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## Civil Engineering for Mitigation of Risk from Natural Hazards

# GEOTECHNICAL EARTHQUAKE ENGINEERING

**Institutions:** University of Pavia and IUSS Pavia

**Curriculum:** ROSE

**Term:** Academic Year 2025-2026 – 2<sup>nd</sup> Semester

**Credits (CFU):** 6

**Instructor:** Prof. Carlo G. Lai (E-mail: [carlogiovanni.lai@unipv.it](mailto:carlogiovanni.lai@unipv.it))

**Teaching assistant:** TBA

**Class duration:** March 4, 2026 – June 19, 2026 (60 hours of classes + 8 hours of tutoring)

**Class schedule:** Wednesday (room E7) 4-6 PM and Thursday 11-13 PM (room 2) @ Polo Cravino (UniPV)  
Friday (room F2) 2-4 PM @ Polo Cravino (UniPV) occasionally

**Office hours:** Contact the instructor or the teaching assistant via email to schedule a talk

### OUTLINE

Scope of the course is to introduce students to the basic theories and methods of earthquake geotechnical engineering and soil dynamics. Topics include propagation of mechanical waves in geomaterials, ground response analyses, soil liquefaction, seismic instability of slopes, surface fault rupture, dynamic soil-structure interaction, seismic analysis of foundations and earth-retaining systems.

In the first part of the course, basic concepts of propagation of mechanical body waves are discussed in elastic, viscoelastic and poroelastic homogeneous and heterogeneous continua. Surface Love and Rayleigh waves and their dispersive properties are also introduced including a discussion of the Lamb problem and of the differences between 2D vs. 3D radiation.

Next, fundamental concepts of seismometry are presented jointly with basic techniques of digital signal processing of earthquake recordings. Basic notions of engineering seismology are also briefly reviewed. These include probabilistic and deterministic seismic hazard, design earthquake, intensity measures of ground motion, acceleration and displacement response spectra, selection of seismic- and spectrum-compatible accelerograms. These concepts will be applied to study ground response analyses of soil deposits in 1D linear and linear-equivalent modeling after introducing the concept of transfer function in elastic and viscoelastic layered systems. Examples of phenomena of ground amplification in well-known earthquakes are presented and thoroughly discussed. More advanced topics like non-linear effective stress analyses, numerical modeling of 2D ground response, basin effects and topographic amplification are succinctly introduced. Finally, ground amplification as treated in well-established building codes (e.g., Italian NTC 2018 and Eurocode EC8 Part 1) is illustrated jointly with the seismic micro-zonation of an extended territory such as an urban centre.

The second part of the course focuses on subjects of soil dynamics. They include the study of drained and undrained response of soils under earthquake loading, concepts of critical state theory, shear strength and stiffness degradation of soils under cyclic loading. These topics are functional to the subject of geotechnical site characterization via in-situ and laboratory investigations and to the study of phenomena of ground failure like earthquake-induced soil liquefaction, lateral spreading ground and seismic instability of natural slopes.

The course ends with an introduction to dynamic soil-structure interaction (SSI) and seismic design of foundation systems. Concerning SSI, the notions of kinematic and inertial interaction are illustrated in association with that of dynamic impedance of a shallow foundation. This concept is used to solve SSI problems via the substructure approach. Finally, the pseudo-static and displacement-based methods are used for the seismic analysis and design of earth-retaining structures and foundation systems.

The course consists of lectures and interactive tutorial sessions. Each subject is illustrated with examples and well-documented case histories from major earthquakes worldwide drawn from the experience of the instructor.

### COURSE REQUIREMENTS

Basic knowledge of geotechnical engineering, mechanics of deformable body and engineering seismology.

### COURSE MATERIAL

The course material is posted at the KIRO web site accessible at the link: <https://elearning.unipv.it/>

## Civil Engineering for Mitigation of Risk from Natural Hazards

### REFERENCES

- Kramer S.L. and Stewart J.P. (2025). *Geotechnical Earthquake Engineering*. CRC Press, pp. 1042. Basic textbook
- Kokusho T. (2017). *Innovative Earthquake Soil Dynamics*. CRC Press, pp. 478. Reference monograph
- Ishihara K. (1996). *Soil Behaviour in Earthquake Geotechnics*. Oxford Press, pp. 350. Reference monograph
- Verruijt A. (2010). *An Introduction to Soil Dynamics*. Springer, New York, 431 pp. Reference monograph
- Lecture notes, scientific articles and reports will be provided by the instructor during the course

### ASSESSMENT

Assignments will be handed over and graded during the course. The final examination will consist of a three hour, written test. The final-exam format is closed-book. An equation-sheet will be provided, if needed. Grading: 40% assignments, 60% final exam.

### FINAL EXAMINATION

Summer Session Appeal: *July 27, 2026*, from 2:00 to 5 PM (classroom A1 – UniPV).

SCHEDULE OF LECTURES	HOURS	# LECTURES
1. Review of basic concepts of Fourier analysis (continuous and discrete)	6	1-3
2. Propagation of mechanical waves in deformable continua	6	4-6
3. Principles of seismometry and of signal processing	6	7-9
4. Review of engineering seismology and seismic hazard analysis*	4	10-11
5. Local site effects and ground response analyses†	8	12-15
6. Site characterization and geotechnical subsoil modeling‡	8	16-19
7. Seismic stability of slopes	4	20-21
8. Surface fault rupture and foundation interaction	2	22
9. Liquefaction susceptibility and risk of soil deposits§	8	23-26
10. Dynamic soil-structure interaction	4	27-28
11. Seismic analysis of earth-retaining structures	2	29
12. Seismic analysis of foundation systems	2	30
<b>TOTAL</b>	<b>60</b>	

TOPIC OF TUTORIALS	HOURS	# TUTORIALS
1. Signal processing applied to strong ground motion records	2	1
2. 1D linear equivalent ground response analyses	2	2
3. Seismic stability of slopes using simplified methods	2	3
4. Assessment of liquefaction susceptibility and risk at a site	2	4
<b>TOTAL</b>	<b>8</b>	

### ASSIGNMENTS

1. Signal processing and wave propagation in deformable solids (*tutorial 1*)
2. Case study on linear equivalent ground response analyses (*tutorial 2*)
3. Assessment of seismic slope stability using simplified methods (*tutorial 3*)
4. Assessment of liquefaction susceptibility and triggering at a site (*tutorial 4*)

\*It includes definition of design earthquake and selection of spectrum- compatible accelerograms

†It includes specifications of seismic building codes (e.g., Italian NTC 2018 and Eurocode EC8 Part 1)

‡It includes treatment of in-situ geophysical and laboratory investigations

§It includes fundamentals of stress-strain response of soils under earthquake loading