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Wave propagation in undulated structural lattices

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ABSTRACT

This work investigates wave propagation in undulated square structural lattices. The undulated pattern is obtained by imposing an initial curvature to the lattice's elements. The study considers both periodic undulated structures, in which the undulation is uniform throughout the structure as well as graded undulated patterns, in which the undulation is modulated within the lattice. Undulation is specifically considered in relation to its ability to induce anisotropy in the equivalent mechanical properties and to break the symmetry of the straight square lattice. Results show that wave motion is inhibited within specified frequency ranges owing to the generation of band gaps, and in specific directions as a result of the undulation-induced anisotropy.

1. Introduction

Lattice structures are extensively used in many branches of engineering, such as civil, mechanical and aerospace. Of interest are lattices' mechanical vibration filtering (Martinsson and Movchan, 2003) and wave steering capabilities (Spadoni et al., 2009), which make them suitable for the design of mechanical metamaterials (Deymier, 2013; Hussein et al., 2014). The lattice topologies that have been investigated include for example square, triangular, hexagonal, re-entrant, Kagome and chiral (Casadei and Rimoli, 2013; Gonella and Ruzzene, 2008; Phani et al., 2006; Spadoni et al., 2009), among others. Recently, different approaches have been proposed in order to achieve performance flexibility and properties tunability, for example multi-stable magneto-elastic lattice structures exploit the rearrangement of the topology due to the interaction between mechanical instabilities and magnetic forces, which leads to changes in wave propagation properties (Schaeffer and Ruzzene, 2015). Another example are reconfigurable cell symmetry lattices, where relaxation of the unit cell symmetry is achieved by endowing the lattice with piezoelectric patches shunted to resonant circuits, then tuning the local stiffness of the structure by modifying the relative circuital characteristics (Celli and Gonella, 2015). Topology reconfiguration is an active topic of research in the field of soft materials (Bertoldi and Boyce, 2008), whereby mechanical and wave propagation properties adaptation is sought as a result of topological changes induced by externally applied loads (Shim et al., 2015; Wang et al., 2013). Patterns obtained through topology reconfiguration can be adapted through a formal design process for structural lattice materials, whose properties differ substantially from equivalent straight beams with the same connectivity (Liebold-Ribeiro and Körner, 2014). The presence of curved elements also radically affects the dynamic behavior of the structure, as previously shown for periodically undulated beams and plates (Trainiti et al., 2015) and structural lattices (Warmuth and Körner, 2015). Similar change in behavior is seen in square zigzag lattice structures, in which the presence of bent arms introduces band gaps and favors directional propagation (Wang et al., 2014).

This paper investigates the wave properties of undulated lattice structures by means of a numerical Bloch–Floquet analysis. Band diagrams and group velocity plots for periodic undulated lattices of different configurations, geometrical and material parameters are evaluated and discussed. As expected, the results show that wave propagation properties of lattice structures are highly affected by the specific undulation pattern, which can be the result of a design process, but may also be triggered by static or dynamic loading. For instance, one-dimensional post-buckled structures display an induced undulated pattern, in which finite deformations are source of nonlinearity (Maurin and Spadoni, 2014a, 2014b). In contrast to straight lattices, where the bending stiffness of the elements is decoupled from and much smaller than the axial stiffness, in undulated structures longitudinal and flexural modes strongly interact to produce band gaps, wave speed reduction and wave directionality. The analysis presented in the present work is limited to square undulated lattices, but the effect of undulation can be investigated for other lattice configurations, such a triangular or hexagonal, and

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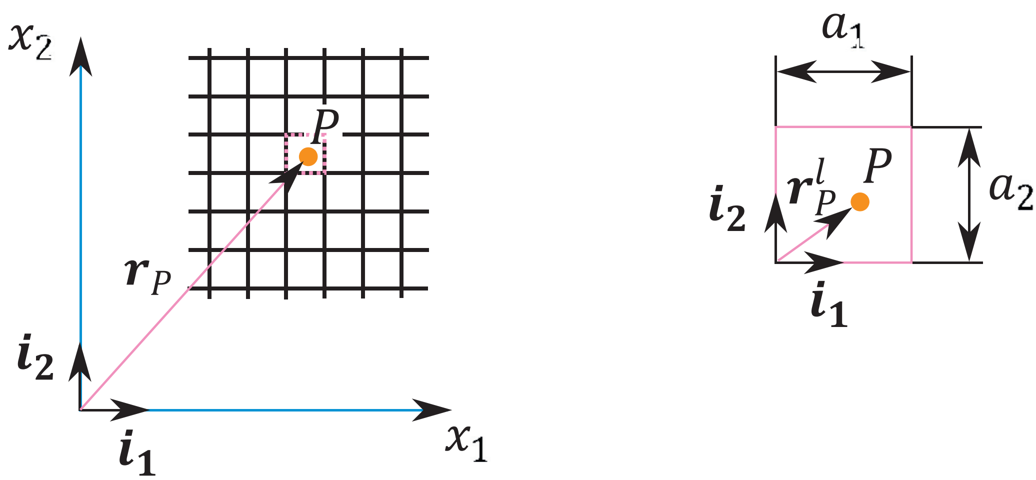
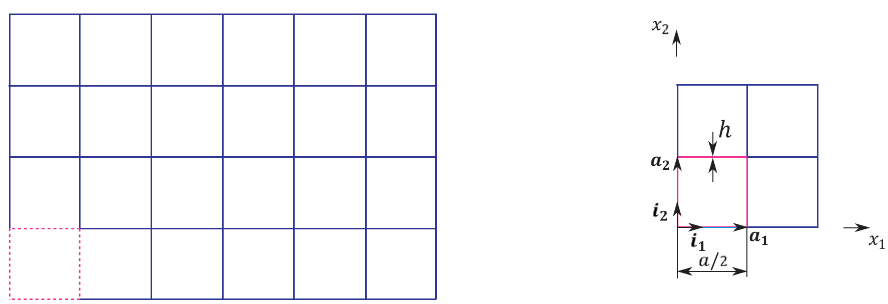
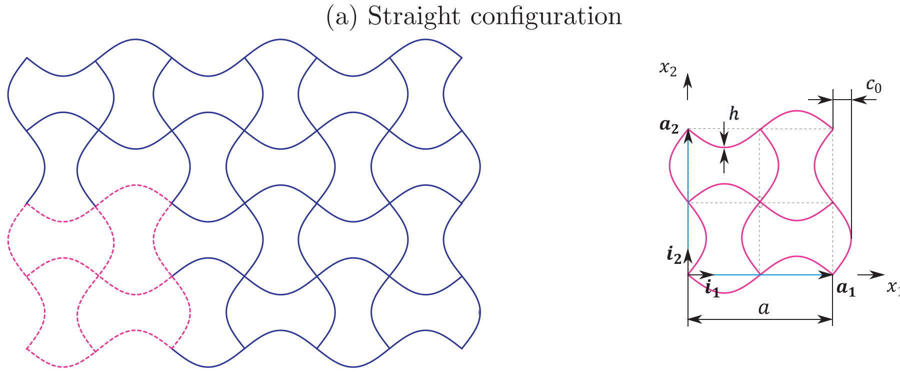


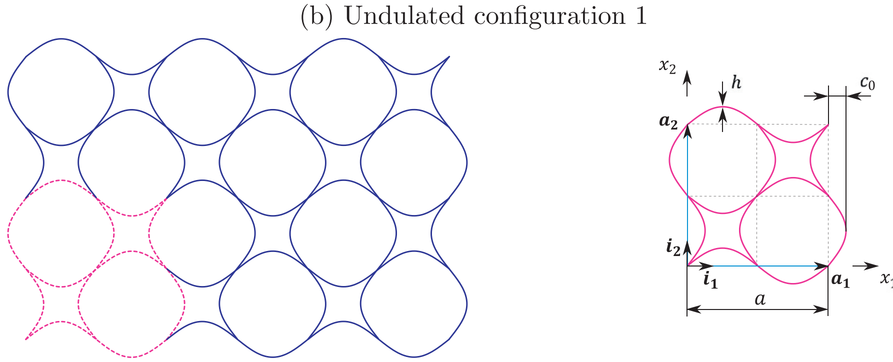
Fig. 1. Position vector $\mathbf{r}_P$ and local position vector $\mathbf{r}^l_P$ of a point P belonging to the lattice.



(a) Straight configuration



(b) Undulated configuration 1



(c) Undulated configuration 2

Fig. 2. Periodic straght and undulated lattice configurations 1 and 2 (left) with relative unit cells (right). The size of the undulated lattices unit cell is twice the size of the straight lattice unit cell.