ROSE School

IUSS Scuola Universitaria Superiore Pavia

Structural health monitoring in earthquake engineering

ROSE PhD program in Earthquake Engineering

Lecturer: Daniele Sivori, IUSS Pavia daniele.sivori@iusspavia.it
Dates: June 8–12 2026, 20 hours (14 lectures + 6 tutorials)
Location: Palazzo del Broletto, Piazza della Vittoria 15, Pavia, Italy (rooms: see schedule)

Description

This short course provides a fundamental introduction to technologies, methods, and systems that can be employed to monitor the health condition of civil structures and support performance-based damage assessment and risk management in earthquake engineering. Lessons are organized to provide an initial theoretical foundation of stochastic processes and inverse problems, followed by hands-on examples in signal processing, dynamic identification, and model updating. The course begins with a general overview of traditional and innovative non-destructive sensing techniques for measuring the static and dynamic response of structures during earthquakes, focusing on vibration-based solutions for buildings. Topics covered include data acquisition and signal processing, analysis of operational vibrations and forced response to earthquake excitation in the time and frequency domains, and inverse problems in experimental dynamics. These concepts are used to discuss the functionality of seismic structural monitoring systems and their capabilities to support the decision-making process by exploiting experimental data (data-driven) and calibrated physical models (model-informed). Upon completion of the course, students will know how to choose sensors and extract information that can be used to assess the health condition of structures subjected to earthquakes.

Topics

- Traditional non-destructive sensing solutions and systems for static and dynamic measurements on structural and non-structural building components
- Overview of smart materials, embedded systems, emerging non-contact technologies
- Basics of data acquisition and signal processing
- Introduction to stochastic processes, time- and frequency-domain analysis
- Dynamic identification, extraction of damage-sensitive features from vibration data
- Sensitivity analysis, uncertainty quantification and model updating
- Data-driven and model-informed methods for seismic structural health monitoring

Learning Outcomes

On completion of this course, students will be able to:

- Select appropriate sensing technology to monitor the response of structural and non-structural elements under operational conditions and during earthquakes
- Process and analyze time histories of structural response acquired from sensors
- Extract the main dynamic properties, response parameters and damage-sensitive features from vibration signals
- Identify suitable techniques to calibrate analytical and mechanical models using experimental data (model updating)
- Use monitoring outputs and calibrated models to assess seismic performance levels and support post-earthquake risk management decisions

Assessment
Assessment consists of a practical exercise related to the core topics of the course (signal processing, dynamic identification, and model updating) to be discussed during the exam.

Schedule

Date	Time/Room	Topic	Hours
Mon 08/06/26	10:00–12:00 Room: **1-17**	**Introduction to structural monitoring in earthquake engineering**. Motivations of structural monitoring. Review of traditional sensors for static and dynamic measurements on structural and non-structural components. Regional seismic monitoring networks. Early warning and structural health monitoring (SHM) systems.	2
	14:00–16:00 Room: **1-17**	**Smart materials and emerging sensing technologies**. Overview of smart sensing materials and IoT/embedded systems. Emerging non-contact technologies and vision-based methods.	2
Tue 09/06/26	10:00–12:00 Room: **1-17**	**Data acquisition and processing**. Architecture of monitoring systems. Data acquisition, digitalization, transmission, synchronization, storage. Trigger-based versus continuous seismic monitoring systems. Fundamentals of data acquisition (sampling, frequency resolution, noise). Error propagation, outliers and missing data. Pre-processing techniques (decimation, de-trending, filtering). Time and frequency analysis.	2
	14:00–16:00 Room: **1-17**	**Stochastic processes, random and earthquake vibrations**. Analysis of stationary processes in the frequency domain (autocorrelation, power spectral density). Stationarity, non-stationarity, ergodicity. Earthquake signals: detection, intensity, frequency content, demand parameters.	2
Wed 10/06/26	10:00–12:00 Room: **1-16**	**Dynamic identification**. Theoretical basis. Examples of input-output and output-only, parametric and non-parametric, time-domain and frequency-domain modal analysis techniques. Uncertainty quantification and confidence intervals. Extraction of natural frequencies, mode shapes, and damping ratios.	2
	14:00–16:00 Room: **1-15**	Hands-on session - Part I: pre-processing of operational structural vibrations and earthquake response signals, filtering, analysis in time and frequency domain (MATLAB/Python).	2
Thu 11/06/26	10:00–12:00 Room: **1-17**	**Model updating**. Introduction to inverse problems in structural engineering. Existence, uniqueness, stability of solutions, ill-posedness, regularization. Optimization methods. Local and global search techniques. Reduced-order models and surrogates. Sensitivity analysis. Bayesian updating.	2
	14:00–16:00 Room: **1-17**	Hands-on session - Part II: frequency-domain analysis of ambient vibrations, modal identification, estimation of demand parameters from earthquake response, damage indices (MATLAB/Python).	2
Fri 12/06/26	10:00–12:00 Room: **1-17**	**Data-driven seismic SHM systems**. Introduction to data-driven SHM framework. Damage-sensitive features, pattern recognition, novelty detection, control charts. Damage indices and performance thresholds. Real-time damage detection and rapid tagging. Examples of physics-informed methodologies. Real-world case studies and their impact on risk management. Current developments and future trends.	2
	14:00–16:00 Room: **1-15**	Hands-on session - Part III: sensitivity analysis, model updating, performance assessment (MATLAB/Python).	2
		Total:	**20**
Mon 15/06/26	09:00–13:00 Room: **1-17**	**Exam:** assignment presentation and discussion	4