

## COMPUTATIONAL GEOMECHANICS (GeoEE 557) Fall 2006

- Instructor:** Derek Elsworth (w) 865-2225 [elsworth@psu.edu](mailto:elsworth@psu.edu)
- Content:** Modeling deformation, flow and transport using finite element, finite difference, and boundary element methods. Coupled processes of flow, deformation, and heat, mass and reactive transport.
- Objectives:** To gain an appreciation of numerical methods through exposure to finite element, finite difference, and boundary element codes. The course is designed for potential users and developers of domain and integral numerical methods that are ubiquitously applied in hydrology and atmospheric sciences; mining, civil, mechanical and petroleum engineering; and the geologic and materials sciences.
- Prerequisites:** Matrix algebra, elementary calculus, elementary programming in MatLab
- Location:** T-Th 4:40-5:30; 25 Deike (3 credits)

### 1. Overview of Coupled Processes

- 1.1. Uncoupled systems
- 1.2. Coupled processes – Thermo-Hydro-Mechanical-Chemical (**T-H-M-C**)
- 1.3. Balances of Mass, Momentum and Energy
- 1.4. Interaction and Onsager Processes
- 1.5. Building representative systems – incorporating couplings
- 1.6. Preliminary examples of THM processes
- 1.7. Key couplings
- 1.8. Dependent variables – their selection and modes of coupling

### 2. Mechanical Behavior (M)

#### Deformation

- 2.1. Conservation of momentum and Hooke's law
  - 2.1.1. Principle of virtual work
- 2.2. Finite element representation
  - 2.2.1. 1-dimensional elements
  - 2.2.2. 2-dimensional behavior
    - 2.2.2.1. CST elements
    - 2.2.2.2. Isoparametric elements
- 2.3. Variational procedures

### 3. Hydraulic Behavior (H)

#### Flow

- 3.1. Conservation of mass and Darcy's law
- 3.2. Steady behavior
  - 3.2.1. 1-dimensional elements
  - 3.2.2. 2-dimensional behavior – 2-D triangular, and 2-D isoparametric elements
- 3.3. Transient behavior
  - 3.3.1. Time stepping methods
- 3.4. Dual porosity flows

### 4. Hydro-Mechanical Coupling (H-M)

- 4.1. Stiffness and conductance terms
- 4.2. Coupling terms and symmetry
- 4.3. Time stepping
- 4.4. 1-dimensional examples
- 4.5. Dual porosity behavior

<b>5. Mass (Chemical) Transport (C)</b>	<b>Transport</b>
5.1. Conservation of mass and Fick's law	
5.2. Steady behavior	
<b>5.3. Transient behavior</b>	
<b>5.4. Considerations of local equilibrium</b>	
<b>6. Hydro-Mechanical-Chemical Coupling (H-M-C)</b>	
6.1. Stiffness, conductance and advective terms	
<b>6.2. Coupling terms and symmetries</b>	
<b>7. Thermal Transport (T)</b>	<b>Transport</b>
7.1. Conservation of Energy and Fourier's law	
7.2. Steady behavior	
7.3. Transient behavior	
<b>8. Thermo-Hydro-Mechanical Coupling (T-H-M)</b>	
8.1. Stiffness, conductance and advective terms	
8.2. Coupling terms and symmetry	
8.3. Time stepping	
8.4. 1-dimensional examples	
<b>9. Thermo-Hydro-Mechanical-Chemical Coupling (T-H-M-C)</b>	
9.1. Stiffness, conductance and advective terms	
9.2. Coupling terms and symmetries	
<b>10. Summary Behaviors</b>	
<b>11. Boundary Element Methods – Introduction</b>	
11.1. Indirect method – General principles	
11.1.1. Groundwater mechanics	
11.1.2. Elasticity	
11.2. Direct Method – General principles	
11.2.1. Groundwater mechanics	
11.2.2. Elasticity	
11.3. Coupled FEM-BEM analysis	
<b>12. Overview and Summary</b>	

Selected texts on reserve in the EMS library.  
Lecture Overheads and Course Notes available online.

Grading:           40%    Mid-term exam  
                  60%    Final project

**Academic Conduct:** Penn State's policy on academic integrity applies to all aspects of course deliverables. Students are encouraged to work together, in groups, but to submit independent work. Further details are available at: <http://www.ems.psu.edu/students/integrity/index.html>