



POLITÉCNICA

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



E.T.S. de Ing. de Caminos
Canales y P.

ANX-PR/CL/001-01

LEARNING GUIDE

SUBJECT

43000445 - Computational Mechanics

DEGREE PROGRAMME

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

ACADEMIC YEAR & SEMESTER

2025/26 - Semester 2

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1. Description

1.1. Subject details

Name of the subject	43000445 - Computational Mechanics
No of credits	4.5 ECTS
Type	Optional/elective
Academic year of the programme	First year
Semester of tuition	Semester 2
Tuition period	February-June
Tuition languages	English
Degree programme	04AM - Master Universitario Ingeniería de Estructuras, Cimentaciones y Materiales
Centre	04 - E.T.S. De Ing. De Caminos Canales Y P.
Academic year	2025-26

2. Faculty

2.1. Faculty members with subject teaching role

Name and surname	Office/Room	Email	Tutoring hours *
Juan Carlos Garcia Orden (Subject coordinator)	ETSI Caminos	juancarlos.garcia@upm.es	Tu - 11:00 - 13:00 W - 11:00 - 13:00 F - 11:00 - 13:00
Diego Guillermo Manzanal Milano	ETSI Caminos	d.manzanal@upm.es	Tu - 11:00 - 13:00 W - 11:00 - 13:00 F - 11:00 - 13:00

* 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

- Some programming experience in any high-level language is highly desirable. Specifically, programming skills with Matlab/Octave are very valuable, since the proposed exercises will demand programming in this environment.

4. Skills and learning outcomes *

4.1. Skills to be learned

CB6 - Poseer y comprender conocimientos que aporten una base u oportunidad de ser originales en el desarrollo y/o aplicación de ideas, a menudo en un contexto de investigación

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.

CG1 - Polivalencia para extender a ámbitos afines las competencias generales adquiridas en el ámbito temático del título.

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

CT3 - Compromiso y capacidad de aplicación de los estándares de deontología en investigación y ejercicio profesional avanzado

4.2. Learning outcomes

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

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

RA24 - Conoce los métodos numéricos para resolver los cálculos estructurales no lineales.

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

RA2 - Presenta comunicaciones orales, escritas y gráficas, estructurada y argumentadamente, en lengua española e inglesa

RA13 - Sintetiza e integra con polivalencia y autonomía las competencias específica de formación científico-técnica para iniciación en I+D+i, para la alta especialización y para la investigación doctoral.

RA9 - Participa en debates en lengua inglesa

RA8 - Utiliza con eficacia recursos de modelización predictiva en una o más de las materias del módulo

RA4 - Utiliza con eficacia recursos de información y comunicación

RA1 - Utiliza con eficacia, autonomía y polivalencia recursos de modelización predictiva en la temática de la materia

RA23 - Conoce la influencia de las diversas causas de no linealidad en el análisis dinámico de estructuras y los métodos de cálculo 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

The main objective of this course is to present the main numerical methods applied to computational mechanics and their corresponding mathematical analysis. At the end of the course a student should have become familiar with the most important algorithms and must know how to choose the most suitable for certain common problems of structural engineering. Specific objectives are:

1. Acquire the necessary knowledge of programming in Matlab / Octave that allows to apply the different methods studied for the solution of mechanical problems
2. To know the basic concepts related to the numerical techniques for the solution of structural problems.
3. To know and to program the most common algorithms for the numerical solution of linear and nonlinear static problems
4. To know and to program the most common algorithms for the numerical solution of nonlinear dynamical problems

The lectures are very detailed, including implementation issues often overlooked by similar courses. As a result, students will have the knowledge to implement all the methods and actually will have to program a lot of them in order to solve several practical exercises that will be proposed along the course. Periodically, students will present their exercises and discuss their results in class.

At the end of the course a student should have become familiar with many algorithms, should have a deep knowledge of the most important ones and must know how to choose the most suitable for certain common problems of structural engineering.

5.2. Syllabus

1. Introduction to Matlab/Octave

1.1. Use of the graphical interface. Elementary operations, definition of variables

1.2. Vectors and matrices: definition, access, sectioning with operator `:`. Element-by-element operations with the operator `.*`. Linear algebra operators

1.3. Loops. Conditional statements. Graphics. Functions

2. Basic concepts on numerical methods

2.1. Errors. Ill-conditioned problems. Stability of algorithms. Accuracy, efficiency, robustness. Notation of order.

2.2. Floating-point representation of real numbers. IEEE standard

2.3. Roundoff errors. Machine precision. Evaluation of expressions. Stabilization

3. Statics of solids and structures. Nonlinear static problems

3.1. Mathematical definition: scalar and system cases

3.2. Basic concepts about iterative methods: rate of convergence, end of iterations

3.3. Basic example: bisection method

3.4. Fixed-point iterations. Scalar case; Aitken method. Systems: contractivity

3.5. Newton's method

3.6. Line-search

3.7. Quasi-Newton methods

3.8. Continuation methods in mechanics: spherical arc-length

4. Linear static problems. Small-medium size models: direct methods

4.1. Backward and forward substitutions

4.2. Gauss method

4.3. LU and Cholesky decompositions

4.4. Vector and matrix norms. Relative errors in positions and forces. Condition number.

4.5. Vectors and matrices in Octave

5. Linear static problems. Large models: iterative methods

5.1. Basic methods: Jacobi, Gauss-Seidel, SOR.

- 5.2. Basic methods: Jacobi, Gauss-Seidel, SOR.
- 5.3. Steepest descent
- 5.4. Conjugate gradient
- 5.5. Preconditioning
- 5.6. Sparse matrices
- 6. Nonlinear dynamics of solids and structures. General concepts about direct integration methods
 - 6.1. Initial value problems. Well-posed problem: Lipschitz condition. Stability. Mechanical models.
 - 6.2. One-step/multi-step ; Explicit/implicit
 - 6.3. Consistency, stability, convergence.
 - 6.4. Implementation
 - 6.5. Absolute stability region. A-stability
 - 6.6. Stiff problem. Stiff methods.
- 7. One-step, Runge-Kutta methods
 - 7.1. Basic interpretation. General definition of a RK method with s stages. Butcher format.
 - 7.2. Explicit RK: order, stability
 - 7.3. Implicit RK: Gauss, Radau, Lobatto. Order, stability, stiff properties
- 8. Multi-step methods
 - 8.1. Adams methods. Basic interpretation, general expression. Explicit (Adams-Bashford) and implicit (Adams-Moulton). Order, stability
 - 8.2. BDF methods. Order, stability
 - 8.3. Predictor-corrector
- 9. Structural methods
 - 9.1. Test equation. Spectral stability
 - 9.2. Beta-Newmark method. Order, stability
 - 9.3. HHT method.
 - 9.4. Central differences. Courant limit.
- 10. Introduction to geometric methods
 - 10.1. Hamiltonian (mechanical) system. Symplecticity, symmetries
 - 10.2. Symplectic integrators

10.3. Conservative integrators. Discrete derivative

10.4. Energy-momentum integrators. G-invariant discrete derivative.

10.5. Variational integrators

6. Schedule

6.1. Subject schedule*

Week	Type 1 activities	Type 2 activities	Distant / On-line	Assessment activities
1				
2				
3				
4				
5				
6				
7				
8				
9				
10				
11				
12				
13				
14				
15				There is not progressive evaluation, just final exams Other assessment Progressive assessment Presential Duration: 00:00
16				
17	There is not progressive evaluation, just final exams Duration: 00:00 Additional activities			Final exam, ordinary Problem-solving test Global examination Presential Duration: 03:00

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.

7. Activities and assessment criteria

7.1. Assessment activities

7.1.1. Assessment

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
15	There is not progressive evaluation, just final exams	Other assessment	Face-to-face	00:00	.1%	5 / 10	CB9 CT3 CE13 CG1 CG4 CB6

7.1.2. Global examination

Week	Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
17	Final exam, ordinary	Problem-solving test	Face-to-face	03:00	100%	5 / 10	CB6 CB9 CT3 CE13 CG1 CG4

7.1.3. Referred (re-sit) examination

Description	Modality	Type	Duration	Weight	Minimum grade	Evaluated skills
Final exam, extraordinary	Other assessment	Face-to-face	03:00	100%	5 / 10	CB6 CB9 CT3 CE13 CG1 CG4

7.2. Assessment criteria

Students will be evaluated, by default, through progressive evaluation.

Seven sheets of exercises are proposed throughout the course. Typically every sheet has a deadline of two-three weeks. They have to elaborate a written report containing a description of the solution, the main results and its discussion, and load it to Moodle. During the class which is right after the deadline, different students are drawn to the front of the classroom to present their results, and their work is open for discussion. The exercises are evaluated and the grades posted in Moodle. Based on the comments made at the presentation, students may modify or complete their exercises and the initial grades may be increased proportionally to the correctness of the additions and the time of the new delivery.

The non-presential procedure for the assessment of the assignments is the same as the presential one because it is carried out in the same exact manner as explained before, substituting the face-to face presentation in the classroom by the face-to-face presentation through video conference.

The grade of the course through continuous evaluation will be determined according to two elements: 1) Participation and debate during the lectures (35% of the grade); 2) Exercises and problems proposed and presented throughout the course (65% of the grade).

The evaluation will check if the students have acquired the competences of the course. Therefore, the final exam will use the same types of evaluation techniques used in the continuous evaluation (EX), and will be carried out at the final dates and times approved by the Academic Board for the current course and semester, except those activities of evaluation of learning results of difficult qualification in a final exam. In this case, these evaluation activities may be carried out throughout the course. In the non-presential mode, 4-5 problems, covering the subjects of the full course, will be delivered to the students at Moodle at the time scheduled in advance. They have to solve them during the exam at home, mainly with the material available from the course, programming the corresponding algorithms that are sent along with representative plots of the results to Moodle before a deadline of 3 hours. The grade is obtained from just from the problems solved during the exam. A minimum of 5 is necessary to pass the course

The evaluation in the extraordinary call will be made exclusively through the final exam procedure.

8. Teaching resources

8.1. Teaching resources for the subject

Name	Type	Notes
García Orden, J.C. "Computational Mechanics"	Bibliography	Course notes
Página web de la asignatura	Web resource	https://moodle.upm.es/titulaciones/oficiales/course/view.php?id=4366
Hubert Selhofer, revised by Marcel Oliver Introduction to GNU Octave., 2008	Bibliography	
A. Quarteroni and F. Saleri. Scientific Computing with MATLAB and Octave. Springer, 2006.	Bibliography	
A. Quarteroni, R. Sacco, and F. Saleri. Numerical Mathematics. Texts in Applied Mathematics. Springer, 2007.	Bibliography	
J.W. Demmel, Applied numerical linear algebra, SIAM, Philadelphia, 1997.	Bibliography	
T.R.J. Hughes. The Finite Element Method. Prentice Hall, 1987.	Bibliography	
Javier Bonet and Richard D. Wood. Nonlinear continuum mechanics for finite element analysis. Cambridge University Press, second edition, 2008.	Bibliography	
Uri M. Ascher and Linda R. Petzold. Computer Methods for Ordinary Differential Equations and Differential-Algebraic Equations. SIAM, Philadelphia, USA, 1998.	Bibliography	

M. Geradin and D. Rixen. Mechanical vibrations. Wiley, 1997.	Bibliography	
J.W. Eaton, David Bateman, and Soren Hauberg. GNU Octave. A high- level interactive language for numerical computations	Bibliography	