ANX-PR/CL/001-01
LEARNING GUIDE

SUBJECT

43000445 - Computational Mechanics

DEGREE PROGRAMME

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

ACADEMIC YEAR & SEMESTER

2022/23 - Semester 2

Index

Learning guide

1. Description....1
2. Faculty....1
3. Prior knowledge recommended to take the subject....2
4. Skills and learning outcomes 2
5. Brief description of the subject and syllabus....4
6. Schedule....7
7. Activities and assessment criteria....9
8. Teaching resources....12

1. Description

1.1. Subject details

Name of the subject	43000445 - Computational Mechanics
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 *
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

* 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

The subject - recommended (passed), are not defined.

3.2. Other recommended learning outcomes

- Some programing 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 estrcuturas

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. Concrete 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

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-byelement 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, stabilty, 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	Classroom activities	Laboratory activities	Distant / On-line	Assessment activities
1	**Presentation** Duration: 00:30 Lecture **Unit 1. Introduction to Matlab/Octave** Duration: 02:00 Lecture		**Presentation** Duration: 00:30 Lecture **Unit 1. Introduction to Matlab/Octave (I)** Duration: 02:00 Lecture	**Oral presentations, Unit 1-a** Individual presentation Continuous assessment Presential Duration: 00:30
2	**Unit 2. Basic concepts about numerical methods** Duration: 02:00 Lecture		**Unit 2. Basic concepts about numerical methods. Floating point representation of real numbers. Roundoff errors** Duration: 02:00 Lecture	**Oral presentations, Unit 1-b** Individual presentation Continuous assessment Presential Duration: 01:00
3	**Unit 2. Basic concepts about numerical methods** Duration: 02:00 Lecture **Unit 3. Nonlinear static problems** Duration: 01:00 Lecture		**Unit 2. Basic concepts about numerical methods** Duration: 02:00 Lecture **Unit 3. Nonlinear static problems** Duration: 01:00 Lecture	
4	**Unit 3. Nonlinear static problems** Duration: 02:00 Lecture		**Unit 3. Nonlinear static problems** Duration: 02:00 Lecture	**Oral presentations, Unit 2** Individual presentation Continuous assessment Presential Duration: 01:00
5	**Unit 3. Nonlinear static problems** Duration: 03:00 Lecture		**Unit 3. Nonlinear static problems** Duration: 03:00 Lecture	
6	**Unit 3. Nonlinear static problems** Duration: 01:00 Lecture **Unit 4. Linear static problems. Direct methods** Duration: 02:00 Lecture		**Unit 3. Nonlinear static problems** Duration: 01:00 Lecture **Unit 4. Linear static problems. Direct methods** Duration: 02:00 Lecture	
7	**Unit 5. Linear static models. Itertive methods** Duration: 03:00 Lecture		**Unit 5. Linear static models. Itertive methods** Duration: 03:00 Lecture	
8	**Unit 6. Nonlinear dynamics. General concepts about direct integration methods** Duration: 02:00 Lecture		**Unit 6. Nonlinear dynamics. General concepts about direct integration methods** Duration: 02:00 Lecture	**Oral presentations, Unit 3** Individual presentation Continuous assessment Presential Duration: 01:00

9	**Unit 6. Nonlinear dynamics. General concepts about direct integration methods** Duration: 03:00 Lecture		**Unit 6. Nonlinear dynamics. General concepts about direct integration methods** Duration: 03:00 Lecture	
10	**Unit 6. Nonlinear dynamics. General concepts about direct integration methods** Duration: 02:00 Lecture		**Unit 6. Nonlinear dynamics. General concepts about direct integration methods** Duration: 02:00 Lecture	**Oral presentations, Unit 4** Individual presentation Continuous assessment Presential Duration: 01:00
11	**Unit 7. One-step, Runge-Kutta methods** Duration: 02:00 Lecture		**Unit 7. One-step, Runge-Kutta methods** Duration: 02:00 Lecture	**Oral presentations, Unit 5** Individual presentation Continuous assessment Presential Duration: 01:00
12	**Unit 8. Multistep methods** Duration: 02:00 Lecture **Unit 9. Structural methods** Duration: 01:00 Lecture		**Unit 8. Multistep methods** Duration: 02:00 Lecture **Unit 9. Structural methods** Duration: 01:00 Lecture	
13	**Unit 9. Structural methods** Duration: 02:00 Lecture		**Unit 9. Structural methods** Duration: 02:00 Lecture	**Oral presentations, Unit 6** Individual presentation Continuous assessment Presential Duration: 01:00
14	**Unit 9. Structural methods** Duration: 02:00 Lecture **Unit 10. Geometric methods** Duration: 01:00 Lecture		**Unit 9. Structural methods** Duration: 02:00 Lecture **Unit 10. Geometric methods** Duration: 01:00 Lecture	
15	**Unit 10. Geometric methods** Duration: 02:00 Lecture		**Unit 10. Geometric methods** Duration: 02:00 Lecture	**Oral presentations, Units 7-8-9** Individual presentation Continuous assessment Presential Duration: 01:00
16				
17				**Final exam** Problem-solving test Final 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.

* 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
1	Oral presentations, Unit 1-a	Individual presentation	Face-to-face	00:30	%	/ 10	CB6 CB9 CT3 CE13 CG1 CG4
2	Oral presentations, Unit 1-b	Individual presentation	Face-to-face	01:00	0%	/ 10	CB6 CB9 CT3 CE13 CG1 CG4
4	Oral presentations, Unit 2	Individual presentation	Face-to-face	01:00	10.83%	/ 10	CT3 CE13 CG1 CG4 CB6 CB9
8	Oral presentations, Unit 3	Individual presentation	Face-to-face	01:00	10.83%	/ 10	CB6 CB9 CT3 CE13 CG1 CG4
10	Oral presentations, Unit 4	Individual presentation	Face-to-face	01:00	10.83%	/ 10	CB6 CB9 CE13 CG4
11	Oral presentations, Unit 5	Individual presentation	Face-to-face	01:00	10.83%	/ 10	CT3 CE13 CG1 CG4 CB6 CB9

13	Oral presentations, Unit 6	Individual presentation	Face-to-face	01:00	10.83%	/ 10	CB6 CB9 CT3 CE13 CG1 CG4
15	Oral presentations, Units 7-8-9	Individual presentation	Face-to-face	01:00	10.83%	/ 10	CB6 CB9 CT3 CE13 CG1 CG4

7.1.2. Global examination

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

7.1.3. Referred (re-sit) examination

No se ha definido la evaluación extraordinaria.

7.2. Assessment criteria

Students will be evaluated, by default, through continuous evaluation. The student wishing to give up the continuous evaluation and to opt for the evaluation by final exam (formed by one or more evaluation activities of the course), must write through the platform Moodle to the coordinator of the course before the seventh week.

Seven sheets of exercises are proposed throughout the course. Typically every sheet has a deadline of two-three weeks. They have to ellaborate a written report cointaining 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, substituing 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) Attendance and participation (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 minumum 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	