscaling, providing a fruitful interaction of Mechanics (multi-scale approach) and Mathematics (uncertainty quantification). The stochastic upscaling truly applies across many scientific and engineering domains, where multiscale structure models are used to replace the testing procedure used to validate structure integrity or structure durability.

The main difficulty pertains to characterizing a number of different failure modes that require the most detailed description and interaction across the scales. Here, we seek to significantly improve the currently dominant experimental approach, because the latter is either not applicable for the sheer size of the structure, or unable to exactly reproduce the extreme loads. We propose to use stochastic upscaling, where extensive small-scale (material) testing is supplemented with large-scale (structure) computations, which allows exploring the real fracture behavior of the system under various load scenarios in optimal design studies, and thus accelerate innovations in this domain. More details are given in refs. [1,2,3, 4].

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