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D3.17 Interim results of EPSP laboratory testing

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ABSTRACT:

This report presents up-to-date results of laboratory work related to the EPSP experiment. The laboratory work will provide data for the subsequent numerical analysis of EPSP behaviour (WP5). Bentonite parameters were determined and compared with other bentonites from the Czech Republic.

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TABLE OF CONTENTS

1 Introduction 4
2 Qualitative requirements oF EPSP building materials 5
3 Current state of laboratory tests 6
4 Results of laboratory tests 9
  4.1 Work performed by the Centre of Experimental Geotechnics, CTU in Prague 9
    4.1.1 Laboratory tests on bentonite 9
    4.1.2 Comparison of B75_2013 with other Czech bentonites 10
    4.1.3 Pellet manufacturing technology and quality verification 12
    4.1.4 Conclusion of CTU work 17
  4.2 Work performed by ÚJV Řež, a. s. 18
    4.2.1 Laboratory tests on bentonite 18
    4.2.2 Laboratory tests on grouting materials 21
    4.2.3 Laboratory tests on concrete/ cement 21
    4.2.4 Laboratory tests on the host rock 25
    4.2.5 Physical models 26
    4.2.6 Conclusion of ÚJV work 30
5 Literature 31
6 List of abbreviations 32

1 INTRODUCTION

The aim of the DOPAS project is to address the design basis of and reference designs and strategies for plugs and seals to be used in geological disposal facilities. The Czech experiment “Experimental Pressure and Sealing Plug” (EPSP) is studying developments concerning the design basis, reference designs and strategies including compliance issues.

Laboratory testing will provide data for the numerical analysis of EPSP behaviour (WP5). The laboratory and in-situ tests have been planned so as to include the verification of the quality of the work carried out by subcontracting companies (rock permeability following rock improvement, deformation and strength parameters, concrete behaviour etc.) and to ensure that the relevant parameters concerning the various rock and concrete plug components have been met in full.

Three groups of data are being produced – input material parameters, material parameters from verification testing (the occasional checking for possible changes as the project progresses) and data from small-scale physical models.

Report D3.17 presents up-to-date results of laboratory testing related to the EPSP experiment. The data presented in this version of the report (by January 2014) was obtained by the Czech DOPAS participants – CTU in Prague and ÚJV Řež, a. s.

This report presents the interim data, which has not been fully quality assured and analysed while the laboratory testing work is still ongoing. This report will inform to the DOPAS Consortium about the status of laboratory work within EPSP and increase the possibility to discuss the achieved results so far within DOPAS Consortium. More comprehensive information on laboratory work done for EPSP and the final results will be reported within D3.21 Final laboratory test report of EPSP, which will be published in 2015.

Indicative time schedule of the project works on EPSP follows:

1. Selection of test location (MS4): 2012
2. Preparing the test site – clean up, engineering networks installation (electricity, technological water, data network, light, ventilation): 01-04/2013
3. EPSP construction – phase 1 – drift shape adjustment, instrumentation boreholes incl. sensors, connecting boreholes incl. casing/tubing, rock improvement: 11/2013-04/2014
4. EPSP construction – phase 2 – plug erection, monitoring and technology installation (MS11): 05-09/2014
5. Pilot testing: 09-12/2014
6. Monitoring and testing of plug: 09/2014-02/2016

2 QUALITATIVE REQUIREMENTS OF EPSP BUILDING MATERIALS

The qualitative requirements of EPSP materials were set out in the DOPAS Deliverable D2.1 Design Bases and Criteria report (White et. al., 2013). *Figure 1* shows EPSP components and their building materials.

Glass fibres will be used as the reinforcement element in the fibre shotcrete. The concrete blocks which serve as a permeable lost formwork may, alternatively, be made from aerated concrete. Czech Ca-Mg bentonite “Bentonit 75” (B75) was selected as the material to be used for the bentonite sealing section of EPSP, i.e. also as the raw material for pellet production. B75 is a Czech Ca-Mg, factory-produced bentonite (raw bentonite is dried, milled and sifted to obtain required granulometry). It was extracted from deposits in Northern Bohemia and produced by KERAMOST, Plc.

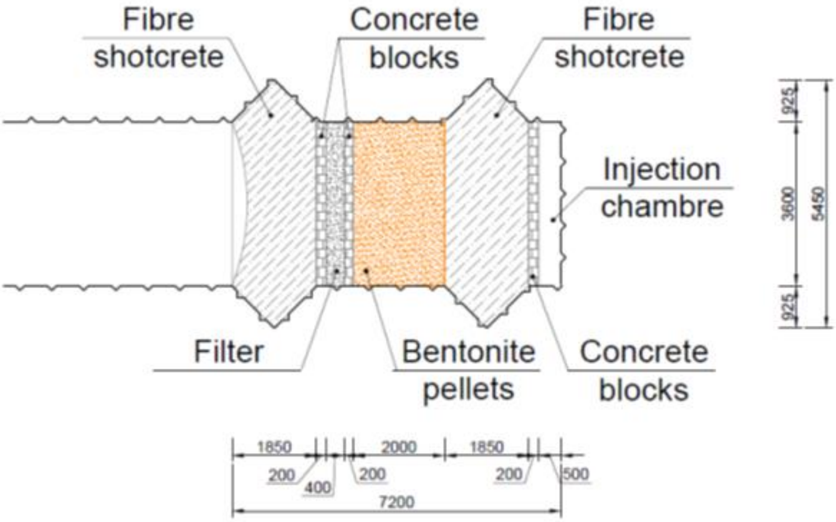

Figure 1 - Scheme of the EPSP conceptual design. Dimensions are in mm. (DOPAS Deliverable D2.1)

The requirements of EPSP materials according to DOPAS Deliverable D2.1 consist of:

- The strength of the concrete shall be sufficient to withstand a maximum applied pressure of 7MPa.
- The emplaced bentonite B75 (mixture of pellets made of B75) shall achieve a density of $1.4 \mathrm{Mg.m^{-3}}$.
- The density of the bentonite seal is specified to achieve a swelling pressure of 2MPa and a hydraulic conductivity of $10^{-12} \mathrm{m.s^{-1}}$.
- The concrete blocks wall shall be constructed of reduced pH concrete, the same as for the shotcrete. The pH of the concrete has not yet been specified but is expected to be below 12.
- Grouting shall be required for 5m around the EPSP niche in order to reduce hydraulic conductivity and to allow sufficient pressurisation for the test.

3 CURRENT STATE OF LABORATORY TESTS

The laboratory testing plan and the relevant responsible persons are provided in the following table according to DOPAS Deliverable 3.16 - Testing plan for the EPSP laboratory experiment. The plan for obtaining input parameters (chapter 4.1 in Deliverable 3.16, Vašíček et. al., 2013) is also shown.

In 2013 several series of initial tests on the bentonite, concrete mixture, rock samples and grouting substances were performed. Testing which should have been performed by the winner of a public tender on “EPSP construction – phase 1” (W1 in the table) has not yet been delivered. The results are expected in April 2014. The results which should have been delivered by W2 (winner of the public tender on EPSP construction – phase 2) are expected in mid-2014. The following table presents the current status of laboratory testing.

Tab. 1- Status of the tests

Material	Parameter	Responsible institution	Responsible person	Test procedure/ Standard	Test and material conditions	Testing period - plan	State as in Dec. 2013
Bentonite	Hydraulic conductivity	CEG CTU	Vašíček	ČSN CEN ISO/TS 17892-11 Geotechnical investigation and testing - Laboratory testing of soil - Part 11: Determination of permeability by constant and falling head	compacted powder, dry densities 1100-1800kg/m^3	12/2013-04/2014	Done
Bentonite	Swelling pressure	CEG CTU	Vašíček	Testing without volume change, internal description following Dixon et. al., 1999; procedure available on Projectplace	compacted powder, dry densities 1100-1800kg/m^3	12/2013-04/2014	Done
Bentonite	Hydraulic conductivity	CEG CTU	Vašíček	ČSN CEN ISO/TS 17892-11 Geotechnical investigation and testing - Laboratory testing of soil - Part 11: Determination of permeability by constant and falling head	pellets compacted to dry densities 1100-1600kg/m^3	04/2014-12/2014	Related to pellets/mixture selection; under preparation
Bentonite	Swelling pressure	CEG CTU	Vašíček	Testing without volume change, internal description following Dixon et. al., 1999; procedure available on Projectplace	pellets compacted to dry densities 1100-1600kg/m^3	04/2014-12/2014	Related to pellets/mixture selection; under preparation
Bentonite	Thermal conductivity, heat capacity	CEG CTU	Vašíček	ISOMET 2104 device	powder - compacted, dry densities 1100-1800kg/m^3	12/2013-04/2014	Ongoing, by 04/2014
Bentonite	Specific density	CEG CTU	Vašíček	ČSN CEN ISO/TS 17892-3 - Geotechnical investigation and testing - Laboratory testing of soil - Part 3: Determination of particle density - Pycnometer method	powder	12/2013-04/2014	Done
Bentonite	Atterberg limits	CEG CTU	Vašíček	ČSN CEN ISO/TS 17892-12: Geotechnical investigation and testing - Laboratory testing of soil - Part 12: Determination of Atterberg limits	powder	12/2013-04/2014	Done
Bentonite	Hydraulic conductivity	UJV	Večerník / Gondolli	ČSN CEN ISO/TS 17892-11 Geotechnical investigation and testing - Laboratory testing of soil	dry densities 1100-1800kg/m^3	12/2013-04/2014	Ongoing, preliminary tests done

Material	Parameter	Responsible institution	Responsible person	Test procedure/ Standard	Test and material conditions	Testing period - plan	State as in Dec. 2013
Bentonite	Gas permeability	UJV	Večerník / Gondolli	Internal procedure based on ČSN CEN ISO/TS 17892-11 Geotechnical investigation and testing - Laboratory testing of soil	dry densities 1100-1800kg/m^3	12/2013-04/2014	Ongoing, preliminary tests done
Bentonite	Porosity	UJV	Večerník / Gondolli	Internal procedure	dry densities 1100-1800kg/m^3	12/2013-04/2014	Ongoing
Bentonite	Swelling pressure	UJV	Večerník / Gondolli	Internal procedure based on ČSN CEN ISO/TS 17892-11 Geotechnical investigation and testing - Laboratory testing of soil	dry densities 1100-1800kg/m^3	12/2013-04/2014	Ongoing, preliminary tests done
Bentonite (pellet technology)	Manufacturing and mixture selection	CEG CTU	Šťástka	Selection of Czech pellets producer with suitable manufacturing technology	mixtures of various pellets types/ particle fractions	2013	Ongoing, by January 2014
	Spraying and compaction field tests	CEG CTU	Šťástka	Internal procedure	mixtures of various particle fractions/ pellets types	03/2013-07/2013	Delayed, expected by March 2014
Concrete	Thermal conductivity, heat capacity	CEG CTU	Vašíček	ISOMET 2104 device	samples taken during installation, according to Standard	09/2013-03/2014	Delayed, expected in mid-2014
Concrete	Compressive strength	W2 (CTU)	Vašíček	ČSN EN 12390 (731302) - Testing of hardened concrete	samples taken during installation, according to Standard	12/2013-02/2014	Delayed, expected in mid-2014
Concrete	Static modulus of elasticity in compression	W2 (CTU)	Vašíček	ČSN ISO 6784 (731319) - Concrete. Determination of static modulus of elasticity in compression	samples taken during installation, according to Standard	12/2013-02/2014	Delayed, expected in mid-2014
Concrete	Static modulus of deformation	W2 (CTU)	Vašíček	ČSN ISO 6784 (731319) - Concrete. Determination of static modulus of elasticity in compression	samples taken during installation, according to Standard	12/2013-02/2014	Delayed, expected in mid-2014
Concrete	Composition and pH of leachate	UJV	Večerník	Based on SKB report R-12-02	leaching into distilled water	07/2013-03/2014	Testing of cement paste and cement+SiO2 done
Concrete	Hydraulic conductivity	UJV	Večerník	Based on ČSN CEN ISO /TS 17892	cylindrical sample	07/2013-03/2014	Delayed, expected in mid-2014
Concrete	Gas permeability	UJV	Večerník	Internal procedure	cylindrical sample	07/2013-03/2014	Expected in mid-2014
Concrete	Porosity	UJV	Večerník	Mercury porosimetry/ water immersion method	external analysis / cubes, discs	07/2013-03/2014	Expected in mid-2014
Concrete	Hardened concrete testing	W2 (UJV)	Večerník	ČSN EN 12390	Compressive strength, Depth of penetration of water under pressure	07/2013-03/2014	Expected in mid-2014
Grouting substances	Interactions	UJV	Večerník	Internal procedure for interaction processes	grouting/plug materials/plug environment	05/2013-06/2015	Influence of alkaline waters on grouting material - preliminary test
Rock samples	Compressive strength	W1 (SURAO)	Dvořáková	ČSN EN 1926 - Natural stone test methods - Determination of uniaxial compressive strength	drilled cores	5/2013-7/2013	Delayed, expected in April 2014
Rock samples	Static modulus of deformation	W1 (SURAO)	Dvořáková	ČSN ISO 6784 (731319) - Concrete. Determination of static modulus of elasticity in compression	drilled cores	5/2013-7/2013	Delayed, expected in April 2014

Material	Parameter	Responsible institution	Responsible person	Test procedure/ Standard	Test and material conditions	Testing period - plan	State as in Dec. 2013
Rock samples	Density	W1 (SURAO)	Dvořáková	e.g. ČSN CEN ISO/TS 17892-2	drilled cores	5/2013-7/2013	Delayed, expected in April 2014
Rock samples	Permeability	UJV	Večerník	Changes in rock permeability due to grouting,	drilled cores	07/2013-03/2014	Delayed, expected in April 2014
Rock samples	Porosity	UJV	Večerník	Mercury porosimetry / water immersion method	external analysis / cubes, discs of plug material	07/2013-03/2014	preliminary tests; Delayed, expected in April 2014
Rock massif	Modulus of deformation	W1 (SURAO)	Dvořáková	Loading plate	1 field test (testing niche)	5/2013-7/2013	Delayed, expected in April 2014
Rock massif	Modulus of deformation	W1 (SURAO)	Dvořáková	Menard presiometer test, Eurocode 7- Part 2	field test, 2 boreholes (5m long)	5/2013-7/2013	Delayed, expected in April 2014
Rock massif	Hydraulic conductivity	W1 (SURAO)	Dvořáková	Hydraulic pressure test	field test, 5 boreholes (5m)	5/2013-7/2013	Delayed, expected in April 2014

CEG CTU - Centre of Experimental Geotechnics, Faculty of Civil Engineering, Czech Technical University in Prague
W1 – winner of public tender on “EPSP construction – phase 1” work
W2 – winner of public tender on “EPSP construction – phase 2” work

4 RESULTS OF LABORATORY TESTS

The following chapters present the latest results obtained from laboratory testing (by December 2013). The work performed is presented in the form of chapters according to the institution responsible for delivery.

The bentonite material labelled as B75_2013 was selected for the DOPAS EPSP seal. B75 Bentonite is a Czech Ca-Mg industrially milled and sifted non-activated bentonite. The B75_2013 material was supplied in 2013. The laboratory tests were performed on the material in order to verify its properties. In some cases the results of B75_2010 testing were used for comparison purposes (B75_2010, i.e. B75 material supplied in 2010, examined in 2010-2013, e.g. Červinka & Hanuláková, 2013 and Červinka et. al., 2012).

Type of water (distilled and/ or "SGW - synthetic granitic water", for composition see *Tab. 2*) used during the laboratory tests is indicated in each sub-chapter. The distilled water has been used when required by the standard (testing method) or when results comparable to former ones were wanted. Laboratory prepared SGW (Havlová et al., 2010) is based on a statistical evaluation of the composition of the groundwater of Czech granite massifs for depths 20-200 meters. In some cases tests with "Josef" groundwater (collected in vicinity of the EPSP drift) are planned.

Tab. 2 - Composition of SGW – Synthetic granitic water (mg/l)

Na	K	Ca	Mg	Cl	SO_4	NO_3	HCO_3	F
10.6	1.8	27.0	6.4	42.4	27.7	6.3	30.4	0.2

4.1 Work performed by the Centre of Experimental Geotechnics, CTU in Prague

The basic laboratory tests were aimed at the estimation of the specific density and Atterberg limits of the bentonite powder. This was followed by the determination of hydraulic conductivity and swelling pressure with regard to compacted samples (several dry density values). Distilled water was used for all tests.

The testing of the most appropriate technology for the manufacture of the pellets, in cooperation with potential Czech producers, was carried out from May to November 2013. Tests aimed at determining the most suitable mixture for spray technology purposes are ongoing. The verification of the technology to be employed for pellet emplacement (a combination of plate compaction and spraying) is planned for early 2014. Large testing cells used for the estimation of the hydraulic conductivity and swelling pressure of the pellet samples have been constructed and initial testing has already commenced. Distilled water has been used.

4.1.1 Laboratory tests on bentonite

- The average of measured values of specific density is 2.855g/cm^3.
- The average liquid limit value was found to be 171% using distilled water for test purposes. This value falls within the anticipated liquid limit range.
- The swelling pressure of bentonite B75_2013 is in the range of approximately from 1 to 8MPa for a dry density value of 1.26–1.64g/cm^3. The dependence of swelling pressure on dry density is shown in *Figure 2*. The value of swelling pressure for a dry density value of 1.4g/cm^3 is 2MPa which indicates that **swelling pressure behaviour corresponds to the initial assumption** (see Chapter 2; taken from DOPAS Deliverable D2.1, White et. al., 2013).

- The hydraulic conductivity of bentonite B75_2013 is in the range 10^{-12} - 10^{-13}m/s for a dry density value of 1.26-1.64g/cm^3; the dependence on dry density is shown in *Figure 3*. **The hydraulic conductivity value determined corresponds to the initial assumption** (see Chapter 2; taken from DOPAS Deliverable D2.1, White et. al., 2013).

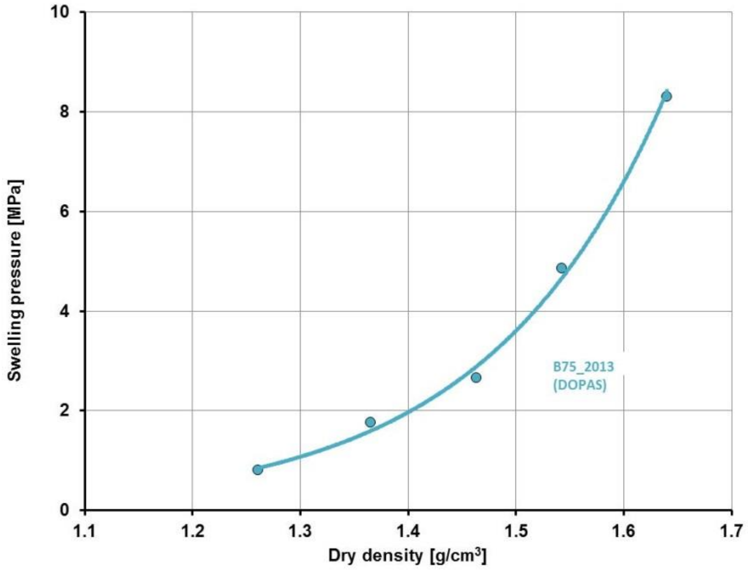

Figure 2 – Swelling pressure of bentonite B75_2013

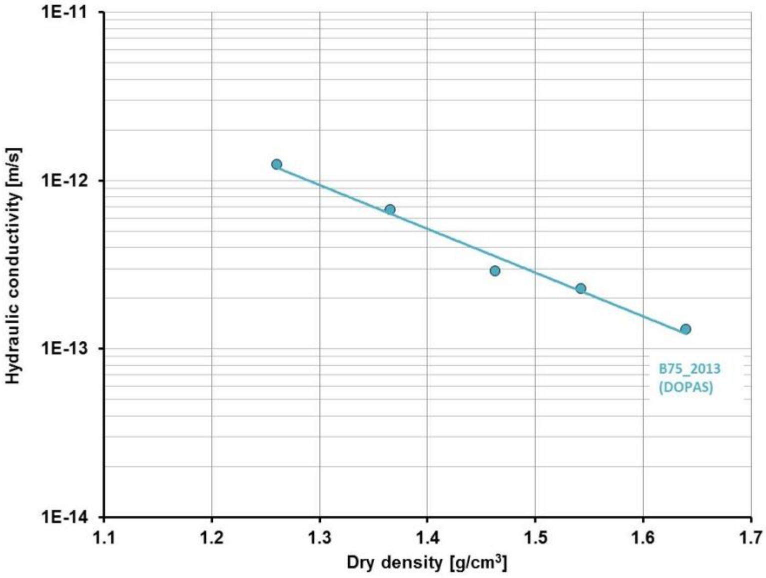

Figure 3 - Hydraulic conductivity of bentonite B75_2013

4.1.2 Comparison of B75_2013 with other Czech bentonites

This chapter provides a comparison of the geotechnical parameters of bentonite B75_2013 with a selection of other Ca-Mg bentonites from the Czech Republic. Activated bentonite SAB65 (Sabenil 65, produced by KERAMOST, Plc.), which is characterized by significantly higher liquid limit and swelling pressure and lower hydraulic conductivity values, was also subjected to comparison.

It was verified that bentonite B75_2013 attains values of hydraulic conductivity and swelling pressure typical for Ca-Mg Czech swelling clays (Figure 4 and Figure 5).

The liquid limit value of B75_2013 lies between that of Ca-Mg bentonite from the Černý Vrch locality and gently (accidentally) activated B75_2010 (*Figure 6*; more on B75_2010 in Červinka & Hanuláková, 2013 and Červinka et. al., 2012).

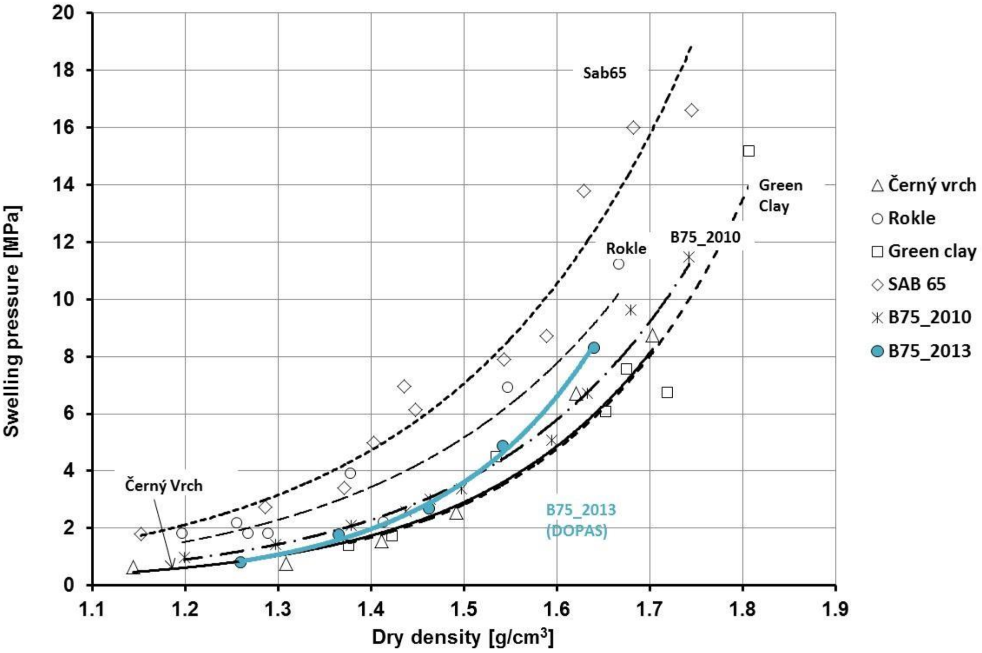

Figure 4 – Comparison of the swelling pressure of B75_2013 and other Czech bentonites

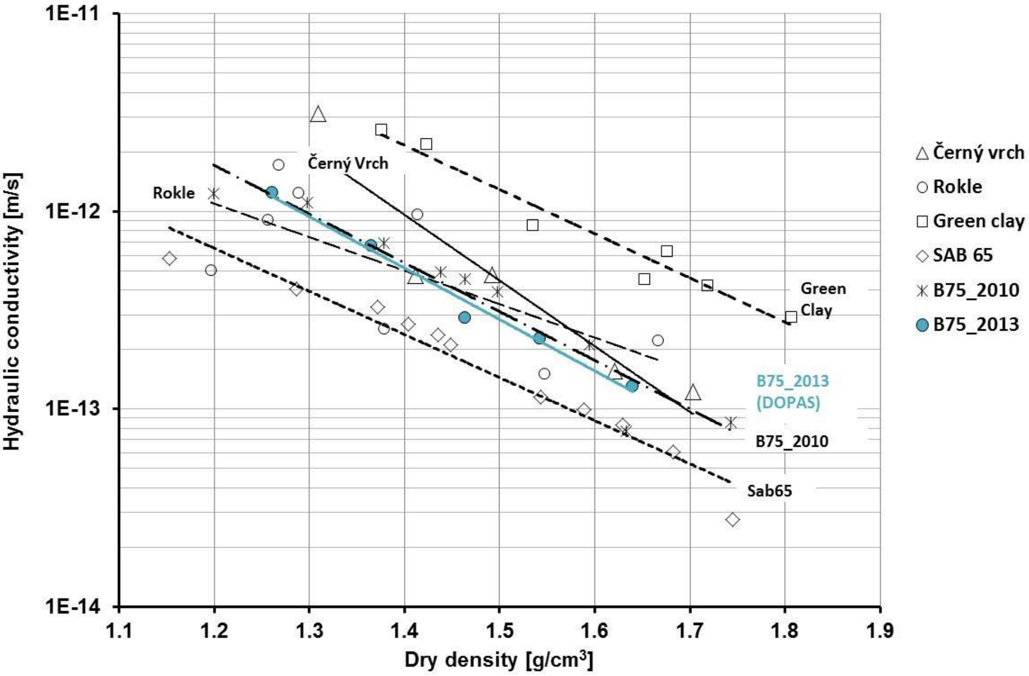

Figure 5 – Comparison of the hydraulic conductivity of B75_2013 and other Czech bentonites

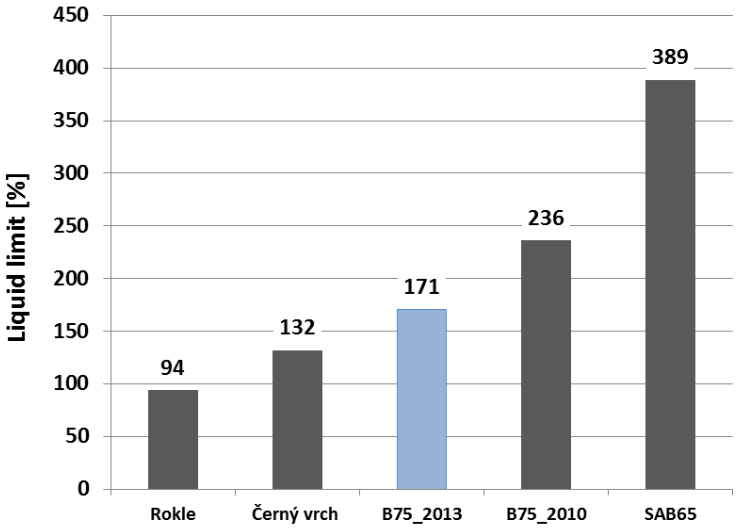

Figure 6 – Comparison of the liquid limit of B75_2013 and other Czech bentonites

4.1.3 Pellet manufacturing technology and quality verification

4.1.3.1 Pellet production

The aim of this part of the project was to find Czech producers of bentonite pellets of a sufficiently high quality level and the production capacity needed for EPSP purposes. It involved establishing contacts with various potential industrial partners in order to verify the quality of their products, i.e. the detailed testing of the relevant properties in terms of use in the EPSP seal. The key issue concerned attaining the ideal dry density level following pellet emplacement, the verification of which concerns the use of a range of techniques: free fall pouring, vibration, spraying and plate compaction.

B75 is produced in powder form which is not ideal for sealing plug purposes due to the low level of compaction. Therefore, the first stage involved the selection of the best compaction technology commercially available in the Czech Republic. Eventually, three technological processes were selected for further consideration.

The first method originated from a factory which produces compacted kaolin clay pellets (cylinders with a diameter of 12mm) by means of a roller compaction machine. A number of tests were conducted concerning the manufacture of the bentonite pellets, the main aim of which was to determine the conditions for the industrial compaction and production of the bentonite pellets with the most suitable dry density value. The final dry density of the compacted pellets depends on the water content of the material; B75_2013 bentonite had to be moistened prior to compaction. The relationship of dry density and various water content levels is shown in *Figure 7* (Šťástka, 2013). Subsequently, material with a water content of around 16% was selected for further experimental testing. The pellets selected from this producer, code-named B75 PEL_12, have a diameter of 12mm, a length of up to 4cm (Figure 8) and a dry density value of 1.80-1.85g/cm^{-3}.

The second compaction method was based on a small roller compaction machine which produced bentonite pellets with a diameter of 8mm. This method, however, was not selected for further testing due to the low level of bentonite compaction and the amount of time required for production.

The third method considered (employing a roller mill) was the result of consultation with a Czech bentonite production company which was followed by laboratory testing. The pellets (fragments of highly-compacted bentonite plate) produced employing this procedure are not available commercially but the machinery involved is in common use. Laboratory testing revealed a good level of compaction (dry density 1.70-1.98g.cm^{-3}) with a relatively low water content value. The advantage of this technology is the production of pellet fragments with various sizes. It allows mixing in various proportions in order to achieve the best dry density value following emplacement. The resulting material was code-named B75_REC (*Figure 9*). A comparison of the dry density and water content of selected B75_PEL_12 and B75_REC pellets is provided in *Figure 10*.

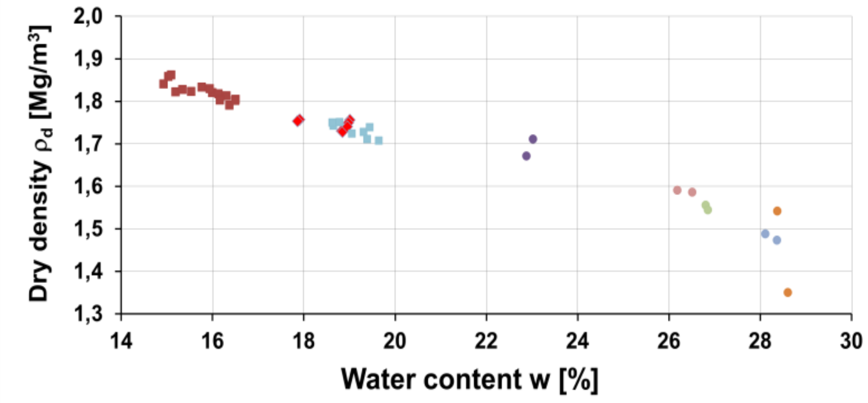

Figure 7 – Range of water content and dry density values of compacted bentonite produced by the roller machine – the red dots show B75_PEL_12 selected for further development

Figure 8 – Compacted bentonite pellets B75_PEL_12 from the roller compaction machine (Šťástka, 2013)

Figure 9 – Compacted bentonite B75_REC

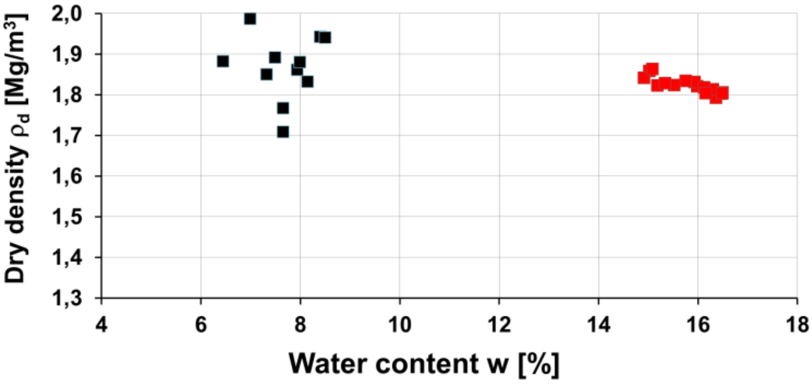

Figure 10 – Comparison of the dry density and water content values of selected materials B75_PEL_12 (red dots) and B75_REC (black dots).

4.1.3.2 Pellet emplacement

Tests for the verification of dry density following pellet emplacement on mixtures based mainly on B75_REC are ongoing. One of the samples was mixed according to the Fuller grain size distribution (here without fine particles below 0.5mm, max. grain diameter 15mm) – code-named B75_REC_F. Particle size distribution of pellets made from B75_2013 follows in *Figure 11*.

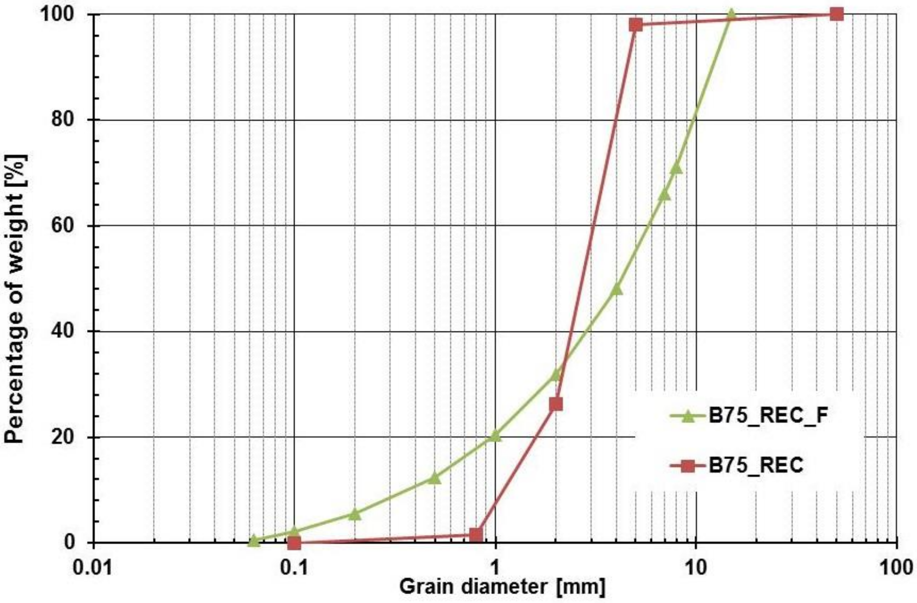

Figure 11 – Particle size distribution of pellets from B75_2013

Three types of technology are being tested for the emplacement of the selected materials (B75_REC; B75_REC_F; B75_PEL_12): free fall pouring, free fall pouring with vibration and spraying using a concrete spray machine. Initial results revealed the impact of compaction and the technology used on the dry density of the tested materials (*Tab. 3*).

A combination of in-situ plate compaction and spraying is anticipated; therefore plate compaction tests will have to be conducted.

Tab. 3 - Dry density results [g/cm^3] following initial tests concerning compaction

Material/Technology	Free fall pouring	Pouring with vibration	Spraying	Compaction plate
B75_REC	1.11	1.20	1.32	Not yet tested
B75_REC_F	1.39	1.55	Not yet tested	Not yet tested
B75_PEL_12	0.98	1.12	No tests planned	No tests planned

It is clear from *Tab. 3* that B75_REC F is very close to the required limit for emplaced dry density - 1.4g.cm^{-3} - using the free pouring method. Vibration during emplacement increases dry density up to a value of 1.55g.cm^{-3}. It is expected that spraying and/or plate compaction will also increase the value of dry density in the case of both the free fall pouring and/or vibration methods. The results were considered particularly satisfactory and it was concluded that the use of the B75_REC F mixture for EPSP purposes should ensure a sufficient level of dry density within the bentonite seal.

The above parameters are comparable to the results obtained at other institutions. *Figure 12* shows the experience obtained to date in the emplacement of bentonite pellets by, particularly, SKB and Posiva (Dixon et. al., 2011).

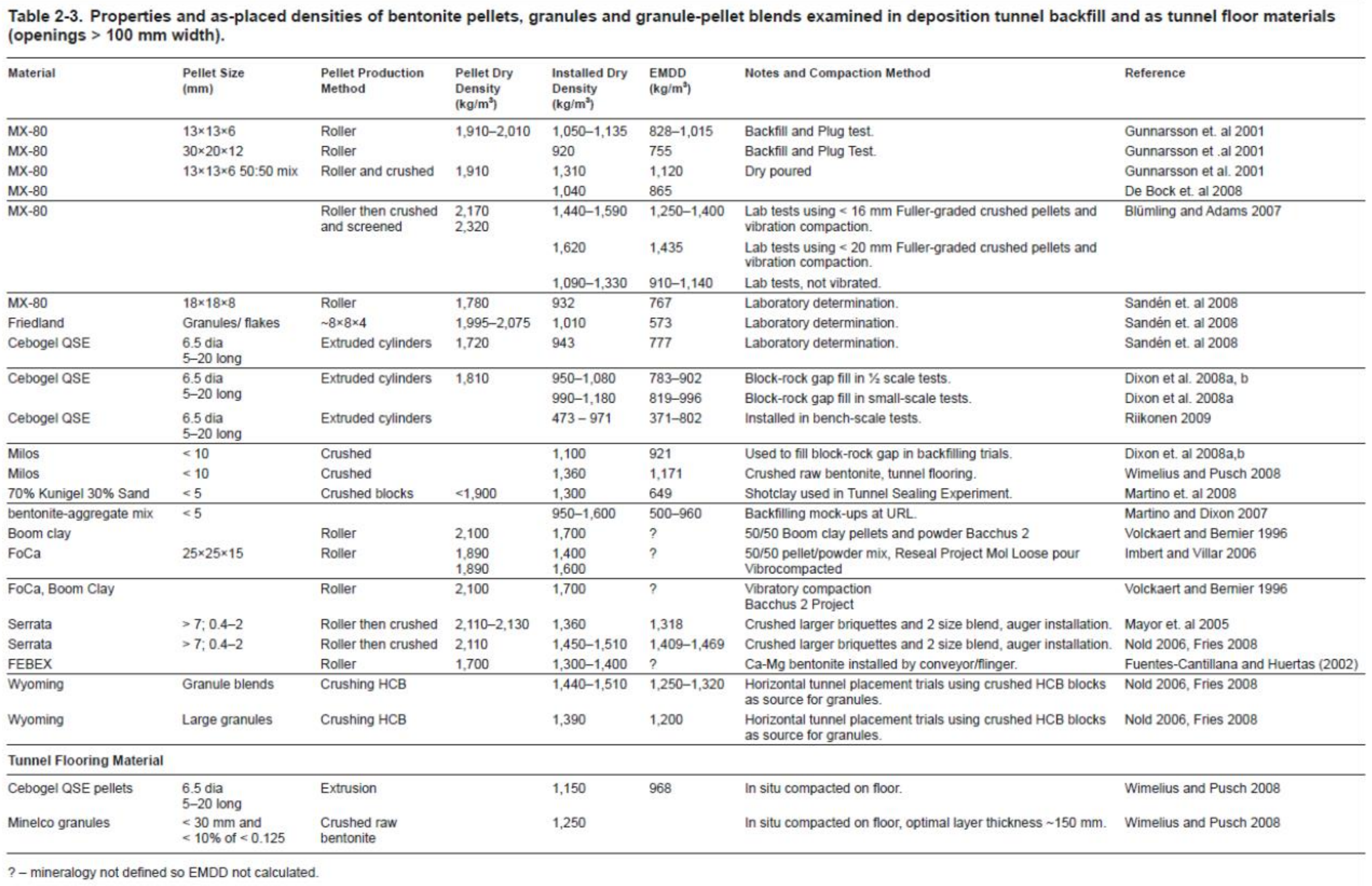

Table 2-3. Properties and as-placed densities of bentonite pellets, granules and granule-pellet blends examined in deposition tunnel backfill and as tunnel floor materials (openings > 100 mm width).

Material	Pellet Size (mm)	Pellet Production Method	Pellet Dry Density (kg/m³)	Installed Dry Density (kg/m³)	EMDD (kg/m³)	Notes and Compaction Method	Reference
MX-80	13×13×6	Roller	1,910–2,010	1,050–1,135	828–1,015	Backfill and Plug test.	Gunnarsson et. al 2001
MX-80	30×20×12	Roller		920	755	Backfill and Plug Test.	Gunnarsson et .al 2001
MX-80	13×13×6 50:50 mix	Roller and crushed	1,910	1,310	1,120	Dry poured	Gunnarsson et al. 2001
MX-80				1,040	865		De Bock et. al 2008
MX-80		Roller then crushed and screened	2,170 2,320	1,440–1,590	1,250–1,400	Lab tests using < 16 mm Fuller-graded crushed pellets and vibration compaction.	Blümling and Adams 2007
				1,620	1,435	Lab tests using < 20 mm Fuller-graded crushed pellets and vibration compaction.	
				1,090–1,330	910–1,140	Lab tests, not vibrated.	
MX-80	18×18×8	Roller	1,780	932	767	Laboratory determination.	Sandén et. al 2008
Friedland	Granules/ flakes	~8×8×4	1,995–2,075	1,010	573	Laboratory determination.	Sandén et. al 2008
Cebogel QSE	6.5 dia 5–20 long	Extruded cylinders	1,720	943	777	Laboratory determination.	Sandén et. al 2008
Cebogel QSE	6.5 dia 5–20 long	Extruded cylinders	1,810	950–1,080	783–902	Block-rock gap fill in ½ scale tests.	Dixon et al. 2008a, b
				990–1,180	819–996	Block-rock gap fill in small-scale tests.	Dixon et al. 2008a
Cebogel QSE	6.5 dia 5–20 long	Extruded cylinders		473 – 971	371–802	Installed in bench-scale tests.	Riikonen 2009
Milos	< 10	Crushed		1,100	921	Used to fill block-rock gap in backfilling trials.	Dixon et. al 2008a,b
Milos	< 10	Crushed		1,360	1,171	Crushed raw bentonite, tunnel flooring.	Wimelius and Pusch 2008
70% Kunigel 30% Sand	< 5	Crushed blocks	<1,900	1,300	649	Shotclay used in Tunnel Sealing Experiment.	Martino et. al 2008
bentonite-aggregate mix	< 5			950–1,600	500–960	Backfilling mock-ups at URL.	Martino and Dixon 2007
Boom clay		Roller	2,100	1,700	?	50/50 Boom clay pellets and powder Bacchus 2	Volckaert and Bernier 1996
FoCa	25×25×15	Roller	1,890 1,890	1,400 1,600	?	50/50 pellet/powder mix, Reseal Project Mol Loose pour Vibrocompacted	Imbert and Villar 2006
FoCa, Boom Clay		Roller	2,100	1,700	?	Vibratory compaction Bacchus 2 Project	Volckaert and Bernier 1996
Serrata	> 7; 0.4–2	Roller then crushed	2,110–2,130	1,360	1,318	Crushed larger briquettes and 2 size blend, auger installation.	Mayor et. al 2005
Serrata	> 7; 0.4–2	Roller then crushed	2,110	1,450–1,510	1,409–1,469	Crushed larger briquettes and 2 size blend, auger installation.	Nold 2006, Fries 2008
FEBEX		Roller	1,700	1,300–1,400	?	Ca-Mg bentonite installed by conveyor/flinger.	Fuentes-Cantillana and Huertas (2002)
Wyoming	Granule blends	Crushing HCB		1,440–1,510	1,250–1,320	Horizontal tunnel placement trials using crushed HCB blocks as source for granules.	Nold 2006, Fries 2008
Wyoming	Large granules	Crushing HCB		1,390	1,200	Horizontal tunnel placement trials using crushed HCB blocks as source for granules.	Nold 2006, Fries 2008
Tunnel Flooring Material							
Cebogel QSE pellets	6.5 dia 5–20 long	Extrusion		1,150	968	In situ compacted on floor.	Wimelius and Pusch 2008
Minelco granules	< 30 mm and < 10% of < 0.125	Crushed raw bentonite		1,250		In situ compacted on floor, optimal layer thickness ~150 mm.	Wimelius and Pusch 2008

? – mineralogy not defined so EMDD not calculated.

Figure 12 – Experience of pellet emplacement (Dixon et. al., 2011)

4.1.4 Conclusion of CTU work

It can be assumed that B75_2013 bentonite fulfils the requirements set out in D2.1 Design Bases and Criteria (see Chapter 2; Deliverable D2.1, White et. al., 2013):

- the required swelling pressure of 2MPa is achieved when the material is compacted to a dry density of 1.4g/cm^{-3} and more,
- hydraulic conductivity of 10^{-12}m/s^{-1} is achieved when the material is compacted to a dry density slightly below 1.3g/cm^{-3} and more,
- The selected mixture of bentonite pellets (B75_REC_F) provides a dry density level very close to the required density of 1.4g/cm^{-3} following free fall pouring (1.39g/cm^{-3}) and a noticeably higher dry density level in excess of the required density limit following pouring with vibration (1.55g/cm^{-3}). Furthermore, it is expected that spraying and plate compaction will also increase dry density values to above the limit.

Thus it can be concluded that the above geotechnical results promise sufficient dry density levels and, therefore, the required geotechnical behaviour of the bentonite seal in the EPSP experiment.

4.2 Work performed by ÚJV Řež, a. s.

4.2.1 Laboratory tests on bentonite

The material used for the construction of the plugs and the laboratory physical models as well as for further testing will consist of commercially produced Bentonit 75 (B75) supplied by KERAMOST, Plc., Czech Republic. This product follows on from the materials studied in previous research focused on barrier materials for deep waste repositories, the parameters of which are described in a report (in Czech only) entitled: "Shrnutí informací o vlivu chemického složení bentonitu Rokle na chemické a fyzikální vlastnosti" - Summary information on the effect of the chemical composition of Rokle bentonites on chemical and physical properties.

The B75 material is currently undergoing laboratory testing. Experiments aimed at the study of chemical and mineralogical composition, leachate analysis, the determination of ion-exchange capacity etc. are underway or planned for the near future. Data obtained to date forms part of the Czech report. Physical properties will be subjected to detailed testing, in particular: porosity at a defined compaction level and permeability to water and gases of a sprayed/compacted sample prepared from pellets and powdered bentonite. The preparation of these samples is planned for early 2014. The samples currently being tested were prepared from powdered bentonite B75 which is used to verify the measuring methods and used devices.

The results of an internal report concerning those bentonites to be used in the plug can be summarised as follows: the literature survey revealed that minor differences exist between two local sources of bentonite in the Czech Republic, i.e. the Doupovské hory volcanic region (main deposit Rokle) and the České středohoří volcanic region (main deposit Braňany-Černý vrch). The differences can be found especially during visual inspection of the raw bentonite samples, but minor differences can be found in chemical composition (especially in the total amount of sodium, potassium and calcium). Nevertheless, the mineralogical composition and crystal chemistry of the bentonites from these two sources as well as the amount of montmorillonite present are very similar, as reported by Franče, 1992. In the present time, the factory-produced bentonite Bentonit 75 (B75) is slightly different from previously studied bentonites coming from the Rokle deposit (raw samples and also factory-produced B75), see *Tab. 4* which shows a comparison of the chemical analyses of bentonite B75_2010 produced in 2010 (used in previous projects) and bentonite B75_2013 produced in 2013 and being used in this project. The testing of pellet production was performed on B75_2013 (by CEG). Differences in the properties of the two materials (free swelling, ionic form, pH of the suspension) could be the result of the processing technology or the different source of the raw bentonite (different deposit or a different part of the same deposit). A comparison of the leachate pH of these two materials in distilled water is provided in *Tab. 5* which shows the suspension pH results for different solid/liquid ratios after 28 days of exposure. The analyses of leachates of B75 in distilled water were performed for bentonite samples from 2010 and 2013 with different solid/liquid ratios. As can be seen in *Tab. 6*, the concentration of Na^+ in B75_2013 leachates is significantly lower than in B75_2010.

The processing technology has been identified as the main factor affecting the properties of B75 produced in recent years. It was found that partial activation and/or contamination caused by the presence of an activation reagent affect the composition of the water suspension or water leachate, cation exchange capacity and bentonite pore water composition. The chemical composition of the B75_2013 (the material chosen for the verification of selected parameters) sample was found to be different from samples studied previously – especially in the amount of total sodium, calcium, iron and carbon/carbonates (see *Tab. 4*).

Tab. 4 - Chemical analyses of bentonite B75; comparison of materials produced in 2010 (B75_2010) and 2013 (B75_2013)

wt %	B75_2010	B75_2013
SiO_2	51.91	49.83
Al_2O_3	15.52	15.35
TiO_2	2.28	2.82
Fe_2O_3	8.89	10.9
FeO	2.95	3.74
MnO	0.11	0.09
MgO	2.22	2.88
CaO	4.60	2.01
Na_2O	1.21	0.67
K_2O	1.27	1.05
P_2O_5	0.40	0.63
CO_2	5.15	3.66

Tab. 5 – pH values of the B75 leachate; comparison of materials produced in 2010 (B75_2010) and 2013 (B75_2013) at different solid/liquid (s/l) ratios, contact time: 28 days

s/l ratio	B75_2010	B75_2013
18.6g/l	9.65	9.52
125g/l	9.34	9.22

Tab. 6 – Chemical analyses of B75 leachates - concentrations of major cations. Comparison of materials produced in 2010 (B75_2010) and 2013 (B75_2013) at different solid/liquid (s/l) ratios

s/l ratio c (mg/l)	18.6g/l	27.9g/l	37.2g/l	62.5 g/l	100g/l	125g/l
B75_2010						
Na^+	93	96	132	190	255	260
K^+	5.6	7.0	7.9	10.8	11.6	11.6
Mg^{2+}	0.54	0.88	1.10	1.70	2.20	2.90
Ca^{2+}	1.91	1.94	2.07	2.19	2.06	2.77
B75_2013						
Na^+	57.9	80.1	85	81.7	123.7	123.5
K^+	8.7	9.3	9.1	8.0	12.4	12.6
Mg^{2+}	3.7	2.5	2.4	3.3	4.1	3.6
Ca^{2+}	1.8	2.1	2.5	2.9	3.4	2.7

Water permeability tests

Laboratory equipment to be used for water permeability testing purposes was successfully verified by means of a preliminary test on a specimen of saturated bentonite. *Figure 13* shows an illustrative test of water permeability through B75_2010 bentonite powder (dry density 1.2g/cm^3, pressure gradient 4bar) in which a hydraulic conductivity value of about 3.6×10^{-12}m/s was obtained. A test set of samples of powdered B75_2013 bentonite compacted to 1.4g/cm^3 was prepared for further study. This value represents the (lower) limit dry density of the material which it is supposed will be achieved by spraying and the compaction of the bentonite pellets and powder for the construction of plug in situ. These samples are fully saturated and water permeability and gas permeability tests at various pressure gradients will be conducted. The pressure range will be specified on the basis of the permeability testing of the grouted rock in the plug construction niche. At the beginning of 2014 a test involving spraying and the compaction of bentonite pellets and powder will be performed by CEG. The preparation of test samples (i.e. sampling from this bentonite barrier itself) will be followed, for which both special equipment and a new sampling procedure are currently in the development stage. The sampling of the bentonite barrier during the plug construction process was also considered so as to obtain a thorough characterization of this part of the plug. All of the above data will be the input for the model description in WP5.

In January 2014 permeability tests commence on fully saturated samples of bentonite materials (dry density 1.4g/cm^3, as is expected in the experimental plug). B75_2013 and Sabenil 65 (S65) samples are currently being tested for water permeability at different hydraulic gradients. The first run involved the testing of S65 samples (1.4g/cm^3, 15mm long) at a pressure gradient of 2MPa. After the equilibration the attainment of a steady state, the gradient will be gradually increased to 7MPa in gradient steps of approx. 3, 5 and finally 7MPa. The same test procedure will be applied to B75_2013 samples (1.4g/cm^3) of different lengths (5, 10 and 15mm). Synthetic granitic water was used for all permeability tests.

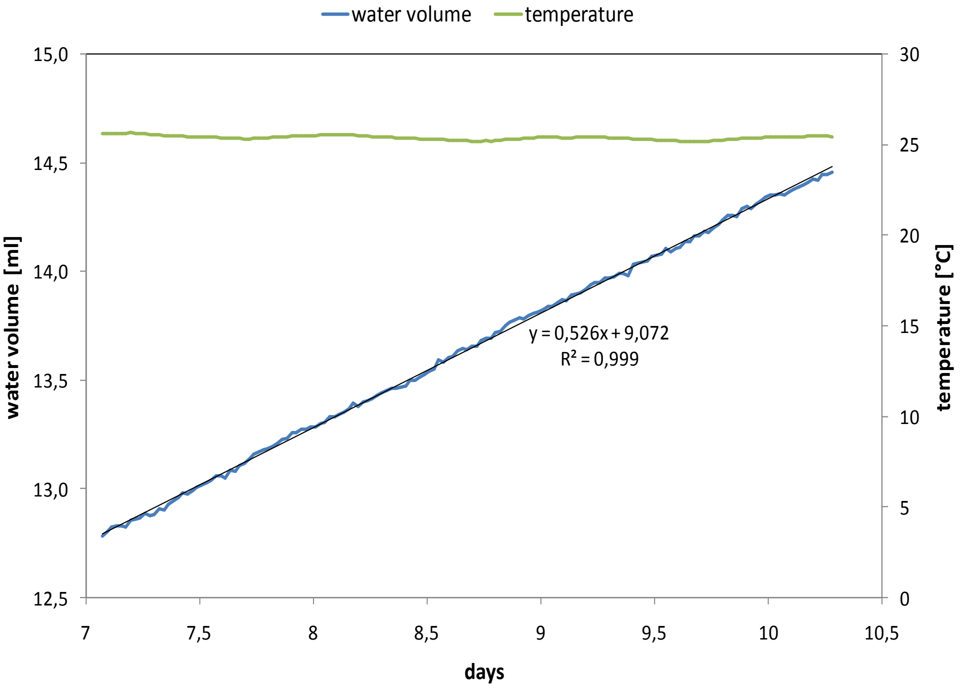

Figure 13 – Illustrative test of water permeability through a specimen of B75_2010 bentonite powder (dry density 1.2g/cm^3, pressure gradient 4 bars)

4.2.2 Laboratory tests on grouting materials

Before the construction of the plug the surrounding rock must be grouted in order to obtain low permeability of the rock mass. Interactions with alkaline solutions released from the concrete barrier of the plug might lead to the degradation of the grouting and thus the mass of the grouted rock could be affected. Due to delays caused by the sub-contractor tender process and complications involving drilling and grouting, work began at the end of 2013. Therefore it has not been possible to date to obtain a sample of injection materials directly used in the work in-situ. Consequently testing has been restricted so far to simple interaction tests on general polyurethane based grouting materials. Injection material samples have been tested in two forms: hard compact and foam (see Figure 14). The samples were immersed in solutions of additionally alkalised SGW (pH up to 13) and monitored over the long term. It was found that the interaction of both forms of material with alkaline solutions is minimal and has no visible effect on the nature and structure of the grouting.

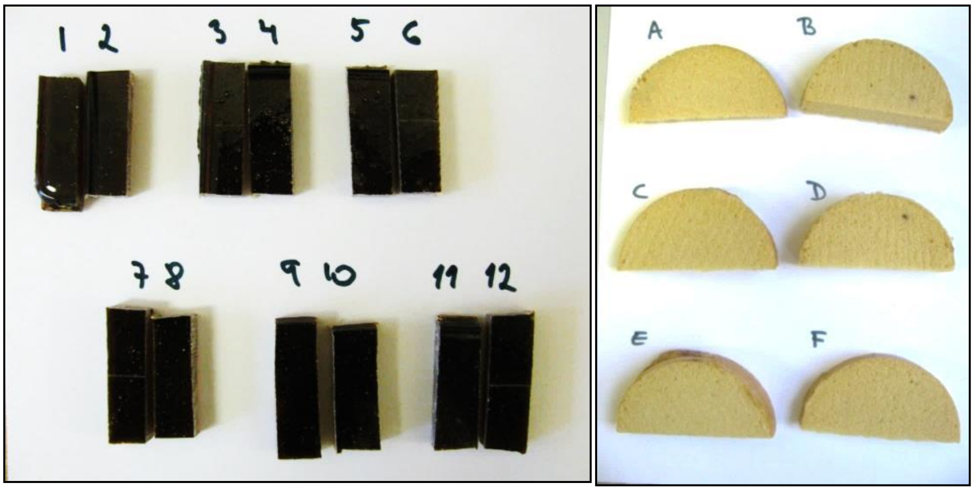

Figure 14 – Samples of polyurethane based grouting materials

4.2.3 Laboratory tests on concrete/ cement

One of the important quantities of the concrete materials used in the construction of the plug consists of the pH value of the extract/leachate. The requirement is that the concrete mixture should be "low-pH concrete", which generally means extract pH values of ~ 11.5 or less. The recommended procedure for the pH determination of low-pH leachates from concretes is described in the SKB R-12-02 report: Development of an accurate pH measurement methodology for the pore fluids of low pH cementitious materials (Alonso et. al., 2012). The ÚJV's previous experience with the preparation of low pH leachate cement mixtures and the experience of a commercial producer of concrete mixtures for building purposes were used in determining the first proposal for the concrete mix composition for the construction of the concrete parts of the experimental plug. The cement mixture formerly developed by ÚJV achieved a pH level of < 11 in the leachate. In comparison, the pH of selected commercially produced materials was pH ~ 12 (see Tab. 7). Although the mixtures developed by ÚJV exhibit low pH leachate, due to their low compressive strength they are unsuitable for practical use in construction projects. All cement/ concrete pH testing are performed by using distilled water.

A reduction in the pH of the leachate of the cement mixture can be obtained by the partial replacement of the cement by another type of binder; it can also be modified by increasing the ratio of fine SiO_2 (microsilica/silica fume) to the cement content. A study of leachate pH changes for cement mixtures with the partial replacement of cement by metakaolin has been prepared in cooperation with CEG.

Measured pH extract results for mixtures tested with the partial substitution of cement by metakaolin (various ratios) are presented in Tab. 8 and Tab. 9. A comparison of these results with the pH values of a cement paste leachate (pH approx. 13) clearly confirms that the addition of metakaolin decreases leachate pH values. It can be seen that the replacement of cement by metakaolin significantly reduces the pH of the extracts after just 1 month of cement mixture ageing. Other additional samples will be tested over a longer period of time. However, the negative influence of the addition of metakaolin into the cement mixture may cause a decrease in strength; this parameter has not yet been tested, but the behaviour of samples used in their preparation of powder form for analysis of pH would seem to indicate that a decrease in compressive strength can be expected. Experiments confirming the time-dependent behaviour of the leachate pH of a cement mixture with SiO_2 are ongoing. According to information available on the practical experience (Poyet et. al., 2013) presented at a recent project meeting pH values decrease after a longer time period. With regard to generally used ageing period of 28 days, this time is not sufficient for the full development of the chemistry of the mixture. Decrease in pH can be expected within a period of approximately 6 weeks or longer. Confirmation experiments have commenced involving materials from the Czech Republic. The experimental results shown in Tab. 11 and Tab. 12 indicate that a decrease in pH value is time-dependent. The experiments are ongoing and future developments in terms of leachate pH values will be closely monitored over time. The results confirm the findings by Poyet et. al. (2013) of and can be applied to the materials of local origin used in this project.

Tab. 7 - Comparison of the pH leachate values of various types of cement and concrete mixes. Mixture T-22, T-23 and P-1 were developed by ÚJV, mixtures S-1 and S-2 (repetition of S-K-1 and S-K-2) are samples of selected commercially produced concretes

sample	pH - suspension	average pH	pH - filtrate	average pH
T-22	**10.94**	**10.9**	**10.78**	**10.8**
	10.88		**10.80**	
	10.89		**10.79**	
T-23	**10.83**	**10.8**	**10.75**	**10.8**
	10.80		**10.76**	
	10.79		**10.76**	
S-1	**11.91**	**11.9**	**11.94**	**12.0**
	11.93		**11.96**	
	11.89		**11.96**	
S-2	**11.93**	**12.0**	**11.94**	**11.9**
	11.95		**11.95**	
	11.98		**11.93**	
S-K-1	**11.85**	**11.8**	**11.73**	**11.8**
	11.85		**11.77**	
	11.84		**11.79**	
S-K-2	**11.99**	**12.0**	**11.89**	**11.9**
	11.97		**11.96**	
	11.97		**11.99**	
P-1	**10.98**	**11.0**	**10.85**	**10.8**
	10.96		**10.77**	
	10.96		**10.75**	

Tab. 8 - Leachate pH values for a paste with the partial replacement of cement with metakaolin; ratio of cement /metakaolin/water = 170/30/100

mixture

CEM II/A-S 42,5R (g)	170
metakaolin (g)	30
water (ml)	100

after 1 week

sample	sample (g)	water (ml)	pH suspension		pH filtrate	
170-30	15	15	13.14	**13.1**	13.09	**13.1**
	15	15	13.09		13.12	
	15	15	13.11		13.12	

after 1 month

sample	sample (g)	water (ml)	pH suspension		pH filtrate	
170-30	10	10	12.57	**12.6**	12.54	**12.6**
	10	10	12.56		12.59	
	10	10	12.56		12.58	

Tab. 9 - Leachate pH values for a paste with the partial replacement of cement with metakaolin; ratio of cement /metakaolin/water = 150/50/100

mixture

CEM II/A-S 42,5R (g)	150
metakaolin (g)	50
water (ml)	100

after 1 week

sample	sample (g)	water (ml)	pH suspension		pH filtrate	
150-50	15	15	13.05	**13.0**	13.08	**13.1**
	15	15	13.01		13.05	
	15	15	12.98		13.06	

after 1 month

sample	sample (g)	water (ml)	pH suspension		pH filtrate	
150-50	10	10	12.42	**12.4**	12.24	**12.3**
	10	10	12.38		12.25	
	10	10	12.44		12.30	

Tab. 10 - Leachate pH values for a paste with the partial replacement of cement with metakaolin; ratio of cement /metakaolin/water = 100/100/100

mixture

CEM II/A-S 42,5R (g)	100
metakaolin (g)	100
water (ml)	100

after 1 week

sample	sample (g)	water (ml)	pH suspension		pH filtrate	
100-100	15	15	12.93	**12.9**	12.89	**12.9**
	15	15	12.92		12.91	
	15	15	12.88		12.88	

after 1 month

sample	sample (g)	water (ml)	pH suspension		pH filtrate	
100-100	10	10	12.18	**12.2**	11.94	**11.9**
	10	10	12.16		11.97	
	10	10	12.14		11.90	

Tab. 11 - Leachate pH values for paste cement + SiO_2; ratio of cement/ SiO_2/water = 100/100/200

mixture

CEM II/A-S 42,5R (g)	100
SiO2 (g)	100
water (ml)	200

after 2 weeks

sample	sample (g)	water (ml)	pH suspension		pH filtrate	
100-100-200	10	10	11.99	**12.0**	11.96	**12.0**
	10	10	11.98		11.95	
	10	10	12.01		11.96	

after 3 weeks

sample	sample (g)	water (ml)	pH suspension		pH filtrate	
100-100-200	10	10	11.98	**12.0**	11.88	**11.9**
	10	10	11.97		11.87	
	10	10	11.98		11.89	

after 5 weeks

sample	sample (g)	water (ml)	pH suspension		pH filtrate	
100-100-200	10	10	11.56	**11.5**	11.31	**11.3**
	10	10	11.50		11.33	
	10	10	11.50		11.30	

after 7 weeks

sample	sample (g)	water (ml)	pH suspension		pH filtrate	
100-100-200	10	10	11.73	**11.7**	11.66	**11.6**
	10	10	11.70		11.60	
	10	10	11.69		11.62	

Tab. 12 - Leachate pH values for paste cement + SiO_2; ratio of cement/ SiO_2/water = 100/100/250

mixture

CEM II/A-S 42,5R (g)	100
SiO2 (g)	100
water (ml)	250

after 2 weeks

sample	sample (g)	water (ml)	pH suspension		pH filtrate	
100-100-250	10	10	11.94	**11.9**	11.92	**11.9**
	10	10	11.93		11.91	
	10	10	1196		11.91	

after 3 weeks

sample	sample (g)	water (ml)	pH suspension		pH filtrate	
100-100-250	10	10	11.89	**11.9**	11.80	**11.8**
	10	10	11.90		11.80	
	10	10	11.90		11.81	

after 5 weeks

sample	sample (g)	water (ml)	pH suspension		pH filtrate	
100-100-250	10	10	11.50	**11.5**	11.34	**11.4**
	10	10	11.49		11.37	
	7	7	11.50		11.35	

after 7 weeks

sample	sample (g)	water (ml)	pH suspension		pH filtrate	
100-100-250	10	10	11.52	**11.5**	11.52	**11.5**
	10	10	11.53		11.52	
	10	10	11.40		11.51	

4.2.4 Laboratory tests on the host rock

At the end of 2013 a drilled core sample of the host rock was taken from the niche in which the experimental plug will be constructed. This sample (see figure below), approximately 30 cm long and 6.12 cm in diameter derive from the new drilled borehole V2 which connects the experimental and technical niches of the EPSP project.

Figure 15 - Host rock sample; drilled core from borehole V2

The drilled core part was sawn into smaller samples to be used for the determination of porosity using the water submersion method (Melnyk and Skeet, 1986). Rock samples were dried and their weights were recorded in first step of this method. Currently the rock samples are undergoing saturation process by SGW. Following full saturation, the saturated weights will be recorded and sample porosity calculated. For permeability measurement purposes this type of drilled core has to be reduced in diameter to approx. 5cm so as to fit into the experimental permeability cell or alternatively, new samples must be drilled of the appropriate diameter.

4.2.5 Physical models

Since the simulation of unsaturated swelling materials is somewhat complicated and the EPSP underground laboratory experiment will not be dismantled during the course of the project, the construction of physical models of plugs at the laboratory scale was proposed in the laboratory work plan. The aim of these experiments is to gain data for the subsequent calibration of numerical models of the saturation of the bentonite material. In all experiments synthetic granitic water is used.

The physical model will consist of a stainless steel chamber of cylindrical shape with approximate dimensions 0.5m in length and 0.1m in diameter and will be equipped with sensors to record the distribution of water content within the bentonite material. Bentonite with an estimated bulk density of from 1.4g/cm^3 to 1.6g/cm^3 (the same bulk density as assumed in the EPSP experiment) will be pressed into the test chamber and gradually saturated with water under pressure. The level of water pressure will be determined by the field testing of the permeability of the grouted rock at the Josef Underground Laboratory. A maximum pressure of 7MPa is assumed. A sample of the bentonite material will be dismantled following the conclusion of the experiment and divided into layers with an estimated thickness of 1cm. The water content in each layer will then be determined. It is assumed that the duration of the experiment will be around 1 year.

Installation of physical models chambers with facilities to observe the progress of water content within the sample was dealt with in time prior to construction of EPSP (2013). Sensors for the measurement of pore water pressure and the drainage needles were tested in a small-scale chamber (Figure 16, detail in Figure 17). Samples of bentonite B75 with bulk densities of 1.2g/cm^3 and 1.6g/cm^3 were pressed into small-scale chambers with internal dimensions of 3cm in diameter and 3cm in height and saturated with water under pressure of 4 bar in the case of the sample with a bulk density of 1.2g/cm^3 and 20 bar in the case of the sample of bulk density 1.6g/cm^3. The volume of the infiltrating water was measured using a volume meter and the volume of water flowing out of the chamber was monitored using a syringe and drainage needles. The results of the testing of the measuring equipment are shown in Figure 18 - Figure 20.

Figure 16 - Small-scale chamber for monitoring the saturation of bentonite

Figure 17 – Detail of drainage needles and sensors for the measurement of pore water pressure

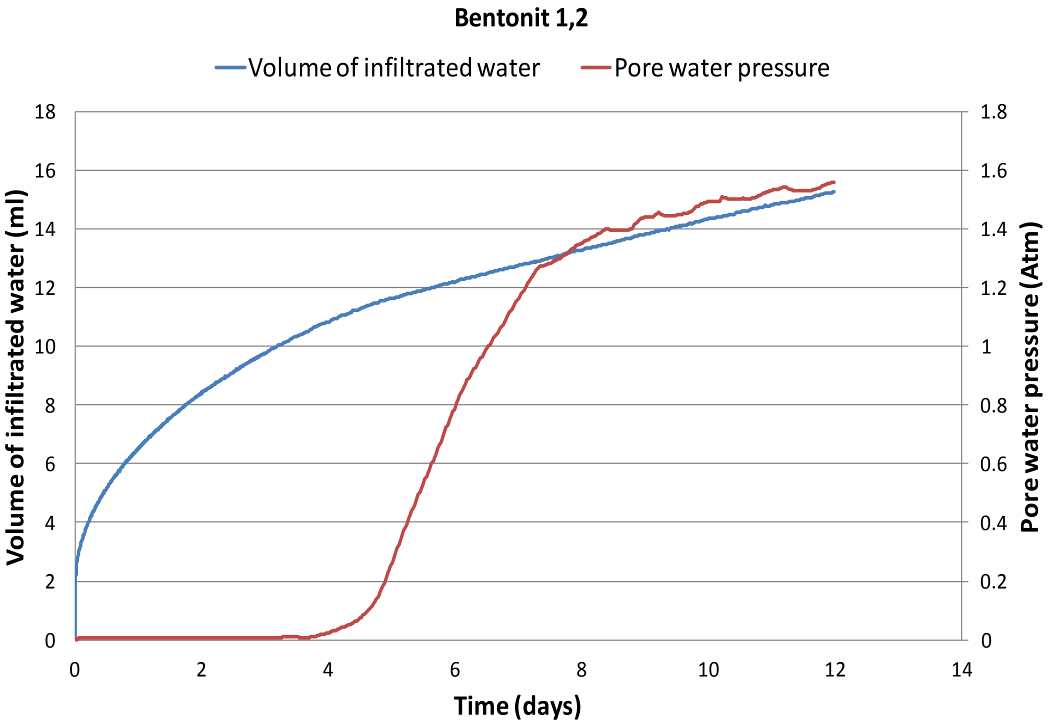

Figure 18 - Development of pore water pressure and volume of infiltrating water for bentonite with a bulk density of 1.2g/cm^3

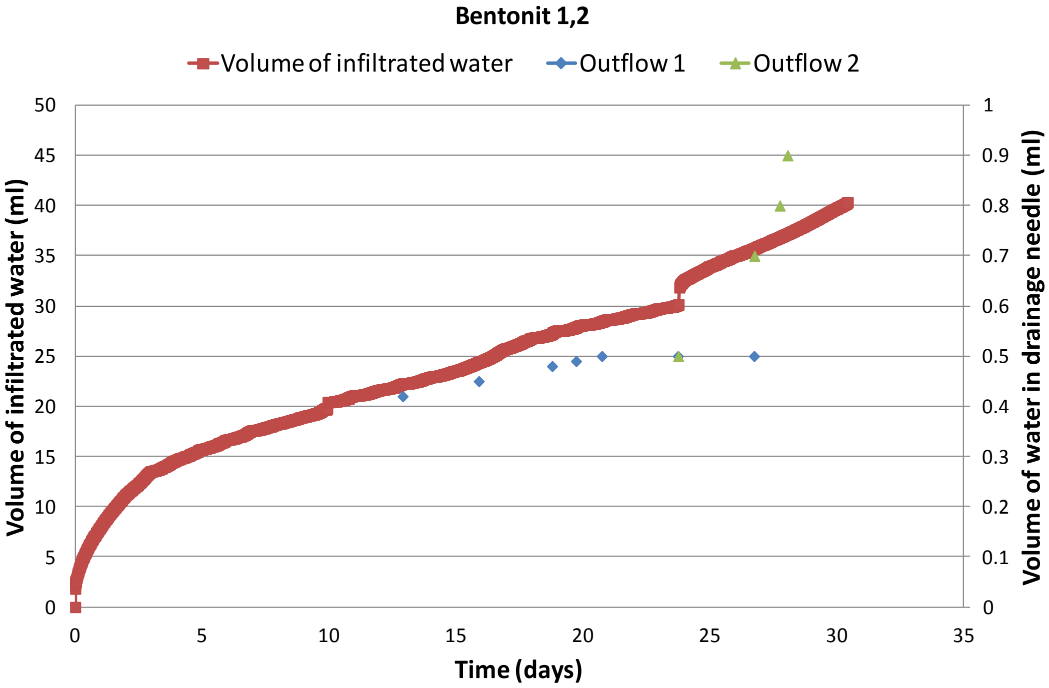

Figure 19 - Development of outflowing water and volume of infiltrating water for bentonite with a bulk density of 1.2g/cm^3

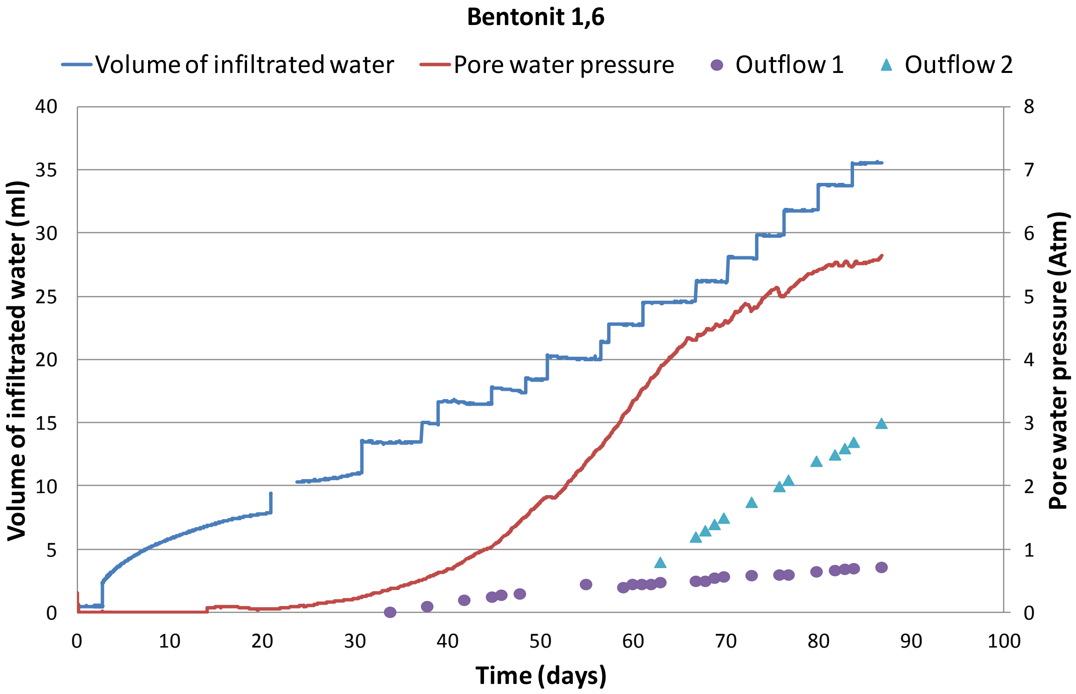

Figure 20 - Development of pore water pressure, outflowing water and volume of infiltrating water for bentonite with a bulk density of 1.6g/cm^3

Figure 20 shows that discharge from the drainage needle occurs when pore water pressure increases to 0.3 bar; the drainage needle sensors for the measurement of pore water pressure are located at the same distance from the beginning of the sample and adjacent within the sample. According to the theory of continuum mechanics, the outflow of water from the porous medium occurs when the material achieves the saturated state which corresponds to the disappearance of negative pore water pressure. The difference of 0.3 bar can be attributed to the resistance applied by the syringe of the drainage needle.

With regard to the samples of bentonite with a bulk density of 1.2g/cm^3, the sensors for the measurement of pore water pressure and the drainage needle were installed within the sample at different times. The first stage consisted of saturation with the sensor (Figure 18), the second with the drainage needle (Figure 19). Despite efforts to prepare the sample in both experiments under the same conditions it is clear that the results are not comparable. In addition, with concern to tests with the drainage needles, the bentonite was leached at the end of the saturation process through the drainage needle. Therefore, it was decided to modify the drainage needles once a porous plate with a high AEV (air entry value) had been pressed on top of the needle (on contact with the sample). There is a significantly higher volume of infiltrated water in the case of the installation chamber with a drainage needle than in the installation chamber with sensors for the measurement of pore water pressure. It is possible that the drainage needle presents a preferential path within the sample that may interfere with flow inside the material.

Experiments with the bulk density of 1.4g/cm^3 samples will be carried out before the final installation of the chamber for the physical models; the small-scale chamber will be equipped with drainage needles simultaneously with that of the sensor for the measurement of pore water pressure. The resistance of the drainage of the syringe needle has been verified. Further attention will be paid to the characteristics of the porous plate so as not to influence the processes at work within the bentonite material.

This experiment will be repeated with the chamber fitted with the sensor for the measurement of pore water pressure only in order to show the effect of the drainage needle (preferential path) on the water content inside the sample. If this effect proves to be significant, the drainage needle will be fitted with closable valves during the saturation of the physical model so that the needle can be closed upon the initial discharge of water from the drainage needle thus preventing the creation of a preferential water flow path from the sample. In the case of the installation of drainage needles with closable valves, a comparative experiment will be conducted with these needles but without the sensors for the measurement of pore water pressure. The physical model chamber will be equipped with several sensors for the measurement of pore water pressure and probably with a number of drainage needles. Early in the 2014 the needles and the sensors will be made in sufficient quantities so as to obtain data for the calibration of numerical models of bentonite saturation. The sensors and the drainage needles will be thoroughly tested on at least one sample in the small-scale chamber before being installed in the physical model chambers.

Interaction models

Physical models for the study of the interaction of materials of experimental plug have already been designed and experimentation will commence in 2014. Exactly the same materials as those in the experimental plug will be used. SGW will be used as a liquid phase for saturation and interaction processes. Final material for the concrete part of the plug will be decided according to the results of the tender for the relevant sub-contractor. Currently, the determination of the design of the experimental cells for the physical models is ongoing.

4.2.6 Conclusion of ÚJV work

The analyses of the chemical composition, the measurement of pH in suspensions of bentonite and distilled water at different ratios and the analysis of leachates (cation concentrations) have all been conducted for B75_2013 bentonite. The analyses of anion concentrations in the leachates and the determination of cation exchange capacities (CEC) are currently under way. X-ray diffraction pattern determination and mineralogical analysis will be conducted on the B75_2013 material in 2014.

Existing available results on the properties of B75_2013 revealed, when compared with previous data on B75 materials, a number of small property changes (chemical composition, leachate properties) occurred within the material during the production process. Nevertheless, it can be assumed that the main characteristics of B75 bentonite remained constant and fulfil all the expectations, limits and requirements for the construction of the experimental plug.

It was found that common polyurethane based grouting materials are not influenced by alkaline solutions and should not be affected by cement leachates in the grouting of the experimental plug.

With regard to cement/concrete materials, ÚJV testing has focused primarily on the measurement of pH. It has been verified that increasing the SiO_2 content in the mixture (ratio cement/SiO_2 = 1/1) leads to a decrease in the pH value of the leachate into distilled water (according to procedure based on Alonso et al. (2012)) to pH ~ 11.5. The pH value of the leachate of the concrete used in the construction of the experimental plug will be verified in laboratory tests conducted during the construction of the experimental plug.

Host rock property tests (porosity, permeability tests conducted in the laboratory) have commenced with the full saturation of rock samples in preparation for porosity determination and further testing.

The measurement equipment for the laboratory physical models has been tested and verified and the final set-up of the equipment will be decided at the beginning of 2014. Subsequently, laboratory tests on these physical models will begin using the same materials as those which will be applied in the construction of the experimental plug in-situ.

5 LITERATURE

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6 LIST OF ABBREVIATIONS

AEV – Air Entry Value

B75 – Czech Ca-Mg bentonite, trade name “Bentonit 75”, produced by KERAMOST, Plc., not activated

B75_2010 – B75 delivered in 2010 (tested in 2010-2013)

B75_2013 – B75 delivered in 2013, used in DOPAS – EPSP

B75_PEL_12 – Pellets made from B75 2013 bentonite, diameter 12mm, made by commercial roller compaction technology for kaolin pellet production

B75_REC – Pellets (crushed highly-compacted material) made from B75 2013 bentonite, non-commercial product

B75_REC_F – A mixture of several B75 REC fractions according to Fuller‘s curve (of optimal grain size distribution), here without fine particles below 0.5mm

CEC – Cation Exchange Capacity

CEG – Centre of Experimental Geotechnics, Faculty of Civil Engineering, Czech Technical University in Prague

EPSP – Experimental Pressure and Sealing Plug

SAB65, S65 – Czech bentonite, trade name “Sabenil 65”, produced by KERAMOST, Plc., activated

SGW – Synthetic Granitic Water

ÚJV – ÚJV Řež, a. s.