Course guide
250COD015 - 250COD015 - Computational Modelling of Materials

Last modified: 09/07/2026

Unit in charge: Barcelona School of Civil Engineering
Teaching unit: 751 - DECA - Department of Civil and Environmental Engineering.

Degree: MASTER'S DEGREE IN COMPUTATIONAL AND DATA-ASSISTED ENGINEERING (Syllabus 2026). (Optional subject).

Academic year: 2026 **ECTS Credits:** 5.0 **Languages:** English

LECTURER

Coordinating lecturer: MARINO ARROYO BALAGUER

Others: Dialamishabankareh Soltani, Narges

TEACHING METHODOLOGY

The course combines theoretical sessions with slides, blackboard explanations and exercises, together with hands-on computer sessions with finite element software to understand and develop implementations of various constitutive models, and to perform numerical experiments to gain insight into different nonlinear material responses.

Python codes will be provided by the lecturers, and minor modifications or additional implementation will be required from the students.

The teaching methodology also relies on projects where students use or modify the provided software to study a specific application.

LEARNING OBJECTIVES OF THE SUBJECT

Introduction to the mathematical and computational modeling of nonlinear material responses of solid, focusing on classical engineering materials (part I) and on soft and biological materials (part II). The course combines fundamental topics with an introduction to selected contemporary topics.

The main objective of the course is to enable students to:
* Understand physically the different sources of nonlinearity in the constitutive response of solids, ranging from classical engineering materials to soft and biological materials.
* Acquire basic expertise in the modeling frameworks and computational implementations used to describe nonlinear material behavior in engineering materials undergoing infinitesimal deformations, focusing on elasto-plasticity and elasto-damage.
* Understand the fundamentals of transient thermal and thermo-mechanical analysis, including their application in finite element frameworks.
* Acquire basic expertise in the modeling frameworks and computational implementations used to describe elastic materials undergoing finite deformations, as well as in finite deformation anelasticity.
* Apply these frameworks to model soft materials, ranging from nonlinearly elastic or viscoelastic to active and growing materials.
* Understand the significance of these models in the fields of soft robotics, bioengineering and mechanobiology.

STUDY LOAD

Type	Hours	Percentage
Self study	80,0	64.00
Hours large group	45,0	36.00

Total learning time: 125 h

CONTENTS

PART I: Computational modeling of soft, responsive, growing and active materials

Description:
Session 1: Background and nonlinear elasticity (1)
Motivation: morphogenesis of plant and animal tissues, technologies based on soft materials such as soft robotics. Brief review of nonlinear elasticity for isotropic and anisotropic, compressible and incompressible materials. Examples of hyperelastic potentials.

Session 2: Background and nonlinear elasticity (2)
Total Lagrangian finite element implementation, solution methods (Newton's method, dynamical relaxation, energy minimization). Presentation of the course's code. Numerical experiments. Buckling and wrinkling (loss of stability, non-uniqueness, symmetry breaking).

Session 3: Theory of nonlinear anelasticity.
Geometrically nonlinear anelasticity based on the multiplicative decomposition. Kinematics. Balance laws for open systems. Onsager's variational formalism of irreversible thermodynamics: Free energy, dissipation, power input and Rayleighian functionals.
Session 4: Applications. Finite deformation viscoelasticity.
Two-potential formulation. Simple analytical solutions and finite element implementation. Time-incremental minimization principles. Numerical experiments.
Session 5: Applications. Growth and remodeling.
Different scenarios. Constant density/volume growth, fiber reorientation. Simple analytical solutions and finite element implementation. Numerical experiments.
Session 6: Applications. Wet soft matter OR active matter.
Wet soft matter: coupling mechanics and solvent diffusion. Active matter: coupling mechanics and reaction-diffusion equations. Simple analytical solutions and finite element implementation. Numerical experiments.
Session 7: Project of part II presentations.

Full-or-part-time: 21h
Theory classes: 21h

PART II: Constitutive models for engineering materials

Description:
Session 8: Introduction to Transient Analysis I
Introduction to thermal and thermo-mechanical problems, including their physical foundations and relevance in engineering applications. Overview of the FEM solver interface through a guided tutorial.
Session 9: Introduction to Transient Analysis II
Application of thermo-mechanical analysis to a real case study. Hands-on practice to consolidate the understanding of transient simulations.
Session 10: NL Constitutive Equations - Elasto-plasticity I
Introduction to computational methods for nonlinear analysis. Constitutive modeling of engineering materials (e.g., metals), including elastic limits, hardening mechanisms, and inelastic strains.
Session 11: NL Constitutive Equations - Elasto-plasticity II
Practical implementation of elasto-plastic models through guided tutorials. Application to nonlinear problems with emphasis on plasticity.
Session 12: NL Constitutive Equations - Elasto-damage I
Constitutive modeling of quasi-brittle materials (e.g., concrete and soils). Discussion of yield strength, softening behavior, and damage variables.
Session 13: NL Constitutive Equations - Elasto-damage II
Practical application of damage models through numerical examples and problem-solving sessions focused on nonlinear analysis.

Full-or-part-time: 18h
Theory classes: 18h

GRADING SYSTEM

* Practical assignments for part I: 45%
* Final project for part II: 45%
* Participation and small activities: 10%

BIBLIOGRAPHY

Basic:
- Zienkiewicz, O. C. The Finite element method : its basis and fundamentals [on line]. 8th ed. Cham: Elsevier Science & Technology, 2024 [Consultation: 29/07/2026]. Available on: https://www-sciencedirect-com.recursos.biblioteca.upc.edu/book/monograph/9780443160448/the-finite-element-method. ISBN 0443160457.
- Zienkiewicz, O. C; Taylor, Richard Lawrence; Fox, D.D. The Finite element method : for solid & structural mechanics. 7th ed. Amsterdam [etc.]: Elsevier Butterworth-Heinemann, 2014. ISBN 9781856176347.
- Goriely, A. The Mathematics and Mechanics of Biological Growth [on line]. New York, NY: Springer, 2017 [Consultation: 10/07/2026]. Available on: https://link-springer-com.recursos.biblioteca.upc.edu/book/10.1007/978-0-387-87710-5. ISBN 038787710X.
- Bonet, Javier; Wood, Richard D. Nonlinear continuum mechanics for finite element analysis [on line]. Second edition. Cambridge: Cambridge University Press, 2008 [Consultation: 10/07/2026]. Available on: https://www-cambridge-org.recursos.biblioteca.upc.edu/core/books/nonlinear-continuum-mechanics-for-finite-element-analysis/67AD6DBAAB77E755C09E7FB82565DA0B. ISBN 9780521838702.
- Holzapfel, Gerhard A. Nonlinear solid mechanics : a continuum approach for engineering. Chichester, England: John Wiley & Sons, cop. 2000. ISBN 0471823198.