FORGE Symposium and Workshop
Extended abstract

The role of the Excavated Damaged Zone in HG-A Field-Scale Experiment Modelling

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Summary

HG-A field scale experiment has been developed in Mont-Terri Underground Research Laboratory to investigate the hydro-mechanical evolution of a backfilled and sealed tunnel section in Opalinus Clay. Based on this experiment, this study deals more particularly with the numerical modelling of the microtunnel excavation and ventilation. To take into account the anisotropic behaviour of Opalinus Clay, four sources of anisotropy are considered: in-situ stress, elastic modulus, failure criterion and water permeability. This modelling puts in evidence how the Excavated Damaged Zone, which developed around the microtunnel, plays a significant role in the hydro-mechanical behaviour observed in situ.

1. Introduction

The objective of the HG-A experiment is to investigate the hydro-mechanical evolution of a backfilled and sealed tunnel section [1]. In particular, the goals concern:

- understanding of the Excavated Damaged Zone (EDZ) generation and evolution in Opalinus Clay,
- upscaling of hydraulic conductivity determination from the lab test to the tunnel scale,
- investigation of self-sealing processes,
- estimation of gas leakage rates.

The geometry of the problem consists in a tunnel of 13m in length and 1.035m in diameter drilled in Opalinus Clay. More than 20 observation boreholes have been drilled parallel and oblique to the microtunnel axis and equipped with multipacker piezometer systems, inclinometer chains, chain deflectometers and stress cells to monitor the correspondent parameters in the host rock. After excavation, the micro-tunnel has also been instrumented with surface extensometers, strain gages, time domain reflectometers (TDRs), piezometers and geophones. The test plan consists in 6 stages:

- Phase 0: the drilling and instrumentation of the boreholes,
- Phase 1: the excavation of the microtunnel followed by backfilling and sealing,
- Phase 2: installation and inflation of the megapacker,
- Phase 3: hydraulic constant pressure and constant rate injection tests,
- Phase 4: gas injection tests,
- Phase 5: second hydraulic test series.

However, this particular study mainly concerns the numerical modelling of these two first stages to characterize the effects of anisotropic Opalinus Clay behaviour and the effects of damage on excavation and gallery ventilation processes.

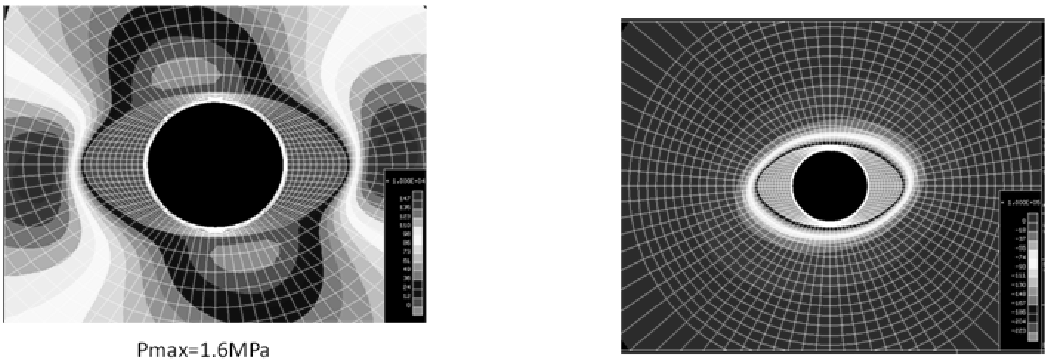
2. Methodology

The numerical modelling of HG-A experiment is performed in the finite element code Lagamine from Université de Liège. The hydro-mechanical behaviour of Opalinus Clay around the excavated gallery has been simulated through a 2D plane strain approach. To reproduce the dependency of the shear strength with the bedding orientation, an extended Drucker-Prager model with an anisotropic cohesion has been developed [2]. Then, four sources of anisotropy are considered to govern this behaviour: in-situ stress, elastic modulus, failure criterion and water permeability.

First, the ability of that model to reproduce the behaviour of Opalinus Clay has been proved by numerical simulations of triaxial tests performed with different orientations of loading with respect to bedding plane (see [2]). Second, numerical simulations of HG-A microtunnel are carried out. It consists in one week of excavation followed by one year of ventilation. Ventilation is putted in place with a relative humidity RH = 83% and a temperature T = 13°C in average. To reproduce gallery ventilation, pore water pressure is linearly decreased from 0 to a given suction in 7 days and then a constant pressure is maintained at -23.8 MPa.

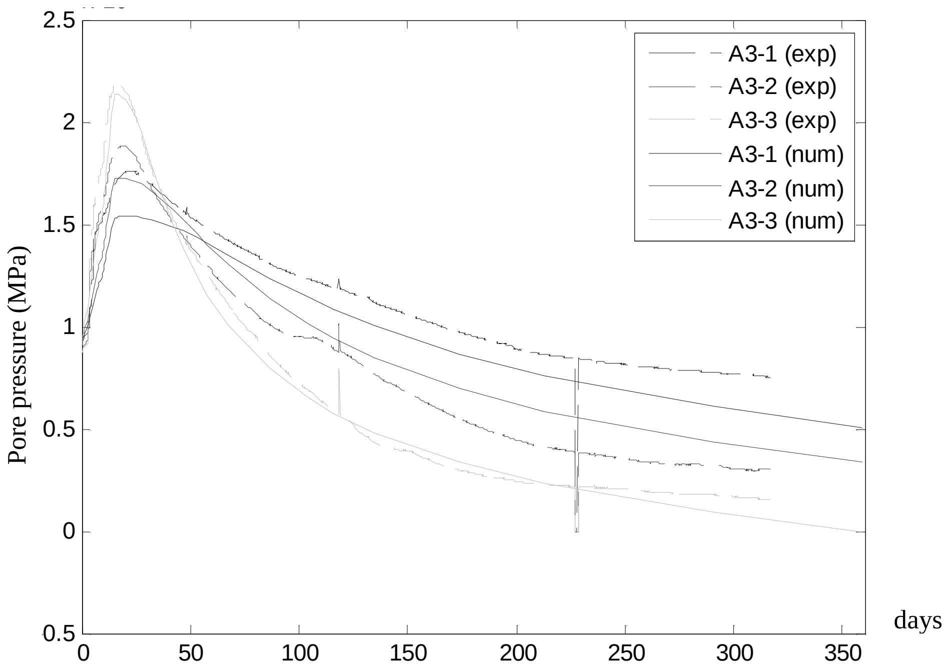
3. Results

The modelling of HG-A microtunnel excavation and ventilation has shown that the hydro-mechanical response of the Opalinus Clay around excavation is fully governed by the four sources of anisotropy, keeping quite complex the global response of Opalinus Clay (see [2]). Nevertheless, good agreements with available in-situ measurements in term of displacement and water pressure evolutions can be obtained by also considering a damaged zone (EDZ) around HG-A microtunnel in numerical analysis. Based on plastic indicator PI field around the tunnel, an elliptic EDZ is expected (defined by PI > 0.5 or half-larger axis equals to 1m and half-smaller axis equals 0.6). This EDZ amplifies hydro-mechanical effects: tunnel convergence is higher and water pressure and suction fields increase after ventilation phase (Fig. 1). Model calibration on available in-situ measurements indicates that parameters have to be significantly modified in EDZ because of strong damage effects in Opalinus Clay: Young moduli have to be divided by 10, permeabilities have to be multiplied by 10^5 (Fig. 2). However, these modifications are not unrealistic for Opalinus Clay if we refer to what has been observed on SELFRAC experiment [3,4].

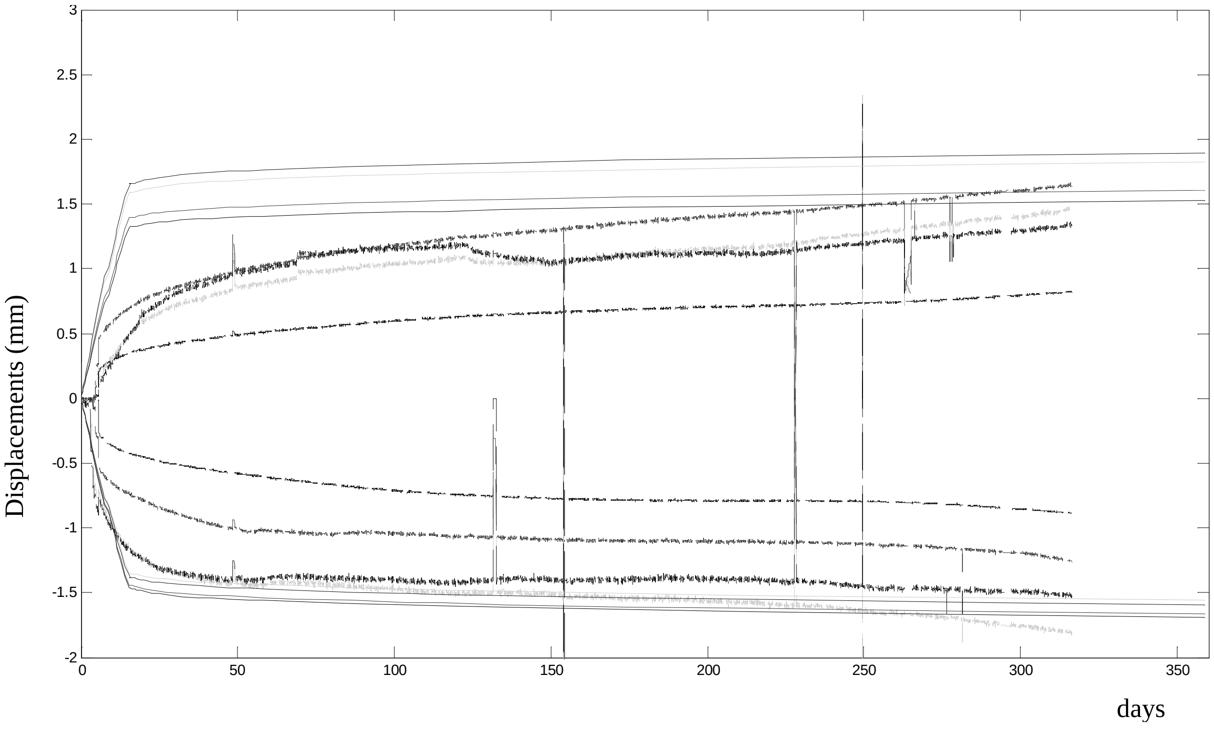


(a) water pressure *(b) suction*

Figure 1: Water pressure and suction fields after ventilation phase



(a) water pressure evolution (A3 borehole)



(b) displacement evolution (A7 and A5 boreholes)

Figure 2: Water pressure and displacement evolutions with time

Furthermore, the presence of EDZ combined with clay anisotropies permits to justify the observed damaged (Fig. 3, [5]). Horizontally, damage (noted b) can be related to stress concentration providing plasticity and larger water pressures evolutions. At 45°, damage (noted a) results from hydraulic effects during ventilation when the gradient of saturation degree strongly decreases. Moreover, on the top of the microtunnel, the presence of a tectonic fault provides additional stress concentrations that amplify the damage, as we have shown numerically in [2].

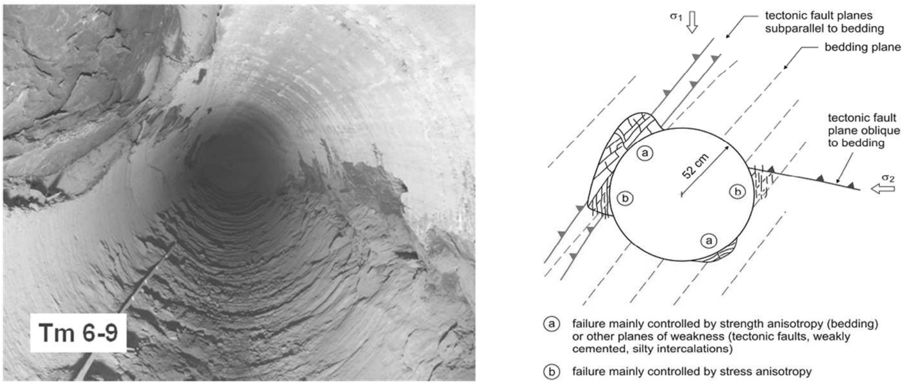


Figure 3: Damage observed in situ in HGA microtunnel (from [5])

4. Discussion

By the modelling of HG-A field-scale experiment, we have shown that hydro-mechanical response of the Opalinus Clay around excavation is strongly governed by 4 sources of anisotropy: in-situ stress, elastic modulus, failure criterion and water permeability. But these anisotropies are not sufficient to explain in situ observations. Displacements and water pressure fields are affected by a damaged zone that developed around HG-A borehole. An EDZ yields to larger overpressures at the interface between EDZ and undamaged zone and a realistic delay in water pressure evolution after excavation. Then, the proposed 2D modelling is very relevant on Opalinus Clay hydro-mechanical behaviour charaterization. However, it would be necessary in the future to improve the modelling calibration process with available in-situ measurements by establishing a more accurate relationship between EDZ parameter evolutions and plastic or damaged state of Opalinus Clay.

5. Acknowledgements

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