TIME TABLE

TIME	Monday September 5	Tuesday September 6	Wednesday September 7	Thursday September 8	Friday September 9
09:00 - 09:50	*Registration*	Lai	Kausel	Detmann	Marzani
10:00 - 10:50	Lai	Lai	Kausel	Detmann	Marzani
11:10 - 12:00	Lai	Kausel	Detmann	Steeb	Guenneau
12:10 - 13:00	Kausel	Kausel	Detmann	Steeb	Guenneau
14:30 - 15:20	Kausel	Steeb	Steeb	Marzani	Guenneau
15:30 - 16:20	Lai	Steeb	Steeb	Marzani	Guenneau
16:40 - 17:30	Lai	Detmann	Marzani	Guenneau	Quiz session (optional)
17:40 - 18:30		Detmann	Marzani	Guenneau	

COURSE VENUE AND REGISTRATION

The course will be held in Pavia (Italy) a charming medium sized town situated 40 km south of Milan renown also internationally for one of the world oldest academic institutions. In fact, the University of Pavia was founded in 1361 and until the 20th century was the only university in the region of Lombardy. Today it hosts more than 23,000 students including several from foreign countries.

The course venue is *Collegio Ghislieri*, a historical university residence of excellence located in downtown Pavia founded in 1567 by Pope Pio V. The lectures of the course will be held in the *Goldonian auditorium*. Coffee breaks will be organized in the *Saint Pio lounge*.

The registration fee is 450,00 € for PhD students and postdocs and 650,00 € for researchers of regular staff of universities and research centers. A limited number of applications at the special rate of € 300 will be accepted from PhD students and researchers from the University of Pavia. Due to Covid-19 restrictions, the *Goldonian auditorium* can host up to a maximum of 50 participants. Reservations will be made on a first-come, first-served basis. Applicants can register at the course via the website http://mech-waves-course.unipv.it/registration/ no later than **July 30, 2022**.

ACCOMMODATION

The town of Pavia has a number of accommodation facilities to host the participants. A list of hotels and B&B in Pavia is available at the link http://mech-waves-course.unipv.it/accommodation/. Please note that several conferences and summer schools are scheduled in town in the month of September, therefore the participants interested in attending the course are strongly encouraged to book the accommodation in advance.

A limited number of PhD students and post-docs who are not supported by their own academic or research institutions can apply to student residences in Pavia which offer lodging at a particularly convenient rate. Requests should be addressed to the Secretariat of the Department of Civil and Architectural Engineering of the University of Pavia (see below the contact details) by **July 15, 2022** together with the applicant's CV and a letter of support signed by the student's supervisor confirming that the institution cannot provide funding.

For further information please contact:

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E-mail: mech-waves-course@unipv.it
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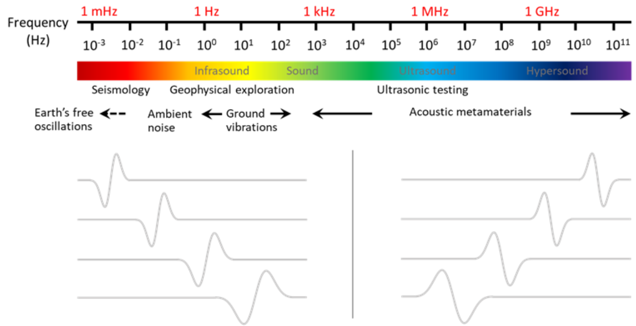
UNIVERSITÀ DI PAVIA
Dipartimento di Ingegneria Civile e Architettura

Intensive School for Advanced Graduate Studies
ISAGS – Summer Schools 2022

PROPAGATION OF MECHANICAL WAVES IN DEFORMABLE SOLIDS AND META-MATERIALS



Pavia (Italy)

September 5 - 9, 2022

IL COLLEGIO
FONDAZIONE GHISLIERI

PROPAGATION OF MECHANICAL WAVES IN DEFORMABLE SOLIDS AND META-MATERIALS

The exploitation of the properties of **mechanical waves** propagating in the interior and along the boundary of a deformable solid is the basis of **fundamental achievements** in science and engineering. To mention a few, in **seismology** what we currently know about the interior structure of the Earth is to a large extent drawn from the interpretation of earthquake recordings. In **geophysics**, mechanical waves are used to explore the depths of the Earth's crust in search of oil and gas reservoirs or large geological cavities for CO_2 storage. In **seismic engineering**, earthquake disasters are often caused by the amplification of ground motion which is a typical wave-related phenomenon. In **civil, mechanical and aerospace engineering**, ultrasonic techniques are used as non-invasive diagnostic tools for detecting defects of structural components and they are based on exploiting the properties of high-frequency surface and bulk mechanical waves. Lastly, when a **high-speed train** exceeds a critical velocity, shock mechanical waves are generated and they are conceptually similar to the ones sparked by a supersonic aircraft with all the implications for the vibrational impact induced in the surroundings of the railway line.

Despite the diversity of the aforementioned examples, also for the **characteristic wavelengths**, the underlying physics of the phenomena involved is the same and linked to various properties of mechanical waves. The **mathematical modeling** may be different owing to a variety of constitutive assumptions that may be employed to simulate material behaviour. Examples include one-constituent elasticity, viscoelasticity, and multi-component poroelasticity. However, steel, concrete, aluminum and even soils or rocks are still **conventional deformable materials**. Over the past thirty years or so, a new class of materials have made their appearance. They are the so-called **engineered metamaterials** as they are purposely designed to have properties that are not found in ordinary materials. For instance, seismic metamaterials can inhibit or manipulate the propagation of seismic waves over certain frequency bands. They are made of ordered assemblies of multiple elements constituting composite periodic structures. Wave phenomena such as the **acoustic rainbow trapping**, are artificially created in elastic metamaterials to protect constructions from the earthquake ground motion. The recent development of these innovative classes of materials introduces a **new paradigm** in engineering and science for the design of **smart materials** and structures.

The course aims at covering the above-mentioned variety of topics by treating them in a **unified framework**. It is **trans-disciplinary** and delivered by top specialists in their respective areas of research. The course is addressed to PhD students and scholars working in different yet interacting research fields of dynamics of continua including but not limited to geophysics, seismology, structural mechanics, geotechnical engineering, material science and applied mathematics.

LECTURERS

- B. Detmann – University of Duisburg-Essen, Germany
  6 lectures on: *Poroelastic theories for wave propagation in fluid-saturated and partially saturated porous media*.

- S. Guenneau – CNRS & Imperial College London, United Kingdom
  6 lectures on: *Metamaterials applications on the shielding properties of meta-materials in engineering*.

- E. Kausel – Massachusetts Institute of Technology, Boston, USA
  6 lectures on: *Wave propagation in elastic media and layered half-spaces. Vibrations induced by moving loads with applications to fast and super-fast trains*.

- C.G. Lai University of Pavia, Italy
  6 lectures on: *Classification of wave motion. Waves in elastic waveguides. Wave motion in linear dissipative continua*.

- A. Marzani – University of Bologna, Italy
  6 lectures on: *Wave propagation in phononic and resonant mechanical metamaterials and metasurfaces.*

- H. Steeb – University of Stuttgart, Germany
  6 lectures on: *Acoustic waves in poroelastic media: The role of heterogeneities across scales*.

PRELIMINARY SUGGESTED READING

Books

Achenbach, J.D. (1984). Wave Propagation in Elastic Solids, Vol. 16, *North-Holland Publishing Co.*, pp. 425.

Albers, B. (2010). Modeling and Numerical Analysis of Wave Propagation in Saturated and Partially Saturated Porous Media. Habilitation thesis. Veröffentlichungen des Grundbauinstituts der Technischen Universität Berlin, *Shaker-Verlag*, Vol. 48.

Bensoussan, A., Lions, J.L., Papanicolaou, G. (1978). Asymptotic Analysis of Periodic Structures. Studies in Mathematics and its Applications, Vol. 5, *North-Holland Publishing Co.*, pp. 721.

Bourbie, T., Coussy, O., Zinszner, B. (1987). Acoustics of Porous Media. *Editions Technip*, Paris, pp. 334.

Brillouin, L. (1953). Wave Propagation in Periodic Structures. *Dover Publ.*, 2nd Edition, New York, pp. 255.

Christensen, R. M. (2003). Theory of Viscoelasticity. 2nd Edition. *Dover Publication*, pp. 364.

Kausel, E. (2006). Fundamental Solutions in Elastodynamics, *Cambridge Press Publisher*, pp. 251.

Krylov, V.V. (2019). Ground Vibrations from High-Speed Railways: Prediction and Migration. Publisher: *Institution of Civil Engineers* (ICE), pp. 367.

Lai C.G., Wilmanski K. (Eds). (2005). Surface Waves in Geomechanics: Direct and Inverse Modeling for Soils and Rocks, CISM Lecture Notes N. 481, *Springer Publishing Co.*, pp. 385.

Whitham, G.B. (1999). Linear and Nonlinear Waves, *Wiley-Interscience Publishing Co.*, pp. 658.

Articles

Albers, B. (2009). Analysis of the Propagation of Sound Waves in Partially Saturated Soils by Means of a Macroscopic Linear Poroelastic Model, *Transport in Porous Media*, Vol. 80 (1), pp. 173-192.

Brûlé, S., Enoch, S., Guenneau, S. (2019). Role of Nanophotonics in the Birth of Seismic Mégastructures. *Nanophotonics*, Vol. 8 (10), pp. 1591-1605.

Detmann, B. (2018). On Models for Porous Media Containing One, Two or Three Pore Fluids and the Determination of Associated Macroscopic Material Parameters. *Mechanics Research Communications*, Vol. 93, pp. 35–40.

Hussein, M.I., Leamy, M. J. and Ruzzene, M. (2014). Dynamics of Phononic Materials and Structures: Historical Origins, Recent Progress, and Future Outlook. *Applied Mechanics Reviews*, Vol. 66 (4), pp. 38.

Kausel, E., Estaire, J., Crespo-Chacón, I. (2020). Proof of Critical Speed of High-Speed Rail Underlain by Stratified Media. *Proceedings of the Royal Society A*, Vol. 476 (2240).

Kausel, E. (2013). Lamb's Problem at its Simplest. *Proceedings of the Royal Society A*, Vol. 469 (2149).

Quintal, B., Steeb, H., Frehner, M., Schmalholz, S. M. (2011). Quasi-Static Finite Element Modeling of Seismic Attenuation and Dispersion Due to Wave-Induced Fluid Flow in Poroelastic Media. *Journal of Geophysical Research: Solid Earth*, Vol. 116, Issue B1.

Steeb, H. and J. Renner (2019). Mechanics of Poro-Elastic Media: A Review with Emphasis on Foundational State Variables. *Transport in Porous Media*, Vol. 130 (2): 437-461.

Wilmański, K., Albers, B. (2003). Acoustic Waves in Porous Solid-Fluid Mixtures, in: Dynamic Response of Granular and Porous Materials under Large and Catastrophic Deformations, N. Kirchner, K. Hutter (Ed.), Lecture Notes in Applied and Computational Mechanics, *Springer*, Berlin, Heidelberg, pp. 285-313.