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Effective treatment of wave propagation in microstructured media: Dispersion, nonlocality, skin effect, and diffraction

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Abstract

While the overall mechanics of heterogeneous media has been well understood through the celebrated micromechanics approach and its extensive mathematical techniques, the dynamics of microstructured materials present fundamental challenges for treatment with effective descriptions. The ability to assign dynamic effective properties to a homogeneous or gradient medium that would produce the same response as the original microstructured medium is not just academic curiosity, but in fact is critical in developing practical devices with desired performance. Standard homogenization techniques work well when the length scale of the dynamic loading (and correspondingly its time scale) is significantly larger than the microstructural length scale. However, the recent intense interest in dynamic mechanical metamaterials has not been generated at such regime and in fact more often explores length and time scales near resonances. In this talk we will discuss the applicability and limitations of dynamic homogenization techniques. We note the need for frequency dependent and tensorial density and elastic (or compliance) moduli. However, it is shown that dispersive local descriptions will fail to provide correct representation in relatively simple cases. The need for spatial dispersion significantly complicates this effort. Additionally, it is observed that for proper treatment of finite domains (which is essential for any practical

application), the boundary regions of microstructured media must be treated differently than the bulk interior domains, and the depth and properties of this skin region may be determined via numerical optimization. Finally, the microstructure will also lead to diffractive behavior at interfaces which is also associated with its length scale not being negligible compared to the wavelength of interest. While a multi-modal treatment of such systems is possible, the level of complexity of the treatment may be too cumbersome. From a technological perspective, however, a reduced order model of such systems is in fact not impossible to manage given the high computational capacity of easily available modern hardware and software. Such ROMs can be used in optimization and even generative design quite successfully. In summary, this talk presents a number of major challenges and their proposed treatment for effective treatment of microstructured media for applications involving wave propagation. We finish by mentioning some of the future areas of research such as nonlinear analysis and design as well as aperiodic and disordered systems.

Keywords:

Dynamic Mechanical Metamaterials Effective Properties Microstructured Media Reduced Order Modeling