Predictive HM-modeling in the heterogeneous Opalinus Clay of the Mont Terri rock laboratory

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Introduction

Since initial excavation of the security gallery of the Mont Terri highway tunnel in 1989, every 10 years or so the Mont Terri Project Partners have excavated new, and extended existing, galleries and niches in the Opalinus Clay. Currently, 700 m of galleries and niches are actively being used for experiments. Besides rock mechanical experiments, the Project Partners have conducted six mine-by experiments with different tunnel orientations, five in the shaly facies and one in the sandy facies. In 2018/19 another 500 m of galleries and niches will be excavated south of the existing rock laboratory, mainly in the stiffer sandy facies. In November 2018 we will carry out a new mine-by test, the MB-A experiment (hydromechanical characterization of the sandy facies before and during excavation), along a 30 m tunnel section oriented parallel to bedding strike. We will sample both the sandy and carbonate-rich sandy facies that are sandwiched between the shaly facies. Here, we present data from predictive modeling that was carried out for the heterogeneous, anisotropic, and elastic/plastic case to estimate the hydro-mechanical behavior of the rock mass during excavation. We also present first results from a large-scale HM-numerical simulation of the entire rock laboratory, including topography, large-scale rock mass heterogeneity, and the main evolutionary steps of the rock laboratory.

Results of a model of pore-water pressure evolution during sequential excavation in the sandy facies of the Opalinus Clay (MB-A experiment)

The model dimensions for the predictive modeling of the mine-by test are 50x50 m in x- and z-direction and 70 m along the gallery. The modeling sequence included the pre-excavation of the two niches dedicated to instrumentation at the end of the 30 m long mine-by section, the excavation of 20 m gallery before the mine-by section, a 15 day sequential excavation of a 30 m mine-by section, and the equilibration of the entire system after excavation. We applied a simple elastic approach in Code_Aster, including anisotropy and heterogeneity of the rock mass (Madaschi & Laloui, 2017). The parameter set is based on data from Jaeggi & Bossart (2014), constrained by numerous lab tests (Ferrari & Laloui, 2017). The main focus was the highly instrumented target section in the middle of the MB-A tunnel. An example of the modeled evolution of pore-water pressure is shown in **Figure 1**.

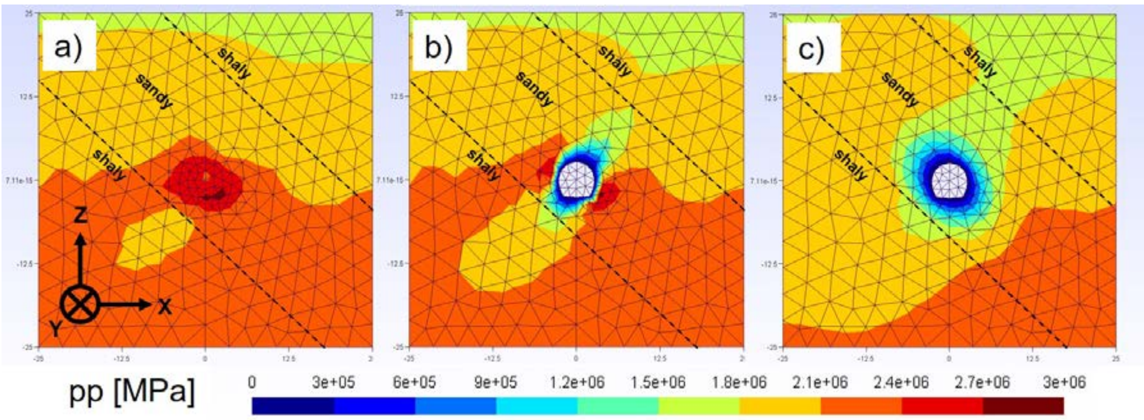

Fig. 1: Contours of pore-water pressure just before reaching the highly instrumented target section of gallery MB-A (a), just after excavation (b), and after another 75 days (vertical sections perpendicular to sense of excavation).

The results of our model predict overpressures along bedding immediately at the initiation of excavation and a pressure decrease vertical to bedding that results in a long-term pressure decrease parallel to bedding. Modeled pressures at instrumented boreholes rise from 2.0 MPa to 2.8 MPa just before excavation and drop to 1.2 MPa after excavation. Deformation within the rock mass at distances >3 m from the tunnel are in the mm-range, which seems to be reasonable for sandy facies. Modeled tunnel convergences are in the range of 10 mm and comparable to existing monitoring data. However, it must be noted that monitoring data from convergence profiles generally underestimate the real total magnitudes. At present we have no field data on the deformation of a tunnel in sandy facies. This data will be collected in November 2018 with the highly instrumented MB-A tunnel. Thus we will soon be able to improve and/or validate our numerical models. Damage, which is common at least in the shaly facies of the Opalinus Clay, was not implemented in our elastic modeling approach.

Results of a large-scale HM simulation of the rock laboratory, incl. surface topography

The large-scale model of the Mont Terri rock laboratory is 300x240 m in area and 600 m in height, and capped with the topography between 220-350 m above the laboratory level. The HM numerical model considers the evolution of the Opalinus Clay in the rock laboratory (Ga88, Ga98, Ga08 and Ga18) using model excavations in time steps of 10-years (Ga18 is currently being excavated). The simulation was performed using an isotropic elastic model implemented with FLAC3D from ITASCA™ (Thoeny, 2017).

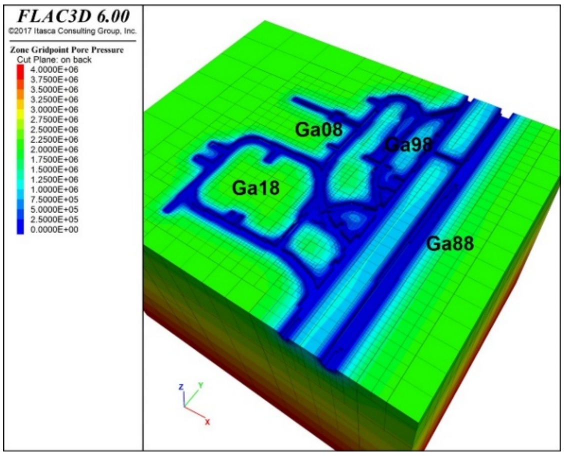

Fig. 2: Contours of pore-water pressure 10 years after extension in 2018/19 (horizontal section).

Modeling results indicate that there is a significant increase in volume of the hydraulically disturbed zone (blue areas around galleries) in the old parts of the rock laboratory, where pore-water pressures are far below the initial pore-water pressure of 2.0 MPa at rock lab level (**Figure 2**). However, in the new part (Ga18) of the rock laboratory, this zone is much smaller, even 10 years after excavation. As a result of the different rock mass deformability, displacement magnitudes are highest within the shaly facies of the Opalinus Clay, intermediate within the sandy facies, and lowest within the limestone formations below and above. Due to changes in topography, slightly lower vertical stresses are expected in the newer part of the rock laboratory (Ga18). Topographical effects on the stress situation at rock lab level are on the order of 0.3 MPa, which is within the uncertainty range of the sub-vertical stress magnitude. Thus, application of a constant stress tensor with a vertical depth gradient alone would be sufficient to model HM effects at rock lab level.

References

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