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Variational coarse-graining procedure for dynamic homogenization

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Abstract

We present a variational coarse-graining framework for heterogeneous media in the spirit of FE^2 methods, that allows for a seamless transition from the traditional static scenario to dynamic loading conditions, while being applicable to general material behavior as well as to discrete or continuous representations of the material and its deformation, e.g., finite element discretizations or atomistic systems. The method automatically delivers the macroscopic equations of motion together with the generalization of Hill's averaging relations to the dynamic setting. These include the expression of the macroscopic stresses and linear momentum as a function of the microscopic fields. We further demonstrate with a proof of concept example, that the proposed theoretical framework can be used to perform multiscale numerical simulations. The results are compared with standard single-scale finite element simulations, showcasing the capability of the method to capture the dispersive nature of the medium in the range of frequencies permitted by the multiscale strategy.

Keywords: Dynamic homogenization, Hill's theorem, RVE-based multiscale solver

1. Introduction

Elastic composite/metamaterials have exhibited a rapid increase of interest due to their surprising dynamic properties (Craster and Guenneau, 2012; Deymier, 2013; Hussein et al., 2014). They can exhibit subwavelength bandgaps (Liu et al., 2000), behave as materials with negative effective elastic constant and/or density in a certain frequency range (Li and Chan, 2004) and can lead to frequency-dependent elastic anisotropies (Ruzzene et al., 2003). They are considered as a promising avenue for dynamic tunability (Sigmund and Jensen, 2003; Hussein et al., 2007), vibration isolation (Krödel et al., 2015), active control of wave propagation (Babaee et al., 2015a,b) and energy harvesting (Gonella et al., 2009; Lv et al., 2013).

The design and optimization of these novel materials architectures call for an enhanced understanding of the microstructure-properties relations when micro-inertia effects or scattering events may start to play a macroscopically observable role. However, homogenization procedures under dynamic loading are still at their infancy compared to classical static homogenization techniques. Among the many difficulties, we can highlight the fact that macroscopic dynamic equilibrium equations do not necessarily follow the Newtonian laws for deformable bodies with a macroscopic

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