Dr. C. Arson
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CEE 6460: Theoretical Geomechanics – Spring 2023

Meeting Times: Mondays and Wednesdays, 9.30am-10.45am
Classroom: CoC 53
Office hours: Tue. & Wed. 3pm-4pm on Zoom (https://gatech.zoom.us/j/96950524028)
Any time on Piazza.

Prerequisites: COE undergraduate coursework.

Catalog description: Field equations of linear elasticity, solutions of boundary value problems, steady/transient flow in porous media. Yielding and failure of soils; plasticity theory and limit analyses. Constitutive soil models. Introduction to finite elements with geotechnical engineering applications.

Course contents: This course provides an introduction to the theories of elasticity, plasticity, poro-mechanics, fluid flow in porous media and unsaturated soil mechanics. It covers analytical and numerical methods to solve and analyze boundary value problems in geomechanics. The material presented can be of general interest to students who are not majoring in geotechnical engineering, in particular, students interested in solid mechanics, groundwater hydraulics and Earth systems modeling. Topics include general theorems of elasticity, an introduction to poromechanics, fundamental principles of perfect plasticity, elastoplastic constitutive models for dry, saturated and unsaturated geomaterials, limit analysis for slope and foundation stability, iterative resolution procedures for non-linear behavior, and a practical introduction to the Finite Element Method (FEM). Applications focus on energy geotechnologies and climate change.

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 basic boundary problems of elasticity, such as circular cavity expansion
4. Predict the occurrence of plasticity and calculate plastic strains in dry, saturated, and unsaturated geomaterials
5. Approximate the solution of Partial Differential Equations (PDEs) by using finite difference schemes
6. Calculate the bounds of the critical load in undrained and drained conditions
7. Assess the stability of slopes and foundations in undrained and drained conditions, by using limit analysis and the FEM
8. Model the effect of temperature and moisture variations on soil elasto-plastic behavior
9. Design geotechnical structures subjected to climate change

Textbook: You will have access to my own notebook. Below are references that I recommend for further study.

- Continuum mechanics, elasticity, plasticity, elasto-plastic models for soils and rocks, limit analysis:
  - Atkinson, J. (1981). *An introduction to the mechanics of soils and foundations: through critical state soil mechanics*. John Wiley & Sons, New-York.
  - Jaeger, J.C., Cook, N.G., & Zimmerman, R. (2009). *Fundamentals of rock mechanics*. Wiley.
  - Mase, G.T., Smelser, R.E., & Rossmann, J.S. (2020). *Continuum mechanics for engineers*. CRC Press.
  - Yu, H. S. (2007). *Plasticity and geotechnics* (Vol. 13). Springer Science & Business Media.
- Poromechanics and fluid flow in porous media:
  - Coussy, O. (2011). *Mechanics and physics of porous solids*. John Wiley & Sons.
  - Dormieux, L., Kondo, D., & Ulm, F. J. (2006). *Microporomechanics*. John Wiley & Sons.
- Finite Element Method:
  - Reddy, J.N. *An Introduction to the Finite Element Method,* 3rd edition (2006), McGraw-Hill
  - Reddy, J.N. *An Introduction to the Nonlinear Finite Element Analysis,* (2004), Oxford University Press
  - Zienkiewicz, O. C., Chan, A. H. C., Pastor, M., Schrefler, B. A., & Shiomi, T. (1999). *Computational geomechanics*. John Wiley.

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Tentative schedule:

Week	HW	Topics
1 (01/09, 11)		**Mathematical introduction.** Review of tensor algebra; properties and operations of vectors and tensors, tensor calculus, Gauss theorem, review of matrix algebra.
2 (01/18)		
3 (01/23, 25)	HW 1	**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 conditions.
4 (01/30, 02/01)	HW 2	
5 (02/06, 08)	HW 3	**Linear elasticity.** Formulation of field equations; two-dimensional problems in rectangular and polar coordinates (e.g., cavities expansion problems); method of displacements; superposition; principle of virtual work; uniqueness of solution; reciprocal theorem.
6 (02/13, 15)	HW 4	
7 (02/20, 22)		**Plasticity.** Introduction: yield function, flow rule, normality rule, perfect plasticity, isotropic hardening, kinematic hardening. Perfect plasticity: associated flow rule for cohesive soils (Tresca and von Mises models); non-associated flow rule for frictional soils (Mohr-Coulomb and Drucker-Prager models); Hoek and Brown's model for rocks.
8 (02/27, 03/01)	HW 5	
9 (03/06, 08)	HW 6	**Limit analysis.** Upper bound and lower bound theorems, resolution method, stresses on slip fans. Undrained stability of soil structures (vertical cut, retaining wall, foundation), drained stability of soil structures (infinite slope, smooth retaining wall, foundation). Practical applications with the FEM.
10 (03/13, 15)		
11 (03/27, 29)	HW 7	**Poro-elasticity.** Introduction to porous media. Concept of REV. Equations of poro-elasticity with one fluid (one phase and one species): momentum and mass conservation equations, constitutive relationships. 1D consolidation. Permeability models.
12 (04/03, 05)	HW 8	
13 (04/10, 12)		**Poro-plasticity.** Introduction to the critical state theory. Cam-Clay model. Unsaturated soil mechanics. Water Retention Curve. Barcelona model. Simulation of triaxial stress paths with the Finite Difference Method. Applications: consolidation in unsaturated porous media, subsidence above a hydrocarbon reservoir, evapo-transpiration, nuclear waste disposals.
14 (04/17, 19)	HW 9	
15 (04/24)	HW 10	

Course Assessment: There will not be any exam. Homework (HW) will cover calculus, mechanical analysis, and numerical modeling. Each homework will comprise three problems in average, for an estimated workload of 4 to 10 hours per assignment. In the absence of valid excuse, a penalty of 5% per day will be applied for late homework submission.

Grading: *Final grade*: F<60%≤D<70%≤C<80%≤B<90%≤A≤100%
Score: 10 HW @ 10% each = 100%.

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Academic Integrity: Working in group on homework and projects is allowed (and encouraged). However, each student must write up and turn in his/her own solutions. In-class exams 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/.

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.

Diversity Statement: I consider the classroom (physical or virtual) to be a place where you will be treated with respect, and I 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: I am a member of a Safe Zone Ally community network, and I am available to listen and support you in a safe and confidential manner. As a Safe Zone Ally, I 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. I will gladly honor your request to address you by an alternate name or gender pronoun. Please advise me of this preference early in the semester so that I may make appropriate changes to my records. My goal is to help you be successful and to maintain a safe and equitable campus.