Finite Element Method for Coupled Processes in Geomechanics
(FEM Coupled Processes Geomech.)
Georgia Institute Of Technology

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Finite Element Method for Coupled Processes in Geomechanics - Fall 2013

Meeting Times: Monday & Wednesday, 1.05pm-2.25pm
Classroom: Mason 3133

Prerequisites: COE undergraduate coursework. Recommended: CEE 4405 Geotechnical Engineering.

Scope of the course: Course contents will cover basic knowledge of variation methods, space and time discretization, and non-linear resolution algorithms. Applications will focus on coupled geomechanical processes, i.e. problems in which fluid and/or heat transfer affect the deformation of a granular or porous medium. Implementation of coupled thermo-hydro-mechanical governing equations into Finite Element Methods will be treated for elastic processes. If time allows, non-elastic constitutive models of soils and rocks will be studied from a numerical perspective: incremental laws will be derived, stiffness matrix coefficients will be computed, and convergence issues will be examined for different thermo-hydro-mechanical stress paths.

Learning Objectives:
1. Identify the components of a mathematical model (e.g., governing equations, initial conditions, essential and natural boundary conditions, primary and secondary variables).
2. Approximate the solution of Partial Differential Equations (PDEs) using the weighted-residual formulation and using variational methods.
3. Build a Finite Element Model (weak form, interpolation functions, element governing equation, global stiffness matrix) for singe-variable problems in 1D - including eigenvalue and time-dependent problems.
4. Solve axis-symmetric, plane strain and plane stress geomechanical problems with the Finite Element Method, by using analytical and numerical computations.
5. Interpret numerical errors and convergence problems.
6. Derive and program incremental stress/strain relationships for a non-elastic behavior model of soil/rock.
7. Recommend a simulation plan for soil & rock behavior characterization and geotechnical design.

Course Assessment: Sample problems will be solved in class before ***exams*** (one mid-term exam, one final exam). ***Homework*** will include calculus, analysis and programming (mostly in MATLAB).

Interested students will have the opportunity to substitute four of the homeworks by a project aimed to design an impactful energy geotechnical system (e.g., geothermal foundation, nuclear waste repository, landfill…). The report shall contain a literature review on the geosystem of interest, a simulation plan to examine various technological concepts, Finite Element results for at least two geological scenarios (i.e. two different sets of behavior models), interpretations of potential numerical errors, and recommendations for design.

Computation & Programming Tools: at least one of the following: MATLAB, Fortran, ABAQUS, PLAXIS.

Recommended References:
- Reddy, J.N. *An Introduction to the Finite Element Method,* 3rd edition (2006), McGraw-Hill
- Potts, D. M., & Zdravković, L. *Finite element analysis in geotechnical engineering: Theory*. (1999) London: New York: Thomas Telford.

For further reading:
- Potts, D. M., & Zdravković, L. *Finite element analysis in geotechnical engineering: Application*. (2001) London: New York: Thomas Telford.
- Reddy, J.N. *An Introduction to the Nonlinear Finite Element Analysis,* (2004), Oxford University Press

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Outline & Schedule: Examples of laboratory-scale (L) and field –scale (F) problems are related to Finite Element discretization issues in the outline of the course, below. The time schedule is tentative. The pace of the lectures and the specific geomechanical problems studied (L & F) will be adjusted as needed in the course of the semester. Tentative exam dates and homework deadlines are indicated, and may slightly change if appropriate.

Week	Exams & HW due	Topics
08/19		The components of a numerical problem: balance equation, constitutive relationship, dependent variable, boundary conditions, initial conditions. Review of calculus of variations. Weighted Integral Formulation.
08/26		Variational Methods.
09/02	**HW#1**	Single-variable problems in 1D. Steady state heat transfer in Cartesian and polar coordinates. **L4 w/o deformation**. Euler-Bernouilli and Timoshenko beam elements. **F1**.
09/09	**HW#2**	
09/16		
09/23	**HW#3**	Eigenvalue and time-dependent (transient) problems in 1D. Coupled problems in 1D (multiple dependent variables): **L3 (for linear elasticity), L4, F2**.
09/30	**Mid-term**	
10/07	**HW#4**	2D-Finite Element models. Triangular and rectangular elements, higher order elements, serendipity elements, coordinate transformation, master elements. Stiffness matrix in plane elasticity. **L1 (in elasticity), F3, F4.**
10/14		
10/21	**HW#5**	
10/28	**HW#6**	Non-linear FEM: incremental evolution laws (consistency conditions, associate and non-associate flow rules), main iterative processes (Picard Method, Newton-Raphson Method, modified Newton-Raphson method), scaling back factor, automatic time sub-stepping. **L1-L6.**
11/04		
11/11	**HW#7**	
11/18	**HW#8**	
11/25*		
12/02		
12/11**	**Final**	**2.50pm-5.40pm**

(*) Thanksgiving week: class schedule may change. (**) Official Final Exam Date from the Registrar.

L1. Drained triaxial compression test. Mohr-Coulomb and Drucker-Prager yield surfaces.
L2. Undrained triaxial compression test. Cam-Clay model.
L3. Consolidation test. Hyperbolic elasticity.
L4. Drained Heating Test. Thermo-elasticity and thermo-plasticity.
L5. Suction-controlled triaxial compression test. Barcelona model.
L6. Undrained Heating Test. Barcelona model extended to thermal effects, Hueckel & Pellegrini's models.
F1. Axially and laterally loaded piles (modeled as a 1D-beam, no lateral friction).
F2. Geothermal piles (Laloui's 1D thermo-elastic model).
F3. Elastic stress and strain around cavities (validation of a numerical prediction against an analytical solution)
F4. Seepage problem under a dam: settlements and flow nets (e.g., using PLAXIS)

Grading: *Final grade*: F<60%≤D<70%≤C<80%≤B<90%≤A≤100%
Score, option 1: 8 HW @ 7.5% each = 60%. Mid-Term Exam: 15%. Final Exam: 25%.
Score, option 2: 4 HW @ 7.5% each = 30%. Project: 30%. Mid-Term Exam: 15%. Final Exam: 25%.

Academic Honor Code: Working in group on homework and projects is allowed (and encouraged). However, each student must write up and turn in his/her own solutions. Full compliance with the GT Academic Honor Code (available at www.honor.gatech.edu) is expected.