DOPAS EPSP Experiment Monitoring

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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 EPSP plug has been designed as a prototype plug for a future Czech deep geological repository. 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. 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.

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.

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.

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 et. al., 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.

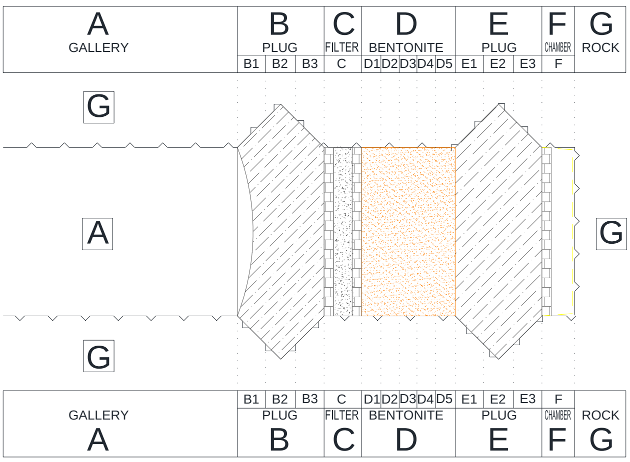

Figure 1 - Scheme of EPSP (measurement profiles)

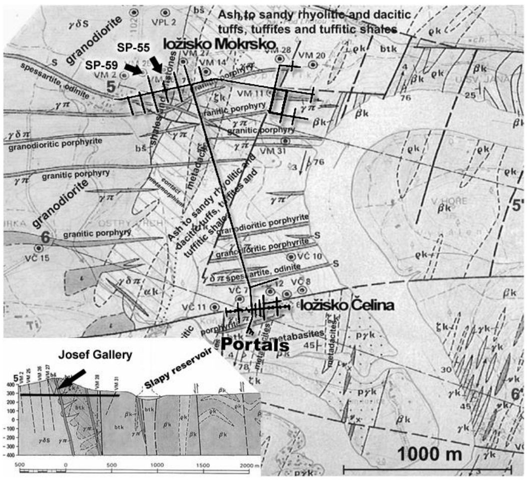

Figure 2 – EPSP location in Josef URL

2 EPSP Location

The EPSP experiment has been built in the Josef Underground Laboratory (Josef URL). 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 troughs).

More in Svoboda et al., 2016, DOPAS Seminar, DOPAS EPSP experiment.

3 Monitoring of EPSP

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.

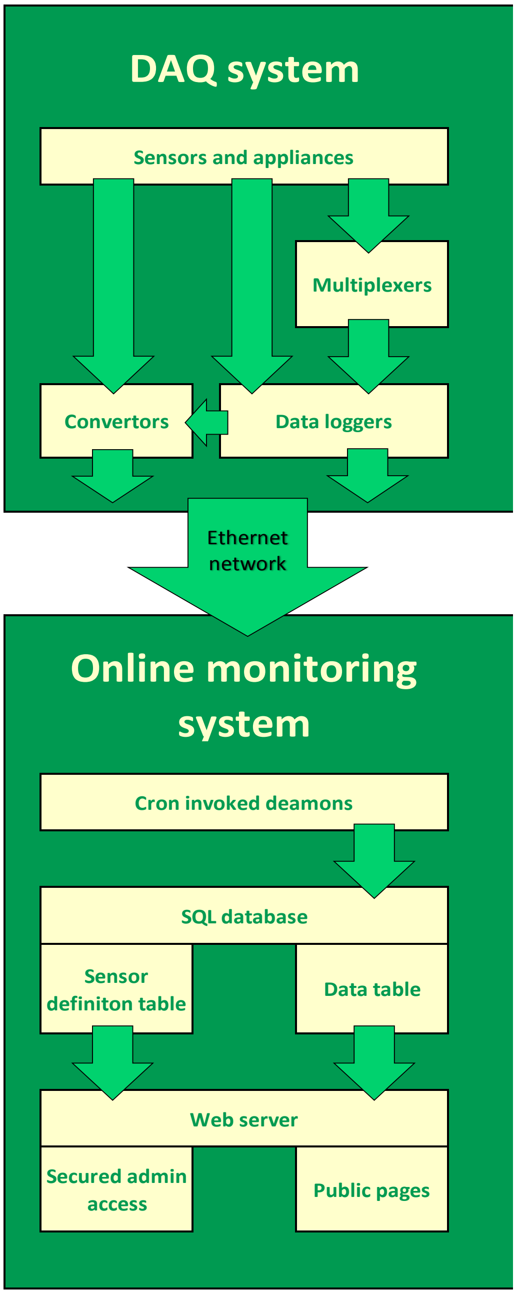

Figure 3 - EPSP measurement system

4 Measurement system

The data acquisition and monitoring systems are based on components previously developed and used at the Czech Technical University in Prague (CTU), Centre of Experimental Geotechnics (CEG) (Pacovský et al. 2006, 2010; Levorová & Vašíček 2012, Vašíček & Svoboda 2011).

The system has two main elements: the data acquisition system (DAQ) and the online monitoring system (Figure 3). The DAQ forms the main hardware element and is responsible for the actual taking of measurements. The online monitoring system is responsible for data collection, storage and presentation to end-users.

5 Data acquisition system

The data acquisition system (DAQ) is responsible for measurement performance and the preparation of data for the monitoring system.
There are two key components: the sensors and the data loggers/convertors.

5.1 Sensors

The sensors used for DOPAS EPSP were selected to capture important processes inside the experiment – with focus to monitor water distribution, pressures, deformation and temperature. Where possible sensors based on different principles were used to measure same phenomena in order to enhance reliability.
Following sensors were used:

- Temperature – digital thermometers DS18B20, analogue LM35DZ and NTC resistors
- Water distribution – relative humidity sensors EE071 and TDR sensors 5TE
- Pressure – VW pressure cells 4810X-10MPa and piezometers 4500SHX-10MPa
- Deformation – VW strain gauges (4200A-2) and instrumented rock bolts (4911-4X)

More over pressurisation technology was monitored including water inflow into experiment.

Figure 4 - temperature sensor in protective housing

Figure 5 - RH sensor including cabling protection

Figure 6 - Sensors ready to be put into assembly

Figure 7 - Cable head preparation

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 (Figure 4 and Figure 5). 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).
In the experiment the sensors are organised into profiles (Figure 1) for easier orientation.

5.2 Data loggers/convertors

Three main types of data loggers are being used in the DAQ system:

- Campbell Scientific CR1000-based system
- GeoKon LC2x16
- CTU in-house built data loggers for digital thermometers

Moreover, several media convertors are being used to connect the digital sensors directly into the DAQ network.

6 Online monitoring system

The online monitoring system has been designed as part of the CEG's DAQ and monitoring system. From the point of view of hardware, it consists of a heterogeneous collection of various sensors, data loggers, network infrastructure and servers on top of which is located the software stack which features two main components: the backend and frontend. Mainly open source programs are used within the system.

6.1 Backend

The backend is responsible for data collection and storage. Data collection is handled by a set of daemons each of which is custom built to fit a specific data logger or digital sensors/equipment. These daemons are responsible for data collection, data format transformation and storage in the open source MariaDB SQL database. They typically run at 10-minute intervals (using Cron) so as to ensure the collection of the very latest data.

6.2 Frontend

The frontend is the most visible part of the system since it is the part with which the user interacts. The frontend is web based and runs on an nginx (http://nginx.org/) web server; it consists of a specialised web site written in the php programming language and JavaScript.
The system pulls all the necessary data from the backend database and presents it to the user. The system rapidly calculates results for the user from the raw data. The results of calculations are cached and held in a separate database in order to speed up the system and to reduce system processing power requirements; this significantly reduces system overheads.
The website provides online information on the status of the experiment and the simple data visualisation interface (2D charting and 3D visualisation). For more comprehensive analytical purposes direct data export is available using specialised URLs.

7 Monitoring performance

Performance of monitoring equipment during construction works and bentonite emplacement was good. The monitoring system has been able to reliably monitor hydration heat evolution and shrinkage of the concrete plugs.
During the pilot test and subsequent run, the instrumentation performed well too. It was able to reliably track the development inside the experiment especially in the sealing section.
Cabling perpendicular to the experiment axis helped to reduce the negative influence of possible flow along cabling.
There have been some problems with water leakage into sensors during high pressure tests (one of the sensors caused back flooding of several others). The leak has been resealed and the affected sensors disconnected. Fortunately, the sensors affected were temperature sensors which already fulfilled their primary purpose (hydration heat monitoring), therefore the impact on the system was minimal. Compartmentalisation and redundancy built into the system helped greatly to reduce the impact of the incident.
The influence of the monitoring system on the erection process was mostly negative (but manageable). The fixed cabling creates obstacles for the sprayed concrete. This could lead into the creation of "shadows", e.g., weaker parts behind the obstacles. This could be mitigated to a large

extent by good operation of the shotcrete nozzle by the operator. However, places around such objects are known to be usual weak spots. On the other hand, the protective steel tubing acts as some sort of reinforcement of the plug (although very minor).

8 Conclusions

Monitoring is important part of every experiment as it provides insight into what is going on. Properly designed and maintained monitoring system is therefore essential to get valuable data. The monitoring system itself has influence on the experiment itself and it is very important to design monitoring in such a way that the impact is minimised. That includes not only impact on experiment performance itself but also to experiment construction process.

Reliability and precision of system is another important point. For the EPSP this has been achieved by redundancy and careful selection of sensors types complementing each other. This allowed to cross check the data between sensors of different principles.

It also proved to be important to start monitoring before the construction itself. This way a correct baseline state is captured and experiment implementation has been monitored. The data coming from the experiment provide important basis to the evaluation of the EPSP performance.

9 Acknowledgement

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10 References

Levorová, M., Vašíček, R.: The Response of Tunnel Lining on Thermal Loading. Rudarsko-Geološko-Naftni Zbornik. 2012, vol. 2012 (1), p. 67-71. ISSN 0353-4529.

Pacovsky, J., Svoboda, J. (2010), In situ monitoring at the Josef Underground Facility, Modern workshop Troyes - PP18 - http://www.modern-fp7.eu/fileadmin/modern/docs/Deliverables/MoDeRn_D2.2.1_Troyes_Monitoring_Technologies_Workshop.pdf

Pospíšková, I. et al.,2008-2012: Aktualizace referenčního projektu hlubinného úložiště radioaktivních odpadů v hypotetické lokalitě, ÚJV Řež,a.s.

SÚRAO,2011, Update of the Reference Project of a Deep Geological Repository in a Hypothetical Locality. Accompanying Report. Report EGP 5014-F-120055.

Svoboda et al., 2014, D3.18 Testing plan for EPSP instrumentation and monitoring

Vašíček R., Hausmannová L., Šťástka J., Svoboda J., Nádherná D., Pacovská D., Hubálovská J., Vašíček, R. - Svoboda, J.: Long-term lining performance - Civil engineering problem of potential retrieval of buried spent nuclear fuel. Nuclear Engineering and Design. 2011, vol. 241, no. 4, p. 1233-1237. ISSN 0029-5493.

Večerník P., Trpkošová D., Gondolli J., Dvořáková M., Hanusová I., Bělíčková L. (2016): Final results of EPSP laboratory testing, Deliverable D3.21, EU FP7 project DOPAS no. 323273, Czech Technical University in Prague, Prague

Večerník P, Vašíček, R., Šťástka J.,Trpkošová D., Havlová V., Hausmannová L., Smutek J., Svoboda J., Dvořáková M., 2016, DOPAS Seminar, Performance of Czech Bentonite Material in the Plug in Geological Disposal Demonstrations.