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Strength and stability of fractured rocks:

Experiment and modeling towards field scale applications

Srutarshi Pradhan
Researcher, PoreLab, NTNU

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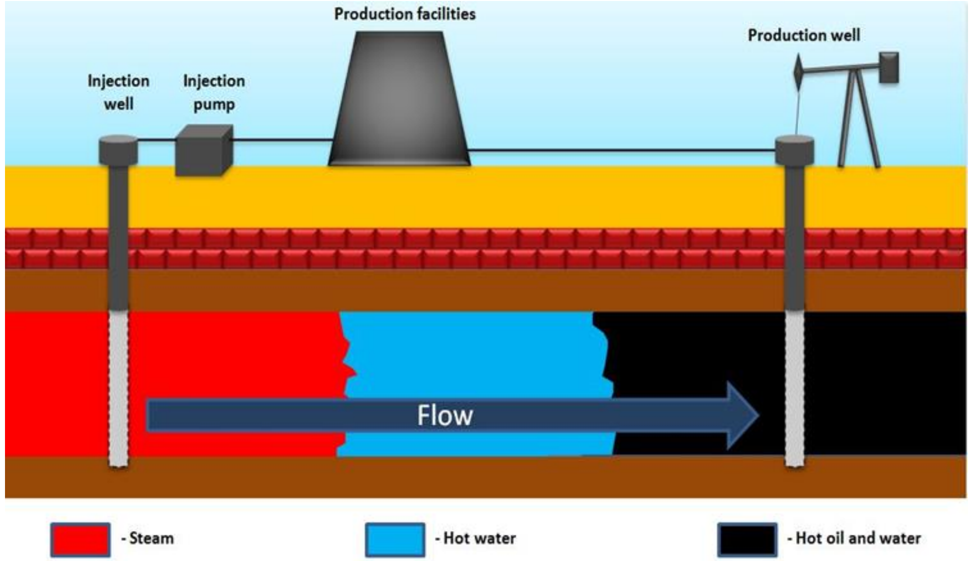
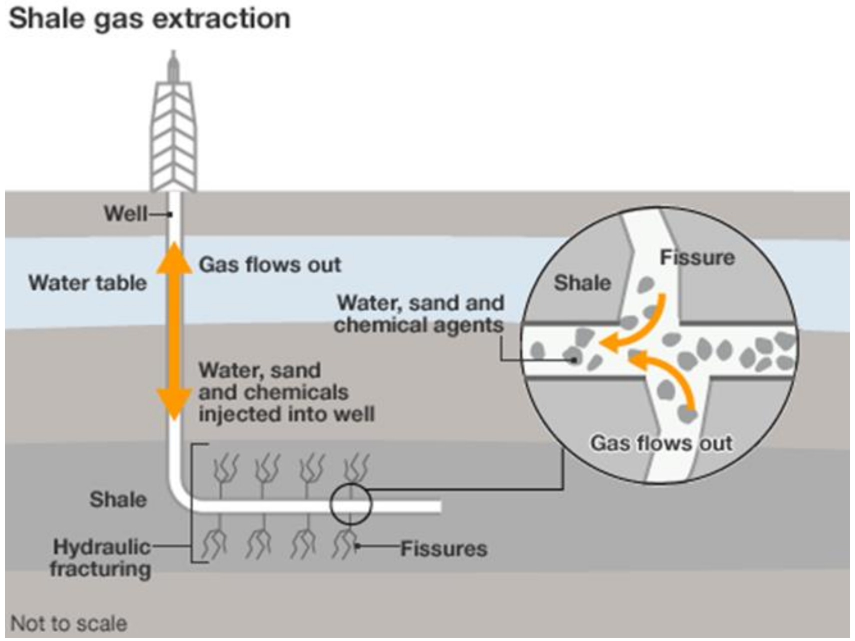
Outline

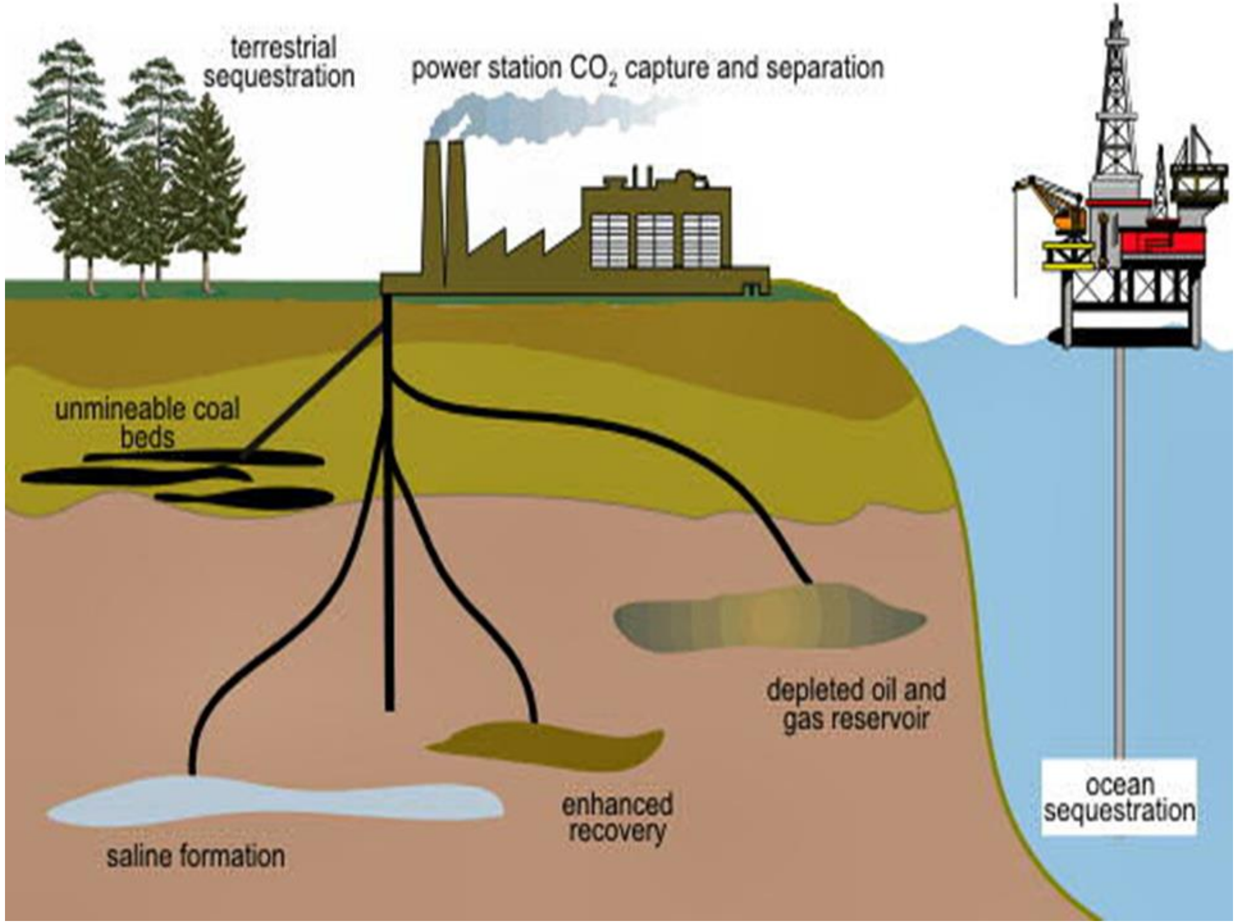
- Why strength and stability of rocks are important?
- Field problems
- Explanation and research targets
- Experiment and analysis
- Discrete element model simulation
- Prediction of collapse point
- Conclusion

Oil & Gas production (EOR/EGR)

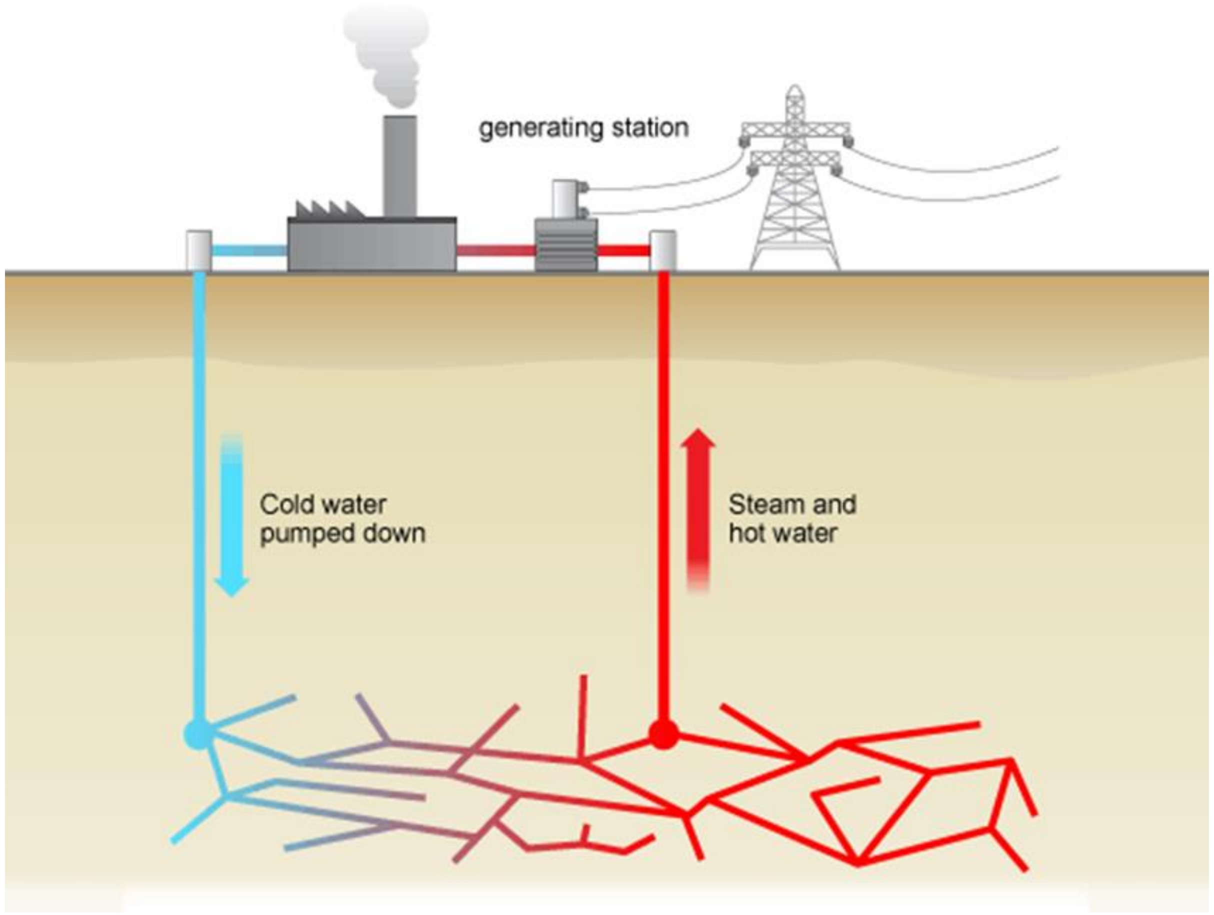




Underground CO_2 storage



Geothermal energy production



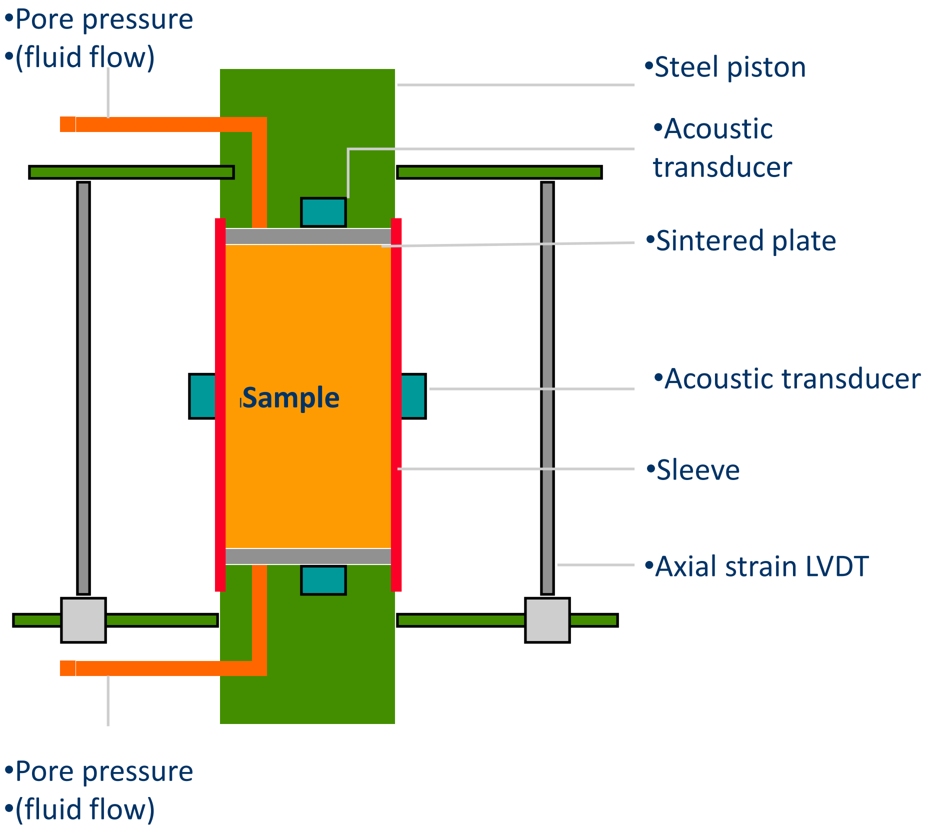
Problems: Field cases

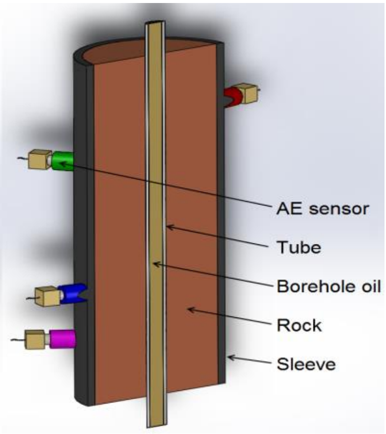
- Mud-loss events during drilling
- Borehole collapse
- Leakage in gas-wells
- A lot of activities (micro-seismic) - far from injection well (CO_2 storage, US)
- Field permeability is much higher (10 times or more) than estimated value (lab test + theory)

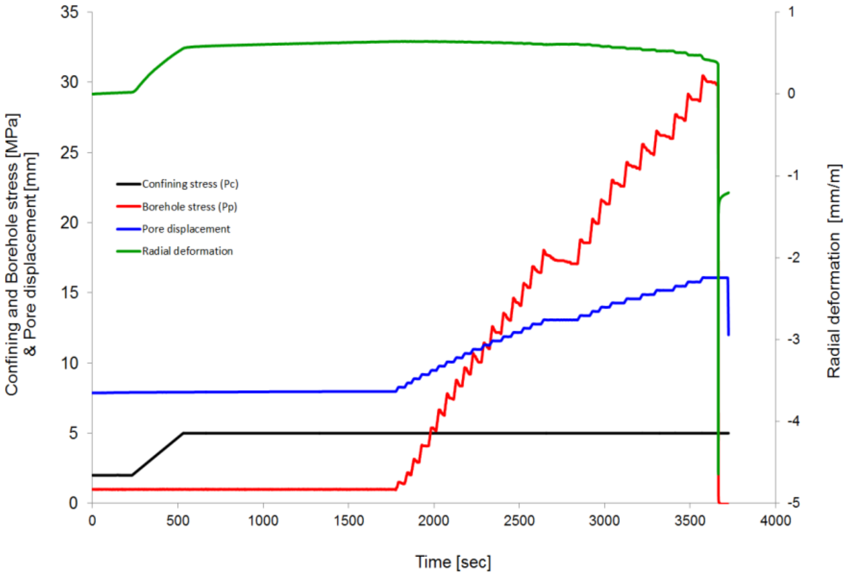
Solution/explanation

- How and when fracture opens up ?
- How important is porosity level?
- What is the role of pre-existing fractures/faults ?
- How can we characterize a fracture network inside rocks?
- Can we calculate fracture propagation velocity?
- Can we assess leakage possibility?
- How can we predict the collapse point?

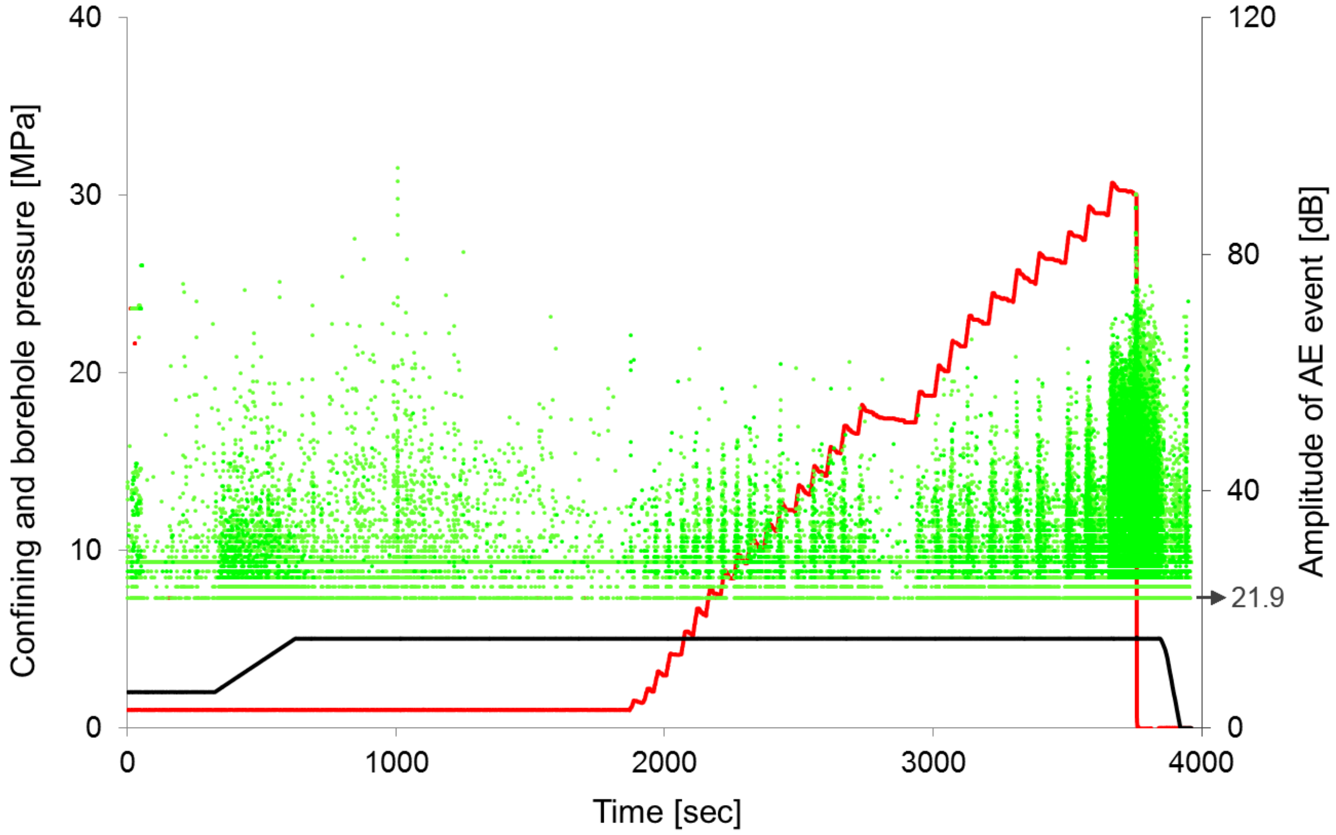
Experiments: Fracturing by fluid injection



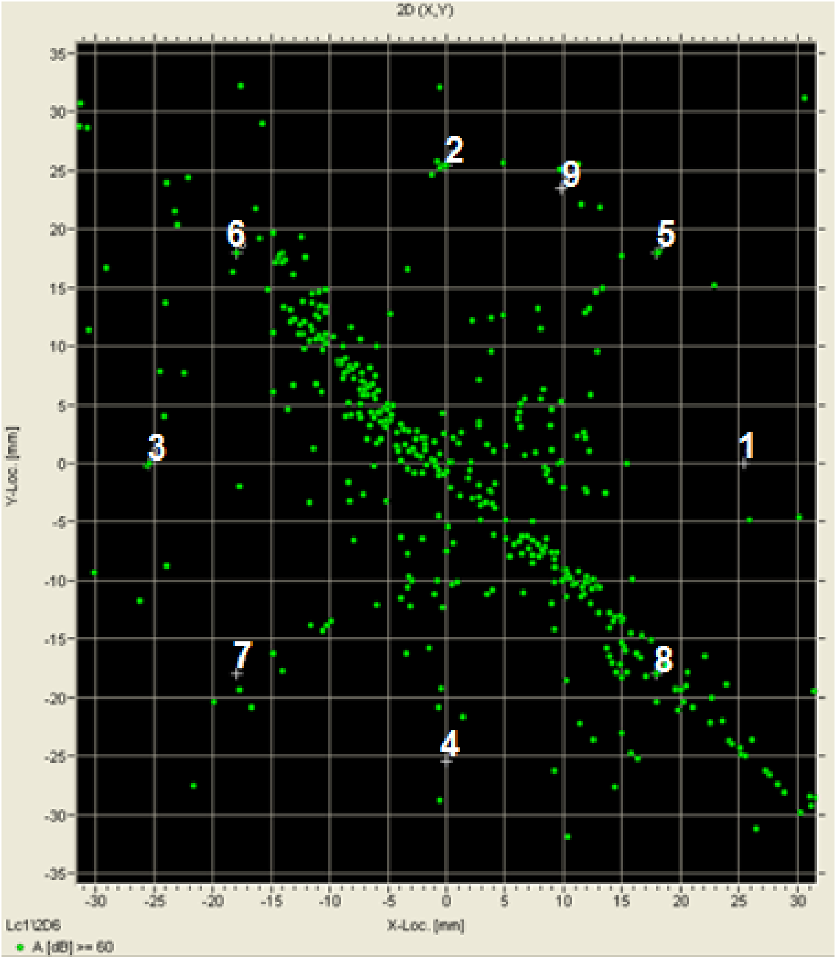


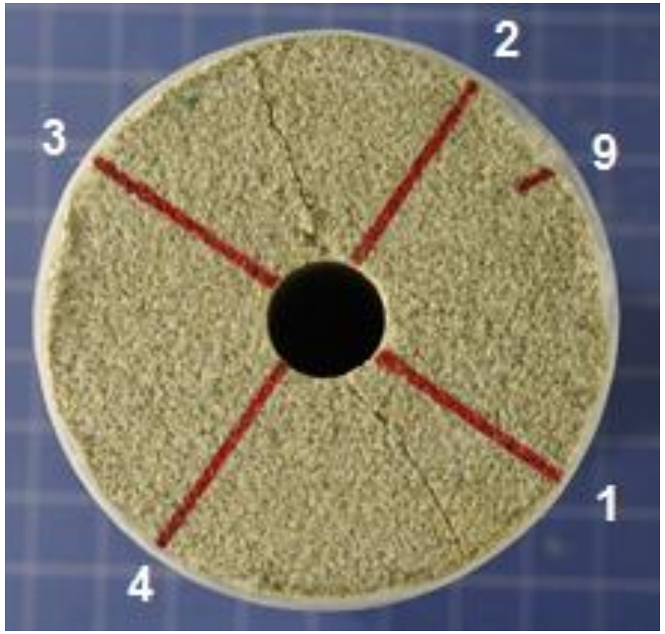


AE events during fracturing test

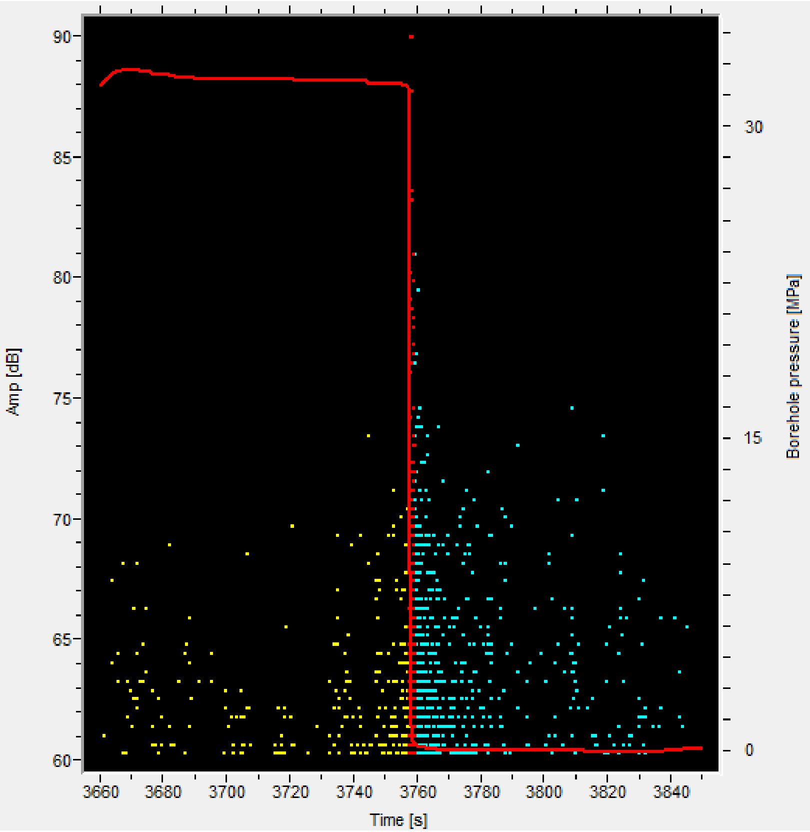


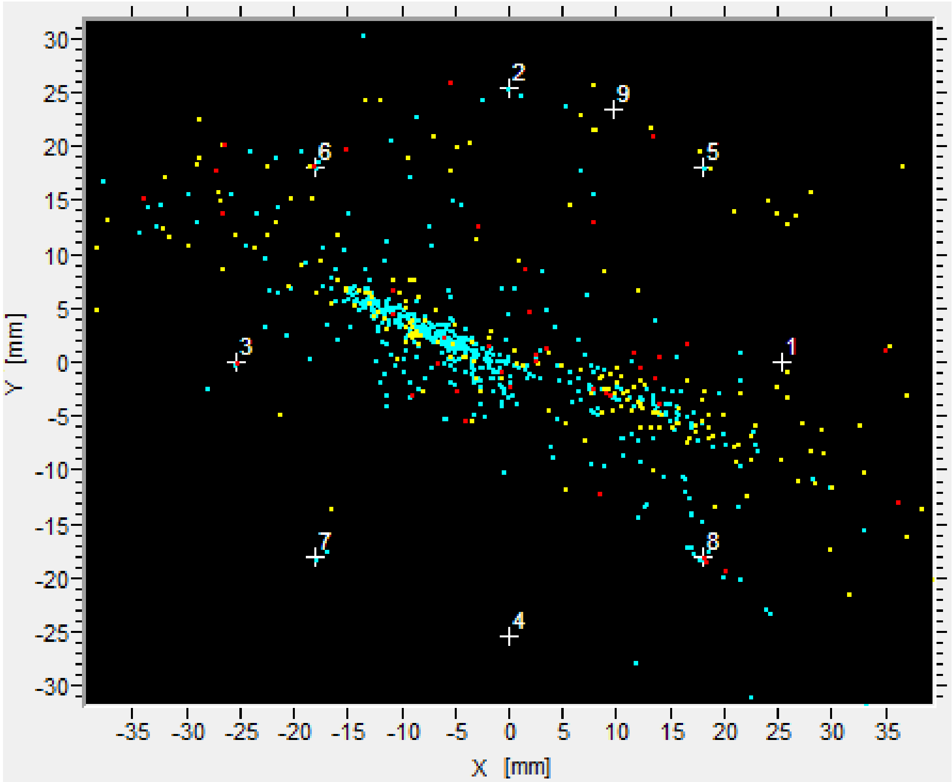
AE event locations





AE analysis near fracturing point

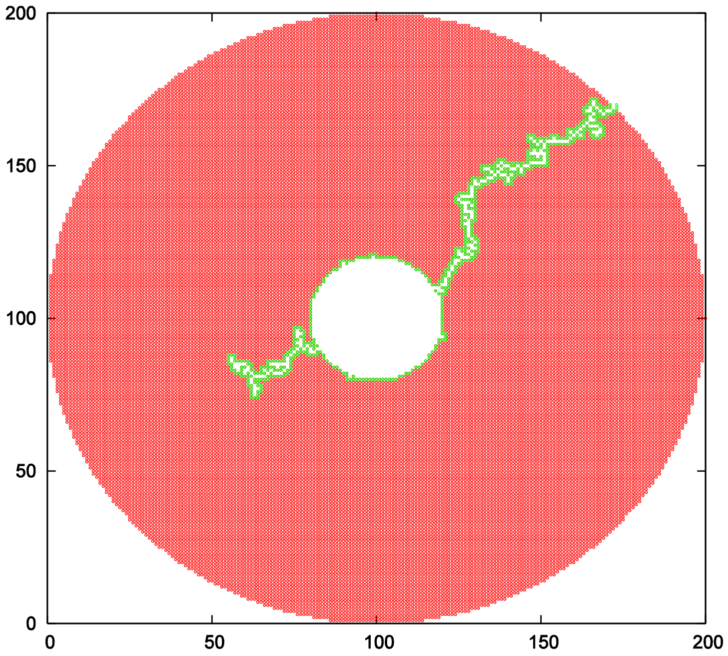




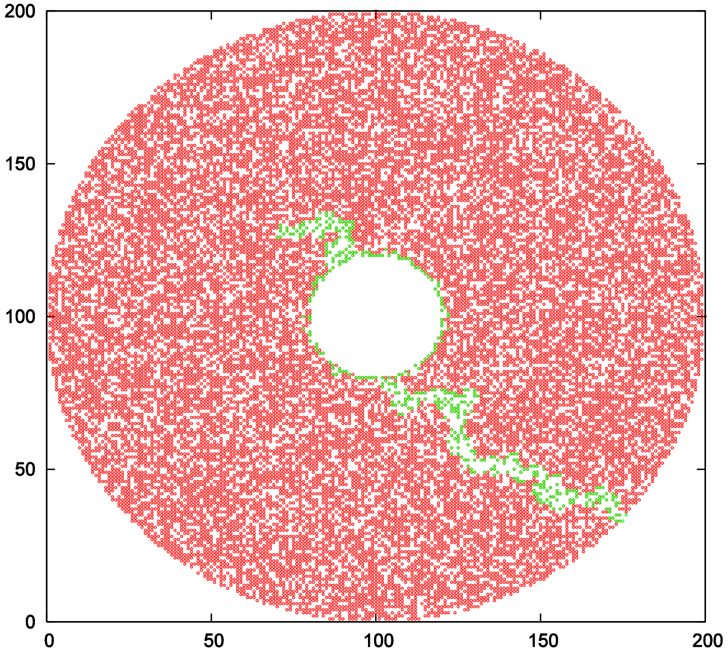
S. Pradhan et al. "Stress-induced fracturing of reservoir rocks: Acoustic monitoring and μCT image analysis", Int. J. of Rock Mechanics and Rock Engineering, (2015).

DEM: Fracturing by fluid injection

Idea: Invasion percolation + distance dependent K
Inputs: Tensile strength dist.
breaking criteria, porosity, sample size, borehole pressure

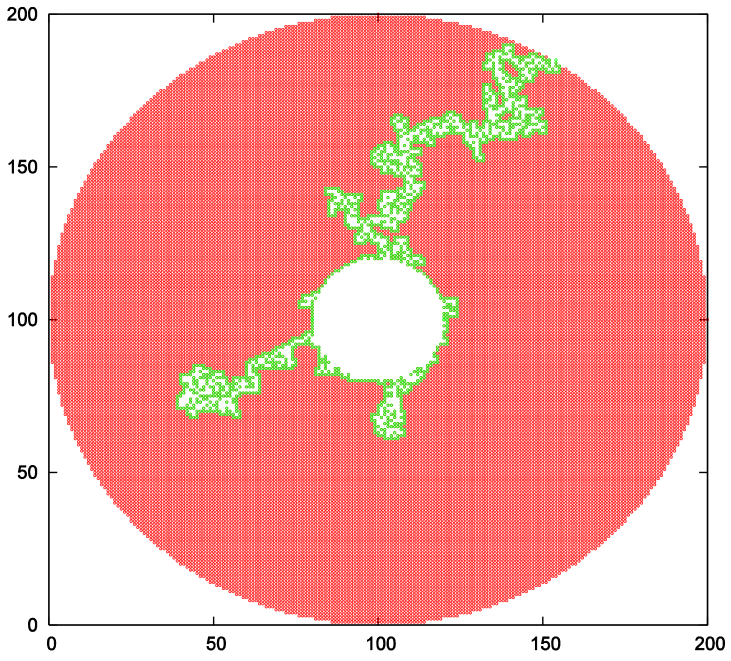


Porosity = 0

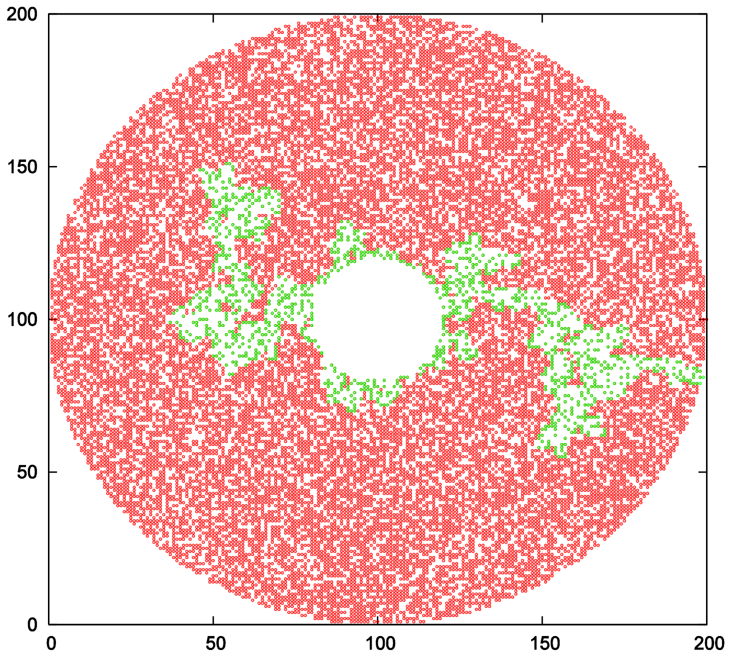


Porosity = 30 %

DEM: Less brittle rocks



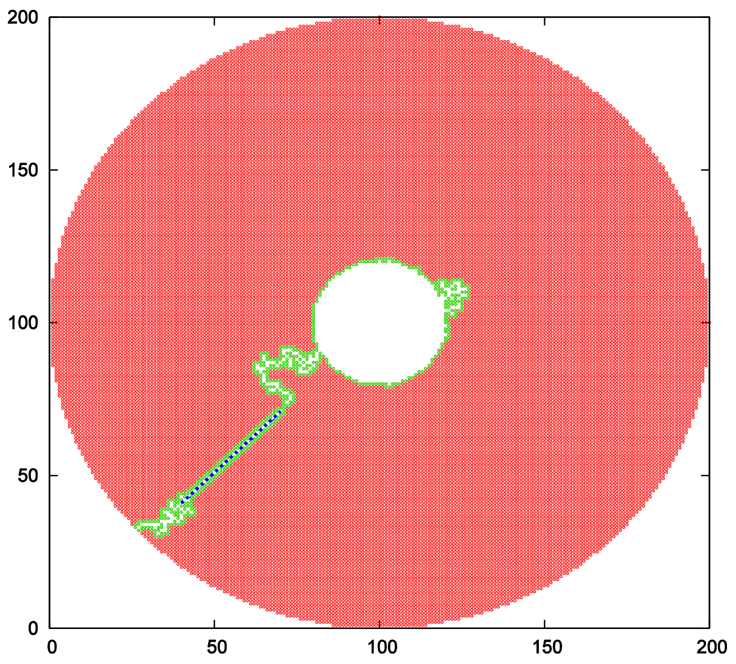
Porosity = 0



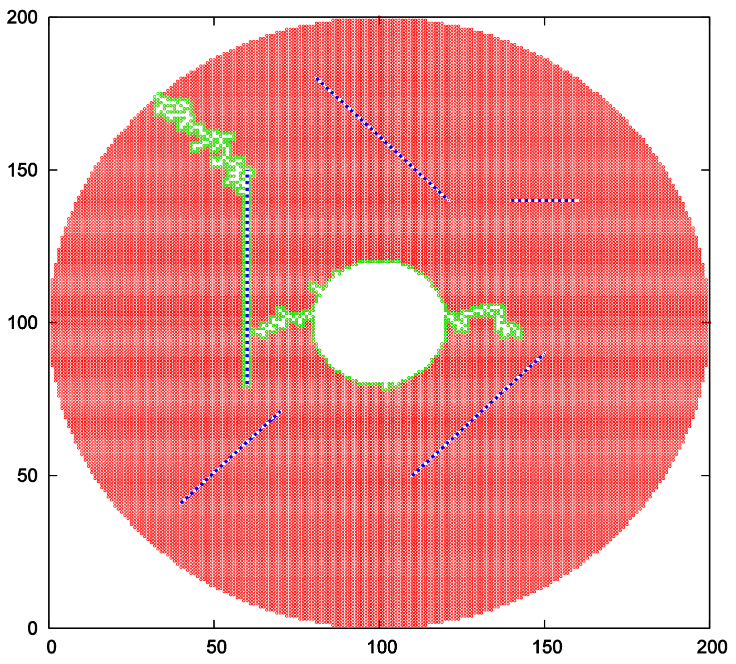
Porosity=30 %

S. Pradhan, "Fracture propagation in porous media during fluid injection", Oral presentation at Interpore2020.

Pre-existing fractures



1 Fracture

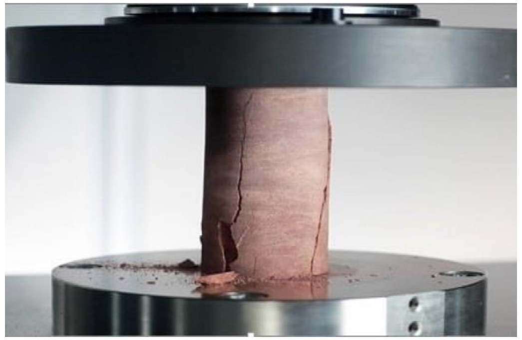


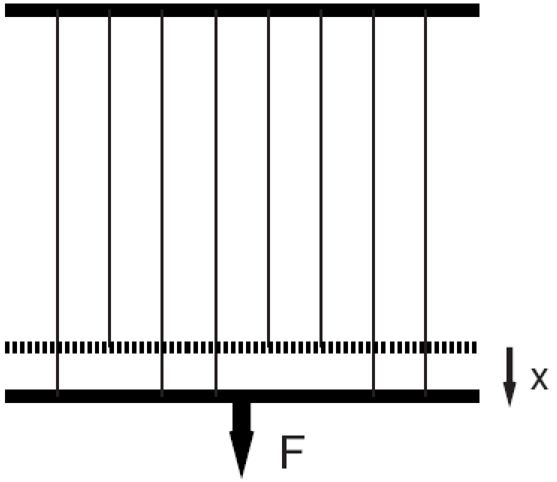
5 Fractures

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:

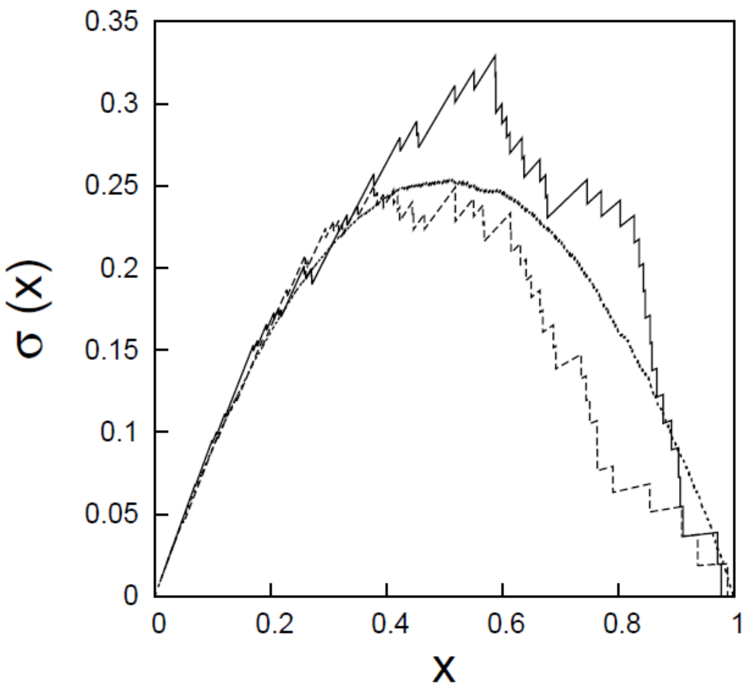
ELS, LLS, mixed-mode, hierarchical

Static: Force-displacement

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

$$P(y) = \int_0^y p(x)dx$$

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



Energy Budget: Signal of upcoming failure

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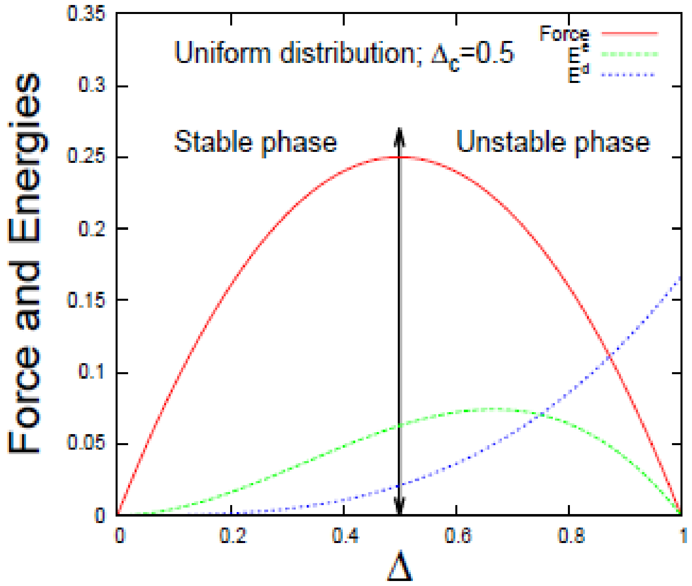
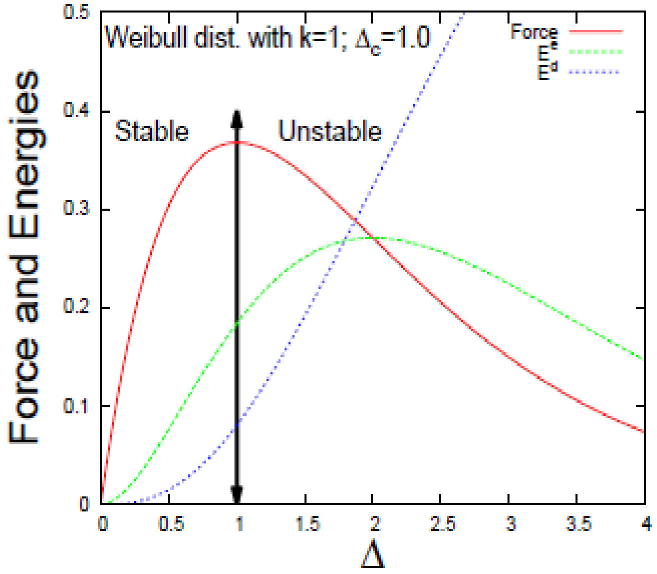
$$E^e(\Delta) = \frac{Nk}{2}\Delta^2\ (1\text{-}P(\Delta))$$

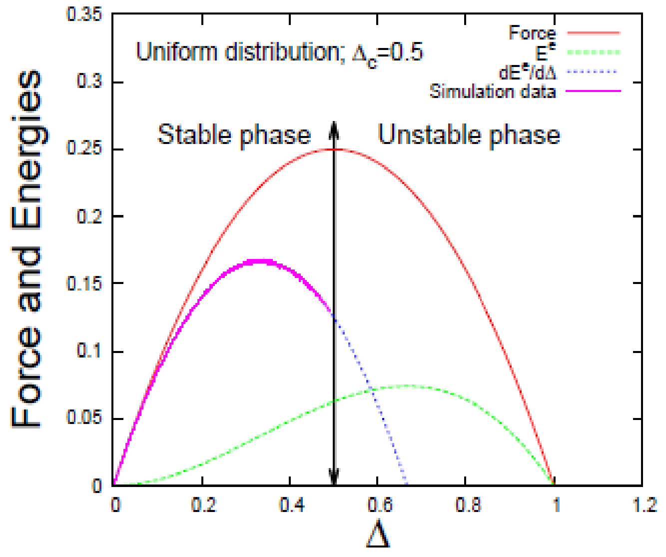
$$E^d(\Delta) = \frac{Nk}{2}\int_0^{\Delta} x^2 \mathrm{p(x)dx}$$

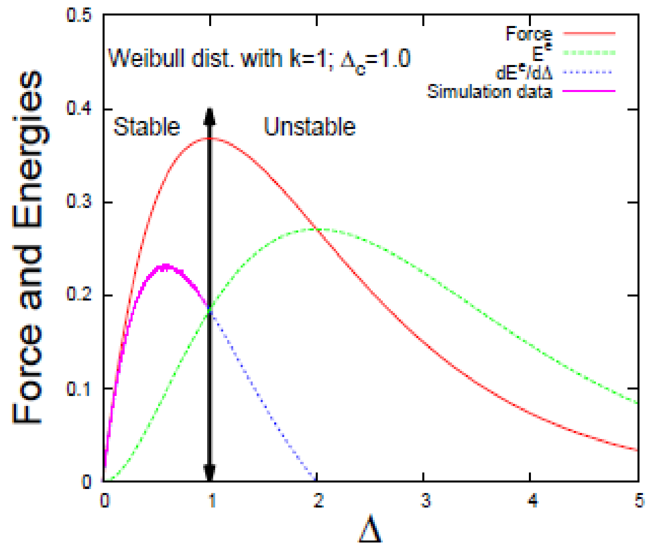




Energy Budget: Signal of upcoming failure

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





S. Pradhan, J. T. Kjellstadli and A. Hansen, "Variation of elastic energy shows reliable signal of upcoming catastrophic failure", Front. Phys. Vol. 7 106 (2019).

Conclusions

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- 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 CO_2 storage but they can help things by enhancing CO_2 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

Collaborators

- Bikas K. Chakrabarti, SINP, Kolkata, India
- Alex Hansen, NTNU, Trondheim, Norway
- Per C. Hemmer, NTNU, Trondheim, Norway
- Jonas T. Kjellstadli, NTNU, Trondheim, Norway
- Erling Fjær, SINTEF, Trondheim, Norway
- Jørn Stenebråten, SINTEF, Trondheim, Norway
- Anna Stroisz, SINTEF, Trondheim, Norway
- Chandreyee Roy, SNBNCBS, Kolkata, India

THANK YOU

Contact:
srutarshi@gmail.com
srutarshi.pradhan@ntnu.no