Ben-Gurion University of the Negev
Faculty of Natural Sciences
Department of Geological and Environmental Sciences

Reservoir Rock Mechanics

Course No.: 206-2-3921
Place and Time:
Lecture: Bldg. C58, Room 018, Tuesday 12:00 – 14:00.
Exercise: Bldg. C58, Room 018, Tuesday 14:00 – 15:00
Instructor: Prof. Yossi Hatzor. Office hours: Bldg. C58, Room 019. Sunday 14:00 – 15:00
Teaching Assistants and office hours:
Omri Shitrit: Bldg. 60, room 08, Sunday 10:00-12:00
Yair Gordin: Bldg. 60, room 08, Monday 10:00-12:00

Course Outline

Lecture No. 1: 2018-3-6 – Introduction

- Useful index properties of rocks and their determination
  - Phase relationships and definitions
  - Porosity
  - Permeability
  - Thermal Conductivity
  - Sound velocity
  - Point load compressive strength
  - Brazilian tensile strength
  - Schmidt hammer test
  - Slake durability test
  - Rock strength determination from scratch test

Further reading: Goodman R. E., 1989. *Introduction to Rock Mechanics*. Wiley. Chapters 1,2. TA - **Yair Gordin**.

Lecture No. 2: 2018-3-13 – Stress Analysis in two dimensions

- Definition of traction and stress
- The stress tensor
- Analysis of stress in two dimensions
- Graphical representation of stress in two dimensions

Further reading: Jaeger, Cook, and Zimmerman, 2007. *Fundamentals of Rock Mechanics*. Blackwell Publishing. Chapter 2. T.A: **Yair Gordin**.

Lecture No. 3: 2018-3-20 – Stress Analysis in three dimensions

- Stresses in three dimensions
- Stress transformations in three dimensions

- Principal stresses and stress invariants
- Mohr's representation of stress in three dimensions

Further reading: Jaeger, Cook, and Zimmerman, 2007. *Fundamentals of Rock Mechanics*. Blackwell Publishing. Chapter 2. T.A: **Yair Gordin.**

Lecture No. 4: 2018-3-27 – Strain Analysis

- Displacement and strain
- Infinitesimal strain in two dimensions
- Infinitesimal strain in three dimensions
- Determination of principal stresses or strains from measurements

Further reading: Jaeger, Cook, and Zimmerman, 2007. *Fundamentals of Rock Mechanics*. Blackwell Publishing. Chapter 2. T.A: **Yair Gordin.**

2018-4-3 - *Pesach break* ☺

Lecture No. 5: 2018-04-10 – Linear elasticity

- Stress-strain relations for an isotropic linear elastic solid
- Special cases
    - Uniaxial compression
    - Hydrostatic compression
    - Uniaxial strain
    - Pure shear
    - Plane stress
    - Plane strain
- Stress-strain relations for anisotropic materials
- Elastic moduli and seismic wave velocity

Further reading: Jaeger, Cook, and Zimmerman, 2007. *Fundamentals of Rock Mechanics*. Blackwell Publishing. Chapter 5. Zoback, M. D. 2010. *Reservoir Geomechanics.* Cambridge. Chapter 3. T.A: **Yair Gordin.**

Lecture No. 6: 2018-04-17 – Friction on rock surfaces

- Amonton's Law
- The contribution of asperity inclination
- Testing methods of rock discontinuities
- Ideal and real force displacement curves
- Stick slip oscillations
- Water pressures in the joints
- Failure of intact rock due to pore pressures
- Fault slip due to pore pressure

Further reading: Jaeger, Cook, and Zimmerman, 2007. *Fundamentals of Rock Mechanics*. Blackwell Publishing. Chapter 3. T.A: **Yair Gordin.**

Midterm Exam: Tuesday, 2018-04-24, 12:00-15:00, Room 018, Bldg. 58, on lectures 1-5.

Lecture No. 7: 2018-05-01 – Deformation and failure of rocks

- Sliding on a plane of weakness – theory in two dimensions
  - Influence of joint orientation
  - Effect of confining pressure
- The stress – strain curve
  - Rock deformation under non deviatoric compression
  - Rock deformation under deviatoric compression
- Temperature effect and brittle ductile transition
- Scale effects
- The Coulomb failure criterion
- Mohr's hypothesis
- Failure under true triaxial conditions
- The effect of anisotropy in strength
- Creep

Further reading: Jaeger, Cook, and Zimmerman, 2007. *Fundamentals of Rock Mechanics*. Blackwell Publishing. Chapter 4, 9. Goodman R. E., 1989. *Introduction to Rock Mechanics*. Wiley. Chapter 3. T.A: **Omri Shitrit.**

Lecture No. 8: 2018-05-8 – Laboratory testing of rocks

- Modes of failure in rocks
  - Shear failure
  - Compressive failure
  - Tensile failure
- Laboratory tests designed to emulate field conditions
  - Hydrostatic tests
  - Uniaxial compression
  - Triaxial tests
    - Strain softening behavior
    - The machine – rock system
  - True triaxial tests
  - Diametral compression of cylinders (Brazilian)
  - Torsion of circular cylinders (time permitting)
  - Bending tests (time permitting)
  - Hollow cylinders (time permitting)

Further reading: Jaeger, Cook, and Zimmerman, 2007. *Fundamentals of Rock Mechanics*. Blackwell Publishing. Chapter 6. Goodman R. E., 1989. *Introduction to Rock Mechanics*. Wiley. Chapter 3. T.A: **Omri Shitrit.**

Lecture No. 9: 2018-05-15 – Introduction to Poroelasticity

- Introduction

- Hydrostatic Poroelasticity
- Bulk and pore compressibility
- Bulk and pore strain
- Undrained compression
- Undrained bulk compressibility
- Skempton coefficient
- Undrained pore compressibility
- Poroelasticity and effective stress
- Measuring the first Biot parameter in the lab
- Measuring Skempton coefficient in the lab

Jaeger, Cook, and Zimmerman, 2007. *Fundamentals of Rock Mechanics*. Blackwell Publishing. Chapter 7.
Further reading: Zoback, M. D. 2010. *Reservoir Geomechanics.* Cambridge. Chapter 3. T.A: **Omri Shitrit**

Lecture No. 10: 2015-05-22 – Initial stresses in reservoirs

- Introduction
    - Empirical estimates of in *situ stress*
    - The vertical stress in offshore areas
    - Erosion effect on horizontal stress magnitude
    - Upper and lower limits of horizontal stress
    - Topographic effects on stress magnitude and orientation
    - Structural effects on vertical stress magnitude
- Relative stress magnitude and E. M. Anderson's classification scheme
- Overpressure in reservoirs
    - Reservoir Compartmentalization
    - Mechanisms of overpressure generation
    - Estimating pore pressure at depth
- Estimating *in situ* stress from geological indicators
- World stress map

Further reading: Zoback, M. D. 2010. *Reservoir Geomechanics.* Cambridge. Chapters 1, 2. Goodman 1989. *Introduction to rock mechanics*. Chapter 4. T.A: **Omri Shitrit.**

Lecture No. 11: 2015-05-29 – Estimates of *in situ* stress – borehole breakouts

- Well bore imaging
    - Ultrasonic borehole televiewer (BHTV)
    - Electrical imaging devices
- Stress concentration around a cylindrical hole
- Kirsch solution
- Kirsch solution in terms of effective stresses
- Zone of compressive wellbore failure
- Borehole Breakouts
- Drilling induced tensile fractures

- Estimating stress orientation from drilling induced tensile fractures
- Determination of breakout orientation from caliper logs

Further reading: Zoback, M. D. 2010. *Reservoir Geomechanics.* Cambridge. Chapters 5,6. T.A: **Omri Shitrit.**

Lecture No. 12: 2018-06-05 – The hydraulic fracturing, flat jack, and over-coring methods

- The hydraulic fracturing method
  - historical perspective
  - scope
  - Test setup in the field
  - Real and ideal HF output data
  - Data interpretation
  - Accounting for pore pressure
- Alternative methods to obtain S_{hmin} during routine drilling operations
  - Extended leak off tests
  - Minifrac tests
  - Step rate tests
  - Wellbore failure and determination of S_{Hmax}
- The flat jack method
- The over-coring method

Further reading: Zoback, M. D. 2010. *Reservoir Geomechanics.* Cambridge. Chapter 7. Goodman 1989. *Introduction to rock mechanics*. Chapter 4. Amadei B. and O. Stephansson 1997. *Rock stress and its measurements.* Chapman & Hall. T.A: **Omri Shitrit.**

Lecture No. 13: 2018-06-12 – Current issues in reservoir rock mechanics

- Reservoir depletion
- Boundaries on in-situ stress around reservoirs
- Geomechanics of Shale gas

Preparation for exam: 2018-06-17. 16:00 – 18:00 (room will be announced).

Final exam: Tuesday June 19, 2018. Bldg. 32 Room 307, Time 12:00 – 15:00.

Rules of the Game

- Class attendance is not mandatory, but highly recommended…
- 10 homework assignments must be submitted one week after they are assigned
- Homework assignments will be checked but will not be graded.
- Final grade structure:
  - HW assignments 10%
  - Midterm 20%
  - Final exam 70%

Enjoy!