Engineering Design

Engineering design is defined as a creative, iterative and open-ended process, subject to constraints imposed through legislative codes, project economics, health, safety, environmental and societal considerations.
Engineering Design & Problem Uncertainty

Geotechnical engineers routinely deal with natural conditions that are largely unknown and must be inferred from limited and costly observations. Yet, many of the design tools used are borrowed from other engineering disciplines where the accuracy and completeness of the problem conditions are significantly different.

Structural engineering is largely deductive: we start from reasonably well known conditions, where models are employed to deduce the behavior of a reasonably well-specified problem.

In contrast, geological/geotechnical engineering is both deductive and inductive: we start from limited observations, and use judgment, experience, knowledge of geology and statistical reasoning to infer the behavior of a poorly-defined universe.

Complexity & Uncertainty

Discuss: What types of design uncertainty do you think are typically encountered on large engineering projects, for example the design of a large open pit mine?
Complexity & Uncertainty

Geological Uncertainty: represents the unpredictability associated with the identification, characterization and interpretation of the site geology and hydrogeology.

Parameter Uncertainty: concerned with spatial variations and the lack of data for key parameters.

Model Uncertainty: arises from gaps in the scientific theory that is required to make predictions on the basis of causal inference.

Human Uncertainty: ranges from subjectivity and measurement error to differing professional opinions.

Prediction competition - collapse height of slope in soft clay. A substantial amount of shear strength data was provided to the 31 participants.

Design & Geological Uncertainty

Palabora (South Africa)
Classification = block cave copper mine
History = transition to underground mining following completion of open pit
Production = 30,000 tons/day
Ore grade = 0.7% Cu

Moss et al. (2006)
www.resolutioncopper.com

Resolution Deposit
Geological Cross Section
Mined, Argillite Deposits Lead to Copper Culture

Resolution (Arizona)
Reserves = 1.624 billion tonnes (inferred)
Grade = 1.47 % Cu
Development cost = $6 Billion
Start of Production = 2020 (est.)
**Complexity & Uncertainty**

What makes Geological Engineering unique is the **complexity and uncertainty** involved when interacting with the natural geological environment.

Often, field data (e.g. geology, geological structure, rock mass properties, groundwater, etc.) is limited to surface observations and/or limited by inaccessibility, and can never be known completely.

Rock masses are **complex systems**!
Data collection provides us with a means to manage uncertainty, but not to eliminate it!

Hoek (1991)

Parameter Uncertainty

Mean shear strength

Mean driving stress

Operations (Performance)
Observed/Monitored/Back-Analyzed

Feasibility (Investigated)
Quantitative/Measured

Pre-Feasibility (Inferred)
Qualitative/Empirical

Model Uncertainty ...
hammer, meet nail
Rock Mass Properties - Behaviour

Granite

Rock Mass Properties - Behaviour

Granite
Rock Mass Behaviour - High Stresses

Weak rock under high stresses may lead to squeezing ground conditions, which may result in damage/failure to the ground support system, or require the costly re-excavation of the tunnel section.

In strong brittle rock, high stress conditions may lead to rockbursting (the sudden release of stored strain energy). Bursts manifest themselves through the sudden ejection of rock into the excavation.
Course Overview & Learning Goals

This course will examine different principles, approaches, and tools used in geotechnical design. The examples and case histories reviewed will focus primarily on rock engineering problems, although many of the analytical, empirical and numerical techniques reviewed are also used in other areas of geological/geotechnical engineering.

Course Overview & Learning Goals

Through this course, you will develop an awareness of the different design methodologies and tools available to practicing geological engineers. More importantly, you will learn how to approach problem solving in the context of geological complexity and uncertainty. Emphasis will be placed on the importance of using design tools to aid in the thought and decision making process, as opposed to relying on them for outright predictions.
# Course Learning Goals

By the end of this course you will be able to:

1) Explain the essential methods of Geological Engineering design and practice, including the integration of site characterization, monitoring and analysis, hazard and risk assessment, and professional issues such as loss control, worker safety and professional ethics.

2) Recognize and differentiate the adverse effects that geology and geological processes can have on site conditions and engineering designs, and that engineering designs can have on the site conditions and natural environment.

3) Assess the limitations of “textbook approaches” to Geological Engineering design and means to manage uncertainty and reduce risk related to geological variability and uncertainty.

4) Compare and contrast different analytical, empirical and numerical tools used in geotechnical design, and demonstrate how these should not be used as a substitute for thinking but as an aid to the engineering thought and decision making process.

5) Justify design assumptions and level of detail in design calculations relative to the project stage (from prefeasibility through to construction, implementation and performance), and update accordingly through iterative design as new data and knowledge is gained.

6) Compare and contrast examples of true life Geological Engineering design problems, solutions implemented and lessons learned, and argue the value of case histories and need for lifelong learning and professional development for Geological Engineers.
Course Webpage

EOSC 433 - Geotechnical Engineering Practice
(1017/18 Course Material - PDF Downloads)

Course Outline

Week 1: Introduction
- coarse overview; rock as an engineering material; design methodologies.

Lab 1 - Problem set #1

Week 2: New Tools for Data Collection
- data quality and confidence; remote sensing tools for discontinuity mapping.

Lab 2 - Problem set #2

Week 3: Observational Approach
- phenomenological vs mechanistic approaches; Terzaghi's observation method; use of monitoring data in design.

Lab 3 - Lab Introduction to Design Process

Week 4: Kinematic Analysis
- structurally controlled failure; wedge volume calculations; key block theory.

Lab 4 - UNWEDGE exercise & Design Problem #1

https://www.eoas.ubc.ca/courses/eosc433/lecture-material/eosc433-downloads.htm
## Course Outline

### Week 5: Empirical Design
- derivation and application; rock mass classification vs. characterization; GSI.

### Lab 5 - Problem Set #3

### Week 6: No Lecture
- Design problem work session.

### Lab - No lab. Design problem drop-in.

### Week 7: Limit Equilibrium Analysis
- factor of safety; back & forward analysis; probabilistic analysis.

### Lab 6 - SLIDE/LEM exercise & Design Problem #2

### Week 8: In Situ Stress
- stress as a boundary condition; direct vs. indirect measurement methods.

### Lab 7 - Design Problem Peer Review.

### Week 9: Stress Analysis
- Kirsch equations; boundary-element method.

### Lab 8 - EXAM2D/BEM exercise & Design Problem #3

### Week 10: Rock Stabilization Principles
- support vs. reinforcement strategies; ground response curves; support interaction curves.

### Lab 9 - RocSupport exercise.

### Week 11: Analysis of Yielding Rock
- constitutive behaviour; failure criterion; elasto-plastic yield; finite-element analysis.

### Lab 10 - RS2/FEM exercise and Design Problem #4.

### Week 12: Analysis of Jointed Rock
- joint stiffness & strength; scale-effects; distinct-element analysis.

### Lab 11 - UDEC/DEM exercise.

### Week 13: Stress-Controlled Failure
- brittle fracture processes; spalling; rock bursting.

### Lab - No lab.
General Information

Lectures: Thursdays from 13:00 to 15:00 (ESB 2012)

Labs: L2A-Fridays from 14:00 to 16:00 (EOS-M 203)
L2B-Thursdays from 16:00 to 18:00 (EOS-M 203)

TA's: Afshin Amini (aamini@eoas.ubc.ca)

Grades:
- problem sets (2) 10%
- lab assignments (best 5 of 6) 10%
- open-ended design problems (4) 30%
- final exam 50%

Contact Info
- Office: 251 EOS South
- E-mail: erik@eoas.ubc.ca

Course Web Page - /eoas.ubc.ca/courses/eosc433/eosc433.htm

Text Book
- The textbook (optional) to be used for this course is:

... or another option that isn't as mining-oriented:


Lecture Notes
- PDF's of these Powerpoint slides will be made available for download via the course web page.
Influence of Geological Factors

In the context of the mechanics problem, we should consider the material and the forces involved. As such, five primary geological factors can be viewed as influencing a rock mass.

- We have the intact rock which is itself divided by discontinuities to form the rock mass structure.
- We find then the rock is already subjected to an \textit{in situ} stress.
- Superimposed on this are the influence of pore fluid/water flow and time.

With all these factors, the geological history has played its part, altering the rock and the applied forces.
Uncertainty & Variability

Aleatory (Natural variability)
- Temporal
  - e.g. Groundwater level
- Spatial
  - e.g. Joint strength

Epistemic (Knowledge uncertainty)
- Site characterisation
  - e.g. Sampling
- Model
  - e.g. Strength criterion
- Parameter
  - e.g. Empirical inputs

Site Investigation & Data Collection

Geological investigations
Geophysical investigations
geological model
Rockmass processes
Integrated Risk Assessment

Düzgün & Lacasse (2005)

- Geology
- Geometry
- Strength
- Groundwater
- Dynamic loads
- Elements at Risk

Site Investigation & Data Collection

Rockmass processes

Failure kinematics

Geotechnical monitoring

Stability analysis

Controlling mechanism(s)

Willenberg et al. (2008)
Successful engineering design involves a design process, which is a sequence of events within which design develops logically. Bieniawski (1993) summarized a 10 step methodology for rock engineering design problems, incorporating 6 design principles:

1. Statement of the problem (performance objectives)  
2. Functional requirements and constraints (design variables and design issues)  
3. Collection of information (geological characterization, rock mass properties, ground water, in situ stresses, etc.)  
4. Concept formulation (geotechnical model)  
5. Analysis of solution components (e.g. numerical, empirical, observational methods)  
6. Synthesis and specifications for alternative solutions (shapes, sizes, locations, orientations of excavations)  
7. Evaluation (performance assessment)  
8. Optimization (performance assessment)  
9. Recommendation  
10. Implementation (efficient execution, and monitoring)

Design Principle 1: Clarity of design objectives and functional requirements.

Design Principle 2: Minimum uncertainty of geological conditions.

Design Principle 3: Simplicity of design components (e.g. geotechnical model).
Step 5: Analysis of solution components

- Observational, analytical, empirical, numerical methods

Step 6: Synthesis and specification for alternative solutions

- Shapes and sizes of excavations
- Rock reinforcement options and associated safety factors

Step 7: Evaluation

- Performance assessment
- Consideration of non-rock engineering aspects (ventilation, power supply, etc.)

Step 8: Optimization

- Analysis of solution components

Step 9: Recommendation

- Lessons learned
- Feasibility study
- Preliminary & final designs

Step 10: Implementation

- Efficient excavation and monitoring

Design Principle 3: Simplicity of design components.

Design Principle 4: State of the art practice.

Design Principle 5: Optimization of design (through evaluation of analysis results, monitoring, etc.).

Design Principle 6: Constructability (can the design be implemented safely and efficiently).

Engineering Judgement

Palmström & Stille (2007)
Lecture References


