

Advanced Finite Elements

ME EN 7540 **Syllabus** **Spring 2006**

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- **Office:** 166 Kennecott Bldg.
- **Classroom:** EMCB 114
- **Class times:** Tuesday, Thursday 3:45 pm - 5:00 pm
- **Office hours:** Tuesday, Thursday 11:30 am - 1:00 pm, by appointment, or knock on my door when I am in.
- **Web Page:** `http://www.eng.utah.edu/~me7540`
- **TA:** Seubpong Leelavanichkul, Phone: 585-7663, E-mail: sleela@math.utah.edu
  Office: JWB 105 (Math Building)
  Office hours: Monday, Wednesday 1:00 pm - 3:00 pm or make an appointment.
- **Textbook:** *An Introduction to Nonlinear Finite Element Analysis* by J. N. Reddy, Oxford University Press, 2004, ISBN 019852529X.
- **Additional Reading:**
  1) *Nonlinear Finite Elements for Continua and Structures* by T. Belytschko, W. K. Liu, and B. Moran, John Wiley and Sons, 2000.
  2) *Computational Inelasticity* by J. C. Simo and T. J. R. Hughes, Springer, 1998.
  3) *The Finite Element Method: Linear Static and Dynamic Finite Element Analysis* by T. J. R. Hughes, Dover Publications, 2000.

Prerequisites

A basic understanding of vectors, matrices, and partial differential equations for thermal and mechanical problems. An introductory knowledge of finite element analysis will be beneficial. The most important requirements are curiosity, a desire to learn, and willingness to work hard.

Course Objectives

- To provide the mathematical foundations of the finite element formulation for engineering applications (solids, heat, fluids).

- To expose students to some of the recent trends and research areas in finite elements.

Course Outline

1. Mathematical Preliminaries (2 classes).
   Set Notation, Function Notation, Vectors, Matrices, Tensors, Partial Differential Equations, Variational Calculus.

2. Finite Element Basics. (2 classes)
   Weak Form of PDEs, Linear Time-Dependent Heat Equation, Finite Element Basis Functions, Time Integration.

3. Nonlinear Finite Element Basics. (3 classes)
   Nonlinear Heat Equation - 1 Dimension, Basic Nonlinear Continuum Mechanics of Solids, Total and Updated Lagrangian Approaches.

4. Nonlinear Bending of Beams. (2 classes)

5. Nonlinear Bending of Plates and Shells (4 classes)
   Basic Linear Plate and Shell Elements, Nonlinear Plates and Shells, Time-dependent Deformation of Shells.

6. Nonlinear Finite Elements of Solids.
   Material Nonlinearities, Objective Rates, Nonlinear Elasticity, Plasticity, Viscoplasticity, Viscoelasticity.

7. Advanced Topics (depending on time and interest).
   Dynamic Fracture, Stochastic Finite Elements, Contact, Mesh Generation, Multi-scale Methods, Multi-physics Problems.

8. Verification and Validation.

Course Strategy

- The textbook will be used as a guide and other sources will be consulted as necessary. Reading will be assigned in class. There is much that can be studied in this course. The sequence of topics to be covered will be determined as the course progresses.

- Students will be expected to work in teams of two or three.

- Homework will be assigned each week. The homework will consist of mathematical derivations and numerical simulations. Students are expected to complete the homework in teams. However, each student is required to submit his/her homework individually.

- Research papers from the literature will be provided to the students on a frequent basis. Each team will be required to read the papers and work out the mathematical details of the papers. The team will also be required to run sample calculations from the papers using ANSYS, LS-DYNA, some other finite element tool, or their own code. A report showing the detailed calculations and results of simulations performed will be required for each paper assigned.

- Students will be expected to write simple finite elements programs in order to get a better grasp of the material covered in the course. Students will also be expected to learn how to run nonlinear structural and thermal simulations in ANSYS (or some other package of their choice) and the present results from these simulations. The instructor will **not teach** the students how to run these finite element packages.
- Students are expected to participate actively in the course. 5% of the final grade will be based on class participation.
- Each team will complete a class project. Class projects will be on topics of current research. A list of topics will be prepared by the instructor. Each team will be required to choose a topic from the list. A written progress report on the class project is required at the middle of the semester. A final project report and a group oral presentation is required of each team at the end of the semester.
- There will be frequent quizzes but no midterm or final examinations. Quizzes will be announced in class. At least a week's notice will be given prior to a quiz.

Grading Strategy

- Homework (Problem Sets and Research Papers) - 50%.
- Quizzes - 15%.
- Class Project - 30%.
- Class Participation - 5%.
- Grades will be assigned as follows:
  A : $>$ 85%, A- : $>$ 80%, B+ : $>$ 75%, B :$>$ 70 %, B-: $>$ 65 %, C+: $>$ 55%, C : $\leq$ 55%.

References

- Finite Element Analysis:
  - T.J.R. Hughes (2000), *The Finite Element Method: Linear Static and Dynamic Finite Element Analysis*, Dover Publications.
    Introductory finite element text written by an engineer for engineers with a mathematical bend.
  - J.C. Simo and T.J.R. Hughes (1998), *Computational Inelasticity*, Springer.
    An excellent resource on nonlinear material behavior and the related finite element techniques.
  - K-J. Bathe (1996), *Finite Element Procedures*, Prentice-Hall.
    Useful repository of information on nonlinear finite elements.

  - J. N. Reddy (1993), *An Introduction to the Finite Element Method*, McGraw-Hill.
    This book is referred to a number of times in the text.
  - O. C. Zienkiewicz and R. L. Taylor (2000), *The Finite Element Method: Volume 2 Solid Mechanics*, Butterworth-Heinemann.
    Another excellent repository of information of nonlinear finite elements geared toward the Civil Engineers.

- Continuum Mechanics:
  - R. M. Brannon (2004), *Large Deformation Kinematics.*
    `http://www.me.unm.edu/~rmbrann/Deformation.pdf`
    An excellent introduction to kinematics.
  - R. M. Brannon (2004), *Rotation.*
    `http://www.me.unm.edu/~rmbrann/rotation.pdf`
    Almost everything you ever wanted to know about rotations.
  - A.J.M Spencer (2004), *Continuum Mechanics*, Dover Publications.
    An excellent introduction to continuum mechanics. You should own a copy for your personal library.
  - L.E. Malvern (1969), *Introduction to the Mechanics of a Continuous Medium*, Prentice-Hall.
    A good reference for continuum mechanics.

- Mathematics:
  - R. M. Brannon (2004), *Elementary Vector and Tensor Analysis for Engineers.*
    `http://www.me.unm.edu/~rmbrann/Tensors.pdf`
    This free online book is the best introduction I have seen for vector and tensor analysis for nonlinear mechanics.
  - R. M. Brannon (2004), *Curvilinear Coordinates.*
    `http://www.me.unm.edu/~rmbrann/curvilinear.pdf`
    Very useful if you wish to follow the literature on the nonlinear deformation of shells.
  - B. Daya Reddy (1998), *Introductory Functional Analysis: With applications to boundary value problems and finite elements.*, Springer-Verlag.
    Excellent book for engineers who want to understand the terminology used in the finite element literature and how error analysis is done.
  - A.P.S. Selvadurai (2000), *Partial Differential Equations in Mechanics 1,2.* Springer.
    Excellent introductory text on partial differential equations with engineers in mind.

Students With Disabilities

Reasonable accommodation will gladly be provided to the known disabilities of students in the class. Please let the instructor know of such situations as soon as possible. If you wish to qualify for exemptions under the Americans With Disabilities Act (ADA), you should also notify the Center for Disabled Students Services, 160 Union Building.