Course guides
250406 - ENGCOMP - Computational Engineering

Last modified: 06/10/2020

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

Degree: MASTER'S DEGREE IN CIVIL ENGINEERING (PROFESSIONAL TRACK) (Syllabus 2012). (Compulsory subject).
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Academic year: 2020 **ECTS Credits:** 6.0 **Languages:** English

LECTURER

Coordinating lecturer: ANTONIO RODRIGUEZ FERRAN

Others: ANTONIO RODRIGUEZ FERRAN, PABLO SAEZ VIÑAS

DEGREE COMPETENCES TO WHICH THE SUBJECT CONTRIBUTES

Specific:
8200. The ability to apply knowledge of soil and rock mechanics to the study, design, construction and operation of foundations, cuts, fills, tunnels and other constructions over or through land, whatever its nature and state, and whatever the purpose of the work.
8228. Knowledge of and competence in the application of advanced structural design and calculations for structural analysis, based on knowledge and understanding of forces and their application to civil engineering structures. The ability to assess structural integrity.
8230. The ability to plan, dimension, construct and maintain hydraulic works.
8231. The ability to plan, evaluate and regulate the use of surface water and groundwater resources.
8233. Knowledge of and the ability to understand dynamic phenomena of the coastal ocean and atmosphere and respond to problems encountered in port and coastal areas, including the environmental impact of coastal interventions. The ability to analyse and plan maritime works.
8234. Knowledge of transport engineering and planning, transport types and functions, urban transport, management of public transport services, demand, costs, logistics, and financing of transport infrastructure and services.

Transversal:
8559. ENTREPRENEURSHIP AND INNOVATION: Being aware of and understanding the mechanisms on which scientific research is based, as well as the mechanisms and instruments for transferring results among socio-economic agents involved in research, development and innovation processes.
8562. EFFECTIVE USE OF INFORMATION RESOURCES: Managing the acquisition, structuring, analysis and display of data and information in the chosen area of specialisation and critically assessing the results obtained.

8563. FOREIGN LANGUAGE: Achieving a level of spoken and written proficiency in a foreign language, preferably English, that meets the needs of the profession and the labour market.

TEACHING METHODOLOGY

Taught module delivery: fifteen weeks of teaching, coursework and self-study. Apart from the 4 hours per week in the classroom, self-study must last an average of 6 hours per week.

LEARNING OBJECTIVES OF THE SUBJECT

Students will learn to design computational models for the mechanics of continuous media and for solving diagnostic problems encountered in engineering.

Upon completion of the course, students will be able to:

Develop computational models based on mechanics of continuous media and apply them to different areas of civil engineering, including soil and rock mechanics, structural analysis, hydrology and water resources, ports and coastal systems;
Develop discrete computational models and use them for network design in different areas of civil engineering, in particular transport, logistics, power distribution and infrastructure mapping;
Apply the uncertainty principle to data on the external actions and internal properties of systems;
Apply stochastic computational models and subject the results to statistical processing;
Use the results of computational models as the basis for design, analysis, optimisation and decision-making in civil engineering.

Computational engineering techniques for the modelling and solution of continuous equilibrium and evolution problems; Application to structural engineering, geotechnical engineering, transport engineering, maritime engineering and environmental engineering; Continuous optimisation techniques (linear programming and nonlinear programming): Application to optimal design, parameter identification and resource allocation; Discrete optimisation and combinatorial optimisation techniques: Application to network design; Monte Carlo simulation: Application to decision-making in management and planning

STUDY LOAD

Type	Hours	Percentage
Theory classes	17,4	11.60
Guided activities	2,0	1.33
Self study	96,0	64.00
Laboratory classes	26,2	17.47
Practical classes	8,4	5.60

Total learning time: 150 h

CONTENTS

1.- Modelling with ODEs

Description:
Boundary value problems in engineering
The shooting method for boundary value problems
Solution of two problems (fields: structural analysis / geotechnics)
Adaptive numerical techniques
Variable step: step adaptation based on error control
The Runge-Kutta-Fehlberg 45 method (RKF45)
Solution of a case study (field: structural analysis)

Specific objectives:
To identify whether an engineering problem is an initial value problem or a boundary value problem
To know the strategy to solve boundary value problems, based on iterations (shoots) of an associated initial value problem
To model two case studies as boundary value problems: ODEs and boundary conditions
To sketch the solution of the boundary value problems with the shooting method
To be able to assess and control the quality of the numerical solution
To know and to be able to apply the RKF45 method to initial value and boundary value problems
To solve a boundary value problem with the RKF45 method (command ode45 in Matlab)
To be able to choose the accuracy needed in a computation depending on the output of interest

Full-or-part-time: 19h 12m
Theory classes: 4h
Practical classes: 2h
Laboratory classes: 2h
Self study : 11h 12m

2.- Modelling with PDEs

Description:
Solution of two problems (field: hydraulics / soil mechanics)
Solution of a case study (field: structural analysis) with the FEM
Eigenvalue problems in engineering
Wave equation (vibrations, sea waves, sound). Eigenmodes and eigenfrequencies
Standard and generalized eigenvalue problems
Properties of the symmetric eigenvalue problem
Methods of direct vector iteration and inverse vector iteration
Solution of two case studies (field: structural dynamics / marine engineering)
Diffusion and convection-diffusion problems in engineering
Solution of evolution problems with the FEM

Solution of a case study (field: environmental engineering)
Nonlinear equilibrium problems in engineering
Incremental-iterative strategy: the Newton-Raphson method
Solution of a case study (field: structural analysis) with the FEM

Specific objectives:
To model two case studies as equilibrium problems: PDEs and boundary conditions
To sketch the solution of equilibrium problems with the finite element method (FEM)
To know the internal organization of a finite element code
To be able to solve equilibrium problems with a finite element code
To interpret results, to evaluate and control the quality of outputs of interest
To know the most relevant eigenvalue problems in engineering
To give a physical interpretation to eigenvectors (modes) and eigenvalues (frequencies)
To know numerical techniques to determine the eigenvalues and eigenvectors of interest
To be able to determine eigenfrequencies and eigenmodes of interest
To understand the basic idea of modal analysis
To identify whether a problem is an equilibrium or an evolution problem
To know numerical techniques to treat time variation and convection
To model a case study as a convection-diffusion problem
To sketch its solution with the FEM
To identify the different sources of nonlinearity in engineering
To know numerical FEM techniques for nonlinear problems
To model nonlinearity in a case study
To be able to solve nonlinear problems with a finite element code To understand the large difference in complexity between linear and nonlinear problems

Full-or-part-time: 43h 12m
Theory classes: 8h
Practical classes: 4h
Laboratory classes: 6h
Self study : 25h 12m

Test #1

Full-or-part-time: 4h 48m
Laboratory classes: 2h
Self study : 2h 48m

3.- Optimization and simulation

Description:
Introduction to optimization.
Types of problems in engineering

Numerical techniques for continuous optimization problems without constraints
Models in engineering with unknown parameters
Nonlinear least-squares fitting from experimental measures
Numerical techniques: Newton, Levenberg-Marquardt
Heuristic techniques: genetic algorithms
Solution of a case study (field: soil mechanics / structural analysis)
Optimization problems in engineering
Equality and inequality constraints
Optimization with equality constraints: Lagrange multipliers
Optimization with inequality constraints: active constraints, barrier functions, penalty functions
Solution of a case study
Linear programming problems in engineering
Linear goal function and linear constraints
The simplex method
Solution of a case study (field: resource allocation)
Network problems in engineering
Exact and heuristic algorithms in discrete and combinatorial optimization
Simulation: Montecarlo method
Resolution of proposed exercises

Specific objectives:
Identify the different types of engineering problems: direct, optimal design, optimal identification and optimal control.
Establish the relationship between unconstrained minimization and the solution of nonlinear systems of equations

To discuss whether a model is linear or nonlinear in its parameters
To formulate parameter identification as a minimization problem To know how to apply Levenberg-Marquardt method for parameter fitting
To know the basic idea of genetic algorithms
To model a case study as a problem of parameter identification
To solve it with the Levenberg-Marquardt method
To know the different types of optimization problems in engineering
To understand the role played by the constraints
To understand the different numerical treatment of problems with and without constraints
To know the basic idea of numerical techniques for constraints
To model a case study as a problem of constrained optimisation
To know different types of linear programming problems in engineering
To understand the basic rules of the simplex method
To model a resource allocation case study as a linear programming problem
To solve it with the simplex method
To formulate network design problems as discrete /combinatorial optimization problems
To know the basic idea of the two types of techniques: exact and approximate
Decision making

Full-or-part-time: 52h 48m
Theory classes: 14h
Practical classes: 4h
Laboratory classes: 4h
Self study : 30h 48m

Test #2

Full-or-part-time: 4h 48m
Laboratory classes: 2h
Self study : 2h 48m

GRADING SYSTEM

1. The module is graded with the following elements:
* Class work (CW), to be carried out either individually or in teams.
* A course project (CP), to be carried out in teams.
* Two tests (T1 and T2), which are strictly individual.

2. Class work (CW) refers, among others, to:
* Exercises in the classroom.
* Assignments in the computer room.
* Participation in class.

3. The course project (CP) is a small project in computational engineering, to be presented in two different formats: a report and a poster.

4. Tests T1 and T2 will cover all the topics presented from the beginning of the module.

5. Academic dishonesty (including, among others, communication during tests, plagiarism and falsification of results) will be severely punished, in accordance with current academic regulations: any such act will imply a final mark of 0 in the module.

6. The final mark for the module is obtained as

Mark = (0.5*T1+0.5*T2)^0.5 * (0.5*CW+0.5*CP)^0.5

EXAMINATION RULES.

1. Tests T1 and T2 are strictly individual.

2. Tests are closed-book. This means that:

* Class notes, textbooks, solved problems or any other documents cannot be used.
* Mobile phones, computers, tablets or similar electronic devices are not allowed.

3. Please bring to tests:
* A calculator with no internet connection.
* A watch (mobile phones not allowed!).

BIBLIOGRAPHY

Basic:
- Dennis, J.E.; Schnabel, R.B. Numerical methods for unconstrained optimization and nonlinear equations. Philadelphia: SIAM, 1996. ISBN 0898713641.
- Bathe, K.J. Finite element procedures. [S. l.]: Prentice Hall, 2006. ISBN 9780979004902.
- Deuflhard, P.; Bornemann, F. Scientific computing with ordinary differential equations. New York: Springer, 2002. ISBN 0387954627.
- Donea, J.; Huerta, A. Finite element methods for flow problems [on line]. Chichester: John Wiley & Sons, 2003 [Consultation: 15/01/2020]. Available on: https://onlinelibrary.wiley.com/doi/book/10.1002/0470013826. ISBN 0471496669.
- Nocedal, J.; Wright, S.J. Numerical optimization [on line]. 2nd ed. Berlin: Springer, 2006 [Consultation: 15/01/2020]. Available on: http://dx.doi.org/10.1007/978-0-387-40065-5. ISBN 0387303030.

Complementary:

- Belytschko, T.; Liu, W.K.; Moran, B.; Elkhodary, K.I. Nonlinear finite elements for continua and structures [on line]. 2nd ed. Chichester: Wiley, 2014 [Consultation: 05/02/2020]. Available on: https://ebookcentral.proquest.com/lib/upcatalunya-ebooks/detail.action?docID=1501634. ISBN 9781118632703.
- Zienkiewicz, O.C.; Taylor, R.L.; Nithiarasu, P. The finite element method: vol. 3 for fluid dynamics. 7th ed. Amsterdam: Elsevier Butterworth-Heinemann, 2014. ISBN 9781856176354.