PHONONICS 2019: 5th International Conference on Phononic Crystals/Metamaterials, Phonon Transport and Topological Phononics

Tucson, Arizona, USA, 3-7 June 2019

PHONONICS-2019-0080

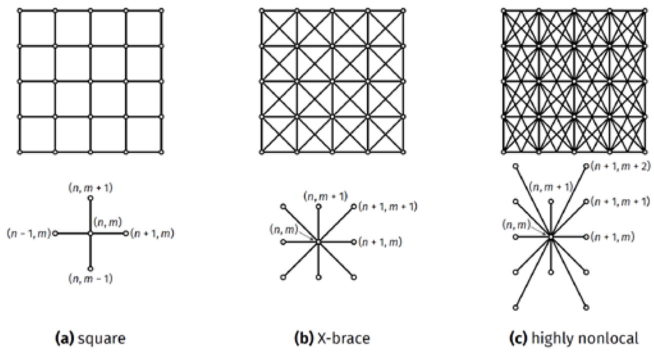
Recent Findings and Perspectives in "Zero-Frequency" Phononics

Eduard G. Karpov, **John T. Klein, Larry A. Danso**

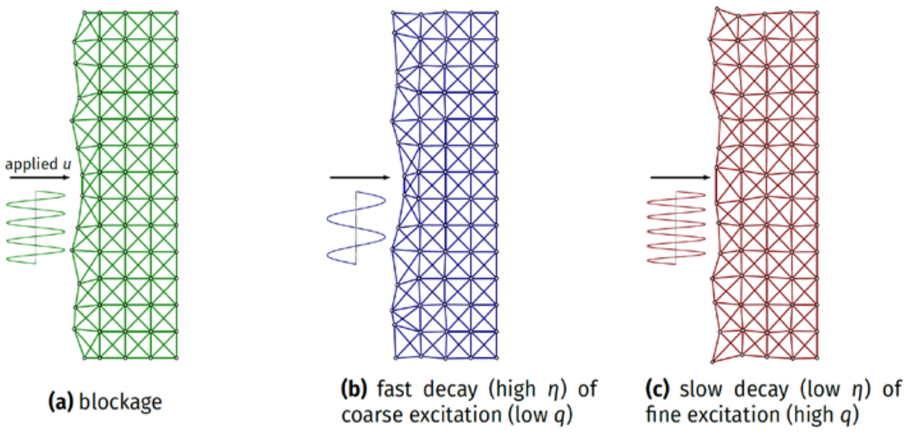
Department of Civil & Materials Engineering, University of Illinois at Chicago,
842 W Taylor St, Chicago, IL 60607, U.S.A.
ekarpov@uic.edu, jklein27@uic.edu, lappia2@uic.edu

Abstract: We discuss some recently realized anomalous quasistatic phenomena in highly non-local periodic lattice materials. They include pressure wave blockade, Saint-Venant's principle violation, non-monotonous Shannon's entropy behavior, and strain energy redirection at super-low actuating frequencies or at initial stages of impact loads, when oscillatory processes are not yet established in the material.

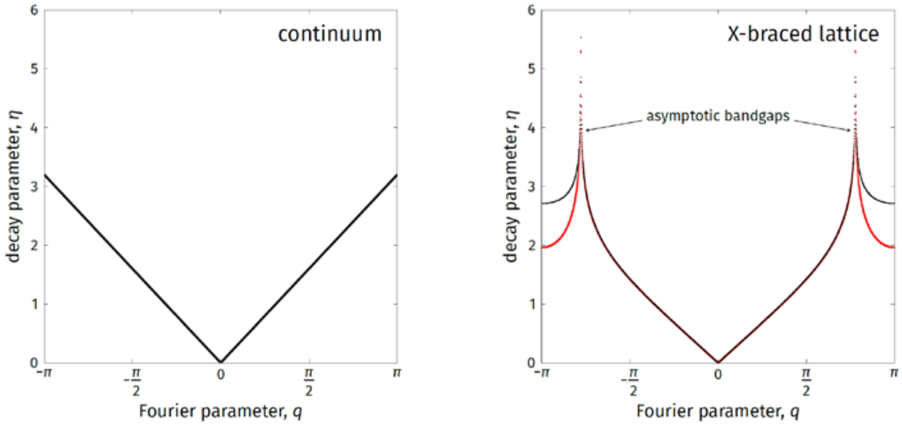
Mechanical metamaterials represent a novel interesting class or structural composites that manifest behaviors beyond the scope of traditional materials mechanics [1-3]. Those include negative elastic moduli and basic symmetries breaking, such as reciprocity of mechanical deformation. The ongoing research aims to understand relationships between a desired property, which often corresponds to an exotic domain in the overall design space, and the material's internal structure. Other studies use multistabilities at the unit cell level to deploy a load-induced polymorphic phase transformation in an entire material sample, resulting in unexpected outcomes.



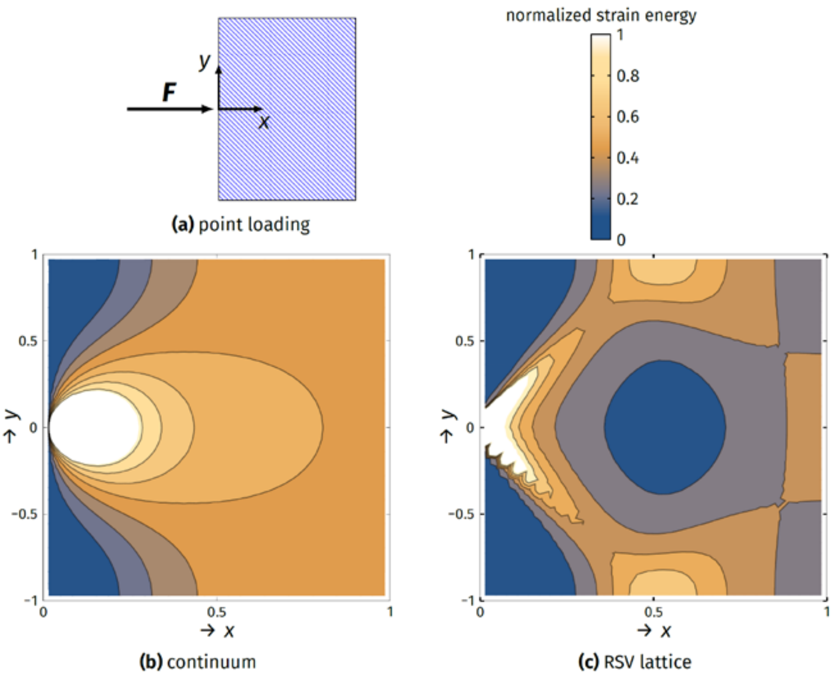
Studies by our group suggest that properly designed highly nonlocal periodic lattices can also provide metamaterials with anomalous spectral properties leading to reversal of the Saint-Venant's edge effect. This phenomenon, in turn, suggests broad opportunities for the quasistatic strain energy control and redistribution by design. The reverse Saint-Venant's (RSV) metamaterials invented by our group [4-5] are structured as lattice networks (Figure on the right), exploit geometry and connectivity of elastic members in order to realize a host of unconventional macroscopic responses. For instance, lattices with a high degree of non-local connections, where elastic connections extend beyond only nearest neighbors on the nodal grid, exhibited fast decay of coarse surface fluctuations as well as slow decay of fine surface fluctuations. These phenomena oppose the behavior of continuum solids where coarse patterns of surface strain dissipate over longer distances compared to fine patterns of surface strain. In addition to this inverse reaction to the applied pattern of deformation, highly non-locally interacting lattice structures showed other anomalous effects in response to surface excitation including near-surface deformation arrest or blocking, filtering and phase shifts. Anomalous behavior of the entropy of deformation is also expected [6]. None of these effects are seen in continuous solids or even simpler two-dimensional lattice structures [7-8].



Reversal of Saint-Venant's effect occurs when coarse modes of strain fluctuation dissipate slowly with distance while fine modes of strain fluctuation dissipate quickly. In addition to exhibiting these two scenarios, RSV lattices are able to completely block some modes of strain fluctuation at the surface (Figure above).



Coarseness or fineness of applied surface strain is measured by the Fourier parameter, the wavenumber q. Low q corresponds to coarse surface excitations while high q corresponds to fine surface excitations. The rate at which a static mode of deformation decays with distance is defined by the exponential decay parameter η. The deformation decay spectrum, or Raleigh spectrum shows the η-distribution as a function of q. In highly nonlocal lattices, the deformation decay spectrum can be engineered to control which types of loading patterns are amplified, filtered or blocked. Deformation decay spectra are shown in Figure on top for a continuum material and the X-braced lattice. The continuum solution shows a monotonous relationship between q and η, adhering to Saint-Venant's principle. The X-brace lattice is designed to exhibit simultaneous bandgaps in both degrees of freedom. At the bandgap, the Fourier mode will be blocked; stresses will not propagate to more internal nodes. The non-monotonous decay spectrum leads to the reversal of St.-Venant's effects where coarse modes (low q) decay faster than fine modes (high q).



Highly non-local metamaterials are capable of directing how stresses translate through the medium. Proof of concept is demonstrated in Figure on the right. The material drastically manipulates the strain energy distribution, inverting and bending the flow of energy. A major goal of the study is to provide the design criteria and numerical procedures to influence the distribution of energy over the area of 2D plate-like materials and through the volume of 3D materials.

References

[1] T. Klatt, M. R. Haberman, *Journal of Applied Physics* **114**, 033503 (2013).
[2] Y. Wu, Y. Lai, Z.-Q. Zhang, *Physical Review Letters* **107**, 105506 (2011).
[3] J. Qu, M. Kadic, M. Wegener, *Applied Physics Letters* **110**, 171901 (2017).
[4] E. G. Karpov, *Acta Materialia* **123**, 245-254 (2017).
[5] L. A. Danso, E. G. Karpov, *Materials* **11**(10), 2050 (2018).
[6] E. G. Karpov, L. A. Danso, *International Journal of Mechanical Sciences* **148**, 676-683 (2018).
[7] N. A. Fleck, X. Qiu, Journal of the Mechanics and Physics of Solids 55, 562–588 (2007).
[8] A. S. Phani, N. A. Fleck, Journal of Applied Mechanics 75, 021020 (2008).