MECH 420/563 – Finite Element Applications

Term – SUMMER 2015 (201505)

Instructor

Russ Rook, M.A.Sc., E.I.T.
Phone: 250.370.4520
E-mail: rook@camosun.ca

Office Hours

Days: Monday afternoons
Time: By appointment
Location: TEC 133A (Camosun College, Interurban)

Teaching Assistant

Reza Harirforoush
Phone: 250.721.6292
E-mail: rharirfo@uvic.ca

Office Hours

Days: TBA
Time: By appointment
Location: EOW 131

Course Objectives

MECH 420/563 focuses on the solution to differential equations that arise in the field of applied mechanics using the Finite Element Method (FEM). The course addresses problems of elasticity (in bars, beam, grid, and plate elements), heat transfer, idealized fluid flow, and structural dynamics. By taking such a multi-physics approach, the course intends to illustrate the generality of the modern FEM.

FE analysis is first introduced as a numerical solution process for deformation analysis of elastic structures. For these problems, the finite elements are derived using the direct stiffness/displacement method (DSM), also referred to as matrix structural analysis (MSA). The formulation of bar, beam, frame, and grid finite elements will be demonstrated and these elements will be used to solve force-deformation problems. The assembly of elements is illustrated in tutorial examples and reinforced through recommended problems from the course textbook.

In the latter stages of the class, the generalization of the finite element method will be presented. A succinct overview of weighted residual and variational element formulations will facilitate the application of the FEM to plane stress and strain, heat transfer, ideal fluid flow, and structural dynamics problems. At the end of the course, a brief introduction to numerical integration will be given. This introduction will show how the FEM and numerical integrators are used together to perform dynamics simulation.

Learning Outcomes

By the completion of MECH 420, students will be able to:

1. Execute the direct stiffness method to calculate the deformation of trusses, frames and grids, including:
    a. Decompose, conceptually, a structure into a logical collection of idealized solid elements.
    b. Infer appropriate displacement interpolating polynomials based on the assumed loading conditions.
    c. Derive force-displacement element equations for bar, beam, frame and grid elements.

d. Assemble multiple element equations to form a single global system of equations.
e. Anticipate the structure of assembled equations based on the node and element numbering scheme.
f. Apply force and displacement boundary conditions at the node points of the element assembly to solve global equation sets.
g. Recover internal forces and deformations within the structure.
h. Judge the validity of solutions and recognize limitations imposed by the various steps in the solution process.
2. Apply the principle of stationary potential energy to form the general finite element equations for structural elements.
3. Form displacement interpolating polynomials for 3 and 4 node plane stress and plane strain finite elements.
4. Derive plane stress and plane strain finite element equations using the general finite element equations.
5. Relate the method of weighted residuals to the principle of stationary potential energy in structural problems.
6. Apply the method of weighted residuals to two-dimensional heat transfer problems and structural dynamics.
7. Use open quadrature formulae to numerically evaluate integrals within the weighted residuals method.
8. Determine natural frequencies of a structure using a finite element model.
9. Numerically integrate finite element equations in time to trace the motion of a structure.
10. Use commercial software in the solution of assembled finite element equations, including:
    a. Use ANSYS in the solution of spatial frame/truss deformation and plane stress problems.
    b. Conduct convergence analysis using ANSYS output.
    c. Manipulate matrix equations (row and column operations) in Matlab.
    d. Use Matlab to assemble and solve finite element equations.

Syllabus

Dates (mm.dd)	Textbook Sections	Topics Covered
MODULE I – Bars and Beams.		
05.04-05.08	1.1-1.7, A.1-A.5, 2.1-2.5	Course introduction; FEM introduction; introduction to the DSM; spring elements; assembly; boundary conditions.
05.11-05.15	3.1-3.9	Truss elements, global stiffness, rotation operators, skewed supports.
05.18-05.22 05.25-05.29	4.1-4.6, D.1	(***NOTE:*** Victoria Day holiday on Monday, May 18); Beam elements, distributed loads, nodal hinges.
06.01-06.05		**MODULE I Examination**
MODULE II – Frames, Grids, and the CST.		
06.08-06.12	5.1-5.4	Torsion in beams, plane frame and spatial grids.
06.15-06.19	2.6,3.10-3.12,4.7-4.8,E.1	Virtual work, strain energy, variational formulations, weighted residual formulations.
06.22-06.26	6.1-6.5	Plane stress and strain elements, the CST, body forces and surface tractions; review (time permitting).

MODULE III – Isoparametric Elements and Multiphysics Applications.		
06.29-07.03	6.6,8.1-8.3,10.5	**MODULE II Examination**; Higher-order 2D elements (LST, Q4, Q8).
07.06-07.10	10.1-10.4	Isoparametric element formulations; Gaussian quadrature.
07.13-07.17 07.20-07.24	13.1-13.8, 14.1,14.3	Heat and mass transfer and 2D fluid flow in porous media.
07.27-07.31	16.2-16.3,16.6	Structural dynamics: simulation and numerical integration.

A-Section(s): A01   T01   Reza Harirforoush, T.A. (rharirfo@uvic.ca)
Days: Monday   Thursday
Time: 16:00-18:50   16:30-17:20
Location: ECS 124   ECS 124

Lecture hours will be devoted to introducing, reviewing, and discussing the course material. It is the responsibility of the student to attend classes and observe the progress of the course. Students should note that the assignment and exam scheduling provided in this course outline are tentative, and that notice regarding any changes will be given during the lectures. The tutorial will provide the student with a chance to review relevant problems with the T.A. and ask questions regarding the class material. Although the tutorials are not compulsory, students are strongly encouraged to attend the tutorial.

Required Text   **Optional Text**
Title: *A First Course in the Finite Element Method*   Title:
Author: D.L. Logan   Author:
Publisher: Cengage Learning   Publisher:
Year: 2012   Year:

References:

- *Finite Element Analysis from Concepts to Applications*, D.S. Burnett, 1987
- *The Finite Element Method – 4th Ed.*, Vol. 1: Basic Formulation and Linear Problems, O.C. Zienkiewicz, R.L. Taylor, 1989

MECH 420 Assessment:

Assignments: 20%   Due Dates: May 25; June 4; July 6; July 27; Aug. 7
Module I Exam   25%   Date: June 1, 2015
Module II Exam   25%   Date: June 29, 2015
Module III Exam   30%

MECH 563 Assessment:

Assignments: 35%   Due Dates: May 25; June 4; July 6; July 27; Aug. 7
Module I Exam   20%   Date: June 1, 2015
Module II Exam   20%   Date: June 29, 2015
Module III Exam   25%

The final grade obtained from the above marking scheme for the purpose of GPA calculation will be based on the percentage-to-grade point conversion table as listed in the current Undergraduate Calendar.

Note: **MECH 563**

The graduate curriculum will follow that of the MECH 420 course. However, there will be additional questions to complete on assignments (Part 3 questions).

The additional assignment questions will allow the graduate student to further explore the basic concepts presented in the lectures and the course textbook. Often, these more advanced questions will require further reading and study, occasionally outside of the context of the course textbook. For MECH 563 students, the assignment grade will constitute 35% of the final grade in this course.

Note: **Assignments**

Several problem sets will be distributed over the course of the term. ***Assignments will usually <u>have two parts</u>*** <u>for MECH 420</u> students, and ***three parts*** <u>for MECH 563</u> students.

In Part 1, recommended problems from the required course textbook are listed. Some of the Part 1 problems produce matrix equations that can be solved on paper***. Handwritten problems must be completed on "Engineering Computation Paper"*** which is available in the UVic bookstore. However, some Part 1 problems include many degrees of freedom and are best solved using a computational package such as MATLAB, which is also acceptable.

In Part 2, an additional problem will be completed using MATLAB and/or ANSYS software. Tutorial documents will be prepared for each Part 2 problem, and provided via the course website. ***Part 2 of each assignment will be graded based on submission of a short report that is to be submitted along with the Part 1 work***. The report requirements will be stated in the problem's tutorial document.

In Part 3, additional handwritten problems will be assigned for graduate students taking MECH 563. These problems will typically be more challenging, and will require a greater level of comprehension of the course material. MECH 420 students will not be expected or required to complete problems from Part 3.

The assignments cover a fairly large range of material. Students should try to get an early start on each assignment and make consistent progress during the respective module of the course. The due dates for the assignments are (tentatively):

	mm.dd
Assignment #1:………………………………………………………………………………………**05.25**	
Assignment #2: …………………………………………………………………………………**06.04**	
Assignment #3:………………………………………………………………………………….…**07.06**	
Assignment #4:………………………………………………………………………………..…**07.27**	
Assignment #5:………………………………………………………………………………….…**08.07**	

Assignments will be graded on completion, with complete solutions to Part 1 and Part 3 problems will be posted on the due date. No late assignments will be accepted for grading.

The MECH 420 course website, with all lecture notes, assignment, and tutorial documentation, can be found at **http://coursespaces.uvic.ca**

Note: **Examinations & Calculators**

The course material is presented in three distinct modules. While each successive module builds on the knowledge of the previous one(s), the problems being solved in each module are quite distinct. As such, there will be three module examinations. **These examinations will be open textbook tests—the course textbook will**

be permitted. However, lecture notes, assignments, and other written resources will not be permitted in any of the examinations.

Self-contained (with no wireless communication capability) calculators are allowed in all examinations. The grading of exam problems will be based heavily on the methodology applied in calculating the final solution. A significant proportion of assignment and test marks are awarded based on a clear and logical description of the solution process. Using such grading criterion, specification of the correct numerical solution constitutes only a portion of the problem's allotted marks.

There will be no supplemental examination for this course.

Note to Students:

Students who have issues with the conduct of the course should discuss them with the instructor first. If these discussions do not resolve the issue, then students should feel free to contact the Chair of the Department by email or the Chair's Secretary to set up an appointment.

Accommodation of Religious Observance
See entry in current Undergraduate Calendar

Policy on Inclusivity and Diversity
See entry in current Undergraduate Calendar

Standards of Professional Behaviour

You are advised to read the Faculty of Engineering document Standards for Professional Behaviour in current Undergraduate Calendar, which contains important information regarding conduct in courses, labs, and in the general use of facilities.

Cheating, plagiarism and other forms of academic fraud are taken very seriously by both the University and the Department. You should consult entry in current Undergraduate Calendar for the UVic policy on academic integrity.

Course Lecture Notes

Unless otherwise noted, all course materials supplied to students in this course have been prepared by the instructor and are intended for use in this course only. These materials are NOT to be re-circulated digitally, whether by email or by uploading or copying to websites, or to others not enrolled in this course. Violation of this policy may in some cases constitute a breach of academic integrity as defined in the UVic Calendar.