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PAPER

Large scale mechanical metamaterials as seismic shields

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Abstract

Earthquakes represent one of the most catastrophic natural events affecting mankind. At present, a universally accepted risk mitigation strategy for seismic events remains to be proposed. Most approaches are based on vibration isolation of structures rather than on the remote shielding of incoming waves. In this work, we propose a novel approach to the problem and discuss the feasibility of a passive isolation strategy for seismic waves based on large-scale mechanical metamaterials, including for the first time numerical analysis of both surface and guided waves, soil dissipation effects, and adopting a full 3D simulations. The study focuses on realistic structures that can be effective in frequency ranges of interest for seismic waves, and optimal design criteria are provided, exploring different metamaterial configurations, combining phononic crystals and locally resonant structures and different ranges of mechanical properties. Dispersion analysis and full-scale 3D transient wave transmission simulations are carried out on finite size systems to assess the seismic wave amplitude attenuation in realistic conditions. Results reveal that both surface and bulk seismic waves can be considerably attenuated, making this strategy viable for the protection of civil structures against seismic risk. The proposed remote shielding approach could open up new perspectives in the field of seismology and in related areas of low-frequency vibration damping or blast protection.

1. Introduction

Of all the possible natural hazards, earthquakes are among the most catastrophic in terms of human, socio-economic and environmental impacts. Every year more than a million earthquakes (roughly two earthquakes per minute) occur worldwide, accounting for nearly 60% of all disaster-related mortality [1, 2]. Traditional seismic isolation systems aim at extending the lifetime of protected structures by means of various passive, active and hybrid control techniques [3, 4]. In general, these systems are inefficient for large earthquakes and cannot be adapted to structural changes [5]. In addition, they produce dangerously large horizontal displacements [6] and ignore soil-foundation interactions that play a key role in the overall earthquake response of buildings [7]. The dynamic behaviour of a structure embedded in the ground is included in a recently-proposed type of foundation with incorporated vibrating inclusions, which can significantly reduce seismic wave energy in certain frequency ranges [5]. However, newly built foundations cannot be used to protect existing buildings of civil, historical, cultural or economic importance. The attenuation of seismic waves before they reach critical targets would be a largely preferable strategy, additionally providing the means to protect distributed areas rather than individual structures. This approach can be implemented via seismic wave barriers made of mechanical metamaterials (phononic crystals and locally resonant metamaterials), which provide wave manipulation possibilities,