INTRODUCTION TO FINITE ELEMENTS – MANE 4240/CIVL 4240

Fall term, 2018 Class Hours: Tu, F 12:00-1:50 PM Room: DCC 330

Course Instructor: Suvranu De
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Location: JEC 1218

TA: Jitesh Rane <ranej@rpi.edu>
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Location: CII 7219

Course website: http://www.rpi.edu/~des/IFEA2018Fall.html
Practicum website: https://afsws.rpi.edu/AFS/dept/eng/cax/mane4240_ife/

Course objective:
The objective of this course is to teach in a unified manner the fundamentals of the finite element method for the analysis of engineering problems arising in solids and structures. The course will emphasize the solution of real life problems using the finite element method underscoring the importance of the choice of the proper mathematical model, discretization techniques and element selection criteria. Finally, students will learn how to judge the quality of the numerical solution and improve accuracy in an efficient manner by optimal selection of solution variables.

Student outcomes:
By the end of this course, students should be able to
(3.1): *Demonstrate an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics*.
(3.6): *Demonstrate an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions.*

Text:
Title: **A First Course in the Finite Element Method**
Author: Daryl Logan
Year Published: 2016
Edition: Sixth
Publisher: Cengage Learning

NOTE: Lecture notes are posted on the course website. The classes will follow these notes closely. While homework exercises will be assigned from the course text, **it is expected that students have read and thoroughly understood the material in the lecture notes as these will serve as the primary reading material**.

<u>Other reference text:</u>

Finite Element Procedures in Engineering Analysis, K. J. Bathe, Prentice Hall
A First Course in Finite Elements, J. Fish and T. Belytschko, Wiley

Prerequisites by Topic: Basics of Linear Algebra; Introductory calculus (differentiation, integration, differential equations); Computer aided design; Engineering statics

Topics:

- Introduction to finite element analysis
- Direct stiffness approach: Spring elements
- Bar and truss elements
- Introduction to differential equations and strong formulation
- Principle of minimum potential energy and weak formulation
- Finite element formulation of linear elastostatics
- Constant strain triangle
- Quadrilateral element
- Practical considerations in FEM modeling
- Convergence of analysis results
- Higher order elements
- Isoparametric formulation
- Numerical integration

Grading policy:

The student's course grade is based on the performance in

- **Home works** (15%). Please make an effort to write clearly **<u>without omitting steps</u>** in calculations. Only **<u>neatly written</u>** home works will be graded. **The <u>two lowest grades will be dropped (EXCEPT HW#1)</u>.** However, **<u>late home works (on any ground</u>**) will **<u>NOT be accepted</u>**.
- **<u>Practicum exercises</u>** (10%). One exercise per practicum worth 2 points each, to be handed in within a week of assignment.
- A **course project** to be handed in by noon of **11th December** (25%)
- **Two in-class quizzes** (2x25%) on **16th October** (covering Lec 1-9) and **11th December** (covering Lec 10-21). Grade challenges must be done within a week of the date the tests are handed back to the students.
- There will be **NO FINAL EXAMS** in this course.
- Grade modifiers that will be used in this course:
  A=4.0, A- =3.67, B+=3.33, B=3.0, B-=2.67, C+=2.33, C=2.0, C-=1.67, D+=1.33, D=1.0, F=0.0 (Fail)
  There will be no D- grade. The minimum passing grade will be D.

<u>NOTES:</u>

1. **All** write-ups MUST contain your **name** and **RIN**
2. There will be **reading quizzes** (announced **<u>AS WELL AS unannounced</u>**) on a regular basis and points from these quizzes will be added on to the homework

<u>Linear Algebra prerequisite:</u>

Basic knowledge of **linear algebra** (matrix analysis) is **necessary** for this course. **Read Appendix A of your text and the first lecture notes (Introduction) for a reading quiz next class**.

PRACTICUM:

There are 5 classes that are designated as "Practicum". You will need to download and install NX 10 on your laptops and bring them to class on these days. Each class will cover practical aspects of finite element analysis. At the end of the class you will be assigned a single problem, which you will need to hand in to the TA within a week of assignment. No late submissions will be entertained.

For installation and setup of NX software, visit the FAQ (RCS login required):
https://afsws.rpi.edu/AFS/dept/eng/cax/cad/NX_FAQ_current.pdf

If you **customize** your installation of NX, please follow the CAD+CAE installation options as outlined in the following document:
https://afsws.rpi.edu/AFS/dept/eng/cax/cad/nx_install_features_current.pdf

COURSE PROJECT:

In this project you will be required to

- choose an engineering system
- develop a mathematical model for the system
- develop the finite element model
- solve the problem using commercial software
- present a convergence plot and discuss whether the mathematical model you chose gives you physically meaningful results.
- refine the model if necessary.

Projects that demonstrate intelligent choice of models to solve comparatively difficult problems are encouraged.

Sample projects (from previous years):

1. Analysis of a rocker arm
2. Analysis of a bicycle crank-pedal assembly
3. Design and analysis of a "portable stair climber"
4. Analysis of a gear train
5. Gear tooth stress in a wind- up clock
6. Analysis of a gearbox assembly
7. Analysis of an artificial knee
8. Forces acting on the elbow joint
9. Analysis of a soft tissue tumor system
10. FEM analysis of proximal femur computed tomography scans

Course project logistics:

1. For the course project, you are required to form **groups of 2** and email the TA by **21st September**. If you need assistance regarding teaming up, please let us know in advance.
2. Choose a tractable problem that you can analyze in depth in the very limited time available and submit a **one-page project proposal** by **12th October**. Projects will go on a **first come first served** basis. Please proceed to work on the project **ONLY if approved by the instructor (zero credits otherwise).**
3. Submit a **one-page progress report** by **6th November**. **This will carry 10% of the project grade.**
4. Submit a project report (typed) by **noon of 11th December**. This report should include:
    a. Introduction
    b. Problem statement

c. Analysis
d. Results and discussion

5. Project grades will be allotted to the group and **NOT individually**.

Collaboration and academic integrity:

Student-teacher relationships are built on trust. For example, students must trust that teachers have made appropriate decisions about the structure and content of the courses they teach, and teachers must trust that the assignments that the students turn in are their own. Acts, which violate this trust, undermine the educational process. Students are expected to conduct themselves in a professional manner at all times.

The Rensselaer Handbook of Student Rights and Responsibilities defines various forms of Academic Dishonesty and you should make yourself familiar with these. In addition, attempts to commit dishonesty , or to assist in the commission or attempt of such act , are also violations of the academic dishonesty policy. If found in violation of the academic dishonesty policy, you may be subject to two types of penalties. The instructor administers an academic (grade) penalty, and you may also enter the institute judicial process and be subject to such additional sanctions as: warning, probation, suspension, expulsion, and alternative actions as defined in the current *Handbook of Student Rights and Responsibilities.* The following specific collaboration rules apply to this class:

1. You are encouraged to collaborate in the solution of HW problems, but **submit independent solutions that are NOT copies of each other**. If you have collaborated in the solution of your homework, please indicate names of the student/s you have collaborated with. If you are found in violation of this policy, **you will receive a grade of zero for the first violation and a grade of 'F' in the course for the second violation**. The same rule applies if you copy from solutions of homework problems distributed in previous years or if you submit previously corrected homework.
2. Groups of 2 are allowed to collaborate for the projects.
3. Collaboration during quizzes is strictly prohibited. **Any violation will result in a grade of zero for that quiz.**

Mobile Devices: All mobile devices (cell/smart phones, computers, pagers, etc.) must be stored securely away during lecture and are not be used unless specifically directed otherwise by the instructor. Use of (or **ANY** interaction with) a mobile device during an exam without explicit permission of the instructor will be interpreted as the illicit transfer of exam data, will be considered an act of cheating and will be treated as such.

If you have any questions concerning this policy before submitting an assignment, please ask for clarification.

Student Complaint Process:

In compliance with Middle States Accreditation, there is now a central complaint procedure for students. These processes apply to all students regardless of school, status, classification, type or location. Complaints not addressed using this process include:

1. Complaints related to alleged violations of Rensselaer's Student Sexual Misconduct Policy and Procedures, which also includes complaints regarding Title IX violations, available from the Institute's Sexual Misconduct Awareness website

2. Substantive complaints regarding the quality of the institution or its academic programs which should be directed to the Institute's Accrediting Body: Middle States Commission on Higher Education.

Time Table for Fall 2018:

Date	Lec #	FRIDAY	Date	Lec #	TUESDAY
31-Aug	1	Introduction	4-Sep	2	**Linear Algebra miniquiz** **(Appendix A + Notes)** Springs
7-Sep	3	Springs	11-Sep	4	Springs
14-Sep		Practicum #1: CAD Refresher & CAE Introduction	18-Sep	5	Bar elements *HW1 due*
21-Sep	6	Truss analysis **Decide project groups** Prac. #1 due	25-Sep		Practicum #2: Truss Example Post-Processing
28-Sep	7	Intro to BVP *HW2 due*	2-Oct	8	Energy principle Prac. #2 due
5-Oct	9	FE shape functions in 1D *HW3 due*	9-Oct	**NO CLASS**	Monday schedule
12-Oct	10	FE in 1D **Proposal for project due**	16-Oct	**QUIZ #1**	Lectures 1-9
19-Oct	11	Numerical integration in 1D *HW4 due*	23-Oct		Practicum #3: 2D & 3D Examples: Plate & Bar
26-Oct	12	Elasticity review	30-Oct	13	FE for 2D elasticity *Prac. #3 due*
2-Nov	14	The constant strain triangle *HW5 due*	6-Nov	15	The quadrilateral element **One page project report due**
9-Nov	16	Practical considerations in FE modeling *HW6 due*	13-Nov		Practicum #4: Geometry Preparation, Meshing Considerations
16-Nov	17	Convergence	20-Nov	18	Higher order elements *HW7 due &* Prac. # 4 due
23-Nov	**NO CLASS**	Thanksgiving break	27-Nov		Practicum #5: Contact & Assembly
30-Nov	19	Isoparametric formulation	4-Dec	20	Isoparametric formulation Prac. #5 due
7-Dec	21	Numerical integration in 2D *HW8 due*	11-Dec	**QUIZ #2**	Lec # 10-21 **Project due**