DOMPLU - filter and seal design, construction and results (DOPAS Project)

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The deposition tunnels in a KBS-3V repository for spent nuclear fuel will be sealed with a plug at the end of the tunnels in order to withstand the swelling of the backfill and to seal off out-flowing groundwater. A full scale test of the dome plug system (The DOMPLU test) is currently performed at the Äspö Hard Rock laboratory (HRL) in a joint project between SKB and Posiva. The full-scale test consists of a number of components: bentonite backfill and seal (both blocks and pellets) and filters (Leca beams and gravel). These components are instrumented with sensors for measurement of total pressure, pore pressure, relative humidity and displacements at several positions. The bentonite-based components and the filter were installed in January 2013 and pressurization by natural groundwater inflow began in October 2013. The installation was preceded by a blind prediction of the evolution of hydro-mechanical processes using a finite element model (Code_Bright). Sensor data have been analyzed together with calculated evolutions of RH, stresses and displacements.

1 Background

The deposition tunnels in a planned repository for spent nuclear fuel will be sealed with a plug at the end of the tunnels in order to withstand the swelling of the backfill and to seal off out-flowing groundwater. The principle design of the plug includes several components, among which the most important are the concrete dome, the bentonite seal and the filter (Figure 1). The groundwater leakage past the plug has to be small enough in order to build up a water pressure inside the plugged volume, and to prevent loss of bentonite from the deposition holes due to erosion throughout the operational phase of the repository. During construction of the plug system and while the concrete dome cures until it is finally grouted for a tight contact to rock (a total period of 4 to 5 months) the construction site must be kept free from water. Wet tunnels therefore require a filter section which can drain the water coming from the inner parts of the tunnel and temporarily let it by-pass the plug. These issues and demands have been addressed in the joint SKB and Posiva project "System design of dome plug for deposition tunnels". The project aims to ensure that the reference configuration of the KBS-3V deposition tunnel end plug works as intended, and includes a recognized need for demonstration of plug performances. The project included verification of the modified dome plug design by analytical and numerical calculations, laboratory examinations of all plug component materials and several scale tests (Börgesson et al. 2015). The main activity though, was to test the dome plug system in full scale (The DOMPLU test) at the Äspö Hard Rock laboratory (HRL). The rock conditions at Äspö HRL are not as good as found in Forsmark, the site for the Swedish Spent Fuel Repository, but nevertheless the experiment could be carried out at similar depth (450 m) in crystalline rock with comparable overburden pressure.

2 Design

The full-scale test consists of a number of components, each with its own purpose (Figure 1). The innermost component is a 1 m backfill zone which consists of a stack of bentonite blocks with a surrounding pellet filling. The next component is the filter section which is composed of 0.3 m thick LECA-beams and a 0.3 m layer of gravel (2-4 mm). The filter serves for drainage of groundwater during construction as well as for artificial wetting of the bentonite seal when the drainage is finally closed. The gravel and the bentonite seal are separated by a geo-textile which also facilitates distribution of water into the sealing. The bentonite seal consists of a 0.5 m stack of highly compacted MX-80 bentonite blocks with a surrounding MX-80 pellet filling closest to the rock. Finally, the restraining concrete structure is designed as an octagonal dome plug, cast in-situ by low-pH concrete. The diameter of the concrete dome is 8.8 m while the concrete thickness is 1.79 m in the hub. The design load for the desirable watertight structure is 7 MPa and the water flux past the plug will be restricted to a maximum of 0.1 l/min.

3 Installation

Besides extensive monitoring of the concrete dome structure, the inner plug components are instrumented with sensors for measurement of total pressure, pore pressure, relative humidity and displacements at several positions. The bentonite-based components and the filter were installed in January 2013 (Figure 2) while the concrete dome was cast in March 2013 (Grahm et al. 2015). Pressurization by natural groundwater inflow began in October 2013 (day 243). The artificial pressurization was increased to 4 MPa, stepwise during the period from December 2013 to February 2014, and has been maintained at this level after that. The measured leakage past the plug on September 17, 2014 was 44 ml/min (day 595, blue line Figure 3). One year later, this was only marginally lower (approximately 20-30 ml/min). Monitoring of DOMPLU will continue until late 2016.

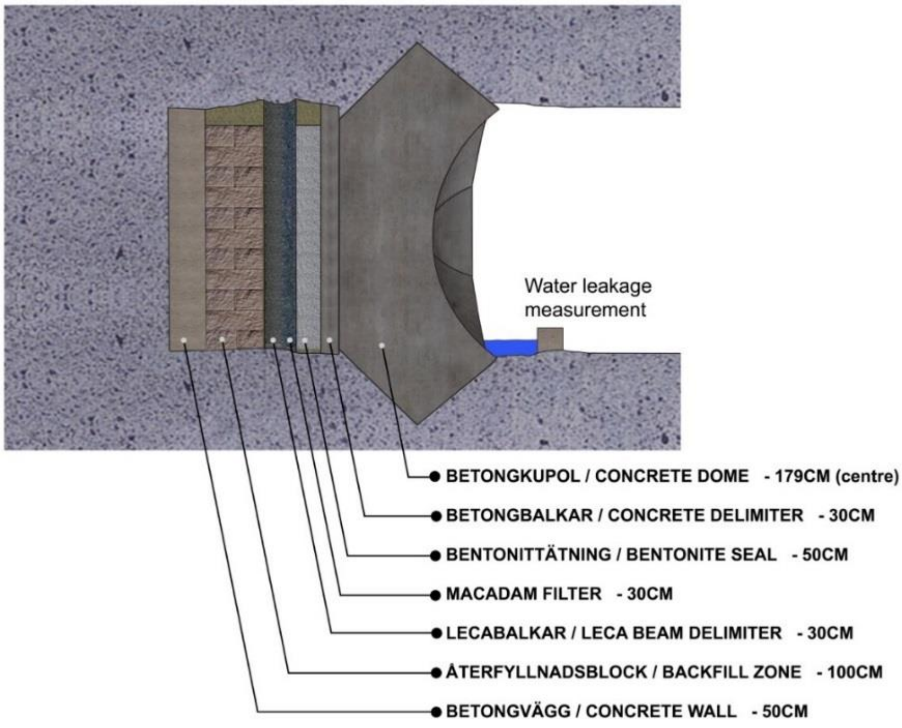

Figure 1. Schematic section of DOMPLU.

Figure 2. Installation of backfill blocks behind Leca beams (left) and seal blocks behind concrete beams (right).

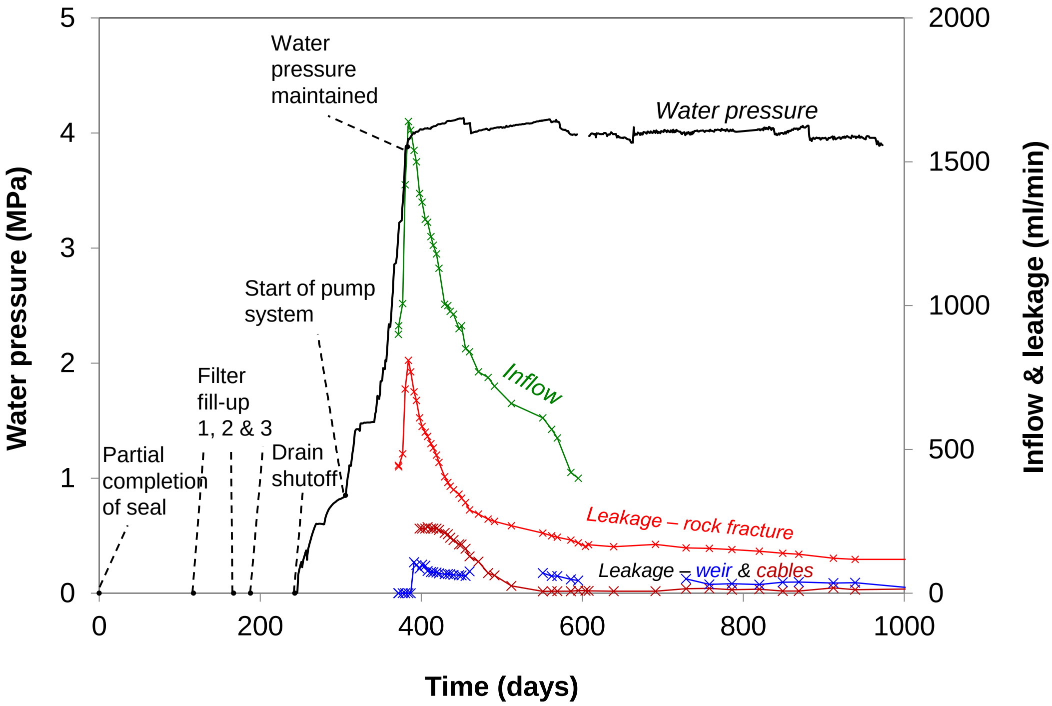

Figure 3. Timeline of major events, water inflow, measured leakage and water pressure.

4 Predictions

A blind prediction of the evolution of hydro-mechanical processes in the full-scale test was performed with a 2D axisymmetric Code_Bright model prior to the installation. This model included representation of bentonite backfill and seal (both blocks and pellets) as well as filter materials (Leca beams and macadam), see Figure 4. The mechanical processes of the bentonite-based materials were modelled with the thermoelastoplastic constitutive laws, based on the Barcelona Basic Model (BBM). The adoption of the mechanical parameter values followed the same strategy as for the data report for SR-Site (Åkesson et al, 2010). All materials were modelled with an initial suction and the build-up of stresses were driven by the bentonite hydration. Water was supplied through surface boundary defined in the pellets and filter materials. Details on the model is given by Börgesson et al. 2015.

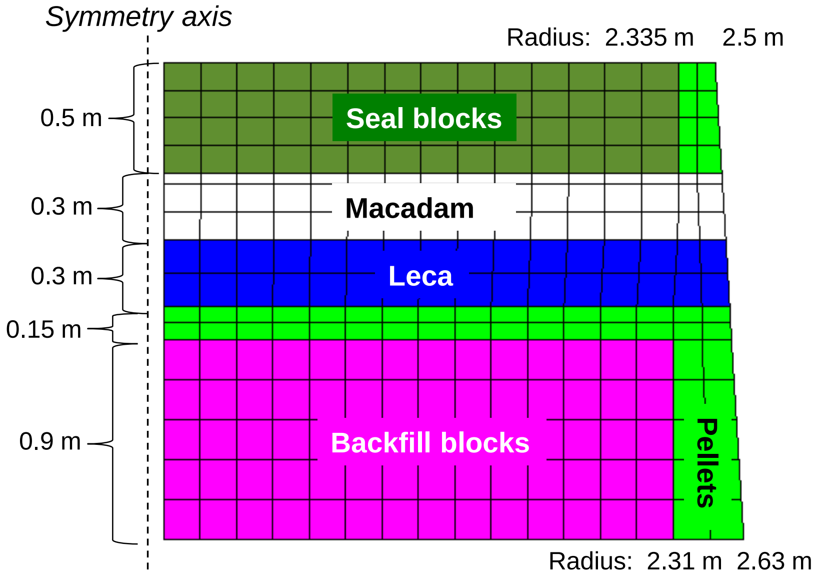

Figure 4. Numerical model: geometry and mesh.

5 Results

Measured and calculated evolutions of RH, axial stresses and displacements at different positions are shown in Figure 5. For the numerical prediction, it was assumed that the filter would be filled with water immediately after installation, whereas this occurred after day 188 in the full-scale test. Nevertheless, the prediction of the early evolution showed a fairly good agreement with data from the RH sensors, and an explanation for this may be that the bentonite had access to some groundwater before the filling of the filter. Still, the measure increase in RH was generally more rapid than the predicted evolution after the filling of the filter, and an explanation for this may be an effect of the pressurization. Predicted stresses and displacements, on the other hand, showed a more rapid evolution than the corresponding data from the full-scale test, especially before the water filling of the filter. The reason for this may be that the gaps between the blocks, which were not represented in the model, had to be closed before any stresses could build up. The general magnitude of the predicted displacements were fairly accurate, especially concerning the still functioning sensor at the interface between the Leca beams and the pellets-filled slot.

6 Concluding remarks

Results from the full-scale test, both sensors data and leakage measurements, show together with the numerical prediction that the plug components have functioned as intended. This concerns both the drainage capacity of the filter and sealing ability of the bentonite seal, although the concrete dome probably also has a significant sealing ability. It should be noted that the reduction of the leakage during the last year was fairly marginal. The pellet-filled slot behind the filter also appears to have reduced the build-up of stresses as intended.

7 Acknowledgements

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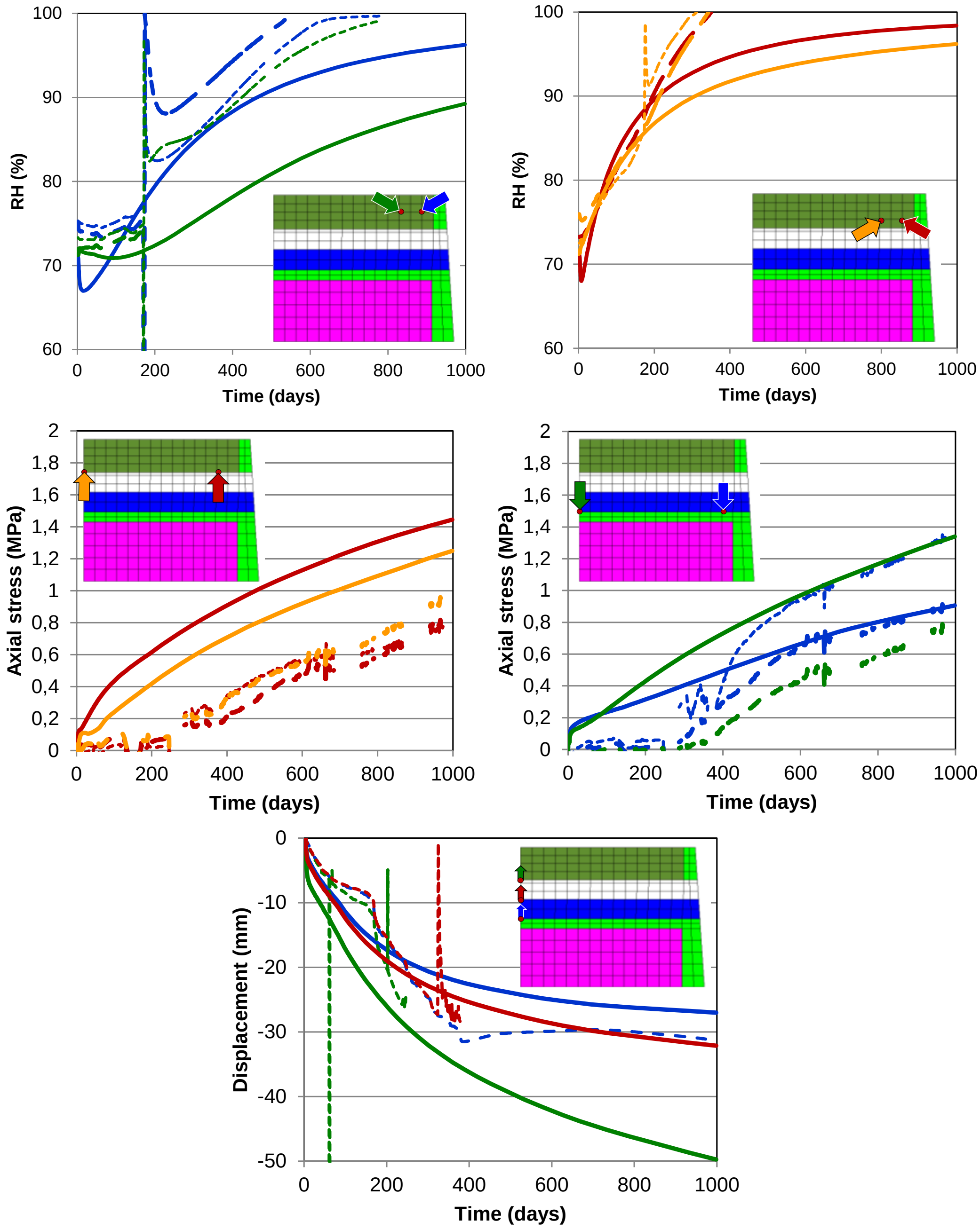

Figure 5. Evolution of relative humidity (upper), axial stresses (centre, evaluated as total pressure - water pressure) and axial displacements (lower). Model (solid lines) and experimental results (dashed lines). Sensor location indicated with arrows in figure with same color as lines.

8 References

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