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SPRAYED CLAY TECHNOLOGY FOR THE DEEP REPOSITORY OF HIGH-LEVEL RADIOACTIVE WASTE

TEHNOLOGIJA PRSKANE GLINE ZA DUBOKA ODLAGALIŠTA VISOKORADIOAKTIVNOG OTPADA

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Key words: bentonite, backfill, sprayed clay technology

Abstract

The sealing barrier will play very important role in the Czech disposal concept of high level radioactive waste. It follows Swedish SKB3 design where granitic rock environment will host the repository. Swelling clay based materials as the most favorable for sealing purposes were selected. Such clays must fulfill certain requirements (e.g. on swelling properties, hydraulic conductivity or plasticity) and must be stable for thousands of years. Better sealing behavior is obtained when the clay is compacted. Technology of the seal construction can vary according to its target dry density. Very high dry density is needed for buffer (sealing around entire canister with radioactive waste). Less strict requirements are on material backfilling the access galleries. It allows compaction to lower dry density than in case of buffer. One of potential technology for backfilling is to compact clay layers in most of the gallery profile by common compaction machines (rollers etc.) and to spray clay into the uppermost part afterwards. The paper introduces the research works on sprayed clay technology performed at the Centre of Experimental Geotechnics of the Czech Technical University in Prague. Large scale in situ demonstration of filling of short drift in the Josef Gallery is also mentioned.

Sažetak

Brtvena barijera će igrati vrlo važnu ulogu u češkom konceptu odlaganja visokoradioaktivnog otpada. Ovaj koncept slijedi švedski SKB3 dizajn u kojem je odlagalište okruženo granitnim stijenama. Kao najpogodniji materijal za brtvljenje odabrani su materijali bazirani na bubrivim glinama. Takve gline moraju udovoljiti određenim zahtjevima (na primjer, značajke bubrenja, hidraulička vodljivost ili plastičnost) i moraju biti stabilne tisućama godina. Bolje brtvljenje postiže se ukoliko je glina zbijena. Tehnologija konstrukcije barijere može varirati prema ciljanoj suhoj gustoći. Vrlo visoka suha gustoća potrebna je za tampon (brtvljenje oko cijelog spremnika radioaktivnog otpada). Nešto su blaži zahtjevi glede materijala za ispunjavanje pristupne galerije. On omogućava zbijanje na nižu suhu gustoću nego u slučaju tampona. Jedna od potencijalnih tehnologija za ispunjavanje je zbijanje slojeva gline u većini profila galerije uobičajenim strojevima za zbijanje (valjci, itd.) i nakon toga prskati glinu u najgornji dio. Članak prikazuje istraživanje tehnologije prskane gline u Centru za eksperimentalnu geotehniku Tehničkog sveučilišta u Pragu. Također je spomenuta „in situ" demonstracija zapunjavanja kratkog hodnika u Josef Galeriji.

1. Introduction and context

The construction of a deep geological repository for the storage of spent nuclear fuel (see Figure 1) will require the use of several hundred thousand tons of natural swelling clay (bentonite). This material possesses excellent swelling and self-healing abilities, high levels of plasticity and allows minimal hydraulic conductivity. The main function of the bentonite sealant will be to limit water transport around the canister containing spent fuel and thus prevent the eventual potential release of radionuclides into the biosphere. The highly compacted bentonite (buffer) around the canister will form one element of the multi-barrier sealing system in each of the individual deposition chambers. Compacted bentonite (backfill) will fill the access galleries following the closure of each section (a pre-determined number of deposition chambers) of the repository.

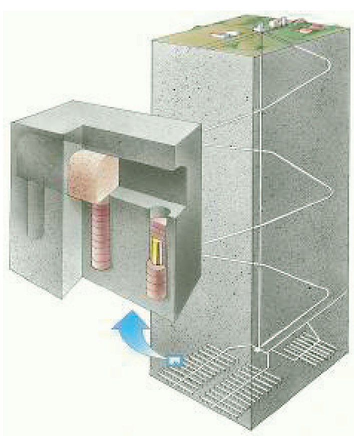

Figure 1 Scheme of the Deep geological repository for high level waste. (according to SKB, 2008).

Slika 1. *Shema dubokog geološkog odlagališta za visokoradioaktivnog otpada (prema SKB 2008).*

2. Sprayed clay technology

The objective of the research being carried out at the Centre of Experimental Geotechnics (CEG) is to develop technology for the application of backfill material using spraying.

The procedure is based on commonly employed sprayed concrete technology (shotcrete). Of the two existing technological procedures used in shotcreting ("dry" and "wet" methods), the dry process was selected for the delivery of sprayed backfill.

During the dry process, the sprayed material is transported pneumatically, via transport hoses, from the spraying machine to the spraying nozzle, where is material mixed with water. Thus the sprayed material is hydrated to the desirable moisture content level within the nozzle.

Backfilling of access galleries will consist of two parts. Major space will be filled by compaction machines. The uppermost part (no space for using any machine for compaction) will be filled by spraying. It is shown in Fig. 2.

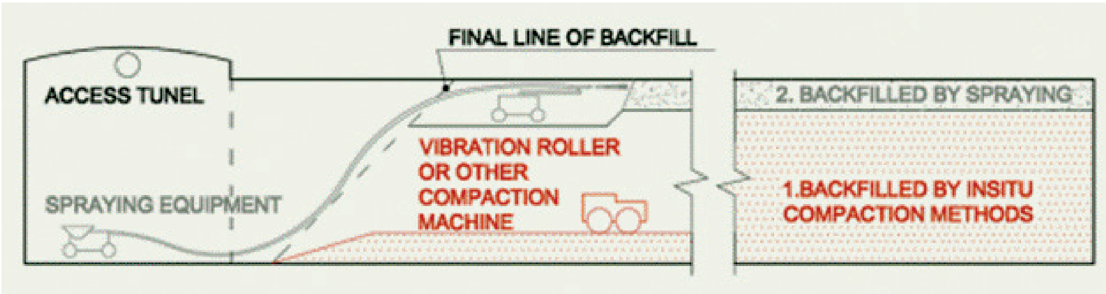

Figure 2 Scheme of Backfilling

Slika 2. *Shema skladištenja*

2.1. Spraying equipment

The spraying assembly consists of five components: air compressor, spraying machine, nozzle, hoses and water flow regulator (Figure 3).

Figure 3 Up: Spraying set, Down: water flow regulator and spraying nozzle.

Slika 3. *Gore: Oprema za prskanje, Dolje: regulator protoka vode i mlaznica*

Testing of various components for use with bentonite and harmonisation of their function in the complex were some of the key issues of the development of spraying technology (modification of spraying nozzle, optimum pressure of air, dosage of material to the nozzle, particle size of material and optimum water inflow).

All the components are the same as commonly used in shotcrete technology. However the spraying nozzle had to be adapted for this particular purpose due to very specific behaviour of bentonite (swelling and very high plasticity; Pacovský & Šťástka, 2009).

2.2. Material testing

The main focus of the research is targeted at characterising the conditions in which bentonite can be sprayed successfully with respect to the required high level of dry density, the potential use of various types of bentonite, admixtures (added sand, gravel - particle size three times lower than inside diameter of nozzle, etc.) and the conditions to be applied during the application procedure itself (optimum amount of water 75 l/h, optimum spraying pressure up to 1.5 MPa). Another important task is to limit fall-out of the material during spraying and dustiness (see Figure 4). Czech bentonite is being used. Granulated form was selected as the most suitable according to previous research at CEG.

Figure 4 Optimisation of spraying procedure.

Slika 4. *Optimizacija procedure prskanja*

2.2.1. Requirements on buffer and backfill

Required properties of buffer and backfill were specified in e.g. Rautioaho & Korkiala-Tanttu, 2009. The key geotechnical parameters are hydraulic conductivity and swelling pressure. Required values for buffer: hydraulic conductivity $k < 10^{-12}$ m/s, swelling pressure $\sigma sw > 1$MPa and for backfill: $k < 10^{-11}$ m/s, swelling pressure $\sigma sw >$ 0.1 MPa. Both parameters are strongly dependent on dry density.

2.2.2. Chosen material for spraying

The CEG uses granulated bentonite from Czech deposit (northern Bohemia) as the basic material during the development of sprayed backfill technology. Bentonite is basically residual clay-type rock with extremely good sorption, swelling and plasticity abilities reflected in minerals which make up the clay, particularly montmorillonite. The choosen material is a Czech bentonite with a montmorillonite content of 65 – 80 %. It possesses very good swelling and self-healing abilities, high plasticity and minimum permeability. Its plasticity index Ip is around 70 %. Highly compacted to a dry density of 1.75 Mg/m^3 it is able to develop swelling pressures of up to 6 MPa with a hydraulic conductivity in such a highly compacted state of $k = 10^{-13}$ m/s.

To achieve desired values of required parameters it is necessary to compact bentonite at least to certain value of dry density. Value for this chosen bentonite is for buffer circa 1.5 Mg/m^3 and for backfill around 1.35 Mg/m^3 (Šťástka et. al., 2010).

2.2.3. Evaluation of sprayed samples

The main indicator of success spraying is dry density, so it has to be evaluated after each spraying attempt. It is calculated from mass water content and density of taken samples. Two different methods of sampling can be used. Either the clay is sprayed directly into the sampling rings or cubes (of which the volume is known) or the core drilling provides cylindrical samples (Figure 5 and Figure 6). The samples must be adjusted for determination of volume by common laboratory methods (dimensions measuring by caliper or by measuring in water based on Archimedes´ principle; second way is preferred because it gives more accurate results).

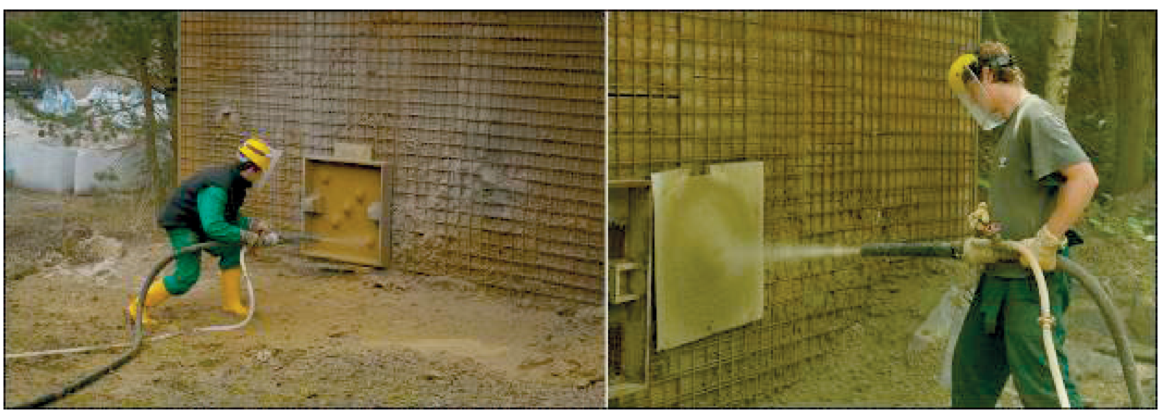

Figure 5 Two spraying scenarios according to type of sampling: spraying into the forms (left) and before core drilling (right).

Slika 5. *Dva scenarija prskanja ovisno o tipu uzorkovanja: prskanje u kalupe (lijevo) i prije jezgrovanja (desno)*

Figure 6 Various samples: filled forms (left) and core drilling (right).

Slika 6. *Različiti uzorci: ispunjeni kalupi (lijevo) i bušenje jezgri/jezgrovanje (desno)*

2.3. Results

The works were focused on optimisation of technology – achievement of sufficiently high dry density, limiting of fallout of the sprayed material and dustiness mainly. Water plays a key role during the spraying process – its amount (rate to mass of the applied clay), pressure and distribution inside the clay material.

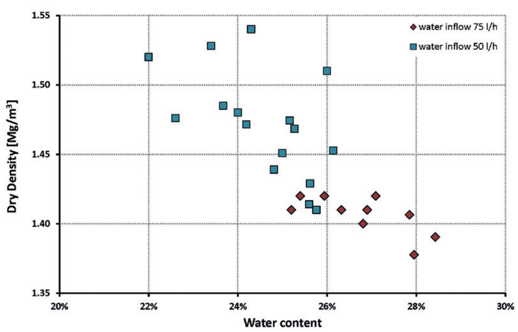

Figure 7 Influence of amount of water during application.

Slika 7. *Utjecaj količine vode tijekom primjene*

Sufficiently high values of dry density were reached by spraying especially due to use of clay material with optimised particle size distribution. Relation between dry density and water content of results is shown on Figure 7. Water flow 50 and 75 l/hour was used.

2.4. Large Scale in-situ experiment

After optimisation of technology a large scale in-situ backfilling experiment was designed at the Josef Gallery (Underground Research Centre URC Josef; www.uef-josef.eu). The design generally followed the backfilling scheme shown in Figure 2. The short gallery was partly backfilled with mixture of crushed rock and bentonite. Ordinary compaction board was used. The uppermost part was plugged by spraying afterwards (Figure 8).

Figure 8 In-situ backfill demonstration at the Josef underground facility.

Slika 8. *Prikaz"in-situ" zapunjavanja u podzemnom objektu Josef*

3. Conclusion

In the Centre of Experimental Geotechnics technological procedure for bentonite spraying was developed. The quality of the application assures sufficiently high dry density of sprayed material which is required for backfilling of the deep repository. The in-situ demonstration test was also successfully performed at the Josef URC.

Requirements on buffer are stricter than on backfill. Their fulfillment will require even higher quality (dry density) of the application.

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