The CIGEO FSS Experiment
Construction of a Seal Industrial Prototype
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----SUMMARY----

The **Full Scale Seal** (**FSS**) Experiment is one of various experiments implemented by Andra, within the frame of its Deep Geological Repository (aka DGR or Cigéo) Project development, to demonstrate the construction feasibility of the plugs and seals likely to be built, at the time of Cigéo progressive closure operations, in work openings such as shafts, ramps, drifts and/or disposal vaults.

FSS was built inside a reinforced concrete built horizontal drift model (aka “test box”) fabricated for the purpose, and located inside a surface hangar in Saint-Dizier (France) to mimic the *in situ* conditions.

The main FSS components concerned by the construction experiment (backfilling) were the 2 low pH concrete monoliths (aka “containment walls”) and the swelling clay core (bentonite) between them (cf. Fig.1). A support wall made of low pH concrete blocks was also erected to maintain the swelling clay core during the backfilling of the test box.

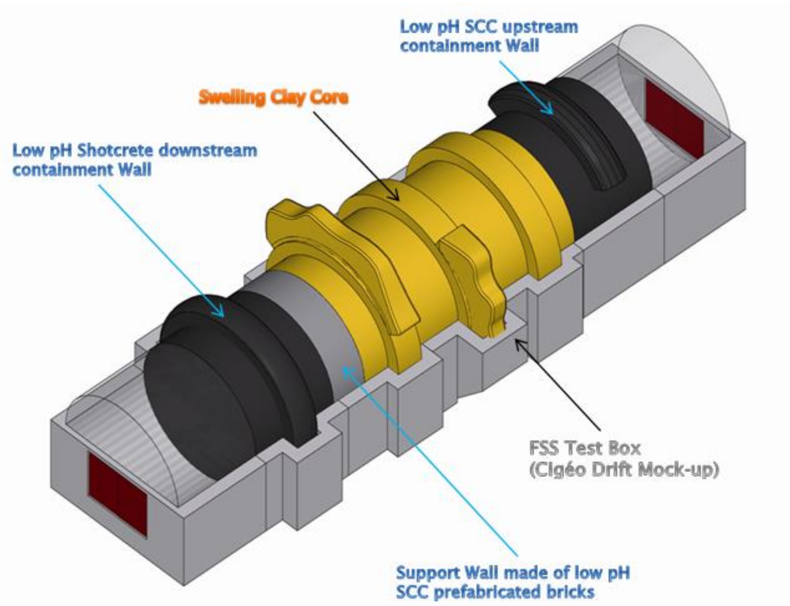

Fig.1: The FSS test components

The development of the materials used in FSS (low pH SCC and shotcrete, bentonitic mix) and their use in the construction process are shown. The construction story and the main experiment outcomes are also briefly summarized in the **FSS Poster**.

1. Introduction

The drift model specifically built for the FSS experiment was 7.60 m ID and 35.5 m long. The drift section made with reinforced concrete was 70 cm thick, incorporating “host formation break outs” (recesses) likely to be generated (i.e. in real Cigéo underground conditions) by the drift lining deposition (Fig.2 shows the test box before backfilling operations). Representative underground ambient conditions (i.e. temperature around 18-30°C & hygrometry level at some 75%) and mine like ventilation were maintained within the drift during the construction period. The low pH 5m long self-compacting concrete (upstream) and shotcrete containment walls (backstream) closed the volume of the swelling clay core (13.5 m long).

Polycarbonate windows were positioned for observation needs and reservations were integrated to the model structure for further monitoring and logging needs. The seal construction was preceded by laboratory work tasks including mainly the formulation and characterization of the materials concerned, in order to check that the measured performances would be in line with the specified requirements. This was true for the clay material constituting the swelling core (most likely bentonite pellets and bentonite powder), the low pH shotcrete and the low pH self-compacting concrete (to make sure that the formulations could fulfil the physical as well as the chemical specifications). Then a campaign of intermediate scale emplacement tests (metric or plurimetric) was run before adopting the final industrial solutions to check whether the fact of working at a larger scale had an impact on the emplaced material characteristics or on the emplacement method *per se*.

The FSS construction experiment being a technological demonstrator, it did not focus on the phenomenological survey (and as a consequence on the performance and behaviour forecast of the bentonitic material emplaced). A specific saturation test at a metric scale (cf. **REM Poster** and **REM Paper**, N. Conil *et al.)* was specifically and separately launched for this purpose.
Dry density measurement methods and tools were implemented, using specific devices (TDR sensors, gamma-gamma logging tool, and also a specific penetrometer) for the bentonite material. To follow the concrete behaviour during hydration, temperature and shrinkage were also monitored, thanks to sensors pre-positioned inside the test box (before backfilling).

The FSS started on mid-2012 and was completed by end of 2014 with a “clever dismantling” of the test box and seal components: it was a “post-mortem” investigation added to the initial construction objectives of FSS. All the work sequences were video-taken and a chronogram of operations established to assess the overall time needed to build a complete seal in Cigéo.

The main milestones were:

i. Studies, formulations & characterization of materials (slow pH SCC and shotcrete): end 2012-mid 2013,

ii. Construction of test box: end 2012-mid 2013,

iii. Construction of seal components (SCC monolith, swelling clay core and shotcrete monolith): mid 2013 – end 2014,

iv. Monitoring and commissioning of seal components: end 2013 – end 2014,

v. Dismantling & additional investigations: mid 2015 - end 2015.

Fig.2: The FSS test box equipped with mine like ventilation before backfilling operations

2. Outcomes of FSS Construction & measurement systems

2.1 Construction issues

The aim of the FSS experiment was to demonstrate the industrial feasibility of the emplacement of large volumes of bentonite (clay core) and low-pH concrete (containment walls) in a full scale seal. Andra is satisfied with the outcomes of the experiment and considers that the GME consortium, who was responsible for conducting the FSS experiment, has demonstrated this feasibility, even though Andra had to revise down the swelling pressure technical specification for bentonite performance (i.e., from 7 MPa to 4 MPa).

Andra considers that construction feasibility is now proven at a one-to-one scale. The low-pH SCC containment wall construction was undertaken with existing civil engineering technology, demonstrating that there is no requirement for novel technology developments for emplacement of such structures in a repository. It was also concluded that low-pH shotcrete use in the repository should be discarded or minimized to be considered only in the building of the support walls or of the surrounding concrete liner support.

The feedback from this construction will be useful in defining the future full-scale seal tests to be conducted at the beginning of Cigéo during the Industrial Pilot Phase. During this Pilot Phase, Andra will build a replica of the future real seal underground, but equipped with various monitoring systems (while no intrusive systems will be allowed inside the real Cigéo seal swelling clay core, at the time of closure).

The production of dust during the bentonite mix transfer or backfilling operations needs some additional mitigation (e.g. water mist forming a curtain or/and some tarps around the silos).

2.2 Measurement systems for the low pH concrete containments walls

Low-pH SCC and shotcrete shrinkage and curing temperature sensors worked well. They could be kept in the Cigéo containment walls as a quality control tool. Intrusive monitoring is not an issue in this case, since the containment walls have no hydraulic performance requirements.

Evaluation of quality of the contact between the host rock and the concrete is challenging. Measuring the volume of injected bonding grout is an indicator of the residual volumes to be filled. Practically, it is probable that 3D scanning before and after casting a containment wall will be carried out and compared with the measurement of the concrete volume poured inside the form. Besides, the progressive creeping of the rock will ensure a full contact with the concrete before the core swelling induced forces take place, minimising this issue.

2.3 Measurement systems for the swelling clay core

Two issues are of concern to commission the swelling clay core:

- Compliance of the measured average dry emplaced density of the bentonite mix with the specified requirements.
- Assessing the space variability of the emplaced mix in the core volume to determine the backfilling heterogeneity, even if no variability parameters have been defined so far by Andra.

On the basis of the works carried-out in FSS, Andra's temporary conclusions on the monitoring and commissioning tools deployed are as follows:

- Penetrometry is a promising solution but is far from ready for Cigéo application (as calibration is difficult and should be reconsidered for oblique and longitudinal applications). Andra will further explore this technical development in the future.
- Observation windows: visual observation was difficult at times due to dust build-up on the polycarbonate folio. This type of device is not applicable to Cigéo. When observable, it was noticed that effectively, the summital recesses were less properly backfilled (e.g. containing pellets only) than the bottom recesses, qualitatively corroborating the measures provided by gamma-gamma logging or Penetrometry.
- Results obtained from gamma-gamma logging are consistent with measured values made Penetrometry and TDR technology. This device however needs additional development and a better calibration. Besides, logging requires pipes inside the bentonite core, including organic materials. This application to the real Cigéo seals is not considered and no further development is envisaged at this stage.
- For operations, mass weighing of bentonite and 3D scanning will be used in Cigéo.
- No other non-intrusive solutions to estimate residual voids have been identified so far. Using the TDR technology is intrusive, even if much less space is needed than for gamma-gamma logging. Andra has not decided yet if this TDR technology will be deployed for the future full-scale seal tests to be conducted at the beginning of Cigéo during the Industrial Pilot Phase.