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

2018/19 - 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	2018-19

2. Faculty

2.1. Faculty members with subject teaching role

Name and surname	Office/Room	Email	Tutoring hours *
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
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

Felipe Gabaldon Castillo	Lab Mec Comp	felipe.gabaldon@upm.es	W - 09:00 - 11:00 W - 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

* 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
,	c.velarde@upm.es	Goicolea Ruigomez, Jose Maria

2.3. External faculty

Name and surname	Email	Institution
Khanh Nguyen	khanhng1982@gmail.com	UPM contratado OTT

3. Prior knowledge recommended to take the subject

3.1. Recommended (passed) subjects

- Elementos finitos

3.2. Other recommended learning outcomes

- Numerical methods

- Computer programming

- 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.

CE5 - Capacidad para la participación en actividades de I+D+i mediante la utilización de recursos de modelización predictiva en Métodos computacionales para Mecánica estructural

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

CT1 - Capacidad de preparar y presentar comunicaciones orales, escritas y gráficas, estructurada y argumentadamente.

4.2. Learning outcomes

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

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

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

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 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 gelogical 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 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. Application lectures: #1: Industrial problems; #2: Industrial problems; #3: Coupled problems
11. Final course projects (assignment and discussion: presentation: Workshops for discussion and assignement 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 gelogical 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	Other face-to-face activities	Assessment activities
1	**Lesson 1** Duration: 02:00 Lecture			
2	**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		**Lesson 1 presentation** Individual presentation Continuous assessment and final examination Duration: 01:30
4	**Lesson 2** Duration: 02:00 Lecture			**Lesson 2-1 presentation** Individual presentation Continuous assessment and final examination Duration: 01:30
5	**Lesson 3** Duration: 02:00 Lecture			**Lesson 2-2 presentation** Individual presentation Continuous assessment and final examination Duration: 01:30
6	**Lesson 4** Duration: 02:00 Lecture			**Lesson 3 - Presentation** Individual presentation Continuous assessment and final examination Duration: 01:30
7	**Lesson 5** Duration: 02:00 Lecture			**Lesson 4 - Presentation** Individual presentation Continuous assessment and final examination Duration: 01:30
8	**Lesson 6** Duration: 02:00 Lecture			**Lesson 5 - Presentation** Individual presentation Continuous assessment and final examination Duration: 01:30
9	**Lesson 7** Duration: 02:00 Lecture			**Lesson 6 - Presentation** Individual presentation Continuous assessment and final examination Duration: 01:30

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

The independent study hours are training activities during which students should spend time on individual study or individual assignments.

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 subject schedule is based on a previous theorical planning of the subject plan and might go to through experience some unexpected changes along throughout the academic year.

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 CE5 CT1 CE13
4	Lesson 2-1 presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE5 CT1 CE13
5	Lesson 2-2 presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE5 CT1 CE13
6	Lesson 3 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE5 CT1 CE13
7	Lesson 4 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CE5 CT1 CE13
8	Lesson 5 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE5 CT1 CE13
9	Lesson 6 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE5 CT1 CE13

10	Lesson 7 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE5 CT1 CE13
11	Lesson 8 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE5 CT1 CE13
12	Lesson 9 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE5 CT1 CE13
12	Attendance	Group work	Face-to-face	00:00	5%	5 / 10	CG4 CT1
13	Attendance	Group work	Face-to-face	00:00	5%	5 / 10	CG4 CT1
14	Attendance	Group work	Face-to-face	00:00	5%	5 / 10	CG4 CT1
16	Presentation of final course project	Individual work	Face-to-face	00:00	35%	5 / 10	CB9 CG4 CE5 CT1 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 CE5 CT1 CE13
4	Lesson 2-1 presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE5 CT1 CE13
5	Lesson 2-2 presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE5 CT1 CE13

6	Lesson 3 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE5 CT1 CE13
7	Lesson 4 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CE5 CT1 CE13
8	Lesson 5 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE5 CT1 CE13
9	Lesson 6 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE5 CT1 CE13
10	Lesson 7 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE5 CT1 CE13
11	Lesson 8 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE5 CT1 CE13
12	Lesson 9 - Presentation	Individual presentation	Face-to-face	01:30	5%	5 / 10	CB9 CG4 CE5 CT1 CE13
12	Attendance	Group work	Face-to-face	00:00	5%	5 / 10	CG4 CT1
13	Attendance	Group work	Face-to-face	00:00	5%	5 / 10	CG4 CT1
14	Attendance	Group work	Face-to-face	00:00	5%	5 / 10	CG4 CT1
16	Presentation of final course project	Individual work	Face-to-face	00:00	35%	5 / 10	CB9 CG4 CE5 CT1 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	