PHYS 640: Finite Element Analysis of Solids and Fluids

Spring 2023

Lecture: Wednesdays 4:30 pm – 7:10 pm
Classroom: Exploratory Hall 1004

Instructor: Professor Chi Yang
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Email: cyang@gmu.edu
Office Phone: 703-993-4077
Office Hours: Tuesdays 2:30pm – 4:00pm, and by appointment

Course Description

This course introduces the fundamentals of finite element analysis of solid, structural, fluid, and heat transfer problems in a unified manner. Topics of the course include governing equations for heat transfer, solid and fluid mechanics; their finite element formulations and solution procedures; appropriate use of finite element methods including setting up an appropriate model, interpreting the results, and assessing the solution error.

The finite element methods studied in this course are practical procedures that are employed extensively in the mechanical, civil, ocean, automobile and aeronautical industries. The finite element methods are also becoming popular in simulation-based computer-aided designs. In addition to providing students with the basics of the finite element technique, this course also provides a numerical tool for the solution of different classes of problems in heat transfer, solid mechanics and fluid mechanics. This course will prepare students with the necessary skills to solve complex real-world problems in science and engineering using finite element methods.

Students are expected to develop their own finite element code and complete two projects for given problems in addition to the homework. Students will also have the opportunity to learn a FEM package.

Course Prerequisites

PHYS 620 (Continuum Mechanics) or permission of instructor

Course Objectives

- To familiarize students with the general steps of finite element methods.
- To understand the basic finite element formulation techniques.
- To be able to derive equations in finite element methods for 1D, 2D and 3D problems.
- To be able to formulate and solve basic problems in heat transfer, solid mechanics and fluid mechanics.
- To be able to write computer programs based on finite element methods.

- To be able to use FEM packages to solve basic engineering problems in heat transfer, solid mechanics and fluid mechanics.

Tentative Course Schedule

Week 1: Introduction to the background and the basic concept of the finite element method
  - How does the finite element method work?
  - A general procedure for finite element analysis
  - Brief history of finite element analysis
  - Examples of finite element analysis
  - FEM packages

Week 2: Integral formulations and variational methods
  - Weak formulation of boundary value problems
  - Variational methods of approximation

Week 3: Discretization and interpolation
  - Discretization of the domain
  - Interpolation models
  - High order and isotropic elements

Week4: Second-order differential equations in one dimension: finite element models
  - Second-order boundary value problems
  - Basic steps of finite element analysis
  - Bar elements
  - Applications to heat transfer, fluid mechanics and solid mechanics

Week 5: Fourth-order differential equations in one dimension: finite element models
  - Bending of beams
  - Euler-Bernoulli beam element
  - Plane truss and Euler-Bernoulli frame elements
  - Applications to solid mechanics

Week 6: Eigenvalue and time-dependent problems
  - Eigenvalue problems
  - Time-dependent problems
  - Applications to dynamics analysis and heat transfer

Week 7: Numerical integration and computer implementation
  - Isoparametric formulations and numerical integration
  - Computer implementation
  - Project 1: 1D problem

Week 8: Spring recess, no classes from Monday March 13 to Sunday March 19.

Week 9: Second-order partial differential equation in two dimensions: finite element models
- Single-variable problems
- Basic steps of finite element analysis
- Some comments on mesh generation and imposition
- Triangular elements
- Rectangular elements
- Applications to heat transfer, fluid mechanics and solid mechanics

Week 10: Interpolation functions, numerical integration, and modeling considerations
- Library of elements and interpolation functions
- Numerical integration
- Modeling considerations
- Project 2: 2D problem

Week 11: Plane elasticity
- Governing equations
- Weak formulations
- Finite element model
- Evaluation of integrals
- Assembly and boundary and initial conditions

Week 12: Flow of viscous incompressible fluids
- Governing equations
- Velocity-pressure finite element model
- Penalty–finite element model

Week 13: Open-source FEM packages

Week 14: Project presentation

Week 15: Review and Discussion

Week 16: Final exam

Recommended Textbooks

- Singiresu S. Rao "The Finite Element Method in Engineering," Fifth Edition, Butterworth-Heinemann, 2011, ISBN: 978-1-85617-661-3. Sixth Edition, Butterworth-Heinemann, Nov. 2017, ISBN-10: 0128117680; ISBN-13: 978-0128117682.

- J. N. Reddy "An Introduction to the Finite Element Method," Third Edition, McGraw Hill,2006

References

- D.V. Hutton “Fundamentals of Finite Element Analysis,” McGraw Hill, 2004.
- J. Fish and T. Belytschko "A First Course in Finite Elements," J. Wiley, 2007.
- K.-J. Bathe “Finite Element Procedures, Prentice-Hall,” 1996.
- E. Madenci and I. Guven “The Finite Element Method and Applications in Engineering Using ANSYS,” Springer, 2015.
- Klaus-Jürgen Bathe. 2.092 Finite Element Analysis of Solids and Fluids I. Fall 2009. Massachusetts Institute of Technology: MIT OpenCourseWare, https://ocw.mit.edu. License: Creative Commons BY-NC-SA.
- Klaus-Jürgen Bathe. 2.094 Finite Element Analysis of Solids and Fluids II. Spring 2011. Massachusetts Institute of Technology: MIT OpenCourseWare, https://ocw.mit.edu. License: Creative Commons BY-NC-SA.

Grading

- Homework 35%
- Projects: 40%
- Final Exam: 25%

The course grade will be a letter grade. The following graduate grading is available at the university catalog.

Grade	Quality Points	Graduate Courses
A+	4.00	Satisfactory/Passing
A	4.00	Satisfactory/Passing
A-	3.67	Satisfactory/Passing
B+	3.33	Satisfactory/Passing
B	3.00	Satisfactory/Passing
B-	2.67	Satisfactory/Passing
C	2.00	Unsatisfactory/Passing
F	0.00	Unsatisfactory/Failing

Email Communications:

Students must use their Mason email account to receive important University information, including communications related to this class. I will not respond to messages sent from or send messages to a non-Mason email address. Please see https://its.gmu.edu/service/office365-email/ for more information.

Student and Faculty Names and Pronouns:

Name and pronoun use: If you wish, please share your name and gender pronouns with me and indicate how best to address you in class and via email. I use she/her/hers for myself and you may address me as Chi, or Dr./Prof. Yang in email and verbally.

Academic Integrity:

It is expected that students adhere to the George Mason University Honor Code as it relates to integrity regarding coursework and grades. The Honor Code reads as follows: "To promote a stronger sense of mutual responsibility, respect, trust, and fairness among all members of the George Mason University Community and with the desire for greater academic and personal achievement, we, the student members of the university community, have set forth this Honor Code: Student Members of the George Mason University community pledge not to cheat, plagiarize, steal, or lie in matters related to academic work." More information about the Honor Code, including definitions of cheating, lying, and plagiarism, can be found at the Office of Academic Integrity website at http://oai.gmu.edu.

Office of Disability Services:

If you are a student with a disability and you need academic accommodation, please see me and contact the Office of Disability Services (ODS) at 993-2474. All academic accommodation must be arranged through the ODS. https://ds.gmu.edu

Mason Diversity Statement:

https://stearnscenter.gmu.edu/purpose-and-mission/mason-diversity-statement/

Other Useful Resources:

Academic Calendar: https://registrar.gmu.edu/calendars/spring_2023

Writing Center: A114 Robinson Hall; (703) 993-1200; http://writingcenter.gmu.edu

University Libraries: "Ask a Librarian" https://library.gmu.edu/

University Policies: The University Catalog, http://catalog.gmu.edu , is the central resource for university policies affecting student, faculty, and staff conduct in university academic affairs. Other policies are available at http://universitypolicy.gmu.edu . All members of the university community are responsible for knowing and following established policies.