Syllabus for

PHYS 640: Finite Element Analysis of Solids and Fluids

Spring 2022

Contact Information

- Day(s) and Time: Tuesdays 4:30 pm – 7:10 pm
- Location: Exploratory Hall 1004
- Instructor: Prof. Dhafer Marzougui
- Email: dmarzoug@gmu.edu
- Phone: 703-993-4680
- Office Hours: Tuesdays 1:00 pm – 3:00 pm or 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 a necessary skill 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 a project for a given problem. Students will also have the opportunity to learn a commercial 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 program 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.

Course Schedule

Introduction (week 1)

- Week 1: Introduction and basic concept of the finite element analysis. Introduction to FEM package

Basic procedure (week 2 - 4)

- Week 2: Discretization and interpolation
  - Discretization of the domain
  - Interpolation models
  - High order and isotropic elements
- Week 3: Derivation of element matrices and vectors
  - Variational approach (Rayleigh-Ritz)
  - Weighted residual approach (Galerkin and least squares)
  - Derivation of finite element equations using various approaches
- Week 4: Finite element solution
  - Assembly of element matrices and vectors
  - Derivation of system equations
  - Numerical solution of finite element equations

Application to solid mechanics problems (week 5 – 9)

- Week 5: Basic equations and solution procedure
  - Basic equations of solid mechanics
  - Formulation of solid and structural mechanics
  - Formulation of finite element equations (static analysis)
- Week 6: Analysis of trusses, beams, and frames
  - Space truss element
  - Beam element
  - Space frame element
- Week 7: Analysis of plates
  - Triangular membrane element
  - Numerical results with membrane element
  - Quadratic triangle element
  - Rectangular plate element
  - Finite element of plates in bending
  - Analysis of three-dimensional structures using plate element
- Week 8: Analysis of three-dimensional problems
  - Tetrahedral element
  - Hexahedron element
  - Analysis of solids of revolution
- Week 9: Dynamic analysis
  - Dynamic equations of motion
  - Consistent and lumped matrices
  - Free vibration analysis
  - Dynamic response using finite element method

Application to heat transfer problems (week 10 – 11)

- Week 10:
  - Formulation and solution procedure
  - Basic equations of heat transfer
  - Derivation of finite element equations
  - One-dimensional problems
  - Finite element formulation for one-dimensional conduction
  - Finite element formulation for one-dimensional conduction with convection
  - Unsteady state problems
- Week 11:
  - Two-dimensional problems
  - Finite element formulation for heat transfer in two dimensions
  - Unsteady state problems
  - Three-dimensional problems
  - Finite element formulation for axisymmetric heat transfer
  - Finite element formulation for heat transfer in three dimensions
  - Unsteady state problems

Application to fluid mechanics problems (week 12 – 13)

- Week 12: Inviscid and incompressible flows
  - Governing equation for incompressible flow
  - Potential function formulation
  - Finite element solution using Galerkin approach
  - Stream function formulation
- Week 13: Viscous flows
  - Stream function formulation (using variational approach)
  - Velocity-pressure formulation (using Galerkin approach)
  - Solution of Navier-Stokes equations
- Week 14: Project presentation, Review and Discussion
- Week 15: Final Exam

References

- 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
- 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 30%
- Projects: 25%
- Midterm: 20%
- Final Exam: 25%

Course grade will be a letter grade. The following graduate grading is available at 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

Academic Integrity

All students will be expected to abide by the Honor Code: Student members of the George Mason University community pledge not to cheat, plagiarize, steal, or lie in matters related to academic work. GMU honor code is available at https://oai.gmu.edu/mason-honor-code/

University Policy

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/.

Disability Accommodations

If you have a learning disability or other condition that may affect academic performance, please:

a) Make sure documentation is on file with Office of Disability Services (SUB I, Rm. 4205; 993-2474; http://ods.gmu.edu) to determine the accommodations you need; and
b) Talk with the instructor to discuss your accommodation needs.