Tunneling and Mining: Mechanics and Engineering
Georgia Institute Of Technology

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Office Hours: Tu & Th 9.30am-10.30am
or by appointment

Tunneling and Mining: Mechanics and Engineering - Fall 2014

Meeting Times: Tuesday & Thursday, 8.05am-9.25am
Classroom: Mason 3132

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

Scope of the course: The course focuses on the fundamental principles of tunnel and underground mining design. Background lectures will review basic rock physics and mechanics, fracture characterization, fluid flow in porous media and fracture networks. Design issues will include: site geology and tunnel alignment, excavation plans, support techniques, drainage systems, long-term behavior. Applications will include the prediction of settlements and subsidence, and design strategies for energy geotechnologies, e.g., heat and fluid extraction, mine excavations, Compressed Air Energy Storage (CAES), long-term nuclear waste storage.

Learning Objectives:

1. Design a laboratory test plan to determine rock physical and mechanical properties
2. Calculate stresses around cavities and excavations
3. Calculate the displacements at a tunnel wall, in the short and long terms
4. Recommend excavation support and drainage systems
5. Design an excavation plan
6. Simulate rock deformation and damage with Finite Element Methods
7. Predict the response of rock to Thermo-Hydro-Mechanical coupled stresses around cavities used for energy and waste storage

Outline & Schedule (tentative – subject to minor changes)

1. **How do excavations disturb the stress field in elastic rock?** [Week 1-3, Homework 1]
    - 1.1. Determination of rock in situ stress
      Strain rosette, flat jack, hydraulic fracturing, borehole breakout
    - 1.2. Underground excavations
    - 1.3. Analytical solutions of stress distribution in elasticity
      Plane strain analysis of circular excavations, complex variable method, Kirsch equations, Leeman & Hayes's solution for stress distributions around cavities subject to 3D stress
    - 1.4. Application to stress prediction in geological conditions
      Zone of influence of an excavation, effect of planes of weakness, optimal shape of an excavation, zone of fracture initiation and damage, zone of rock failure and spalling

2. **How to design mining supports to avoid failure?** [Weeks 4-6, Homework 2-3]
    - 2.1. Laboratory characterization of rock deformation and strength
    - 2.2. Failure criteria in rock mechanics
    - 2.3. Tunneling: convergence-confinement method
    - 2.4. Mining: design of reinforcements and supports
      Pillars, backfill

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3. **How to design a mine?** [Week 7, Mid-term exam, Design projects assigned]
    3.1. Excavation techniques
    Stopping and caving techniques, room-and-pillar and longwall mining
    3.2. Construction planning
    3.3. Monitoring

4. **Why are fractures controlling the rock mass?** [Week 8-10, Homework 4]
    4.1. Rock discontinuities
    Scales of rock discontinuities, stereographic projection
    4.2. Excavation design in stratified rock
    4.3. Excavation design in blocky rock
    4.4. Mining subsidence
    Troughs, discontinuous subsidence, crown holes, pillar collapse, chimney caving

5. **Fluid flow in rock** [Week 11-13, Homework 5, Design project collected, Research project assigned]
    5.1. Porosity-permeability relationships
    5.2. Flow in fractured porous media
    Double porosity, fractures/matrix interactions, double-permeability models
    5.3. Implications and applications for mining design
    Drainage systems

6. **Rock thermo-poro-elasticity** [Week 14-16, Research project collected]
    6.1. Biot's poro-elastic theory
    6.2. Thermo-poro-elasticity
    6.3. Application to the design of geological and engineering barriers

Course Assessment:

Five individual homeworks will include calculus, analysis and design. ***One mid-term exam*** will test the ability of students to do rapid hand calculations and make design recommendations based on basic rock mechanics and engineering principles. Students will work on a ***design project*** for six weeks, in groups of two. Then students will complete an individual ***research project*** in three weeks.

Possible design projects:
- Tunnel stability: time-dependent behavior (creep), drainage systems, bolt reinforcements…
- Mining design: exploitation and closure of a mine, subsidence…
- Urban planning: zone of influence of excavations, multi-usage tunnels…
- Maintenance, restoration and adaptation of existing underground structures: serviceability, risks…
- Underground storage: cyclic loading of abandoned salt mines for Compressed Air energy Storage (CAES), oil and gas storage…

The design report shall contain a presentation of the geological and engineering constraints of the project; a presentation of several engineering options to meet the requirements, supported by hand computations; a Finite Element analysis for at least two of these options; interpretations of potential numerical errors; conclusions and recommendations for the design and construction of the geotechnical structure. Computation and programming tools used for the project shall include at least one of the following: MATLAB, PLAXIS, COMSOL, ABAQUS, ANSYS, Fortran.

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Possible research projects:

- Cyclic loading of salt caverns: CAES, oil and gas storage…
- Nuclear waste storage: long-term thermo-hydro-mechanical rock behavior, excavation damaged zone
- Geothermal boreholes
- Carbon dioxide sequestration

Students will prepare a presentation and a short paper to explain a research question related to energy geotechnology, state the geological and design constrains at stake, review 5-7 publications (e.g. academic journal papers, technical reports, press articles), analyze models proposed by other authors from hand calculations and/or FEM simulations, and highlight potential research areas.

Recommended references:

For rock engineering design:

- B.H.G. Bradi, E.T. Brown. *Rock Mechanics for Underground Mining, third edition*. Springer, 2004.

…with examples from:

- J.A. Hudson, J.P. Harrison. Engineering Rock Mechanics, An Introduction to the Principles. Pergamon, 1997.
- W.G. Pariseau. *Design Analysis in Rock Mechanics*. Taylor & Francis, 2007.

For general rock mechanics:

- E. Hoek, *Practical Rock Engineering*, e-notes, 2007 http://www.rocscience.com/education/hoeks_corner
- J.C. Jaeger, N.G.W. Cook, R.W. Zimmerman. *Fundamentals of rock Mechanics, fourth edition*. Blackwell Publishing, 2007.

For fluid flow and poromechanics:

- O. Coussy, *Mechanics and Physics of Porous Solids*, Wiley, 2010.
- Y. Guéguen, V. Palciauskas. *Introduction to the Physics of Rocks*, Princeton University Press, 1994.

In all chapters, selected original research papers will be studied and posted on the course website.

Grading: *Final grade*: F<60%≤D<70%≤C<80%≤B<90%≤A≤100%
Score: 5 homeworks @ 8% each: 40%. Mid-term exam: 20%. 2 projects @ 20% each: 40%.

Academic Honor Code: Projects are group assignments, but homeworks are individual. Working in group on homework 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.