INTRODUCTION TO FINITE ELEMENTS – MANE 4240/CIVL 4240 (Section 1)

Fall term, 2021
Class Hours: T, F 12:00-1:50 PM
Room: SAGE 3101

Course Instructor: Suvranu De
Office: JEC 2052   Phone: 276-6351   E-Mail: des@rpi.edu
Webex link

Office Hours: T 2:00-3:00 PM, F 2:00-3:00 PM (or by appointment).

Practicum Instructor: Jeff Morris
Webex personal room: https://rensselaer.webex.com/meet/morrij5
Office: JEC 7030   Phone: 276-2613   E-Mail: morrij5@rpi.edu
Office Hours: http://homepages.rpi.edu/~morrij5/Office_schedule.pdf

TA: Jitesh Rane < ranej@rpi.edu>
Webex personal room: https://rensselaer.webex.com/meet/ranej
Office Hours: Monday 4:00-5:00 pm; Thursday 1:00-2:00 pm
Location: CII 7219

NOTE: Guided by Rensselaer’s campus reopening plan for Fall 2021, office hours are to be conducted primarily on Webex. Face-to-face meetings for the office hours will be limited to special circumstances when such meetings are absolutely necessary and must be done with prior consultation with the faculty member or TA (i.e., just do not “show up” at the offices). Appropriate social distancing must be observed in such meetings.

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 in LMS. 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.

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

Format: The lectures will be in-person only. Classes will not be recorded or posted on LMS. Homework, practicum assignments, and quizzes will be submitted through Gradescope.

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:
- Homework 15%
- Practicum exercises 10%
- Course project 25%
- Two in-class quizzes (equally weighted) 50%

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. The final grade may be curved based on the overall grade distribution. This grading policy is subject to change. Your grades will be recorded for individual assignments and exams in LMS. It is your responsibility to check that these are recorded correctly within one week of posting.

All submissions must have your full name and RIN. There will be NO FINAL EXAM.

Linear Algebra prerequisite:
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.
HOMEWORK
Please make an effort to write clearly without omitting steps in calculations. Only neatly written assignments will be graded. Two of the lowest scores will be dropped (with the exception of HW#1) from your overall grade calculation. However, no late submissions will be accepted. In this course, collaboration is permitted and encouraged on the weekly assigned problems to a degree. It is expected that each student’s work will be his or her own, in both form and content. This means that even if students collaborated in working on problems in the homework assignment, the final work that is submitted must not be a clone of another student’s work. It is good practice to list the people that you collaborated with. Late submissions will not be entertained without valid excuse.

PRACTICUM
Practicum sessions will enable you to model and solve physical problems using commercial finite element software. You will need to download and install the latest version of NX on your laptops and bring them to class on these days. A Windows 10 Operating System is required and at least 15 GB hard drive space free AFTER installation of NX. Each class will cover practical aspects of finite element analysis. At the end of the class, you will be assigned a practicum problem, which you will need to submit by the due date. 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

Practicum website: https://afsws.rpi.edu/AFS/dept/eng/cax/mane4240_ife/

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 the appropriate choice of models to solve comparatively complex 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:**

All course project related submissions are to be submitted to the following email address:
ifea2021fall@gmail.com

1. For the course project, you are required to form **groups of 2** and submit that by **emailing to ifea2021fall@gmail.com** by 24th 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 limited time available and submit a **one-page project proposal to ifea2021fall@gmail.com** by 8th October. Projects will go on a **first-come-first-served** basis. Please initiate work on the project **ONLY if approved by the instructor** (zero credits otherwise).

3. Submit a **one-page progress report by email to ifea2021fall@gmail.com** by 5th November. **This will carry 10% of the project grade.**

4. Submit a project report by **noon of 10th December by email to ifea2021fall@gmail.com.** This report **should not exceed 5 pages,** including figures. It should include the following sections:
   a. Introduction
   b. Problem statement
   c. Analysis
   d. Results and discussion

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

**QUIZZES:**

Two equally weighted tests will be administered during this course on **19th October** (covering Lec 1-11) and **10th December** (covering Lec 10-21).

Grade challenges must be done within a week of the date the tests are handed back to the students. A missed test will result in a grade of zero unless permission is granted beforehand. Permission will not be granted except for serious illness or a family emergency. Such situations must be documented through the Student Experience Office (Academy Hall, x 8022, se@rpi.edu) and approved by the instructor. In such cases, the test will be rescheduled for an alternative date and time. All requests with pre-approved exceptions for scheduling conflicts, additional exam time and/or minimum distraction environment must be submitted to the instructor at least one week before the first test, preferably sooner for organized arrangements.

There will be NO FINAL EXAM for this course.

**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 on the projects.

3. **Collaboration during tests or receiving help from external or online sources is strictly prohibited. Any violation will result in a grade of ‘F’ in the course.**

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

**Diversity and Inclusion Statement:**

Inclusion is a core value for our course, which fosters and supports individual and organizational diversity and inclusion to advance equity in all facets of our university. We embrace and derive value from the variety of views that diverse backgrounds and individuals bring to a task and create a supportive learning environment to foster open communication of diverse perspectives and realities.

People from all diverse backgrounds and perspectives be well served by this course. Everyone’s learning needs will be addressed both in and out of classes, and the diversity that students bring to this course be viewed as a resource, strength, and benefit. We intend to present materials and activities respectful of diversity, including gender, sexuality, disability, age, socioeconomic status, ethnicity, race, and culture. We intend to support an inclusive learning and communication
environment where diversity and individual differences are understood, respected, appreciated, and recognized as a source of strength.

Students in this course are encouraged to speak up and participate during lectures and meetings. Because the participants in this course represent a diversity of individual beliefs, backgrounds, and experiences, every student, instructor, and teaching assistant must show respect for every other member. We expect everyone to respect differences and demonstrate diligence in understanding how other peoples’ perspectives, behaviors, and worldviews may be different from their own. Each member is encouraged to let the instructor know about ways to improve the effectiveness of the course, both personally and for other members or student groups. Also, if any of our course meetings conflict with religious events, each member should inform the instructor in advance to make suitable arrangements.

To receive any academic accommodation due to disability, the student must be registered with the Office of Disability Services for Students (dss@rpi.edu; 518-276-8197, 4226 Academy Hall).
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<thead>
<tr>
<th>Date</th>
<th>Lec #</th>
<th>TUESDAY</th>
<th>Date</th>
<th>Lec #</th>
<th>FRIDAY</th>
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<tbody>
<tr>
<td>31-Aug</td>
<td>1</td>
<td>Introduction and Linear Algebra recap</td>
<td>3-Sep</td>
<td>2</td>
<td>Linear Algebra miniquiz (Appendix A + Notes)</td>
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<td>7-Sep</td>
<td><strong>NO</strong></td>
<td>Monday schedule</td>
<td>10-Sep</td>
<td>3</td>
<td>Springs</td>
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<td>14-Sep</td>
<td>4</td>
<td>Springs</td>
<td>17-Sep</td>
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<td>Practicum #1: CAD Refresher &amp; CAE Introduction</td>
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<td><em>HW1 due</em></td>
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<td>21-Sep</td>
<td>5</td>
<td>Bar elements</td>
<td>24-Sep</td>
<td>6</td>
<td>Truss analysis</td>
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<td><strong>Decide project groups</strong></td>
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<td>28-Sep</td>
<td>7</td>
<td>Intro to BVP</td>
<td>1-Oct</td>
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<td>Practicum #2: Truss Example; Post-Processing</td>
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<td><em>HW2 due</em></td>
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<td>5-Oct</td>
<td>8</td>
<td>Energy principle</td>
<td>8-Oct</td>
<td>9</td>
<td>FE shape functions in 1D</td>
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<td><strong>HW3 due</strong></td>
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<td><strong>Proposal for project due</strong></td>
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<td>12-Oct</td>
<td>10</td>
<td>FE in 1D</td>
<td>15-Oct</td>
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<td>Numerical integration in 1D</td>
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<td><em>HW4 due</em></td>
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<td>19-Oct</td>
<td><strong>QUIZ #1</strong></td>
<td>Lectures 1-11</td>
<td>22-Oct</td>
<td>13</td>
<td>Elasticity review</td>
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<td>26-Oct</td>
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<td>Practicum #3: 2D &amp; 3D Examples: Plate &amp; Bar</td>
<td>29-Oct</td>
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<td>FE for 2D elasticity</td>
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<td><em>HW5 due</em></td>
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<td>2-Nov</td>
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<td>Practicum #4: Geometry Preparation, Meshing</td>
<td>5-Nov</td>
<td>14</td>
<td>The constant strain triangle</td>
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<td>Considerations</td>
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<td><strong>One page project report due</strong></td>
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<td><em>Prac. #3 due</em></td>
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<td>9-Nov</td>
<td>15</td>
<td>The quadrilateral element</td>
<td>12-Nov</td>
<td>16</td>
<td>Practical considerations in FE</td>
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<td><em>HW6 due</em></td>
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<td><em>Prac. #4 due</em></td>
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<td>16-Nov</td>
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<td>Convergence</td>
<td>19-Nov</td>
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<td>Practicum #5: Contact &amp; Assembly</td>
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<td><em>HW7 due</em></td>
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<td>23-Nov</td>
<td>18</td>
<td>Higher order elements</td>
<td>26-Nov</td>
<td><strong>NO</strong></td>
<td>Thanksgiving break</td>
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<td>30-Nov</td>
<td>19</td>
<td>Isoparametric formulation</td>
<td>3-Dec</td>
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<td>7-Dec</td>
<td>Numerical Integration in 2D</td>
<td>10-Dec</td>
<td>QUIZ #2</td>
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<td>12-21</td>
<td>Project due</td>
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