COMPOSITE FOUNDATION BASED ON METAMATERIALS

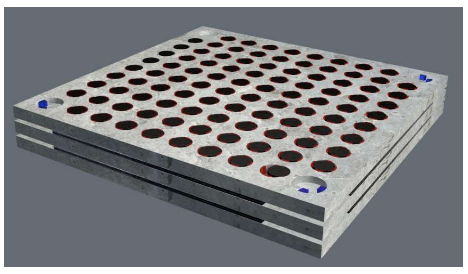
Massimo CHIAPPINI[1], **Giovanni FINOCCHIO**[2], **Francesca GARESCI'**[2]

[1] INGV – Istituto Nazionale di Geofisica e Vulcanologia, Italy
[2] University of Messina, Italy

DESCRIPTION OF COMPOSITE FOUNDATION

Metamaterials can be engineered to interact with waves in entirely new ways, finding application on the nanoscale in various fields such as optics and acoustics. In addition, acoustic metamaterials can be used in large-scale experiments for filtering and manipulating seismic waves (seismic metamaterials). Here, we propose seismic isolation based on a device that combines some properties of seismic metamaterials (e.g., periodic mass-in-mass systems) with that of a standard foundation positioned right below the building for isolation purposes. The concepts on which this solution is based are the local resonance and a dual-stiffness structure that preserves large (small) rigidity for compression (shear) effects. In other words, this paper introduces a different approach to seismic isolation by using certain principles of seismic metamaterials. The experimental demonstrator tested on the laboratory scale exhibits a spectral bandgap that begins at 4.5 Hz. Within the bandgap, it filters more than 50% of the seismic energy via an internal dissipation process. Our results open a path toward the seismic resilience of buildings and a critical infrastructure to shear seismic waves, achieving higher efficiency compared to traditional seismic insulators and passive energy dissipation systems.

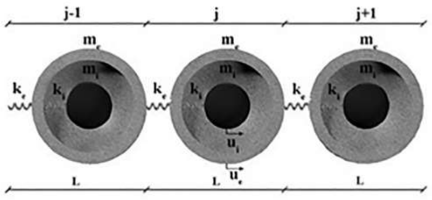
MODEL OF COMPOSITE FOUNDATION

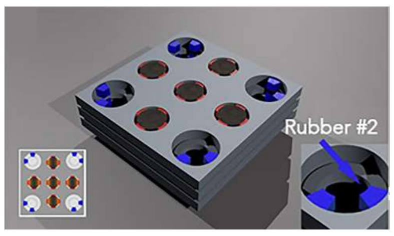


Mass-in-mass	Composite foundation	Conversion factors
m_e	Reinforced-concrete plate V_p (plate volume), ρ_c (concrete density)	$m_e = \rho_c \cdot V_p$ $\rho_c = 2400\,\mathrm{kg/m^3}$ $V_p = 13.21 \times 10^{-2}\,\mathrm{m^3}$
m_i	Steel cylinder n_c (number of cylinders), V_c (cylinder volume), ρ_s (concrete density)	$m_i = n_c \cdot \rho_s \cdot V_c$ $n_c = 5$ $\rho_s = 7800\,\mathrm{kg/m^3}$ $V_c = 6.28 \times 10^{-3}\mathrm{m^3}$
k_e	Rubber #1 (connection) E_{re} (Young's modulus of rubber), A_{re} (area of external element's rubber), L_{re} (length of external element's rubber)	$k_e = 2\frac{E_{re} \cdot A_{re}}{L_{re}}$ $E_{re} = 1.8 \times 10^6\mathrm{Pa}$ $A_{re} = 3.75 \times 10^{-3}\mathrm{m^2}$ $L_{re} = 8.75 \times 10^{-2}\mathrm{m}$
k_i	Rubber #2 (connection) E_{ri} (Young's modulus of rubber), A_{ri} (area of internal element's rubber), L_{ri} (length of internal element's rubber), n_c (number of cylinders)	$k_i = n_c\frac{E_{ri} \cdot A_{ri}}{L_{ri}}$ $n_c = 5$ $E_{ri} = 1.80 \times 10^6\mathrm{Pa}$ $A_{ri} = 3.00 \times 10^{-3}\mathrm{m^2}$ $L_{ri} = 2.50 \times 10^{-2}\mathrm{m}$

DEMONSTRATOR: SCALABLE SYSTEM 1:20

- ☐ 4 reinforced concrete plates (1m x 1m x 0,2 m) (in addition, one concrete plate is used as basement)
- ☐ each plate has a matrix of 9 cylindrical inclusions (4 mechanical connections, and 5 resonators)
- ☐ each plate is disconnected from the others by an ultralow damping surface





m_e = 2400x13.21x10^{-2} =317 kg

m_i = 7800x6.28x10^{-3} = 48.984 kg

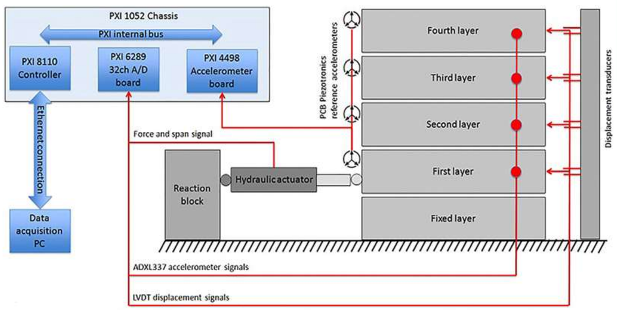
5xm_i = 48.36 x 5 = 244,92 kg

m_e+5 m_i = 562 kg

Total weight = 562kg x 5 = 2810 kg
2.81 ton

Mass-in-mass	Composite foundation	Conversion factors
m_e	Reinforced-concrete plate V_p (plate volume), ρ_c (concrete density)	$m_e = \rho_c \cdot V_p$ $\rho_c = 2400\,\mathrm{kg/m^3}$ $V_p = 13.21 \times 10^{-2}\,\mathrm{m^3}$

EXPERIMENTAL RESULTS



42 channels with a sampling frequency of 100 Hz

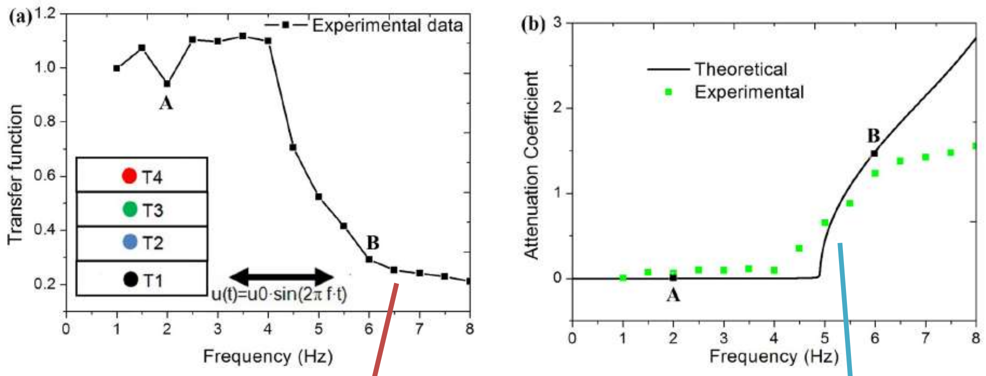
The resonators are monitored by using a special resin to glue the accelerometers to the upper surfaces of the resonators

accelerometers "sacrificial" low-cost MEMS

The sensors register:

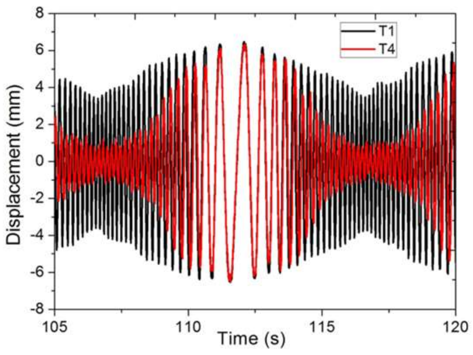
- displacement and accelerations of each late
- accelerations of internal resonator

Input: u_0 sin (ωt) - Applied at layer 1 in a range between 0.5-8 Hz



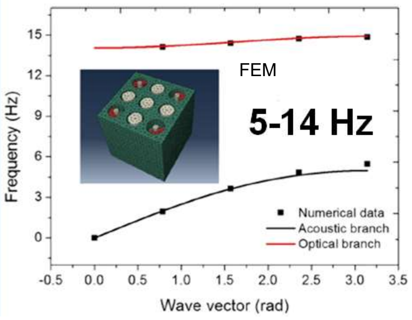
Transfer function of the CF as the ratio of :
- Displacement amplitude measured by the sensor T4
- Input signal measured by T1

Theoretical and Experimental attenuation coefficient



Time-domain traces measured by sensors T1 (black line) and T4 (red line) for an input up/down chirp signal applied to layer 1. The signal frequency increases from 1Hz to 8 Hz.

ANALITICAL RESULTS



Plates are separated by an ideal disconnection element that simulates zero damping between the plate

$$L = 0.2\ \mathrm{m}, \quad m_e = 317\,\mathrm{kg}, \quad k_e = 155 \times 10^3\ \mathrm{N/m}, \quad m_i = 245\,\mathrm{kg}, \quad k_i = 1080 \times 10^3\ \mathrm{N/m}$$

$$m_e m_i \omega^4 - [k_i(m_e + m_i) + 2k_e m_i(1 - \cos qL)]\omega^2 + 2k_e k_i(1 - \cos qL) = 0.$$

$$f_{BG,f} = \frac{1}{2\pi}\sqrt{\frac{[k_i(m_e + m_i) + 4k_e m_i] - \sqrt{[k_i(m_e + m_i) + 4k_e m_i]^2 - 16 m_e m_i k_e k_i}}{2 m_e m_i}}.$$

$$f_{BG,i} = \frac{1}{2\pi}\sqrt{\frac{[k_i(m_e + m_i)]}{m_e m_i}}$$

PATENT

N° ME2014A000001- PCT/IB2017/052126

A COMPOSITE FOUNDATION FOR THE SEISMIC PROTECTION OF THE STRUCTURES , 2014

1. Casablanca O., Ventura G., Garescì F., Azzerboni B., Chiaia B., Chiappini M., Finocchio G. - Seismic isolation of buildings using composite foundations based on metamaterials - (2018) Journal of Applied Physics, 123 (17), art. no. 174903 - DOI: 10.1063/1.5018005
2. Zivieri R., Garescì F., Azzerboni B., Chiappini M., Finocchio G. - Nonlinear dispersion relation in anharmonic periodic mass-spring and mass-in-mass systems – (2019) Journal of Sound and Vibration, 462, art. no. 114929 - DOI: 10.1016/j.jsv.2019.114929
3. Finocchio G., Casablanca O., Ricciardi G., Alibrandi U., Garescì F., Chiappini M., Azzerboni B. - Seismic metamaterials based on isochronous mechanical oscillators - (2014) Applied Physics Letters, 104 (19), art. no. 191903 - DOI: 10.1063/1.4876961

CONTACT INFORMATION

Massimo Chiappini, INGV _ Istituto Nazionale di Geofisica e Vulcanologia, Italy
E-mail**:** massimo.chiappini@ingv.it

Giovanni Finocchio: University of Messina, Italy
E-mail: gfinocchio@unime.it

Francesca Garescì: University of Messina, Italy
E-mail: fgaresci@unime.it