



POLITÉCNICA

INTERNATIONAL
CAMPUS OF
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COORDINATION PROCESS OF
LEARNING ACTIVITIES
PR/CL/001



E.T.S. de Ingenieros de
Caminos, Canales y Puertos

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

2020/21 - Semester 2

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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 of 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	2020-21

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	M - 12:00 - 14:00 M - 16:30 - 17:30 Tu - 12:00 - 14:00 Tu - 16:30 - 17:30
Fco. Javier Martinez Cutillas	Torre, 9ª	francisco.martinez@upm.es	M - 15:00 - 17:30 M - 19:00 - 20:30 Tu - 15:00 - 19:00 Tu - 20:00 - 21:00

Felipe Gabaldon Castillo	Lab Mec Comp	felipe.gabaldon@upm.es	W - 09:00 - 11:00 W - 16:30 - 17:30
Jose Maria Goicolea Ruigomez (Subject coordinator)	Torre, 9. ^a	jose.goicolea@upm.es	M - 12:00 - 14:00 M - 16:30 - 17:30 Tu - 12:00 - 14:00 Tu - 16:30 - 17:30

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

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 problemas estructurales y de mecánica de sólidos no lineales

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

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 consists of 13 2h lessons. Out of these 10 will be dedicated to lectures and 3 will be dedicated to applications. 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 FEAP will be also given. The 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 it will be possible to use either FEAP or ABAQUS finite element programs.

Students are expected to have a good basic background in finite elements, for which in principle the course given in the 1st semester "Finite Element Method / Método de los elementos finitos" is required.

Documentation will be provided in the way of presentation notes and papers. A binary version of FEAP will be provided for use of the students within this course.

In some lessons a homework assignment will be given to students who must complete the work individually and return the worked out report through the moodle course site. A total of 8 homework exercises will be proposed. Additionally the students will be asked to develop an individual final project for the course. These final projects will be presented by the students to the whole class in a special workshop.

Program of 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 geological and cohesive-frictional materials Material properties and models. Concrete: properties and models in compression and tension.
5. Constitutive models for nonlinear elasticity and viscoelasticity Models for incremental hypoelasticity. Hyperelastic models. Elastomers. Anisotropy. Soft biological tissue. Viscoelasticity.
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 problems 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. Application lectures: #1: Industrial problems; #2: Industrial problems; #3: Coupled problems
11. Final course projects (assignment and discussion: presentation: Workshops for discussion and assignment of final course projects, and presentation of projects by each students. 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 geological and cohesive-frictional materials
5. Constitutive models for nonlinear elasticity and viscoelasticity
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 lectures
11. Final course projects (assignment and discussion: presentation)

6. Schedule

6.1. Subject schedule*

Week	Face-to-face classroom activities	Face-to-face laboratory activities	Distant / On-line	Assessment activities
1	Lesson 1 Duration: 02:00 Lecture		Lesson 1 Duration: 02:00 Lecture	
2	Lesson 1 Duration: 02:00 Lecture	Exercise lesson 1 Duration: 01:00 Laboratory assignments	Lesson 1 Duration: 02:00 Lecture Exercise lesson 1 Duration: 01:00 Laboratory assignments	
3	Lesson 2 Duration: 02:00 Lecture	Exercise lesson 2 Duration: 01:00 Laboratory assignments	Exercise lesson 1 Duration: 01:00 Laboratory assignments Exercise lesson 2 Duration: 01:00 Laboratory assignments	Lesson 1 presentation Individual presentation Continuous assessment and final examination Presential Duration: 01:30
4	Lesson 2 Duration: 02:00 Lecture		Lesson 2 Duration: 02:00 Lecture	Lesson 2-1 presentation Individual presentation Continuous assessment and final examination Presential Duration: 01:30
5	Lesson 3 Duration: 02:00 Lecture		Lesson 3 Duration: 02:00 Lecture	Lesson 2-2 presentation Individual presentation Continuous assessment and final examination Presential Duration: 01:30
6	Lesson 4 Duration: 02:00 Lecture		Lesson 4 Duration: 02:00 Lecture	Lesson 3 - Presentation Individual presentation Continuous assessment and final examination Presential Duration: 01:30
7	Lesson 5 Duration: 02:00 Lecture		Lesson 5 Duration: 02:00 Lecture	Lesson 4 - Presentation Individual presentation Continuous assessment and final examination Presential Duration: 01:30
8	Lesson 6 Duration: 02:00 Lecture		Lesson 5 Duration: 02:00 Lecture	Lesson 5 - Presentation Individual presentation Continuous assessment and final examination Presential Duration: 01:30

9	Lesson 7 Duration: 02:00 Lecture		Lesson 5 Duration: 02:00 Lecture	Lesson 6 - Presentation Individual presentation Continuous assessment and final examination Presential Duration: 01:30
10	Lesson 8 Duration: 02:00 Lecture		Lesson 8 Duration: 02:00 Lecture	Lesson 7 - Presentation Individual presentation Continuous assessment and final examination Presential Duration: 01:30
11	Lesson 9 Duration: 02:00 Lecture		Lesson 8 Duration: 02:00 Lecture	Lesson 8 - Presentation Individual presentation Continuous assessment and final examination Presential Duration: 01:30
12	Lesson 10 Duration: 02:00 Lecture		Lesson 10 Duration: 02:00 Lecture	Lesson 9 - Presentation Individual presentation Continuous assessment and final examination Presential Duration: 01:30 Attendance Group work Continuous assessment and final examination Presential Duration: 00:00
13	Lesson 10 Duration: 02:00 Lecture		Lesson 10 Duration: 02:00 Lecture	Attendance Group work Continuous assessment and final examination Presential Duration: 00:00
14	Lesson 10 Duration: 02:00 Lecture		Lesson 10 Duration: 02:00 Lecture	Attendance Group work Continuous assessment and final examination Presential Duration: 00:00
15	Definition of course projects Duration: 02:00 Problem-solving class		Definition of course projects Duration: 02:00 Problem-solving class	
16				Presentation of final course project Individual work Continuous assessment and final examination Presential Duration: 00:00
17				

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. Continuous assessment

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
3	Lesson 1 presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE13
4	Lesson 2-1 presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CG4 CE13 CB9
5	Lesson 2-2 presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE13
6	Lesson 3 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE13
7	Lesson 4 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CE13
8	Lesson 5 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE13
9	Lesson 6 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE13
10	Lesson 7 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE13
11	Lesson 8 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE13
12	Lesson 9 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE13
12	Attendance	Group work	Face-to-face	00:00	5%	5 / 10	CG4
13	Attendance	Group work	Face-to-face	00:00	5%	5 / 10	CG4

14	Attendance	Group work	Face-to-face	00:00	5%	5 / 10	CG4
16	Presentation of final course project	Individual work	Face-to-face	00:00	35%	5 / 10	CB9 CG4 CE13

7.1.2. Final examination

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
3	Lesson 1 presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE13
4	Lesson 2-1 presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CG4 CE13 CB9
5	Lesson 2-2 presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE13
6	Lesson 3 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE13
7	Lesson 4 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CE13
8	Lesson 5 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE13
9	Lesson 6 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE13
10	Lesson 7 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE13
11	Lesson 8 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE13
12	Lesson 9 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE13
12	Attendance	Group work	Face-to-face	00:00	5%	5 / 10	CG4
13	Attendance	Group work	Face-to-face	00:00	5%	5 / 10	CG4
14	Attendance	Group work	Face-to-face	00:00	5%	5 / 10	CG4
16	Presentation of final course project	Individual work	Face-to-face	00:00	35%	5 / 10	CB9 CG4 CE13

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 and complete the homework assignments, 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 (50% of grades)
3. Final coursework: report, presentation and discussion (35% 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	