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Description Theory and practice of nonlinear finite element methods focused on solid mechanics. Introduction to this very broad topic. Emphasis on geometric nonlinear kinematics during first half of course, on inelastic material response in second half of course.

Lecture M/W 4:30-5:45pm 402 John D. Tickle
Office Hours W 3:00-4:00pm; R 2:30-3:30pm (Truster), Tickle Bld. 318
Other times by appointment, as discussed below.

Prerequisite CE 561 (linear finite elements for solid mechanics) and CE560 Advanced Structural Mechanics, or equivalent courses. Knowledge of at least one programming language, including MATLAB or C++.

Textbooks Ted Belytschko, W.K. Liu, B. Moran, K.I. Elkhodary, Nonlinear Finite Elements for Continua and Structures, 2nd Edition, Wiley & Sons, 2014. J.C. Simo & T.J.R. Hughes, Computational Inelasticity, Springer, 1997. E.A. de Souza Neto, D. Peric and D.R.J. Owen: Computational Methods for Plasticity: Theory and Applications, Wiley, 2008.
Electronic copies of these books and some of those below are available.

Technology Canvas@UT. Tentatively, this syllabus, course notes, and grades will be posted.

References ●The Finite Element Method: Linear static and dynamic finite element analysis by Thomas J.R. Hughes, 2000. ●Concepts and Applications of Finite Element Analysis, 4th Edition, Robert D. Cook, David S. Malkus, Michael E. Plesha, Robert J. Witt, Wiley. ●Peter Wriggers, Nonlinear Finite Element Methods, Wiley, 2008. ●Bonet and Wood, Nonlinear Continuum Mechanics for Finite Element Analysis, Cambridge Press, 2000. ●MATLAB resources: Canvas@UT

Grading

Midterm Project	25%
Final Project:	25%
Homework	40%
Linear FEM code	10%

Letter grades and quality points are assigned according to the following scale:

Grade	Quality Points	Percentage	Grade	Quality Points	Percentage
A	4.0	93% - 100%	C	2.0	73% - 77%
A-	3.7	90% - 93%	C-	1.7	70% - 73%
B+	3.3	87% - 90%	D+	1.3	67% - 70%
B	3.0	83% - 87%	D	1.0	63% - 67%
B-	2.7	80% - 83%	D-	0.7	60% - 63%
C+	2.3	77% - 80%	F	0.0	0% - 60%

Office Hour Bookings: Besides the two posted office hours, I am using Bookings for arranging meetings for longer questions to be held on Zoom as well as in my office. You can select an appointment time here https://outlook.office365.com/owa/calendar/DrTrustersAcademicMeetings@live.utk.edu/bookings/ for the estimated amount of time. Note that a lead time of 1 hour is built in. You can still visit my office and knock if the door is open, but there is a significant chance that I'll be busy if you don't book ahead.

In-Class Etiquette: I will be recording Zoom class lectures during the class period to subsequently post to campus. Since this is not an online-only class, I won't be monitoring the chat. If you have questions, try clicking the "Raise Hand" button first. If I seem to ignore you too long, go ahead and unmute to gently interrupt. Likely somebody else has a similar question. Class engagement will help me, you, and your peers.

Pre-Class Prep: I may make short videos and post them before the class. Regardless, I make attempts to communicate the upcoming relevant textbook sections to read. These readings are suggested for the content of that lecture. Handouts for filling in notes during the lecture will be uploaded to Canvas; you can print them out to write or type into during the class period. Lectures will be given by me speaking and writing into OneNote pages corresponding to these handouts. I will be posting my annotated notes as a PDF.

Attendance and Absence: Hopefully no one gets sick, but there is a good chance someone will. We will figure out how to make up work if that time comes. Lecture recordings will be posted, and homework must be submitted online. So keep up whatever pace you find manageable, and don't get in physical contact with your peers if you have symptoms.

Homework Homework will typically involve shorter programming exercises or hand derivations of equations/formulations. All submissions will be online through Canvas which may include both written discussion and programming files. You are encouraged to work together to understand concepts and develop approaches for programming. However, each student must submit his/her own work. Evidence of inappropriate collaboration (e.g., two students submitting assignments that are essentially identical) will result in no credit for that assignment. Submissions are due 11:59pm on the date indicated.

Project The topic of finite elements is best (if not only) learned by actually programming the method into a computer and learning from your mistakes and by solving actual problems. Currently, two projects are planned for the course. The first is the development of a nonlinear elastostatics finite element code for hyperelasticity (finite strains) in 2D. The second project is at the discretion of the student although standard coding projects are available. This semester, I am intending to modify the deliverables such that the student may either program the methods in their individual code from scratch or else with an open-source or UTK-commercially-available software suitable for nonlinear solid mechanics

finite element analysis. This intention may be revised in the first month of the class.

Academic Integrity

At the University of Tennessee, we set high technical and ethical standards. You are expected to maintain the utmost level of academic integrity for all of your work in this course. As noted above for assignments, you may work with other students to understand concepts and procedures, but ultimately the step-by-step calculations, figures, and explanations should be you own. Using assignments or exams from previous semesters along with solutions manuals, etc., as reference materials is prohibited (except for material provided by the instructor). During exams, communicating with other students is prohibited. Violation of these standards is a serious breach of academic integrity and can result in receiving a failing grade for the course, and possible suspension or dismissal from the University. See further policies on the honor code at http://catalog.utk.edu/content.php?catoid=14&navoid=1305#hono_stat

University Policies

Freedom to Learn: The responsibility to secure and to respect general conditions conducive to the freedom to learn is shared by all members of the academic community. The university welcomes and honors people of all races, creeds, cultures, and sexual orientations, and values intellectual curiosity, pursuit of knowledge, and academic freedom and integrity.
Other relevant policies can be found in the online catalog at:
http://catalog.utk.edu/content.php?catoid=14&navoid=1305

Students with Disabilities Policy

The University of Tennessee, Knoxville, is committed to providing an inclusive learning environment for all students. If you anticipate or experience a barrier in this course due to a chronic health condition, a learning, hearing, neurological, this course due to a chronic health condition, a learning, hearing, neurological, mental health, vision, physical, or other kind of disability, or a temporary injury, you are encouraged to contact Student Disability Services (SDS) at 865-974-6087 or sds@utk.edu. An SDS Coordinator will meet with you to develop a plan to ensure you have equitable access to this course. If you are already registered with SDS, please contact your instructor to discuss implementing accommodations included in your course access letter.

Topical Outline

1. **Introduction to Nonlinear Finite Element Method:**
   Review of linear FEM; sources of nonlinearity; Newton-Raphson algorithm applied to one dimensional problem
2. **Nonlinear Statics:**
   Small deformation nonlinear elasticity; linearized operators; formulation; programming
3. **Methods of Solving Nonlinear Algebraic Systems:**
   Newton and Modified-Newton Methods; consistent linearization; line search techniques; approximate tangents
4. **Finite Strain Hyperelasticity:**

Continuum mechanics background; weighted residual form; total and updated Lagrangian formulation; finite element discretization; material and geometric stiffness

5. **One Dimensional Plasticity and Viscoplasticity:**
   Local governing equations; elastoplastic boundary value problem; tangent moduli; integration algorithms for rate-independent plasticity; discrete variational form
6. **Two Dimensional Rate-Independent Plasticity and Viscoplasticity:**
   J2 flow theory with isotropic/kinematic hardening; principle of maximum plastic dissipation; associative hardening plasticity; rate-dependent viscoplasticity and generalized Duvant-Lions model
7. **Return Mapping Algorithm for Time Integration:**
   Strain-driven problem; cutting plane algorithm; closest point projection; operator split methodology; extension to viscoplasticity; extension to nonlinear hardening laws
8. **Other Possible Special Topics:**
   Finite strain plasticity, objective stress rates, integration algorithms, B-bar method for incompressibility, mixed methods, contact mechanics, …

Tentative Schedule

Last time in Spring 2021, this course had 5 homework assignments during the semester between the 2 projects and initial linear code; similar plan is expected.

Acknowledgement Portions of these course materials are adapted from the following individuals with permission: Arif Masud, PhD.