Utilizing Meta-Structures for Mitigating Low Frequency Groundborne Train Vibrations

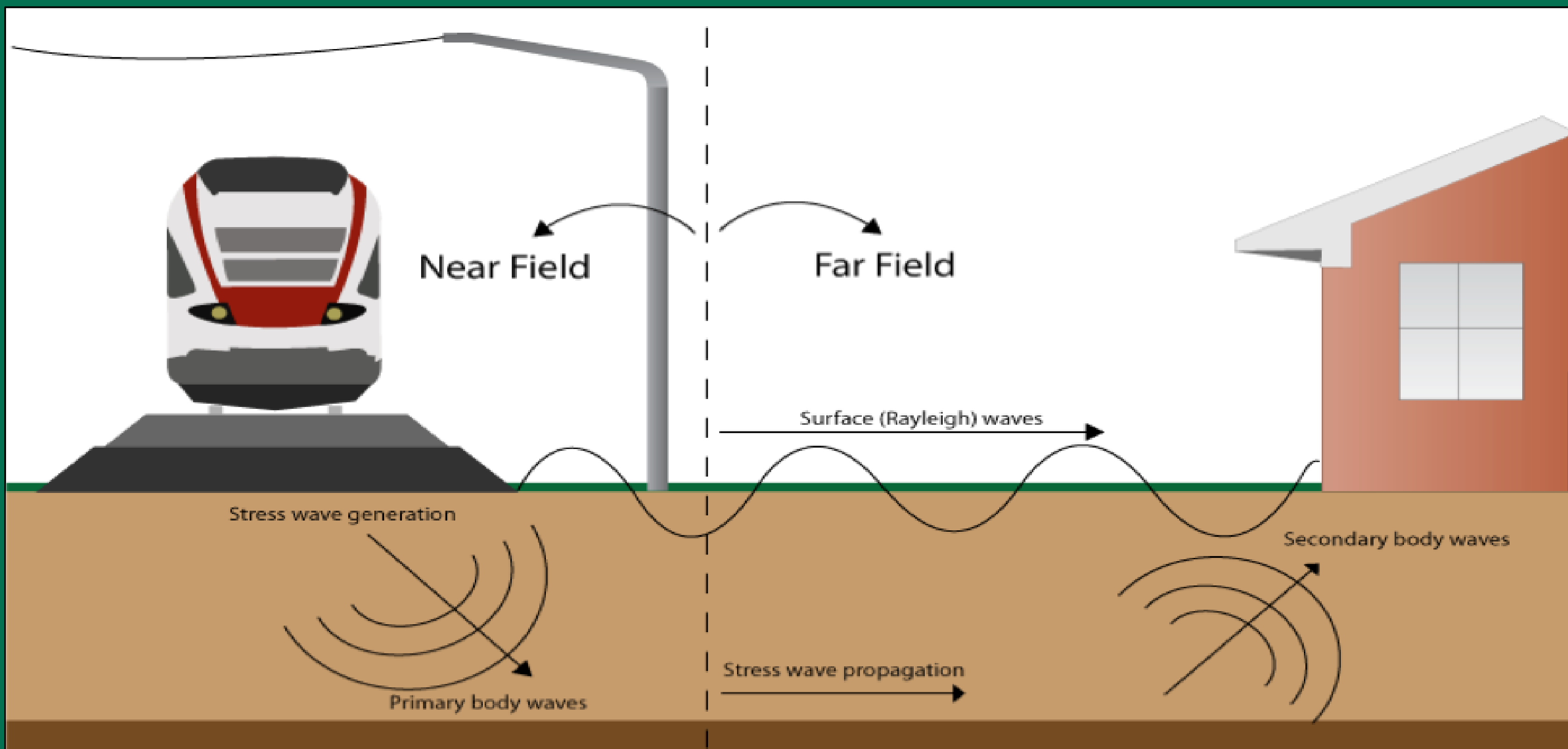
Christopher Layman

ATS Consulting, Senior Associate

Pasadena, CA

Rail Conference APTA

Groundborne Train Vibrations

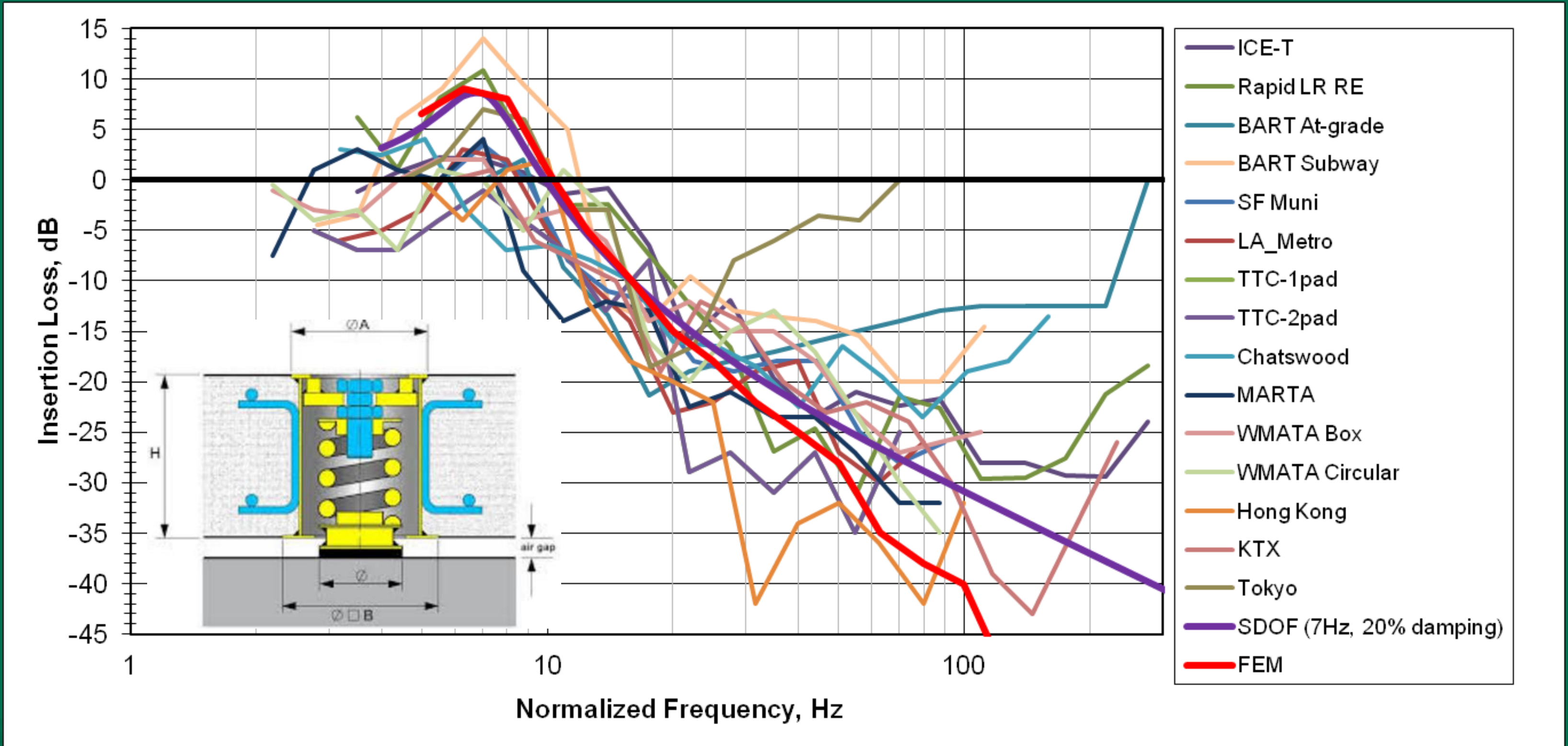


Mitigation of Groundborne Vibrations

- Source
  - Track/Vehicle Maintenance
  - Resilient Fasteners/FST (mid to high freq)
- Path
  - Impedance Barriers
- Receiver
  - Building Treatments

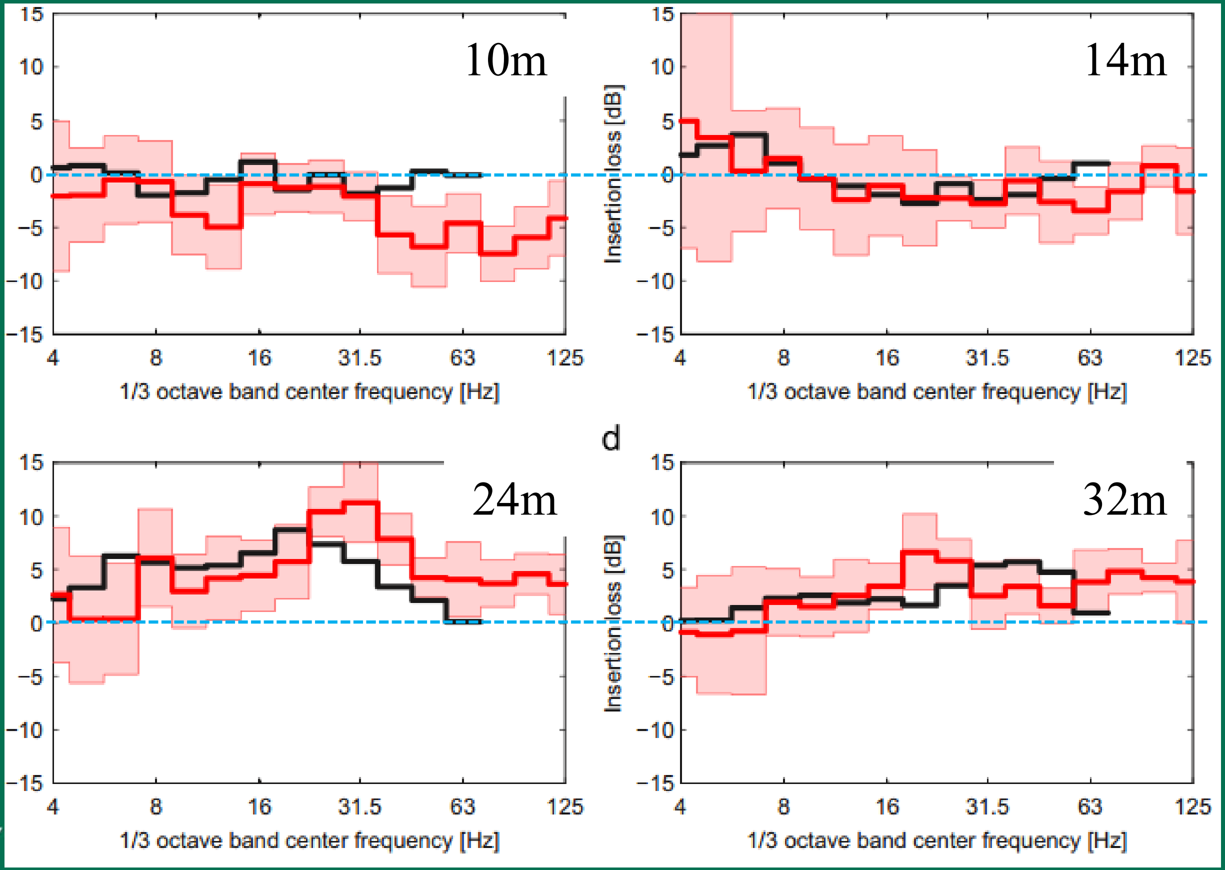
Source Mitigation

Typical Floating Slab Performance



Path Mitigation

Typical WIB Performance



Soil Dynamics and Earthquake Engineering 77 (2015) 238–253

Path Mitigation

- Wave impeding blocks generally follow Mass Density Law: TL = 10 Log$[1+(\frac{\rho\ d\ \omega}{2\ z0})^2]$
- Low Frequencies hard to mitigate. To increase the TL by 6 dB requires doubling ρ or d, may be impractical

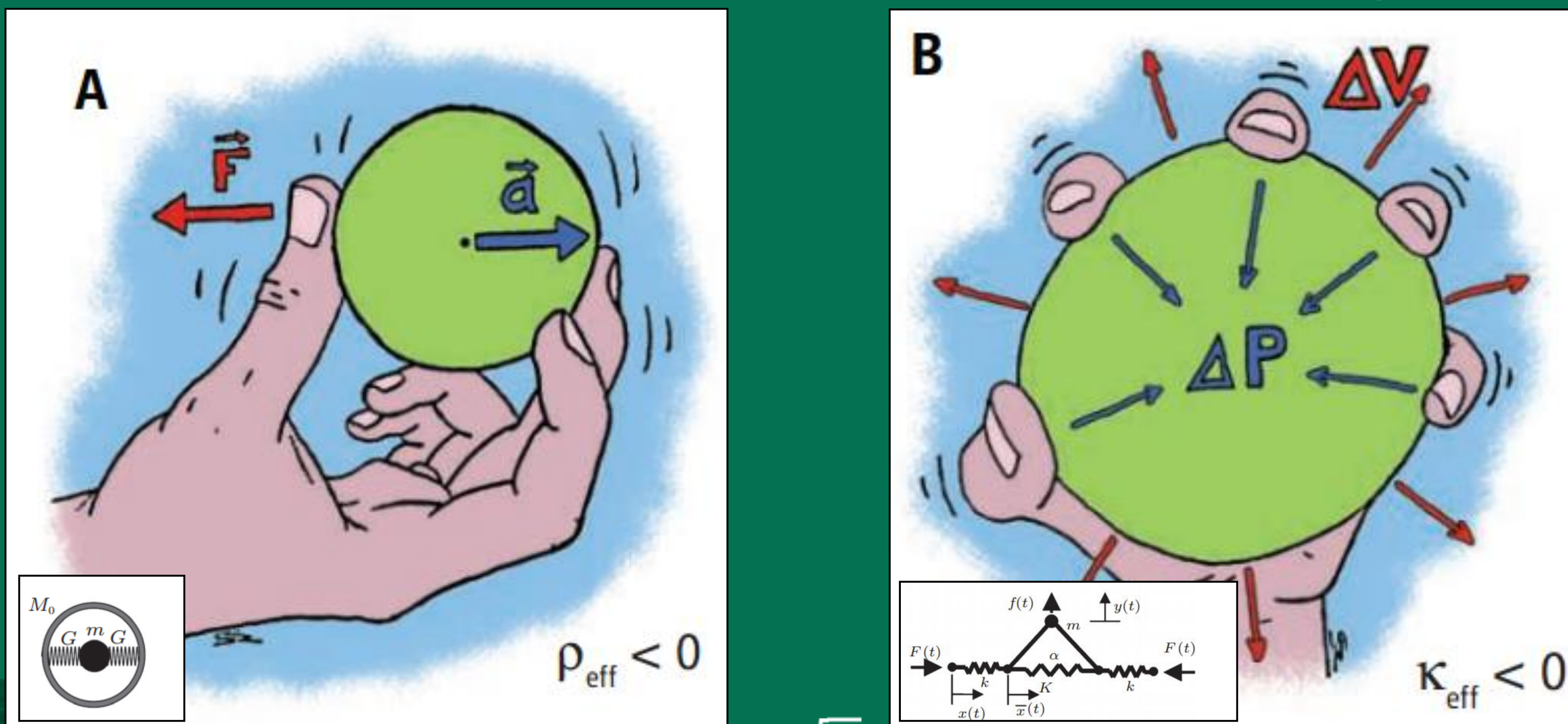
Metamaterials !

- *<u>Definition</u>*: Artificially structured materials used to control and manipulate light, sound, and other physical phenomena. "On-Demand" properties.

- *Common Properties*:
  - Repeating elements much smaller than the probing wavelength. Effective medium applies.
  - Bulk properties based on both on composition and geometry.

Negative Mass & Negative Compression

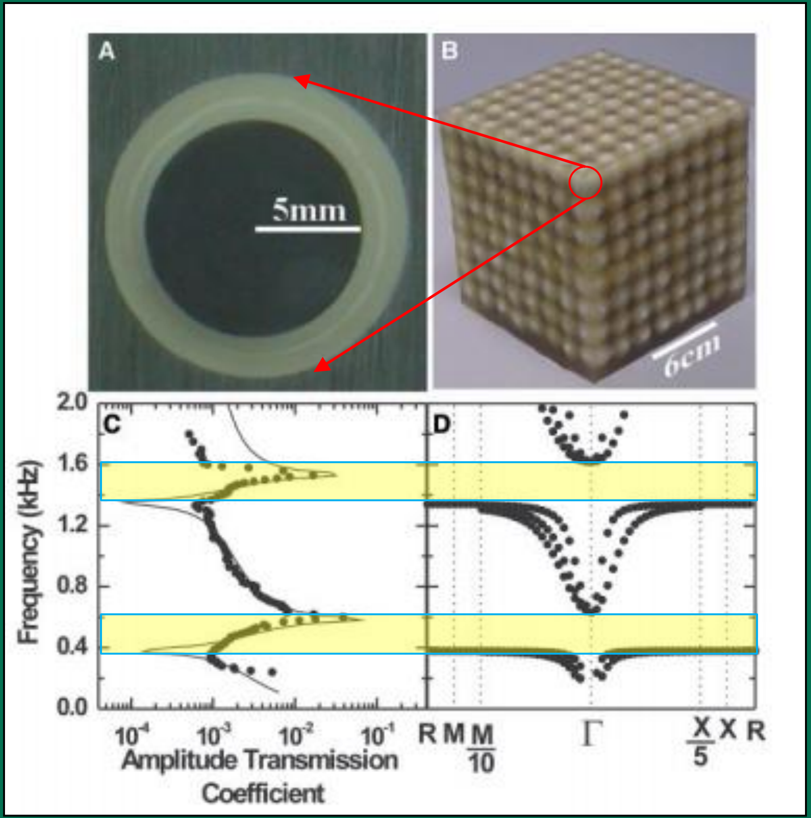
- Object with resonant frequency ω_0
- Forcing is in-phase when $\omega < \omega_0$
- Forcing is out-of-phase when $\omega > \omega_0$



Wave Speed $= \sqrt{\frac{K}{\rho}}$

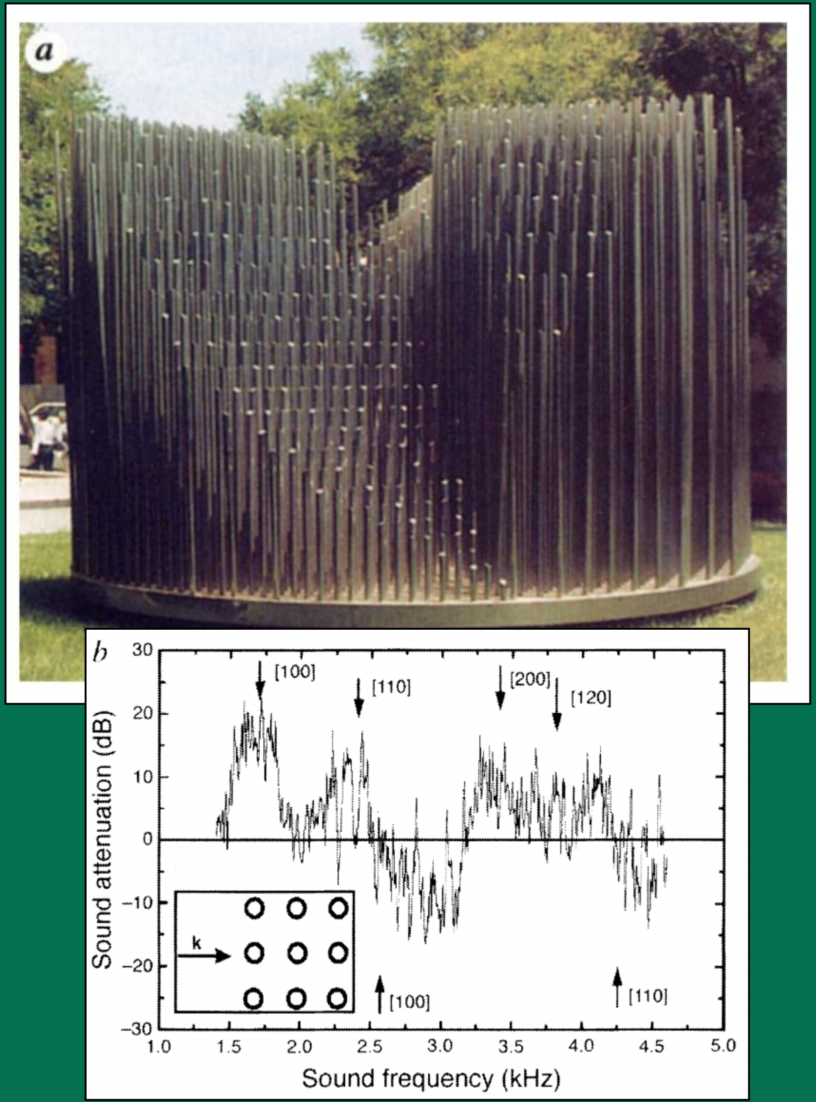
Metamaterial Examples

Extreme Absorbers



Z. Liu et al., Science 289, 1734 (2000)

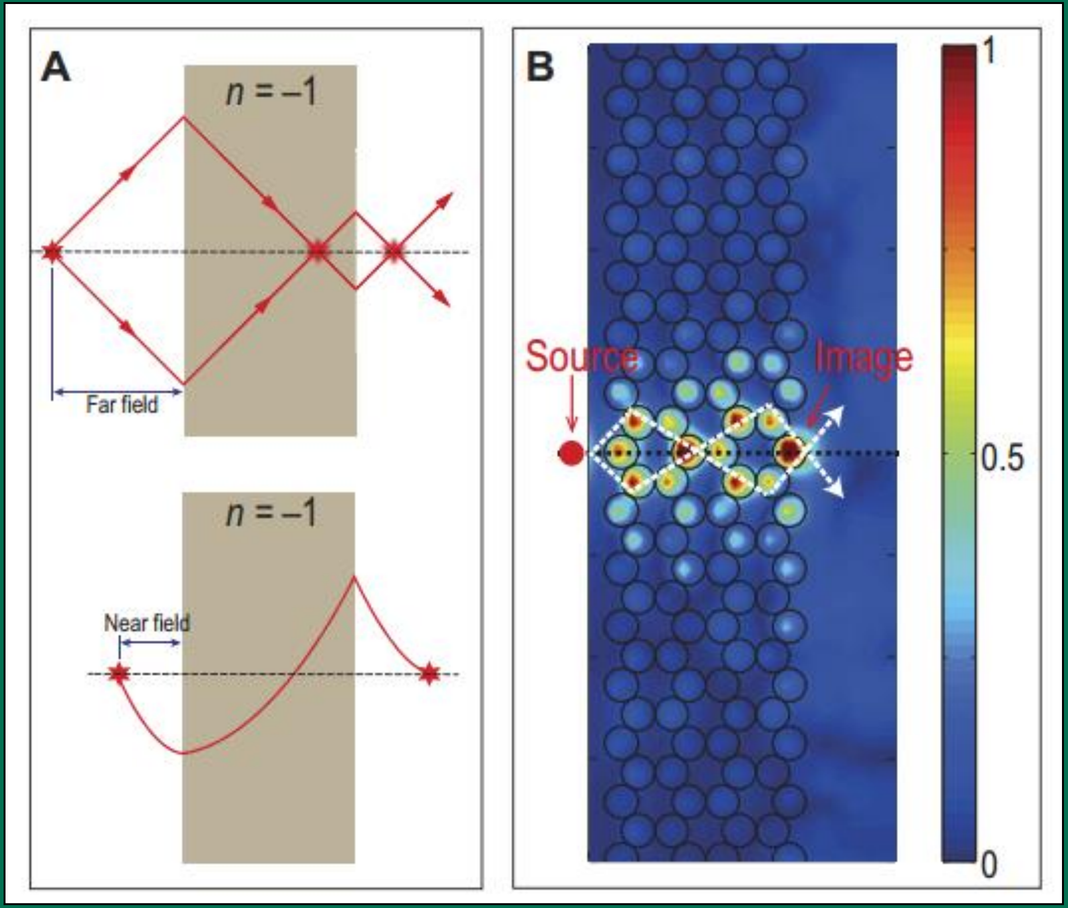
Extreme Reflectors



Nature **378**, 241 (16 November 1995);

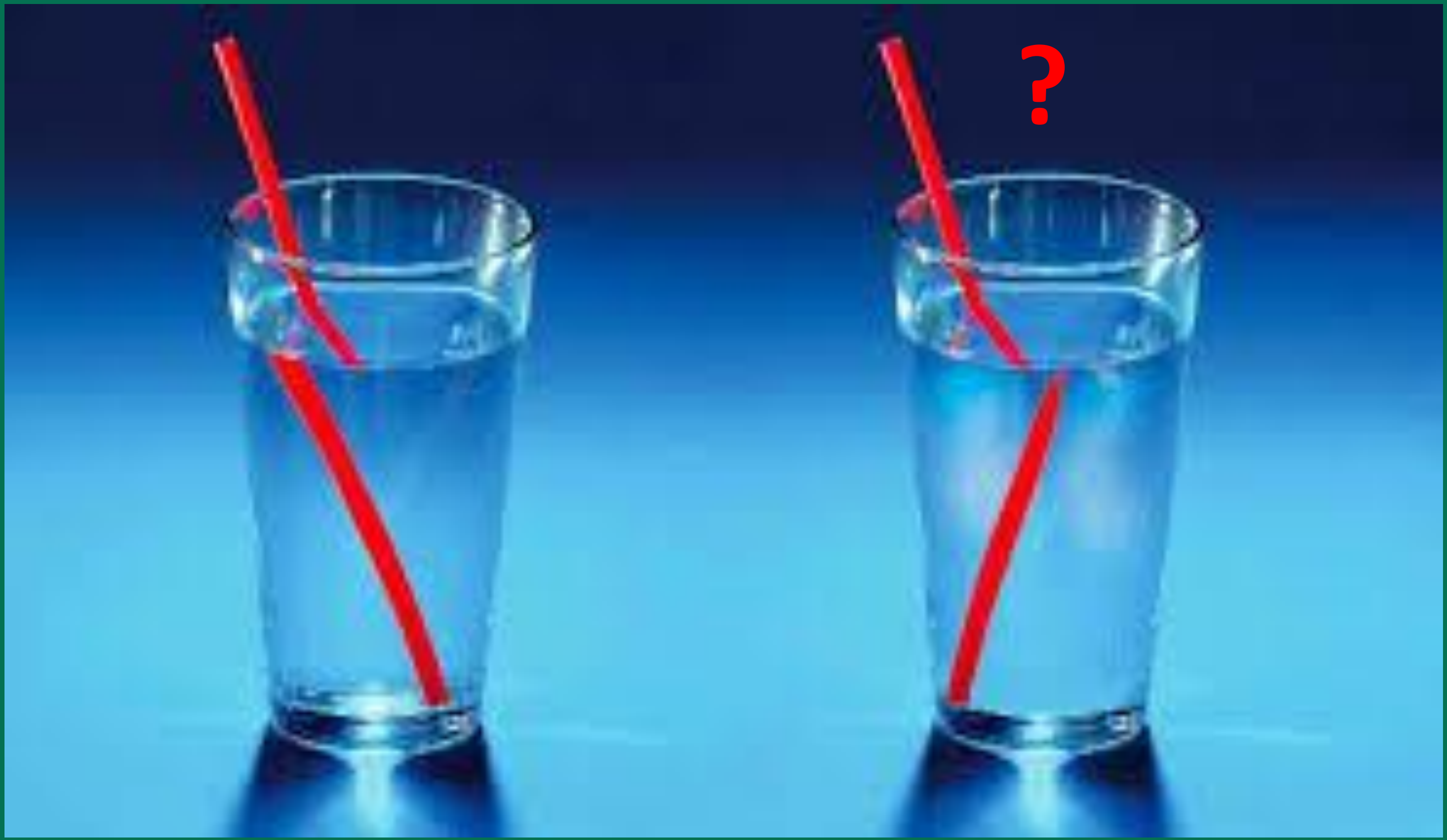
Metamaterial Examples

Flat Lenses (Negative Media)



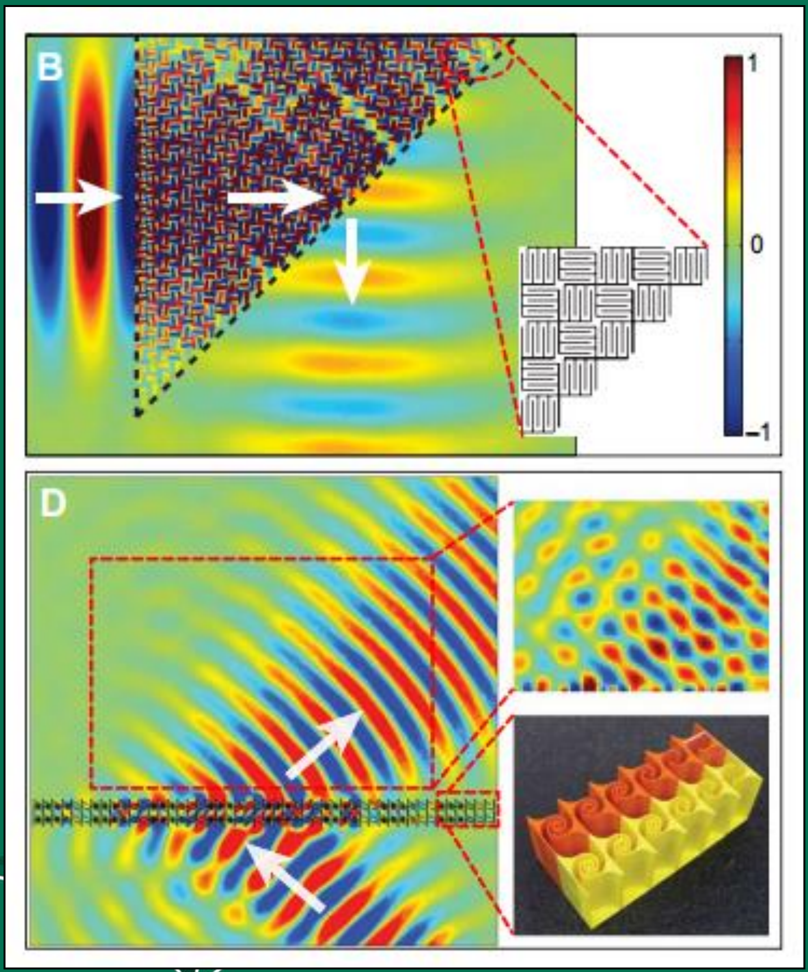
Kaina et al., Nature 525, 77–81 (2015)

Negative Index of Refraction



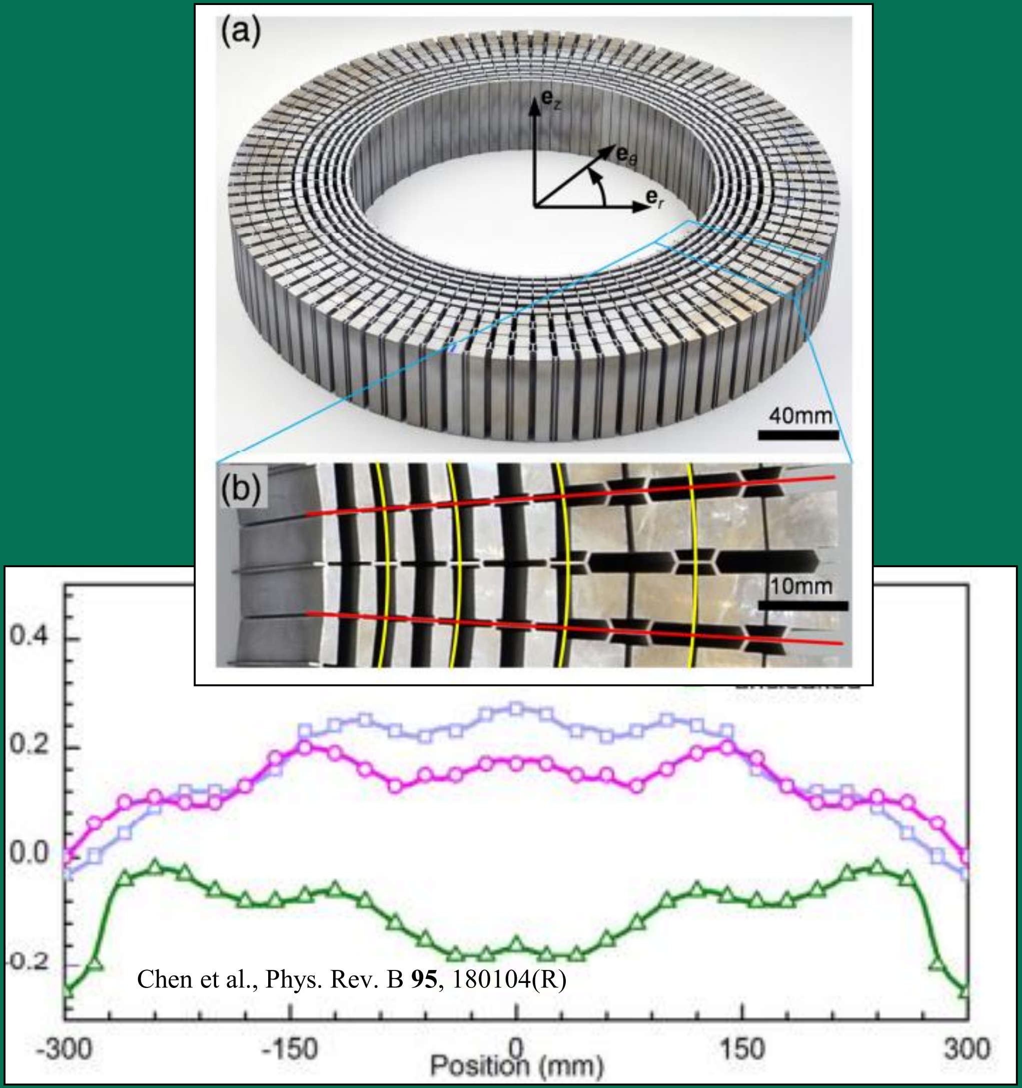
Metamaterial Examples

Custom Refraction



Z. Liang, J. Li, Phys. Rev. Lett. 108, 114301 (2012).

Cloaking



Chen et al., Phys. Rev. B **95**, 180104(R)

Low Frequency Vibration Mitigation With Metamaterials

Two Approaches for Mitigating Groundborne Vibrations with Metamaterials:

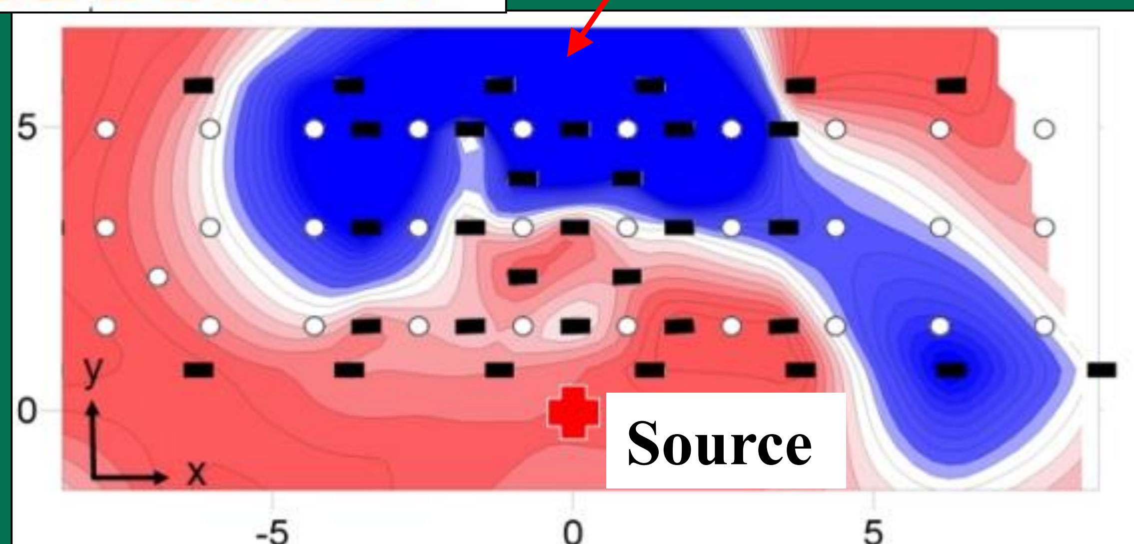
1. Absorption / Reflection
2. Redirecting / Steering

Reflection Based Metamaterials

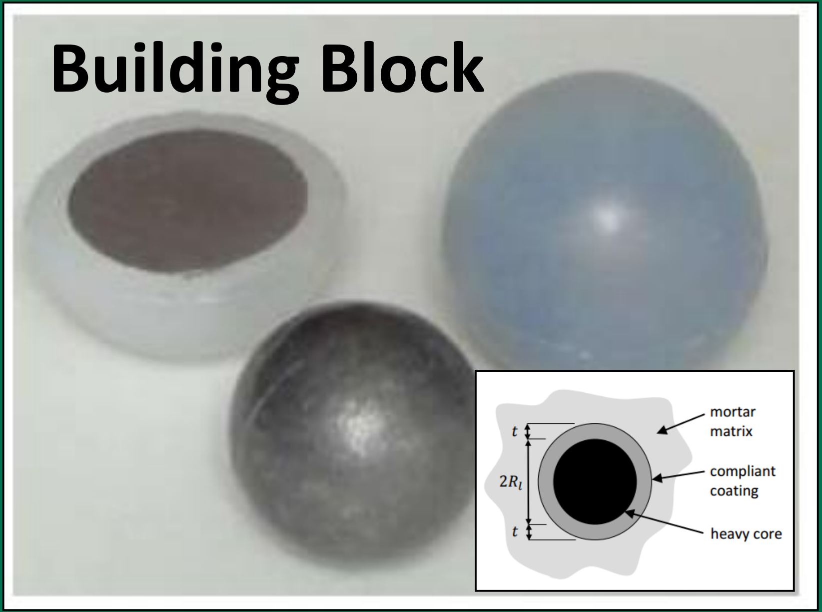
Brule et al., PRL 112, 133901 (2014)

Periodic
Boreholes
5 Meters
Deep

Low
Transmission



Absorption Based Metamaterials
New Structural Building Material: Meta-Concrete!



Mitchell, PhD Thesis, 2015

Traditional Aggregate

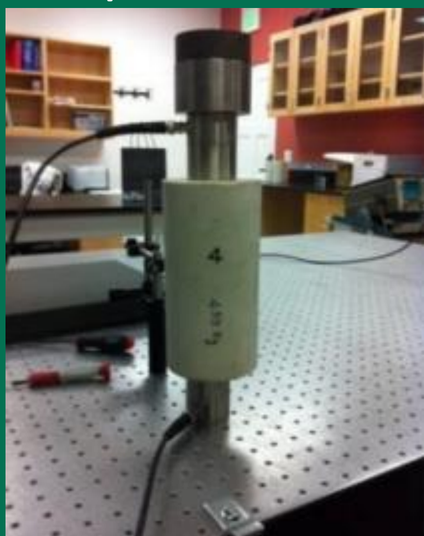
Concept: A modified concrete where traditional aggregates are replaced by resonant engineered inclusions.

Inclusions Consist of:

- Heavy core (high density such as lead)
- Compliant outer layer (e.g. silicone)

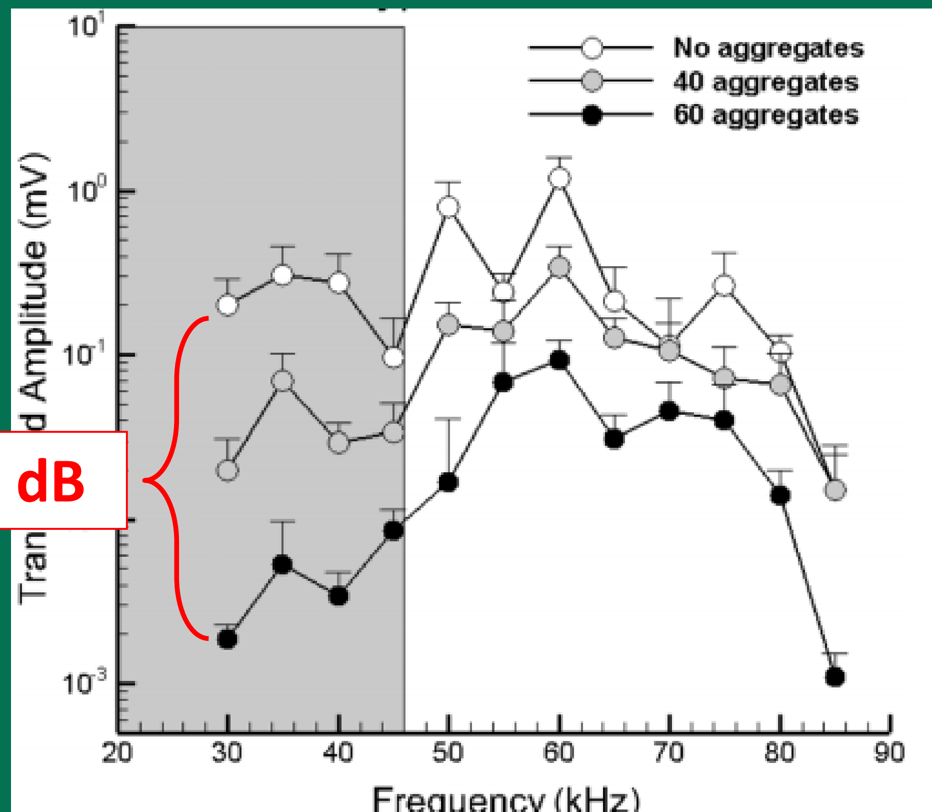
Absorption Based Metamaterials
New Structural Building Material: Meta-Concrete!

Small Scale Experiments



Transmission Through Meta-Concrete

40 dB

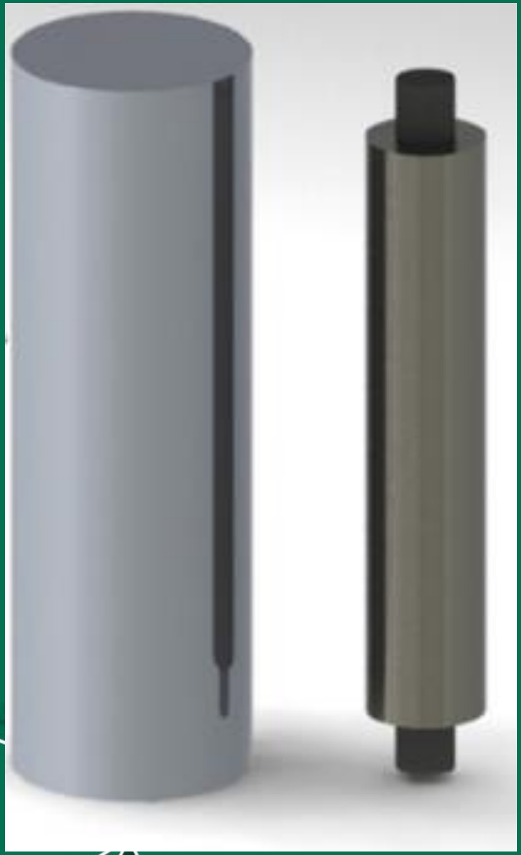


Pandolfi et al., J. Appl. Mech. 84 031001, 2017

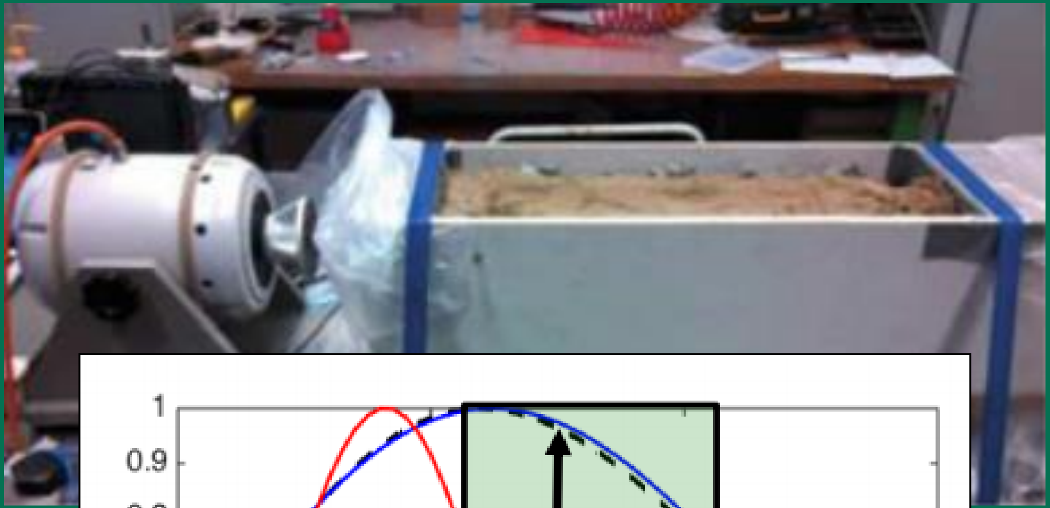
Absorption Based Metamaterials

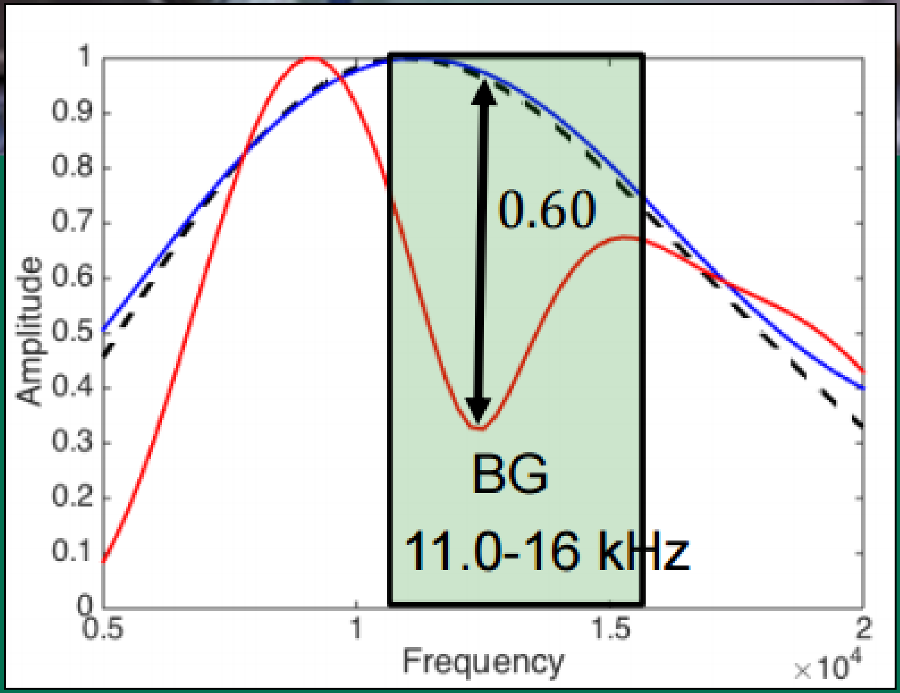
Buried Inertial Resonators

Cylindrical Tube with Heavy Suspended Core



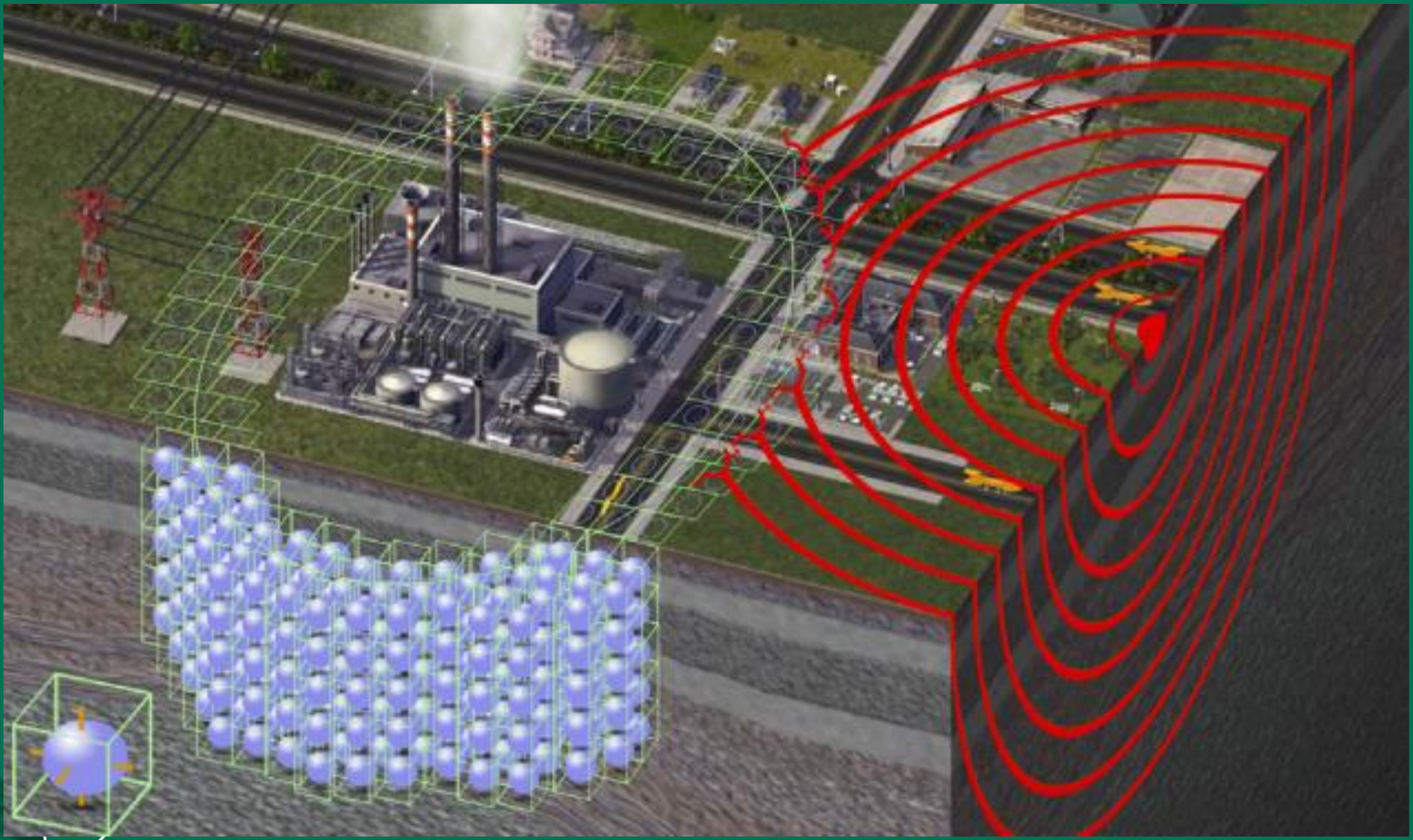
1:30 Experiments





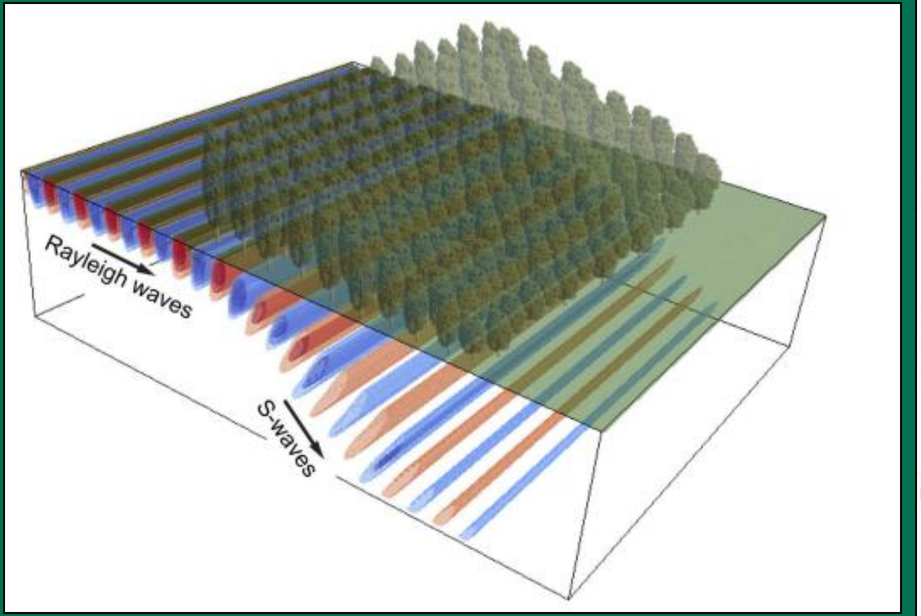
Absorption Based Metamaterials

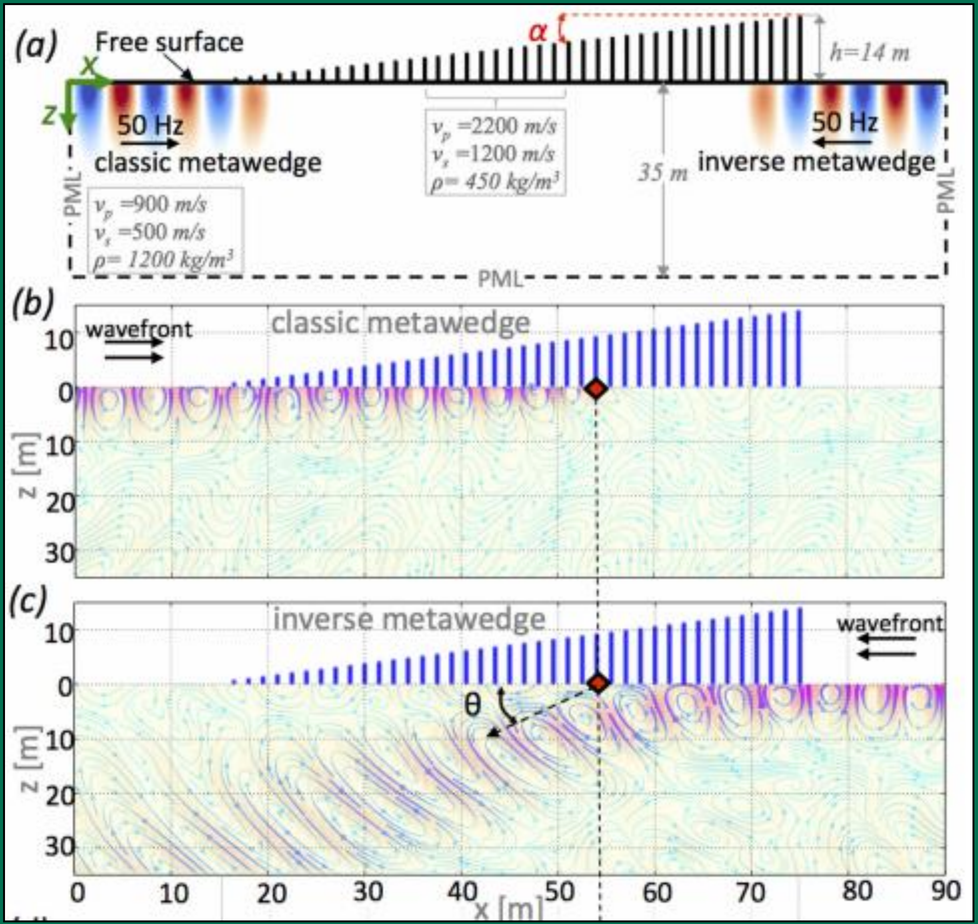
Large Scale Protection



Steering Based Metamaterials

Seismic Meta-Wedge

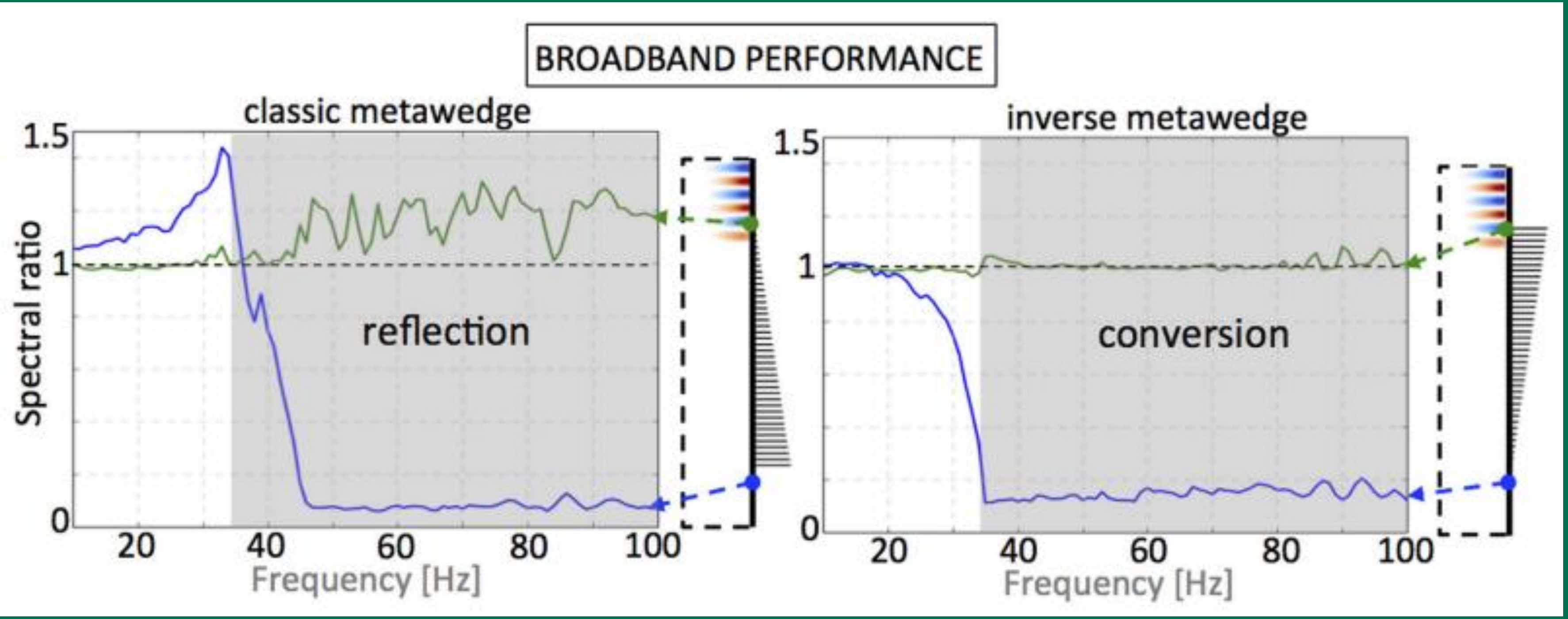




Colombi et al., DOI: 10.1038/srep27717

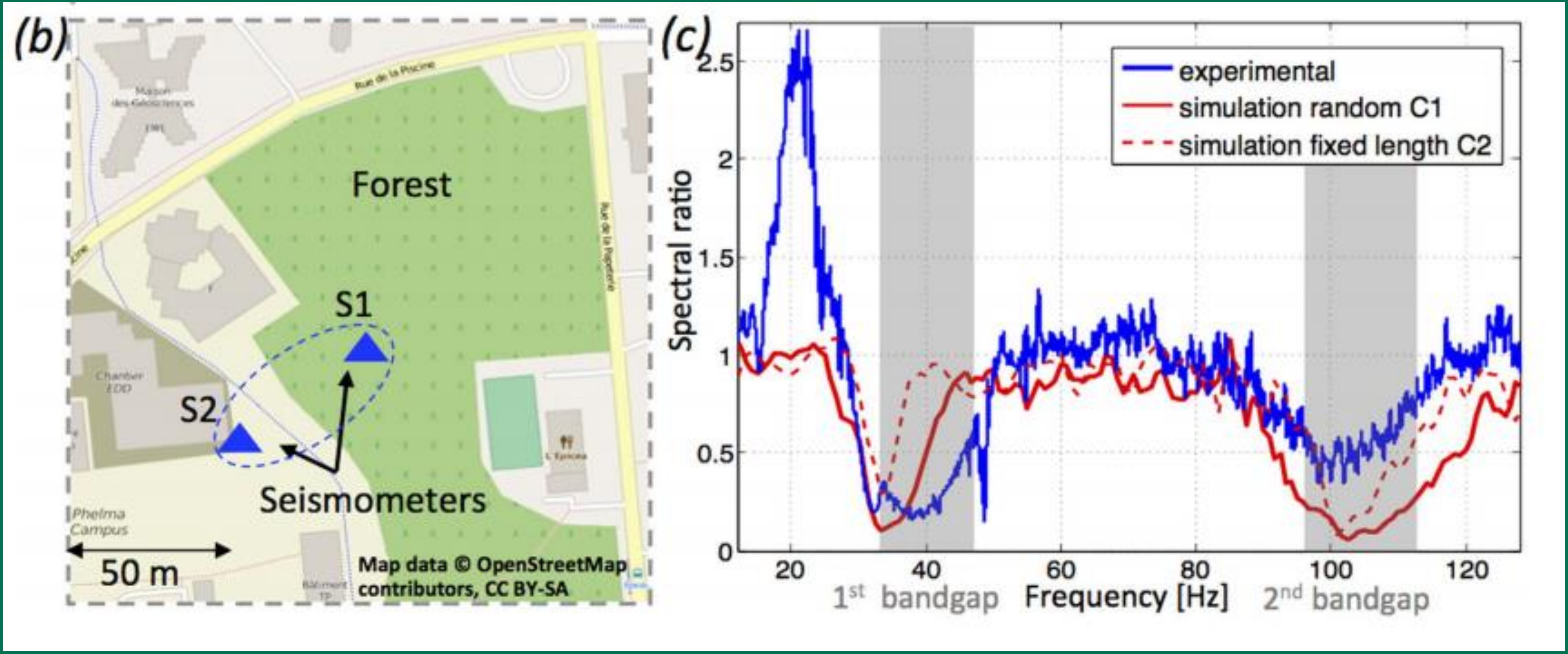
Steering Based Metamaterials

Seismic Meta-Wedge



Steering Based Metamaterials

Seismic Meta-Forest



Conclusions

THE GOOD

- Metamaterials / Meta-Structures provide mitigation alternatives to conventional designs: *lighter, thinner, more efficient*.
- Can be scaled to any frequency range.

THE BAD

- Bandwidths need to be broadened (gradient of sizes).
- Performance degraded by intrinsic material losses.
- Still in laboratory stage (> 10 years).

THE UGLY

- Difficult and expensive to actually scale up and test at useful sizes.
- Fabrication is a serious bottleneck.

Thank You !

End