PhD in Civil and Environmental Engineering XXXVII Cycle

POLITECNICO DI TORINO
DISEG

H2 Underground Storage: Geomechanical Characterization and Modelling

Supervisors:
Prof. Guido Musso
Prof. Sebastiano Foti

Ph.D. Candidate: TRISHALA DAKA

UNDERGROUND HYDROGEN STORAGE

Hydrogen is being considered globally as a key future low-carbon energy carrier. The United Nations Industrial Development Organisation [1], has defined hydrogen as a true paradigm shift in the area of more efficient energy storage, especially for renewable energy on an industrial scale. Renewable energy sources are greatly dependent on seasonally fluctuating atmospheric events, which can give rise to excesses or deficits. Therefore, for a successful energy transition, a storage system is essential. Underground storage systems are advantageous in many regards. They provide large storage capacity and can be smoothly integrated with the urban plan of cities with the least modifications.

The experience of underground natural gas storage can be incorporated while studying underground hydrogen storage, yet the behaviour of hydrogen stored underground is complex and several aspects must be taken into consideration. From a mechanical point of view, the seasonal injections and withdrawals create cyclic loading on caprocks. The rate of reservoir deformation is controlled by the rate of stress change (the rate of pore pressure cycling).

The objective of the study is to obtain a suitable workflow for the geomechanical characterization and modelling of underground hydrogen storage. As an initial step, current work focuses on numerical modelling of the cyclic behaviour of cap rocks.

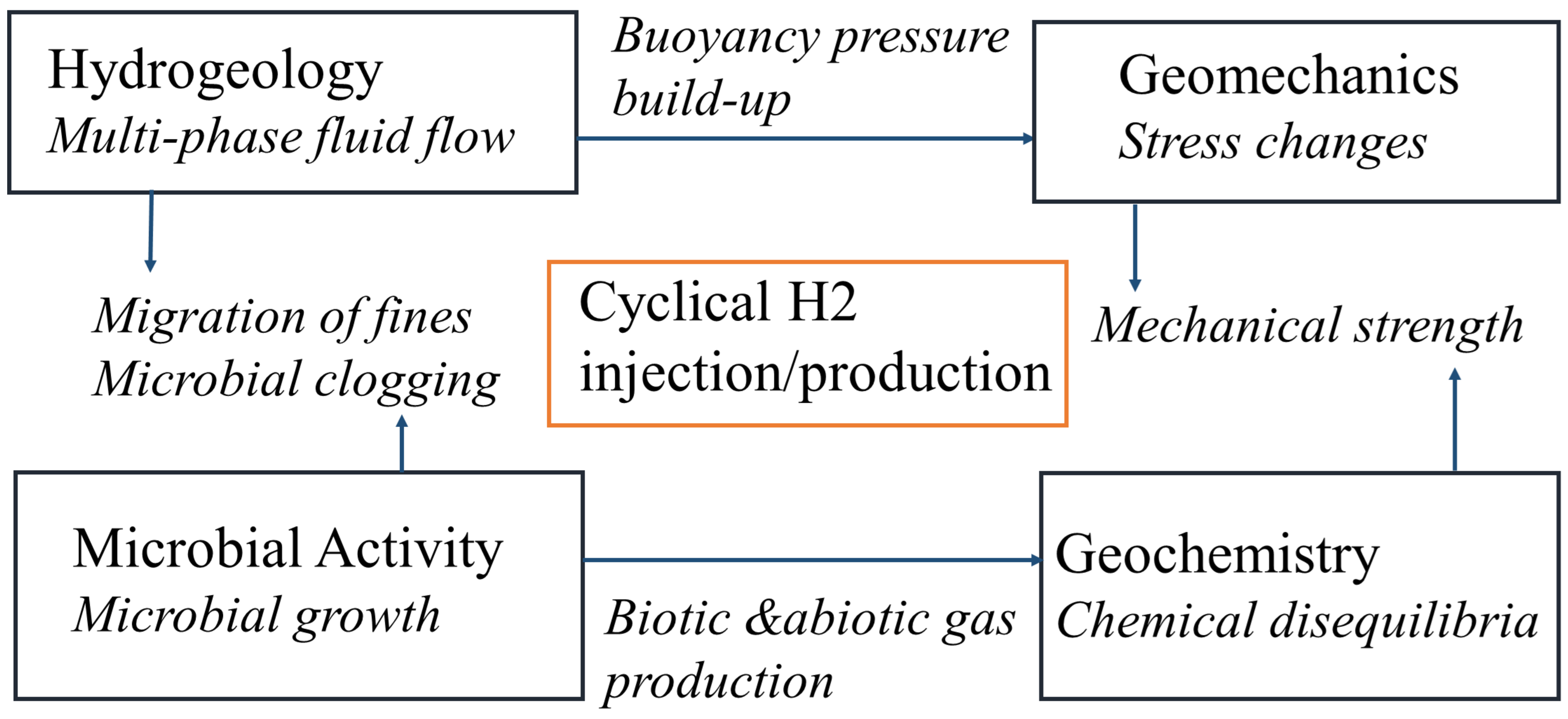

Figure 1: Aspects involved in the underground hydrogen storage in porous media, [2]

CONSTITUTIVE MODEL

In the literature review on constitutive models for cyclic loadings: Clay Hypoplasticity model, PM4Silt, Bounding Cam Clay, and Saniclay-B are identified as potential models to reproduce the cyclic behavior of caprocks. Considering feasibility and simplicity in the model, Saniclay-B [3] is adopted through OpenSees.

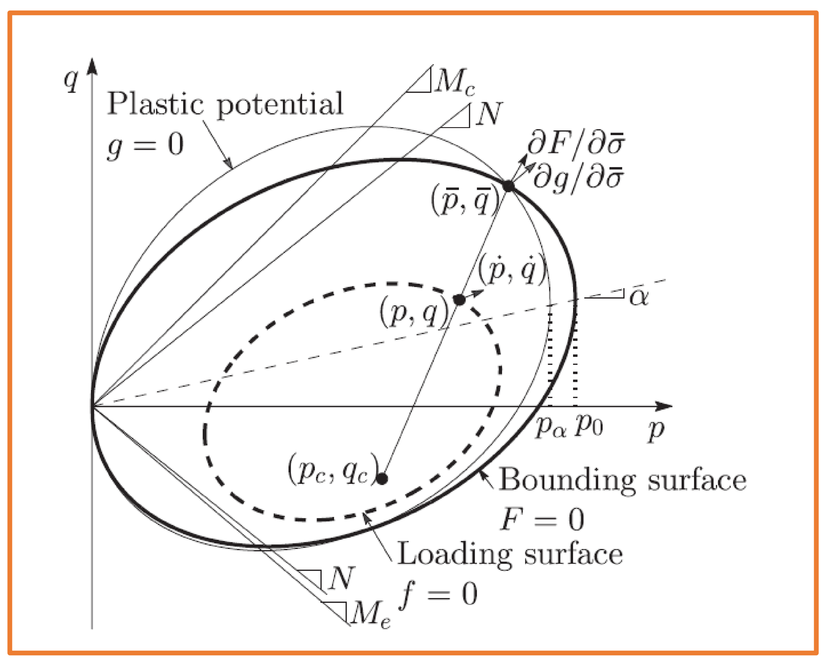

Figure 2: Schematic illustration of the loading, bounding, and plastic potential surfaces, [3].

The Model requires calibration of 11 model constants: 5 constants of MCC, 1 for non-associated flow rule, 2 for anisotropic hardening, 1 for isotropic destructuration mechanism, and 2 for constants related to the bounding surface formulation.

The Oedometer test and the monotonic triaxial test performed on the reconstituted sample are modeled with Saniclay-B in OpenSees and the influence of parameters is being studied.

NUMERICAL MODELING

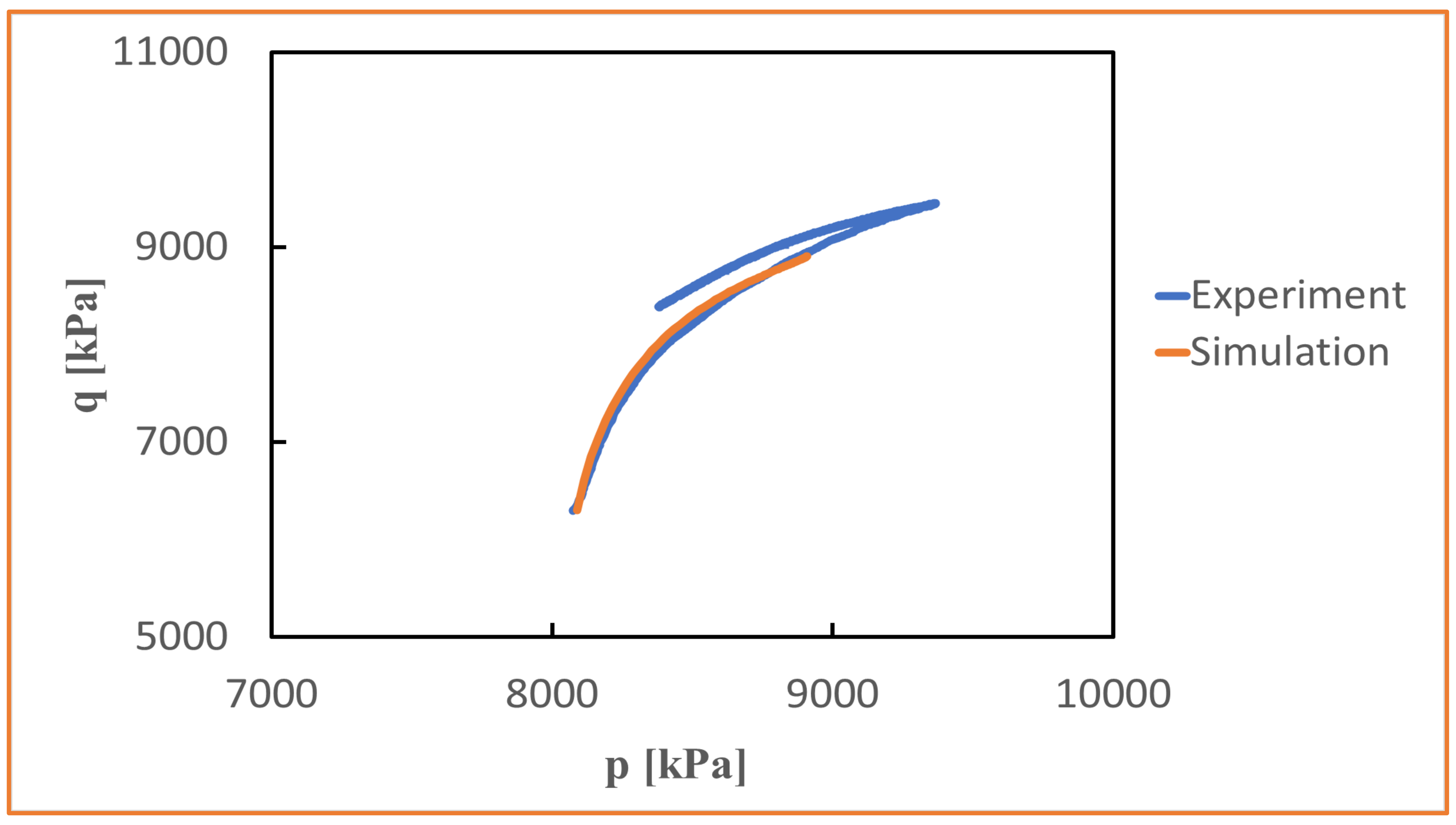

Figure 3:Comparison of experiment and simulation for undrained triaxial test, OCR =1.5

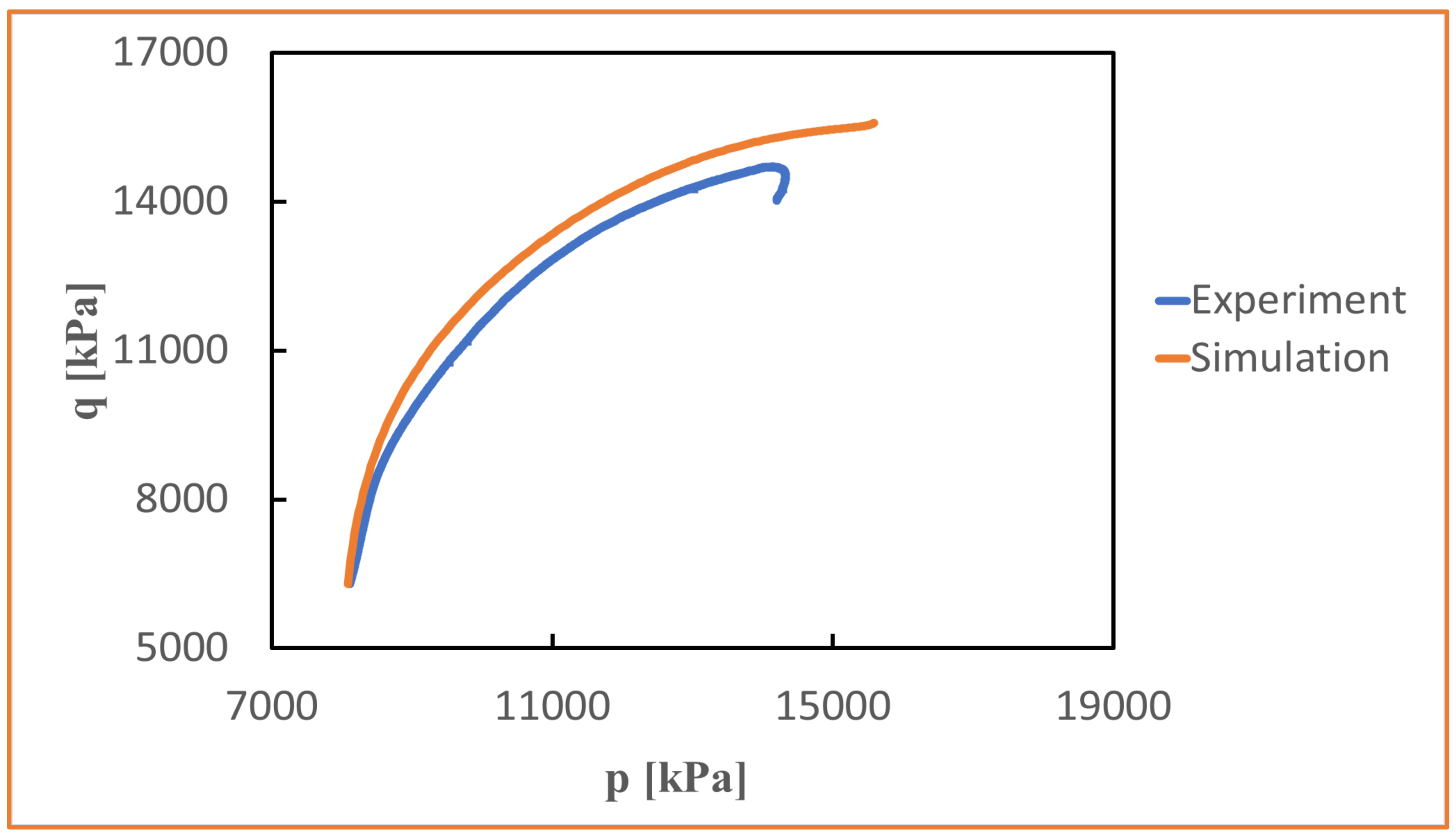

Figure 4:Comparison of experiment and simulation for undrained triaxial test, OCR =3

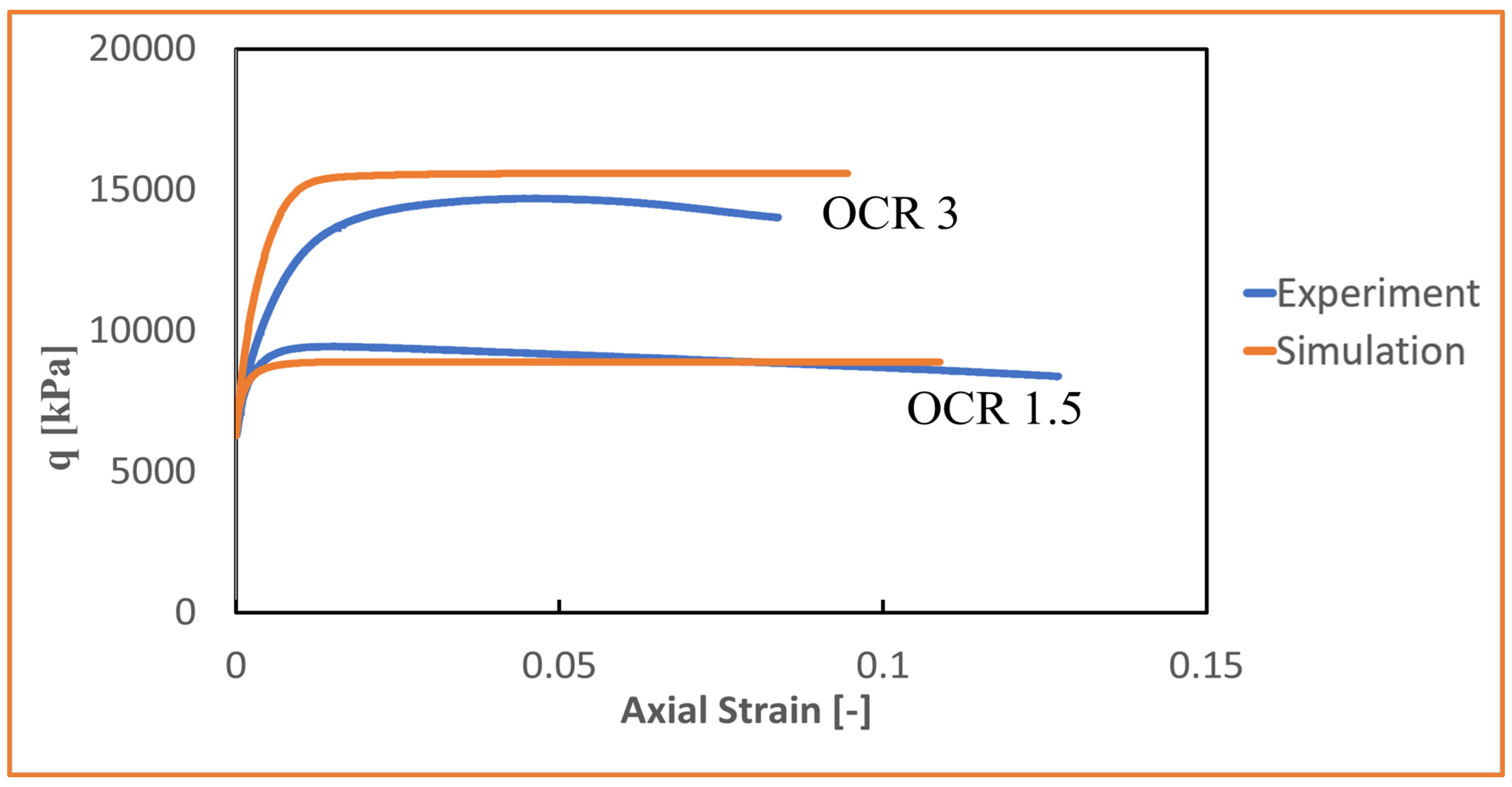

Figure 5:Comparison of experiment and simulation for undrained triaxial test

FURTHER WORK

The cap rock behavior under cyclic deviatoric loading will be studied with Saniclay-B [3] and with more advanced constitutive models. The simulations will be extended to the reservoir scale, accounting for realistic geometries of reservoir and caprocks, and the actual stress path in the rock will be evaluated. The knowledge obtained will be applied to cases of interest to Eni E&P.

TRAINING ACTIVITIES

- Energy Geosystems
- Non-renewable energy in the 21st Century: changes and challenges
- Underground Energy Storage
- SDG13 – Climate action
- Exploration Geophysics
- Energy Geostructures
- All you need to know about research data management and open access publishing
- Research Integrity
- The Hitchhiker's Guide to the Academic Galaxy

REFERENCES

[1] UNIDO, in On the sidelines of the 24th Session of the Conference of the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) – COP24, 2018, p. 12.
[2] N.Heinemann et al., Enabling large-scale hydrogen storage in porous media- the scientific challenges, Energy Environ.Sci., 2021,14: 853-864.
[3] S.Gaziz and T.Mahdi, Bounding surface SANICLAYplasticity model for cyclic clay behavior, *Int. J. Numer. Anal. Meth. Geomech.* 2014; 38:702–724