MECHANICAL BRANCH GUIDE

I METHODOLOGICAL GUIDANCE

I.1 GENERAL ASPECTS

Due to the heterogeneous knowledge and experiences of the students a course such as this , the provision of a multidisciplinary approach ranging from the most basic knowledge of certain essential subjects to other more difficult subjects which deepen in specific areas has been attempted. Furthermore, some freedom has been left to professors so they can approach each subject from their own perspective, losing uniformity, but gaining a variety of viewpoints. Nevertheless, the extensiveness of the F.E.M. and virtual simulation makes more teaching hours necessary in order to cover all the specific aspects of the course, therefore every subject has been limited in its length and depth to its credits or corresponding hours. Students interested in deeper understanding of certain aspects of the syllabus may start with the additional bibliography specified in the syllabus of each subject and shall consult with the professor/tutor of the subject.

It is very important to highlight that, in a distance learning course, the students must have the self-discipline to follow the timetable of teaching hours for each subject, according to the given guidelines and order of the course (section I from the general guide).

During the weeks devoted to each subject in the schedule, and two additional weeks once the subject is finished, there are four hours per week of tutorships or consultation about the taught subjects.

Finally, the continuous assessment booklets must be completed during the term of the corresponding subject and exams must be taken at the end of the term as detailed in section I.8 and I.10 from the general guide.

If the students do not take or do not pass their exams, they cannot obtain the corresponding diploma.

I.2 EXPERT MODULE SUBJECTS. THEORETICAL FOUNDATIONS

AF.1. - F.E.M GENERAL THEORY

Subject's professors: Mr. Juan José Benito Muñoz PhD

Mr. Ramón Álvarez Cabal PhD

Mr. Mariano Rodríguez-Avial Llardent PhD

Mr. Enrique López del Hierro Fernández PhD

1. - OBJECTIVES

The aim of this subject is to consolidate the foundations of the Finite Element Method, by thinking mainly about its application in structure analysis, although the basic ideas can be generalized without any difficulty.

Furthermore, it should be pointed out that the subject starts with the most basic concepts, initially treated intuitively in order to allow them to be easily assimilated.

2. - CONTENT

The organization of basic ideas, already known to the student, is the beginning of the subject´s syllabus which tries to organize them using a matrix approach so that the structural calculation will be more effective. It will immediately set out the heart of the formulation of the direct rigidity method and the problem will be reassessed from a more powerful and general point of view. At the beginning it will also deal with the linear elements, which are easier to handle.

Subsequently, the elastic-linear problems are set out, taking a further step in the generalization of ideas, and the C_0 shape functions are studied in detail.

Finally, the theme of plates is discussed with the aim of laying the foundations for a later study about this important structural type and, above all, of presenting general ideas about the problems raised previously and the solutions adopted in the demanding cases of C_1 continuity.

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3.2.2. - Generalization to Structures under Bending Beams Case

3.3. - Element Idea. Shape Functions

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10.7.3. - Quadrilateral Elements

10.8. - Conclusions

3. - BASIC TEXT AND OTHER TEACHING MATERIALS

Course Learning Units

4. - BIBLIOGRAPHICAL REFERENCES

ALARCÓN, A., ALVAREZ, R. & GÓMEZ-LERA, S. *Cálculo Matricial de Estructuras*. Barcelona, España: Ed. Reverté, S.A., 1986. ISBN: 84-291-4801-9.

BATHE, K.J. *Finite Element Procedures in Engineering Analysis*. New Jersey, USA: Ed. Prentice-Hall, Inc., 2007. ISBN-10: 097900490X / ISBN-13: 978-0979004902.

OÑATE, E. *Cálculo de Estructuras por el Método de Elementos Finitos. Análisis Estático Lineal*. España: Ed. CIMNE, 1995. ISBN: 9788487867002.

ZIENKIEWICZ, O.C. & TAYLOR, R.L. The Finite Element Method: Its Basis and Fundamental. 6th edition. Oxford, UK: Ed. Elsevier Butterworth-Heinemann, 2005. ISBN-10: 0750663219/ ISBN-13: 9780750663212.

Spanish version: ZIENKIEWICZ, O.C., TAYLOR, R.L. *El Método de los Elementos Finitos. Formulación Básica y Problemas Lineales*. 4th edition. Barcelona, España: Ed. CIMNE - Mc. Graw-Hill, 1994. ISBN: 9788495999528.

5. - CONTINUOUS ASSESSMENT BOOKLETS

In the distance learning booklets, the given exercises and problems must be directly resolved and it is necessary to use the software in order to compare the results obtained.

6. - SPECIFIC RECOMMENDATIONS

It is advisable that the problems included in the distance learning booklets are resolved as the student moves forwards in the study of the learning units for the purpose of sequentially clarifying, as soon as possible, any doubts that may arise.

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The student will upload the continuous assessment exercises in the virtual classroom.

AF.2. - INTRODUCTION TO F.E.M PROGRAMMING

Subject Professor: Mr. Luis Gavete Corvinos PhD

1. - OBJECTIVES

The objectives of this course are focused on teaching students to use and introduce desired changes on a small computer program using the Finite Element Method. To that end, the student is provided with solid basis of programming with some basic algorithms related to data structure and numerical calculation. Thus, using this basis and simple programming language the programming of the Finite Element Method is addressed.

We believe, therefore, that the objectives of the course are covered by the information provided, although students can improve the programmingthemselves so that the programs will be more effective. We have opted for clarity over the efficiency of the program. Therefore, we have used the BASIC language because of its ease of use and its wide dissemination.

2. - CONTENT

The Introduction of F.E.M programming course is divided into three large sections. In the first section, called “Programming introduction” (Warnier Method in a freeware version), which is perfectly adapted to solving mathematical problems through numerical methods. This section includes the first chapters and it gives the basis to understand perfectly (starting from scratch) the programming of complex problems. Furthermore, it includes the basic algorithms which are often used in Finite Element Method programming. Obviously, this could be totally or partly ignored by those students who already have a good knowledge of programming.

The second section constitutes the actual introduction to F.E.M programming which is performed for the two dimensional linear elasticity case using the simplest finite element (three nodes triangle). This section includes two chapters, the first one addresses the two dimensional elasticity case including a simple graphic processor which allows the user to see the model and the calculation results; the second one contains a brief introduction to storage improvements.

Finally, the third section addresses error estimation in F.E.M. It includes a simple application example as well as its programming.

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8.8. - Full Computer Program

8.9. - Chapter 8 references

IX. Bibliography

Annex: Creating a Form

3. - BASIC TEXT AND OTHER TEACHING MATERIALS

Course Learning Units

4. - BIBLIOGRAPHICAL REFERENCES

ALARCÓN, A., ALVAREZ, R., GÓMEZ-LERA, S. *Cálculo Matricial de Estructuras*. Barcelona, España: Ed. Reverté, S.A., 1986. ISBN: 84-291-4801-9.

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6. - ADDRESS FOR SENDING THE CONTINUOUS ASSESSMENT BOOKLETS

The student will upload the continuous assessment exercises in the virtual classroom.

AF.3.- NUMERICAL CALCULATION

Subject Professor: Mr. Luis Gavete Corvinos PhD

1. - OBJECTIVES

The purpose of this text is to introduce basic numerical calculation techniques to the student, which are employed in the Finite Element Method, and to serve as the first contact base with the numerical methods.

Thus, all the mathematical concepts have been simplified as much as possible and a series of examples has been provided in order to facilitate the student work. Being a "distance learning" course, it is necessary that the text is accompanied by the required self-taught manual.

Furthermore, the numerical techniques needed in order to do static and dynamic analysis by finite elements in linear and non-linear cases have been covered.

2. - CONTENT

The text consists of two simple introductory chapters containing basic introductory concepts about matrices and numerical calculation to allow the student to move forward to the second part of numerical calculation.

This second part has a chapter on interpolation (focused on Lagrange Interpolation) with some "spline" function concepts. Subsequently, the numerical integration is covered, focusing on Gauss integration.

Three chapters are dedicated to the basic concepts of numerical Algebra: a) equation systems; b) non-linear equation systems; c) eigenvalues and eigenvectors. The intention is to cover the most common algorithms areas in the finite elements programs.

There is also a chapter based on the resolution of the second order differential equation systems which originate the dynamic analyses, and there is another chapter which contains an introduction to the equations in partial derivatives and methods of resolving them.

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X. Bibliography

3. - BASIC TEXT AND OTHER TEACHING MATERIALS

Course Learning Units

4. - BIBLIOGRAPHICAL REFERENCES

Software: manuals

BATHE, K.J. & WILSON, E. *Numerical Methods in Finite Element Analysis.* Ed. Prentice Hall, 1976. ISBN-10: 0136271901 / ISBN-13: 978-013627901.

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TURNER, P. *Numerical Analysis*. Lancaster, UK: Ed. Macmillan Press Ltd, 1994.

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The student will upload the continuous assessment exercises in the virtual classroom.

AF.4. - LAWS OF MATERIALS BEHAVIOUR

Subject professors: Mr. Enrique Alarcón Álvarez PhD
Mr. Alberto Fraile de Lerma PhD

1. - OBJECTIVES

The main objective of the subject is to show the possibilities of representing the non-linear behavior of the materials through mathematical models.

Therefore, it starts with hyperelastic materials which allow us to observe the importance of thermodynamic concepts in materializing reversibility and, later, it sets out the Clausius-Duhem equation as a restriction to the satisfaction of any formulation.

The thermodynamics of irreversible processes based on the local state principle allow the outling of a global frame where the theories of viscoplasticity, damage, etc. are found, which, in themselves, constitute another objective of the course.

2. - CONTENT

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4.3.2. - Non-linear Finite Element Method: Algorithm

3. - BASIC TEXT AND OTHER TEACHING MATERIALS

Course Learning Units

4. - BIBLIOGRAPHICAL REFERENCES

LEMAÎTRE, J. & CHABOCHE, J.L. *Mecanique des Materiaux Solides*. Ed. Dunod, 1988. ISBN: 9782100013975.

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The student will upload the continuous assessment exercises in the virtual classroom.

II EXPERT MODULE SUBJECTS. THEORY AND PRACTICE: MECHANICAL BRANCH

AP.1. - INTRODUCTORY COURSE OF THE USE OF THEORETICAL AND PRACTICAL SOFTWARE

Subject Lecturers: Mr. José Luis Cuadros

Mr. Rubén Establés Antón

1. - OBJECTIVES

In an engineering project, the Finite Element Method requires the use of algorithms programmed by computer and the basis of calculation is set out, in most cases, using finite element commercial programs; so it is necessary to supplement the theoretical training in the finite element method with the use of software. To that end, the MSC Patran/Nastran program has been chosen since it is a general-purpose program, which in addition will allow the use of a specific license for the Master's. The MSC brand, a standard of F.E. programs, permits the user to put into practice all the knowledge that has been taught on the course and in its specific modules.

The aim of this subject, as its name indicates, is to introduce the student tothe use of an analysis program based on Finite Elements and for the student feel sufficiently at ease from the beginning to acquire knowledge continuously during the course in the rest of the subjects of Theory and Practice.

2.-CONTENT

This subject is eminently practical and both its content and its structuring are focused on the student becoming familiar with the use of the program from the beginning of the course since it will be useful throughout, and will be the means of materializing and to applying the knowledge acquired to different subjects.

The subject has been structured into the following chapters:

1. Overview
2. MD Patran Graphical User Interface and Files
3. Geometric Modeling
4. Meshing

Obtaining a proper model is frequently the longest step in the realization of an Analysis using a Finite Element Method Application program, especially in those cases in which the models present complex geometrical forms.

Similarly, the accuracy of the results will largely depend on obtaining an element model with proper forms and sizes (mesh density).

To that end, the use of Solid and Meshing Model generation techniques of the Patran practical program will be described in detail.

3. - BASIC TEXT AND OTHER TEACHING MATERIALS

The teaching material for this subject is composed of the MSC Patran/Nastran software and the four first chapters of the subject book (Original MSC texts for the introductory course).

4. - BIBLIOGRAPHICAL REFERENCES

The course includes an interactive help section with specific help for each of the different themes dealt with.

It is important that the students familiarize themselves with the software help.

5. - CONTINUOUS ASSESSMENT BOOKLETS

The students should do the exercises that the professor uploads in the virtual classroom in order to have a continuous assessment.

6. - SPECIFIC RECOMMENDATIONS

It is important that the students familiarize themselves with analysis configuration using the Patran graphical interface, and also know that Patran has a command language called PCL which allows the creation of command files and to have a parameterized model.

Practicing with the computer and consulting the online help section of the software is recommended.

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8. - ADDRESS FOR SENDING THE CONTINUOUS ASSESSMENT BOOKLETS

The student will upload the continuous assessment exercises in the virtual classroom

AP.2. MODELING TECHNIQUES. USE OF AUTOMATIC MESHING

Subject lecturers: Mr. José Luis Cuadros

Mr. Rubén Establés Antón

1. - OBJECTIVES AND CONTENT

This subject focuses on the study of Patran. An introduction to Nastran and its language will be also made.

In this subject the specific themes which allow the configuration of the model (load application, contour conditions, materials, elements properties, etc.), the configuration of the solution, post-processing techniques and Patran/Nastran tools (working with groups, lists, etc.) will be studied.

1. The chapters of this subject are:Viewing and Display
2. Groups
3. Lists
4. Fields
5. Load and Boundary Conditions
6. Materials
7. Element Properties
8. Analysis Setup
9. Viewports
10. Results
11. Result Animation
12. File Management

Furthermore, a theoretical introduction to the Finite Element Method will be made in the chapter:

- Brief Introduction to the Finite Element Method.

In addition, an introduction to the Nastran Input files, with its language and particular commands (.bdf files) will be made.

2. – BASIC TEXT AND OTHER TEACHING MATERIALS CONTENT

The basic texts that compose the Teaching Unit are:

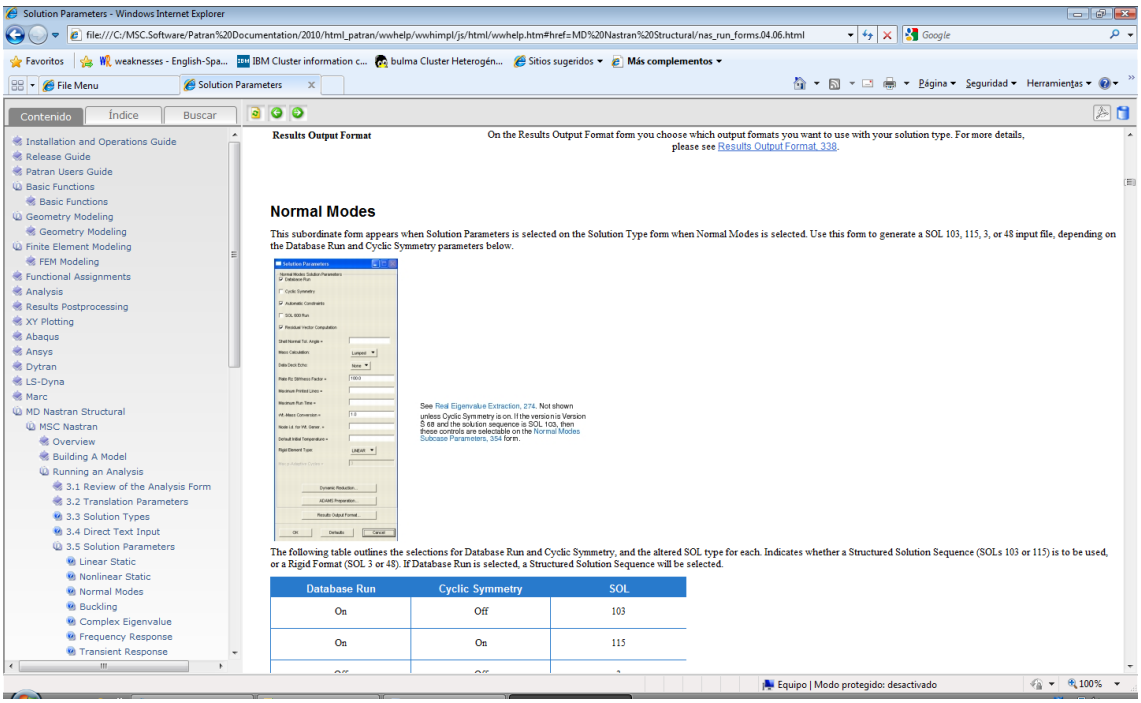
Patran introductory course: *Chapters 5 to 7*

Nastran introductory course: *Chapters 1 and 2*

Another essential teaching material for this subject is the practice program itself and its “online” documentation.

3. – BIBLIOGRAPHICAL REFERENCES

The bibliographical references are the interactive documentation of the program (Help):



4. - CONTINUOUS ASSESSMENT BOOKLETS

The student should do the exercises uploaded by the professor in the virtual classroom in order to have a continuous assessment.

5. - SPECIFIC RECOMMENDATIONS

It must be taken into account that Patran, which is a Pre/Post, uses PCL language and Nastran, which is only a solver, has its own language (.bdf files)

The objective of Patran is to generate an input file in order for Nastran to resolve it. To do this Patran has its graphical user interface and the PCL commands language.

Nastran input files (.bdf files) created by Patran have their own language. These files can be also created from scratch with a text editor. Becoming familiar with these Nastran input files is part of the objective of the course.

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7. - ADDRESS FOR SENDING THE CONTINUOUS ASSESSMENT BOOKLETS

The student will upload the continuous assessment exercises in the virtual classroom.

AP3. - APPLICATION PRACTICES. EXAMPLES

Subject lecturers: Mr. José Luis Cuadros

Mr. Rubén Establés Antón

1.-OBJECTIVES

The objective of the course is to complete, with exercises which must be done using MSC Patran/ Nastran, the concepts explained previously in the theoretical and application courses of the modules AF and AP.

The exercises of this subject will be done as the chapters of the AP1 and AP2 courses are studied.

2.-CONTENT

The exercises represent a review of the concepts introduced in the subjects taken until now, as well as the orderly use of the Patran/Nastran programs:

1. Piston Head Analysis
2. Cantilevered Plate
3. Frame Model Creation Using Curves, and Analysis
4. Mid-Surface Extraction Example
5. Frame Surfaces Creation
6. Frame Surfaces Model Analysis
7. Parasolid Solid Example
8. Various Methods of Solid Meshing
9. Anchor Geometry Creation
10. Tetmeshing Anchor Geometry and Verifying Mesh Quality
11. Using Lists and Groups
12. Anchor Loads and Boundary Conditions Using a Field
13. Cantilevered Beam Using 1D or 2D Elements, and Analysis

14. Anchor Material and Element Properties
15. Anchor Analysis
16. Stiffened Plate
17. Box Beam With Transient Load
18. Connecting Rod Using 2D Elements
19. Connecting Rod Using 3D Elements From Sweep

3. - BASIC TEXT AND OTHER TEACHING MATERIALS

The teaching material is given with the proposed and resolved exercises

4. - BIBLIOGRAPHICAL REFERENCES

Subjects of this course:

-AF.1: FEM general theory

-AF.3: Numerical calculation

-AP.1: Introductory course to use of the practice program

-AP.2: Solid and meshing modeling techniques.

5. - CONTINUOUS ASSESSMENT BOOKLETS

The student should follow the instructions specified in the virtual classrooms by the professors.

6. - SPECIFIC RECOMMENDATIONS

This subject must be taken after having finished subject AP.1 using the user's guide, manual of procedures and the online documentation of the corresponding commands, so that the main teachings of the different chapters can be completed and assimilated through practice.

Each exercise should not take more than three hours, although it is recommended that the student practices as much as he/she can do with the menu in the post-process phase and analyzes and interprets the physical sense of the results obtained.

7. - TUTORSHIPS: OFFICE HOURS

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8. - ADDRESS FOR SENDING THE CONTINUOUS ASSESSMENT BOOKLETS

The student will upload the continuous assessment exercises in the virtual classroom.

III SPECIALIZED MODULE SUBJECTS

III.1 MODULE A

A.1. – FEM THEORY APPLIED TO STRUCTURE DYNAMIC ANALYSIS

Subject professor: Mr. Francisco Montans Leal PhD

1. - OBJECTIVES

The initial objectives are to analyze the problems that are presented when a structure calculation is going to be made with a commercial Finite Element program and to provide some criteria to resolve these, and to focus later on some specific structural type such as plates and sheets.

Finally, it is also intended to provide the essential concepts and to identify the fundamental parameters which characterize the dynamic behavior of structural systems.

2. - CONTENT

In the first chapter, it is intended to present an overview of the problems and different decisions that an analyst must take when a structure analysis is done.

The second chapter deals with the plate and sheet theories. In addition, the plate theory is established for thin plate cases from the hypothesis of Kirchhoff and for thick plates from the Mindlin-Reisner hypothesis. In both cases, the study addresses the case of linear elasticity for homogeneous, isotropic, of constant thickness, perpendicular charged to its mid-surface plates.

Both linear theory and the membrane theory are developed for the constant thickness of thin sheets, and also for the linear case and supposing homogeneous and isotropic material.

In the last chapters, the structural dynamic analysis is addressed. Thus, after a brief introduction and a review of the essential concepts, the treatment of the systems is studied with a degree of freedom in order to continue, after the mass and consistent damping matrix has been introduced, with the study of structural systems whose dynamic response can be characterized through a number of finite degrees of freedom.

INDEX

4.6. - Response to a General Dynamic Load Type

4.7. - Response Spectrum

V. Systems with N Freedom Degrees

5.1. - Formulation of Displacement Equations

5.2. - Mass and Buffer Matrices

5.3. - Undamped Free Vibrations. Natural Frequency and Vibrations Modes. Vibration Modes Properties.

5.4. - Dynamic Response Analysis. Normal Modes Method

5.5. - Damped System Response

5.6. - Modes Superposition

3. - BASIC TEXT AND OTHER TEACHING MATERIALS

Course Learning Units

4. - BIBLIOGRAPHICAL REFERENCES

ALARCÓN, A., ALVAREZ, R. & GÓMEZ-LERA, S. *Cálculo Matricial de Estructuras*. Barcelona,Spain: Ed. Reverté, S.A., 1986. ISBN: 84-291-4801-9.

CLOUGH R.W. & PENZIEN J. *Dynamics of Structures.* 2nd edition. London, UK: Ed. Mc Graw-Hill, 1993. ISBN-10: 0071132414 / ISBN-13: 9780071332411.

HOU-CHENG HUANG. *Static and Dynamic Analysis of Plates and Shells.* Berlin, Germany: Ed. Springer-Verlag, 1989. ISBN-10 : 0387195386 / ISBN-13 : 9780387195384.

LAROZE S. & BARRAN, J.V. *Mécanique des Structures. Solides Èlastiques, Plasques et Coques. Vol. 1. Paris, France : Ed. Eyrrolles-Masson.*

PRZEMIENIECKI J.S. *Theory of Matrix Structural Analysis.* New York, USA: Ed. Dover Publications, 1986. ISBN-10: 0486649482 / ISBN-13: 9780486649481.

RAO S.S. *Mechanical Vibrations.* 5th edition. Singapore: Ed. Pearson Education Center, 2011. ISBN: 9788177588743.

TIMOSHENKO, S. & WOINOWSKY-FRIEGER, S. *Theory of Plates and Shells*. New York, USA: McGraw Hill, 1989. ISBN: 9780000858206.

Spanish version: TIMOSHENKO, S. & WOINOWSKY-FRIEGER, S. *Teoría de Placas y Láminas.* Bilbao, Spain: Ed. Urmo, 2005. ISBN: 9788431401160.

ZIENKIEWICZ, O.C. *Finite Element Method*. 5th edition. Oxford, UK: Ed. Butterworth-Heinemann, 2005.

Spanish version: ZIENKIEWICZ, O.C. El Método de los Elementos Finitos. Barcelona, Spain: Ed. Reverté, S.A., 2004.

5. - CONTINUOUS ASSESSMENT BOOKLETS

6. - SPECIFIC RECOMMENDATIONS

It is generally advisable to resolve the simple exercises analyzing the results which are obtained with different meshes and to verify to what extent the hypotheses made are fulfilled in the theoretical approaches.

On the other hand, it should not be forgotten that only with training in calculus can clear criteria be acquired. Therfore, it is recommended that students try to do similar exercises to the ones proposed as continuous assessment, but use problems from his/her professional activity as a base.

7. - TUTORSHIPS: OFFICE HOURS

Professor: Dr. Francisco Montans Leal

E-mail: fco.montans@upm.es

8. - ADDRESS FOR SENDING THE CONTINUOUS ASSESSMENT BOOKLETS

The student will upload the continuous assessment exercises in the virtual classroom.

A.2. - INTRODUCTION TO DYNAMIC ANALYSIS WITH PRACTICAL SOFTWARE

Subject lecturers: Mr. Miguel A. Moreno Fdez. de Yepes PhD

Mr. Ambrosio Baños Abascal

1. - OBJECTIVES

The purpose of the subject is to introduce the student to the basic concepts of Dynamic Analysis of structures by using the practice program to resolve different types of dynamic analysis, so that theoretical concepts studied in previous chapters can be assimilated. Real problems will be studied with a Finite Element program (Patran/Nastran).

2. - CONTENT

The subject is structured into fourteen chapters which describe the different types of analysis, how to do them and give examples of what each one resolves.

1. Review of Fundamentals
2. Mass Modeling
3. Normal Modes Analysis
4. Normal Modes Analysis for Pre-Stiffened Structures
5. Model Checkout
6. Reduction in Dynamic Analysis
7. Response Method
8. Damping Overview

9. Transient Response Analysis

10. Frequency Response Analysis

11. Residual Vector Method

12. Enforced Motion

13. Random Analysis

14. Response/Shock Spectrum Analysis

15. Complex Eigenvalue Analysis

16. Glued Contact in Normal Modes Analysis

3. - BASIC TEXT AND OTHER TEACHING MATERIALS

Course Learning Units

4. - BIBLIOGRAPHICAL REFERENCES

For bibliographical references, it is useful to use the Nastran *Quick Reference Guide,* which is available in:

C:\MSC.Software\MD_Nastran\md2008\doc\pdf_nastran\reference\qrg.pdf

And also the Patran help in its dynamic analysis sections (opened from the Patran interface).

5. - CONTINUOUS ASSESSMENT BOOKLETS

The student must follow the instructions given in the virtual classroom by the professor.

6. - SPECIFIC RECOMMENDATIONS

This subjects is very large and interesting, it offers a complete and exhaustive treatment of the different types of dynamic analysis that are made today using Finite Elements software.

7. - TUTORSHIPS: OFFICE HOURS

Lecturer: Mr. Ambrosio Baños Abascal

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8. - ADDRESS FOR SENDING THE CONTINUOUS ASSESSMENT BOOKLETS

The student will upload the continuous assessment exercises in the virtual classroom.

A.3. - DYNAMIC ANALYSIS PRACTICES

Subject lecturers: Mr. Miguel A. Moreno Fdez. de Yepes
Mr. Ambrosio Baños Abascal

1. - OBJECTIVES

The main aim of this subject is to complete the study of the dynamic analysis of the proposed exercises, which must be done with MSC Patran/Nastran. These exercises will explain the concepts that have been studied in the previous chapters of this module.

2. - CONTENT

Various exercises are proposed, involving the following topics: Modal Analysis, Transitory Analysis, Analysis of Harmonic Response and Spectral Analysis.

INDEX

E. Modal Analysis of Tuning Fork using 1D Elements

6) A. Modal Analysis of a Tower
   B. Modal Analysis of a Tower with Soft Ground Connection

7) A. Normal Modes Analysis for Pre-stiffened Plate Model
   B. Modal Analysis for Pre-stiffened Turbine Blade at Different RPM

8) Effective Mass
9) Direct Transient Analysis
10) Direct Transient Analysis of a Car Chassis
11) Modal Transient Analysis
12) Modal Transient Analysis of the Tower Model with Seismic Input
13) Direct Frequency Response Analysis
14) Modal Frequency Response Analysis
15) Frequency Response Analysis of a Circuit Board
16) Modal Frequency Analysis of a Car Chassis
17) Direct Transient Response with Enforced Acceleration, Matrix Partition Approach
18) A. Random Analysis with Single Excitation Using MSC.Random
    B. Random Analysis with Multiple Excitations Using MSC.Random

19) Random Vibration Analysis of a Satellite Model Using MSC.Random
20) Calculate Response Spectra
21) Response Spectrum Analysis
22) Normal Modes, Glued Contact
23) Direct Transient Response with Enforced Acceleration, Large Mass Method

3. - BASIC TEXT AND OTHER TEACHING MATERIALS

The documentation provided with the proposed and resolved exercises pertaining to the dynamic analysis of MSC course composes the teaching material.

4. - BIBLIOGRAPHICAL REFERENCES

Subjects of this course:

A.1. - Static and Dynamic Structural Analysis Foundations

A.2. - Dynamic Analysis Course. Application with the Practice Program

Patran and Nastran Documentation

5. - CONTINUOUS ASSESSMENT BOOKLETS

The student must follow the instructions given in the virtual classroom by the professor.

6. - SPECIFIC RECOMMENDATIONS

This subject must be taken once after having finished subject A.2 using the user's guide and the online documentation of the corresponding commands and onscreen menus, so that the different chapter's main teachings can be completed and assimilated through practice.

7. - TUTORSHIPS: OFFICE HOURS

Lecturer: Mr. Ambrosio Baños Abascal

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8. - ADDRESS FOR SENDING THE CONTINUOUS ASSESSMENT BOOKLETS

The student will upload the continuous assessment exercises in the virtual classroom.

II.2 MODULE B

B.1. - F.E.M THEORY APPLIED TO NON-LINEAR STRUCTURES CALCULATION

Subject professor: Mr. José M[a] Sancho Aznal PhD

1. - OBJECTIVES

The purposes of this subject are to learn and understand the formulation, using the Finite Element Method, of non-linear problems in structures from an engineering perspective, the application of large displacement problems, large deformations and stiffening by stress; as well as the introduction to non-linear mechanics of solids, and in addition to the formulation of beam elements and its methods of solution.

2. - CONTENT

INDEX

4.3. - Arch-length Methods

4.4. - Instability Points Calculation. Linearized Buckling

3. - BASIC TEXT AND OTHER TEACHING MATERIALS

Teaching Units

4. - BIBLIOGRAPHICAL REFERENCES

Teaching units and references are in the same unit.

5. - CONTINUOUS ASSESSMENT BOOKLETS

6. - SPECIFIC RECOMMENDATIONS

7. - TUTORSHIPS: OFFICE HOURS

Professor: Dr. José Mª Sancho Aznal

Fridays, from 10:00 am to 2:00pm

E-mail: jose.sancho@upm.es

8. - ADDRESS FOR SENDING THE CONTINUOUS ASSESSMENT BOOKLETS

The student will upload the continuous assessment exercises in the virtual classroom.

B.2. - INTRODUCTION TO NON LINEAR ANALYSIS WITH PRACTICAL SOFTWARE

Subject lecturer: Mr. José Luis Cuadros Fernández

1. - OBJECTIVES

The first objective of the course is to find answers to some basic questions of non-linear structural calculation such as the following: What is a non-linear structure? What kind of problems require a non-linear analysis? What are the causes of non-linear behavior? What is different in a non-linear analysis? What is different in a non-linear analysis by finite elements? What are the essential peculiarities of a non-linear analysis by finite elements? The second objective is to learn to solve the questions through the use of a Finite Elements program like MSC Patran/Nastran.

2. - CONTENT

The content of this subject is structured into different chapters in which are described the different non-linearities, the proceedings to address them, examples of each one and recommendations for their treatment.

In this subject the various types of non-linear behavior with MSC Patran/Nastran are studied, which can be grouped in three main groups:

- Geometric non-linearities
- Material non-linearities
- "Status" change non-linearities

Furthermore, some examples of the application of the different types of non-linear behavior are presented.

These topics will be seen in the following chapters:

1. Introduction to MD Nastran
2. Nonlinear versus Linear Analysis
3. Nonlinear Solution Strategy
4. Nonlinear Materials

5. Nonlinear Elements
6. Contact
7. Heat Transfer
8. Nonlinear Transient Dynamics

3. - BASIC TEXT AND OTHER TEACHING MATERIALS

The basic text for the course is the *Structural Non-linearities User's guide* of the Nastran software edited by MSC.

4. - BIBLIOGRAPHICAL REFERENCES

Of the aforementioned references, the following have been chosen:

- *Patran Analysis Guides*

- *Nastran Quick Reference Guide*

These documents are included in the documentation attatched to the software and are sent to the students at the beginning of the course.

5. - CONTINUOUS ASSESSMENT BOOKLETS

The student must follow the instructions given in the virtual classroom by the professor.

6. - SPECIFIC RECOMMENDATIONS

This subject is very large as non-linear problems are found in a wide range of technical applications.

It is advisable for students, after studying each chapter, to follow the resolution of the exercises and the problems highlighted in the subject text on their computers and to resolve the exercises of subject B.3 in the continuous assessment booklet.

7. - TUTORSHIPS: OFFICE HOURS

Lecturer: Mr. José Luis Cuadros Fernández

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8. - ADDRESS FOR SENDING THE CONTINUOUS ASSESSMENT BOOKLETS

The student will upload the continuous assessment exercises in the virtual classroom.

B.3. - NON-LINEAR ANALYSIS PRACTICES

Subject lecturer: Mr. José Luis Cuadros Fernández

1. - OBJECTIVES

The main goal of this subject is to complete, with exercises that have to be done using Patran/Nastran, the concepts explained in the Theoretical and Application subjects of module B.

2. - CONTENT

The exercises refer to each non-linearity dealt with in the application course.

1. Linear and Nonlinear Analysis of a Cantilever Beam
2. Normal Modes Analysis of a Pre-stiffened Blade
3. Necking of a Test Specimen
4. Creep of a Steel Tube
5. Balljoint Analysis
6. Buckling of a Composite Plate
7. Rubber Door Seal
8. Thermo-Structural Analysis of an Integrated Circuit Board
9. Dynamic Collapse of a Cylinder

3. - BASIC TEXT AND OTHER TEACHING MATERIALS

The basic documentation of the subject is provided with the proposed and resolved exercises.

4. - BIBLIOGRAPHICAL REFERENCES

The references are the same as in the application subject.

5. - CONTINUOUS ASSESSMENT BOOKLETS

The student must follow the instructions given in the virtual classroom

6. - SPECIFIC RECOMMENDATIONS

This subject must be taken after having finished subject B.2 using the user's guide, the analysis guides and the online documentation of the corresponding onscreen commands , so that the different chapter's main teachings can be completed and assimilated through practice.

7. - TUTORSHIPS: OFFICE HOURS

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8. - ADDRESS FOR SENDING THE CONTINUOUS ASSESSMENT BOOKLETS

The student will upload the continuous assessment exercises in the virtual classroom.

III.3 MODULE C

C.1. - F.E.M THEORY APPLIED TO HEAT TRANSFER

Subject Professor: Mr. Julio Hernández Rodríguez PhD

1. - OBJECTIVES

This course aims to provide the theoretical knowledge about heat transfer and the finite element method necessary for its specific application in the resolution of heat transfer problems, as well as in stationary or non-stationary systems.

2. – CONTENT

INDEX

3.1. - Introduction

3.2. - Dimensional Analysis

3.3. - Laminar Flow and Turbulent Flow

3.4. - Forced Convection along the Flat Plates

3.5. - Forced Convection within Ducts

3.6. – Heat Transfer from a Cylinder in Cross Flow

3.7. – Heat Transfer from Tube Banks in Cross Flow

3.8. - Free Convection

IV. Heat Transfer by Radiation

4.1. - Radiation Intensity. Diffuse Emission

4.2. - Radiation Exchange between Black Bodies

4.3. - Radiation Exchange between Gray Bodies

SECOND PART: FINITE ELEMENT METHOD IN FLUID-DYNAMICS AND HEAT TRANSMISSION PROBLEMS

I. Introduction

II. Fluid Mechanic Foundations. General Equations and Contour Conditions

III. Equations Classification

IV. Weighted Residual Methods

V. Finite Element Method

5.1. - Introduction

5.2. - Spatial Discretization and Approximation Functions

5.3. - FEM Application Examples to Heat Transfer Problems

5.3.1. - Variational Formulation of an Stationary Problem of Heat Conduction

5.3.2. - Stationary and One-Dimensional Heat Conduction Example

5.3.3. - Comparison between the Variational Formulation and the Formulation based in the Galerkin Weighted Residuals Method

5.3.4. - Galerkin FEM Application to a Non Stationary Problem of Heat Transfer with Convection Effects

VI. Exercises

3. - BASIC TEXT AND OTHER TEACHING MATERIALS

Teaching Units

4. - BIBLIOGRAPHICAL REFERENCES

CHAPMAN, A.J. *Heat Transfer.* 4th edition. New York, USA: Ed. Collier- McMillan, 1984. ISBN-10: 0023214708 / ISBN-13: 978-0023214707.

CUVELIER, C., SEGAL, A. & VAN STEENHOVEN, A.A. *Finite Element Methods and Navier-Stokes Equations*. Dordrecht, NL: Ed. Springer, 1986. ISBN-10: 90277221483/ ISBN-13: 978-9027721488.

FLETCHER, C.A.J. *Computational Techniques for Fluid Dynamics.* 2nd edition, vols. I and II. Sydney, Australia: Ed. Springer-Verlag, 1991. ISBN-10: 3540530584/ISBN-13: 978-3540530589.

LEWIS, R.W., ET AL. *The Finite Element Method in Heat Transfer Analysis*. West Sussex, UK: Ed. Wiley, 1996. ISBN-10: 0471943622/ ISBN-13: 9780471943624.

MCADAMS, W.H. *Heat Transmission*. 3rd edition. New York, USA: Ed McGraw-Hill, 1954.ISBN-10: 0070447993/ISBN-13: 9780070447998.

PEYRET, R. & TAYLOR, T.D. *Computational Methods for Fluid Flow.* USA: Ed. Springer-Verlag, 1983. ISBN-10: 3540111476/ISBN-13: 9783540111474.

TANNEHILL, J.C., ANDERSON, D.A., & PLETCHER, R.H. *Computational Fluid Mechanics and Heat Transfer*. 2nd edition. Philadelphia, USA: Ed. Taylor & Francis, 1997. ISBN: 9781591690375.

WENDT, J.F. *Computational Fluid Dynamics: An Introduction*. 3rd edition. Belgium: Springer-Verlag, 2009. ISBN: 9783540850557.

ZIENKIEWICZ, O.C. *Finite Element Method*. 5th edition. Oxford, UK: Ed. Butterworth-Heinemann, 2005.

5. - TUTORSHIPS: OFFICE HOURS

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6. - ADDRESS FOR SENDING THE CONTINUOUS ASSESSMENT BOOKLETS

The student will upload the continuous assessment exercises in the virtual classroom.

C.2. - INTRODUCTION TO HEAT TRANSFER ANALYSIS WITH PRACTICAL SOFTWARE

Subject lecturers: Mr. Ambrosio Baños Abascal
Mr. Rubén Mariño Díaz

1. - OBJECTIVES

In this course, the students come into contact with and manage, from an analysis by finite elements perspective, the basic concepts of heat transfer such as: conduction, convection and radiation, at the same time as resolving stationary or transient heat transfer problems and other peculiarities of the thermal processes, which can be treated like non-linearities.

The software, which allows the numerical treatment of problems, is MSC Patran/Nastran.

2. - CONTENT

The content of this subject is presented in a series of chapters where the following themes appear:

1. Overview
2. MD Nastran Thermal Analysis
3. Conduction
4. Convection
5. Transient Thermal Analysis (SOL 159, 400, 600)
6. Radiation
7. Additional Topics

8. Basic Thermal Analysis Theory
9. Non-linear Solvers

3. - BASIC TEXT AND OTHER TEACHING MATERIALS

The basic text is the *Heat Transfer User's guide* of MSC.

4. - BIBLIOGRAPHICAL REFERENCES

Expanding the aforementioned references, the following have been chosen:

- *Patran Analysis Guides*

- *Nastran Quick Reference Guide*

5. - CONTINUOUS ASSESSMENT BOOKLETS

The student must follow the instructions given in the virtual classroom.

6. - SPECIFIC RECOMMENDATIONS

Even though the subject is short in length, it has its own peculiarities, so the student must handle the heat transmission concepts very well and must apply them to each case. In the beginnning, the student must manage the concepts of conduction, convection and radiation well, and know what kind of elements are useful to simulate this phenomenon. At the same time, the student must know to distinguish whether the problem is stationary or transitory.

7. - TUTORSHIPS: OFFICE HOURS

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8. - ADDRESS FOR SENDING THE CONTINUOUS ASSESSMENT BOOKLETS

The student will upload the continuous assessment exercises in the virtual classroom.

C.3. - HEAT TRANSFER PRACTICES

Subject lecturer: Mr. Ambrosio Baños Abascal

Mr. Rubén Mariño Díaz

1. - OBJECTIVES

The main aims of this subject are to complete, with exercises that have to be done using MSC Patran/Nastran, the concepts explained in the Heat Transfer Course (C1) and to apply them using the Practice Program.

2. - CONTENT

The exercises represent a review of the concepts introduced in the subjects studied so far relating to heat transmission as well as the ordered use of the practice program in this field for which a series of exercises containing the physics of thermal analysis will be proposed throughout the course:

1. Getting Started, Creating a Conduction Model
2. Circuit Board and Chips Using Conduction and Heating
3. Free Convection From Printed Circuit Board
4. Forced Air Convection From Printed Circuit Board
5. Axisymmetric Flow in a Pipe
6. Typical Avionics Flow
7. Thermal Contact Resistance
8. Transient Thermal

9. Transient Thermal Analysis of a Cooling Fin
10. Transient Analysis With Radiation Source
11. Heating a Block of Ice cream
12. Solution of a Simple Radiation to Space Problem
13. Directional Heat Loads
14. Radiation Enclosures
15. Thermal Stress Analysis With Directional Heat Loads
16. Thermal Stress Analysis of a Two-Metallic Plate
17. Import IGES File and Auto Tet Mesh
18. Create Group and List
19. MSC.Nastran Bulk Data
20. Shield
21. Thermal stress
22. MD Nastran SOL 400 3D Composite Element
23. Calculation of VF Using the Pixel Hemi-cube Method

3. - BASIC TEXT AND OTHER TEACHING MATERIALS

The basic documentation of the subject is provided with the proposed and resolved exercises.

4. - BIBLIOGRAPHICAL REFERENCES

Subjects of this course:

C1. - FEM Theory Applied to Heat Transfer

C2. - Heat Transfer Course. Application with the Practice Program

In addition to the accompanying documentation specified in C1 and C2, it is recommended the use of:

- *MSC Patran Procedure Manual*
- *Nastran Quick Reference Guide*

5. - CONTINUOUS ASSESSMENT BOOKLETS

The student must follow the instructions given in the virtual classroom.

Each exercise should not take more than three hours, although it is recommended that the student practices as much as he/she can with the menu in the post-process phase and analyzes and interprets the physical sense of the results obtained.

6. - TUTORSHIPS: OFFICE HOURS

Lecturer: Mr. Ambrosio Baños Abascal

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Lecturer: Mr. Rubén Mariño Díaz

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8. - ADDRESS FOR SENDING THE CONTINUOUS ASSESSMENT BOOKLETS

The student will upload the continuous assessment exercises in the virtual classroom.

III.4 MODULE F

F.1. - FEM THEORY APPLIED TO FLUID MECHANICS

Subject professor: Mr. Julio Hernández Rodríguez PhD

1. - OBJECTIVES

In the first section of this subject, fluid mechanics foundations are studied with a particular emphasis on deduction and analysis of mass conservation equations, movement quantity and energy. Furthermore, the characteristics of different flow types are described and the conditions in which the different simplified shapes of general equations can be applied are discussed.

The comparative study of the different treatments, equations and contour conditions used will allow the student a better all-round understanding of the subject and the acquisition of indispensable knowledge in order to set out and carry out the numeric resolution of fluid-mechanics problems of interest in engineering.

In the second part of the subject, an introduction to the finite element method application to some of the flow types studied in the first part is made.

2.-CONTENT

FIRST PART: FLUID MECHANICS FOUNDATIONS

I. Introduction

1.1. - Basic Fluid Characteristics

1.2. - Continuum Hypothesis

1.3. - Forces in Fluids

1.4. - Thermodynamics Concepts

1.5. - Transport Phenomena

II. Fluid Kinematics

2.1. - Flow Field Description. Substantial Derivative. Acceleration of a Fluid Particle

2.2. - Concepts of Path and Path of a Fluid Particle, Trace and Streamline

2.3. - Some Particular Types of Fluids

2.4. - Analysis of the Relative Motion in the Vicinity of a Point

2.5. - Circulation. Irrotational Motions

III. General Fluid Mechanics Equations

3.1. - Time Derivatives of Integrals Extended to Fluid Volumes

3.2. - Equation of Mass Conservation

3.3. - Equation of Conservation of Momentum

3.4. - Equation of Energy Conservation

3.5. - Summary and Discussion of the Fluid Mechanic Equations and Contour Conditions

IV. Dimensional Analysis and Physical Similarity

V. Approximate Shape of Conservation Equations

5.1. - Introduction

5.2. - Approximations of Kinematic Type

5.3. - Simplifications of Constitutive Laws or Equations of State

5.4. - Approaches Based on Considerations on the Problem's Dynamics

SECOND PART: FINITE ELEMENT METHOD IN FLUID MECHANICS

I. Hyperbolic , Parabolic and Elliptical Equations

1.1. - Examples of Different Equation Types

II. Initial and Contour Conditions

III. Methods of Weighted Residuals

3.1. - Introduction

3.2. - Approach to the Methods of Weighted Residuals

IV. Weak Formulation

4.1. - One-Dimensional Case

4.2. - Multi-Dimensional Case

V. Galerkin Finite Element Method

VI. FEM Application to Different Flow Types

6.1. - Potential Flows

6.2. - Convection-Diffusion Problems

6.3. - Navier-Stokes Equations in Two-Dimensional Incompressible Flows

3. - BASIC TEXT AND OTHER TEACHING MATERIALS

Teaching Units

4. - BIBLIOGRAPHICAL REFERENCES

ARIS, R. *Vectors, Tensors, and the Basic Equations of Fluid Mechanics*. New York, USA: Ed. Dover Publication, Inc, 1990. ISBN-13: 9780486661100 / ISBN-10: 0486661105

BAKER, A.J. *Finite Element Computational Fluid Dynamics*. USA: Ed. Hemisphere, 1983. ISBN-10: 0070034656/ ISBN-13: 978-0070034655.

BATCHELOR, G.K. *An Introduction to Fluid Dynamics*. USA: Ed. Cambridge University Press, 2000. ISBN-10: 0521663962 / ISBN-13: 978-0521663960.

CRESPO, A. *Mecánica de fluidos*. Madrid, Spain: Ed. Paraninfo, 1997. ISBN: 9788497322928.

CUVELIER, C., SEGAL, A. & VAN STEENHOVEN, A.A. *Finite Element Methods and Navier-Stokes Equations*. Dordrecht, NL: Ed. Springer, 1986. ISBN-10: 90277221483/ ISBN-13: 978-9027721488.

FLETCHER, C.A.J. *Computational Techniques for Fluid Dynamics.* 2nd edition, vols. I and II. Sydney, Australia: Ed. Springer-Verlag, 1991. ISBN-10: 3540530584/ ISBN-13: 978-3540530589.

GRESHO, Ph.M. (1989). *The Finite Element Method in Viscous Incompressible Flows*,

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HIRSCH, C. *Numerical Computation of Internal and External Flows*. 2nd edition, vols. 1 and 2. Oxford, USA: Ed. John Wiley and Sons, 2007. ISBN-13: 9780750665940/ ISBN-10: 0750665947.

LIÑÁN, A. *Mecánica de Fluidos*. Spain: Ed. Publicaciones de la ETS de Ingenieros Aeronáuticos, 1967.

PEYRET, R. & TAYLOR, T.D. *Computational Methods for Fluid Flow.* USA: Ed. Springer-Verlag, 1983. ISBN-10: 3540111476/ISBN-13: 9783540111474.

PIRONNEAU, O. *Finite Element Methods for Fluids*. Chichester, UK: Ed. John Wiley and Sons, 1989. ISBN-13: 9780471922551 /ISBN-10: 0471922552.

WENDT, J.F. *Computational Fluid Dynamics: An Introduction*. 3rd edition. Belgium: Springer-Verlag, 2009. ISBN: 9783540850557.

WILCOX, D.C. *Turbulence Modeling for CFD*. USA: DCW Industries, 2006. ISBN-13: 9781928729099.

5. - TUTORSHIPS: OFFICE HOURS

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6. - ADDRESS FOR SENDING THE CONTINUOUS ASSESSMENT BOOKLETS

The student will upload the continuous assessment exercises in the virtual classroom.

F.2. - INTRODUCTION TO FLUID MECHANICS ANALYSIS WITH PRACTICAL SOFTWARE

Subject lecturers: Mr. Sergio de Rico Herrero

Ms. Sheila Coca Sola

1. - OBJECTIVES AND CONTENT

The objective of this subject is to provide a tool or a numerical calculation codex, based on the finite volumes method, as is described in subject F1. The software which serves as the introduction to this method is the CFD++ software.

Thus, in subject F2, how the different types of analysis studied in subject F1 can be treated numerically will be explained. To that end, it will be necessary to know the resources of the program in order to treat and resolve the peculiarities of the laminar and turbulent flows of the incompressible and compressible fluids of thermal analysis, etc. Furthermore, it makes reference to the content developed in subject F1 when the resources of the program are explained to resolve one problem or another, but it supposes the characteristics of such problems are already known.

The software will be studied in the following chapters:

Chapter 1: CFD++ in General

Chapter 2: A) Section 1: CFD++ Basics

B) Section 2: CFD++ Information Sets, Equations and Physics

Chapter 3: CFD++ GUI

Chapter 4: A) Section 1: Introduction to Turbulence

B) Section 2: Laminar and Turbulent Incompressible Fluid

Chapter 5: Analysis of Flows with Heat Transfer

Chapter 6: Compressible Flow and High Temperature Flow Modeling

Chapter 7: Transient Flow Modeling

In addition, the Model Generation of Finite Volumes with MIME will also be studied.

2. - BASIC TEXT AND OTHER TEACHING MATERIALS

Teaching Units

3. - BIBLIOGRAPHICAL REFERENCES

WHITE, F. M. Fluid Mechanics. 7th edition. New York, USA: Ed. McGraw Hill, 1979. ISBN: 9780073529349.

JOHNSON, R. W. *The handbook of Fluid Mechanics.* Heidelberg, Germany: Ed. Springer, 1998. ISBN-10: 3540646124 /ISBN-13: 978-3540646129.

DAUGHERTY, R. L. *Fluid Mechanics with Engineering Applications.* 7th edition. Ed. McGraw Hill, 1985. ISBN-10: 0070154279 /ISBN-13: 978-0070154278.

SAAD, M.A. *Compressible Fluid Flow.* Upper Saddle River, US: Prentice Hall, 1985. ISBN-13: 9780131613737 /ISBN-10: 0131613731.

4. - TUTORSHIPS: OFFICE HOURS

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Lecturer: Ms. Sheila Coca Sola

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5. - ADDRESS FOR SENDING THE CONTINUOUS ASSESSMENT BOOKLETS

The student will upload the continuous assessment exercises in the virtual classroom.

F.3. - FLUID MECHANICS PRACTICES

Subject lecturers: Mr. Sergio de Rico Herrero

Ms. Sheila Coca Sola

1. - OBJECTIVES AND CONTENT

The objective of this subject is to assimilate the concepts taught in subject F1 and the use of the CFD++ program as a calculation tool (which has been developed intensively in subject F2), in order to enter the fluid mechanics field with clear concepts and with a calculation tool. For this purpose some exercises of progressive difficulty have been described, which the student will be able to resolve without difficulty, at the same time the student will verify the evolution of different magnitudes related to the fluid that he/she studies, as well as the nature of the type of flow which corresponds to the physical phenomenon studied.

2. - BASIC TEXT AND OTHER TEACHING MATERIALS

Exercises proposed:

1. Laminar Flow in a Double-Throated Nozzle
2. Low Speed Cylinder Flow
3. A High-Speed Ogive-Cylinder Flow
4. Natural Convection within a Rectangular Cavity
5. Incompressible Flow in a T-Junction
6. Incompressible Flow in a S-Bend
7. Low Speed Flow in a Pipe
8. Low Speed Flow over a Back Step
9. Conjugate Heat Transfer in a Ribbed Channel
10. Unsteady Flow over a Cylinder

3. - BIBLIOGRAPHICAL REFERENCES

WHITE, F. M. Fluid Mechanics. 7th edition. New York, USA: Ed. McGraw Hill, 1979. ISBN: 9780073529349.

JOHNSON, R. W. *The handbook of Fluid Mechanics.* Heidelberg, Germany: Ed. Springer, 1998. ISBN-10: 3540646124 /ISBN-13: 978-3540646129.

DAUGHERTY, R. L. *Fluid Mechanics with Engineering Applications.* 7th edition. Ed. McGraw Hill, 1985. ISBN-10: 0070154279 /ISBN-13: 978-0070154278.

SAAD, M.A. *Compressible Fluid Flow.* Upper Saddle River, US: Prentice Hall, 1985. ISBN 13: 9780131613737 /ISBN 10: 0131613731.

4. - TUTORSHIPS: OFFICE HOURS

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5. - ADDRESS FOR SENDING THE CONTINUOUS ASSESSMENT BOOKLETS

The continuous assessment exercises will be published in the virtual classroom.

III.5 MODULE J

J.1. - FEM THEORY APPLIED TO LOW FREQUENCY ELECTROMAGNETIC ANALYSIS

Subject professors: Mr. Francisco Blázquez García PhD

Mr. José Ángel Sánchez Fernández PhD

1. - OBJECTIVES

The objective of the course is to understand the application of the finite elements theory in different electromagnetic systems with the final goal of studying its behavior and even conditioning its design.

2. - CONTENT

After a brief review of the basic electromagnetic and mathematical foundations, Maxwell's equations are developed for different electromagnetic systems starting from the most basic, electrostatic systems in steady state, and finishing the most complex, magneto-dynamic systems, where transitory magnetic magnitudes and mechanic magnitudes are involved.

Chapter 1: **Mathematical Foundations**

This first chapter aims to refresh in the student's memory some basic algebraic concepts like gradient, divergence and rotational operators applied to scalar and vector magnitudes. The basic purpose is to establish the terminology which is going to be used in this whole module.

Chapter 2: Electromagnetic Foundations. Maxwell's Equations in Electrostatic, Magneto-static and Magneto-dynamics Fields

After a short review of the basic concepts of electromagnetic fields such as electric and magnetic fields, electric displacement, magnetic induction, permittivity, permeability, volume charge density and conductivity; the four Maxwell laws are presented in their most generic form.

These laws acquire a specific expression when they are applied to each one of the three low frequency electromagnetic branches: Electrostatic, Magneto-static and Magneto-dynamic. In any case, when Maxwell Laws are adapted to volumes and real surfaces, they lose generality and cannot be adapted to other cases; for instance, the shape that they adopt for the study of an electric machine is not valid for any other device. However, they can be applied in integral form to many cases and, to obtain them, the Stokes theorem is applied.

By particularizing Maxwell's equations for electric fields, the Electrostatic laws are developed, defining the concepts of electrical load (and associated phenomena: electric field, force, potential), electromotive force, refraction of the electric field, of dielectric stiffness and applying the Laplace law for insulator and conductor mediums.

In the same way, by particularizing Maxwell's equations for stationary magnetic fields the Magneto-static laws are developed, analyzing in detail these equations, deducing the Biot-Savart law for H field calculation and studying concepts like field refraction, energy and magnetic properties of the materials (diamagnetic, paramagnetic, ferromagnetic and permanent magnets).

Regarding ferromagnetic materials, a simple analysis about the importance of using materials of very high permeability for the magnetic circuit of electric machines to pursue high intensities of the field in the air gap is proposed.

Regarding permanent magnets, a very basic analysis is proposed, which will analyze the saturation curve of permanent magnets and their functioning points within the curve when the magnetic circuit to which the magnet belongs contains at least one air gap.

Finally, Maxwell's equations are developed in the magneto-dynamic case, where field variation in time is looked at. First of all the Lenz-Faraday law is deduced and the phenomenon of the useful induced flows (induction machine) or parasites (Eddy-current) is introduced. This chapter finishes by considering the penetration of fields in ferromagnetic and non-ferromagnetic materials.

Chapter 3: Basic Foundations of the Finite Element Method for the Analysis of Electromagnetic Systems

The development and the massive use of the finite element method have always been linked to the development of computational systems. The finite element method has been applied to electromagnetism using variational methods or the residual method. Nowadays, most software uses the latter method because it is established from the physics equations which it aims to resolve, because of this they are easier to understand and apply.

The purpose of this chapter is to clearly introduce the essential concepts and show how the methods relate each other with the purpose of making a basic program that resolves a specific problem, rather than making a thorough analysis of the different methods.

Overall, the method proposed is based on discretizing all the space in first order elements (the triangle is the most basic element) where the potential varies in linear form. The chosen element has *n* nodes or degrees of freedom (3, in the case of a triangle) so knowing the potential of them, the potential value can be determined for any point of that domain. Moreover the solution obtained using this method is not exact, thus by applying this solution to the target function the value obtained is different from zero called residue. To force the residue to zero, it is necessary to apply a weighting function.

Chapter 4: Application of the Finite Element Method to Different Electromagnetic Systems

After presenting the finite element method which is used in electromagnetism, it is particularized for different electromagnetic systems paying special attention to its physical meaning and its characteristics for each system shown.

This chapter begins showing some static cases, in both electric and magnetic fields. The interest in its study is because many dynamic cases can be studied as a composition of static cases. By using Maxwell's equations, the Laplace and Poisson equations (partial derivatives of second order) are established, using the scalar and vector potentials as primary variables.

Secondly, some cases with variable magnetic fields are presented which imply the emergence of eddy-currents. In principle, the resolution of these cases shows an additional complication that consists of the equations' integration depending on the coordinates systems chosen, the application of a transformation matrix before obtaining the final result being necessary.

Within this mode with eddy-currents, the simplest case to study is that in which the fields have a sinusoidal variation in time of constant frequency. Here, the equation to be solved is shown in terms of complex potential so, by solving only one matrix, the real and imaginary parts of the field are obtained and, therefore, their magnitude and phase angle regarding the flows. Furthermore, an additional advantage of this method is that it allows easy calculation of the impedances of the electrical circuit that excites the magnetic core. The essential limitation of the method is that it can only be used in linearity cases of the magnetic circuit, which for real ferromagnetic materials would mean working with low levels of magnetic saturation.

In the more general case of eddy-currents study, it is necessary to use the discretization in time of the potential, which basically consists of replacing the temporal variables with incremental functions. This approach is more valid when the time interval chosen for the discretization is small, so obtaining accurate results requires a greater capacity and calculation time.

In contrast to permittivity and conductivity which are considered constants, permeability is not in the case of ferromagnetic materials, since it depends on the

intensity of the H magnetic field (B-H curve, or characteristic curve). In order to resolve the problem and set out the finite element matrix is necessary to know the permeability of the nodes but, as the definitive value of this depends on the solution, it will be necessary to establish an iterative process to obtain a proper solution. Furthermore, in this chapter different alternatives to establish this iterative process are presented.

Finally, how the analysis of any electromagnetic system can be simplified when certain conditions of symmetry and periodicity exist is studied.

Chapter 5: Study of Electromagnetic Systems Coupled with Electrical Circuits

In the previous chapters all the electromagnetic systems proposed were excited with a known flow density. However, in reality, on many occasions the electromagnetic systems are fed in tension; therefore the equations of field and of tension in the excitement circuit must be resolved simultaneously.

In some occasions, for instance in the control of electric machines, the electromagnetic systems are fed through an electronic converter so a detailed study of the influence of the harmonics introduced by these feeding systems is necessary.

In the case of three-phase systems, the influence of the different connection types: series-parallel, star-delta, etc. will be also studied.

Chapter 6: Study of Systems in Movement. Mechanical Efforts Calculation

Some of the electromagnetic systems of frequent use like relays, switches and rotating electrical machines are subjected to mechanical and movement forces. Applying the finite element method to these systems has the extra complication of variation of the model's geometry due to movement, thus special attention must be paid to discretization in the areas close to the moving parts (air gap).

In this chapter the technique to discretize the air gap in order to simulate the displacement of the model's moving parts without losing accuracy in the results obtained is presented.

If the results obtained are considered exclusively in the case of electrical machines, it is essential to make a detailed analysis of the interaction between the electrical magnitudes and torque in order to establish the balance of energy . In this sense, this chapter shows different ways of calculating torque in the machine starting from electromagnetic magnitudes.

Chapter 7: Determination of the Magnetic Core Losses

Overall, the core losses of a specific electromagnetic system can be divided into three components: losses to parasitic currents, hysteresis losses and additional losses. In this chapter the nature of each one of these three components and the method for calculating them using Finite Elements are described.

On many occasions it is enough to use a simple method consisting of calculating the magnetic induction without considering the effects of the losses effects in it, by calculating the losses a posteriori using analytical expressions well known in the electrical engineering field.

Nevertheless, when the losses in the magnetic core have an influence on the waveform of the current and consequently of the induction, it is necessary to integrate the loss models to calculate the field, which requires a more complex analysis.

3. - BASIC TEXT AND OTHER TEACHING MATERIALS

Subject text.

4. - BIBLIOGRAPHICAL REFERENCES

FRAILE MORA, J. *Electromagnetismo y Circuitos Eléctricos*. 4th edition. Madrid, Spain: Ed. McGraw Hill, 2005. ISBN: 9788448198435.

FRAILE MORA, J. *Máquinas Eléctricas*. 6th edition. Madrid, Spain: Ed. McGraw Hill, 2008. ISBN: 9788448161125.

SILVESTER, P.P. & FERRARI, R.L. Finite Elements for Electrical Engineers. 3rd edition. Cambridge, UK: Ed. Cambridge University Press, 1996. ISBN-13: 9780521449533/ ISBN-10**:** 0521449537.

MCLYMAN, W. T. *Transformer and Inductor Design Handbook*. Bosa Roca, USA: Ed. Taylor & Francis Inc., 2011. ISBN-13: 9781439836873 /ISBN-10: 1439836876.

TOLIYAT, H. A. & KLIMAN, G. B. *Handbook of Electric Motors*. 2nd edition. New York, USA: Ed. Marcel Dekker, Inc., 2004. ISBN-13: 9780824741051/ ISBN-10: 0824741056.

HANDI, E. S. *Design of Small Electrical Machines*. Chichester, UK: Ed. John Wiley & Sons Ltd, 1994. ISBN-13: 9780471952022/ ISBN-10: 0471952028.

5. - TUTORSHIPS: OFFICE HOURS

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6. - ADDRESS FOR SENDING THE CONTINUOUS ASSESSMENT BOOKLETS

The student will upload the continuous assessment exercises in the virtual classroom.

J.2. - INTRODUCTION TO EMAG ANALYSIS WITH PRACTICAL SOFTWARE

Subject lecturer: Mr. Ambrosio Baños Abascal

1. - OBJECTIVES

The objective of this subject is for the student to have contact with and to manage practically the basic concepts of low frequency electromagnetic calculation through the use of the finite element software provided.

2. - CONTENT

The subject is structured into seven topics which further the capacities of the ANSYS low frequency electromagnetic module.

The topics are:

Theme 1: Introduction

Theme 2: 2D Planar Axisymmetric Magnetostatic Analysis

Theme 3: 2D Planar and Axisymmetric Harmonic Analysis

Theme 4: 2D Planar Transient Analysis

Theme 5: 3D Magneto-static Analysis. Scalar Potential

Theme 6: Harmonic and 3D Transient Analysis. Methods

Theme 7: Modeling Strategies. Procedures

3. - BASIC TEXT AND OTHER TEACHING MATERIALS

- Basic text of the subject
- ANSYS Software

4. - BIBLIOGRAPHICAL REFERENCES

Books of General Electromagnetic Purpose

KNOEPFEL, H. E**.** *Magnetic Fields. A Comprehensive Theoretical Treatise for Practical Use*. 1st edition. USA: Ed. Wiley- Interscience, 2000. ISBN: 0471322059.

JACKSON, J. D. *Classical Electrodynamics.* 3rd edition. USA: Ed. Wiley, 1998. ISBN: 047130932X.

LEVICH, B. G. *Teoría Del Campo Electromagnético Y Teoría De La Relatividad Vol 1.* ISBN: 84-291-4061.

LEVICH, B. G. *Física Estadística. Procesos Electromagnéticos En La Materia Vol 2*. Spain: Ed. Reverté, 2002. ISBN: 84-291-4062-X.

Books of the Finite Element Method Applied to the Electromagnetism

BRANCHI, N. *Electrical Machine Analysis Using Finite Elements*. USA: Ed. CRC Press, 2005. ISBN: 0-8493-3399-7

DI BARBA, P., SAVINI, A. & WIAK, S. *Field Models in Electricity and Magnetism*. Italy: Ed. Springer, 2010. ISBN: 9789048177356

ANSYS Software

The ANSYS Help will be used during the study of the subject. Please see the notes about the subject in the virtual classroom.

5. - CONTINUOUS ASSESSMENT BOOKLETS

The continuous assessment is done jointly with the application and practice subjects of this electromagnetism module. The evaluation form in the practice subject is discussed.

6. - TUTORSHIPS: OFFICE HOURS

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J. 3. - EMAG PRACTICES

Subject lecturer: Mr. Ambrosio Baños Abascal

1. - OBJECTIVES

The purpose of this subject is to do exercises with the ANSYS software so that the student assimilates the concepts previously explained in subjects J1 and J2 of the Electromagnetism Module, and becomes familiarized with the use of the software.

2. - CONTENT

The subject aims for the completion of eight exercises corresponding to electromagnetic calculation examples:

Exercise 1: Magnetic Clutch

Exercise 2: Loads

Exercise 3: Skin Effect in a Solid Conductor of Rectangular Cross-Section

Exercise 4: Switch: Flux Effect inside the Device

Exercise 5: DC Electromagnet and Contact

Exercise 6: Electromagnetic Gear Induction Heating

Exercise 7: Metal Detector

Exercise 8: Use LMATRIX to Determine Keeper Force

3. - BASIC TEXT AND OTHER TEACHING MATERIALS

- Basic text of the subject
- ANSYS Software
- Help of ANSYS

4. - BIBLIOGRAPHICAL REFERENCES

See the application subject.

5. - CONTINUOUS ASSESSMENT BOOKLETS

It is advisable that the student initially sends the subject's professor the purged logs and a brief report of the results of exercises 2 and 3 of the practice subject.

Once the results of these exercises have been analyzed and understood, the student can study how ANSYS manages the Lenz law with the geometry of exercise 3. The student must send the purged log and a report detailing what has been studied.

More exercises will be proposed in the virtual classrooms along the course. The exercises must be sent through the virtual classroom.

6. - TUTORSHIPS: OFFICE HOURS

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IV MASTER'S FINAL PROJECT

A. Master's Final Project Assignment

In order to assign the master's final projects, there are two options:

1. *Making a master's final project proposed by the course*

The course has proposed various Master's Final Projects, related to the student´s specialities, so that the students can choose the most appropriate one:

- Interpolation Methods and Numerical Approximation -1.
- Interpolation Methods and Numerical Approximation -2.
- Posteriori Error Estimation in the Finite Element Method.
- Fire Resistance 2D Analysis of the World Trade Center.
- Jules Verne's Cannon.
- Dynamic Analysis Of The Structural Response Of A Tall Building Subjected To Aircraft Impact.
- Design Methods of Reinforced Concrete Shells
- Comparison of Winkler Soil Models with a Three-dimensional Elastic Model.
- Buckling Analysis of Concrete Piles.
- Study of Embedment Depths in Diaphragm Walls.

According to the project chosen, a tutor will be assigned to the student.

2. *The student wishes to propose a specific project*

Students can propose their own topic for their final projects which may be of interest to the company where the student works, or it can be related to the student's personal interests or their future plans for professional activity.

When proposing the final project, students must take into account the size limitations of the educational practice program unless they have access to university facilities with greater capabilities, or a commercial installation in their respective companies.

Similarly, the final project must be related to the *Specialized Module Group* covered . Students should indicate on the application form the professor/lecturer that they would like to be their tutor for their Master's Final Project. The professor/lecturer should correspond to the modules studied by the students.

The Final Project must have the entity and the appropriate scope to be finally accepted.

To apply, students must send the application form according to the these guidelines by e-mail to the following address: c.pizarro@ingeciber.com / g.ramos@ingeciber.com (the application form has a maximum of 3pages).

B. Awards for the Master's Final Project of the Theoretical and Practical Application of Finite Element Method and CAE Simulation

Competition Explanation

The Theoretical and Practical Application of Finite Element Method and CAE Simulation Master concludes, at its highest level, with the Master's Final Project. This project gathers all the knowledge acquired by the student throughout his/her study phase of the Expert and Specialist modules, and concentrates in a sole project all the student's aptitudes and capabilities with a common goal.

The training acquired by students, in addition to their own personal career, will substantially influence the industrial capacities of our society, providing it with highly qualified technicians for its development, prosperity and wellness.

For these reasons, we wish, on an annual basis, to reward the dedication of the student and the excellence of the best Master's Final Project presented on the course. The National Distance Learning University (UNED), through its Superior School of Industrial Engineers, rewards in this way the student's effort and his/her contribution to the study of the practical application of the Finite Element Method.

Competition Foundations

1. *Organization*

The competition is organized by the Superior School of Industrial Engineers of UNED, with its headquarters at the following address: calle Juan del Rosal, 12, 28040, Madrid. To contact with the secretariat of the master's, you should follow the established channels (c.pizarro@ingeciber.com/ g.ramos@ingeciber.com) to which you should send any correspondence.

2. *Competition's aim*

To reward the best Master's Final Project made in the corresponding Theoretical and Practical Application of Finite Element Method and CAE Simulation Master's.

3. *Participation*

In order to participate in the Competition it will be an essential that the Master's Final Projects have received at least a grade of "good" (ECTS: C) during the academic year corresponding to the competition. All the projects made during the course which fulfill this characteristic will participate in the Competition.

4. *Competition schedule*

The competition will be annual.

5. *Projects presentation*

All the students, who have received a mark of "good" or better in the Master's final project during the academic year in which the competition is held, will be automatically entered in the Competition.

If the student does not want to participate in the Competition, he/she must notify the master's secretariat.

The presentation implies agreement, to the Competition Rules in their entirety.

6. *Steering committee, selection criteria and awards of prizing*

The Directors of the Superior School of Industrial Engineers of UNED or the Commission delegated will be the responsible for the judging of the files and the awards of the prizes. The committee will be composed of the School Director or his/her delegate, the Director, the Coordinator and two master's professors.

The jury's decision will not be open to appeal and they will indicate the projects considered to merit the prize, and are also able to declare the prize unawarded.

The winners will be contacted in due time and will be made public before the prize-giving.

7. *Appraisal criteria*

The projects will be evaluated according to their grade of:

- Difficulty: up to 5points
- Originality and Innovation: up to 5 points

8. *Awards*

The prize that the Jury of the Master's Final Project award will be the following:

- The enrollment fees corresponding to the Master's Final Project.

9. *Ownership and Submission of the projects*

The intellectual property of the winning projects and the material property of the documents that integrate them will correspond to the Author of these. The Superior School of Industrial Engineers of UNED reserves the right to keep in its documentary collection winning projects which considers of special relevance or merit.