ANX-PR/CL/001-01
LEARNING GUIDE

SUBJECT

43000444 - Nonlinear Finite Element Models For Solids And Structures

DEGREE PROGRAMME

04AM - Master Universitario Ingenieria De Estructuras, Cimentaciones Y Materiales

ACADEMIC YEAR & SEMESTER

2022/23 - Semester 2

Index

Learning guide

1. Description

1.1. Subject details

Name of the subject	43000444 - Nonlinear Finite Element Models For Solids And Structures
No of credits	4.5 ECTS
Type	Optional
Academic year ot the programme	First year
Semester of tuition	Semester 2
Tuition period	February-June
Tuition languages	English
Degree programme	04AM - Master Universitario Ingenieria de Estructuras, Cimentaciones y Materiales
Centre	04 - Escuela Tecnica Superior De Ingenieros De Caminos, Canales Y Puertos
Academic year	2022-23

2. Faculty

2.1. Faculty members with subject teaching role

Name and surname	Office/Room	Email	Tutoring hours *
Sergio Blanco Ibañez	1.13 Planta 1	sergio.blanco@upm.es	Sin horario. No fixed timetable
Fco. Javier Martinez Cutillas	Torre, 9ª	francisco.martinez@upm.es	Sin horario. No fixed timetable

Felipe Gabaldon Castillo	Lab Mec Comp	felipe.gabaldon@upm.es	Sin horario. No fixed timetable
Jose Maria Goicolea Ruigomez (Subject coordinator)	Torre, 9.ª	jose.goicolea@upm.es	Sin horario. No fixed timetable
Alfredo Camara Casado	Torre, 9.ª	alfredo.camara@upm.es	Sin horario.
Pedro Navas Almodovar	Planta 1	pedro.navas@upm.es	Sin horario. No fixed timetable

* The tutoring schedule is indicative and subject to possible changes. Please check tutoring times with the faculty member in charge.

2.2. Research assistants

Name and surname	Email	Faculty member in charge
Tarque Ruiz, Sabino Nicola	nicola.tarque@upm.es	Goicolea Ruigomez, Jose Maria

2.3. External faculty

Name and surname	Email	Institution
Javier Naranjo Pérez	javier.naranjo@externos.upm.es	Postdoc Margarita Salas en UPM
Khanh Nguyen Gia	khanhnguyen.gia@upm.es	ETSI Aeronáuticos, UPM

3. Prior knowledge recommended to take the subject

3.1. Recommended (passed) subjects

- Elementos Finitos

3.2. Other recommended learning outcomes

- Computer programming

- Numerical methods

- Vector calculus

4. Skills and learning outcomes *

4.1. Skills to be learned

CB9 - Que los estudiantes sepan comunicar sus conclusiones y los conocimientos y razones últimas que las sustentan a públicos especializados y no especializados de un modo claro y sin ambigüedades

CE13 - - Capacidad para el ejercicio profesional de alta especialización o para la investigación predoctoral mediante la utilización de recursos de modelización predictiva en Análisis y diseño estructural en régimen dinámico y/o no lineal.

CG4 - Capacidad de comunicación académica de contenido técnico y científico, oral y escrita en lengua inglesa.

4.2. Learning outcomes

RA20 - Conoce las causas de no linealidad geométrica en estructuras y los métodos de cálculo en los distintos niveles.

RA37 - Conoce y sabe aplicar los métodos de cálculo dinámico no lineal por elementos finitos

RA35 - Conoce y sabe aplicar los modelos de elementos finitos a preoblemas estructurales y de mecánica de sólidos no lineales

RA33 - Conoce y sabe aplicar los fenómenos no lineales en cálculo de estrcuturas

RA36 - Conoce y sabe aplicar los métodos de resolución de ecuaciones no lineales

RA34 - Conoce y sabe aplicar la mecánica de medios continuos no lineal, incluyendo grandes rotaciones y deformaciones, y comportamiento no lineal de los materiales

RA22 - Conoce las causas de no linealidad en estructuras originadas por las condiciones de sustentación y los métodos de cálculo estructural aplicables.

* The Learning Guides should reflect the Skills and Learning Outcomes in the same way as indicated in the Degree Verification Memory. For this reason, they have not been translated into English and appear in Spanish.

5. Brief description of the subject and syllabus

5.1. Brief description of the subject

Background and objectives of course

The course includes 11 topics, practical assignments to be solved with advanced Finite Element software for each case and an individual final course project by each student. In the lectures the key concepts for the mathematical and numerical models will be explained. Practical indications for solving the exercises with finite element program ABAQUS will be also given. Application lessons will include full discussions of real world applications of advanced finite element models, within research projects or technological development projects.

For solving the assignments the recommended software is ABAQUS finite element program (Student version).

Students are expected to have a good basic background in continuum mechanics, elasticity and finite elements. The course "Finite Element Method / Método de los elementos finitos", delivered during the 1st semester of tis master's program, or an equivalent course, is required.

Documentation will be provided in the way of presentation notes and papers. ABAQUS Student version is available free of charge by students.

The students will be asked to develop an individual final project for the course. A tutor will be assigned to each student for these final projects, who will approve the topic and assist in the development of the project. The results will be presented by the students to the whole class in a special workshop.

Program of topics / lessons

1. Introduction to nonlinear problems. Nonlinear behaviour in mechanical and structural applications. Detailed analysis of basic examples for understanding the nature of the problems and of the finite element solutions. Sources of nonlinear behaviour in solids and structures. Required features of nonlinear FE programs. State of the art in advanced applications of FE to engineering problems.
2. Concepts in nonlinear continuum mechanics. Large strain formulation. Kinematics. Strain tensors. Stress tensors. Balance principles and conservation theorems. Thermodynamics. Constitutive equations of materials: general principles.
3. Constitutive models for plasticity and viscoplasticity. Elastic-plastic models. Finite strain elastoplasticity. Integration of the equations of plasticity. Tangent elastoplastic matrix. Algorithmic consistent tangent.

Viscoplasticity. Applications.

4. Constitutive models for gelogical and cohesive-frictional materials. Material properties and models. Models for Rocks and soil. Concrete: properties and models in compression and tension.
5. Applications to Biomechanics. Nonlinear elasticity, viscoelasticity and damage. Anisotropic behaviour with fibres. Soft biological tissue.
6. Formulation of the discrete nonlinear equations. Total Lagrangian and updated Lagrangian weak formulations. Linearization of the weak formulation. Interpolation of strains. Evaluation of internal forces. Tangent stiffness matrix. Finite element equations.
7. Mixed and hybrid elements for nonlinear probelms. Enhanced assumed strains. Elements u-p-theta. Finite elements for incompressible Navier-Stokes flow.
8. Solution algorithms for the nonlinear equations. Equilibrium solutions and implicit time integration. Linearization and iterative solutions. Line search for acceleration convergence. Continuation methods: arc-length. Stability.
9. Models for nonlinear dynamics. Explicit methods. Implicit time integration. Contact and impact. Rigid bodies. Constraints. Energy-momentum method.
10. Nonlinear problems in bridge engineering.
11. Meshless methods (SPH)
12. Final course projects. (assignment and discussion: presentation: Workshops for discussion and assignement of final course projects, and presentation of projects by each student. Projects will be carried out individually.

5.2. Syllabus

1. Introduction to nonlinear problems

2. Concepts in nonlinear continuum mechanics

  2.1. Large strain formulation. Kinematics. Strain tensors. Stress tensors.

  2.2. Balance principles and conservation theorems. Thermodynamics. Constitutive equations of materials: general principles.

3. Constitutive models for plasticity and viscoplasticity

4. Constitutive models for gelogical and cohesive-frictional materials

5. Applications to biomechanics

6. Formulation of the discrete nonlinear equations

7. Mixed and hybrid elements for nonlinear problems

8. Solution algorithms for the nonlinear equations

9. Models for nonlinear dynamics

10. Application to nonlinear problems in bridge engineering

11. Meshless methods (SPH)

12. Final course projects: assignment, development, presentation and discussion

6. Schedule

6.1. Subject schedule*

Week	Classroom activities	Laboratory activities	Distant / On-line	Assessment activities
1	**Lesson 1** Duration: 01:30 Lecture	**Exercise lesson 1** Duration: 01:30 Laboratory assignments		
2	**Lesson 2** Duration: 01:30 Lecture	**Exercise lesson 2** Duration: 01:30 Laboratory assignments		
3	**Lesson 2** Duration: 01:30 Lecture	**Exercise lesson 2** Duration: 01:30 Laboratory assignments		
4	**Lesson 3** Duration: 01:30 Lecture	**Exercise lesson 3** Duration: 01:30 Laboratory assignments		
5	**Lesson 4** Duration: 01:30 Lecture	**Exercise lesson 4** Duration: 01:30 Laboratory assignments		
6	**Lesson 5** Duration: 01:30 Lecture	**Exercise lesson 5** Duration: 01:30 Laboratory assignments		
7	**Lesson 6** Duration: 01:30 Lecture	**Exercise lesson 6** Duration: 01:30 Laboratory assignments		
8	**Lesson 7** Duration: 01:30 Lecture	**Exercise lesson 7** Duration: 01:30 Laboratory assignments		
9	**Lesson 8** Duration: 01:30 Lecture	**Exercise lesson 8** Duration: 01:30 Laboratory assignments		
10	**Lesson 9** Duration: 01:30 Lecture	**Exercise lesson 9** Duration: 01:30 Laboratory assignments		
11	**Lesson 10** Duration: 01:30 Lecture	**Exercise lesson 10** Duration: 01:30 Laboratory assignments		
12	**Lesson 11** Duration: 01:30 Lecture	**Exercise lesson 11** Duration: 01:30 Laboratory assignments		
13	**Definition of course projects** Duration: 03:00 Problem-solving class			
14		**Development of course projects** Duration: 03:00 Laboratory assignments		

15		**Development of course projects** Duration: 03:00 Laboratory assignments		
16		**Development of course projects** Duration: 03:00 Laboratory assignments		
17				**Assistance to lectures and responses to short questionnaires, during each lecture** Individual work Continuous assessment and final examination Presential Duration: 00:00 **Exercises and practical assignments, developed weekly for each lesson** Problem-solving test Continuous assessment and final examination Presential Duration: 00:00 **Presentation of final course project** Individual work Continuous assessment and final examination Presential Duration: 00:00

Depending on the programme study plan, total values will be calculated according to the ECTS credit unit as 26/27 hours of student face-to-face contact and independent study time.

* The schedule is based on an a priori planning of the subject; it might be modified during the academic year, especially considering the COVID19 evolution.

7. Activities and assessment criteria

7.1. Assessment activities

7.1.1. Assessment

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
17	Assistance to lectures and responses to short questionnaires, during each lecture	Individual work	Face-to-face	00:00	15%	4 / 10	CB9 CE13 CG4
17	Exercises and practical assignments, developed weekly for each lesson	Problem-solving test	Face-to-face	00:00	45%	5 / 10	CB9 CE13 CG4
17	Presentation of final course project	Individual work	Face-to-face	00:00	40%	5 / 10	CB9 CE13 CG4

7.1.2. Global examination

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
17	Assistance to lectures and responses to short questionnaires, during each lecture	Individual work	Face-to-face	00:00	15%	4 / 10	CB9 CE13 CG4
17	Exercises and practical assignments, developed weekly for each lesson	Problem-solving test	Face-to-face	00:00	45%	5 / 10	CB9 CE13 CG4
17	Presentation of final course project	Individual work	Face-to-face	00:00	40%	5 / 10	CB9 CE13 CG4

7.1.3. Referred (re-sit) examination

No se ha definido la evaluación extraordinaria.

7.2. Assessment criteria

For passing the course it will be required to assist to the lectures, including short questionnaires, and complete the practical assignments / exercises, as well as the final course project.
The grades will be based on three criteria:

1. Attendance and participation in classes (15% of grades, with a minimum attendance of 70% of classes)
2. Assignments and exercises (45% of grades)

3. Final coursework: report, presentation and discussion (40% of grades)

8. Teaching resources

8.1. Teaching resources for the subject

Name	Type	Notes
ABAQUS	Equipment	Finite Element Software
FEAP	Equipment	Finite Element Software
J. Bonet: Nonlinear Continuum Mechanics for Finite Element Analysis, Cambridge, 2008 (2nd edition) (available at biblioteca ETSI Caminos)	Bibliography	
P. Wriggers: Nonlinear Finite Element Methods. Springer, 2008. ? T. Belytschko: Nonlinear Finite Elements for Continua and Structures, Wiley, 2000.	Bibliography	
G.A. Holzapfel: Nonlinear Solid Mechanics, Wiley, 2000 (available at biblioteca ETSI Caminos)	Bibliography	

J.C. Simó, T.J.R. Hughes: Computational Inelasticity, Springer, 1998. (available at biblioteca ETSI Caminos)	Bibliography	
R.L. Taylor: FEAP - A Finite Element Analysis Program, Version 8.1 User and Theory Manuals, Robert L. Taylor, University of California at Berkeley	Bibliography	
O.C. Zienkiewicz, R.L. Taylor: The Finite Element Method: Vol 1 - The Basics; Vol 2 - Solid mechanics, Butterworth Heinemann, 2000. (available at biblioteca ETSI Caminos)	Bibliography	
M. Crisfield: Nonlinear Finite Element Analysis of Solids and Structures, Vols I, II, Wiley, 1991, 1997. (available at biblioteca ETSI Caminos).	Bibliography	

9. Other information

9.1. Other information about the subject

Tis course is related to Sustainable Development Goals SDG 4 (Quality education) and SDG 9 (Industry, innovation and infrastructure)