THE FINITE ELEMENT METHOD AND ITS APPLICATIONS IN ENGINEERING USING ANSYS

Course contents:

The finite element method (FEM) has become a staple for predicting and simulating the physical behavior of complex engineering systems. The commercial finite element analysis (FEA) programs have gained common acceptance among engineers in industry and researchers at universities and government laboratories. Therefore, academic engineering departments include graduate or undergraduate senior-level courses that cover not only the theory of FEM but also its applications using the commercially available FEA programs. The aim of this course is to provide students with a theoretical and practical knowledge of the finite element method and the skills required to analyze engineering problems with ANSYS®, a commercially available FEA program. This course designed for master students, as well as practicing engineers, is introductory and self-contained in order to minimize the need for additional reference material.

Subjects covered by the lectures are

- Fundamentals of ANSYS
- Fundamentals of Discretization
- ANSYS Preprocessor
- ANSYS Solutions and PostProcessing
- Finite Element Method Equations
- Use of Commands in ANSYS
- Linear Structural Analysis
- Linear Analysis of Field Problems (Heat Transfer Problems. Steady-state Analysis. Transient Analysis. Radiation Analysis. Moisture Diffusion)
- Nonlinear Structural Analysis
- Advanced Topics in ANSYS
- Numerical Solutions of Elasticity Problems
- Numerical Solutions of Stress Concentration Problems
- Numerical Solutions of Fracture Mechanics Problems
- Numerical Solutions of Damage Mechanics Problems

Learning outcomes of the course :

Through a deep understanding of the theory and the realization of a project, the student will be able to apply numerical tools to use the finite element method and study a wide class of mechanical problems. In particular:

- He will have a deep understanding of the finite element method and will be able to apply it, realise and explain the results.
- He will be able to apply the FEM method realization in different software.
- He will be able to apply the method to a wide class of problems.
- He will be able to analyse and to evaluate (justify and criticise) these method.
- He will be able to analyse new problems.
- He will be able to apply Mechanical ANSYS for complex problems of solid mechanics.
- He will be able to apply Mechanical ANSYS for complex problems of fracture mechanics.
- He will be able to use proper modeling techniques for capturing crack-tip singularities in fracture mechanics problems.
- He will be able to use Mechanical ANSYS to create meshes appropriate for fracture studies.
- He will be able to calculate stress intensity factors and contour integrals around a crack tip.
- He will be able to simulate material damage and failure.
- He will be able to simulate crack growth using cohesive behavior, VCCT, and XFEM.
- He will be able to simulate low-cycle fatigue crack growth.

Prerequisites and co-requisites/ Recommended optional programme components :

Basic knowledge in

- Differential Equations
- Elasticity Theory
- Plasticity Theory
- Creep Theory
- Fracture Mechanics

Planned learning activities and teaching methods :

Exercises with professor assistance and personal project.

Mode of delivery (face-to-face ; distance-learning) :

Face-to-Face

Required readings :

- Kattan P.I., Voyiadjis G.Z. Damage Mechanics with Finite Elements: Practical Applications with Computer Tools. Springer, 2012. 113 p.
- Smith I.M., Griffits D.V., Margetts L. Programming the Finite Element Method (Wiley Series in Computational Mechanics). Wiley, 2013. 682 p.
- Zienkiewicz O.C., Taylor R.L. The Finite Element Method for Solid and Structural Mechanics. Amsterdam, Boston, Heidelberg, London, New York, Oxford, Paris, San Diego, San Francisco, Singapore, Sydney, Tokyo: Elsevier, 2005. 648p.
- Kuna M. Finite Elements in Fracture Mechanics. Theory – Numerics – Applications. Springer Dordrecht Heidelberg New York London. V. 201. 2010.
- Wriggers P. nonlinear Finite Element Methods. Berlin, Heidelberg: Springer-Verlag, 2008. 566 p.
- Efendiev Y., Hou T.Y. Multiscale Finite Element Methods. Theory and Applications. Springer, 2009. 242 p.
- Fish J., Belytschko T. A First Course in Finite Elements. Willey, 2007. 345 p.
- Segerlind L.J. Applied Finite Element Analysis. Wiley, 1976. 392 p.
- ANSYS 10.0. Workbench Tutorial. ANSYS Inc.

Assessment methods and criteria :

Evaluation is based on the realization of a project related to the use / development of finite element method relalized in Mechanical ANSYS and applied to specific to Solid Mechanics Problems and on an examination.
The examination is based on the whole content of the class. Problems similar to the ones studied during the classes, and new problems will be part of the questions. Justification using the theoretical content is also asked.
Participation to the examination and achievement of the project are mandatory.

Socratic Teaching Method: Class participation is mandatory. Everyone is expected to participate in discussions relating to reading materials, homework, exams and lectures.

Guaranteed Recipe for Success:
1) Take notes during lecture and sections.
2) After each lecture but before the next lecture review your notes. Identify the parts you do not understand.
3) Come to each lecture and discussion section with specific questions.
4) Keep up with the reading so that you have some familiarity with each topic prior to hearing about it in the lecture.
5) Find at least one "partner" in the class with whom you can meet at least once or twice a week to discuss materials from the lectures, the reading assignments and the homework.
6) Take the homework assignment seriously. Do not try to do the whole assignment the night before it is due. Some version of the homework questions will appear on the exams.

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Course Contents

1 INTRODUCTION
1.1 Basic Concepts. 1.2 Nodes. 1.3 Elements. 1.4 Direct Approach. 1.4.1 Linear Spring Model. 1.4.2 Heat Flow. 1.4.3 Assembly of the Global System of Equations. 1.4.4 Solution of the Global System of Equations. 1.4.5 Formulation of Boundary Conditions.
2 FUNDAMENTALS OF ANSYS
2.1 Useful Definitions. 2.2 Before an ANSYS Session. 2.2.1 Analysis Discipline. 2.2.2 Time Dependence. 2.2.3 Nonlinearity. 2.2.4 Practical Modeling Considerations. 2.3 Organization of ANSYS Software. 2.4 ANSYS Analysis Approach. 2.4.1 ANSYS Preprocessor. 2.4.2 ANSYS Solution Processor. 2.4.3 ANSYS General Postprocessor. 2.4.4 ANSYS Time History Postprocessor. 2.5 ANSYS File Structure. 2.5.1 Database File. 2.5.2 Log File. 2.5.3 Error File. 2.5.4 Results Files. 2.6 Description of ANSYS Menus and Windows. 2.6.1 Utility Menu. 2.6.2 Main Menu. 2.6.3 Toolbar Instruments. 2.6.4 Input Field. 2.6.5 Graphics Window. 2.6.6 Output Window. 2.7 Using the ANSYS Help System. 2.7.1 Help Contents. 2.7.2 Help Index. 2.7.3 Search in Help. 2.7.4 Verification Manual.
3 FUNDAMENTALS OF DISCRETIZATION
3.1 Local and Global Numbering. 3.2 Approximation Functions. 3.3 Coordinate Systems. 3.3.1 Generalized Coordinates. 3.3.2 Global Coordinates. 3.3.3 Local Coordinates. 3.3.4 Natural Coordinates. 3.4 Shape Functions. 3.4.1 Linear Line Element with Two Nodes. 3.4.2 Quadratic Line Element with Three Nodes: Centroidal Coordinate. 3.4.3 Linear Triangular Element with Three Nodes: Global Coordinate. 3.4.4 Quadratic Triangular Element with Six Nodes. 3.4.5 Linear Quadrilateral Element with Four Nodes: Centroidal Coordinate. 3.5 Isoparametric Elements: Curved Boundaries. 3.6 Numerical Evaluation of Integrals. 3.6.1 Line Integrals. 3.6.2 Triangular Area Integrals. 3.6.3 Quadrilateral Area Integrals 3.7 Problems.
4 ANSYS PREPROCESSOR
4.1 Fundamentals of Modeling. 4.2 Modeling Operations. 4.2.1 Title. 4.2.2 Elements. 4.2.3 Real Constants. 4.2.4 Material Properties. 4.2.5 Element Attributes. 4.2.6 Interaction with the Graphics Window: Picking Entities. 4.2.7 Coordinate Systems. 4.2.8 Working Plane. 4.3 Solid Modeling. 4.3.1 Bottom-up Approach: Entities. 4.3.2 Top-down Approach: Primitives. 4.4 Boolean Operators. 4.4.1 Adding. 4.4.2 Subtracting. 4.4.3 Overlap. 4.4.4 Gluing. 4.4.5 Dividing. 4.5 Additional Operations. 4.5.1 Extrusion and Sweeping. 4.5.2 Moving and Copying. 4.5.3 Keeping/Deleting Original Entities. 4.5.4 Listing Entities. 4.5.5 Deleting Entities. 4.6 Viewing a Model. 4.6.1 Plotting: Pan, Zoom, and Rotate Functions. 4.6.2 Plotting/Listing Entities. 4.6.3 Numbers in the Graphics Window. 4.7 Meshing. 4.7.1 Automatic Meshing. 4.7.2 Manipulation of the Mesh. 4.8 Selecting and Components. 4.8.1 Selecting Operations. 4.8.2 Components.
5 ANSYS SOLUTION AND POSTPROCESSING

5.1 Overview 5.2 Solution. 5.2.1 Analysis Options/Solution Controls. 5.2.2 Boundary Conditions 5.2.3 Initial Conditions. 5.2.4 Body Loads. 5.2.5 Solution in Single and Multiple Load Steps. 5.2.6 Failure to Obtain Solution. 5.3 Postprocessing. 5.3.1 General Postprocessor. 5.3.2 Time History Postprocessor. 5.3.3 Read Results. 5.3.4 Plot Results. 5.3.5 Element Tables. 5.3.6 List Results. 5.4 Example: One-dimensional Transient Heat Transfer.

6 FINITE ELEMENT EQUATIONS

6.1 Method of Weighted Residuals 6.1.1 Example: One-dimensional Differential Equation with Line Elements. 6.1.2 Example: Two-dimensional Differential Equation with Linear Triangular Elements. 6.1.3 Example: Two-dimensional Differential Equation with Linear Quadrilateral Elements. 6.2 Principle of Minimum Potential Energy. 6.2.1 Example: One-dimensional Analysis with Line Elements. 6.2.2 Two-dimensional Structural Analysis. 6.3 Problems.

7 USE OF COMMANDS IN ANSYS

7.1 Basic ANSYS Commands. 7.1.1 Operators and Functions. 7.1.2 Defining Parameters. 7.2 A Typical Input File. 7.3 Selecting Operations. 7.4 Extracting Information from ANSYS. 7.5 Programming with ANSYS. 7.5.1 DO Loops 7.5.2 IF Statements. 7.5.3 /OUTPUT and *VWRITE Commands. 7.6 Macro Files. 7.7 Useful Resources. 7.7.1 Using the Log File for Programming. 7.7.2 Using the Verification Problems for Programming.

8 LINEAR STRUCTURAL ANALYSIS

8.1 Static Analysis. 8.L1 Trusses. 8.1.2 Beams. 8.1.3 Three-dimensional Problems. 8.1.4 Two-dimensional Idealizations. 8.1.5 Plates and Shells. 8.2 Linear Buckling Analysis. 8.3 Thermomechanical Analysis. 8.4 Fracture Mechanics Analysis. 8.5 Dynamic Analysis. 8.5.1 Modal Analysis. 8.5.2 Harmonic Analysis. 8.5.3 Transient Analysis.

9 LINEAR ANALYSIS OF FIELD PROBLEMS

9.1 Heat Transfer Problems. 9.1.1 Steady-state Analysis. 9.1.2 Transient Analysis. 9.1.3 Radiation Analysis. 9.2 Moisture Diffusion.

10 NONLINEAR STRUCTURAL ANALYSIS

10.1 Geometric Nonlinearity 10.1.1 Large Deformation Analysis of a Plate 10.1.2 Post-buckling Analysis of a Plate with a Hole 10.2 Material Nonlinearity 10.2.1 Plastic Deformation of an Aluminum Sphere 10.2.2 Plastic Deformation of an Aluminum Cylinder. 10.2.3 Stress Analysis of a Reinforced Viscoelastic Cylinder. 10.2.4 Viscoplasticity Analysis of a Eutectic Solder Cylinder. 10.2.5 Combined Plasticity and Creep. 10.3 Contact. 10.3.1 Contact Analysis of a Block Dropping on a Beam. 10.3.2 Simulation of a Nano-indentation Test.

11 ADVANCED TOPICS IN ANSYS

11.1 Coupled Degrees of Freedom 11.2 Constraint Equations. 11.3 Submodeling. 11.4 Substructuring: Superelements. 11.4.1 Generation Pass. 11.4.2 Use Pass. 11.4.3 Expansion Pass. 11.5 Interacting with External Files. 11.5.1 Reading an Input File 11.5.2 Writing Data to External ASCII Files. 11.5.3 Executing an External File. 11.5.4 Modifying ANSYS Results. 11.6 Modifying the ANSYS GUI. 11.6.1 GUI Development Demonstration. 11.6.2 GUI Modification for Obtaining a Random Load Profile. 11.6.3 Function Block for Selecting Elements Using a Pick Menu.

Further Reading

1. Madenci E., Guven I. The Finite Element Method and Applications in Engineering using ANSYS. New York: Springer, 2006. 695 p.

2. Huebner, K. H., Dewhirst, D. L., Smith, D. E., and Byrom, T. G. The Finite Element Method for Engineers. New York: John Wiley & Sons, 2001.

3. Ibrahimbegovic A. Nonlinear Solid Mechanics. Theoretical Formulations and Finite Element Solution Methods. New York, Springer, 2009. 588 p.

4. Mohammadi S. Extended Finite Element Method: for Fracture Analysis of Structures. Wiley-Blackwell, 2008. 280 p.

5. Kattan P.I., Voyiadjis G.Z. Damage Mechanics with Finite Elements: Practical Applications with Computer Tools. Springer, 2012. 113 p.

6. Barbero I.J. Finite Element Analysis of Composite Materials using Abaqus. CRC Press, 2013. 444 p.

7. Smith I.M., Griffits D.V., Margetts L. Programming the Finite Element Method (Wiley Series in Computational Mechanics). Wiley, 2013. 682 p.
8. Zienkiewicz, O.C. and Taylor, R.L., The Finite Element Method, Vol. 1: The Basis, fifth ed., Butterworth- Heinemann, Oxford, 2000.