P-13-09

Effects of water inflow into a deposition hole

Influence of pellets type and of buffer block manufacturing technique

Laboratory tests results

Lars-Erik Johannesson, Viktor Jensen
Clay Technology AB

October 2012

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co

Box 250, SE-101 24 Stockholm
Phone +46 8 459 84 00

ISSN 1651-4416
SKB P-13-09
ID 1387993

Effects of water inflow into a deposition hole

Influence of pellets type and of buffer block manufacturing technique

Laboratory tests results

Lars-Erik Johannesson, Viktor Jensen
Clay Technology AB

October 2012

Keywords: Buffer, Deposition hole, Bentonite pellets, Piping, Erosion.

Abstract

During the installation of buffer and canister in a deposition hole a number of different problems can arise. The problems are mainly connected to water flow from fractures in the rock into the deposition hole. According to the reference design for the KBS-3V concept, the buffer is protected with a special sheet made of rubber during the installation phase. This protection sheet will at some stage be removed and the outer gap between the buffer blocks and the rock surface will be filled with bentonite pellets.

The interaction of buffer blocks and pellets have previously been investigated. The focuses of those studies were the following processes:

1. **Erosion**. Erosion of bentonite from the deposition hole up into the tunnel backfill material. This process will continue until a tunnel plug has been installed and the backfill is saturated.
2. **Heave**. Early wetting of the pellets filling may cause a heave of the buffer blocks into the backfill that will decrease the density of the buffer.

The laboratory tests presented in this study are complementing previous investigations by focusing on how the choice of manufacturing process for the bentonite blocks (isostatic or uniaxial compaction) and pellets (roller compaction or extrusion) are affecting erosion and the heaving effect.

The most important results from the laboratory tests are:

- There is a very clear relation between the applied water inflow rate and the rate and magnitude of the heave of the buffer. A larger water inflow results in a larger heaving of the blocks.
- The manufacturing technique used for the pellets seems to affect the magnitude of heaving. The test with extruded pellets showed a larger heaving compared with the tests made with roller compacted pellets.
- The manufacturing technique for the blocks was not affecting the measured heaving.
- Most of the heaving seems to occur at the most upper blocks in the test which indicates that the heaving is depending on the vertical stresses on the blocks. This has also been shown in previous tests (Sandén and Börgesson 2010).
- The heaving depends both on cracks which occur during the test and on the volume change of the buffer block caused by the water uptake.
- The observed pattern of wetting with extruded pellets differs from the one observed in previous made tests with roller compacted pellets (Sandén and Börgesson 2010). In general larger volume of the pellets was wetted in the new test compared to the old test with roller compacted pellets.

Sammanfattning

Vid installation av buffert och kapsel i ett deponeringshål kan flera olika typer av problem uppstå. Problemen är i huvudsak kopplade till vatteninflöde från sprickor i berget som korsar deponeringshålen. Enligt nuvarande referensutformning för KBS-3V ska bufferten skyddas av ett gummimembran under installationsfasen. Membranet ska under något skede av installationen tas bort och den yttre spalten mellan buffertblock och deponeringshålets ytas ska fyllas med pellets.

Interaktionen mellan buffertblocken och pellets har studerats i andra projekt. Dessa undersökningar berörde främst följande aspekter:

1. **Erosion.** Erosion av bentonit från den installerade bufferten i deponeringshålen och ut i tunnelns återfyllning. Erosionen upphör först när en plugg i tunneln har installerats och återfyllningen blivit vattenmättad.
2. **Hävning.** En tidig bevätning av pellets kan förorsaka en hävning av buffertblocken som kommer att medföra en minskad densitet.

Resultaten som pressenteras i denna undersökning kompletterar tidigare framtagna resultat. Undersökningen fokuserats på hur tillverkningstekniken av blocken (enaxlig eller isostatiskt kompakterade) och pellets (kompakterade eller extruderade) påverkar erosion och hävning.

De viktigaste resultaten från laboratorietesterna är:

- Det finns ett klart samband mellan det pålagda vatteninflödet och hastigheten på och storleken av hävningen av bufferten. Ett stort inflöde ger en större hävning.
- Tillverkningstekniken för pellets tycks påverka hävningens storlek. Försöken med extruderade pellets gav större hävning än försöken med kompakterade pellets.
- Tillverkningstekniken för buffertblocken påverkade inte de uppmätta hävningarna.
- Största delen av den uppmätta hävningen uppkom i de övre blocken vilket indikerar att hävningen påverkas av den vertikala spänningen på blocken. Detta har också påvisats i tidigare gjorda tester (Sandén och Börgesson 2010).
- Hävningen beror både på sprickor som uppkommer under försöken och av volymförändringen av blocken på grund av vattenupptaget.
- De bevätningsmönster som observerades med extuderade pellets var olika jämfört med det med kompakterade pellets (Sandén och Börgesson 2010). Större pelletsvolymer hade tagit upp vatten i de tester som gjordes med extruderade pellets.

Contents

1 Introduction

1.1 Background

During installation of the buffer and canister in a deposition hole a number of different problems can arise. The problems are mainly related to water flow from fractures in the rock into the deposition hole, see Figure 1-1. According to the reference design for the KBS-3V concept, the buffer is protected with a special sheet made of rubber during the installation phase. This protection sheet will at some stage be removed and the outer gap between the buffer blocks and the rock surface will be filled with bentonite pellets.

Wetting of the buffer (pellet and buffer blocks) can be divided into three different phases:

1. The time between the finalized installation of the deposition hole (buffer, canister and pellet have been installed) and the installation of backfill above the deposition hole (installation phase). The time allowed for this phase depends mainly on the water inflow rate into the deposition hole.
2. The time from finished backfilling of the tunnel above the hole until the large voids in the pellets filling in the deposition hole and the tunnel have been filled with water. During this phase erosion of bentonite from the buffer may take place. This phase is not the focus of this experiment.
3. The time until the buffer is fully saturated (the saturation phase). This phase is not the focus of this experiment.

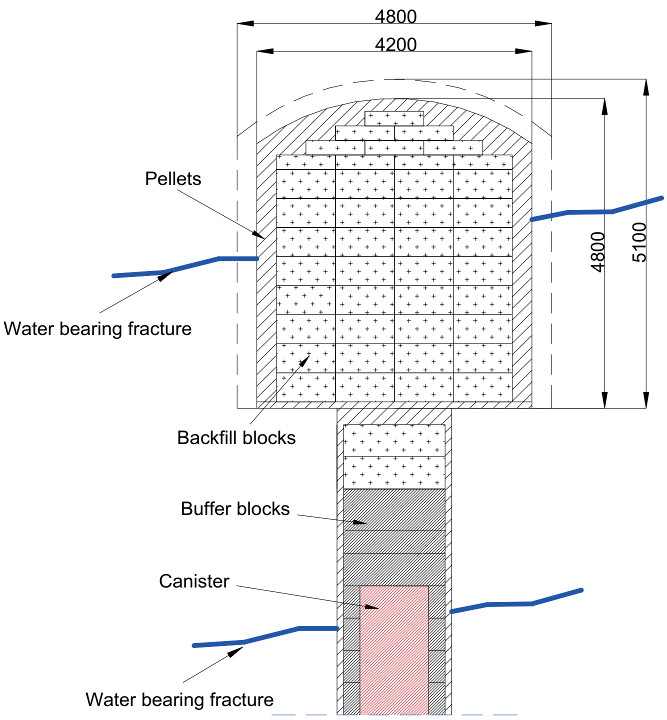

Figure 1-1. *A schematic drawing showing of a cross section of a deposition hole and a backfilled tunnel.*

A previous made report (Sandén and Börgesson 2010) studied two processes that can occur and are possible to strongly influence the buffer during installation:

1. **Erosion**. After installation of the canister and the buffer blocks, the slot around the blocks will be filled with bentonite pellets. The pellets cannot stop the flowing water due to the rather low density of the filling in combination with the water pressure that will be built up. Water flowing from the deposition hole up to the tunnel can erode away bentonite from the deposition hole up to the voids in the tunnel backfill. This process will continue until a tunnel plug have been built and the voids in the backfill are filled with water.
2. **Heaving**. If the installation phase time is too long and the water inflow to the deposition hole is high, the pellets filled slot will be filled with water and there may be upwards displacements of the buffer (heaving) resulting in a lower buffer density around the canister.

1.2 Objectives

The aim with this study was to complement earlier studies by answering the following questions:

1. How do different water inflow rates affect the heave of the buffer?
2. How do different types of blocks (isostatic/uniaxial compaction) affect the heave of the buffer?
3. How do different types of pellets (extruded or roller compacted) affect the heave of the buffer?
4. What erosion rate can we expect from water leaving the deposition hole?

2 Test setup

2.1 Materials used in the tests

The clay material used in these tests is MX-80 which is a sodium bentonite with a smectite content of above 90% according to specifications from the producer American Colloid Company. Measurements of the montmorillonite content of the used bentonite has also been done with XRD and modeling of the data with the program Sirocuont. These data (three determinations) are showing a montmorillonite content of about 90%.

Altogether three tests have been made. For two of the tests the blocks were manufactured in a rigid mold and compacted using uniaxial compression with a pressure of 50 MPa. The blocks had a height of about 100 mm, an inner diameter of 110 mm and an outer diameter of about 280 mm.

The blocks for the third test were isostatic compacted and afterwards machined to similar dimensions as for the uniaxial compacted blocks.

Pellets made of MX-80 were used in all of the tests. The pellets were manufactured by extrusion.

Water with a salinity of 1% (50/50 $NaCl/CaCl_2$) was used in all tests.

The results from the tests are compared with previous made tests where roller compacted pellets, with the dimensions 18×18×8 mm of MX-80 were used (Sandén and Börgesson 2010).

2.2 Test description

The tests described in this report have been performed in the scale 1:4 in regards to heaving and in the scale 1:1 in regards to erosion from the slot (buffer diameter scaled 1:4 but slot scaled 1:1). Similar tests in scale 1:1 (diameter scale 1:1 and with the height 1 m) have been performed at the Äspö laboratory (Åberg 2009).

The test equipment used in the experiments included a steel cylinder (inner diameter 400 mm and height 600 mm) with bottom, simulating a deposition hole. The cylinder was filled with bentonite blocks with an outer diameter of about 280 mm and a height 100 mm. The blocks were piled around a central copper tube with a diameter of 100 mm, see Figure 2-1. The slot between the blocks and the steel wall had a width of about 60 mm i.e. the slot width was almost in scale 1:1 in a real deposition hole. The slot is according to the reference design for the KB3 concept 50 mm.

A point inflow of water was applied at the bottom of the steel cylinder. At the top of the steel cylinder a number of notches with a width of 1 mm and a depth of 50 mm were made in order to let the water reaching the top leak out and be collected in a ditch surrounding the steel cylinder on the outside. The out-flowing water was collected and analyzed for determine the amount of eroded material.

Four perpendicular directions (denoted direction 1, 2, 3 and 4 clockwise) were defined for the experiment set up where direction 1 was defined as the direction for the inflow point of water, see Figure 2-1 and Figure 2-2.

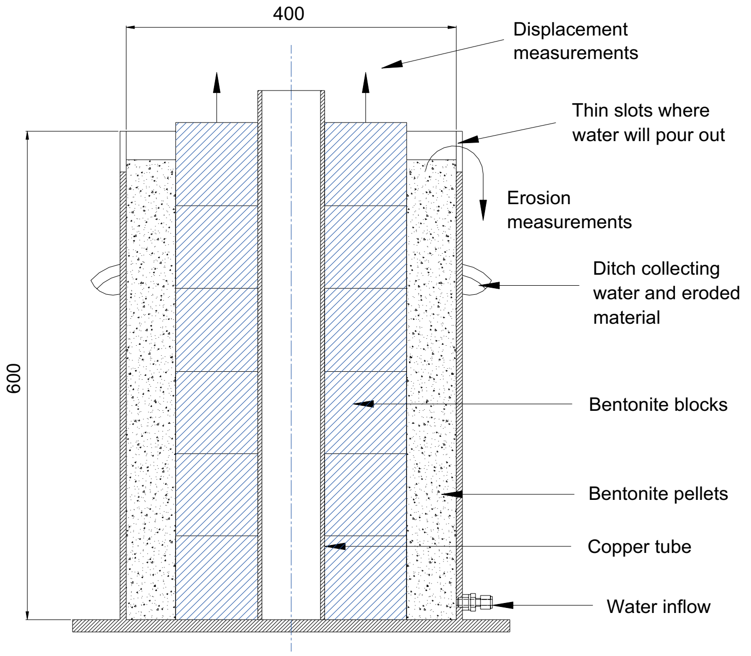

Figure 2-1. *Schematic drawing of the test equipment used for testing the influence of water inflow to a deposition hole during the installation phase.*

Figure 2-2. *Photo of the test equipment used for testing the influence of water inflow to a deposition hole during the installation phase.*

The following was controlled or measured during the tests:

- **Water flow into the test cylinder.** This was set to a selected value on the microprocessor controlled pump used to supply water to the test.
- **Water flow out from the test cylinder.** Samples were taken from the out-flowing water. The cups with water samples were weighed and then placed in an oven at 105° where the water was evaporated. After drying, the cup was weighed again. With this procedure the amount of out-flowing water at a certain time interval could be calculated.
- **Water pressure on the inflow water**. This was measured continuously with a pore pressure transducer.
- **Displacement of the upper surface of the bentonite blocks.** Three displacement sensors were continuously measuring the displacement of the upper surface of the stack of blocks, see Figure 2-1.
- **The final displacement of the individual blocks in the pile.** The positions in vertical direction of each of the blocks were determined before and after the tests.
- **Water content and density of the buffer.** The water content and the density were determined in two radial directions for each block installed in the three tests, one wet and one dryer direction. Furthermore the water content of the pellets was determined in four directions.
- **The amount of eroded material in the water**. The water samples taken from the exiting water, as described above, were also used to determine the amount of clay in the water by evaporating the water in an oven at 105°C and determining the residue. The mass remaining was corrected for salt in the water. For water flow rates of 0.01 l/min, water samples were taken from the downstream exit at regular intervals. For the test with an inflow rate of 0.0125 l/min no water samples were taken.
- **Observations.** A digital camera was used in order to register the behavior of the buffer both during the saturation phase and at the dismantling.

2.3 Laboratory determinations

A number of laboratory determinations were used during the course of the tests. The techniques used are described below.

2.3.1 Water content

The determination of the water content was made in the following way:

1. The balance was checked with reference weights before the starting of the measurements.
2. A small baking tin of aluminum was placed on the balance and the weight (m_{bt}) was noted in a protocol.
3. The sample was placed in the baking tin and the weight of sample and tin is noted in a protocol ($m_{bt} + m_{bulk}$).
4. The tin with the sample was placed in an oven with a temperature of 105°C for 24 h.
5. After the drying the weight of the baking thin and the sample ($m_{bt} + m_{solid}$) was measured and noted in a protocol.

The mass of water dried from the sample was determined according to Equation 2-1:

$$m_{water} = m_{bulk} - m_{solid} \qquad (2\text{-}1)$$

and the water content (w) was calculated according to Equation 2-2.

$$w = \frac{m_{water}}{m_{solid}} \qquad (2\text{-}2)$$

2.3.2 Density

The bulk density of the samples was determined by weighing the samples both in air and immerged in paraffin oil with a known density. The determination was made as follows:

1. A piece of thread was weighed.
2. The sample was weighed hanging on the thread underneath the balance (m_{bulk}).
3. The sample was then lowered in the paraffin oil with the density $\rho_{paraffin}$ and the weight ($m_{paraffin}$) was noted.

The volume of the sample (V_{bulk}) and the density (ρ_{bulk}) were calculated according to Equations 2-3 and 2-4.

$$V_{bulk} = (m_{bulk} - m_{paraffine}) / \rho_{paraffine} \tag{2-3}$$

$$\rho_{bulk} = \frac{m_{bulk}}{V_{bulk}} \tag{2-4}$$

2.3.3 Dry Density

The dry density (ρ_{dry}) can be calculated according to Equation 2-5.

$$\rho_{dry} = \frac{\rho_{bulk}}{(1+w)} \tag{2-5}$$

2.3.4 Degree of Saturation

The degree of saturation (S_r) can be calculated according to Equation 2-6. For calculating the degree of saturation the values of the density of the solid particles ρ_s = 2,780 kg/m^3 and the density of water to ρ_w = 1,000 kg/m^3 are used.

$$S_r = \frac{w \times \rho_{bulk} \times \rho_s / \rho_w}{\rho_s \times (1+w) - \rho_{bulk}} \tag{2-6}$$

2.3.5 Void ratio

The void ratio (e) can be calculated according to Equation 2-7.

$$e = \frac{\rho_s - \rho_{bulk}}{\rho_{bulk} - \rho_w \times S_r} \tag{2-7}$$

3 Test results

Totally three tests were performed. Primary results are presented here while supplementary diagrams and photos from the tests are provided in Appendix 1-3.

The following main test parameters were varied:

- **Water inflow rate**. Two different rates were used, 0.01 l/min and 0.00125 l/min. The tests with the lowest inflow rate was made in order to determine if the buffer can stand for sufficiently long time without unacceptable expansion of blocks and outflow of water, which means that buffer protection is not needed.
- **Block manufacturing technique**. In two of the tests were unixaial compacted blocks used while in one tests the blocks were compacted isostatic.

The main test parameters and results of all tests are compiled in Table 3-1. Note that the density of the isostatic compacted blocks is lower compare to the uniaxial blocks.

3.1 Block movements (heaving)

The axial displacement or heave of the blocks with time was measured in all tests. A compilation of the results from the three new tests (solid lines) together with two previous made test with roller compacted pellets (dotted lines) is shown in Figure 3-1. The test results yield the following conclusions:

- The influence of inflow rate is very clear; higher flow rates result in larger heave of the buffer blocks.
- Also with the smallest water inflow rate (0.00125 l/min) a displacement could be measured, see Figure 3-1.
- The manufacturing technique of the buffer blocks seems to have small effects on the heaving of the blocks (compare blue solid curve with green solid curve in Figure 3-1).
- The manufacturing technique of the pellets seems to affect the heaving of the blocks. The recorded heaving after 170 h and at an inflow of 0.00125 l/min is more than three times higher for the extruded pellets compared to the test with roller compacted pellets (c.f. the red curves in Figure 3-1).

At the dismantling of the tests, the blocks were removed one by one. This made it possible to determine the displacement of the upper surface of the individual blocks. This was done in four perpendicular directions both at the outer and inner diameter of the blocks. The data from these measurements are plotted in the included Appendixes.

The average displacements of the blocks are plotted in Figure 3-2. The figure is indicating that the largest swelling of the individual blocks occurred in block 5 and 6 although the water inlet was placed at the bottom of the test equipment, i.e. at the level of block 1. This implies that the swelling is a function of the overburden load on the blocks, which is in consistent with previous made investigations (Sandén and Börgesson 2010).

Table 3-1. Compilation of performed tests.

Test No.	Block			Pellets		Flow rate	Test time	Max displ.	Erosion mess.
	Type	w (%)	Dry dens (kg/m^3)	Type	w (%)	(l/min)	(days)	(mm)	
1	Uniaxial	16.6	1,806	Extruded	19.6	0.01	7	36	Yes
2	Uniaxial	16.6	1,806	Extruded	19.6	0.00125	8	25	No
3	Isostatic	16.6	1,707	Extruded	19.6	0.01	8	38	Yes

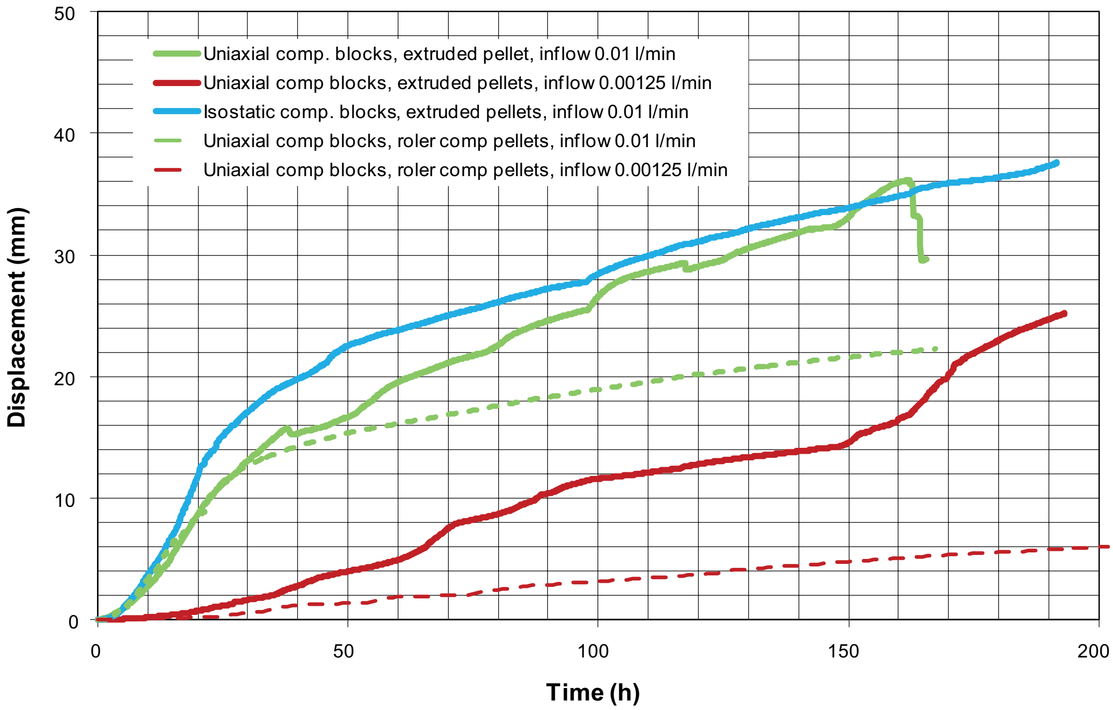

Figure 3-1. *Average displacement plotted vs. time. The curves represent an average of the displacement measured by three sensors for the tests.*

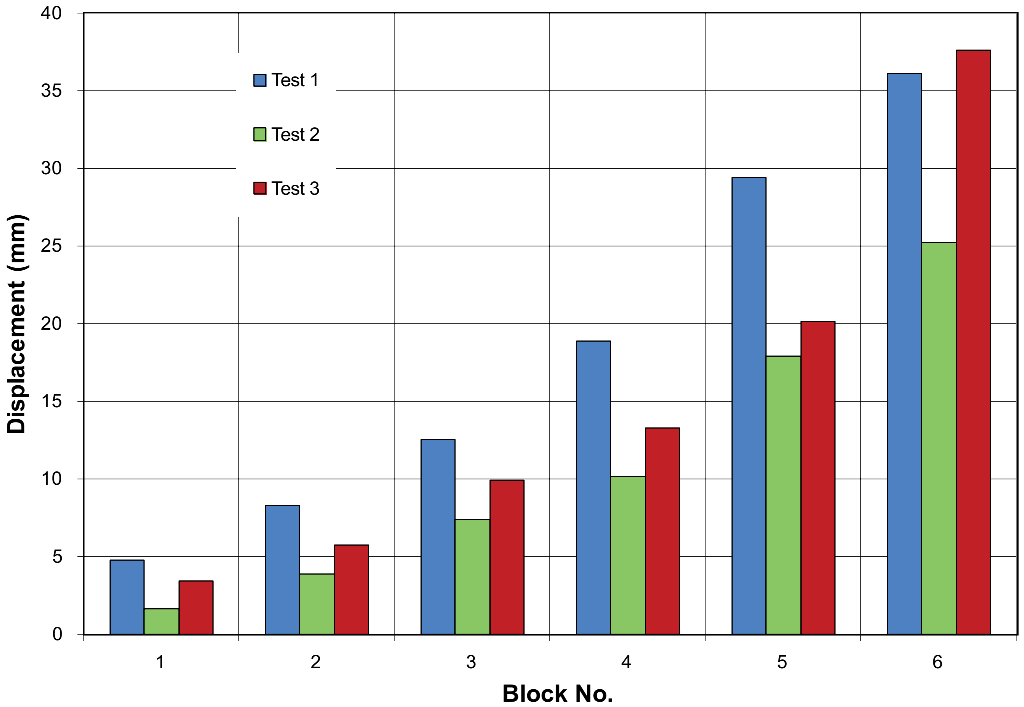

Figure 3-2. *The average displacement of the six installed blocks in three preformed tests.*

3.2 Water content and density of the buffer

The buffer blocks were carefully examined and the density and water content were measured in two profiles from the inner part close to the inner cylinder to the pellets filled outer slot after the test, see Appendix 1–3.

The measured water content and dry density in average is shown in Table 3-2 determined on the five lowest blocks.

With the known initial weight and water content of the blocks it is possible to determine the average amount water, the blocks have taken up, see Table 3-2. Furthermore it is possible from the initial dry density and the average dry density of the samples, taken after the test, to calculate the change in volume of the blocks, see Table 3-2.

A conservative assumption is that the water which has been absorbed by the blocks would cause a volume change equal to the water volume. This is conservative since the blocks were not fully saturated at the start of the tests. Even at this conservative assumption the calculated volume change of the blocks is higher than the volume of the absorbed water.

From the measured displacement of the upper surface of block 5 in Figure 3-2 it is possible to calculate the volume change of the blocks assuming no radial swelling of the blocks to 1.78 l for Test 1, 1.10 l for Test 2 and 1.23 l for Test 3. These values are in the same range as the volume calculated from the measured change in density, see Table 3-2. Since the blocks probably also have expanded in radial direction during the water uptake the measured heaving can not only be explained by the decrease density (increase in volume).

One additional part to the measured heaving is probably caused by the observed cracking of the blocks. When water fills up the voids between the pellets the relative humidity increases and the bentonite blocks starts to take up water from the air. This process affects the blocks in a way that make them crack and also make them curved so that the volume occupied by the blocks increases. This phenomena has also been seen in other projects (Åberg 2009, Sandén and Börgesson 2010). The cracks are large and goes through the blocks. Cracks of this type could be seen on one or several blocks in all three tests.

3.3 Wetting behavior

At the dismantling it was noticed that the wetting behavior of the pellet fillings differed at the different inflow rates. Figures 3-3–3-5 show pictures taken during dismantling. The following influence of inflow rate could be seen:

- 0.01 l/min (Test 1 and Test 3). About two third of the pellet filling was wetted, see Figure 3-3 and Figure 3-5.
- 0.00125 l/min (Test 2). Only about half of the filling was wetted, see Figure 3-5.

The observed pattern of wetting differs from the one observed in previous made tests with roller compacted pellets (Sandén and Börgesson 2010). In general less pellets volume was wetted in those tests and at lower flow rates (less than 0.001 l/min) the water formed a channel trough the pellets filling, see Figure 3-6. This kind of behavior was not observed in the tests made with extruded pellets. This might be an explanation for the larger heaving observed for the tests with extruded pellets compared with the tests made with roller compacted pellets, see Section 3.1.1.

Common for the new and the old tests are that distinguishable cracks were observed both in the test made with extruded pellets and roller compacted pellets, see Figure 3-5 and Figure 3-6.

Table 3-2. Measured weight, water content and dry density of the used blocks in the tests together with the calculated absorbed water and volume changed after the test.

Test No	Initial conditions			After the test		Absorbed water	Volume change
	weight (kg)	w	Dry dens (kg/m^3)	w	Dry dens (kg/m^3)	(l)	(l)
1	54.30	0.166	1,807	0.194	1,691	1.30	1.75
2	54.32	0.166	1,807	0.175	1,757	0.42	0.72
3	51.31	0.166	1,707	0.196	1,617	1.34	1.44

Figure 3-3. *Photos taken at the dismantling of the tests made with extruded pellets. 0.01 l/min uniaxial compacted blocks.*

Figure 3-4. *Photos taken at the dismantling of the tests made with extruded pellets. 0.00125 l/min uniaxial compacted blocks.*

Figure 3-5. *Photos taken at the dismantling of the tests made with extruded pellets. 0.01 l/min isostatic compacted blocks.*

Figure 3-6. *Photos taken during dismantling of the previous made tests with uniaxial compacted blocs and with roller compacted pellets at different inflow rates. Upper. 0.1 l/min: The whole pellet filling is wetted. Distinct cracks were observed in the blocks. Middle. 0.01 l/min: Half of the pellet filling is wetted. Also in this test distinct cracks can be seen in the blocks. Lower. 0.001 l/min: Only a small part of the filling is wetted. The water has ascended in a channel along the "rock" wall (Sandén and Börgesson 2010).*

3.4 Erosion measurements

Erosion was measured in two of the tests. In the test with the lowest water inflow rate 0.00125 l/min, no water leaked out during the test time.

The accumulated dry weight of eroded material is plotted vs time in Figure 3-7 together with the results from previous made tests on roller compacted pellets (Sandén and Börgesson 2010). It is not possible from this data to draw any conclusions whether there are any differences in the erosion between the two types of pellets.

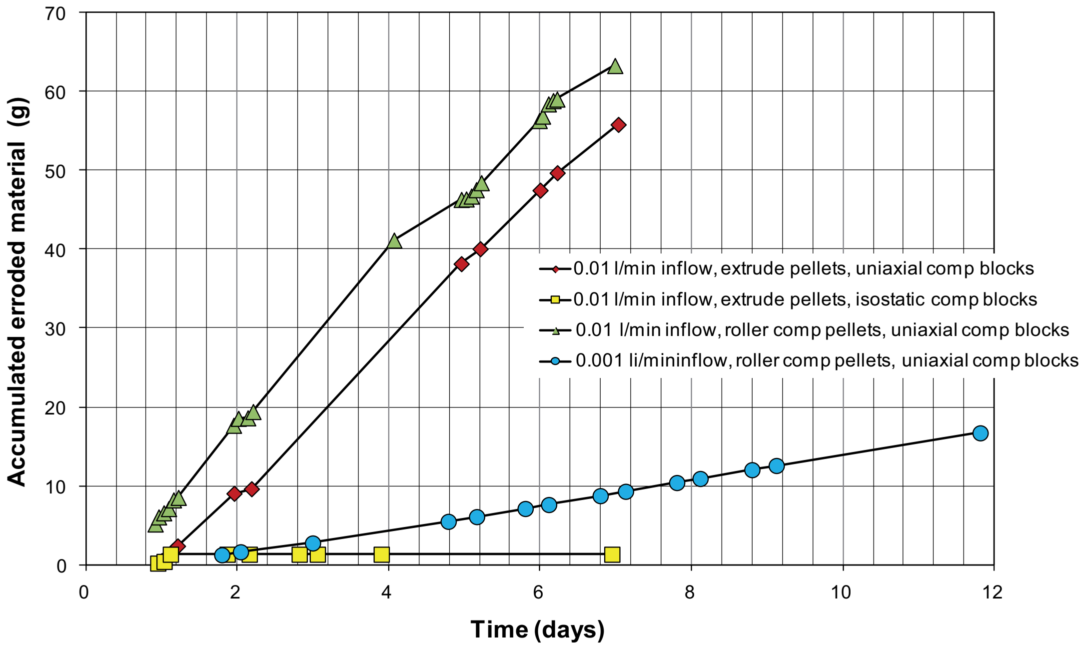

Figure 3-7. *The accumulated dry weight of eroded material plotted vs. time.*

3.5 Density of the pellets filling

In order to find out the expected minimum density of a filling of the different type of pellets simple tests where the pellet were filled in a beaker with known volume and the weight were determined. Furthermore the water content of the pellets is determined. From this data, it is possible to determine the dry density of the pellets filling. The data for the two types of pellets are summarized in Table 3-3.

The data from the measurement of the pellets (bulk density and water content) together with the nominal values of the blocks and the dimensions of the deposition holes are used as input to a calculation of the density of the buffer around the canister as well as above and under the canister after saturation (SKB 2010). These calculations are also presented in Table 3-3.

The calculations are indicating that the density of the buffer is larger than the nominal value of 2,000 kg/m^3 in all part of the buffer for both types of pellets. These calculations are based density measurements of the pellets in laboratory tests and they are not necessary those in achieved in a repository (field conditions). The filling of the outer slot in a full scale deposition hole will probably result in a higher density of the pellets filling.

Table 3-3. Determined lowest bulk density and water content of pellets together with the calculated density at saturation of the buffer assuming reference design of the deposition hole and the buffer blocks.

Pellets type	Bulk density (kg/m^3)	Water content	Dry density (kg/m^3)	Calculated saturated density of the buffer	
				Around the canister (kg/m^3)	Under and above the canister (kg/m^3)
Extruded	1,017	0.196	850	2,006	2,033
Roller comp.	1,030	0.113	925	2,014	2,039

4 Comments and conclusions

The results from the tests can be summarized as follows:

- There is a very clear influence of the applied water inflow rate regarding the rate and magnitude of the heave of the buffer. This is in accordions with previous made tests, i.e. a large water inflow results in a large heaving.
- The manufacturing technique used for the pellets seems to affect the magnitude of heaving. The test with extruded pellets showed a larger heaving compared with the tests made with roller compacted pellets. A possible explanation for this might be that for the roller compacted pellets, a less part of the pellets volume was wetted, see Section 3.1.3.
- The manufacturing technique of the buffer blocks have small effects on the heaving of the blocks.
- Most of the heaving occurs at the most upper blocks in the tests which indicates that the heaving is depending on the vertical stresses on the blocks. This has also been shown in previous tests (Sandén and Börgesson 2010). Since the vertical stresses are larger in a real deposition hole, compare to the those in test set up it is difficult from the test draw any conclusions about the heaving rate and the size of the heaving in a full scale deposition hole.
- The heaving rate seems to be larger the first 50 hours of the test, see Figure 3-1.
- The heaving depends both on cracks which occur during the test and on the volume change of the buffer block caused by the water uptake.
- The observed pattern of wetting differs from the one observed in previous made tests with roller compacted pellets (Sandén and Börgesson 2010). In general larger volume of the pellets was wetted in the new test compared to the old test with roller compacted pellets.
- The measured erosion of the pellets caused by the water flow through the pellets filling was small. It is not possible from this data to draw any conclusions whether there are any differences in the erosion between the two types of pellets.
- The dry density of the filling of extruded pellets was lower compared with filling of roller compacted pellet. The calculated average density of the buffer, when using the measured density of the pellets filling from laboratory tests and the reference design of the buffer blocks, is higher than 2,000 kg/m^3. This means that the reference design of the buffer blocks must be changed in order to fulfill the requirement of an average density at saturation of the buffer of 2,000 kg/m^3. The density of the pellets filling at field conditions (in a real deposition hole) must however be further investigated to be able to more accurate comment on the final buffer density.

References

SKB's (Svensk Kärnbränslehantering AB) publications can be found at www.skb.se/publications.

Sandén T, Börgesson L, 2010. Early effects of water inflow into a deposition hole. Laboratory tests results. SKB R-10-70, Svensk Kärnbränslehantering AB.

SKB, 2010. Design, production and initial state of the buffer. SKB TR-10-15, Svensk Kärnbränslehantering AB.

Åberg A, 2009. Effects of water inflow on the buffer – an experimental study. SKB R-09-29, Svensk Kärnbränslehantering AB.

Data from Test 1

Test 1

Layout: MX-80 block uniaxial compacted, Extruded MX-80 pellets in slot, water inflow: 0.01 l/min.

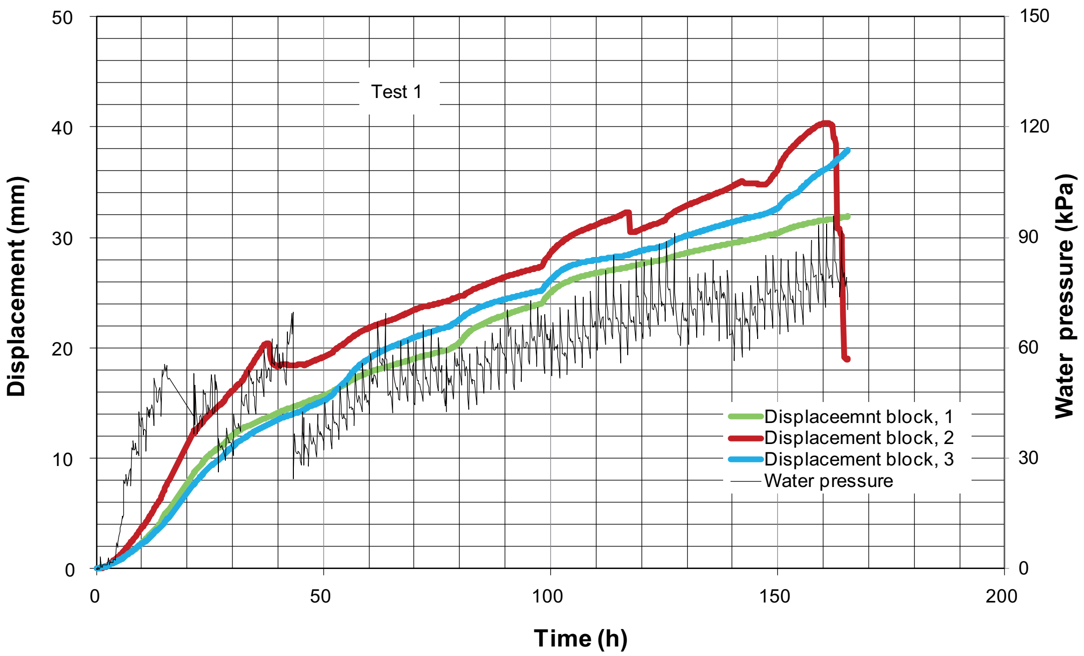

Figure A1-1. *Displacement of block as function of time.*

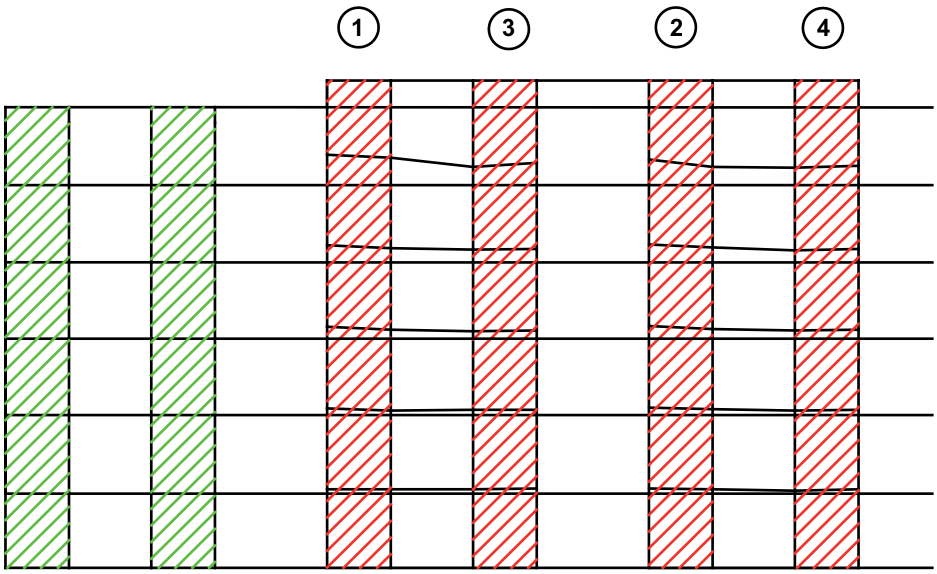

Figure A1-2. *The positions of the individual blocks (the red figure) at the dismantling in four perpendicular directions compared with the position at the installation (green figure). The position of the upper block is calculated from the average measured displacement of the upper surface.*

Test 1

Layout: MX-80 block uniaxial compacted, Extruded MX-80 pellets in slot, water inflow: 0.01 l/min.

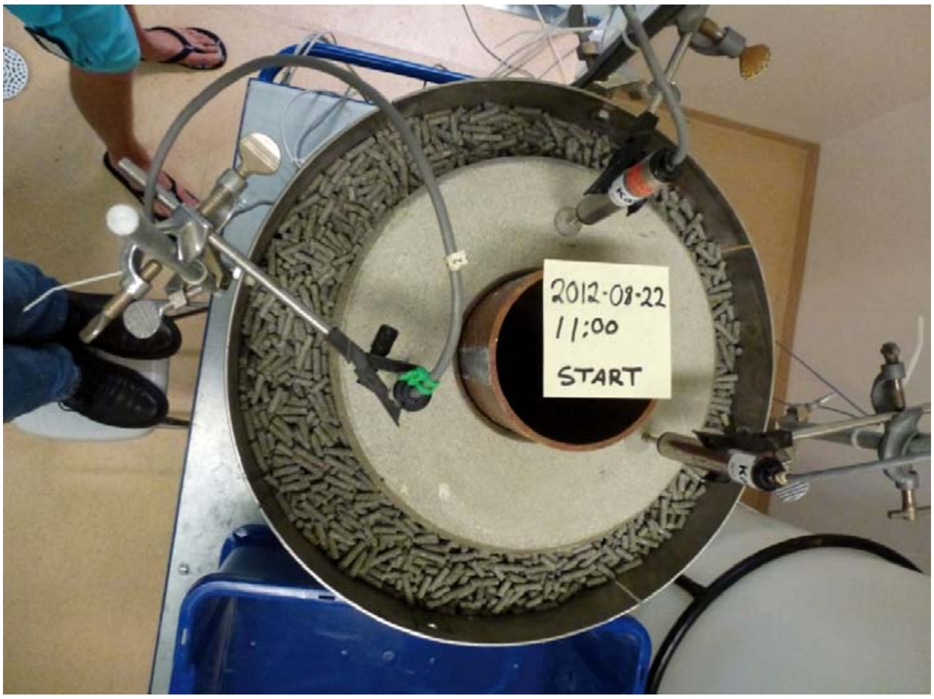

***Figure A1-3.** Photo showing the upper surface of the test just before test start.*

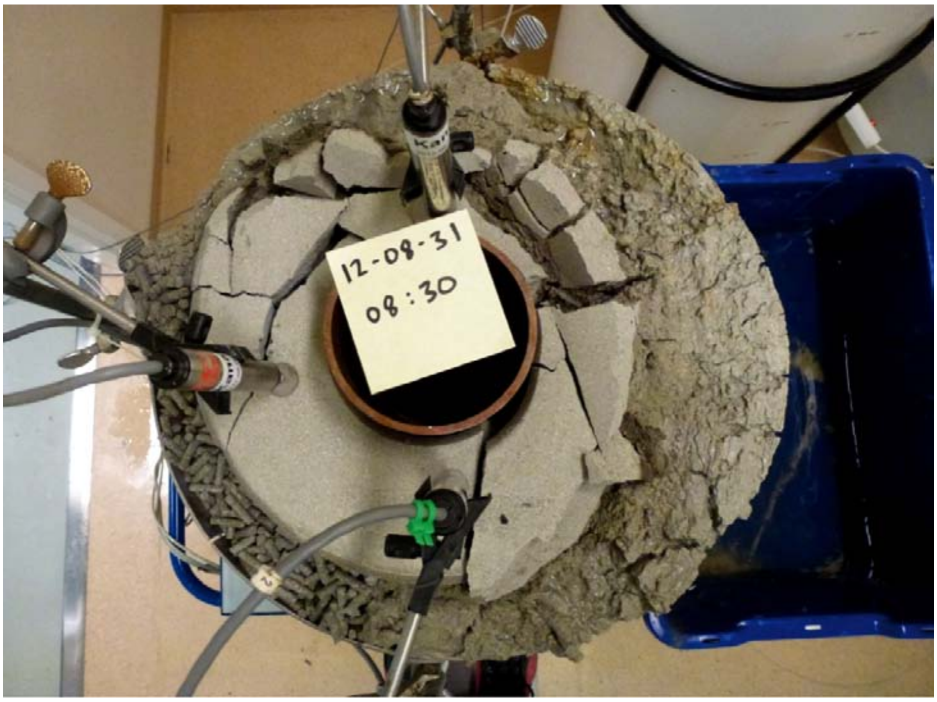

***Figure A1-4.** Photo showing the upper surface of the test just before the dismantling, about 165 hours after the start.*

Figure A1-5. Photo showing the upper surface of a block at the dismantling.

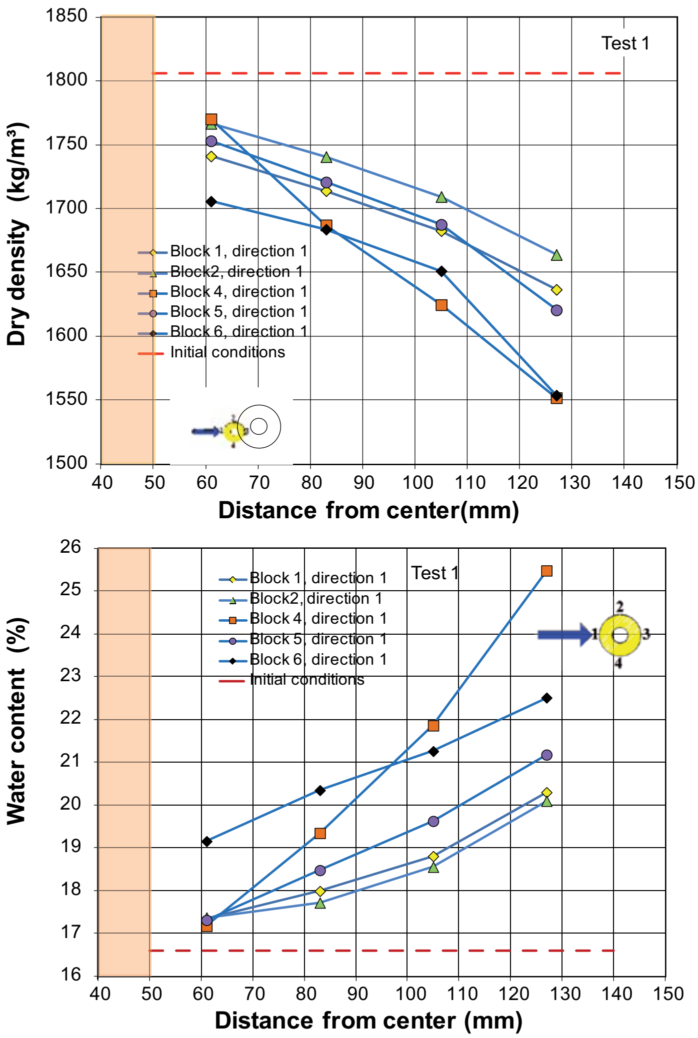

Figure A1-6. The water content and density of the buffer in direction 1. The arrow indicates the position of the inflow point.

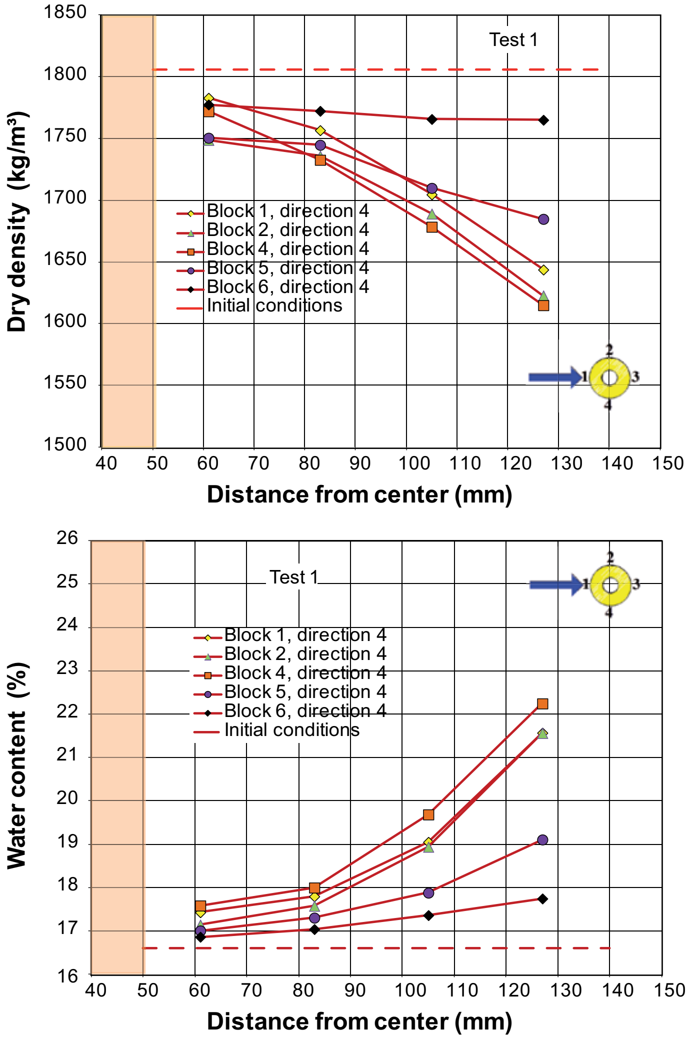

Figure A1-7. *The water content and density of the buffer in direction 4. The arrow indicates the position of the inflow point.*

Data from Test 2

Test 2

Layout: MX-80 block uniaxial compacted, Extruded MX-80 pellets in slot, water inflow: 0.00125 l/min.

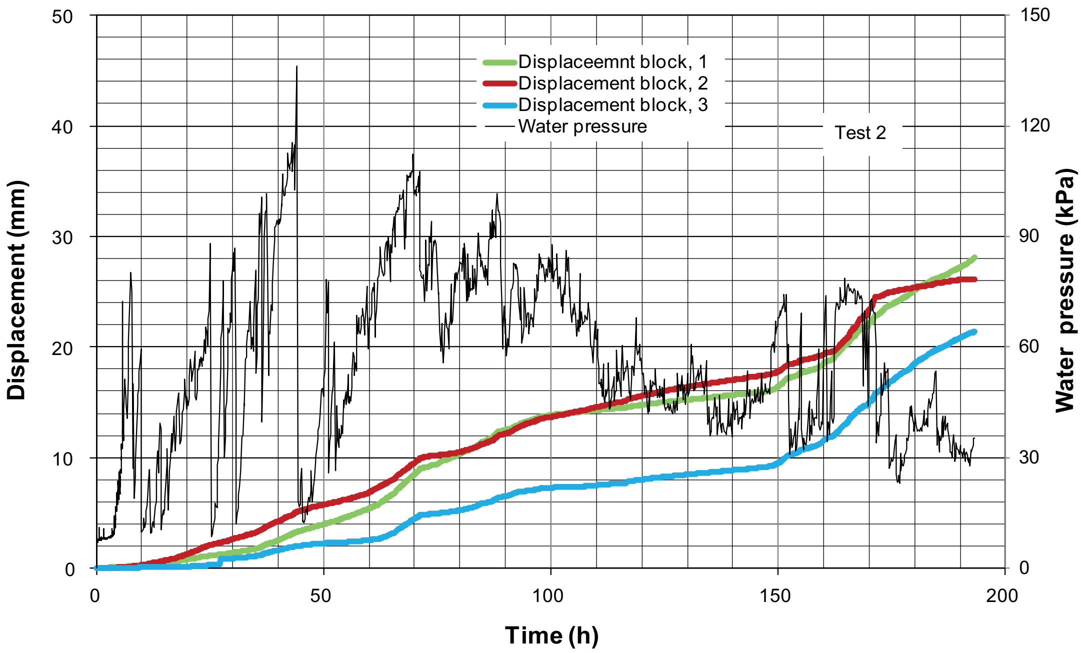

Figure A2-1. *Displacement of block as function of time.*

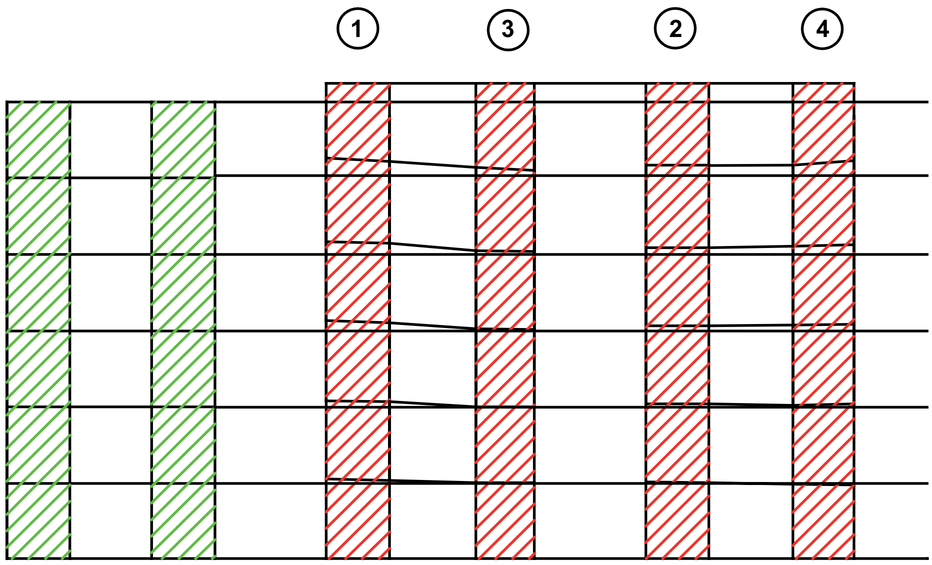

Figure A2-2. *The positions of the individual blocks (the red figure) at the dismantling in four perpendicular directions compared with the position at the installation (green figure). The position of the upper block is calculated from the average measured displacement of the upper surface.*

Test 2

Layout: MX-80 block uniaxial compacted, Extruded MX-80 pellets in slot, water inflow: 0.00125 l/min.

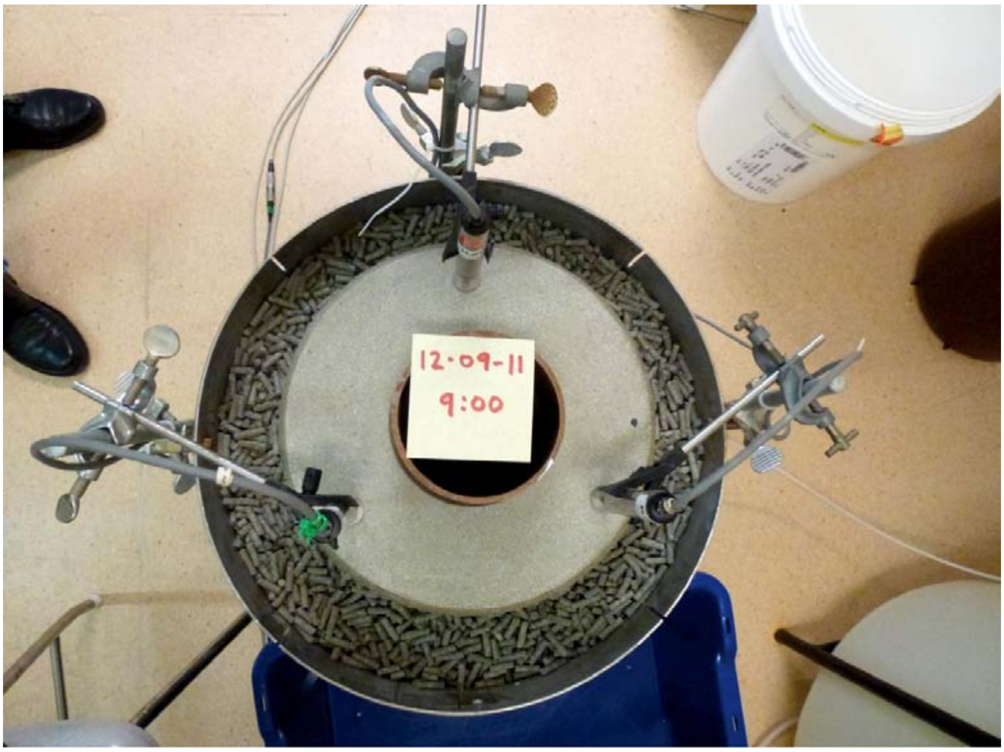

Figure A2-3. *Photo showing the upper surface of the test just before test start.*

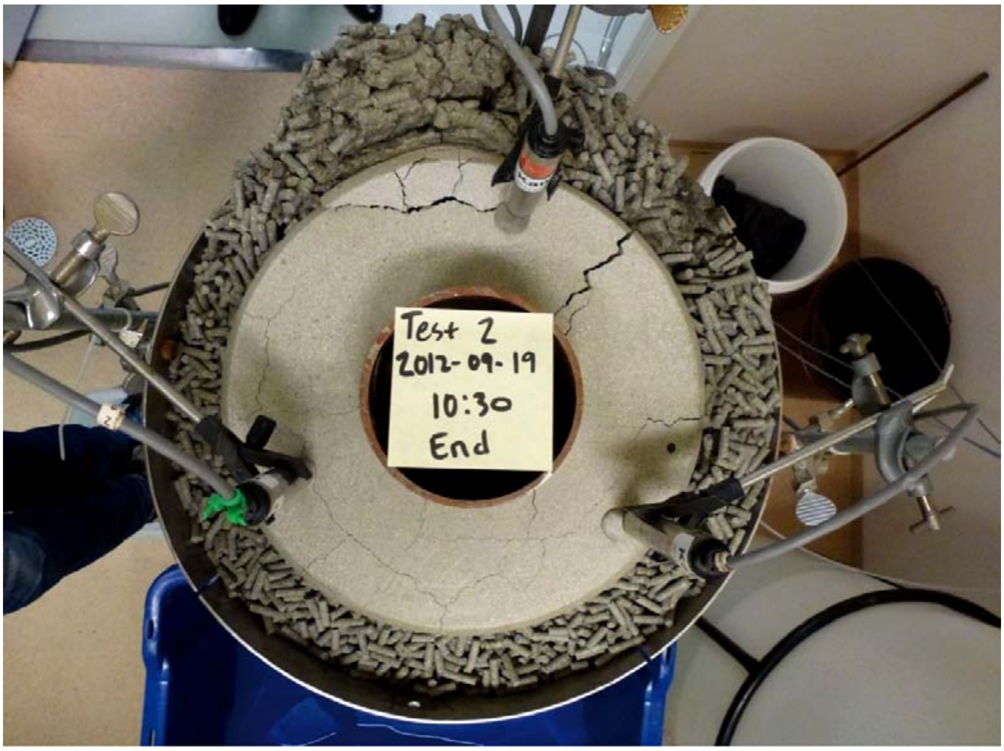

Figure A2-4. *Photo showing the upper surface of the test just before the dismantling, about 165 hours after the start.*

Figure A2-5. Photo showing the upper surface of a block at the dismantling.

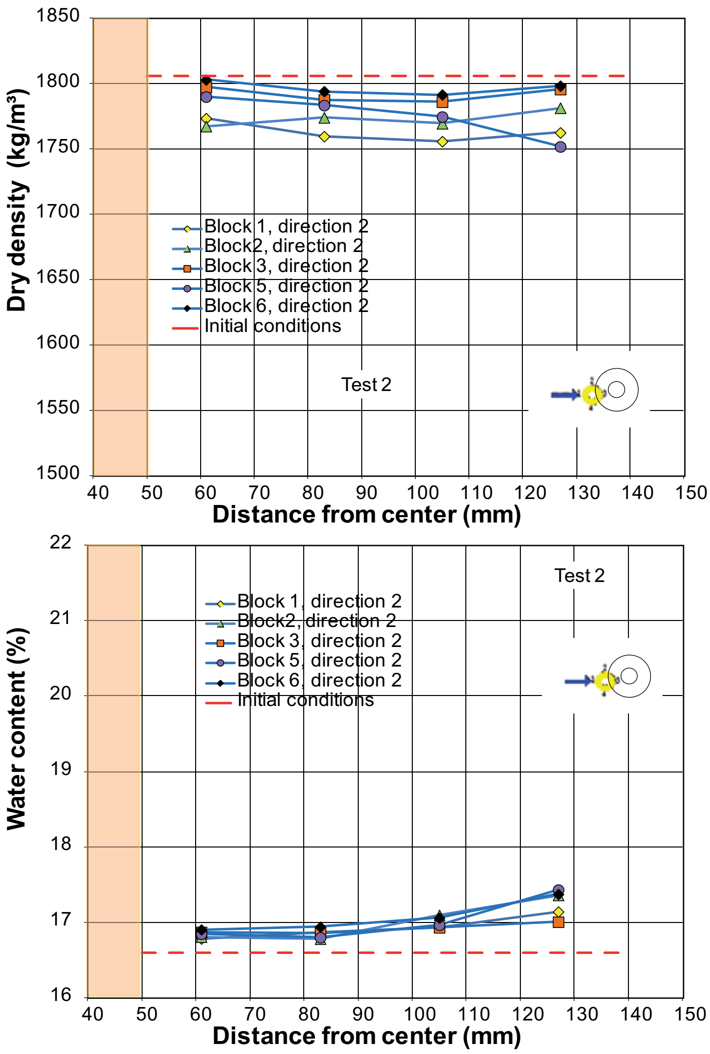

Figure A2-6. The water content and density of the buffer in direction 2. The arrow indicates the position of the inflow point.

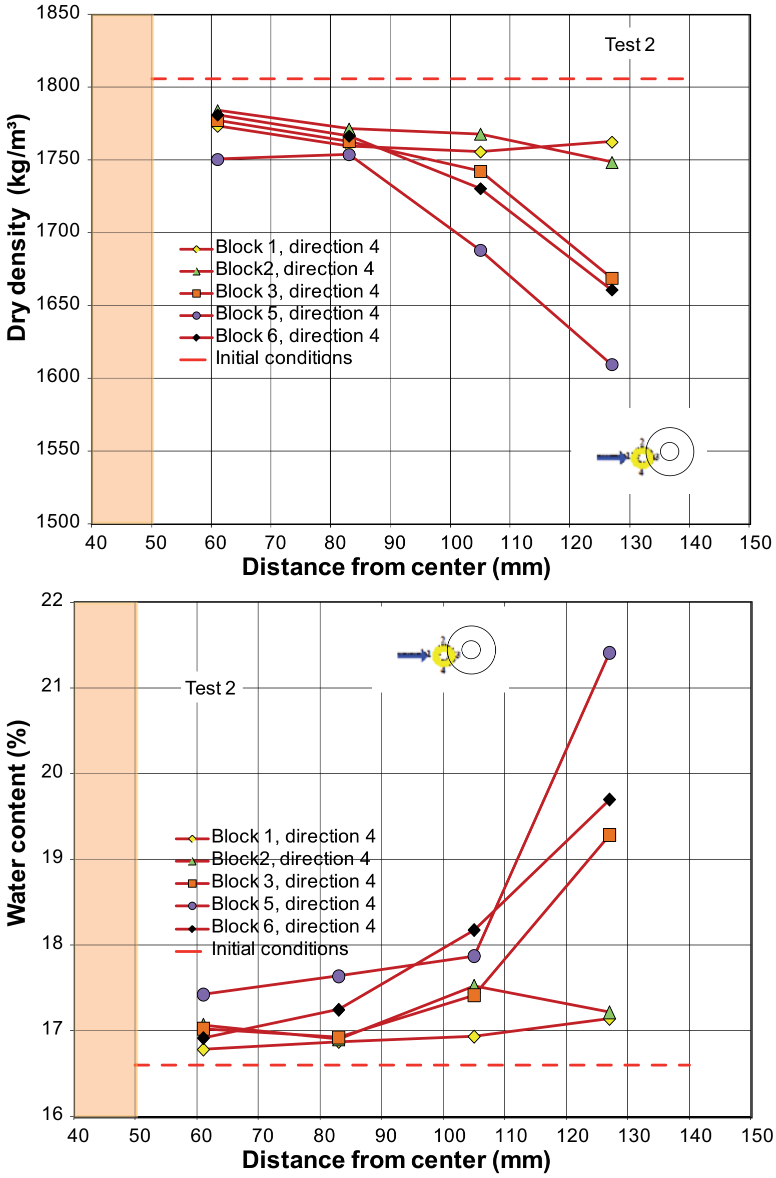

Figure A2-7. *The water content and density of the buffer in direction 4. The arrow indicates the position of the inflow point.*

Data from Test 3

Test 3

Layout: MX-80 block isostatic compacted, Extruded MX-80 pellets in slot, water inflow: 0.01 l/min.

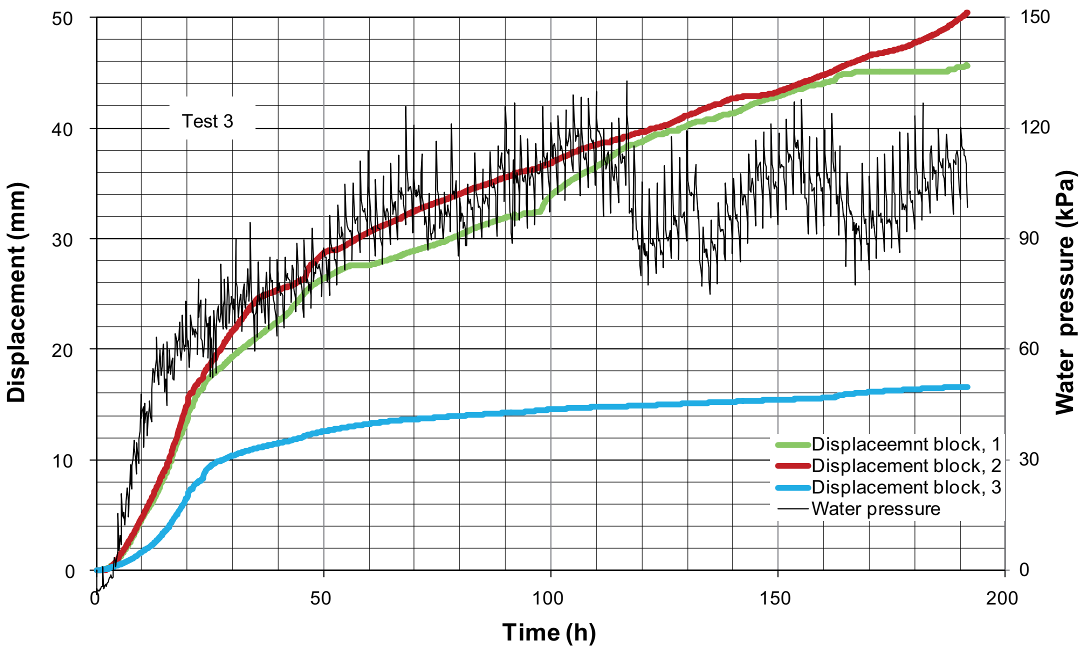

Figure A3-1. *Displacement of block as function of time.*

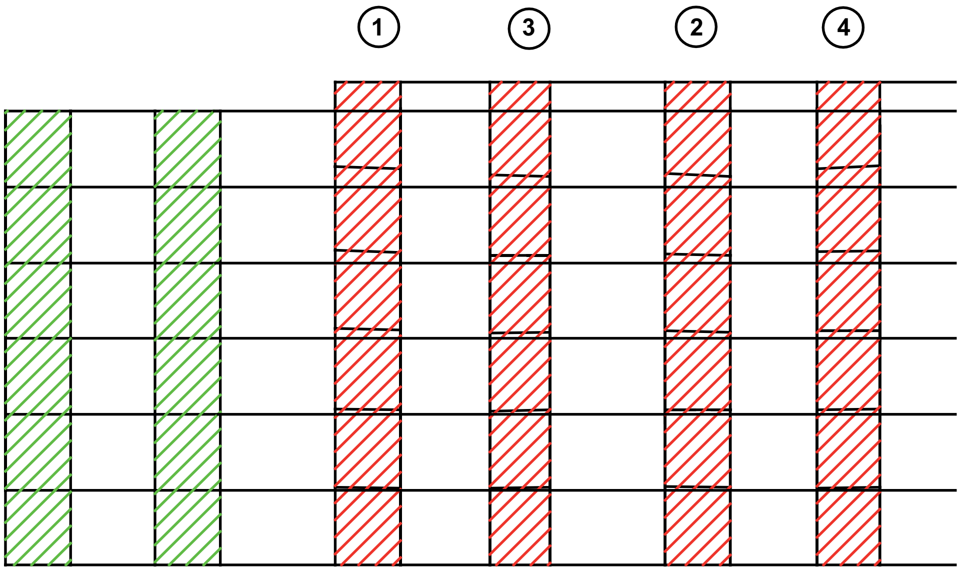

Figure A3-2. *The positions of the individual blocks (the red figure) at the dismantling in four perpendicular directions compared with the position at the installation (green figure). The position of the upper block is calculated from the average measured displacement of the upper surface.*

Test 3

Layout: MX-80 block isostatic compacted, Extruded MX-80 pellets in slot, water inflow: 0.01 l/min.

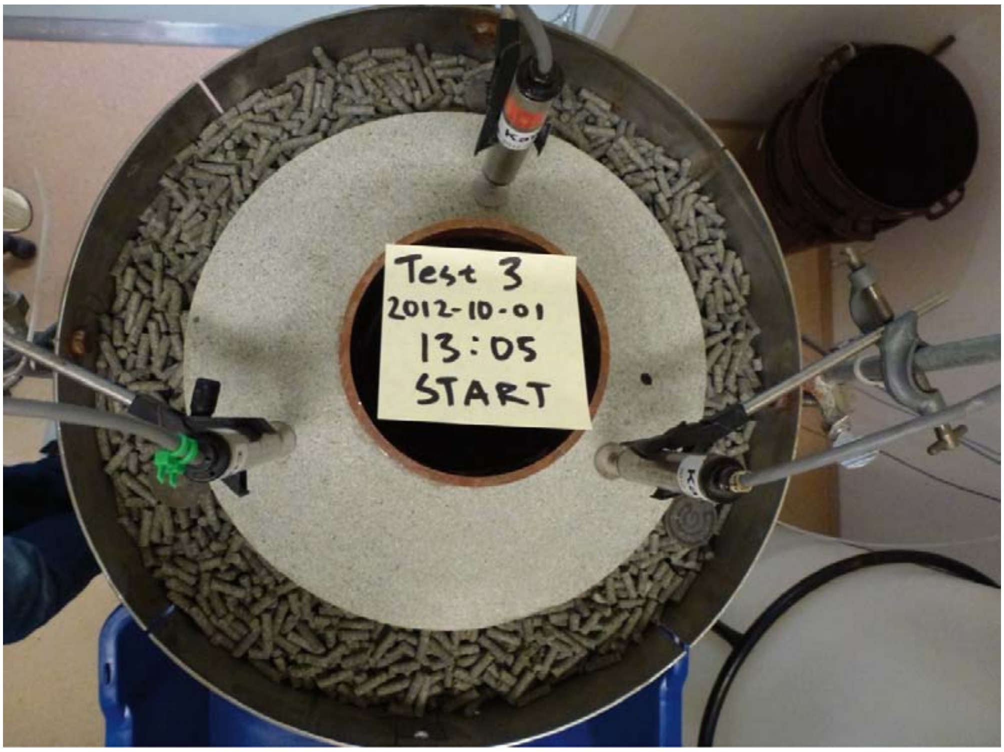

Figure A3-3. *Photo showing the upper surface of the test just before test start.*

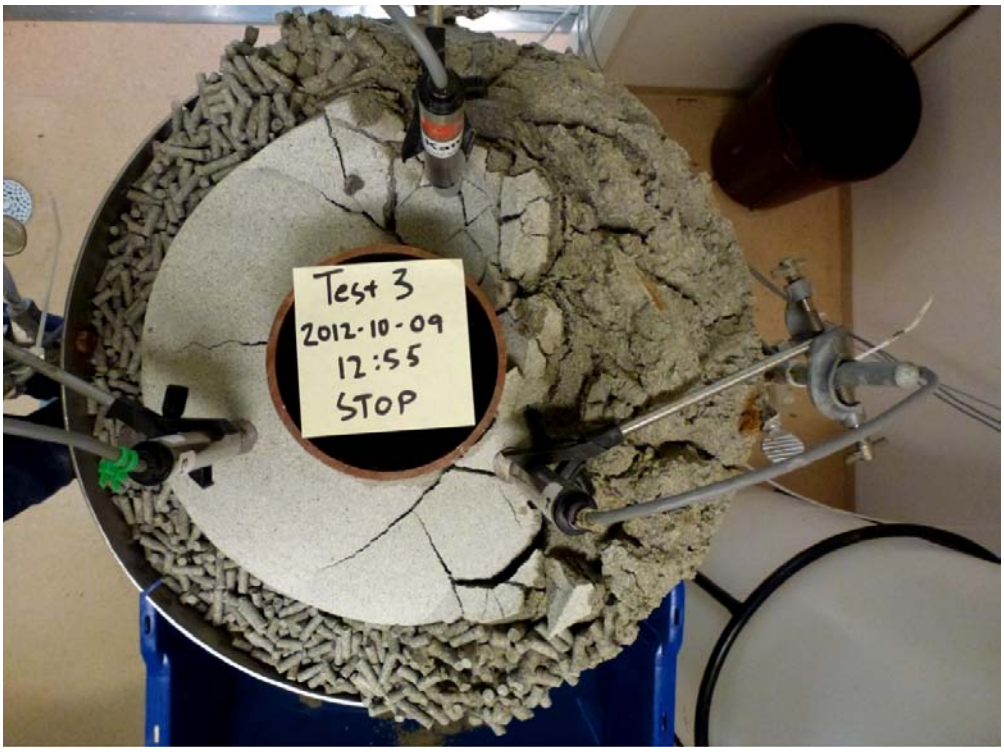

Figure A3-4. *Photo showing the upper surface of the test just before the dismantling, about 165 hours after the start.*

Figure A3-5. Photo showing the upper surface of a block at the dismantling.

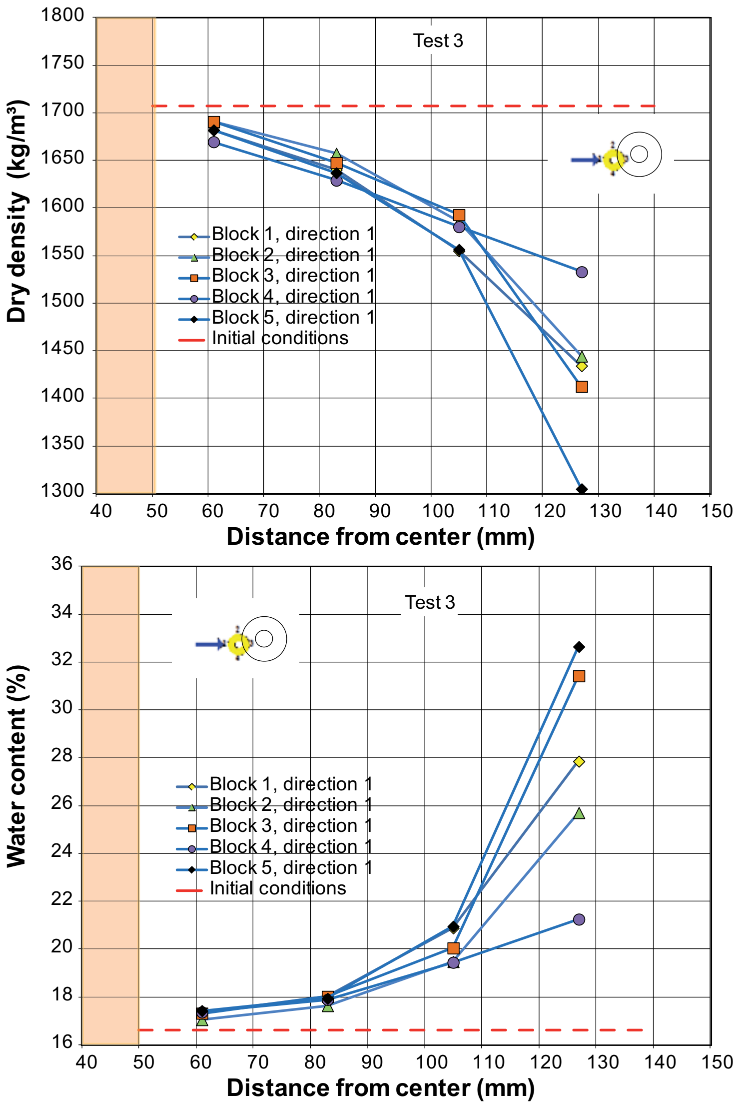

Figure A3-6. The water content and density of the buffer in direction 1. The arrow indicates the position of the inflow point.

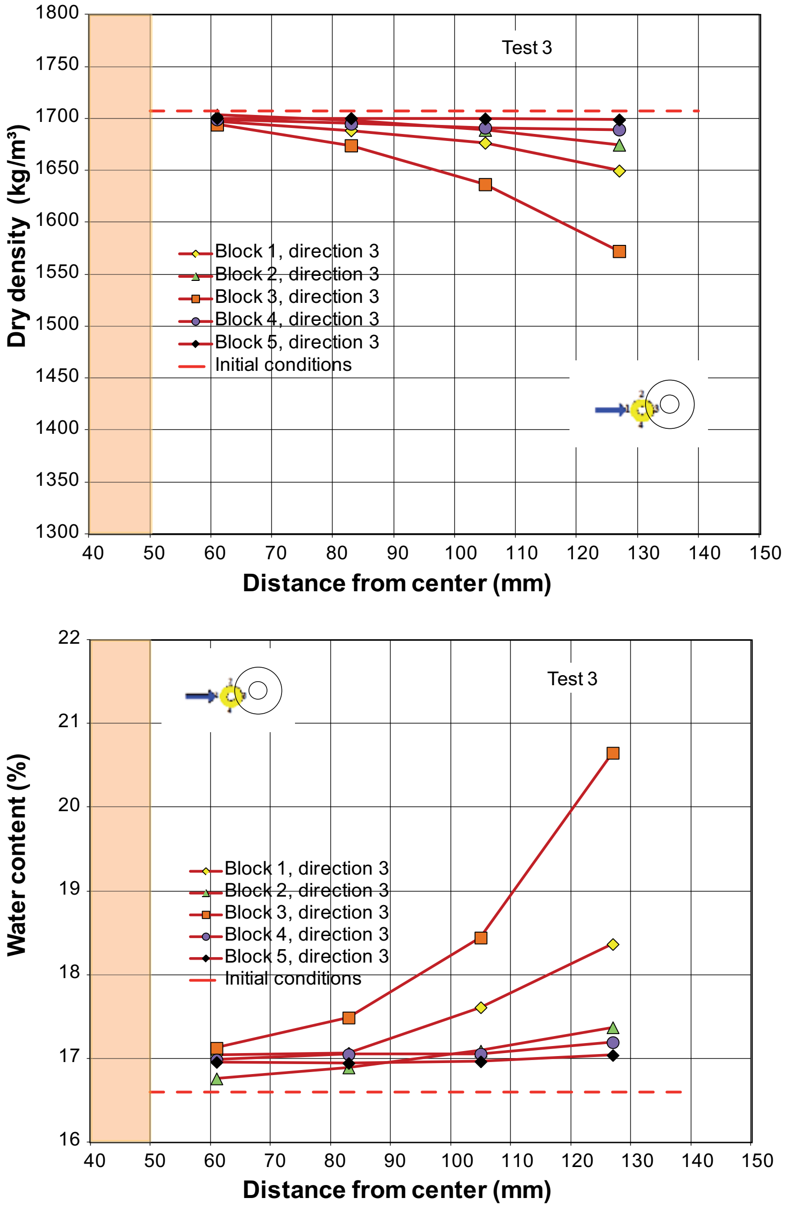

Figure A3-7. *The water content and density of the buffer in direction 1. The arrow indicates the position of the inflow point.*