The Experimental Pressure and Sealing Plug (EPSP) Experiment as part of the wider European DOPAS project - rock mass improvement and construction

Irena Hanusová
SÚRAO (Radioactive Waste Repository Authority), Dlážděná 6, Prague 1, 110 00 Czech Republic, hanusova@surao.cz

Markéta Dvořáková
SÚRAO, Dlážděná 6, Prague 1, 110 00 Czech Republic, dvorakova@surao.cz

Lucie Bělíčková
SÚRAO, Dlážděná 6, Prague 1, 110 00 Czech Republic, belickova@surao.cz

ABSTRACT
The objective of the DOPAS international project is to design a sealing plug system for deep geological repository (DGR) use, provide detailed plans for the design of such plugs, test both the characteristics of the materials to be used and the construction technology and to install 4 experimental in-situ plugs.
This four-year (2012–2016) project is being funded from European Commission financial resources (7th framework programme, EURATOM) and the project coordinator is Finland-based Posiva. A total of 14 partners from 8 European countries are involved in the project (Posiva, ANDRA, DBE-TEC, GRS, Nagra, NDA, SÚRAO, SKB, ČVUT, NRG, GSL, BTECH, VTT, ÚJV Řež).
The Czech EPSP experiment is being conducted in a rock environment consisting of granitoids at the Josef Regional Underground Research Centre (URC). The concept of the experiment is based primarily on the use of Czech materials and technology available in the Czech Republic and the principal aim is to demonstrate the technical viability and functioning of a pressure-resistant plug located in a future DGR.
The completion of the EPSP experiment will contribute towards both the demonstration of how sealing plug systems behave under real underground conditions and the long-term safety of a future DGR in the Czech Republic.

Keywords: plug and seal, EPSP experiment, grouting.

1 INTRODUCTION

The DOPAS project (the Demonstration of Plugs and Seals), which involves the participation of a total of 14 European organisations, is focused on the structural design of sealing plugs to be used in deep geological radioactive waste repositories and the verification of the functionality of such plugs. The project is being funded by the 7th Framework Programme – EURATOM (grant agreement no. 323273).

The Czech contribution to the DOPAS project (the EPSP experiment) is being conducted at the Josef Regional Underground Research Centre some 50km south of Prague. The aims of the EPSP experiment are to develop, monitor and verify the functionality of such plugs and to determine a detailed characterisation of the Czech materials from which the plug is constructed (low pH concrete, Ca/Mg bentonite etc.).

2 EPSP DESCRIPTION

The EPSP experiment has been divided into 4 stages. The first stage primarily concerned the laboratory verification of the suitability of the materials to be used in the construction of the plug. The second stage consisted of the construction of the in-situ experiment which commenced in 2013 with grouting and drilling work in the SP-59 experimental gallery niche. This was followed by the construction of the plug itself. The third stage consists of pressurisation by means of a number of saturation media (air, water and a bentonite suspension) during which the plug will be exposed to pressure of up to 2MPa (limited by the virgin stress of the surrounding rock mass). The final stage of the experiment will consist of the evaluation of the data obtained employing numerical analysis techniques and modelling.

3 EPSP CONSTRUCTION

3.1 Pressurisation chamber

The chamber (Fig. 1) serves as the principal injection point for the pressurisation media; with this aim in mind, the chamber was equipped with four pressurisation tubes (connected to the technical equipment).
Once the shape had been adjusted, the surface of the chamber was treated with a waterproofing layer in order to avoid potential leaks behind the chamber.
The final stage involved the erection of a permeable separation wall between the chamber and the inner plug which served as the formwork for the shotcreting of the inner plug.

3.2 Inner and outer plug

The inner plug was erected over a continuous 23-hour period using shotcrete technology. The concrete was produced at a mixing plant in Prague and subsequently transported by large trucks to the Josef URL (transportation time 1-1½ hours).
The concrete mix was then gradually reloaded onto smaller trucks which transported the wet mix from the tunnel portal to the spraying machine in the experimental niche (distance of 2km).
The plug was erected layer by layer commencing in the rear section (separation wall) so as to gradually fill the plug space with shotcrete. The short time breaks between the separate concreting stages were used for the installation of the instrumentation.
The outer plug was constructed employing the same procedure as that of the inner plug.

3.3 Bentonite emplacement

Bentonite pellets were subsequently emplaced between the inner plug and the filter; the lower parts of the bentonite seal were compacted using the vibration technique.
The upper part of the seal was emplaced using shot clay technology.
The target average dry density following emplacement with respect to both methods was set at a minimum of 1400kg/m^3.

3.4 Filter

The filter serves as a collection point for water which might leak through the EPSP. The filter consists of gravel which is held in place by two permeable separation walls. The filter structure was built gradually in a number of stages as the emplacement of the bentonite progressed – its function is to hold the bentonite in place.
The separation wall of the outer filter has an additional function, i.e. it serves as a hidden formwork for the outer plug.

4 GEOLOGY OF THE EXPERIMENTAL LOCATION

The EPSP experiment is underway in the underground research laboratory (URL) of the Josef facility, a former experimental gold mine which is located near the Slapy dam close to the villages of Čelina and Mokrsko in the Příbram district of Central Bohemia, Czech Republic.
The Josef experimental gallery runs in a NNE direction through the Mokrsko hill rock massif. Geological diversity makes up one of the major advantages of the Josef facility which features two basic geological formations each with very different histories and contact zones (Morávek, 1992).

Moreover, each of the formations exhibits different physical and material properties which change in character towards the contact zone and which feature a variety of local fracture zones and intrusions. This provides a high level of flexibility with regard to choosing the best location for the conducting of experiments depending on the conditions required, for example fracture systems, rock stability, rock strength, mineralogy, etc.

The EPSP experiment itself is located within the M-SCH-Z/SP-59 experimental gallery niche.

The support technology required by the experiment is located in parallel niche M-SCH-Z/SP-55.

The niches are interconnected by means of cased boreholes equipped with tubing for the purpose of the circulation of the pressurisation media (4 leading into the filter and 4 leading into the pressurisation chamber) and for monitoring (5 boreholes equipped with sealed cables).

The experimental gallery niche is traversed by quartz and quartz-carbonate veins with a maximum thickness of 14cm. Information on the dominant joint systems is recorded in historical mining documentation which was subsequently updated according to map source documents owned by Geofond – Dobříš 1-9/34-24, M-SCH-Z/SP-59.

The detailed mineralogical study of the filling of the fissures was conducted in 2013 in niche SP-59 (Dvořáková et al., 2014).

5 ROCK MASS RESHAPING

The EPSP consists of two circular fibre shotcrete plugs (1.8m wide and 3.6m high) emplaced into the rock massif (Fig.1 and Fig. 2). The inner plug is located at a distance of 0.5m from the tunnel face and the outer plug ends at a distance of 7.2m from the tunnel face. The space between the two plugs consists of bentonite pellets with a thickness of 2000mm and a gravel filter positioned between the concrete block structures. The total length of the experimental construction plug is 7.2 metres extending from the excavation tunnel face.

Prior to the commencement of the construction phase of the EPSP experiment, it was necessary to reshape the experimental gallery niche; the main aim of this stage was to prepare the SP-59 niche according to plug requirements.

Work started in October 2013 with initial 3D scanning following which the excavation work necessary for EPSP emplacement began in the SP-59 niche. A Darda EP hydraulic splitting set with a Darda C9N hydraulic wedge was employed for enlargement purposes. The profile of the niche was modified so as to form an approximately circular profile 3.6m in diameter (Záruba, 2015).

Subsequently, 23-meter 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.

Five steel cable heads (Fig. 3) to be used for the passage of cables from the measurement sensors located within the experiment were then installed in the SP-59 niche. In addition, a total of 12 measuring bolts to be used for the measurement of stress were installed in pre-drilled holes around the future plug.

6 ROCK IMPROVEMENT

The surrounding rock mass was injected with polyurethane resin at high pressure so as to improve the quality of the host rock (Fig. 4). The required permeability value of the massif following injection was a minimum of 10^{-8}m/s. The requirement was to improve the quality of the massif surrounding the experiment up to a radius of 5m. The injection mixture, consisting of WEBAC 1401 polyurethane resin, was injected into a total of 72 injection boreholes which were fitted with mechanical packers. The resin was injected into the boreholes by means of a WEBAC IP 2 high-pressure grouting set. Injection was terminated once a pressure level of approximately 35MPa had been attained. A total of 760.45kg of WEBAC 1660, WEBAC 1410, WEBAC 4170T, WEBAC 150 and WEBAC 1403 PU resins

was used so as to achieve the required hydraulic parameters within the rock mass in the required area (Záruba, 2015).
Following the construction of both the inner and outer EPSP plugs additional grouting using CarboPurWF and CarboPurWFA resins was performed.

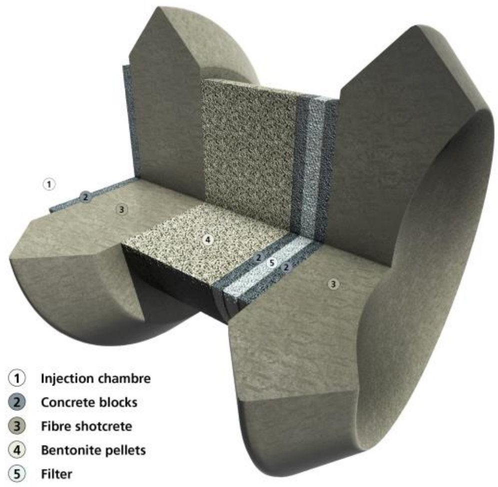

Figure 1 Cross-section through the plug

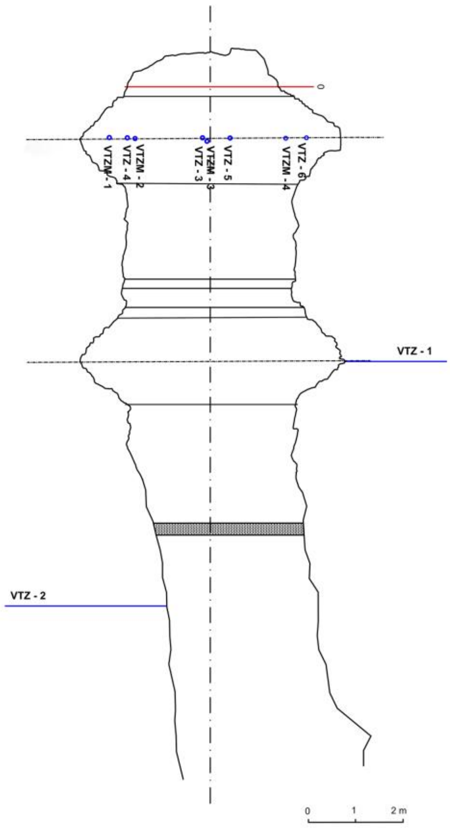

Figure 2 Location of the tested boreholes (WPT in the SP-59 niche)(Záruba, 2015)

Figure 3 Cable head

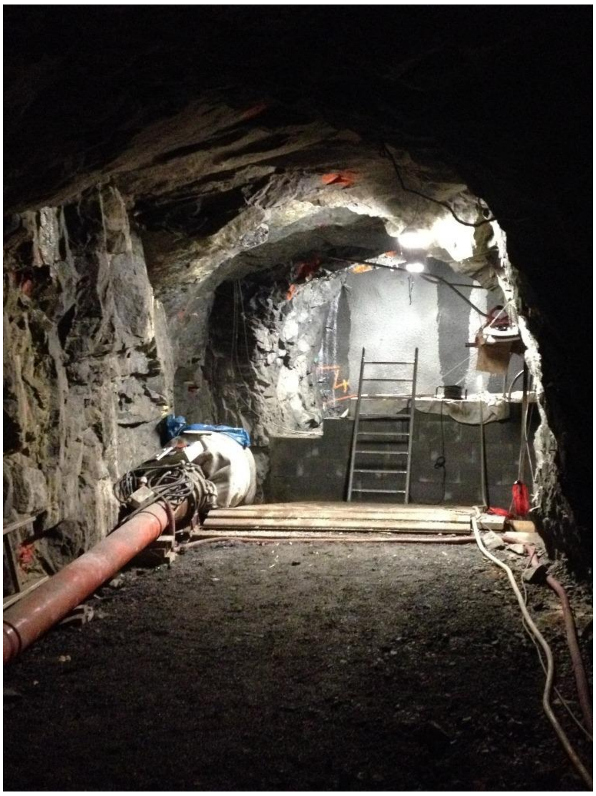

Figure 4 Grouting work in the SP-59 niche

7 RESULTS

7.1 In-situ tests

Water pressure tests (WPT) were conducted for the checking of the grouting of the rock mass in the space intended for the plug. A total of six boreholes 76mm in diameter and 3.1m long (see Fig. 2) were drilled so as to verify the sealing capacity of the rock mass up to a depth of 5m. An additional four boreholes 14mm in diameter and 0.3m long (Fig. 2) were drilled for the verification of the sealing capacity of the near-surface layer of the rock massif in the space intended for the outer plug.

Water pressure testing was conducted both prior to and following the injection of the grouting material.

Once the testing procedure was completed, the boreholes were filled using WEBAC 1660 resin.

Water pressure tests were performed in the VTL-2 horizontal verification borehole. Once a test pressure level of 2MPa had been attained, it was verified that the hydraulic parameters ranged from 3.81E-09 to 7.71E-09m/s. After 2MPa was exceeded, an exponential increase in the consumption of test water was observed (see Tab. 1) and effluents were detected on the surface of the niche (Sosna et al., 2014b).

After attaining a test pressure level of 2MPa in the VTL-3 and VTLM-1 horizontal verification boreholes, it was verified that the hydraulic parameters in the rock massif following injection ranged from 1.24E-10 to 2.49E-10m/s (Tab. 2).

Finally, the VTL-4,5,6 and VTLM-2,3,4 ceiling verification boreholes were also subjected to test pressures up to 2MPa and it was verified that the hydraulic parameters in the rock massif following injection ranged from 1.79E-9 to 2.58E-10m/s (Tab. 3).

Goodman-Jack uniaxial press tests were performed in the VTL-2 borehole with a diameter of 76mm and a length of 4.5m. Tests were conducted at eight incremental depth levels between 0.8 and 4.3m at 0.5m intervals employing alternately the horizontal and vertical rotation of the jaws of the test press.

Table 1 Water pressure test VTL-2 (Sosna et al., 2014b).

WPT VTL-2	**time**	**cm**	**Q(m^3/s)**	**k (m/s)**
Level		**Reading consumption**	**Water consumption**	**Hydraulic conductivity coefficient**
1.25-4.5	11	9.8	1.63E-06	3.81E-09
1.25-4.5	9	32.5	6.62E-06	7.71E-09
1.25-4.5	5	45.5	1.67E-05	1.30E-08
3.0-4.5	10	9.8	1.80E-06	7.59E-09
3.0-4.5	10	13.1	2.40E-06	5.08E-09
3.0-4.5	4	24	1.10E-05	1.55E-08
3.0-4.5	0.5	24.7	9.06E-05	9.57E-08

Table 2 Water pressure test VTL-3 (Sosna et al., 2014b).

WPT VTL-3	**time**	**cm**	**Q (m^3/s)**	**k (m/s)**
Level		**Reading consumption**	**Water consumption**	**Hydraulic conductivity coefficient**
1.13-3.1	4	0.0	0.0	Cannot be evaluated - impermeable
1.13-3.1	30	0.1	1.45E-07	2.49E-10
1.13-3.1	30	0.05	7.23E-08	1.24E-10

Table 3 Water pressure tests in boreholes VTL-4,5,6 and 2,3,4-VTLM (Sosna et al., 2014b).

WPT	**time**	**cm**	**Q (m^3/s)**	**k (m/s)**
Level		**Reading consumption**	**Water consumption**	**Hydraulic conductivity coefficient**
VTL4				
1.24-3.05	14	0.1	3.10E-07	5.57E-10
VTL5				
1.24-3.1	10	0.1	4.34E-07	7.80E-10
VTL6				
1.24-3.12	15	0.05	1.45E-07	2.58E-10
VTLM-2				
0.13-0.31	10	0.05	2.17E-07	1.79E-09
VTLM-3				
0.13-0.29	10	0	N/A	
VTLM-4				
0.13-0.295	10	0	N/A	

The tests were performed using the Goodman-Jack apparatus – Hard Rock type. Stepped load increments were chosen of 5MPa to 20MPa, with strain values at the same step value of 5MPa for all the increments and then the second cycle was loaded with the same steps until a maximum value of 40MPa was attained (Sosna et al., 2014a).

The results of the constrained modulus (E_p) and elasticity (E_{def}) tests in borehole VTL-2 are presented in Tab. 4:

Table 4 Constrained modulus (E_p) and elasticity (E_{def}) tests in borehole VTL-2 (Sosna et al., 2014b).

Orientation of the jaws	***Depth***	***$E_{def,1}$ GPa***	***$E_{def,2}$ GPa***	***$E_{def,2all}$ GPa***	***$E_{p,1}$ GPa***	***$E_{p,2}$ GPa***	***$E_{p,2all}$ GPa***
	(m)	***5-20 MPa***	***20-40 MPa***	***5-40 MPa***	***20-5 MPa***	***40-20 MPa***	***40-5 MPa***
horizontal	0.8	8.1	10.9	10.0	8.6	13.9	10.4
	1.8	3.8	8.2	6.8	5.3	14.6	7.8
	2.8	10.0	14.3	11.9	10.0	17.8	12.7
	3.8	2.3	5.4	4.5	3.4	16.5	5.0
vertical	1.3	5.1	9.8	8.7	7.1	15.6	9.7
	2.3	5.3	14.2	13.9	11.9	20.0	14.1
	3.3	7.6	9.4	10.0	11.9	15.1	11.0
	4.3	10.8	14.3	13.1	13.1	16.6	13.1

7.2 Laboratory tests

Laboratory tests were conducted for the determination of bulk density, strength in transverse compression, unconfined compression strength and constrained modulus E_{def} (MPa). The tests were carried out on specimens of the rock mass (tonalite in SP-59). Six 50mm-diameter specimens with a slenderness ratio of 1:2 were analysed. The laboratory tests were performed at the ARCADIS CZ a.s. accredited laboratory (Záruba, 2015).

Table 5 Laboratory determination of modulus of elasticity and constrained modulus, unconfined compression strength and strength in transverse compression - average values taken from six analysed samples (Filala et al., 2015).

Unconfined compression strength (MPa)	***Strength in transverse compression (MPa)***	***Modulus of elasticity (GPa)***	***Constrained modulus (GPa)***
121.78	8.4	79.94	79.98
70	6	undefined	undefined

8 CONCLUSIONS

The rock massif around the EPSP experiment was improved by means of grouting using polyurethane resins. Following injection the rock mass demonstrated significantly lower values of permeability. This was later confirmed by the results of water pressure testing (see Tabs. 1,2,3). Other measurements taken of the various geotechnical parameters concerned the overall conditions of the rock mass (see Tabs. 4,5).

As a result of the successful construction of the EPSP experiment, the first objective (the demonstration of the suitability of the technology) of the DOPAS EPSP experiment has been achieved. “Alternative” technologies (such as shotcreting, shotclay application and GBT) and materials (low pH shotcrete, bentonite pellets) have been successfully tested and the experiment is now ready for the commencement of the experimental stage.

Moreover, the successful application of the construction techniques employed in the first stage of the EPSP experiment have helped to prove the safety of a future deep geological repository for radioactive waste in the Czech Republic.

9 ACKNOWLEDGEMENTS

The research is being funded from the European Union European Atomic Energy Community (Euratom) Seventh Framework Programme FP7 (2007-2013) according to grant agreement no. 323273, the DOPAS project.

10 REFERENCES

Dvořáková, M., Hanusová, I., Svoboda, J. & Vencl, M. (2014). EPSP experiment- construction of a plug for a deep geological radioactive waste repository as part of the european DOPAS project. Tunel 23 (2), 4-10.

Filala, Z., Sosna, K., Šebelová, J. & Záruba, J. (2014). Laboratorní stanovení modulů pružnosti a přetvárnosti, pevnosti v prostém tlaku a pevnosti v příčném tahu, Arcadis CZ a.s. Archív SÚRAO (in Czech).

Geofond – Dobříš 1-9/34-24, M-SCH-Z/SP-59.

Morávek, P. (1992). Zlato v Českém masivu. 1. vyd. Praha, Český geologický ústav.

Sosna, K., Černý, D., Kvarda, M., Tocháček, M. & Záruba, J. (2014a). Stanovení deformačních modulů in situ pomocí zkoušky Goodman Jack, Arcadis CZ a.s. Archív SÚRAO (in Czech).

Sosna, K., Vysoká, H. & Záruba, J. (2014b). Výsledky vodních tlakových zkoušek ve vrtu VTL-4,5,6 a VTLM-2,3,4, Arcadis CZ a.s. Archív SÚRAO (in Czech).

Záruba, J. (2015). Experiment EPSP – DOPAS: As-built Documentation – Grouting, drilling and sealing operations for the EPSP experiment conducted under the DOPAS international project, Arcadis CZ a.s. Archív SÚRAO.