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Äspö Hard Rock Laboratory

Prototype Repository

Laboratory tests on the backfill material in the Prototype Repository

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Abstract

The saturation of the *Prototype Repository* is measured with transducers installed both in the buffer, backfill and surrounding rock. The saturation phase of the *Prototype Repository* is modeled with different computer models for unsaturated conditions. As input for these models, parameters for both the buffer and the backfill are required. This report describes results from some laboratory tests made on the backfill material for evaluating some of the required parameters. The results from the tests are compared with previous made tests on similar backfill materials.

The backfill used in the tests is the same material that has been mixed for and used in the backfill of the *Prototype Repository*. The material consists of a mixture of crushed rock with a maximum grain size of 20 mm (70%) and a sodium converted bentonite from Greece, Milos (30%). The salinity of the water used in the tests is about 0.7%.

The following tests and measurements have been performed on the backfill material:

- Proctor tests
- Hydraulic conductivity and swelling pressure tests
- Measurements of suction
- Water uptake tests

The results from the tests are compared with previous preformed tests on other backfill materials. The results are also used for postulating the properties of the backfill in the *Prototype Repository where* the average dry density is about 1700 kg/m^3. The following conclusions can be made from the tests:

- The Proctor tests yield a maximum dry density of about 2000 kg/m^3 at a water ratio of about 13 %. Compared with the density of about 1700 kg/m^3 achieved in the field tests this means that only 85 % of maximum Proctor density was reached in the field test.
- The expected swelling pressure of the backfill in the *Prototype Repository* according to the performed laboratory tests is about 100 - 200 kPa and the expected hydraulic conductivity is 2E-11 – 5E-11 m/s.
- Performed tests indicate that the hydraulic conductivity of the backfill material is rather insensitive to the pore pressure gradient.
- Taking into account that the salinity of the pore water is somewhat different the new tests agree well with previous performed measurements of hydraulic conductivity on the backfill material used in the *Backfill and Plug Test*.
- The performed suction measurements yield similar results as previously performed measurements on the backfill material in the *Backfill and Plug Test*.

Sammanfattning

Vattenmättnaden i *Prototype Repository* följs med hjälp av givare installerade i bufferten, återfyllnaden och omgivande berget. Vattenmättnadsförloppet modelleras med olika numeriska modeller anpassade för omättade förhållanden. Dessa modeller kräver indata för både buffert och återfyllnad. I denna rapport redovisas resultat från några laboratorieförsök på det återfyllnadsmaterial som använts i *Prototype Reposirtory* för utvärdering av vissa av dessa parametrar. Vidare jämförs dessa resultat från tidigare gjorda försök på andra liknande återfyllnadsmaterial.

Det material som använts i testerna är samma som blandats för *Prototype Repository.* Materialet består av en blandning av krossat berg med maximal kornstorlek på 20 mm (70 %) och en natriumkonverterad bentonit från den grekiska ön Milos (30 %). Salthalten i vattnet som använts för testerna är ca 0.7%.

Följande försök och utvärderingar har utförts på återfyllningsmaterialet :

- Proctorpackning
- Bestämning av hydraulisk konduktivitet och svälltryck
- Suctionmätningar
- Vattenupptagningsförsök

Resultaten från försöken jämförs med tidigare utförda tester på andra liknande återfyllnadsmaterial. Resultaten används också för att prediktera egenskaperna hos återfyllanden i *Prototype Repository* vars torrdensitet i medeltal är ca 1700 kg/m^3. Följande slutsatser kan dras av de utförda testerna:

- Vid Proctorpackningen erhölls en maximal torrdensitet av ca 2000 kg/m^3 vid en vattenkvot på ca 13 %. Jämfört med medeldensiteten som uppmäts i *Prototype Repository* innebär detta 85% av maximal Proctordensitet erhållits i fältförsöket.
- Det förväntade svälltrycket för återfyllnaden i *Prototype Repository* är, enligt utförda laboratorieförsök, ca 100 – 200 kPa och förväntad hydraulisk konduktivitet är ca 2E-11 – 5E-11 m/s.
- Försöken visar att den utvärderade hydrauliska konduktiviteten hos återfyllnadsmaterialet är relativt okänslig för använd portrycksgradient.
- Beaktat att de nya utförda mätningarna av hydraulisk konduktivitet är gjorda med annan salthalt i porvattnet, överensstämmer resultaten väl med tidigare försök på liknande återfyllnadsmaterial.
- Suctionmätningarna gav liknande resultat som tidigare utförda undersökningar på liknande återfyllnadsmaterial.

Contents

1 Introduction

The Prototype Repository Test consists of two sections. The installation of the first Section of Prototype Repository was made during summer and autumn 2001 and Section 2 was installed in spring and summer 2003.

Section 1 consists of four full-scale deposition holes, copper canisters equipped with electrical heaters, bentonite blocks and a deposition tunnel backfilled with a mixture of bentonite and crushed rock and ends with a concrete plug as shown in Figure 1-1. Section 2 consists of two full-scale deposition holes with a backfilled tunnel section and ends also with a concrete plug.

The saturation of the Prototype Repository is measured with transducers installed both in the buffer, backfill and surrounding rock. The saturation phase of the Prototype Repository is modeled with different computer models for unsaturated conditions. As input for these models, parameters for both the buffer and the backfill are required. This report describes results from some laboratory tests made on the backfill material for evaluating some of the required parameters. The results from the tests are compared with previous made tests on backfill materials.

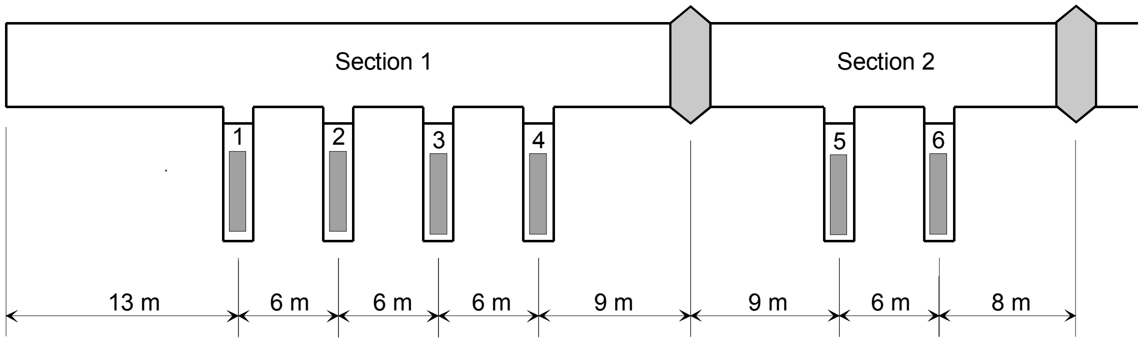

***Figure 1-1**. Schematic view of the Prototype Repository.*

2 Material description

The material for the tests comes from the backfilling of the Prototype tunnel and is taken from the samples saved during mixing of the backfill. The material consists of a mixture of crushed rock with a maximum grain size of 20 mm (70%) and a sodium converted bentonite from Greece, Milos (30%). In Table 2-1 the properties of the Milos bentonite are listed. The backfill was mixed with water pumped out of the ÄHR laboratory to a water ratio of about 12%. The mixing water had a salinity of about 0.6%. The mixing was made in a mobile mixing station. The mixing procedure and the result of the mixing are described in /2-2/.

Table 2-1 Properties of the Milos bentonite after processing /2-1/

Quartz content	1.04 %
Sillica content	51.4 %
K_2O	0.85 %
N_2O	2.90 %
Sulphur content	0.318%
CaO	6.40 %

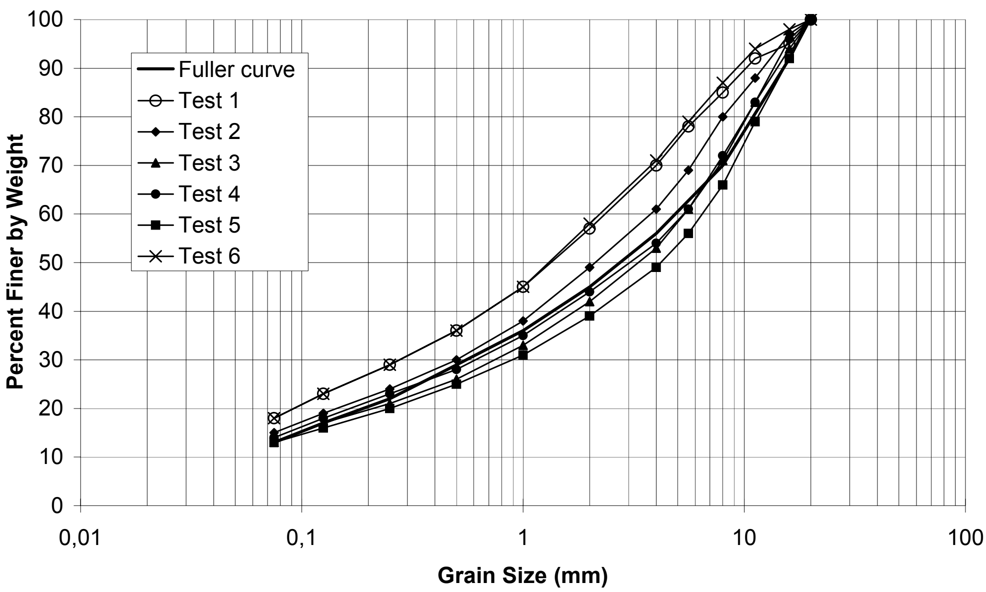

Figure 2-1. *Grain size distribution of randomly taken samples after crushing /2-1/*

Salt water was used for mixing and saturation of the samples in some of the tests. The salinity of the water was supposed to be the same as for the water added to backfill in the Prototype Repository during the water uptake i.e. the salinity of the water in the surrounding rock. The results from measurements of the salinity in the water in the area near the Prototype tunnel are described in /2-3/. Water for the tests was mixed in the laboratory with a similar salinity as the water in the rock. The water had the following composition:

NaCl 4820 mg/liter

$CaCl_2$ 2650 mg/liter

The results from the tests are compared with previous tests made on backfill material for the Backfill and Plug Test (BaPT). In most of these tests the backfill material consisted of a mixture of crushed rock and filler (70%) and bentonite of type MX-80 (30%). Furthermore in some of the tests water with a salinity of about 1.2% was used. Some of these tests were also made with distilled water added. The tests are described in /2-4/.

3 Proctor tests

The tests for investigating the compaction properties were made according to the standard for modified Proctor tests. Water was added to 5 samples in order to get five different water ratios between 7 and 23 %. The final water ratio and density of the samples were determined after compaction. The dry density is plotted as function of the water ratio for the five samples (Proctor curve) and the maximum dry density with corresponding water ratio are determined. The compaction tests were made by Skanska Sverige AB. The results from the tests are plotted in Figure 4-1 together with results from identical test made on the backfill material used in BaPT.

The new tests indicate a maximum dry density of about 2000 kg/m^3 at an optimum water ratio of about 13%, which is similar to the results achieved for the BaPT backfill

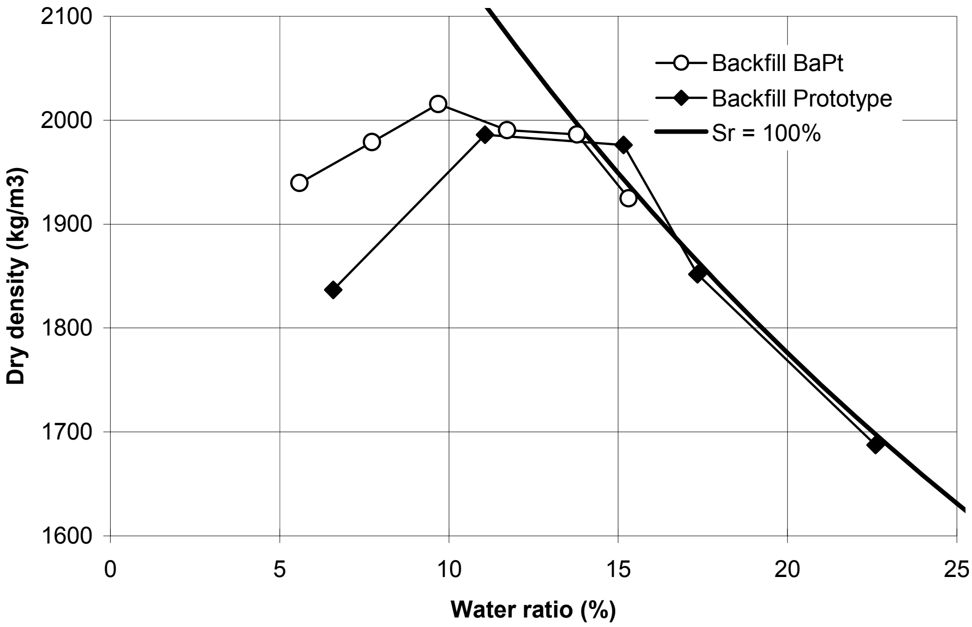

Figure 4-1. *Results from Proctor tests performed on the two backfill materials used in Prototype Repository and BaPT.*

4 Hydraulic conductivity and swelling pressure

The hydraulic conductivity and swelling pressure were determined on three samples which were compacted to dry densities between 1700- 1800 kg/m^3 in oedometers with a diameter of 101.5 mm and a height of about 40 mm (see Figure 3-1). The samples were saturated trough filters placed at the bottom and top of the samples during continuous measurement of the swelling pressure. After saturation the hydraulic conductivity was determined by applying a hydraulic gradient over the sample and measuring the water flow in and out from the samples. The hydraulic conductivity tests were made with a back pressure on the pore water of 100 kPa. Each sample was tested at three different hydraulic gradients. The evaluation of the hydraulic conductivity was done according to Darcy´s law. The water ratio and density of the samples were determined after the tests. The results from the measurement of the swelling pressure and the hydraulic conductivity are summarized in Table 3-1. The swelling pressure for the samples varies between 100 – 200 kPa. These values are somewhat higher compared with the measurement made on the BaPT material at similar densities /2-4/.

Table 3-1 Results from the measurements of hydraulic conductivity and selling pressure.

Test No	Density (kg/m^3)	w	Degree of Saturation	Void Ratio	Dry Density (kg/m^3)	Swelling Press. (kPa)	Gradient	Hydr. Cond. Inlet*) (m/s)	Hydr. Cond. Outlet*) (m/s)
1	2071	0.232	1.00	0,637	1681	104	25 - 255	5.30E-11	4.86E-11
2	2110	0.214	1.01	0,583	1738	100	25 - 127	1.98E-11	1.82E-11
3	2133	0.208	1.02	0,558	1766	198	25 - 127	3.63E-11	3.14E-11

*) Average of measurements made with different gradients

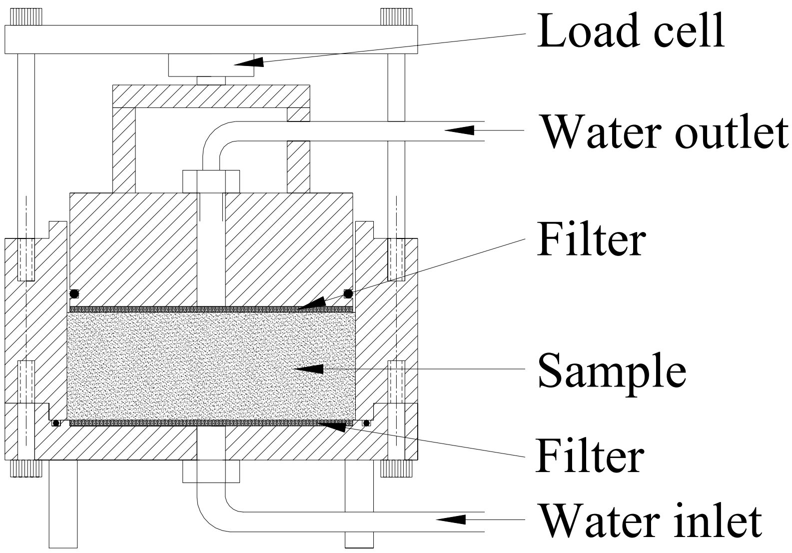

Figure 3-1. *Equipment used for measuring hydraulic conductivity and swelling pressure*

In Figure 3-2 the results from the measurement of the hydraulic conductivity are plotted as function of the hydraulic gradient applied over the samples. The plot show that there is a small influence of the hydraulic gradient on the evaluated hydraulic conductivity but it is negligible.

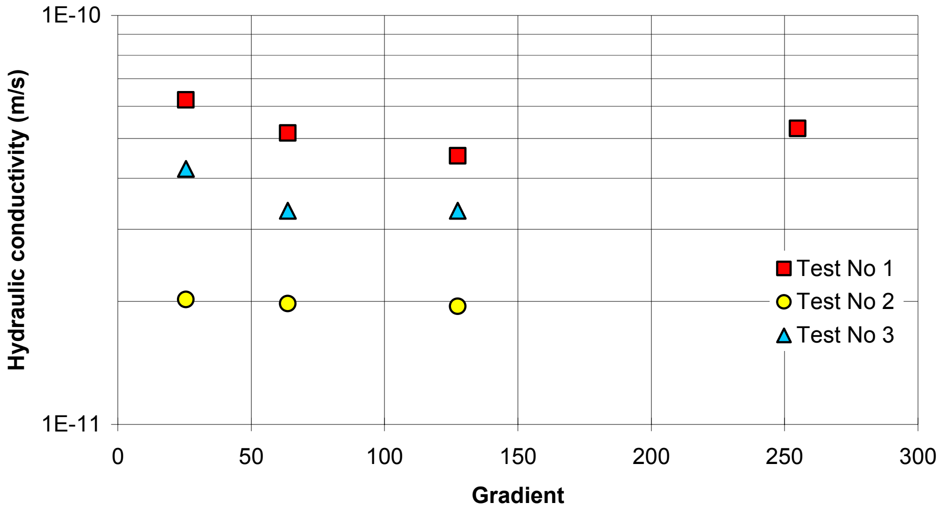

Figure 3-2. *The hydraulic conductivity plotted as function of applied gradient for the three samples.*

The results from the measurement of the hydraulic conductivity are plotted as the average of the results from the tests made at different gradients in Figure 3-2 together with results from previously performed tests on backfill material for BaPT. The backfill material used in the Backfill and Plug Test is described in /3-1/ and the salt content of the water in these tests was 1.2 %. Tests with distilled water were also conducted and the results are shown in the figure. As expected the new tests yield hydraulic conductivities between those measured for the salt content 1.2 % and 0 %, due to the salt content of the used water

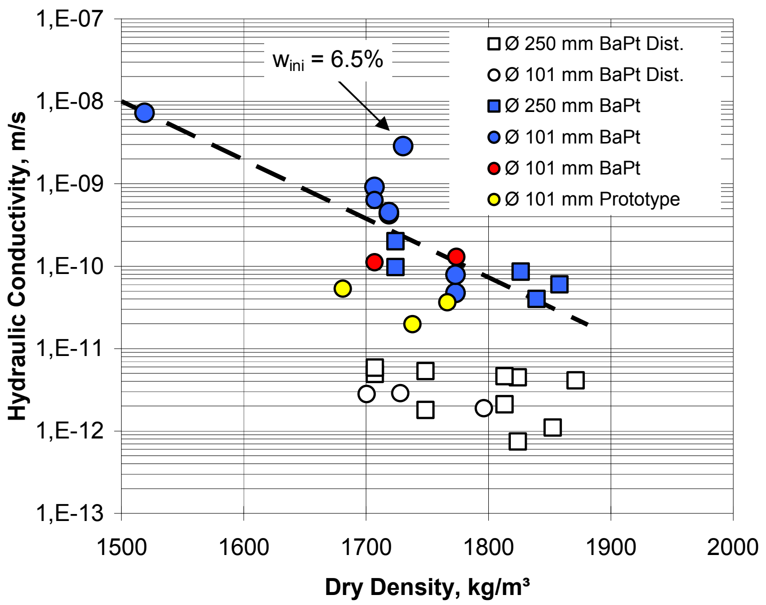

Figure 3-2. *Results from measurements on hydraulic conductivity for backfill materials.*

5 Measurement of suction

5.1 General

In an unsaturated soil a negative pore water pressure called suction is present. Suction, or the water pressure potential, can according to soil mechanical standards be divided into matric suction and osmotic suction (Fredlund and Rahardjo, 1993).

$$S_t = S_m + S_o \tag{5-1}$$

where

S_t = total suction

S_m = matric suction

S_o = osmotic suction

The physical representation of suction in a salt-free granulated soil is the capillary pressure (capillary rise). This type of suction in a granulated soil is related to capillary phenomena in the soil structure and corresponds to matric suction. The matric suction can be calculated as;

$$S_m = u_{air} - u_w \tag{5-2}$$

where

u_{air}= air pressure in the porous system

u_w= water pressure in the porous system

Suction is positive in an unsaturated soil and at atmospheric pressure the water pressure is consequently below the atmospheric pressure. In order to determine the matric suction it is convenient to increase the air pressure so that the measured water pressure will be higher than the atmospheric pressure.

Osmotic suction is associated with the ion concentration in the pores. The total suction is the sum of the matric suction and the osmotic suction. From a thermodynamic standpoint the total suction can be theoretically expressed with Eqn. 5-3 (Kelvin equation);

$$S_t = -\frac{RT}{V_w}\ln(p/p_0) \tag{5-3}$$

where

R= molar gas constant

T= the Kelvin temperature

V_w= the molar volume of water

p/p_0 the relative humidity of the pore air

This way of describing the phenomena is well known for non-swelling soils and assumed to be valid also for bentonite.

5.2 Total suction

Total suction was measured with soil psychrometers of type WESCOR. Water was added to 10 samples in order to get a water ratio between 7 and 27 %. The samples were placed in plastic bags and one soil psychrometer was placed in each plastic bag for measuring the suction in the samples. The soil psychrometer measures the relative humidity in the pore volume of the sample. The total suction can then be determined with Eqn 6-3 (Kelvin equation). Finally the water ratio of the samples was determined.

The results from the measurement of the total suction are plotted in Figure 5-1.

5.3 Matric suction

Matric suction was measured with the filter paper technique. Water was added to 6 samples in order to get a water ratio between 7 and 27 %. The materials were compacted to samples with a height of 40 mm and a diameter of about 100 mm. Filter papers with known retention curve were placed on top and at the bottom of the samples (two at each ends). Plexiglass plates (diameter 100 mm) with a thickness of 20 mm were placed at both ends of the samples in order to ensure direct contact between the filter papers and the samples. The samples were then wrapped in plastic and left for at least 2 weeks so the filter papers could take up water from the samples. At that time it is assumed that the suction in the filter paper is in equilibrium with the suction of the sample (same suction). From the known retention curve for the filter paper it is possible to evaluate the suction of the sample by measuring the water ratio of the filter papers. The water ratios of the samples were also determined. The results from the tests are plotted in Figure 5-1 together with the measurement of the total suction of the material. The matric suction is as expected much lower than the measured total suction,

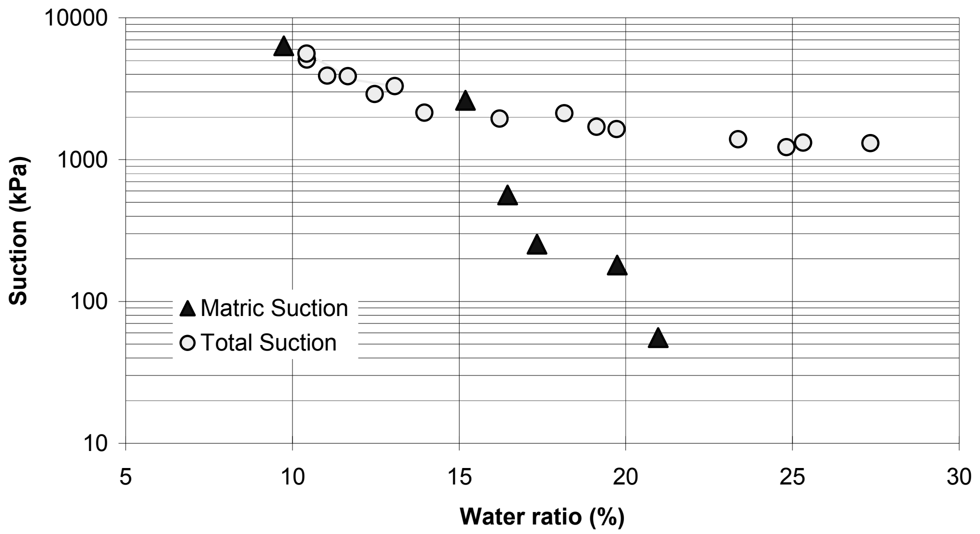

Figure 5-1.*Results from measurement of suction on the backfill material used in Prototype Repository.*

5.4 Comparison with suction measurements made on backfill for BaPT

In Figure 5-2 the suction measurements are compared with previous made measurements on backfill material made used in the Backfill and Plug Test (BaPT). The total suction for the new material is slightly lower than for the material used in BaPT. An explanation for the lower total suction is that the salinity of the water in the new tests is lower. The measured matric suction agrees rather well for the two backfill types although the scatter is quite larger.

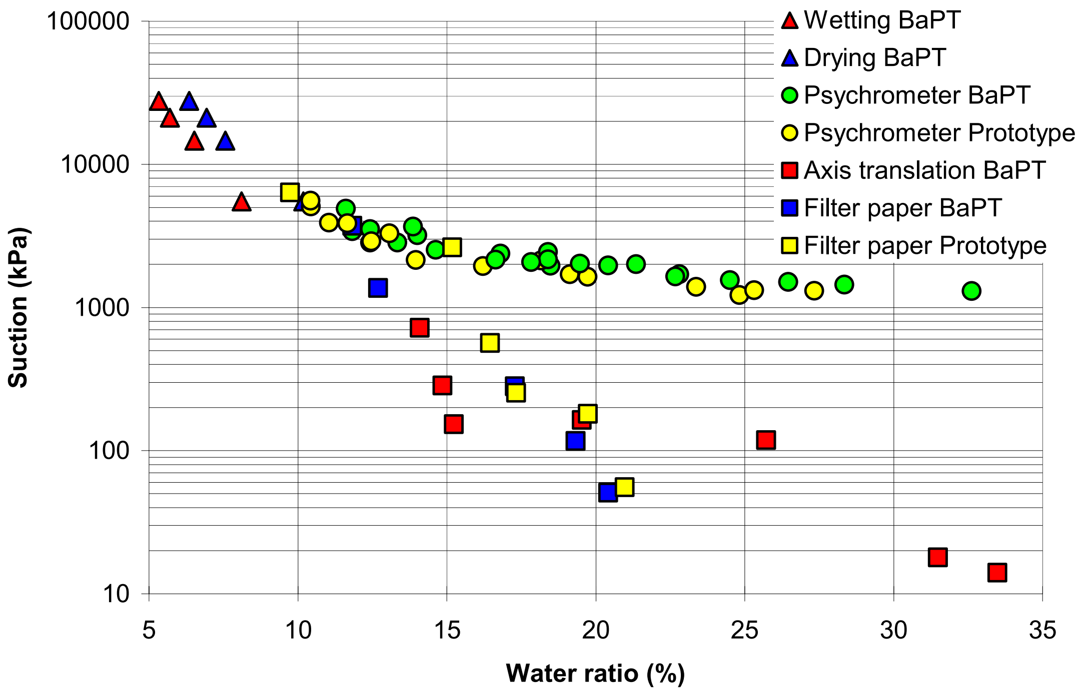

Figure 5-2 *Comparison between suction measurements made on backfill material for Prototype Repository and BaPT.*

6 Water uptake tests

6.1 General

The water saturation in bentonite mixed backfill materials is a rather slow process. The process is modelled to be governed by Darcy's law and driven by the matric suction. The main parameters for modelling this process are thus the matric suction and the hydraulic conductivity of the water unsaturated backfill. These parameters are in their turn functions of the degree of saturation, the void ratio, and the composition of the water. The hydraulic conductivity of unsaturated soils cannot be directly measured. An indirect way is to make well defined laboratory tests of the saturation phase and use them to calibrate the dependency of the hydraulic conductivity on the degree of saturation and the void ratio. Tests have been performed where the water uptake of the backfill materials was studied in the laboratory. The purpose with the tests is to find out what parameters are affecting the water uptake.

6.2 Performed tests

Three identical samples were compacted in cylinders with the height 100 mm and the diameter 101.1 mm. The samples were compacted into the cylinder in 5 layers to a dry density of about 1700 kg/m^3. The average initial water ratio for the samples was about 11.3%. The three samples had access to water from the bottom during about 150 h, 300 h and 600 h. After these time periods the tests were interrupted and the water ratio determined in 5 sections of the samples. The determined water ratios for the three tests are plotted as distance from the bottom of the sample (water inlet) in Figure 6-1. The water ratio at saturation for the samples is 22.5%. The plot indicates that after 150 h the 10 cm close to the water inlet are fully saturated, and the water ratio of the rest of the sample is affected up to a distance of 60 mm from the water inlet. After 600 h the water ratio increase has reached the whole sample.

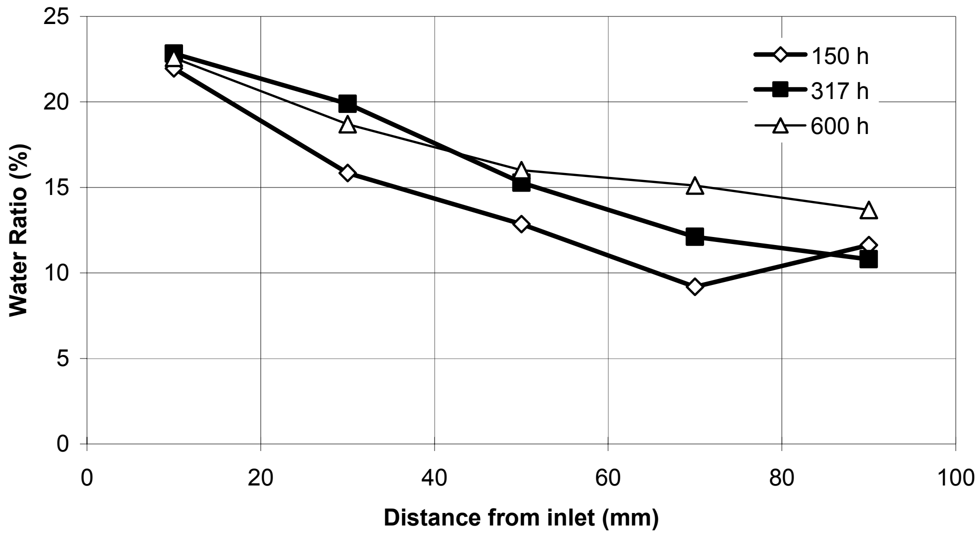

Figure 6-1. *Results from water uptake tests performed on backfill material for Prototype Repository. The initial dry density for the samples was 1700 kg/m^3 and the initial water ratio was 11.3%.*

7 Conclusions

Although the performed laboratory tests are limited the tests are giving similar results as previous performed investigations on backfill for *Backfill and Plug Test*. Most of the tests have been done on samples with a dry density around 1700 kg/m^3. This is the average density which has been reached in the field experiment *Prototype Repository* /7-1/ and /7-2/.

The Proctor tests yield a maximum dry density of about 2000 kg/m^3 at a water ratio of about 13 %. Compared with the density of about 1700 kg/m^3 achieved in the field tests this means that only 85 % of maximum Proctor density was reached in the field test.

The expected swelling pressure of the backfill in the *Prototype Repository* according to the performed laboratory tests is about 100 - 200 kPa and the expected hydraulic conductivity is 2E-11 – 5E-11 m/s.

Performed tests indicate that the hydraulic conductivity of the backfill material is rather insensitive to the pore pressure gradient.

Taking into account that the salinity of the pore water is somewhat different the new tests fit well with previous performed measurements of hydraulic conductivity on the backfill material used in the *Backfill and Plug Test*.

The performed suction measurements yield similar results as previously performed measurements on the backfill material in the *Backfill and Plug Test*.

The water uptake tests performed on the material will later be used for numerical simulations and calibration of parameters.

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