DOPAS EPSP Experiment

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The Experimental Pressure and Sealing Plug (EPSP) experiment being undertaken by Czech Technical University (CTU), SÚRAO and ÚJV a.s. at the Josef underground research centre (URC) and underground laboratory in the Czech Republic as part of the DOPAS project ("Full-Scale **D**emonstration **O**f **P**lugs **A**nd **S**eals"). The project is built around a set of full-scale demonstrations, laboratory experiments, and performance assessment studies and is jointly funded by the Euratom's Seventh Framework Programme and European nuclear waste management organisations. This four year project is running from September 2012 to August 2016, and is being coordinated by Posiva Oy, the nuclear waste management company in Finland.

The EPSP plug has been designed as a prototype plug for a future Czech deep geological repository. It is expected therefore that similar plug will function during the whole of the operational phase of the repository, i.e. 150 years with an expected over-pressure of up to 7MPa. Furthermore, the plug has been designed as a multilayer system consisting of two main structural elements which ensure the overall stability of the system, i.e. concrete blocks and a sealing element - a bentonite section positioned between the concrete blocks. Glass fibre shotcrete with reduced pH was used in the construction of the various elements of the EPSP; the bentonite sealing section was constructed by means of compaction and spray technology.

The plug is tested by means of injecting air/water/a suspension into a pressurizing chamber followed by the monitoring of the performance of the plug.

1 Introduction to EPSP

EPSP is not a specific DGR plug or seal; rather it was built at a similar scale to a disposal tunnel plug and will contribute specifically towards the development of a reference design for such structures. The objective of the EPSP experiment is to test both the materials and technology to be used for implementation, not to test the design and performance of the reference disposal tunnel plug. At this early stage in the Czech geological disposal programme (Pospíšková 2008, SÚRAO 2011), more than 50 years prior to the scheduled commencement of operation, it is considered by those involved more important to build knowledge and experience rather than to refine implementation designs for an, as yet, unidentified site with unknown mechanical, hydrogeological and chemical characteristics.

The conceptual design for EPSP experiment includes the following components:

- Pressure Chamber: The pressure chamber (or injection chamber) is an open area that can be used to pressurise the inner concrete plug. The chamber contains an inlet valve and a drain valve that can be used to fill the chamber with air (gas), water or bentonite slurry. The pressure chamber is sealed with a waterproofing finish.

- Concrete Walls: Concrete walls (made of blocks) were used to facilitate the construction of EPSP. Three concrete walls were built: one between the pressure chamber and the inner concrete plug, one between the bentonite and the filter, and one between the filter and the outer concrete plug.
- Inner Concrete Plug: The inner concrete plug forms one of the sealing components of EPSP and was constructed using sprayed glass-fibre concrete. The concrete is of relatively low pH.
- Bentonite Pellets: The bentonite pellet zone comprises “Bentonit 75”, i.e. a Czech natural and high-smectite content Ca-Mg bentonite. The purpose of the bentonite is to seal and absorb/adsorb any water that leaks across the inner concrete plug. The bentonite zone is 2m long. (more in Vašíček, 2016 and Večerník et. al., 2016)
- Filter: The filter collects any water that is not absorbed by the bentonite. This is most likely to occur if the leakage rate across the inner concrete plug is sufficient for piping and erosion of the bentonite to occur. The filter may also be used to reverse the direction of pressurisation of EPSP.
- Outer Concrete Plug: The outer concrete plug is designed to hold the other components of EPSP in place. However, should the direction of pressurisation of EPSP be reversed, the outer concrete plug have to perform as well as the inner concrete plug, and, therefore, the requirements are the same as the requirements on the inner concrete plug.

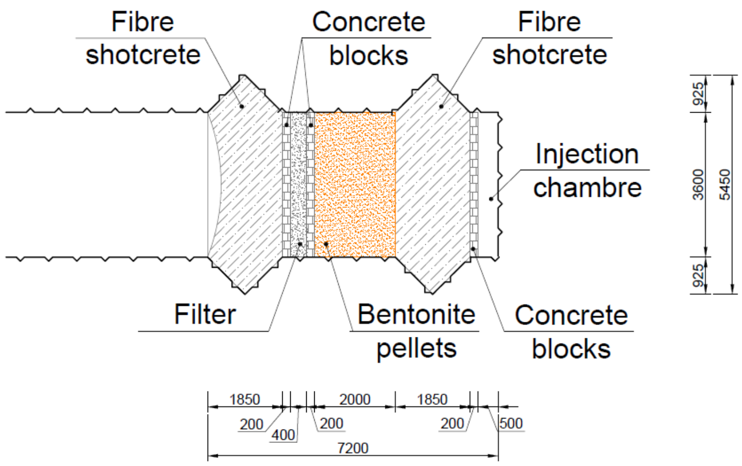

Figure 1 - Scheme of EPSP

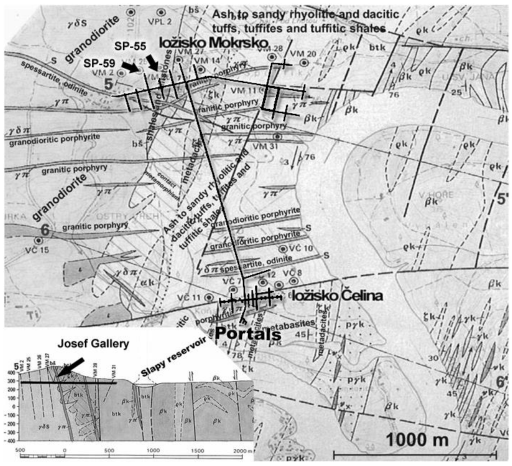

Figure 2 – EPSP location in Josef URL

2 EPSP Location

The EPSP experiment has been built in the Josef Underground Laboratory (Josef URL). Josef URL which opened in June 2007 is a facility of Faculty of Civil Engineering, Czech Technical University in Prague and is operated by the Centre of Experimental Geotechnics (CEG). The Josef URL is employed primarily for the teaching of students from the CTU and other universities. Other activities include research and cooperation on projects commissioned by the public and private sector.

The Josef URL uses Josef gallery which is located Czech Republic 50km south of capital Prague. There is over 8km of galleries and niches of which more than 5km of underground space is currently available and it provides a unique facility for the teaching of students, research connected to a range of projects, training courses, etc.

The EPSP experiment itself is located inside M-SCH-Z/SP-59 experimental gallery niche. The niche was reshaped in advance and surrounding rock has been improved by grouting in order to reduce the water permeability (in order to allow for higher pressures loaded on the plug itself).
The necessary technology for the experiment is located in parallel niche M-SCH-Z/SP-55.
The niches are interconnected by cased boreholes equipped with tubing for pressurization media circulation (4 leading into filter and 4 leading into pressurization chamber) and for monitoring (5 boreholes equipped with sealed cables lead trough).
Experiment construction

3 The experiment construction can be divided in five tasks.

- Task 0 - Niches preparation and documentation
- Task 1 - Rock reshaping & improvement, Instrumented rock bolts, Connecting boreholes, Plugs contact grouting
- Task 2 - Construction works (shotcrete, support structures, filter,…), Technology
- Task 3 - Bentonite sealing
- Task 4 – Monitoring

3.1 Niches preparation and documentation

The niche(s) for the EPSP experiment have been selected in 2012. The selection process was based on results of geological survey of available unground spaces in Josef URC. The detail geological mapping has been subsequently performed once particular niches has been chosen.
In the first part of 2013 the niches have been equipped with networks and prepared for the construction works.

3.2 Rock reshaping and improvement, rock bolts, boreholes

The reshaping and ground improvement activities started in October 2013 with 3D scanning of the existing niche profile. Based on the results of the scanning the precise location of the EPSP experiment was determined.
Once the position of EPSP was fixed, the excavation works started with excavation of the slots in which the shotcrete plugs would be emplaced. The excavation was carried out gradually, at first, rough excavation of rock was undertaken, followed be manual smoothing out.
Selection of the rough excavation method was constrained by a requirement that excavation was undertaken without blasting. This requirement was introduced to minimise the potential for EDZ development. Initially, a hydraulic wedge splitting technique was applied, but this technique was found to be particularly challenging for excavation of the EPSP shotcrete plug slots. Therefore, alternative technique was selected. a second technique was used for construction of part of the outer plug.
The second technique was a pressure disintegration technique using Green Break Technology (GBT) cartridges (non-detonating gas expansion cartridges). The GBT technology significantly accelerated the work on the excavation for the plugs. The excavated opening contour was more precise and smoother, compared to the hydraulic splitter technique.
Following construction of the slots, the rock mass was injected with polyurethane resin at high pressure so as to improve the quality of the host rock.
In parallel to these actions connecting boreholes have been made and later on cased, equipped with cable heads (selected boreholes) and grouted. Thirteen 23 m-long connecting boreholes were drilled between the SP-59 experimental niche and the SP-55 technological niche for the purpose of pressurising the experiment and for instrumentation requirements Eight of the boreholes were used for pressurisation and five for cabling associated with the experiment monitoring system.

The instrumented rock bolts were installed as well. In total 12 instrumented rock bolts has been installed into 3 profiles denoted by the point of origin – originating form niche face, inner slot and outer slot.
These action finished in October 2014.

3.3 Plug erection and technology

The installation of the plug, from installation of the first concrete separation wall to installation of the outer concrete plug, took about 3 months. This does not include the time required for grouting, and monitoring technology. The total time from chamber adjustment to fully operation experiment was 10 months. A major delay was caused by contact grouting of inner plug where several campaigns were done with long waiting time for curing in between. The shotcreting action (plug erection) by itself was very fast. It took less than 24h to erect each plug followed by 1 month curing.

3.3.1 Pressurisation chamber

The walls and floor of the pressurisation chamber were prepared using shotcrete. The thickness of the profiling was such that there was a gap of 100 mm between the remodelled chamber surface and the next structure (the first concrete separation wall). The surface of the remodelled chamber was treated with a 3 mm thin waterproofing finish. The pressurisation chamber was closed by installation of the first concrete separation wall.
The shotcreting of the pressure chamber also served as a test of the technology used for shotcreting of the inner plug.

3.3.2 Inner plug

The inner plug was built using glass-fibre-reinforced low-pH shotcrete. The wet mix shotcreting procedure was used for construction of this plug. The shotcreting was performed in approximately 100 mm thick layers and in a non-stop run in 23 hours. Measurements and observations during the experiment demonstrated that contact grouting between the plug and the rock was necessary to ensure water tightness.
The major influence on the speed of the shotcreting process was logistics. The concrete mix was produced at a concrete plant in Prague and transported by road to the Josef URC and underground laboratory. At the entrance to the facility, the mixture was reloaded into small trucks (each capable of transferring $1m^3$ of concrete), because the small profile of the Josef tunnels limited the size of the trucks that could access the experiment location and therefore limiting the supply.

3.3.3 Filter

The gap between the second and third separation walls was used for the gravel filter. The filter was manually emplaced in steps. At first, the lower part of the walls (approximately one-third to half of the overall height) was erected and the gravel filter was emplaced in the resulting gap. Following this, the bentonite emplacement commenced. Once the bentonite level reached the level of the walls (and the filter) new layer(s) of concrete blocks were constructed and the filter emplaced. The final layer of the separation walls and the gravel was emplaced immediately after shotclaying was completed.

3.3.4 Outer plug

The outer concrete plug was constructed in exactly the same manner as inner plug. The only difference between the inner and outer plug was the installation of grouting tubes around the circumference of the outer plug prior to shotcreting.
Once the plug had cured, grouting was undertaken using the preinstalled tubes. Initial pressure testing of EPSP demonstrated that this grouting was not sufficient and additional grouting was employed in similar way as for inner plug.

3.4 Bentonite sealing

Czech raw Bentonite 75 in powder form was selected as the material to be employed for compaction into pellet form (the powder material was marked as B75 2013). The bentonite B75 was used in form of pellets. Two types of pellets were used. First type (compacted by roller trough die) were used for lower parts. Second type (compacted by rollers, subsequently crashed and sieved) were used for shot clay technology in the upper parts of experiment. More on bentonite selection and pellets manufacturing in Večerník et. Al., 2016 and Vašíček et al.,2016.
Following the results of pilot test (Vašíček et al., 2016) a vibration desk type machines were selected for bulk works. The bentonite was emplaced in horizontal layers with maximal height 3cm which were subsequently vibration compacted. Sprayed clay technology was used for the backfilling of the upper part of the drift. Approx. 5% (1.5m^3) were backfilled using this technology.
The construction of the EPSP bentonite pellet layer were done in 9 days between 5th June and 15th June 2015. The total amount of emplaced material is 39.9 tons which were placed into volume of 23.7m3.
Based on project requirements of minimum swelling pressure of 2MPa and maximum hydraulic conductivity of 10^{-12}ms^{-1} of the bentonite sealing a minimum dry density of 1.4Mgm^{-3} was required after bentonite deposition. Two methods of density verification were employed – sampling and total mass balance. Both method shows dry density more than the required level.

3.5 Monitoring

The primary aim of monitoring of EPSP is to investigate the various processes underway inside each plug component, to verify component behaviour and to assist in assessing their performance in order to build a knowledge base for the construction of a future repository plug.
The key processes and locations inside EPSP have been identified and sensors have been specially selected in order to capture them. Monitoring of EPSP focuses on water movement inside the experiment and the experiment’s response to pressurisation.
Water movement inside the experiment is monitored in terms of water inflow, water content distribution within the bentonite seal and water (pore) pressure distribution.
The mechanical response of the plug is monitored by means of strain gauges installed at key locations in the concrete plugs and instrumented rock bolts positioned within the rock. Moreover, contact stress measurement is deployed between the rock and the plug.
Temperature distribution is monitored since it is important not only to understand the hydration heat generated through curing, but it is also used as a reference base for sensor compensation during the loading of the experiment.
An integral element of the monitoring process consisted of the presentation of the measured data for further analysis; therefore the data were instantly available online to end-users via a simple web interface.
The sensor preparation has been carried out in the workshop of the Josef URC facility. Sensor were assembled and equipped with protective tubing from stainless steel. Complete assemblies were step by step transported into the underground following the process of plug erection. In the underground

the sensors have been installed to their final positions or temporary stored on niche side until their location was ready (and then installed).

4 Pressurisation of EPSP

Experimental testing of EPSP started during construction process. The inner plug has been using water and air injection up to 0.5MPa to check water tightness level in order to determine if grouting is need.

Once the outer plug has been cured the main experimental program started with series of short water injection test followed by long term tests at various pressure levels (starting at 0.1MPa going gradually to up to 1MPa). At 1MPa a possible channelling has been detected.

In order to avoid erosion of the bentonite sealing the testing sequence has been interrupted and the sealing section has been artificially saturated from both filter and pressurisation chamber to allow swelling pressure build up (the swelling pressure was significantly lower than testing pressure at channelling event).

The saturation has been later on followed by short pressure test and by injection of bentonite slurry into pressurisation chamber (up to 2.5MPa). The pressurisation chamber was then cleaned up and water injection test resumed.

5 Conclusions

The aim of the EPSP experiment is to develop and demonstrate the feasibility of plug for DGR of radioactive waste in real conditions.

In order to achieve this not only EPSP plug is constructed but extensive monitoring programme is carried out too. The data coming from the experiment and knowledge obtained from both the in-situ and laboratory experiments will be evaluated using numerical analysis techniques and modelling. The final output will consist of the verification of the operational safety of the various structural elements of plugs to be used in DGRs and detailed recommendations for the future design of DGR.

6 Acknowledgement

The research leading to these results has received funding from the European Union's European Atomic Energy Community's (Euratom) Seventh Framework Programme FP7/2007-2013 under grant agreement no 323273, the DOPAS project, and form Czech Ministry of education, youth and sports under grant agreement no 7G13002.

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