Finite Element Method for Porous Media
CEE 8813-M. FEM Coupled Processes Geomech.
Georgia Institute Of Technology

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Finite Element Method for Porous Media – Spring 2016

Meeting Times: Tuesday & Thursday, 1.35pm-2.55pm
Classroom: SEB 316
Office hours: Tuesday & Wednesday, 3pm-4pm (or by appointment)

Prerequisites: COE undergraduate coursework.

Scope of the course: The course will cover basic knowledge of variation methods, space and time discretization, and thermo-poro-elastic Finite Elements Methods (FEM). Applications will include problems of solid mechanics, heat and mass transfer, consolidation, seepage, precipitation and stress/pressure/temperature variations around cavities. Topics covered include the derivation of coupled thermo-hydro-mechanical FEM equations for elastic problems, the programming of FEM resolution algorithms, the typical convergence issues encountered in coupled problems, the basic modeling strategies used in numerical poro-mechanics and the interpretation of coupled FEM simulations for engineering design.

Learning Objectives:

1. Write the set of equations and constraints necessary to solve a poro-mechanical problem.
2. Approximate the solution of Partial Differential Equations (PDEs) by using the weighted-residual formulation and 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 poro-mechanical problems with the Finite Element Method, by using analytical and numerical computations.
5. Interpret numerical errors and convergence problems.
6. Design an engineering prototype; optimize the performance of a porous medium under thermo-hydro-mechanical constraints with the FEM.
7. Recommend FEM strategies (e.g., meshing, interpolation order, time discretization) for the modeling of coupled processes in porous media.

Course Assessment: There will not be any final examination but there will be ***two tests*** in the course of the semester. Sample problems similar to the ones assigned in the tests will be solved in class beforehand. ***Homework*** will include calculus, analysis and programming (mostly in MATLAB). The ***project*** is an individual assignment aimed to design an engineering structure or system that requires the use of porous media subjected to thermo-hydro-mechanical constraints. Students will do two presentations and write a report. The report shall contain a literature review, a simulation plan to examine various technological concepts, Finite Element results for at least two design options, interpretations of potential numerical errors, and recommendations for design. Students will propose a project topic and, after the instructor's approval, will use the computational software of their choice (e.g. MATLAB, ABAQUS, ANSYS, PLAXIS, DISROC/POROFIS) to do the project.

Example projects from past semesters: Tunnel of the port of Miami; MARTA Peachtree Center Station in Atlanta; Compressed Air Energy Storage in a salt cavern; nuclear waste disposal; heat exchanger piles; oil extraction and CO_2 injection in shale; construction of flow networks in competitive environments; decontamination of cementitious materials with wet poultices; design of composite materials.

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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

Outline & Schedule: Lecture topics, test dates and deadlines will be adjusted as needed in the course of the semester. *Project 1: mid-term presentation. Project 2: final presentation and report.*

Week	Tests & Deadlines	Topics
01/11		Formulation of the Finite Element problem: fundamental and constitutive equations of common engineering problems. Basic principles of thermo-poro-elasticity. Concept of mathematical approximation and principle of the FEM. Review of calculus of variations. Weighted Integral Formulation. Variational Methods.
01/18		
01/25	HW 1	Finite Element Method in 1D problems with one dependent variable: integral formulation, approximation functions, stiffness matrix assembly, boundary conditions, resolution methods and post-processing techniques. Applications in solid mechanics, 1D heat transfer and 1D fluid flow. Introduction to beam elements.
02/01		
02/08	HW 2	
02/15	Test 1	Eigenvalue and transient problems. Time discretization for parabolic and hyperbolic equations. Applications: 1D heat and mass transfer, beam vibration.
02/22		
02/29	Project 1	2D-Finite Element models. 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. Applications: elastic stress and strain around cavities, irrotational flow around impermeable solids, seepage problems.
03/07	HW 3	
03/14		
03/28	HW 4	
04/04	Test 2	Coupled processes with the FEM. Theoretical and numerical resolution of the 1D consolidation problem with the FDM (Finite Difference Method) and with the FEM. Triaxial compression test in drained and undrained conditions. Thermo-elastic response of a layered composite beam. Precipitation problems with conditional boundary conditions (pressure vs. flow).
04/11	HW 5	
04/18		
04/25	Project 2	

Grading: *Final grade*: F<60%≤D<70%≤C<80%≤B<90%≤A≤100%
Score: 2 tests @ 20% each: 40%. Project: 35%. 5 HW @ 5% each = 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 http://www.honor.gatech.edu/content/2/the-honor-code) is expected.