Bentonite buffer material production and emplacement during the Full-Scale Emplacement (FE) Experiment at the Mont Terri URL

Herwig R. Müller[1], Benoit Garitte[1], Hanspeter Weber[1], Sven Köhler[1], Michael Plötze[2]

[1] Nagra, Wettingen, Switzerland; [2] Institute for Geotechnical Engineering, ETH Zurich, Switzerland

The Full-Scale Emplacement (FE) Experiment at the Mont Terri underground research laboratory (URL) is a full-scale heater test in a clay-rich formation (Opalinus Clay). According to the Swiss disposal concept it simulates the construction, waste emplacement and backfilling of a spent fuel (SF) / vitrified high-level waste (HLW) repository tunnel as realistically as possible. The entire experiment implementation as well as the post-closure THM(C) evolution will be monitored using several hundred sensors. These are distributed in the host rock in the near- and far-field, the tunnel lining and the engineered barrier system (EBS) and on the heaters.

Many important tasks, such as the excavation of a small cavern (completed in May 2011), the excavation of the experimental tunnel with a diameter of approx. 3 meters and a length of 50 meters (completed in September 2012) and the instrumentation of the rock in the 'far-field' (completed in April 2012), have already been executed successfully. The instrumentation of the rock in the 'near-field' is currently on-going and planned to be completed by until the beginning of 2014. The installation of the three heaters and of the instrumentation within the tunnel will happen before and during the emplacement of the bentonite buffer. Finally the FE tunnel will be sealed off with a concrete plug and heating will be started by the end of 2014. The general experiment layout without sensors and the bentonite back-fill is displayed in *Figure 1*.

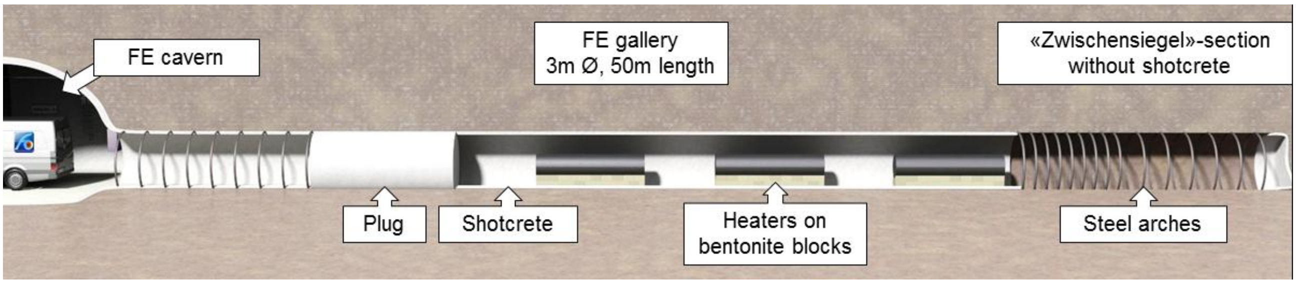

Figure 1: *Visualization of the general experimental layout of the Full-Scale Emplacement (FE) experiment at the Mont Terri URL; sensors and bentonite back-fill are not displayed.*

One of the main aims of the FE experiment is the optimization of the bentonite buffer material production and the investigation of backfilling procedures for realistic (underground) conditions. For this experiment only natural (non-activated) sodium bentonite from Wyoming will be used.

Highly compacted bentonite blocks for the pedestals below the heaters are produced. Although a bentonite block production is nothing new and unknown there are several issues to be considered. One is the strength (e.g. uniaxial compressive strength) of the bentonite block pedestal which is required to hold the heater in place; normally the strength is – for short-term loading – not problematic. But the fact that compacted bentonite is not fully saturated and therefore is in a state of suction can be troublesome, especially for an experimental set-up where the emplacement and the (stabilizing) backfilling may take longer than under repository conditions especially when encountering humid tunnel air. Under such conditions the bentonite blocks will take up water from the air and will start to swell. After a certain period of time the bentonite blocks will then disintegrate and consequently may not be able to carry the load.

The FE experiment is investigating the optimal water content and the optimal compaction pressure and consequently the optimal density and the optimal saturation state for strong and stable bentonite blocks for the expected conditions in the experimental tunnel; one example of such a pre-test is displayed in *Figure 2*.

Initial conditions		Initial conditions		Initial conditions		Initial conditions	
Water content	12%	Water content	12%	Water content	20%	Water content	20%
Compaction pressure	70Mpa	Compaction pressure	130MPa	Compaction pressure	70MPa	Compaction pressure	130MPa
Dry density	1.82g/cm3	Dry density	1.9g/cm3	Dry density	1.73g/cm3	Dry density	1.73g/cm3
Saturation degree	66%	Saturation degree	73%	Saturation degree	91%	Saturation degree	94%
Estimated equilibrium RH	52%	Estimated equilibrium RH	58%	Estimated equilibrium RH	62%	Estimated equilibrium RH	69%

Figure 2: *A rather simple but very effective small-scale pre-test in the framework of the FE experiment, where differently compacted and saturated bentonite blocks are loaded with weights in an environment with humid air. After a few days the blocks with a lower degree of saturation and therefore high suction (left photos) start to disintegrate due to the on-set of swelling.*

Another interesting challenge is the production of the (highly compacted and) granulated bentonite mixture, (hc)GBM, with the ideal properties for the backfilling of the experimental FE tunnel. Recent research confirms that the bentonite back-fill should consist of highly compacted bentonite granules (e.g. pellets) with a very broad grain size distribution, ideally a so-called Fuller-type distribution (Fuller and Thomson, 1907) in order to achieve an overall bulk dry emplacement density of at least 1450 kg/m3, as targeted in the Swiss concept. This density will ensure a low porosity within the bentonite buffer and a low hydraulic conductivity as well as a sufficient swelling pressure.

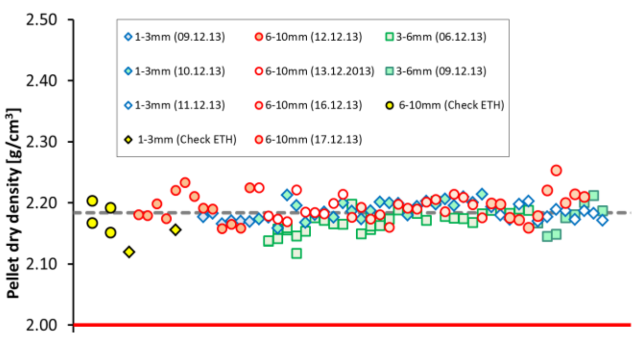

Figure 3: *Preliminary results from the first production of the (highly compacted and) granulated bentonite mixture, (hc)GBM, for the FE experiment. Displayed are the dry densities of the compacted bentonite granules (for different size fractions) measured for quality-control reasons during the production process; the average dry density of all measurements is high (2.18 g/cm3).*

For the FE experiment over 300 tons of bentonite back-fill are being produced. The deliverer of the raw bentonite as well as the producer of the (highly compacted and) granulated bentonite mixture, (hc)GBM, were chosen with the help of a public tender describing precisely the experimental requirements and specifications and targeted properties. The production of the (hc)GBM is done with roller compaction, followed by crushing, sieving and mixing. First measurement results from the compaction plant show very high dry densities of the compacted bentonite granules in the range between 2.12 to 2.25 g/cm3 (see *Figure 3*).

Also challenging is the already started construction of a prototype machine used for backfilling the horizontal FE tunnel; first sketches of this machine are shown in *Figure 4*. This prototype machine will transport, emplace and compress the (hc)GBM using five auger conveyors simultaneously. In order to control the machine parameters as well as the emplacement density several pre- and mock-up tests have been and will be conducted.

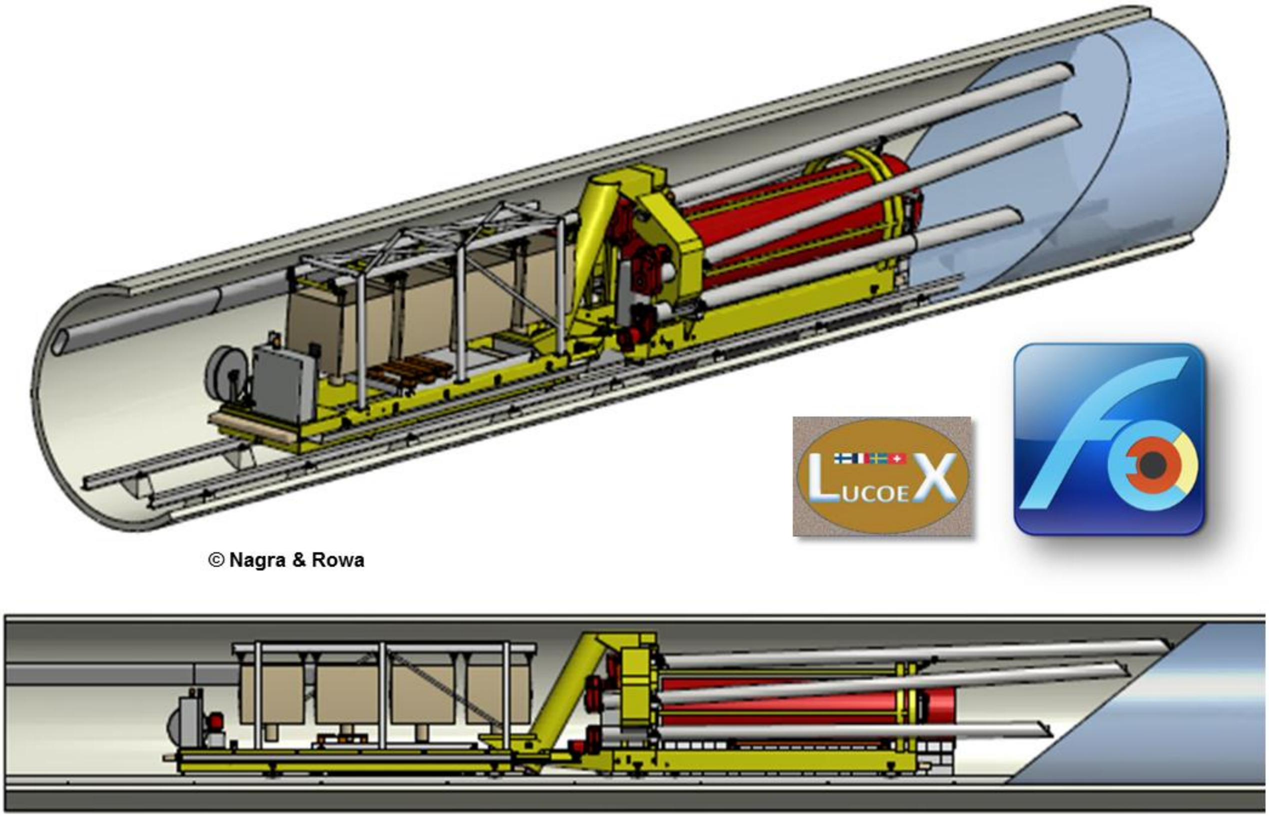

Figure 4: *First sketches (diagonal view & longitudinal section) of the currently constructed prototype machine with five auger conveyors for the emplacement of the (hc)GBM into the FE tunnel at the Mont Terri URL. The emplacement machine is approx. 12m long and fits into the tunnels with a diameter of partially only 2.7m. The machine will be fed with big bags transported with an approx. 6m long feeding device (displayed on the left side in the above sketches). The red object in the above sketches is one of the experimental heaters on top of a bentonite block pedestal.*

This experiment is part of the Mont Terri Project under the directorate of swisstopo. The initiator and lead organization for the experiment is NAGRA (Switzerland); ANDRA (France), DOE/LBNL (U.S.A), NWMO (Canada), GRS (Germany) and BGR (Germany) are participating in the FE Experiment.

The engineering and demonstration components of the FE experiment are also part of NAGRA’s participation in the EC co-funded ‘Large Underground COncept EXperiments’ (LUCOEX) project and therefore receive funding from the European Atomic Energy Community's Seventh Framework Programme (FP7) under grant agreement n269905.