Dr. Chloé Arson
chloe.arson@ce.gatech.edu

CEE 6513 Computational Methods in Mechanics – Fall 2021

Meeting Times: Tuesdays and Thursdays, 2pm - 3.15pm
Classroom: Cherry Emerson 322
Office hours: TBA- To meet students' requirements, needs, and comfort levels, office hours will be offered in-person and virtually (using Blue Jeans).
Grader: TBA

Prerequisite knowledge: Mechanics of Deformable Bodies (e.g., COE 3001 or equivalent), and one of the following courses (or equivalent): CEE 3051 Introduction to Structural Engineering or CEE 4405 Introduction to geotechnical engineering or CEE 4450 Introduction to Petroleum geomechanics.

Catalog description: Generalization of finite element concepts; Galerkin-weighted residual and variational approaches; mixed and hybrid finite element formulations, applications, transient dynamic analysis; software implementation.

Course contents: This course presents a practical application of finite element method to problems in solid mechanics. Taking students from fundamental theory to real-world applications using commercial software, this course reviews theoretical bases of continuum mechanics, introduces the plasticity theory, presents constitutive models relevant to geomaterials and structural materials, explains the fundamental principles of the Finite Element Method (FEM), and applies fundamental concepts of mechanics to solve and analyze problems of civil engineering. Applications focus on - but are not limited to - geotechnical systems, structures and material design. The course is organized in five main modules that each blend theoretical principles and applications with the FEM: (1) Elements of continuum mechanics and elasticity; (2) The Finite Element Method in elasticity for 1D time-independent problems with one dependent variable; (3) Analytical and numerical solutions to eigenvalue and transient problems; (4) The FEM in elasticity for 2D with applications to structures, mass and heat transport; (5) Principles of plasticity, constitutive models in perfect plasticity and numerical applications for civil engineering.

Learning Objectives:

1. Calculate the state of stress in a solid, the principal stresses and the stress invariants
2. Calculate small and large deformations in a solid
3. Solve analytically boundary problems of elasticity that do *not* require complex potentials
4. Predict the occurrence of plasticity and calculate plastic strains in an elastic-perfectly plastic medium
5. Recommend constitutive models for civil engineering materials
6. Approximate the solution of Partial Differential Equations (PDEs) by using variational methods.
7. Build a Finite Element Model (weak form, interpolation functions, element governing equation, global stiffness matrix) for singe-variable problems - including eigenvalue and time-dependent problems
8. Craft finite element models with commercial tools that answer relevant questions given geosystem or structural problems, without including unnecessary complexity
9. Use experimental material data to calibrate material models with application to larger systems
10. Iteratively upgrade models through the analysis process
11. Diagnose errors in finite element models and implement solutions
12. Synthesize and communicate analysis results so that they can be used to communicate behaviors to clients

Textbook: Course material will be developed and made available to the students via the course website. Below are some references that are recommended for further study.

- G.T. Mase, R.E. Smelser, G.E. Mase. *Continuum Mechanics for Engineers*, 3rd ed. (2010), CRC Press
- H.S. Yu. *Plasticity and geotechnics* (2007). Springer Science & Business Media
- J.N. Reddy. *An Introduction to the Finite Element Method,* 3rd edition (2006), McGraw-Hill
- J.N. Reddy. *An Introduction to the Nonlinear Finite Element Analysis* (2004), Oxford University Press

Dr. Chloé Arson
chloe.arson@ce.gatech.edu

Course schedule & Outline: The schedule will be adjusted as needed during the semester.

Week	Tests & Deadlines	Topics
1 (08/23)		**Finite Element Method in 1D problems with one dependent variable.** Galerkin-weighted residual and variational approaches, interpolation functions, stiffness matrix assembly, boundary conditions, resolution methods and post-processing techniques. Equations for FEM models for bars and beams, penalty method for trusses, 1D heat transfer and 1D fluid flow. *Tutorials with ABAQUS:* Structures applications: simulation of bar elongation and truss deformation, heat transfer in a composite wall; Geosystems applications: settlement of a soil column, heat transfer around a geothermal source.
2 (08/30)		
3 (09/06)	HW1	
4 (09/13)	HW2	**Eigenvalue and transient problems.** Time discretization for parabolic and hyperbolic equations. FEM equations for beam vibration and 1D heat and mass transfer. Stability and maximum time step. *Tutorials for ABAQUS:* Structures application: beam vibration; Geosystems application: heating of a rock slab: comparison of the analytical solution with 1D, 2D axis-symmetric and 2D plane strain solutions; simulation of heat transfer around a nuclear waste disposal in 1D, 2D axis-symmetry and 2D plane strain.
5 (09/20)		
6 (09/27)		
7 (10/04)	HW3	**Tensorial mechanics.** Review of tensor algebra; properties and operations of vectors and tensors, tensor calculus, Gauss theorem, review of matrix algebra. *Tutorials for Octave/MATLAB:* Basic commands of calculus and algebra.
8 (10/11)	Project 1	
9 (10/18)		**Elements of continuum mechanics.** Stress at a point; Mohr circle representation; principal stresses; stress invariants and stress decomposition; equilibrium equations and conservation of momentum; measures of deformations and strains, strain compatibility; stress-strain relations; boundary value problem representation.
10 (10/25)	HW4	
11 (11/01)		**Linear elasticity.** Linear elastic constitutive relationships, strain energy function, superposition principle, Saint-Venant's principle, elastostatic equations (equilibrium equations, Navier's equations of motion, Beltrami-Michell's compatibility equations)
12 (11/08)	HW5	**2D-Finite Element models in elasticity.** Triangular and rectangular linear elements, higher order elements, serendipity elements, master elements, coordinate transformation. Numerical integration in 1D and 2D: Newton Cotes quadrature, Gauss quadrature. Stiffness matrix in plane elasticity. Meshing strategies (number and order of elements). *Tutorials for ABAQUS:* Structures applications: Stress and displacement fields in a punched plate subjected to tension, irrotational flow around obstacles; Geosytems applications: 2D plane strain analysis of cavity expansion, 2D plane strain analysis of settlements under a shallow foundation
13 (11/15)		
14 (11/22)	HW6	**Fundamental principles of plasticity.** Yield function, flow rule, normality rule, perfect plasticity, isotropic hardening, kinematic hardening **Perfect plasticity.** Associated flow rule (Tresca and von Mises models); non-associated flow rule (Mohr-Coulomb and Drucker-Prager models) *Tutorials for ABAQUS:* Structures applications: torsion test, column buckling, slab bending; Geosystems applications: 2D plane strain analysis of cavity expansion with plastic zone, 3D model of triaxial compression test with loading platens
15 (11/29)	HW7	
16 (12/06)	Project 2	

Dr. Chloé Arson
chloe.arson@ce.gatech.edu

Course Assessment: Homework will include calculus and analysis. Sample problems will be solved in class. Students will have to turn in two individual projects: one will require using 2D FEM in elasticity and the other will require using FEM in plasticity. Students will be given a list of 3 problems that they will be able to choose from for each of their project.

Grading: *Final grade*: F<60%≤D<70%≤C<80%≤B<90%≤A≤100%
Score: 7 HW @ 7% each = 49%. Project 1: 21%. Project 2: 30%.

Access to FEM software and tutorials: Ansys and COMSOL are available through the VLab (https://mycloud.gatech.edu). CEE enrolled students have access by default. Abaqus has a free student version (https://edu.3ds.com/en/software/abaqus-student-edition). Dassault (the company that made Abaqus) also has a list of free software (https://edu.3ds.com/en/get-software). The FEM tutorials of this course have been designed for Abaqus. More information is available in Abaqus documentation (http://130.149.89.49:2080/v6.14/). Students who prefer to use Ansys may find the Ansys Academic Support webpage useful (https://www.ansys.com/academic/learning-resources). Students who prefer to use COMSOL will find a complete user's manual online (https://doc.comsol.com/5.6/docserver/#!/com.comsol.help.comsol/helpdesk/helpdesk.html), as well as an exhaustive gallery of tutorials (https://www.comsol.com/models).

Academic Integrity: Working in group on homework is allowed (and encouraged). However, each student must write up and turn in his/her own solutions. In-class exams and quizzes are strictly individual. Any student suspected of cheating or plagiarizing on a quiz, exam, or assignment, will be reported to the Office of Student Integrity, who will investigate the incident and identify the appropriate penalty for violations. Georgia Tech aims to cultivate a community based on trust, academic integrity, and honor. Students are expected to act according to the highest ethical standards. For information on Georgia Tech's Academic Honor Code, please visit http://www.catalog.gatech.edu/policies/honor-code/ or http://www.catalog.gatech.edu/rules/18/.

Recordings of Class Sessions and Required Permissions: Classes may not be recorded by students without the express consent of the instructor unless it is pursuant to an accommodation granted by the Office of Disability services. Class recordings, lectures, presentations, and other materials posted on Canvas are for the sole purpose of educating the students currently enrolled in the course. Students may not record or share the materials or recordings unless the instructor gives permission.

Dean of Students Office, CARE Center, Counseling Center, Stamps Health Services, and the Student Center: The **CARE Center** and the **Counseling Center**, Stamps Health Services, and the Dean of Students Office will offer both in-person and virtual appointments. Student Center services and operations are available on the **Student Center** website. For more information on these and other student services, contact the Dean of Students or the **Division of Student Life**.

Information Related to Covid-19: Students are expected to be familiar with and abide by the Institute guidelines, information, and updates related to Covid-19. Find campus operational updates, Frequently Asked Questions, and details on campus surveillance testing and vaccine appointments on the **Tech Moving Forward site.**

Accommodations for Students with Disabilities: If you are a student with learning needs that require special accommodation, please contact the Office of Disability Services at (404)894-2563 or http://disabilityservices.gatech.edu/, as soon as possible, to make an appointment to discuss your special needs and to obtain an accommodations letter. Please also e-mail me as soon as possible in order to set up a time to discuss your learning needs.

Dr. Chloé Arson
chloe.arson@ce.gatech.edu

Diversity Statement: We consider the class environment to be a place where you will be treated with respect, and we welcome individuals of all ages, backgrounds, beliefs, ethnicities, genders, gender identities, gender expressions, national origins, religious affiliations, sexual orientations, ability – and other visible and nonvisible differences. All members of this class are expected to contribute to a respectful, welcoming and inclusive environment for every other member of the class.

Safe Zone Statement: We are members of a Safe Zone Ally community network, and we are available to listen and support you in a safe and confidential manner. As Safe Zone Allies, we can help you connect with resources on campus to address problems you may face that interfere with your academic and social success on campus as it relates to issues surrounding sexual orientation and gender identity. We will gladly honor your request to address you by an alternate name or gender pronoun. Please advise us of this preference early in the semester so that we may make appropriate changes to our records. Our goal is to help you be successful and to maintain a safe and equitable campus.