Strength and stability of fractured rocks:

Experiment and modeling towards field scale applications

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Outline

- Why strength and stability of rocks are important?
- Field problems
- Explanation and research targets
- Experiment and analysis
- Discrete element model simulation
- Prediction of collapse point
- Conclusion
Oil & Gas production (EOR/EGR)
Underground CO\textsubscript{2} storage
Geothermal energy production
Problems: Field cases

- Mud-loss events during drilling
- Borehole collapse
- Leakage in gas-wells
- A lot of activities (micro-seismic) - far from injection well (CO$_2$ storage, US)
- Field permeability is much higher (10 times or more) than estimated value (lab test + theory)
o How and when fracture opens up?

o How important is porosity level?

o What is the role of pre-existing fractures/faults?

o How can we characterize a fracture network inside rocks?

o Can we calculate fracture propagation velocity?

o Can we assess leakage possibility?

o How can we predict the collapse point?
Experiments: Fracturing by fluid injection

- Steel piston
- Acoustic transducer
- Sintered plate
- Sleeve
- Axial strain LVDT
- Pore pressure (fluid flow)

Graph showing changes over time with markers for confining stress, borehole stress, pore displacement, and radial deformation.
AE events during fracturing test
AE event locations
AE analysis near fracturing point

DEM: Fracturing by fluid injection

Idea: Invasion percolation + distance dependent $K$

Inputs: Tensile strength dist., breaking criteria, porosity, sample size, borehole pressure
DEM: Less brittle rocks

Porosity = 0

Porosity = 30%

Pre-existing fractures

1 Fracture

5 Fractures
DEM: Possible studies

➢ Properties of the fracture path - roughness, fractal dimen.

➢ Sample-size/hole-size effect

➢ Effect of pre-existing fractures in the sample

➢ Temperature effect

➢ Effect of mineralogy on fracture pattern & growth

➢ Anisotropic stress situations

➢ Fracture propagation velocity in different rocks

➢ 3D modelling
Fiber bundle model (FBM)

- First used in textile engineering (Peirce, 1926)
- Statistical analysis (Daniels, 1945)
- Different load-sharing rules:
  - ELS, LLS, mixed-mode, hierarchical
Static: Force-displacement

\[ F(x) = N[1 - P(x)]\kappa.x \]

\[ P(y) = \int_{0}^{y} p(x)dx \]

\[ \sigma = \frac{F(x)}{N} = [1 - P(x)]\kappa.x \]
Energy Budget: Signal of upcoming failure

\[ E^e(\Delta) = \frac{Nk}{2} \Delta^2 (1-P(\Delta)) \]

\[ E^d(\Delta) = \frac{Nk}{2} \int_0^\Delta x^2 p(x)dx \]
Energy Budget: Signal of upcoming failure

\[ \frac{dE^e}{d\Delta} \] has a maximum in the stable phase

Conclusions

➢ Fluid injection can trigger rock-fracturing

➢ Induced fracture can reactivate existing fractures/faults

➢ We need better understanding of the dynamics of fracture opening and propagation

➢ Fractures are fatal for borehole stability

➢ EOR/EGR operations need more fractures (controlled ?)

➢ Fractures are safety issues (leakage) for CO₂ storage but they can help things by enhancing CO₂ absorption rate

➢ Geothermal energy production needs better flow channels – perhaps by controlled fracturing

➢ Research Challenges: 1) Strength and stability analysis including prediction of collapse point

2) Active/passive monitoring of fracture propagation through porous rocks

Pradhan et al., «Strength of fractured rocks» arXiv:1503.08958

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Thank you

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