COMPUTATIONAL GEOMECHANICS (GeoEE 557)

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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 4:40-5:55; 218 Hosler (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

5. Mass (Chemical) Transport (C)	**Transport**

5.1. Conservation of mass and Fick's law
5.2. Steady behavior
5.3. Transient behavior
5.4. Considerations of local equilibrium

6. Hydro-Mechanical-Chemical Coupling (H-M-C)
6.1. Stiffness, conductance and advective terms
6.2. Coupling terms and symmetries

7. Thermal Transport (T)	**Transport**

7.1. Conservation of Energy and Fourier's law
7.2. Steady behavior
7.3. Transient behavior

8. Thermo-Hydro-Mechanical Coupling (T-H-M)
8.1. Stiffness, conductance and advective terms
8.2. Coupling terms and symmetry
8.3. Time stepping
8.4. 1-dimensional examples

9. Thermo-Hydro-Mechanical-Chemical Coupling (T-H-M-C)
9.1. Stiffness, conductance and advective terms
9.2. Coupling terms and symmetries

10. Summary Behaviors

11. Boundary Element Methods – Introduction
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

12. Overview and Summary

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

Grading:	20%	Participation
	80%	Final project

TITLE	ACTIVITY	DELIVERABLE	%	DUE
Tentative Topic	Assign/Select Problem	Oral report	-	J 21
1. Introduction & 6. References	Research topic and complete and report literature review	One page narrative and at least 20 references	10%	J 29
2.1 Governing Equations	Define conservation equations, constitutive relations, and boundary and initial conditions	One page max plus figures	10%	F 12
2.2 Formulation	Formulate model	One page max plus figures	10%	F 26
2.3 Solution	Solve using model	One page max plus figures	10%	M 19
3. Validation	Validate	One page max plus figures	10%	A 2
4. Parametric Study	Complete parametric study	One page max plus figures	10%	A 9
5. Conclusions	Distill significant results	One page max plus figures	10%	
0. Abstract and 10 min Presentation	Complete paper and present results	10 minute presentation with one slide for each of 1; 2.1; 2.2; 2.3; 3; 4; 5 (seven slides)	30%	A 22

A**cademic 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