

Strongly Nonlinear Waves at the Mesoscale: Design of Metamaterials

Opportunity

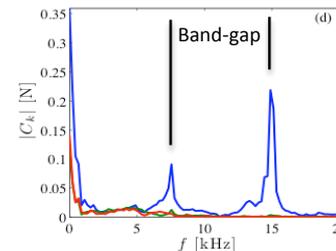
Recent investigations of impact or vibrational excitation of granular media have uncovered unprecedented wave phenomenology ranging from energy trapping and impact mitigation [2] to mechanical band-pass filters [3], the “acoustic diode” effect [4] and acoustic switching and rectification [5]. These emanate from the discrete composition of granular media, the nonlinear relationship between force and displacement between grains and the system’s extreme sensitivity to external load. The interplay between these nonlinear features promote the design and construction of metamaterials for wide ranging applications.

Meso Challenge

- How can remote sensors be incorporated within a 2/3 D granular medium without disrupting wave behavior?
- How can numerical methods capture the contact physics in grain collections without ultra-fine mesh resolution? For example, contact physics occurs in 10^{-5} m range for 10^{-2} sized grains.
- How can grain arrangement and composition be optimized for impact mitigation/enhancement or defect detection in other materials?
- How can mesoscale phenomena inform collective behavior in large heterogeneous systems (e.g. “singing sands”, seismicity in jointed rock, impact of loosely consolidated asteroids)?

Approach

Coupling experimental and numerical techniques demands state-of-the art sensor networks capable of being placed within the meso-structure while remotely communicating their data at microsecond time intervals. Finite element methods may be enhanced with local surface curvature information to improve contact physics while reducing the computational cost of prohibitive mesh refinement.



Experiment showing Band-gap in Strongly Nonlinear Metamaterial

Anomalous wave reflection (R) at the interface of two granular chains with a high impedance mismatch [1].

Impact

All of these newly emergent phenomena occur in collections of 10-100 grains! Fewer particles do not allow time for self-organization and many more may dissipate interesting phenomena. Understanding the complex behavior at the meso-scale provides the foundation for novel design of metamaterials with enhanced energy absorption and transmission properties for wide-ranging applications in condensed matter physics.

- References: 1. Daraio, Nesterenko, Herbold, Jin, PRL, 96, 058002 (2006).
 2. Herbold, Nesterenko, APL, 90, 261902 (2007).
 3. Herbold, Kim, Nesterenko, et. al., Acta Mech. 205, 85 (2009).
 4. Nesterenko, Daraio, Herbold, Jin, PRL, 95, 158702 (2005).
 5. Boechler, Theocharis, Daraio, Nature Mater., 10, 665 (2011).