Computational Poromechanics, Autumn 2014

CLASS SESSIONS
Wednesday 7:00-9:30pm

INSTRUCTOR
Professor: Dr. Steve WaiChing Sun, 614 Mudd, wsun@columbia.edu
Office Hour: Friday 2:00-4:00PM or by appointment

TEXTBOOK
The monographs listed below are highly recommended. However, course materials may differ from those covered in the textbooks. Lecture notes will be provided.

1. *Poromechanics*, O Coussy, John Wiley & Sons, 2004.
2. *Tissue Mechanics*, S.C. Cowin & S.B. Doty, Springer, 2007.
3. *Computational Geomechanics: with special reference to earthquake engineering*, O.C. Zienkiewicz et al., John Wiley & Sons, 1999.
4. *Dynamics of fluids in porous media*, J. Bear, Dover Publications, 1972.
5. *Plasticity: Modeling and Computation*, R.I. Borja, Springer, 2013.
6. *Computational Methods for Plasticity: Theory and Applications,* E.A. de Souza Neto, D. Peric, D.R.J. Owen, John Wiley & Sons, 2008.
7. *Practical Multiscaling,* J. Fish, John Wiley & Sons, 2013.

COURSE DESCRIPTION
A fluid infiltrating porous solid is a multiphase material whose mechanical behavior is significantly influenced by the pore fluid. In particular, the diffusion, advection, capillarity, heating, cooling and freezing of pore fluid, the build-up of pore pressure and the mass exchanges among the solid and fluid constituents may all influence the stability and integrity of the solid skeleton, cause shrinkage, swelling, fracture or liquefaction. These coupling phenomena are important for numerous disciplines, including but not limited to geophysics, biomechanics, and material sciences. The objective of this course is to present the fundamental principles of poromechanics that are essential for engineering practice and to prepare students for more advanced study on porous media.

We will cover a selected number of topics, including but not limited to balance principles, Biot's poroelasticity, mixture theory, constitutive modeling of path independent and dependent multiphase materials, numerical methods for parabolic and hyperbolic systems, inf-sup conditions and common stabilization procedures for mixed finite element models, explicit and implicit time integrators, and operator splitting techniques for poromechanics problems.

PREREQUISITES
Required: ENME E3332x or equivalent course(s).

COURSE LEARNING OBJECTIVES
Students who successfully complete this course will be able to:

- Develop a basic understanding of the engineering properties of porous media.
- Learn and apply basic mathematical and computational techniques to model the transient responses of saturated and unsaturated porous media.
- Master the essential skills to interpret experiential data.

ASSESSMENT AND GRADING POLICY

Student grades will be based on:

Mid-term 30%

Final Project.. 70%

COURSE OUTLINE

- **Introduction (1 week)**
  - Historical background
  - Basic definition
  - Volume fraction concept
  - Pore, grain and continuum scales
- **Flow in porous media (1 week)**
  - General conservation laws
  - Constitutive assumptions for fluid in pore space
  - Darcy's law
  - Unsaturated flow; surface tension.
- **Finite Element Formulation for Fluid Diffusion (3 weeks)**
  - Strong and weak form
  - Galerkin approximation
  - Solution of elliptic and parabolic systems
  - Stabilization procedures
  - Generalized trapezoidal family of methods
  - Convection and bifurcations in rigid porous media.
- **Finite Element Formulation for Solid Deformation (3 weeks)**
  - General conservation principles
  - Constitutive assumptions for porous solid
  - Hookean and non-Hookean materials
  - Objectivity and hyper-elasticity
  - Galerkin approximation and matrix problem
  - Poro-plasticity
  - Solutions of nonlinear systems
- **Hydro-mechanical Properties of Porous Media (3weeks)**
  - Effective stress theory
  - Mixed variational principles
  - Incompressibility constraint
  - Lagrange multipliers and penalty methods
  - Inf-sup conditions
  - Stabilized finite element procedures
  - Staggered and monolithic solvers

- **Advanced Topics on Mutliscale Simulations for Porous Media (3 weeks)**
  - Discrete element method
  - Lattice Boltzmann simulation
  - Coupled lattice Boltzmann-finite element simulations
  - Applications of graph theory on porous media

EXAMINATION AND FINAL PROJECT

One mid-term exam, which weighs 30% of the total grades will be given. 70% of the total grades will be based on the final project. Students will develop their final projects based on their own research interest and discipline. A presentation session will be scheduled for each student to present the findings at the end of the semester.

HOMEWORK

One homework assignment will be set (approximately) every three weeks. The homework will not be graded.

POLICIES AND EXPECTATIONS

Academic Integrity

Students are required to adhere to the Codes of Conduct, Community Standard and Academic Integrity, available online at http://apam.columbia.edu/files/seasdepts/applied-physics-and-applied-math/pdf-files/SEAS_conduct.pdf

Disability Access

In order to receive disability-related academic accommodations, students must first be registered with the Office of Disability Services (ODS). Students who have, or think they may have a disability are invited to contact ODS for a confidential discussion at 212.854.2388 (V) 212.854.2378 (TTY), or by email at disability@columbia.edu. If you have already registered with ODS, please speak to your instructor to ensure that s/he has been notified of your recommended accommodations by Lillian Morales (lm31@columbia.edu), the School's liaison to the Office of Disability Services.