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Non-Linear Elastic Response of Layered Structures, Alternating Pentamode Lattices and Confinement Plates

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Abstract

We study the mechanical response under large elastic strains of pentamode layers confined between stiffening plates, and the potential use of such systems as novel seismic isolation and impact protection devices. We analyze pentamode materials that exhibit three soft deformation modes in the infinitesimal stretching regime that follow by the presence of perfectly hinged connections between the rods. The response of these metamaterials under large elastic strains is characterized by an elastic-stiffening effect in terms of the lateral force-displacement response, which increases in the presence of rigid connections and decreases by increasing the number of layers. Our results lead us to conclude that the analyzed pentamode metamaterials can be effectively employed as novel, performance-based devices for seismic and mechanical vibration protection, by designing the lattice geometry, the stiffness properties of the joints, and the lamination scheme in a suitable manner and as a function of the operating conditions.

1. Introduction

In the last few years, mechanical and acoustic metamaterials have attracted the attention from different areas of research because of their unique behavior. Such smart materials are artificial structured lattices whose mechanical properties are mainly derived by their geometrical structure rather than their chemical composition (refer, e.g., to papers [1][2]). The class of "extremal materials" has been introduced in [3] to define materials that behave as extremely stiff in some deformation modes while very soft in others. These are called uni-mode, bi-mode, tri-mode, quadra-mode and penta-mode materials, from the number of small deformation modes they can achieve. This definition applies to a special class of mechanical metamaterials - composite materials, structural foams, cellular materials, etc. - which feature special mechanical properties. A specific category of extremal materials, called pentamode metamaterials, have received particular attention in the literature. In particular, 3D printing techniques have been employed to manufacture such materials both at the macroscale [4][5] and microscale [6].

Pentamode metamaterials have five very small eigenvalues, meaning that they are very soft in five out of six principal directions of the elasticity tensor. This means that they show a very large bulk modulus (B), as compared to their shear modulus (G). The properties peculiar to pentamode metamaterials lead them to be suitable for many applications, such as transformation acoustics and elasto-mechanical cloak (refer, e.g., to [7]-[10] and the references therein). Their potential in different engineering fields is still only partially explored.

One of the most promising application is the field of protection of structures from dynamic excitations either mechanically as well as naturally induced. For instance, while well established design and construction techniques exist to prevent the collapse of structures during seismic events, the requirement of limited damage was not often considered of paramount importance. Recently instead the structural engineering community recognized the importance to further investigate