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Prototype Repository

Method for opening and retrieval of the outer section

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Keywords: retrieval, buffer, backfill, canister, bentonite, MX-80.

Summary

Prototype Repository is a large-scale trial installed at Äspö. The trial consists of six full-scale deposition holes in the TBM-tunnel, depth 450 metres. Each deposition hole is installed with full-scale bentonite buffer (MX-80) and full-scale canister which are equipped with heaters to simulate heat from a canister containing spent fuel. The trial is divided into two sections, in which the inner section consists of four deposition holes and the outer consisting of two deposition holes. The deposition tunnel is backfilled with a mixture of crushed rock and bentonite (30% bentonite). The trial also includes two concrete plugs which end each section. The trial was installed during the period 2001–2003. Natural wetting from the rock of buffer and backfill continued from that date until the end of year 2010 when section II was breached.

The retrieval of the outer section of the test included the following items:

Dismantling of the outer plug: The technique used for demolishing the plug was to first core drill through the outer part of the plug towards the retaining wall in a cross like pattern. After the drilling the plug was mechanical demolished with the use of a hydraulic hammer.

Excavation of the backfill: The excavation of the backfill was made in inclined layers with a backhoe loader. On every 2 meter the excavation stopped and samples were taken for determination of the water content and density of the backfill material. Several installed sensors were also retrieved for future tests and validation.

Excavation of the buffer in the two deposition holes: The main objectives of the excavation of the buffer was beside to empty the deposition hole also to get samples for determining the density and water content and for other laboratory examinations of the betonite. The excavation was made by first make several core drillings form the upper surface of each buffer block and then remove the rest of the buffer. Several installed sensors were also retrieved for future tests and validation.

The accurate planning and organization of the project took more than one year and the work with the dismantling took over one year to finalize. Few staff were involved in the field activities and they took a large responsibility for the work. Furthermore the people had experience from similar task. Some of them were even involved in the installation work of the test. This made it possible to perform the field work both within the budget and on time.

The field work during the retrieval of the outer section of the Prototype Repository is described in this report. The methods used at the retrieval are described and the experiences from the work are summarized. This report forms part of the basis for the main report Opening and Retrieval of the outer section of the Prototype Repository at Äspö Hard Rock Laboratory – Summary Report (SKB TR-13-22).

Sammanfattning

Prototypförvaret är ett storskaligt försök som installerats på Äspö. Försöket innehåller sex fullskaliga deponeringshål i en TBM-tunnel på djupet 450 m. Deponeringshålen är installerade med fullskaliga bentonitblock av MX-80 och fullskaliga kapslar vilka är utrustade med värmare för att kunna simulera värmen får en riktig kapsel med utbränt bränsle. Försöket är uppdelat i två sektioner där den inre sektionen består av fyra deponeringshål medan den yttre sektionen består av två. Deponeringstunneln är återfylld med ett återfyllningsmaterial som består av 30 % bentonit och 70 % krossat berg. Försöket innehåller också två betongpluggar. Försöket installerades under perioden 2001–2003. Bufferten och återfyllningsmaterialet tog upp vatten från omgivande berg från den tidpunkten till slutet av 2010 då sektion två bröts.

Brytningen av den yttre sektionen inkluderade följande moment:

Brytning av den yttre pluggen: Vid brytningen borrades hål genom betongen med håltagningsborr i ett korsliknande mönster varefter pluggen demolerades med en hydraulisk hammare.

Urgrävning av återfyllningsmaterialet: Utgrävningen gjordes i lutande lager med en traktorgrävare. Efter varannan meter stoppades utgrävningen och prover togs av återfyllningsmaterialet på vilka vattenkvot och densitet bestämdes. Många installerade givare togs också omhand för vidare tester.

Urgrävning av buffertmaterialet i de två deponeringshålen: Huvudmålen med urgrävningen av bufferten var förutom att få bort buffertmaterialet också att ta prover på bufferten för bestämning av vattenkvot och densitet samt för andra laboratorietester. Urgrävningen genomfördes genom att först kärnborra från överytan av varje installerat block och sedan bryta loss och lyfta upp resten av bufferten ur deponeringshålen. Många installerade givare togs också omhand vid brytningen för vidare tester.

Planeringen och organiseringen av projektet gjordes under ett år, och själva brytningen av försöket tog mer än ett år genomföra. Ett fåtal människor var involverade i fältarbetet och dessa personer tog ett stort ansvar för sitt arbete. De hade också erfarenhet från liknande arbeten. Detta sammantaget gjorde att fältarbetet kunde genomföras enligt tidplan och inom budget.

I denna rapport avrapporteras fältarbetet som utfördes i samband med brytningen av den yttre sektionen. Arbetsmetoderna som användes beskrivs och erfarenheterna från fältarbetet sammanfattas. Rapporten är en underlagsrapport för huvudrapporten Opening and Retrieval of the outer section of the Prototype Repository at Äspö Hard Rock Laboratory – Summary Report (SKB TR-13-22).

Contents

1 Introduction

1.1 Background

Prototype Repository is a large-scale trial installed at Äspö. The trial consists of six full-scale deposition holes in the TBM-tunnel, depth 450 metres. Each deposition hole is installed with full-scale bentonite buffer (MX-80) and full-scale canister. The canisters are equipped with heaters to simulate heat from a canister containing spent fuel. The trial is divided into two sections, in which the inner section consists of four deposition holes installed with buffer and canister and the outer consisting of two deposition holes also installed with buffer and canisters. The deposition tunnel is backfilled with a mixture of crushed rock and bentonite (30% bentonite). The trial also includes two concrete plugs which end each section. Furthermore, sensors were installed in the rock, backfill and buffer to monitor pressure build-up and wetting of buffer and backfill. The trial is described in detail by Persson and Broman (2000) and in Svemar and Pusch (2000). The dimensions of the tunnel and the deposition hole are shown in Figure 1-1.

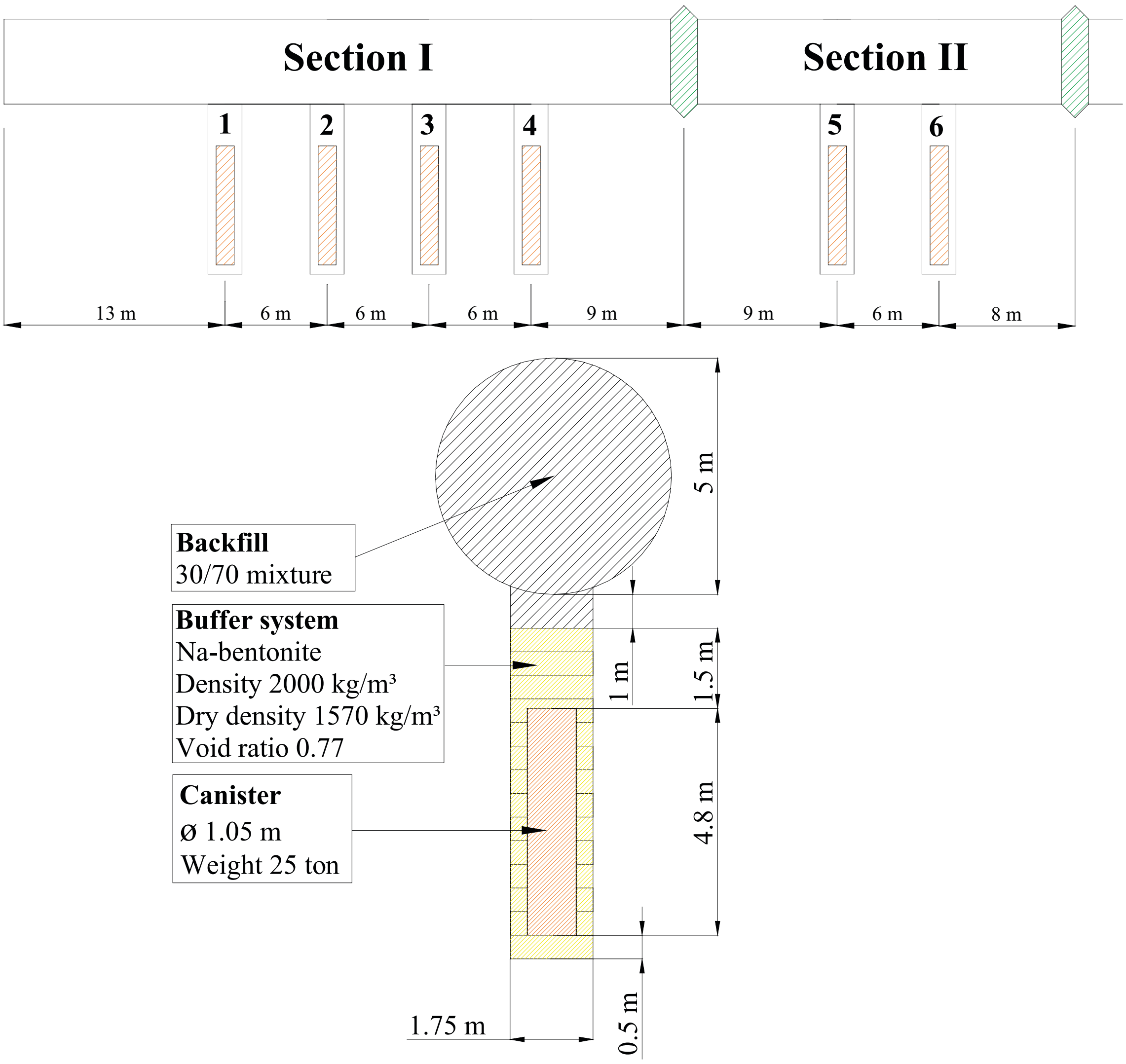


Figure 1-1. *Schematic drawing of the deposition tunnel and the deposition holes of the Prototype Repository.*

The installation of buffer, canister with heater, in situ compaction of backfill, and also the casting of the concrete plug was done during the autumn of 2001 for section I. Corresponding installations for section II were made during the spring and autumn 2003. Heating of the canisters in the two sections was started successively after filling of the tunnel had reached the deposition holes. The heaters in canister 1 were activated on the 3rd of October 2001 and respective heaters in canister 6 were activated on the 23rd of May 2003. The plug in section II was completed on the 11th of October 2003.

Natural wetting from the rock of buffer and backfill continued from that date until the end of year 2010 when section II was breached. The wetting and operation of the inner section is still ongoing.

1.2 Objectives of dismantling

The overall objective of the trial "Prototype Repository" is to test and demonstrate the integrated function of subcomponents in a final repository for spent nuclear fuel under realistic full-scale conditions. Data from the trials shall also be compared to modelling made from the trial.

Sub-objective in the project of the dismantling is to plan and implement breaching of plug, sampling and removal of backfilling and buffer of the outer section of the Prototype Repository. The planning provided a detailed procedure of how an opening should be carried out, time needed for the retrieval and associated tasks, necessary resources in the form of machines and personnel required and also the costs involved.

Objectives of the actual retrieval are as follows:

- To acquire an image of density and water saturation of buffer and backfilling of the outer section of the trial. This was achieved by extensive sampling of buffer and backfill.
- It is also important to find out how the contact between buffer-backfill and backfill-tunnel wall appears after more than 7 years wetting.
- Measurements made of the rock around the two deposition holes indicate that changes have occurred in the rock mass. After removing the backfill, buffer and canister the rock in and around the deposition holes can be studied to confirm or reject these measurements.
- The canister has been subjected to high swelling pressures by the buffer. These pressures might have changed the position and also the shape of the canister. It was therefore important to determine the position and shape of the canister after the wetting period.
- During a short period of the trial the outer plug was subjected to high pressure, about 2 MPa. If possible any damage and changes to the plug should be recorded.
- Biological and chemical activity in the buffer and backfill has been measured during the progress of the trial by sampling of water and gas. Samples were taken to verify these measurements if possible during progress of the retrieval.
- During progress of the trial the buffer has become saturated by water from the surrounding rock. Furthermore, it has been subjected to high temperatures during a long period. This can possibly affect properties of the buffer material. These processes are studied in special trials at Äspö, e.g. LOT and TBT. Tests will also be made on samples taken from this trial with the object of studying possible changes in the bentonite.
- Equipment for studying corrosion of copper in the buffer has been installed in one of the holes (hole 5). Measurements from this equipment will be complemented by sampling from the buffer with the object of studying possible corrosion.

The field work with the retrieval of the outer section of the Prototype Repository is described in this report. The methods used at the retrieval are described and the experiences from the work are summarized. The outcome from the laboratory examinations made on the samples taken at the retrieval are described in separate reports (Johannesson 2013, Olsson et al. 2013, Arlinger et al. 2013). This report is a sub-report for the main report Opening and Retrieval of the outer section of the Prototype Repository at Äspö Hard Rock Laboratory – Summary Report (SKB TR-13-22).

1.3 Activity planning

The work with the retrieval of the Prototype repository was organized in the following activities in chronologic order:

1. Switching of the heaters in deposition hole 6.
2. Testing of the tightness of the plug.
3. Breaching of the plug.
4. Sampling and excavation of the backfill to a section behind deposition hole 6.
5. Excavation of the backfill inside deposition hole 6.
6. Sampling and removal of the bentonite Block C4-C2 and R10-R1 in deposition hole 6.
7. Gas sampling inside the canister in deposition hole 6.
8. Retrieval of the canister in deposition hole 6.
9. Sampling and removal of the bentonite Block C1 in deposition hole 6.
10. Switching of the heaters in deposition hole 5.
11. Continuing of the sampling and excavation of the backfill to the inner plug.
12. Excavation of the backfill inside deposition hole 5.
13. Sampling and removal of the bentonite Block C4-C2 and R10-R1 in deposition hole 5.
14. Gas sampling inside the canister in deposition hole 5.
15. Retrieval of the canister in deposition hole 5.
16. Sampling and removal of the bentonite Block C1 in deposition hole 5.

The above listed field activities were described in Activities plans according to SKB:s Project model. The Activity plans were reviewed and approved before the actual work started. In Table 1-1 the Activity plan related to the field work are listed. The Activity planes were written in Swedish.

Table 1-1. The Activity Plans associated with the field work at the retrieval of the Prototype Repository.

AP number	Title	Version
AP TD KBP1001-10-047	Tightness tests of the outer plug in the Prototype Repository.	1.0
AP TD KBP1001-10-050	Retrieval and sampling of the outer concrete plug, Prototype Repository.	1.0
AP TD KBP1001-10-063	Retrieval and sampling of the backfill material, Prototype Repository.	1.0
AP TD KBP1001-11-013	Retrieval and sampling of the backfill material inside the deposition holes 5 and 6, Prototype Repository.	1.0
AP TD KBP1001-11-014	Retrieval and sampling of the buffer material in deposition holes 6, Prototype Repository.	1.0
AP TD KBP1001-11-039	Gas sampling inside the canister in deposition hole 6, Prototype Repository	1.0
AP TD KBP1001-11-016	Retrieval of the canister in deposition hole 6 (DA3545G01), Prototype Repository	1.0
AP TD KBP1001-11-057	Retrieval and sampling of the buffer material in deposition hole 5, Prototype Repository.	1.0
AP TD KBP1001-11-068	Gas sampling inside the canister in deposition hole 5, Prototype Repository	1.0
AP TD KBP1001-11-088	Retrieval of the canister in deposition hole 5 (DA3551G01), Prototype Repository	1.0

1.4 Outline of report

A large amount of data and photographs have been obtained during the retrieval operation. The actual dismantling operation is described in four chapters (Chapter 2–5). The dismantling of the plug is described in Chapter 2 including the chosen technique and sampling. Tests that were made before the dismantling in order to find out the water tightness of the plug are also described in Chapter 2. The technique for excavation of the backfill is described in Chapter 3, and in Chapter 4 and Chapter 5 describes the excavation and the sampling of the buffer in the two deposition holes. The preparation of the taken samples from the backfill and buffer is described in Chapter 6 and in Chapter 7 the list of the retrieved sensors are provided. In Chapter 8 some experiences from the field work are summarized.

2 Dismantling of the plug

2.1 Introduction

The two plugs in the Prototype Repository consist of two parts, see Figure 2-1. The part close to the backfilled tunnel is a retaining wall, consisting of prefabricated reinforced beams which were bolted to the rock. At the backfilling of the tunnel, the retaining wall prevented the backfill material from sliding into the open part of the tunnel before the plug was casted. Towards the retaining wall, a reinforced concrete plug was casted and about one year after the casting the gap between the plug and the rock surface was grouted (Dahlström 2009). The grouting was made through three pipes installed in the periphery of the plug. The grouting was made after the plug was cooled down in order to get a thermal shrinkage of the plug and thus ensure that the grouting will be distributed between the plug and the rock. The grout material used was primarily cement grout (Ultrafine 16, (UF16) vct 0.8–1.0 with plasticizer, Cement setcontrol). Silica sol was later used as complement, in the middle tube. The grouting was made with a final maximum pressure of 4 MPa. The grouting is described in detail by Dahlström (2009).

The opening of the Prototype Repository began with the removal of the concrete plug. Before this, a simple test of the water tightness of the plug was made. These tests were made at the end of November 2010. Immediately after these tests were finalized, the removal of the plug started. The work with the removal of the plug ended in February 2011.

2.2 Methods

Before the actual breaching of the plug, a simple test of the water tightness was made by applying a water pressure on the inside of the plug and then measuring the water outflow through the plug, see Section 2.3.

A sampling of the interface between the concrete and the rock surface, which was grouted at the installation, was also made before the breaching of the plug. This was done by core drilling through the concrete plug into the surrounding rock, see Section 2.4.

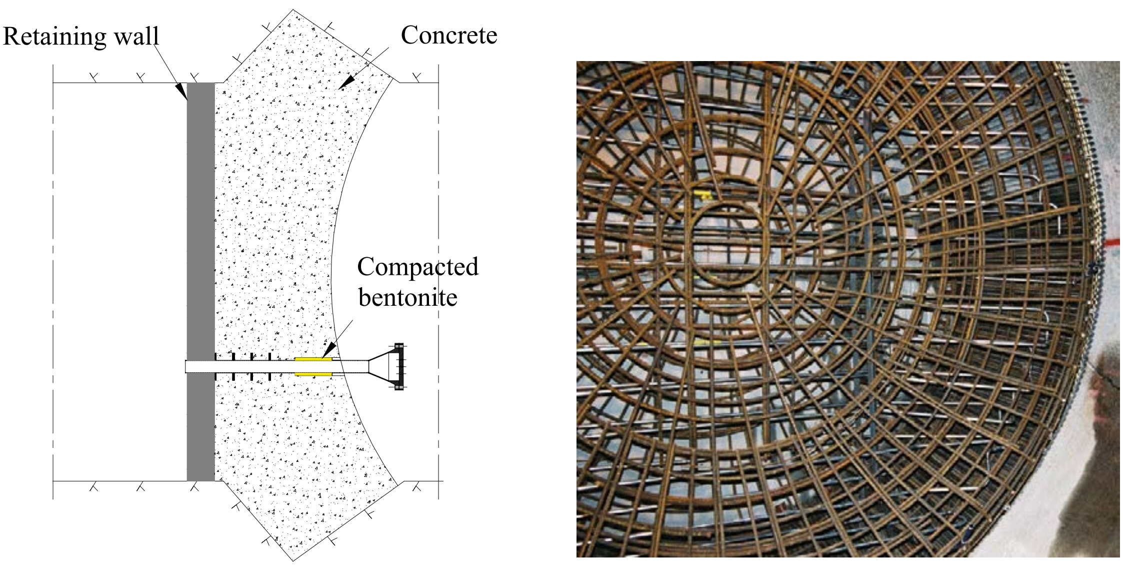


Figure 2-1. Schematic drawing of the concrete plug (left) and the reinforcement (right).

At the planning of the dismantling of the outer plug several techniques were considered. One of the methods was carefully blasting of the plug. Another method was to use more heavy machines for mechanical demolishing of the plug. One important factor which affected the choices of method was the demands of saving the cables which were lead through the plug. The cable came from sensors installed in the surrounding rock of deposition hole 6 for measuring stresses, strains and temperatures. It was of great interest to continue these measurements for as long as possible during the dismantling of the test.

The technique used for breaching the plug was to first core drill through the outer part of the plug towards the retaining wall in a cross like pattern, see Figure 2-2a. After the drilling the plug was mechanically demolished with the use of a hydraulic hammer (Brock). This part of the work was found out to be harder than expected. For that reason the hydraulic hammer was supplemented with a hydraulic breaker, see Figure 2-7c. The hydraulic breaker was vibrated into the concrete and then hydraulic expanded, resulting in a fissuring of the concrete. The plug was then further demolished with the hydraulic hammer. This made the reinforcement visible which was then cut with a cutting blowpipe. Finally, the remaining of the plug was transported out from the tunnel with a front loader. The retaining wall, consisting of several prefabricated and reinforced concrete beams was finally removed by first cutting off the mounts for the beams on the rock wall, see Figure 2-3 and then mechanically demolished with the hydraulic hammer, see Figure 2-2b.

2.3 Testing of tightness of the plug

A filter mat was placed between the concrete beams and the backfill at the installation of the plug, see Figure 2-3. Several tubes were led from the mat through the plug and also through the rock mass to a nearby tunnel. Furthermore a measuring weir, just in front of the plug was installed for continuous measurement of the water outflow through the plug. This arrangement made it possible to make a simple test of the water tightness of the plug before it was retrieved. The tubes were used for applying a water pressure in the mat. The outflow through the plug was measured with the use of the installed measuring weir. The test was made by applying a pore pressure of about 1,300 kPa and measure the outflow as function of time. The data from these tests are shown in Figure 2-4. The figure is showing that the water flow through the plug after about 22 hours was very low (not measurable).

a) b)

Figure 2-2. a) The cross like pattern of the core drilled holes through the plug. b) The machine used at the demolition of the concrete plug.

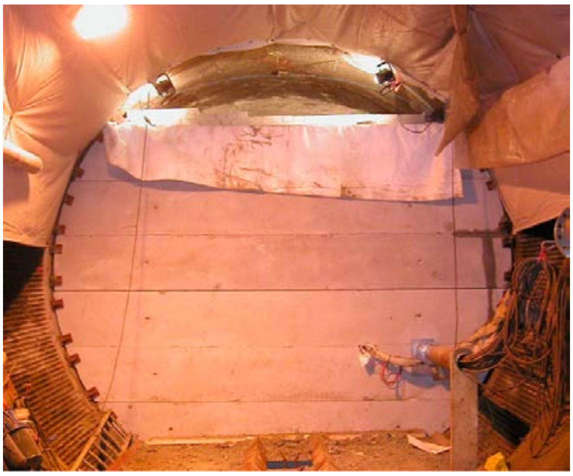


Figure 2-3. The filter math installed inside the retaining wall.

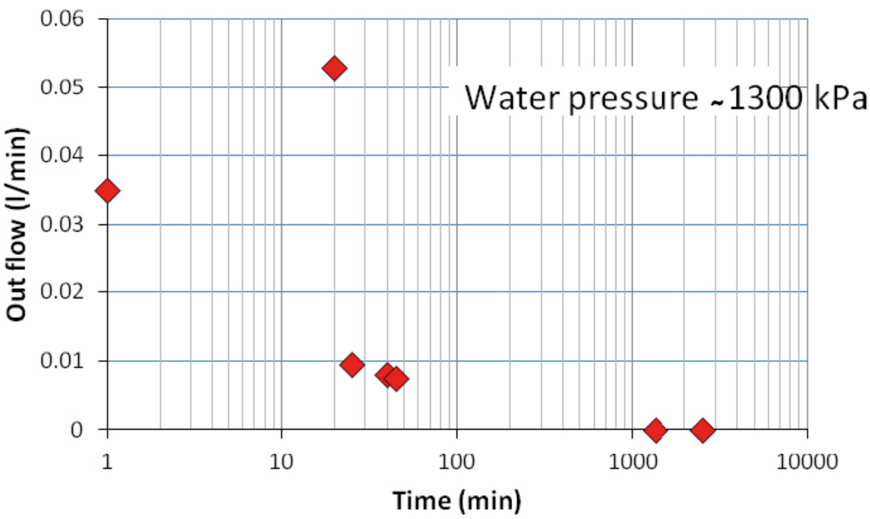


Figure 2-4. The measured outflow through the plug.

2.4 Samples taken at the interface between concrete and rock surface

Four samples were taken of the plug for investigating the interaction between the concrete and the rock surface in the slot of the plug especially to study the outcome of the contact grouting. The samples were core drilled with a boring machine placed in a rig as shown in Figure 2-5. The cores had a diameter of 120 mm. Three of the taken core samples could be recovered for evaluation. The fourth core hit the reinforcement structure and was split into smaller pieces. The examination of the taken cores indicate that the grouting made after casting of the plug filled up very well the gap between the concrete and the rock surface. See photos in Figure 2-6.

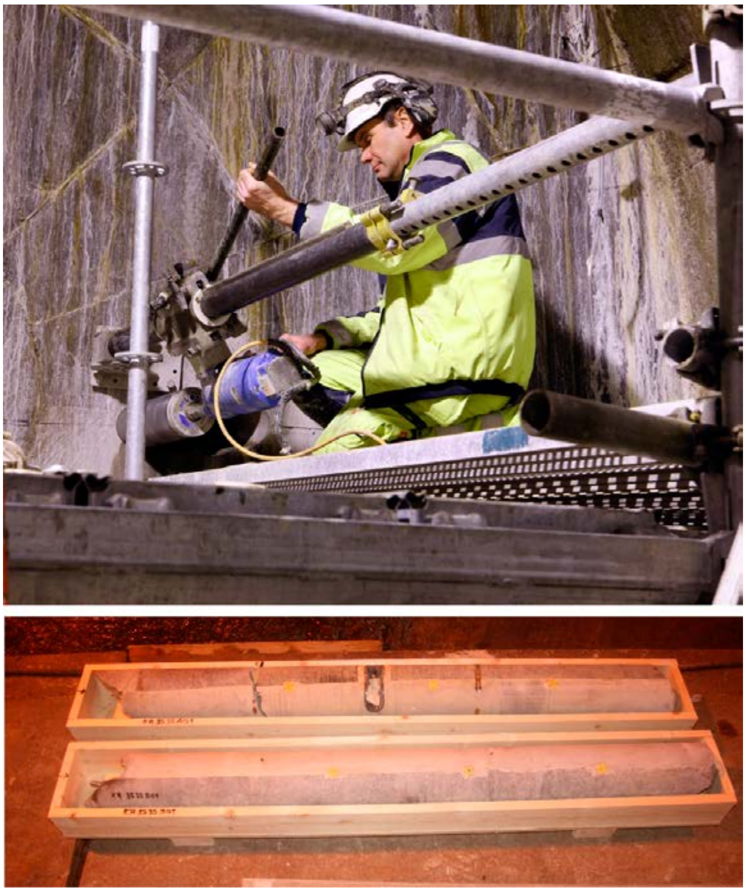


***Figure 2-5.** The rig used for taking the contact samples between the concrete and the rock and some cores from the sampling.*

***Figure 2-6.** Close up pictures of the cores taken from the interface between the concrete plug and the rock. The yellow grouting tubes are embedded in grout.*

2.5 Breaching of the concrete plug

The breaching of the plug started in December 2010 and the work was finalized at the end of February 2011. The core drilling was made, at the most intensive phase with two rigs placed in a frame as shown in Figure 2-7a. The diameter of the drilled holes was 150 mm. A smaller hole was first drilled through the entire plug to ensure that no water pressure was acting on the inner plug surface. The first hole with the planned diameter was drilled through both the concrete plug and the retaining wall, which resulted in a leakage of backfill material through the hole, see Figure 2-7b. In order to minimize the risk of further leakage of material during the drilling, it was decided that the rest of the drilled holes should not enter the retaining wall. The drilling part of the work was handled by two workers and took about 2 months to finalize. The demolishing continued with mechanical impact on the plug with a hydraulic hammer and a hydraulic breaker as described in Section 2.2, see Figure 2-7c. At this part of the demolishing, water was spread over the plug to minimize the dust. This part of the work took about 1 month. Another 2 weeks were used for demolishing the retaining wall, see Section 2.2. The demolishing of the plug was impeded by the desideratum to save the cables lead through tubes placed in the plug, see Figure 2-2.

The concrete from the demolished plug was transported out from the tunnel with a front loader and further transported up to the ground level with trucks. The total weight of the plug was about 145 tons.

a) b) c) d)

__Figure 2-7.__ a) The drilling machines placed on the rig. b) Backfill material squeezed out through a drilled hole in the concrete plug. c) The hydraulic breaker used at the demolition of the plug. d) Remaining of the concrete plug and its reinforcements together with the retaining wall. The cables placed in tubes passing through the plug are visible on the right side.

3 Excavation of the backfill

3.1 Introduction

The backfill material was compacted in situ in inclined layers with the use of a vibrating slope compactor attached on a backhoe loader at the installation of the test, see Figure 3-1. The material consisted of 30% bentonite (from Milos) and 70% crushed rock, with a maximum grain size of 20 mm. The average density of the backfill was about 1,700 kg/m^3 and the water content was about 14%. Test made at the installation indicated that the density of the backfill was lower close to the rock surface of the tunnel, especially close to the ceiling, compared to the central part of the tunnel (Johannesson et al. 2004). The total length of the outer section was about 22 m and about 900 tons of material was compacted into the tunnel.

3.2 Methods

The excavation of the backfill was also made in inclined layers. This was arranged by a backhoe loader, see Figure 3-2. Every second meter the excavation stopped and samples were taken for determination of the water content and density of the backfill material, see Figure 3-3a. In order to be able to stand on the surface of the backfill, when taking samples, steel rods were pushed into the backfill and platforms were placed on them, see Figure 3-3a. The samples taken (about 100 per investigated section) were excavated from the surface with the use of an angle grinder. The position of each taken samples was determined by geodetic surveying, see Figure 3-3b and c. The samples were wrapped in foils with a subsequent evacuation of the air, and transported to the lab for determining of its water content and density, see Figure 3-3d. The determination of the water content and density were made within 48 hours after the samples were taken from the site. The results from the measurements are described and presented in a separate report (Johannesson 2013).

3.3 Removal of the backfill

The work with the excavation of the backfill started immediately after the first beams from the retaining wall were removed. The excavation work was done during two periods. At the first period (March 2011), the excavation was made to a section approximately 3 m behind deposition hole 6. A temporary wooden wall was then placed in front of the backfill to ensure that the rest of the backfill was kept in place during the excavation of the buffer in deposition hole 6, see Chapter 4. The excavation of the backfill continued (August–September 2011) after the buffer and the canister was removed from deposition hole 6. The total amount of backfill removed from the tunnel was about 900 tons.

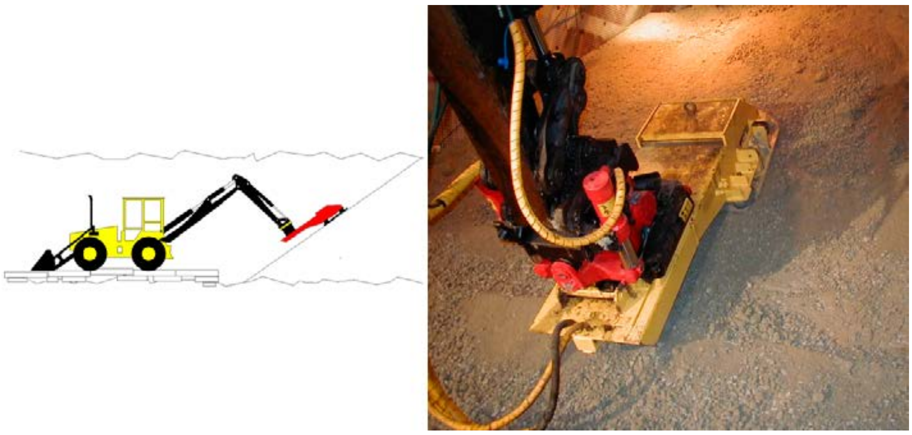


Figure 3-1. *Schematic drawing of the compaction device attached to a backhoe loader and a photo of the compactor.*

Figure 3-2. *The backhoe loader used at the excavation.*

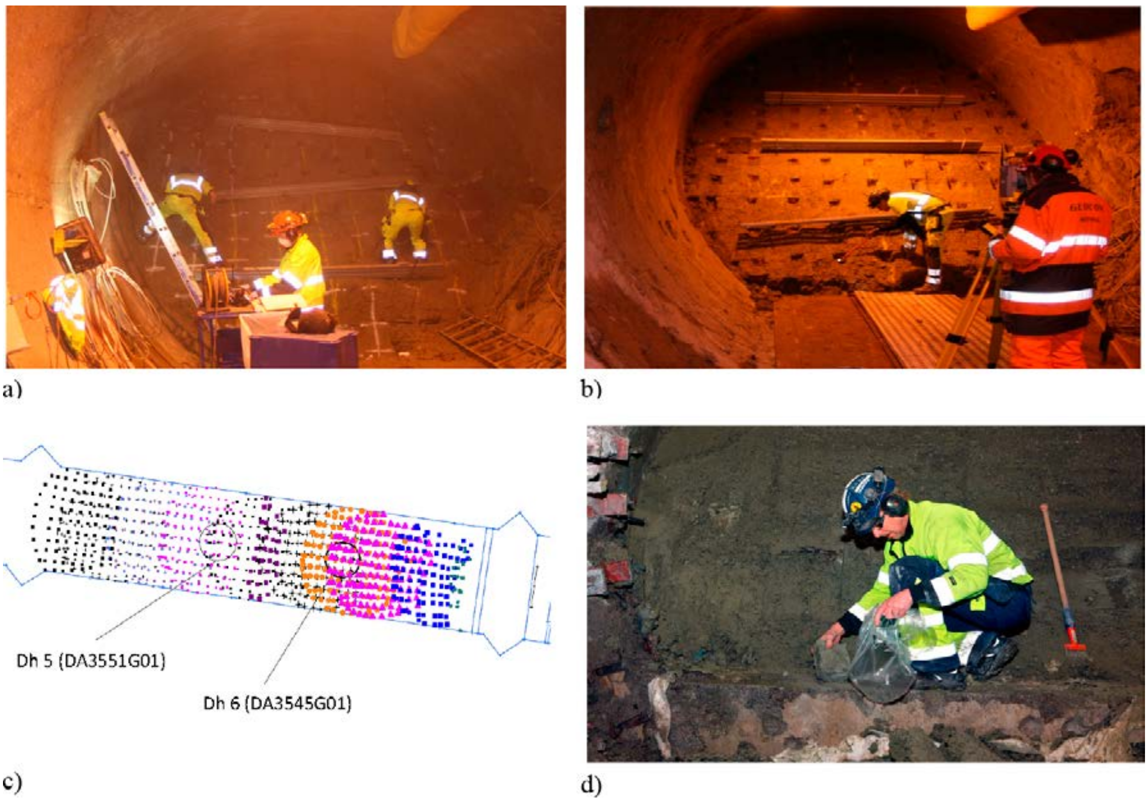


Figure 3-3. *a) Sampling of the backfill material. b) Geodetic surveying of the position of the taken samples. c) An example of data from the geodetic surveying. d) The samples were placed in plastic bags before transportation to the laboratory.*

About 85 sensors for measuring of total pressure, pore pressure, temperature and relative humidity had been installed in the backfill. The plan was to retrieve as many as possible of them. Since heavy machines were used at the excavation only a small part of the installed sensors were found and only a few of them were in the condition after retrieval that they could be tested afterwards, see Chapter 7.

Although the priority at the excavation was to remove the backfill as fast as possible and in a safe way, some effort was made to take care of the installed sensors. Of special importance was the small cups installed in the backfill. Totally three out of four installed cups were found. The cups were retrieved with some backfill material in order to secure that the collected water should not run out from the cup. The samples were then analyzed in the laboratory. The results from these analyzes are described in a separate report (Arlinger et al. 2013)

Some of the installed electrodes for measuring the resistivity in the backfill which were installed by GRS, Germany in year 2003 were also retrieved. In connection with this work samples were taken for determining the water content and density of the material close to the electrodes.

Since samples were taken on every second meter of the backfilled tunnel, the total amount of samples became about 1,000 pieces. The coordinate of each of the taken samples were determined by geodetic surveying. The positions of the samples were described in the Äspö 1996 coordinate system and also recalculated according to the local coordinate system described in Figure 3-4. In the local coordinate system the coordinate y starts at the entrance on ground, which means that the tunnel ends at y = 3,599.8 m. The y-axis runs in the centre of the tunnel, which means that the tunnel walls intersect the z and x-axes at +/–2.5 m. The z-coordinate is determined positive upwards and the x-coordinate is determined positive to the right when facing the end of the tunnel. The coordinates were used at the presentation of the density and water content of the material. Examples of data from determinations of water content, density and degree of saturation are shown in Figure 3-5.

The backfill material placed inside the two deposition holes above the last installed buffer block in each of the deposition holes were excavated by hand, after the material was loosened with a pneumatic hammer. Some samples were also taken from this part of the tunnel backfill on which the water content and the density were measured, see Figure 3-6.

The data from the measurements of the density and water content of the backfill are presented in detail in a separate report (Johannesson 2013).

Beside the samples taken for determining the water content and density samples also were taken close to the inner concrete plug on which chemical and mineralogical examinations were made. These tests are described in Olsson et al. (2013).

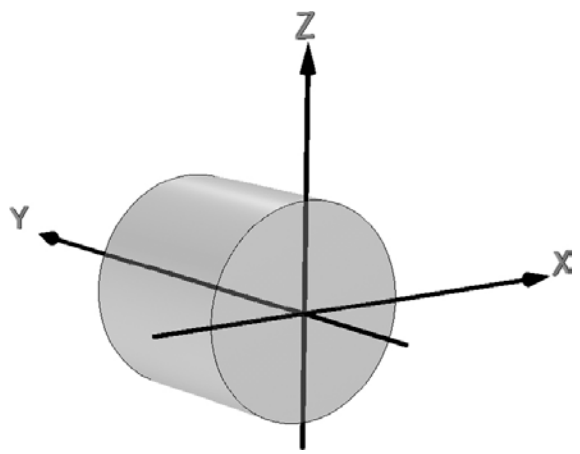


Figure 3-4. *The local coordinate system of the tunnel.*

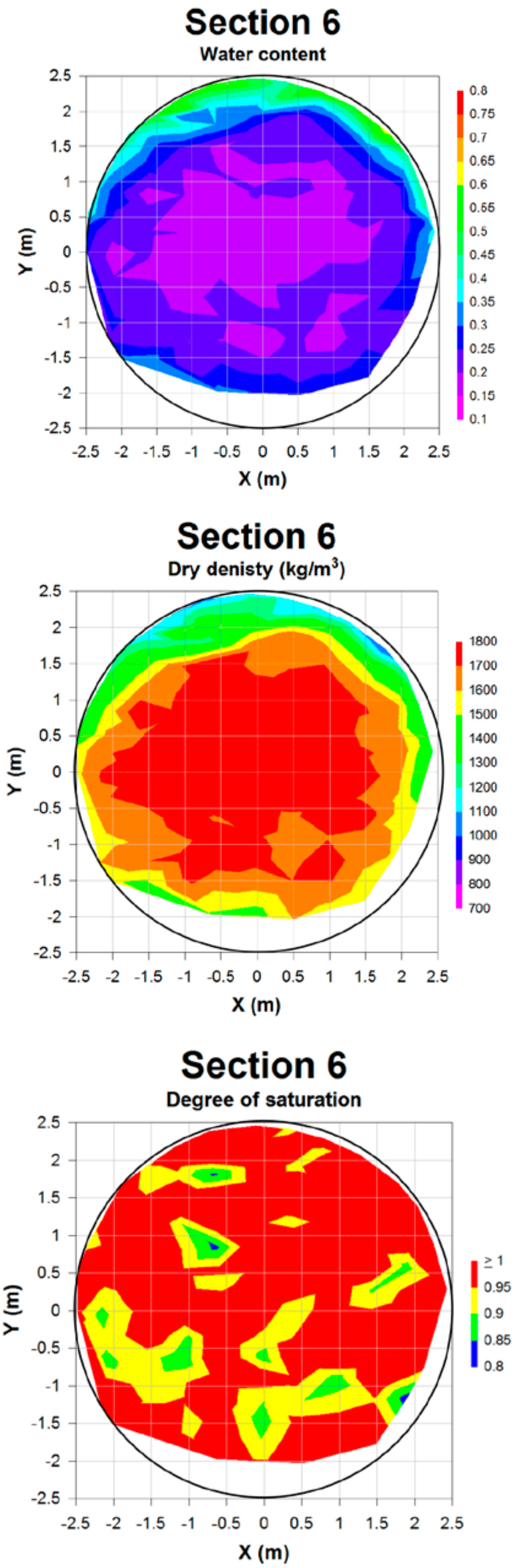


***Figure 3-5.** Examples of data from the determinations of water content, density and degree of saturation on samples taken from section No 6 of the backfill (from Johannesson 2013).*

Figure 3-6. *Samples taken from the tunnel backfill inside a deposition hole together with an installed sensor.*

4 Excavation of the buffer in deposition hole 6

4.1 Introduction

The buffer in the deposition holes consisted of altogether 14 bentonite blocks, one solid block at the bottom (Block C1), 10 ring shaped blocks around the canister (Block R1–R10) and 3 solid blocks on top of the canister (Block C2–C4). Furthermore the outer slot between the blocks and the wall of the deposition hole was filled with pellets of bentonite. In Table 4-1 are the initial conditions of the buffer (at the installation) summarized. The diameter of the deposition hole was in average 1,760 mm and the diameter of the blocks varied between 1,630 (at the top of the block) and 1,750 mm (at the bottom of the blocks) resulting in an average outer slot to the rock of about 60 mm. Furthermore the ring shaped blocks had an inner diameter of 1,070 mm. After the installation of the canister with an outer diameter of 1,050 mm, an inner slot of about 10 mm between the buffer blocks and the canister was created. The blocks had a height of about 500 mm at the installation.

The highly compacted ring-shaped bentonite blocks were, after installation, surrounding the canister. The rings had a total height larger than the length of the canister. The resulting volume between the top of the canister and the top of the last ring was filled with small bentonite blocks (bricks with the dimensions 233 × 114 × 65 mm^3). The height of the volume filled with small bentonite blocks was about 185 mm. In order to have the same density at saturation at the top of the canister as the rest of the buffer, the bulk density of the volume filled with bricks had to be about 1,950 kg/m^3. The bricks were made of MX-80 bentonite with a water content of 17%. Each block had a dry density of 1,700 kg/m^3.

The average density at saturation of the buffer can be calculated from the installed blocks and pellets assuming no axial swelling of the buffer at three sections i.e. underneath and above the canister (solid blocks), just above the lid of the canister (where bricks of bentonite and a ring shaped block were placed) and between the canister and the rock (ring shaped blocks) to 2,034 kg/m^3, 2,067kg/m^3 and 2,012 kg/m^3 respectively (Johannesson et al. 2004).

4.2 Methods

The main objectives of the excavation of the buffer was beside to empty the deposition hole also to get samples for determining the density and water content and for other laboratory examinations of the bentonite. The method to sample and portion the bentonite can be described in the following order:

- Holes were drilled in eight directions with the purpose to get samples for determining the density and water content of the buffer. The drilling was made with core drilling machines standing over the deposition hole on the level of the tunnel floor, see Figure 4-1a and b.
- Additional core drilled holes were made with the purpose to get larger samples of the buffer for tests in the lab, see Figure 4-2b and c. Furthermore smaller samples were taken close to the rock surface and the canister for determining the water content and density, Figure 4-2c.
- After the cores were drilled, larger parts were mechanically loosened and removed from the deposition hole. These parts of the buffer were easy to loosen from the upper surface of the block underneath.

Table 4-1. Determined parameters for blocks used in Prototype Repository Section II.

Block type	Water content (%)	Bulk density (kg/m^3)	Degree of saturation	Dry density (kg/m^3)
Ring	17.3	2,075	0.841	1,770
Cylinder	17.4	2,012	0.778	1,710
Pellets	~13	~1,200	0.223	1,060

Figure 4-1. a) The core drilling machines standing on the tunnel floor. b) Holes from cores taken from a buffer block. Wooden templates were used to position the drill bit.

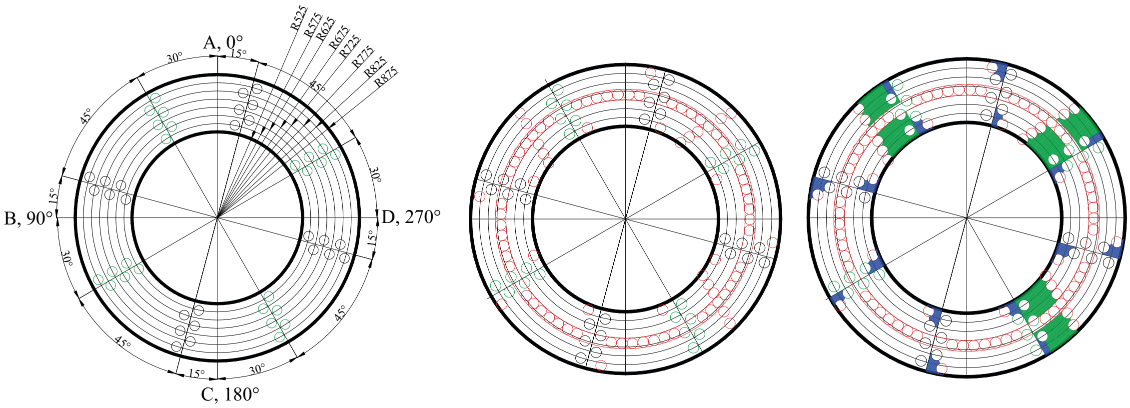


Figure 4-2. a) The cores taken for determination of the density and water content of the buffer. b) The extra cores (red) drilled for loosen the buffer inside the deposition hole. c) The large samples (green) taken from the buffer for further examinations in the lab and the samples (blue) taken for determine the water content and density close to the canister and the rock.

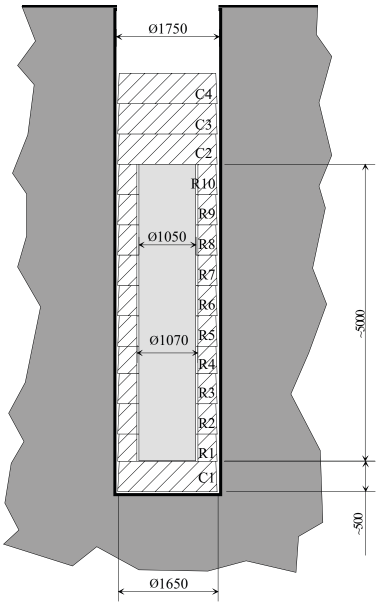
All the samples taken from the buffer blocks were wrapped in foils, deflated and labelled before transport to the Geo-laboratory on the surface. The rest of the bentonite was transported up to the ground surface in containers and further to the municipal landfill where it was used for water-proofing purpose.

4.3 Removal of the buffer

The designation of the bentonite blocks and the coordinate system used for describing the position of the taken samples are shown in Figure 4-3. With the *z*-axis starting from the cement casting in the bottom of the deposition hole and the angle α counted anti-clockwise from direction towards the end of the drift. The denomination of the taken samples was according to the following example:

Dh5:R6:165:575:A where

Dh5	material from Prototype Repository deposition hole 5.
R6	block number (R for ring-shaped blocks, C for massive cylinders).
165	azimuth direction (degrees).
575	radial distance in millimetres from the centre of the canister.
A	vertical level in the block (A at the top, E at the bottom).



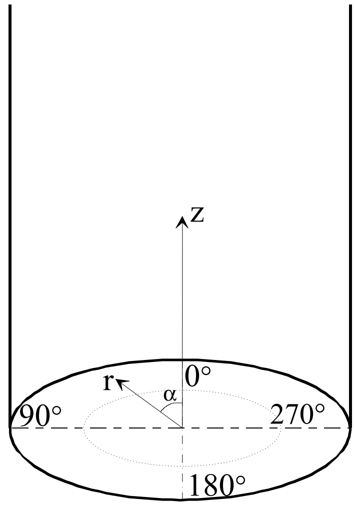


Figure 4-3. *a) The designation of the bentonite blocks and b) the coordinate system used when describing the positions of the taken samples. 0° is the direction towards the end of the drift and 270° is the direction almost to the north.*

The heaters to the canister were switched of the 16th of February 2011 and the sampling of the buffer was made during the period April–July 2011. Whenever the work with removal of the buffer was stopped a plastic sheet was placed on the top of the buffer to minimize the desiccation. No other steps were made for changing the environment at the sampling i.e. the temperature or the relative humidity. The number of samples taken from the blocks in deposition hole 6 are listed In Table 4-2. In Appendix 1 some pictures from the core drilling of the bentonite blocks are shown. From the cores and from the samples taken close to the canister and the rock surface in the deposition holes, smaller samples were taken on which the water content and the density of the buffer material were determined. The large sectors were saved for further laboratory examinations. Totally about 3,500 determinations of water content and density of the buffer were made on the buffer in this hole. The data from these determinations are reported in a separate report (Johannesson 2013). An example form this data is shown in Figure 4-4. About 22 tons of bentonite was removed from the deposition hole. The sampling and removal of one block took about 2 days in average for three workers.

Table 4-2. Number of samples taken from the buffer in deposition hole 6.

Block No	Cores	Samples close to the canister/rock surface	Large sections
C1	103	8	3
C2	115	8	3
C3	112	6	3
C4	111	7	3
R1	40	16	3
R2	40	16	3
R3	40	16	3
R4	40	16	3
R5	40	16	3
R6	40	16	3
R7	40	16	3
R8	39	16	3
R9	40	16	3
R10	40	6	3

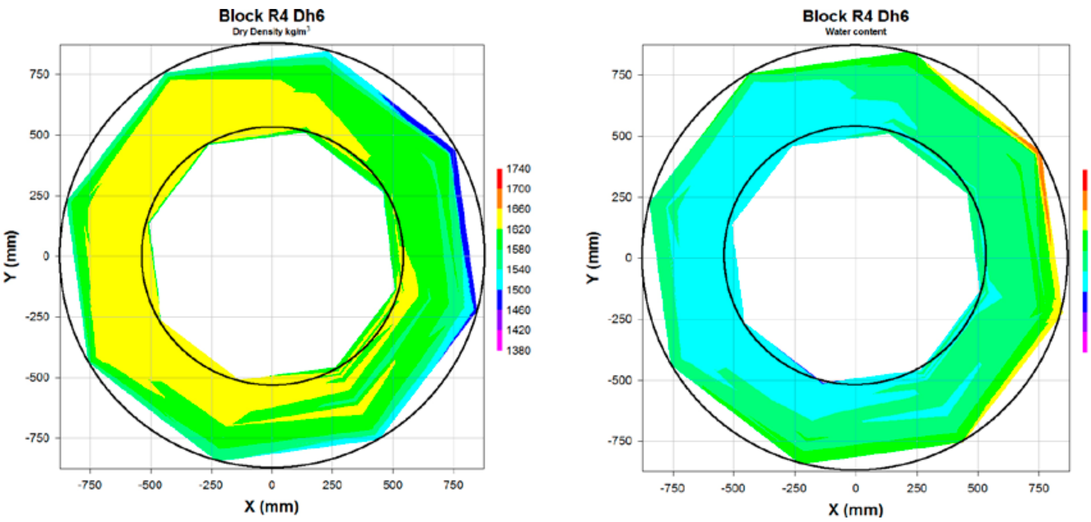


Figure 4-4. *Examples of data from the determination of water content and density on the samples taken of the buffer in deposition hole 6 (from Johannesson 2013).*

4.4 Measurement of block surfaces and canister level

When the buffer in the deposition hole will get access to water or moisture a swelling pressure will be developed. This swelling pressure will act on the surrounding wall of the deposition hole, on the surfaces of the canister and on the backfill on top of the upper bentonite block, see Figure 1-1. This might cause displacements of the canister and the buffer blocks. An upward displacement of the buffer blocks will result in a decrease in the density of the buffer and must therefore be limited. The displacement of the buffer blocks is, beside the magnitude of the developed swelling pressure, also a function of the stiffness of the backfill and the friction between the buffer and backfill, and the wall of the deposition hole. It was important to be able to measure the displacement of the buffer at the retrieval.

At the installation the level of the blocks were determined by geodetic surveying. This was made on at least four positions on each of the installed blocks. Corresponding measurements at the retrieval was also made. The results from the measurements are shown in Figure 4-5 and Figure 4-6. Although the variation in height of the individual block is large, especially at the retrieval where a variation of up to 20 mm were defined, the average displacement of the blocks are large especially for those blocks at the upper part of the buffer. Figure 4-5 is also indicating that the deformations of the blocks at mid height of the canister are very small compared to the deformations of the solid blocks above and underneath the canister.

The level of the canister lid was measured in five positions with small deviances between the measurements. The measurements are showing that the canister has moved upwards with about 23 mm after the installation. Furthermore the measurements are showing that the lid has a horizontal position which indicates that no tilting of the canister has occurred during the saturation phase.

4.5 Retrieval of the canister

As soon as the removal of the buffer has reached the level of the top of the canister, the upper lid was lifted up, see Figure 4-7 and the mixture of sand and bentonite which was placed between the upper and lower lid of the canister in order to protect the cables coming from the heaters was removed, see Figure 4-7. The cables coming from the heaters installed in the canister were at this stage taken care of for inspections. Large damages on the cables were found at outer diameter of the canister which probably was caused by the swelling pressure from the bentonite bending the cables towards the canister lid, see Figure 4-8a. Damages on the cables were also found at the position were the cables are led through the canister lid, see Figure 4-8b.

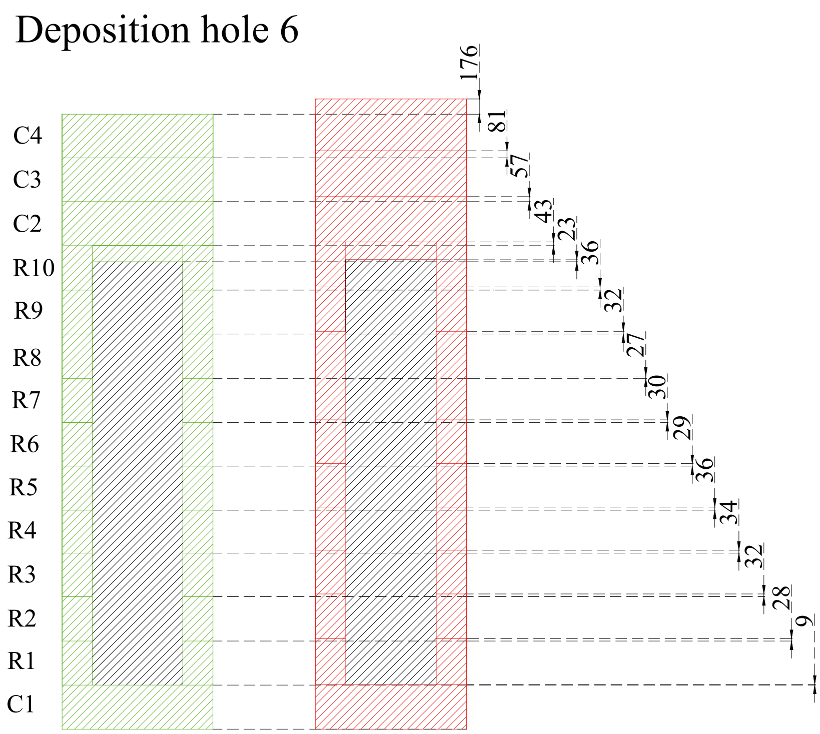


Figure 4-5. *The relative displacement of the upper surface of the blocks in deposition hole 6 at the excavation (red) compared to the position at the installation (green) in mm.*

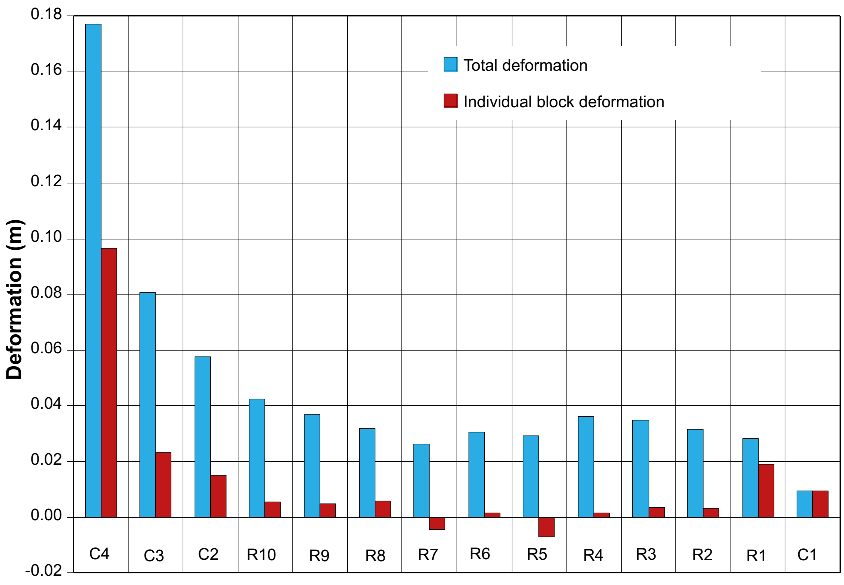


Figure 4-6. *The measured deformation of the individual blocks (red) together with the accumulated deformation (blue) for the 14 installed bentonite blocks in deposition hole 6.*

At the planning of the retrieval operation, it was found out that the risk of hydrogen production inside the canister could not be excluded in this experiment set up and in order to minimize the risk of an explosion it was decided that the canister should be ventilated before the retrieval of the buffer and canister could continue. Ventilation and gas sampling of the canister are described in detail in Section 4.5.1. After this, buffer sampling and removal continued down to the level of the bottom block, block C1, on which the canister was standing. At that stage the canister was lifted up from the deposition hole and transported out from the tunnel. This activity is described in Section 4.5.2.

a) b)

Figure 4-7. *a) The upper lid removed from the canister. b) The mixture of bentonite and sand removed from the lower canister lid.*

a) b)

Figure 4-8. *a) Damages observed at a) close to the periphery of the canister and b) where the cables are going through the lower canister lid.*

4.5.1 Gas sampling of the canister

At the retrieval of the canister in the Canister Retrieval Test (Eng 2008) which was installed with the same type of canister and heating elements inside the canister as for the canisters in the Prototype Repository it was pointed out that there might be a risk of an explosive mixture of hydrogen and oxygen inside the canister. The hypotheses are that hydrogen can be produced from corrosion of the iron inside the canister and that the corrosion is caused by water from the atmosphere inside the canister, from the installed heaters and the cabling. In order to minimize the risk of explosion, it was decided to change the atmosphere inside of the canister before the retrieval could continue. The canister is a completely sealed cylinder and no valves or other devices are installed for facilitating ventilation or gas sampling. One way to be able to ventilate the canister is to drill a hole and mount a valve in a pressurized container without leakages is by the use of a "hot tap" device, see Figure 4-9. This type of device is used when installing valves in gas or gasoline pipes without the need to stop the flow inside the pipe. It consists of a pipe with a valve. The pipe is attached and sealed to the lid of the canister with a threaded hole. This hole is not penetrating through the lid of the canister. The drill is then inserted in the pipe and the final drilling through the lid is made. Inside the pipe and above the valve there are o-rings which seal the drill. Once the drill has penetrated the lid it is pulled above the valve -but not above the o-rings and the valve is closed. The o-rings maintain a seal between the drill and the pipe of the device during the drilling. After the valve is closed the drill can be removed. The drilling inside the pipe, the pulling of the drill and the closing of the valve are activities made remotely by equipment powered by compressed air in order to minimize the risks and the damages of a possible explosion.

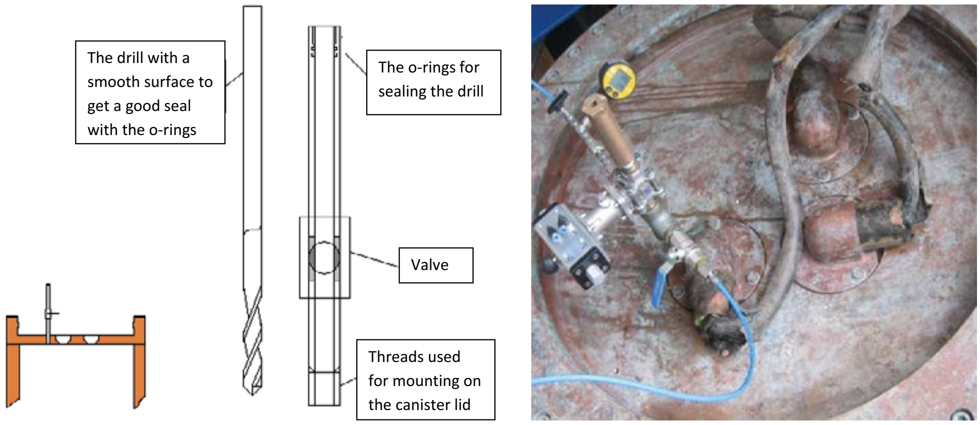


Figure 4-9. *A schematic drawing and a photo of a "hot tap" device.*

Once the "hot-tap" device was in place the sampling of the gas inside the canister started. Although no direct measurement of the pressure could be made it was obvious that the pressure inside the canister was below atmospheric pressure. The first samples were taken by applying a vessel with vacuum to the valve. The samples (totally 4) were analyzed by Micans in Gothenburg and the results are shown in Table 4-3 (No 1-4). The results show that the samples have similar composition as for the air in the tunnel which indicates that the used technique was not suitable for taken samples inside the canister when the pressure is below atmospheric pressure. At the next attempt, a bottle of Argon was applied to the valve on the "hot-tap" device, and the canister was filled with Argon with an over pressure of about 1 bar. After this, new samples of the gas were taken and analyzed by Micans, see Table 4-3 (No 5-8).

Table 4-3. Samples taken of the atmosphere inside the canister in deposition hole 6.

No	Comment	Laboratory	H_2 (%)	O_2 (%)	N_2 (%)	Other gasses (%)
1	Below atm pressure	MICANS	<0.05	19.9	73.4	6.7
2	Below atm pressure	MICANS	<0.05	19.1	73.5	7.3
3	Below atm pressure	MICANS	<0.05	19.0	72.7	8.2
4	Below atm pressure	MICANS	<0.05	19.2	71.4	9.4
5	1 bar pressure Ar	MICANS	1.7	18.2	70.4	9.4
6	1 bar pressure Ar	MICANS	9.6	10.1	53.7	26.6
7	1 bar pressure Ar	MICANS	19.9	1.6	33.6	44.8
8	1 bar pressure Ar	MICANS	19.9	<0.05	33.0	47.1
9	1 bar pressure Ar	OKG	4.3	3.0	–	–
10	1 bar pressure Ar	OKG	5.5	1.6	–	–
11	1 bar pressure Ar	OKG	5.9	0.6	–	–
12	After filled 7 times with N2	OKG	2.7	0.2	–	–
13	After filled 7 times with N2	OKG	3.1	0.1	–	–
14	After filled 7 times with N2	OKG	3.7	0.4	–	–
15	After filled 7 times with N2	MICANS	7.7	3.2	52.8	36.3
16	After filled 11 times with N2	OKG	2.98	0.37	–	–
17	After filled 11 times with N2	OKG	2.98	0.30	–	–
18	After filled 11 times with N2	OKG	2.66	0.76	–	–

The first taken samples are assumed to be affected by the gas trapped in the "hot-tap" device while the next two analyzes are indicating about 20% hydrogen, about 33% nitrogen and 45% not analyzed gas, probably Argon. Samples from the gas inside the canister were also analysed by a laboratory at the nuclear power plant in Oskarshamn (OKG). The results from these analyses are different compared to the results from Micans, see Table 4-3 (No 9-11). After this, the canister was ventilated by filling the canister with nitrogen with an overpressure of about 1 bar and then allowed the gas to flow out from the canister. This was repeated seven times. At the last ventilation the canister was left with an over pressure of 1 bar over the night and thereafter new samples were taken and analyzed by OKG (No 12–14) and by Micans (No 15). These analyses show that both the content of hydrogen and oxygen has decrease significantly after the ventilation. Additional four ventilations were made and at the last ventilation the canister was kept with an overpressure of 1 bar of nitrogen over the weekend and then the final analyses of the gas content was made (No 16–18). The results show similar values as for the samples taken before the last four ventilations. The assessment after the last ventilation was that gas mixture inside the canister could not ignite spontaneously and thus the excavation of the buffer could continue after the hole for the "hot-tap" device was plugged.

4.5.2 Raising of the canister

The canister was removed with the same device which was used at the installation of the test, i.e. a deposition machine prototype which was developed for the large scale tests at Äspö.

The deposition machine, lying on a trailer, was placed over the deposition hole by a truck. Small adjustments of the trailer were made in order to get the deposition machine over the deposition hole. The deposition machine was then lifted vertically, with the adjustable legs and the trailer was moved out from the tunnel. The deposition machine was leveled and the sidewalks on the machine were mounted. The frame of the deposition machine was placed in a vertical position and a lifting plate with two large chains was attached to the lid of the canister. The chains were used for lifting the canister up from the deposition hole. The work was done in the following steps, see Figure 4-10:

- The canister was lifted in a vertical position up from the deposition hole and placed horizontally on the deposition machine by tilting the canister and at the same time move the frame both in horizontal and vertical direction.
- The sidewalks on the sides were removed and the transport locking devices were put in place.
- A trailer was placed under the deposition-machine and then pulled out from the tunnel.

Figure 4-10. *a) The canister lifted vertically up from the deposition hole. b) The canister tilted horizontally. c) The canister placed on the deposition machine. d) The deposition machine with the canister placed on a trailer.*

5 Excavation of the buffer in deposition hole 5

5.1 Introduction

The buffer in deposition hole 5 is similar to the one in deposition hole 6 and this is described in detail in Section 4.1. In addition, this deposition hole was equipped with three large copper electrodes used for estimating the copper corrosion rate, which were installed in the top bentonite block (Block C4). The positions of the electrodes are shown in Figure 5-1.

The average density at saturation of the buffer in deposition hole 5 can be calculated from the installed blocks and pellets assuming no axial swelling of the buffer at three sections i.e. underneath and above the canister, just above the lid of the canister (where the bricks of bentonite were placed) and between the canister and the rock to 2,039 kg/m^3, 2,053kg/m^3 and 2,017 kg/m^3 respectively (Johannesson et al. 2004).

5.2 Methods

The method used for the excavation of this deposition hole is described in Section 4.2 which basically states that samples are taken by core drilling and the large sample pieces were loosened by stitch drilling. In addition, a copper/bentonite interface sample was taken at the canister top by the use of a saber saw and clamps.

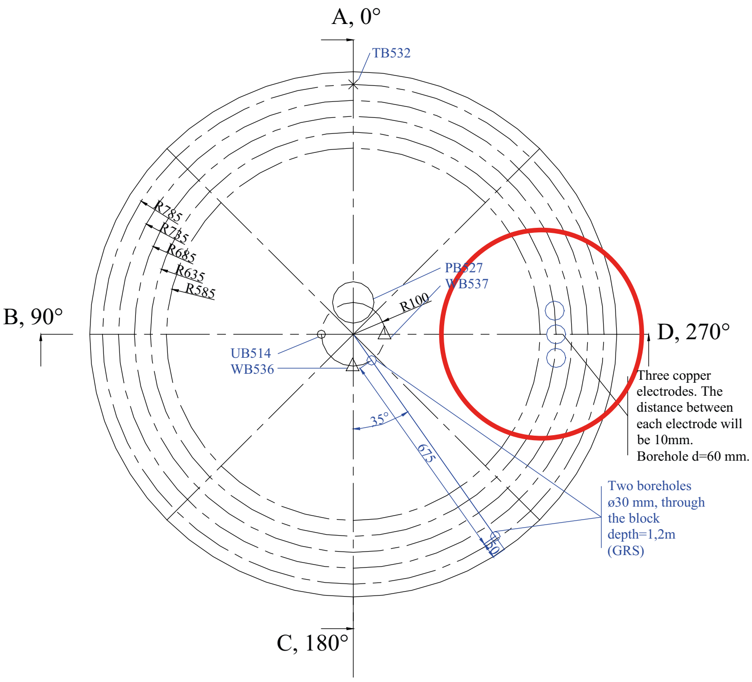


Figure 5-1. The position of the copper electrodes installed in block C4 in deposition hole 5.

5.3 Removal of the buffer

The heaters to the canister were switched of the 15th of July 2011 and the sampling of the buffer was made during the period September–December 2011. Whenever the work with removal of the buffer was stopped a plastic sheet was placed on the top of the buffer to minimize the desiccation. No other steps were made for changing the environment at the sampling i.e. the temperature or the relative humidity. All the samples taken from the blocks in deposition hole 5 are listed In Table 5-1. In Appendix 2 some pictures from the core drilling of the bentonite blocks are shown. From the cores and from the samples taken close to the canister and the rock surface in the deposition holes, smaller samples were taken on which the water content and the density of the buffer material were determined. The large sectors were saved for further laboratory examinations. Totally about 3,500 determinations of water content and density of the buffer were made on the buffer in this hole. The data from these determinations are reported in a separate report (Johannesson 2013). About 22 tons of bentonite was removed from the deposition hole. The sampling and removal of one block took about 2 days in average for three workers.

5.4 Removal of the copper electrodes in block C4

The three copper electrodes which were installed in the top block in deposition hole 5 was retrieved by the use of stitch drilling, see Figure 5-2. After the drilling the piece was mechanically released from the rest of the block and lifted up from the deposition hole. The copper electrodes together with the bentonite were then wrapped in a foil and transported to the laboratory for further examinations of both the bentonite and the copper electrodes.

5.5 Measurement of block surfaces and canister level

At the installation the level of the blocks were determined by geodetic surveying in the same way as for buffer in deposition hole 6, see Section 4.4. This was made on at least four positions on each of the installed blocks. Corresponding measurements at the retrieval was also made. The results from the measurements are shown in Figure 5-3 and Figure 5-4. Although the variation in height of the individual block is large, especially at the retrieval where a variation of up to 20 mm were defined, the average displacement of the blocks are large especially for those blocks at the upper part of the buffer. Figure 5-4 is also indicating that the deformations of the blocks at mid height of the canister are very small compared to the deformations of the solid blocks above and underneath the canister.

Table 5-1. Number of samples taken from the buffer in deposition hole 5.

Block No	Cores	Samples close to the canister/rock surface	Large sections
C1	120	8	3
C2	117	8	3
C3	110	8	3
C4	96	8	3
R1	40	16	3
R2	40	16	3
R3	40	16	3
R4	40	16	3
R5	40	16	3
R6	40	16	3
R7	40	16	3
R8	40	15	3
R9	40	16	3
R10	40	0	–

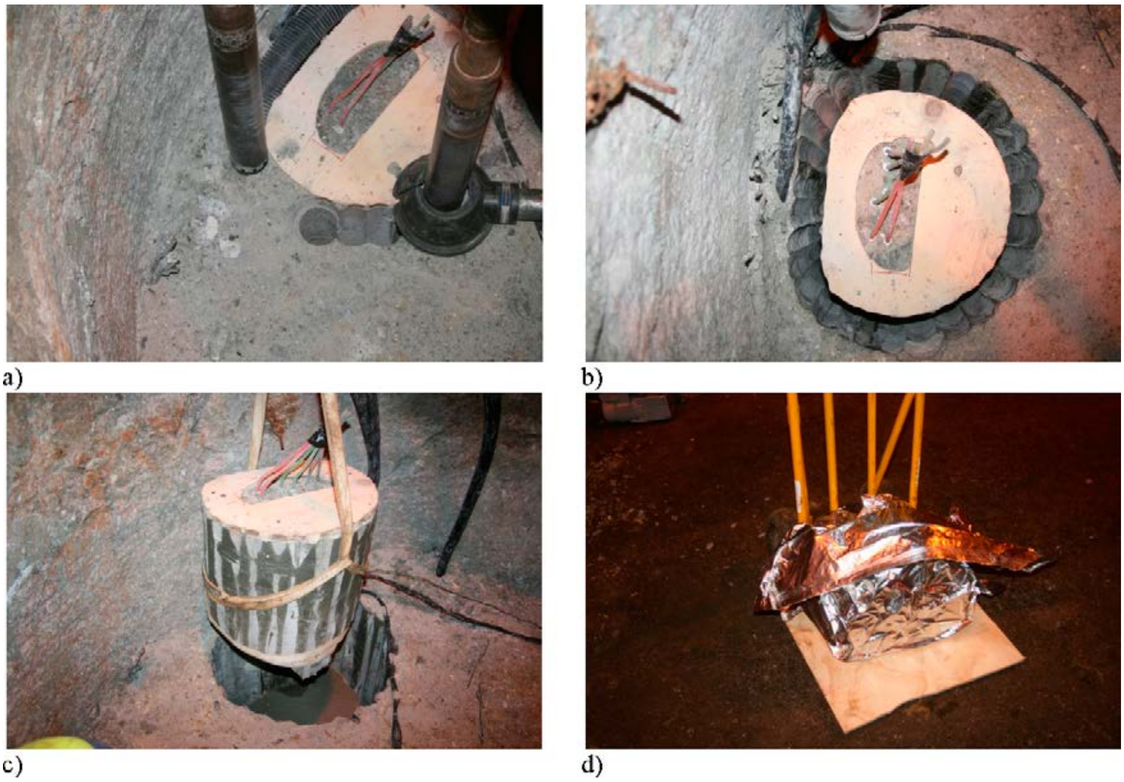


Figure 5-2. *The removal of the copper electrodes installed in block C4 in deposition hole 5. a) The core used for the drilling. b) The stitch drilling around the electrodes. c) The electrodes together with the bentonite lifted up from the deposition hole. d) The bentonite and the electrodes wrapped in plastic.*

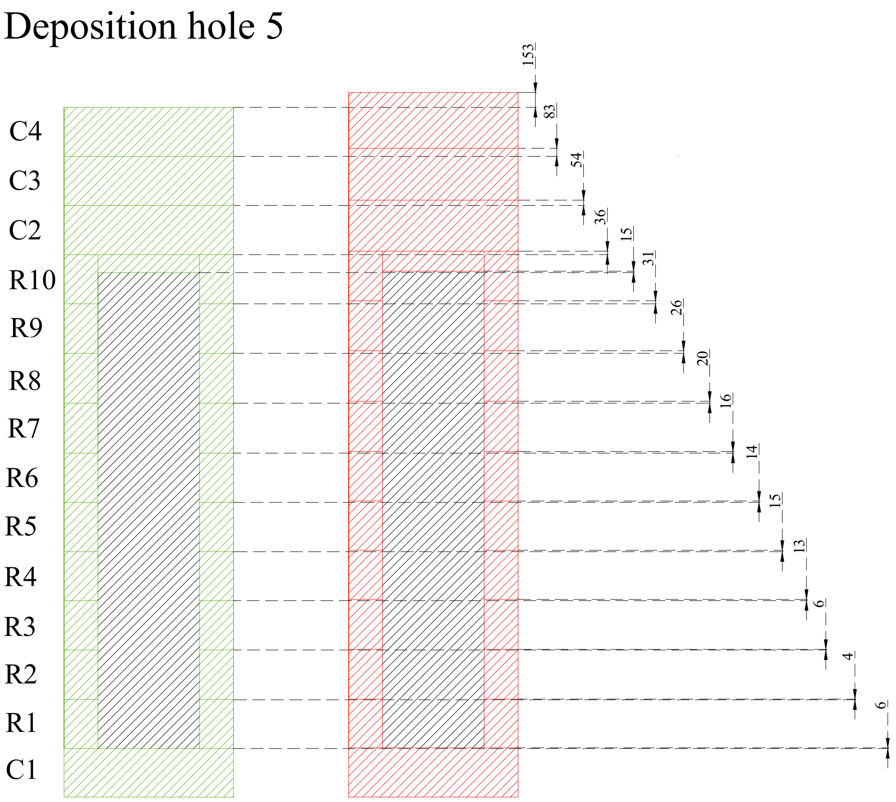


Figure 5-3. *The relative displacement of the upper surface of the blocks in deposition hole 5 at the excavation (red) compared to the position at the installation (green) in mm.*

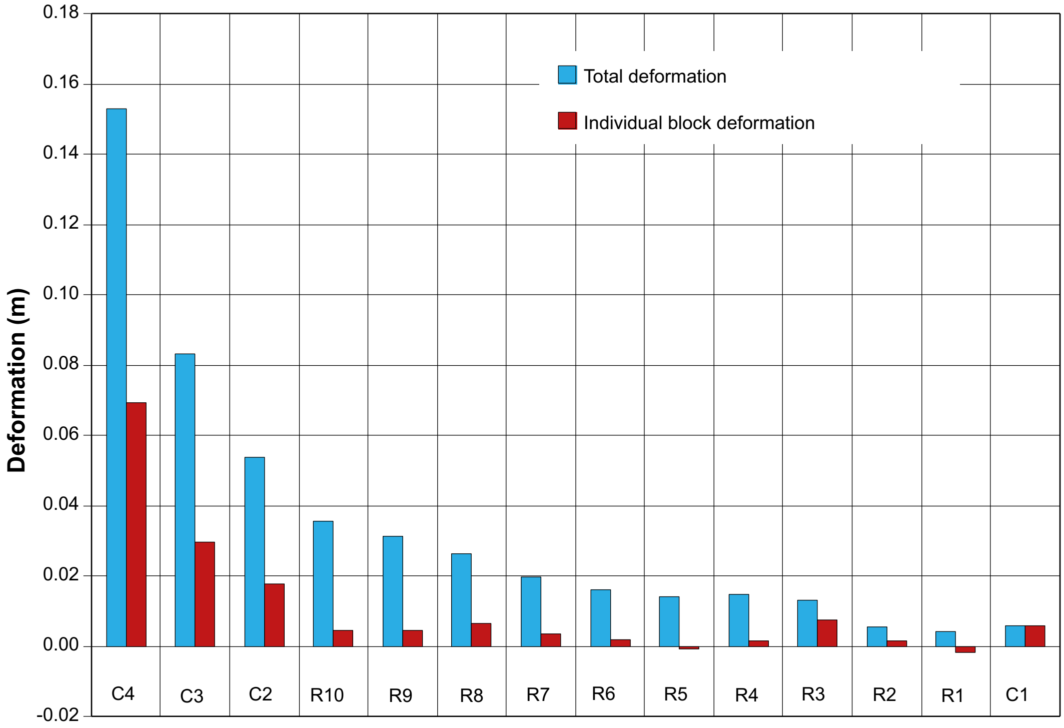


Figure 5-4. *The measured deformation of the individual blocks (red) together with the accumulated deformation (blue) for the 14 installed bentonite blocks in deposition hole 5.*

The level of the canister lid was measured in five positions with no variation between the measurements. The measurements are showing that the canister has moved upwards with about 15 mm after the installation. Furthermore the measurements are showing that the lid has a horizontal position which indicates that no tilting of the canister has occurred during the saturation phase.

Before the backfill inside the deposition hole above the top block was excavated, a hole at the centre of the deposition hole was drilled towards the surface of a sensor for measuring pressure installed at the top of the upper block. This hole was used for measuring of any movements of the upper surface of the buffer during the excavation of the backfill. The excavation of the backfill down to buffer level was finalized after about 52 hours. During this period no deformation was observed of the upper surface of the buffer. This is indicating that the observed upward swelling of the buffer, see Figure 5-4, did not occur at the retrieval and thus is an effect of the water uptake of the buffer.

5.6 Retrieval of the canister

The retrieval of the canister in deposition hole 5 is in principal made in the same way as for the canister in deposition hole 6, see Section 4.5. Also for this deposition hole, samples were taken of the atmosphere inside the canister. This was made with the same type of equipment used for the canister in deposition hole 6, see Section 4.5.1

5.6.1 Gas sampling of the canister

Once the "hot-tap" device was on place the sampling of the gas inside the canister started. The gas pressure inside the canister was measured to about 0.16 bar. The first samples were taken by applying a vessel with vacuum to the valve. The samples (totally 3) were analyzed by Micans in Gothenburg and the results are shown in Table 5-2 (No 1–3). The results show that the major gas inside the canister was Nitrogen with a small amount of Argon. The gas inside the canister was then evacuated and the filled with Nitrogen to a pressure of about 1.5 bar. This was repeated three times and after that, new samples of the gas inside the canister were taken and analyzed. The results from

Table 5-2. Samples taken of the atmosphere inside the canister in deposition hole 5.

No	Comment	Laboratory	N_2 (%)	Ar (%)	H_2 (%)	O_2 (%)	CO_2 (%)
1	0.16 bar pressure	MICANS	95.2	2.2	<0.05	<0.05	<0.1
2	0.16 bar pressure	MICANS	98.8	2.7	<0.05	<0.05	<0.1
3	0.16 bar pressure	MICANS	96.0	2.7	<0.05	<0.05	0.1
4	0.08 bar pressure	MICANS	95.8	3.0	<0.05	<0.05	0.1
5	0.08 bar pressure	MICANS	96.9	3.0	<0.05	<0.05	0.1
6	Broken vessel at delivery	MICANS	–	–	–	–	–
7	0.3 bar pressure	MICANS	100	<1.0	0	<0.1	<0.05
8	0.3 bar pressure	MICANS	97.3	<1.0	0	<0.2	<0.05

the analyzes are shown in Table 5-2 (No 4–5). Vessel No 6 was broken at the delivery to Micans and thus no results were received from this sample. The results are similar to the previous made analyzes i.e. the dominating gas was Nitrogen. After another evacuation and a subsequent filling of Nitrogen, new samples were taken and analyzed (No 7–8). The results show that the gas inside the canister was to almost 100% consisting of Nitrogen. These analyzes indicate that the canister was filled with Nitrogen after the installation of the heaters but before the lid was attached. This has however not been reported in a proper way and was unknown to people involved with retrieval of the canister. Analyzes of the gas with focus on the content of hydrogen was also made by OKG at different stages of the ventilation. These analyses show very little content of hydrogen (less than 0.6%).

When the results from these gas analyses are compared with the analyses made on the gas inside the canister in deposition hole 6 (c.f. Section 4.5.1) it is obvious that the gas compositions are different. The most likely reason for this is that the gas inside the canister in deposition hole 6 was not changed at the installation of the heaters which probably was the case for the canister in deposition hole 5. The large amount of hydrogen found in the canister for deposition hole 6 is probably originating from corrosion of the canister cast iron insert.

The excavation of the buffer inside deposition hole 5 continued after the hole for the "hot-tap" device was plugged.

5.6.2 Sampling of the copper at canister lid

At the planning of the retrieval of the Prototype Repository it was decided not to include any sampling of the copper canister. However during the operation, requests on samples of the copper which had not been exposed to the air in the deposition hole were raised. In order to fulfill these demands it was decided to take samples of the top of the canister together with some bentonite. The idea was that the bentonite should protect the surface of the copper from being exposed to oxygen. The upper part of the canister consists of one lower and one upper lid separated by a copper ring with a height of 5 cm and a thickness of 5 cm. It was decided that the samples of copper and bentonite should be taken of that copper ring. The samples were taken in the following way, see Figure 5-5:

- The bentonite blocks C4–C2 were removed.
- Most of the block R10 was removed. Some part of the bentonite was left close to the canister surface.
- The upper lid was removed
- A part of the copper ring together with the left bentonite was cut out with the use of a saber saw

Photos from the sampling are shown in Figure 5-6.Beside the samples of bentonite/copper also some additional samples of the copper ring were taken. The samples were wrapped in foils and transported to the laboratory where both the copper and the bentonite were further investigated. The results from the analyses of the bentonite are reported in Olsson et al. (2013). The analyses of the copper will be reported in a separate project.

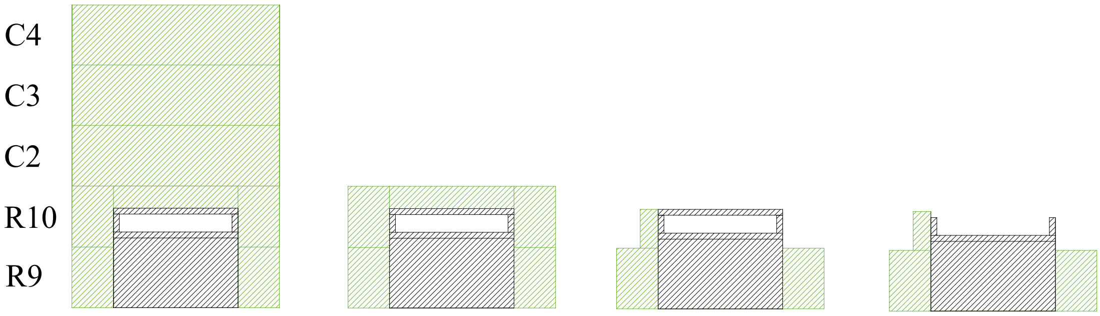


Figure 5-5. *A schematic drawing of the procedure for taking the samples of the copper in the canister.*

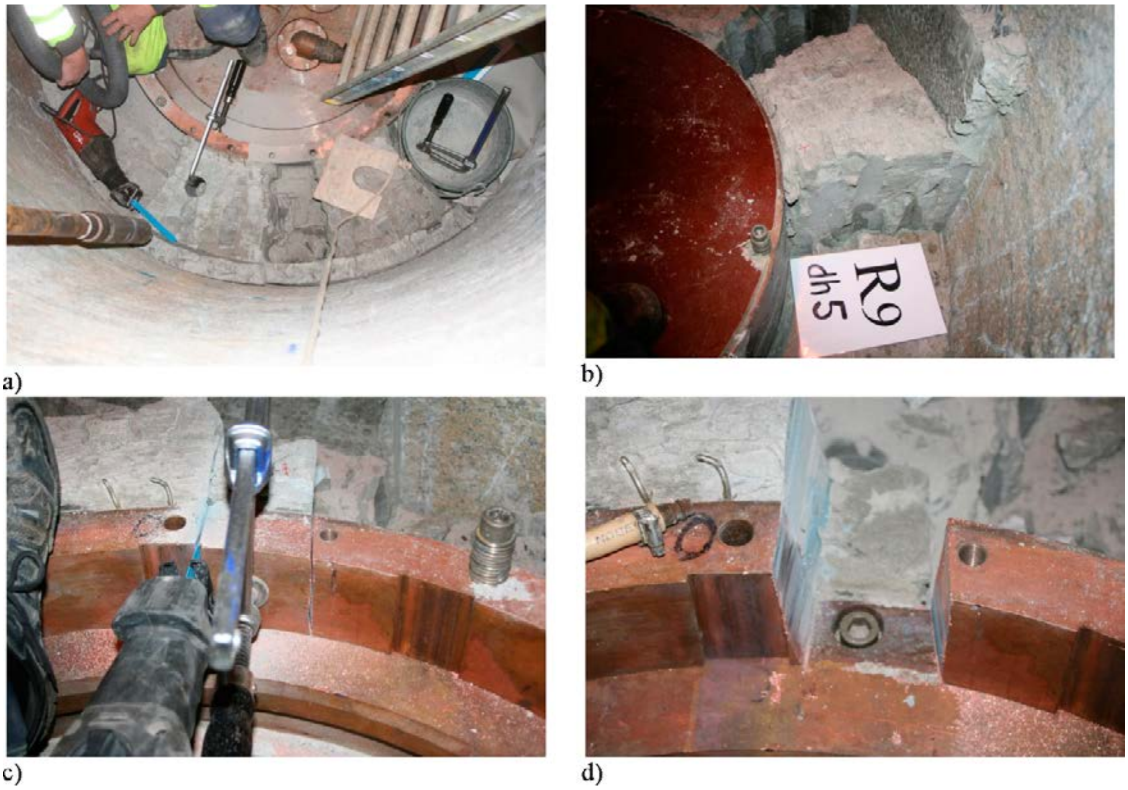


Figure 5-6. *The sample taken of the canister in deposition hole 5. a) The saved part of the buffer seen from above. b) The saved part of the buffer seen from the side. c) The sawing of the copper ring. d) The copper ring after the sample was taken.*

6 Samples from dismantling

Samples were taken both from the backfill and the buffer as described in the Chapter 3 for the backfill and in Chapter 4 for the buffer. A system for denoting the samples from the buffer in the two deposition holes was used, which is described in Section 4.3. The samples were wrapped in foils as fast as possible after they were taken from the buffer and backfill. Those samples which were intended for determine water content and density were transported within the same day to the Äspö HRL geo-laboratory on the ground level, see Figure 6-1. At the laboratory smaller samples were prepared, with the use of a band saw, on which the determinations were made, see Figure 6-2 and Figure 6-3. The large amount of samples taken made it possible to get a detail picture of the variation in the water content and density for the buffer, see Figure 6-4. The preparation and the technique for determining the water content and density are described in detail by Johannesson (2013). The rest of the samples were wrapped in foils and stored for any coming examinations.

The samples taken of the buffer for more comprehensive laboratory tests were also wrapped in foils and stored. Three larger samples from each bentonite block in the two deposition holes were taken (see Section 4.3) and from some of these, smaller specimens were taken on which various laboratory tests were made, see Figure 6-5. Hydro-mechanical tests were performed on samples from one radial profile from the warmest part of each of the buffers (deposition hole 5 and deposition hole 6 respectively) and included determinations of hydraulic conductivity, swelling pressure, unconfined compression strength, and shear strength. Chemical-mineralogical analyses were carried out in parallel on four radial profiles from three blocks with variable water content. The analyses included determinations of water-soluble salts, chemical composition, cation exchange capacity, exchangeable cations, and mineralogy. Supplementary, specialized analyses, including determinations of the oxidation state of iron and copper and element mapping, were performed on selected intervals of some blocks. The same tests/analyses were made on reference samples. The technique used for preparing the samples, the different types of examinations and the results from these examinations are in detail described by Olsson et al. (2013).

Figure 6-1. *Samples taken from the buffer and delivered to the laboratory at the ground level.*

__Figure 6-2.__ The band saw used for sawing the samples.

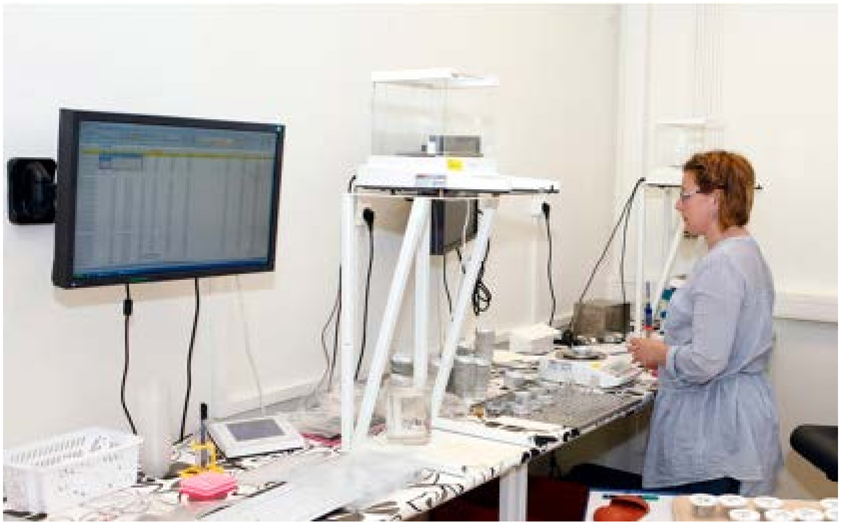


__Figure 6-3.__ The equipment used for determining the density of the samples.

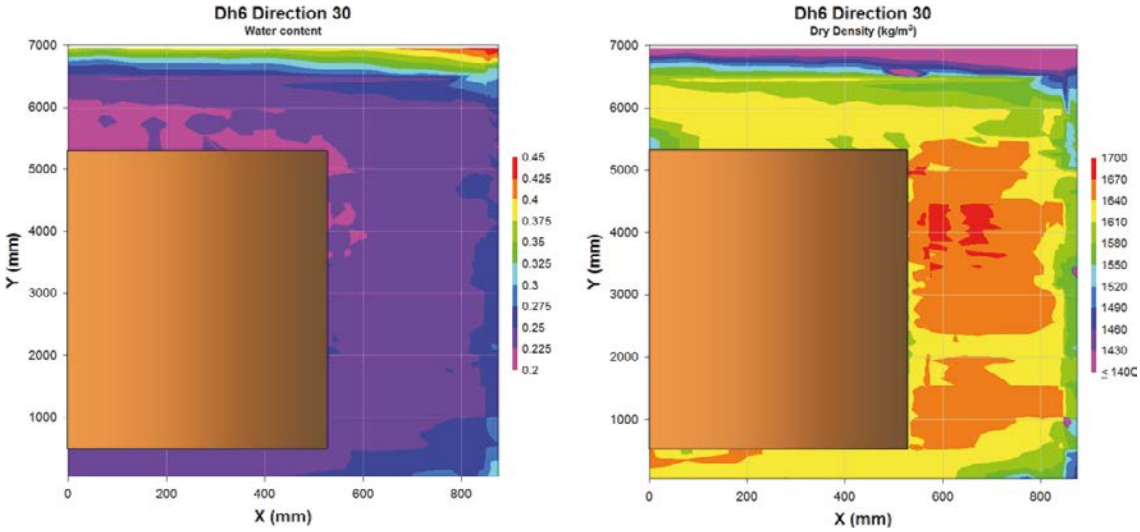


Figure 6-4. *The water content and density of the buffer in deposition hole 6, direction 30° (from Johannesson 2013).*

Figure 6-5. *a) A larger sample taken from the buffer in deposition hole 6. b) A smaller specimen core drilled from the large sample of the buffer.*

The samples taken from the backfill for determining the water content and density were also transported to the Äspö HRL geo-laboratory on the ground level as soon as possible in order to minimize the risk of desiccation. The technique used for the determinations of water content and density and the results from the examinations are described in Johannesson (2013). Beside the samples taken for the determinations of water content and density samples also were taken in a profile at the centre of the tunnel towards the inner concrete plug with the purpose to investigate the interaction between the concrete and the bentonite in the backfill material. Numerous laboratory and field observations have demonstrated that the reactions in concrete might influence the porewater chemistry in the bentonite near a concrete/bentonite interface. Basically, the same chemical and mineralogical parameters were determined for the samples of the tunnel backfill as for the buffer bentonite, see above. The technique used for preparing the samples, the different types of examinations and the results from these examinations are in detail described by Olsson et al. (2013).

7 Collection of sensors

Sensors were placed both in the buffer and the backfill at the installation for measuring temperature, total pressure, pore pressure and relative humidity during the water uptake phase. Sensors were also installed in the surrounding rock for measuring, water pressure, temperature, strains and stresses.

Although the retrieval of the installed sensors in the backfill and the buffer did not have high priority when the project was planned, it was decided that as many as possible of the installed sensors should be retrieved and afterward checked in the laboratory. The reasons for this were mainly two:

- Get feedback and information about which of the installed sensors functioned as planned. This is not least important as input for the planning of instrumentation of upcoming tests. This is important information for the instrumentation planning for upcoming tests.
- Get information if any of the calibration values have changed during the water uptake phase and thus affect the interpretation of the recorded data.

Figure 7-1 shows a picture of an installed sensor at the excavation of the buffer together with the device constructed for validating sensors. In Table 7-1 are the numbers of retrieved and tested sensors from the buffer and the backfill listed. The validation/control of the retrieved sensors is described in detail in a separate report (Nilsson 2013).

The installed sensors in the rock has not been retrieved and thus not been checked.

Table 7-1. Number of retrieved sensors (Nilsson 2013).

Type	Measured parameter	Number installed	Number retrieved	Number validated
Geokon 4800	Total pressure in the buffer	30	23	9
Geokon 4500	Pore pressure in the buffer	12	7	7
Geokon 4850	Total pressure in the backfill	8	7	6
Geokon 4500	Pore pressure in the backfill	15	11	11

a) b)

__Figure 7-1.__ a) A total pressure sensor placed in block C3 in deposition hole 5. b) The vessel filled with water used for validating the total pressure sensors.

8 Summary of practical experiences from the field work

8.1 Introduction

An important input for the planning of the retrieval of the buffer and the backfill was the installation report for the outer section of the Prototype Repository where both the initial condition of the buffer and the backfill and the installed sensors were documented (Johannesson et al. 2004). The accurate planning and organization of the project took more than one year and the work with the dismantling took over one year to finalize. The field work was divided into several activities which were described in detail in separate Activity Plans, see Section 1.3. This way of organizing the work was an important factor to the success with the field work. A continuous follow-up of the field work, on daily basis, made it possible to on very short time adjust the planning of the coming work. Very few staff was involved in the field activities and they took a large responsibility for the work. Furthermore the staff had experience from similar task. Some of them had even been involved at the installation of the test. This contributed to that the field work could be performed both within the budget and on time.

8.2 Experiences from the retrieval of the plug

The work with the dismantling of the plug has overall functioned as planned. The chosen technique, with first core drilling through the plug and then mechanical demolishing of the concrete, functioned well in principal, however a hydraulic breaker, which at the planning of the work was not included, was needed in order to be able to fulfil the work as planned. A perhaps faster and more efficient way of breaching the plug might have been to use careful blasting together with mechanical demolishing. This technique was under consideration but was rejected since there was a requirement that the cables which were led through the plug should be saved and that this could not be ensured with careful blasting of the plug. Another alternative method for breaching the plug was wire-sawing. This method was however considered to be too expensive.

At the planning and installation of a plug it would be wise to prepare it also for a coming tearing by for instance avoid leading cables and tubes through the plug. It might also be possible to prepare the plug for blasting in advance but this differs from the requirements on the reference design.

8.3 Experiences from the excavation of the backfill

The techniques used both for the excavation and samplings of the backfill were working well. By making an extensive sampling and an efficient surveying of the taken samples it was possible to get good picture of the variation in water content and density of the backfill. The way the taken samples were handled e.g. the way they were marked, packed and stored, and the minimizing of the time of storage before the determinations of the water content and density were made, contributed to the good quality of the examination of the backfill material. Some disadvantages were however observed during the work:

1. It was difficult to retrieve all the sensors installed in the backfill, since the excavation was not made with the same inclination as at the installation and thus the sections with installed sensors were cut off at the excavation. Furthermore heavy machines were used and it was impossible to have personnel in front of the machines, for occupational safety reasons. This made it impossible to make a systematic retrieval of the sensors. In order to be able to retrieve more sensors, smaller machines can be used and the excavation should be made in smaller layers with the same inclination as at the installation. This would however extend the schedule for excavation.
2. It was not possible to take samples, for measuring water content and density, close to the floor of the tunnel, mainly due to the chosen inclination of the backfill sample sections. Furthermore water coming in to the tunnel was collected close to the floor and thus made the material wet and not representative.

8.4 Experiences from the excavation of the buffer

The chosen technique for taking samples and excavate the buffer in the deposition hole had been tested in previous retrieved test i.e. CRT and TBT with good results. Even at the excavation of the two deposition holes in the Prototype Repository this technique worked well. At the planning of the excavation of the buffer it was obvious that the buffer was not saturated and that there were a large variation in water content and density between different parts of the buffer. In order to be able to capture this variation it was decided that the sampling of the buffer should be done systematically in eight directions in each bentonite block. This extensive sampling made it possible to get a detailed picture of the water content and density of the buffer. The way the taken samples were handled e.g. the way they were marked, packed and stored, and the minimizing of the time of storage before the determinations of the water content and density were made, contributed to the good quality of the examination of the buffer. Some disadvantages were however observed during the work:

1. A more precise position of the buffer both at the installation and at the retrieval would be favorable i.e. an accurate geodetic surveying on site is required.
2. It was difficult to retrieve all the sensors installed in the buffer, specially the thermo couples. The reason for this is that the lengths of the thermocouples were very long and it was almost impossible to keep them intact during the excavation which is vital to be able to test them.
3. The Relative Humidity sensors were installed with a vessel in which some electrical devices were protected from high water pressure (Vaisala sensors). It was obvious at the retrieval that water had entered into some of the vessels and thus caused a failure of the sensors. This type of sensors where electronic devices are placed outside the actual sensor is not recommended.
4. The cables from the sensors placed in the buffer were led through titanium tubes in the buffer and in plastic tubes through the backfill towards the lead-throughs. At the retrieval damages were observed both on the titanium tubes close to the actual sensors and at the connector between the titanium tube and the plastic tube. One way to avoid this type of damages might be to separate the mechanical protection of the cable from the protection from high water pressure. This might be possible by using a cable which can withstand high water pressure and outside this put a mechanical protection which is not water tight.

8.5 Experiences from the retrieval of the canisters

The retrieval of the canister worked as planned. The problems associated with the retrieval of the canister were mainly three:

1. A more precise position of the canister both at the installation and at the retrieval would be favorable i.e. an accurate geodetic surveying on site is required. Furthermore, accurate measurements of the dimensions of the canisters are required both before and after the test in order to be able determines any changes of the shape of the canister during the test.
2. The atmosphere inside the canisters was unknown at the retrieval. There were indications from previous retrieved canisters that, due to corrosions inside the canister, an explosive gas mixture might be present, which of course can hazard the work environment. At the retrieval of the first canister this concern came true. A complicated and time consuming technique to remotely puncture and change the atmosphere inside the canister was used. In order to avoid this type of problems in the future, the atmosphere should be changed at the assembling of the canister. Furthermore the canister should be equipped with a valve which simplifies sample taking and change of the atmosphere inside the canister.
3. The electrical cables from the installed heater hade major damages. It was obvious that the chosen cables could not withstand the environment with high water content and high temperature close to the canister. It is likely that the damages on the cables were the reason for the problems with the heaters which were observed during the water up take phase. Damages on the cables were also observed caused by the high swelling pressure from the buffer. It is obvious that for new experiments in the future, another type of cable is required.

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Photos from deposition hole 6

Figure A1-1. *Block No C1 deposition hole 6.*

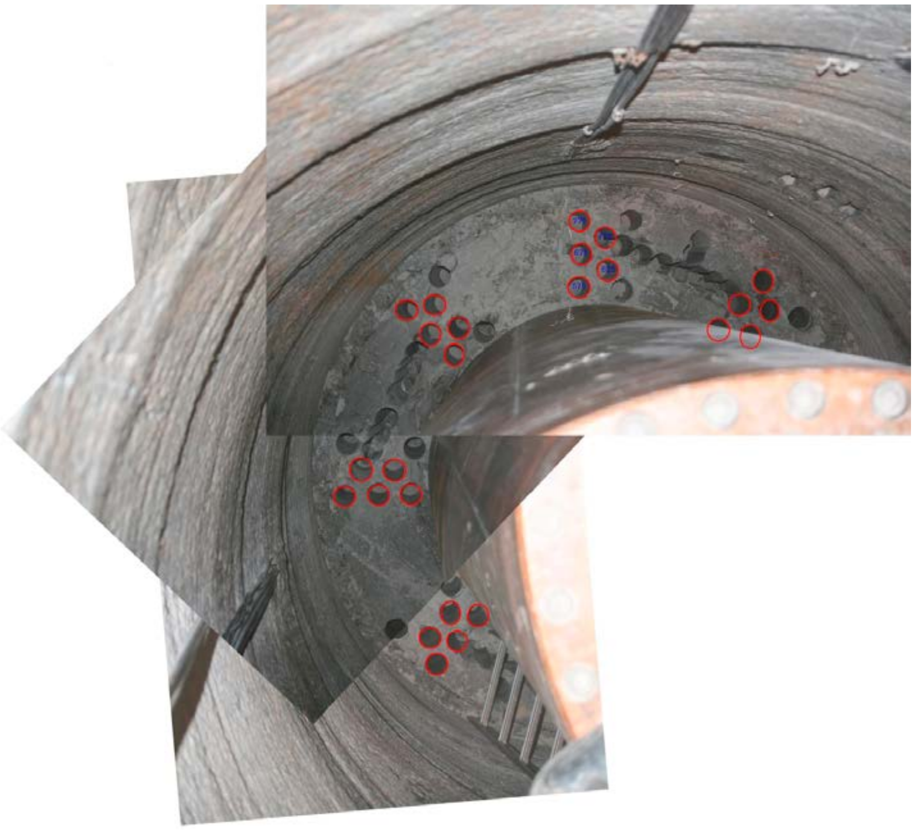

Figure A1-2. *Block No R3 deposition hole 6.*

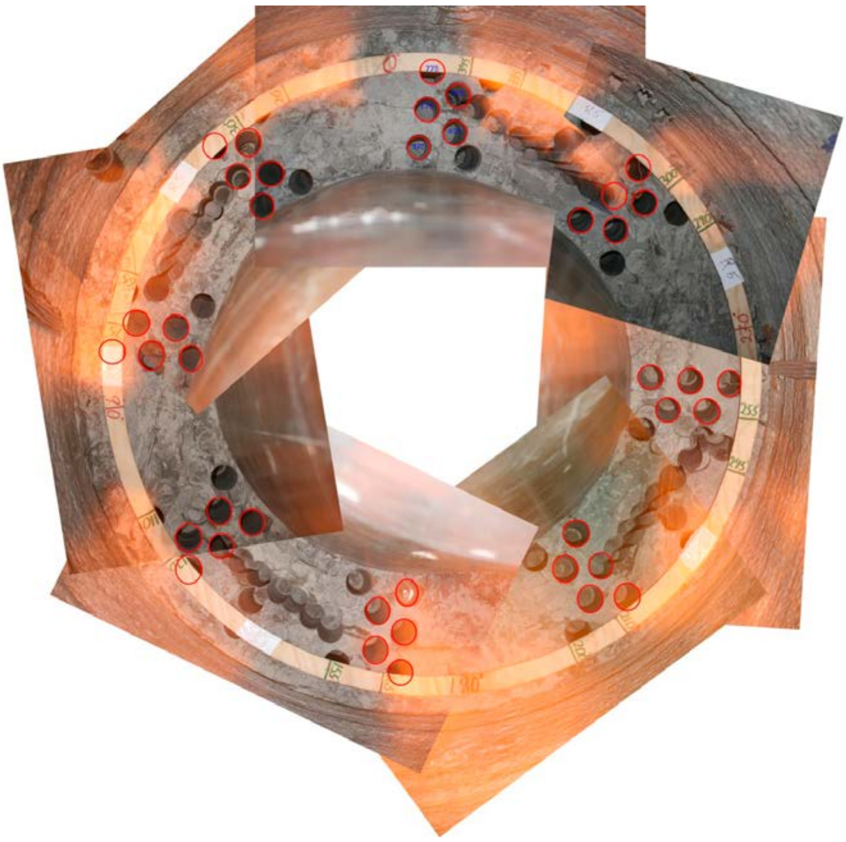

Figure A1-3. *Block No R5 deposition hole 6.*

Figure A1-4. *Block No 7 deposition hole 6.*

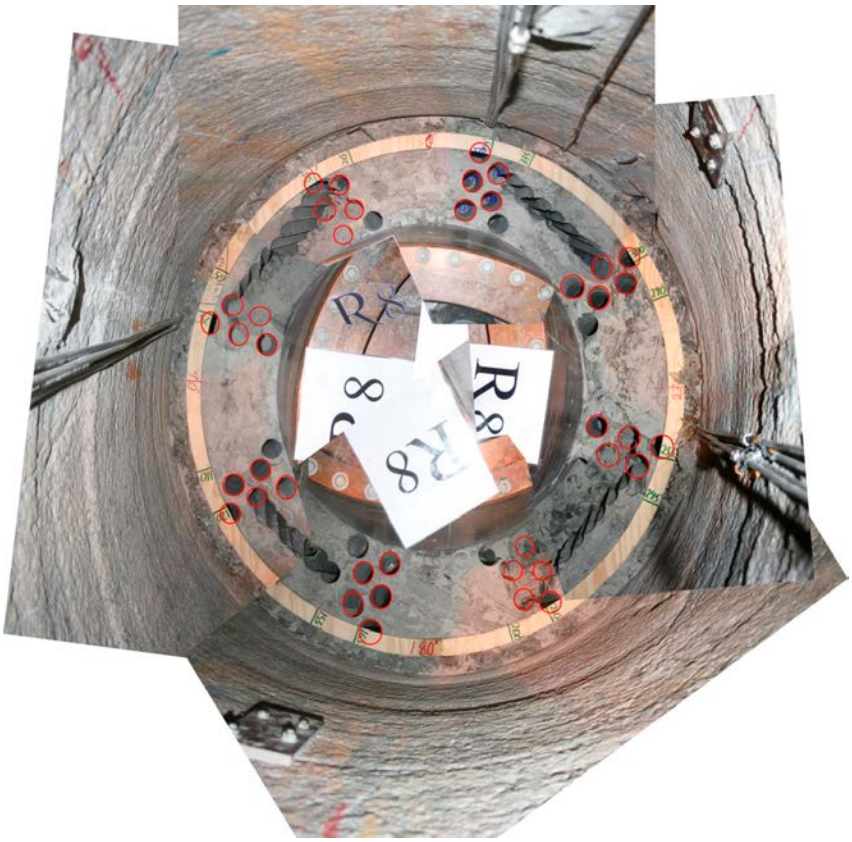

Figure A1-5. *Block No R8 deposition hole 6.*

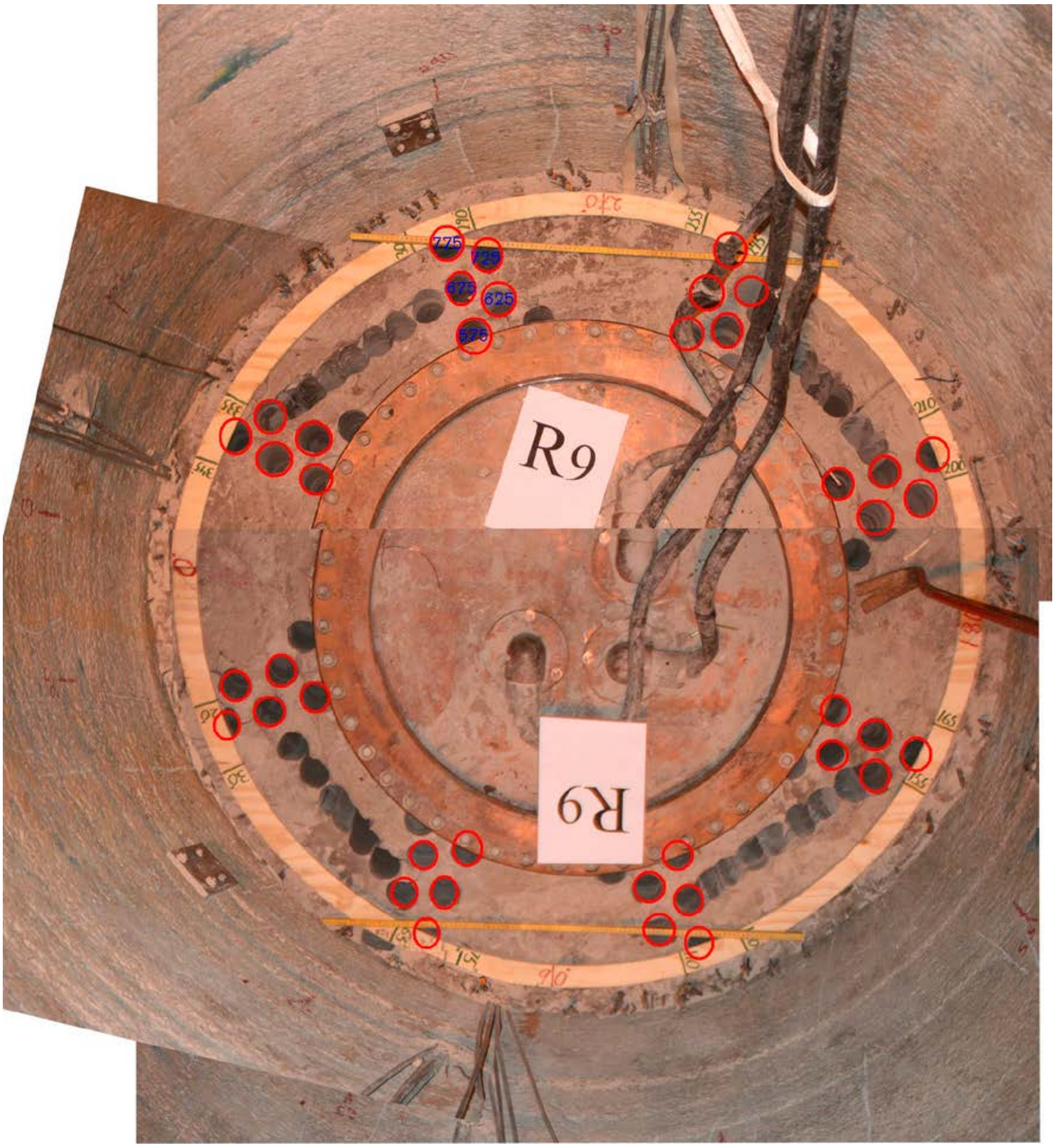

Figure A1-6. *Block No R9 deposition hole 6.*

Figure A1-7. *Block No R10 deposition hole 6.*

Figure A1-8. *Block No C2 deposition hole 6.*

Figure A1-9. *Block No C3 deposition hole 6.*

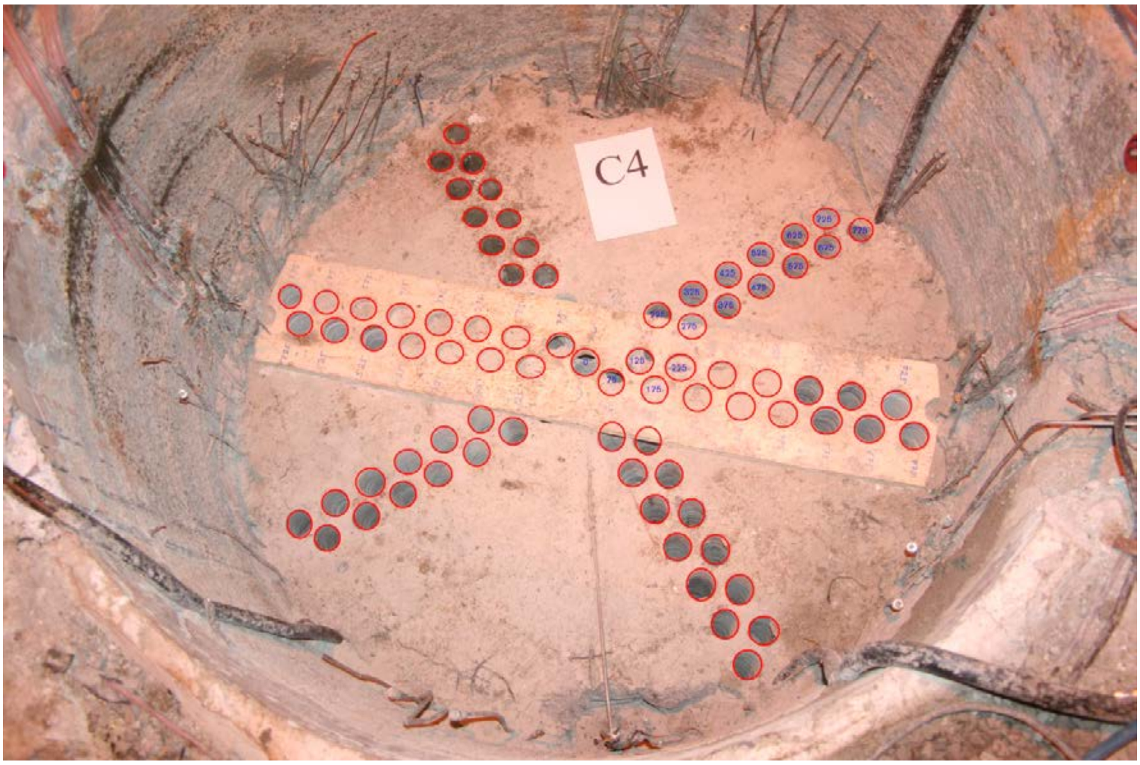

Figure A1-10. *Block No C4 deposition hole 6.*

Appendix 2

Photos from deposition hole 5

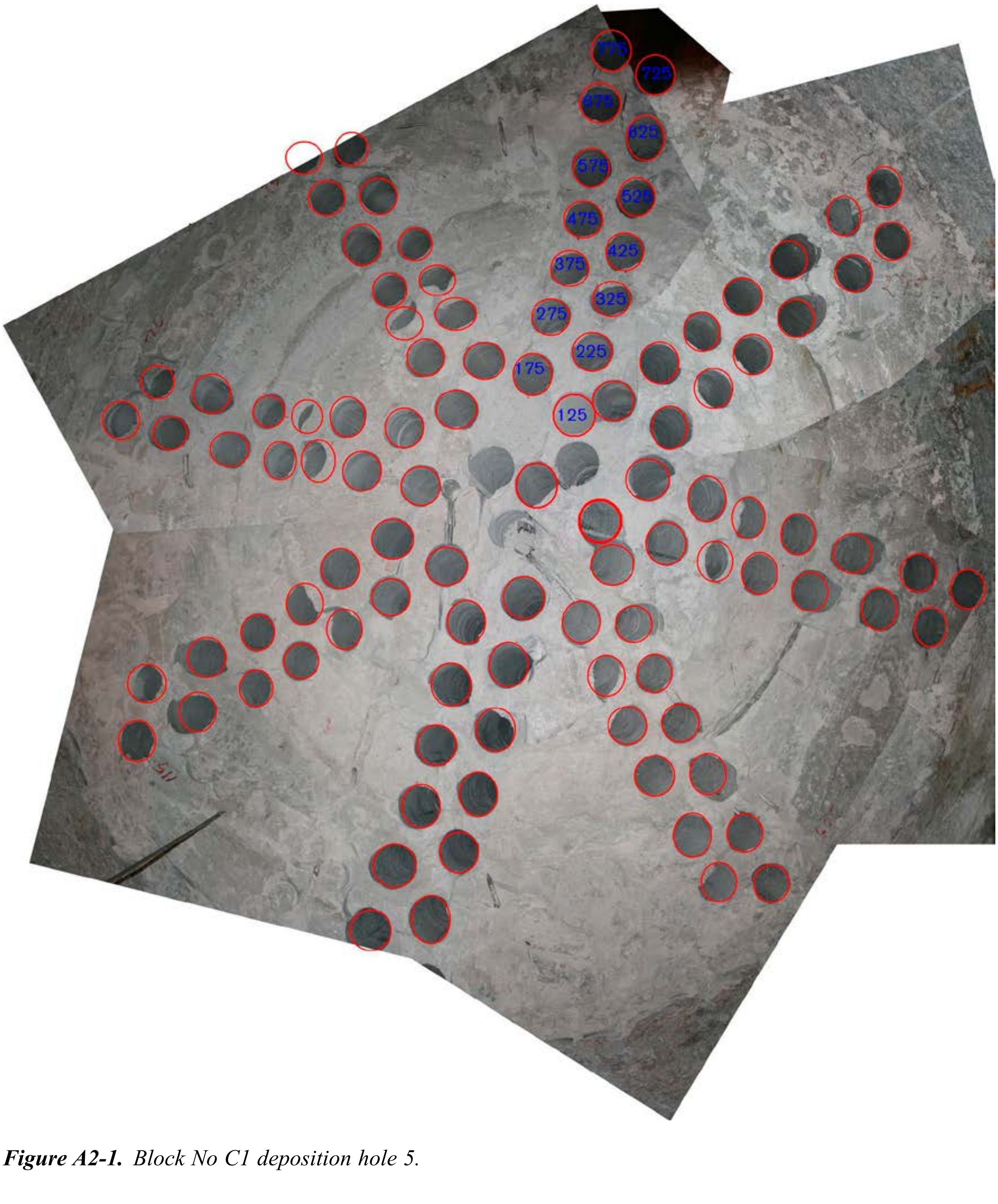

Figure A2-1. Block No C1 deposition hole 5.

***Figure A2-2.** Block No R3 deposition hole 5.*

***Figure A2-3.** Block No R6 deposition hole 5.*

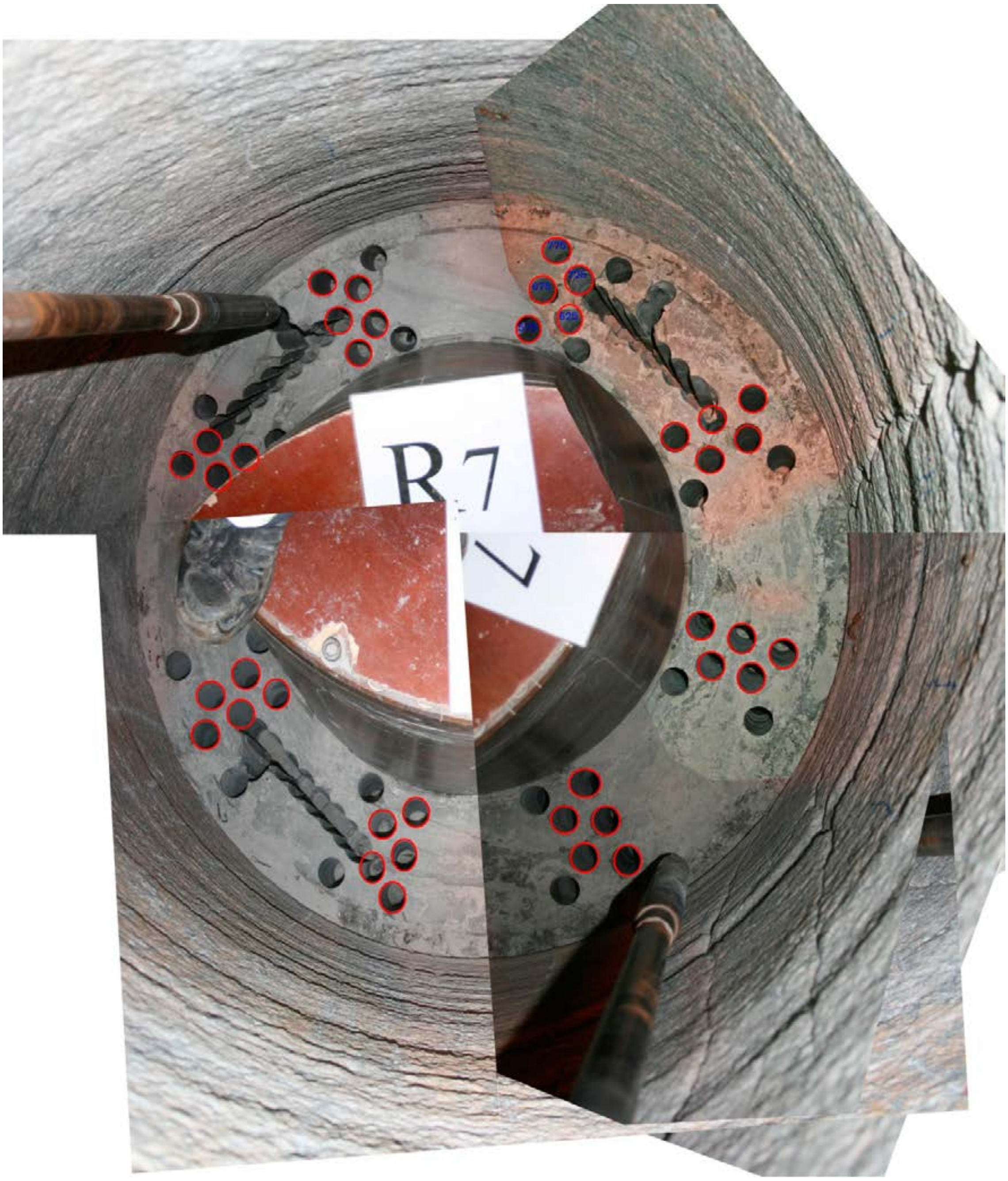

Figure A2-4. *Block No R7 deposition hole 5.*

Figure A2-5. *Block No R8 deposition hole 5.*

Figure A2-6. *Block No R9 deposition hole 5.*

Figure A2-7. *Block No R10 deposition hole 5.*

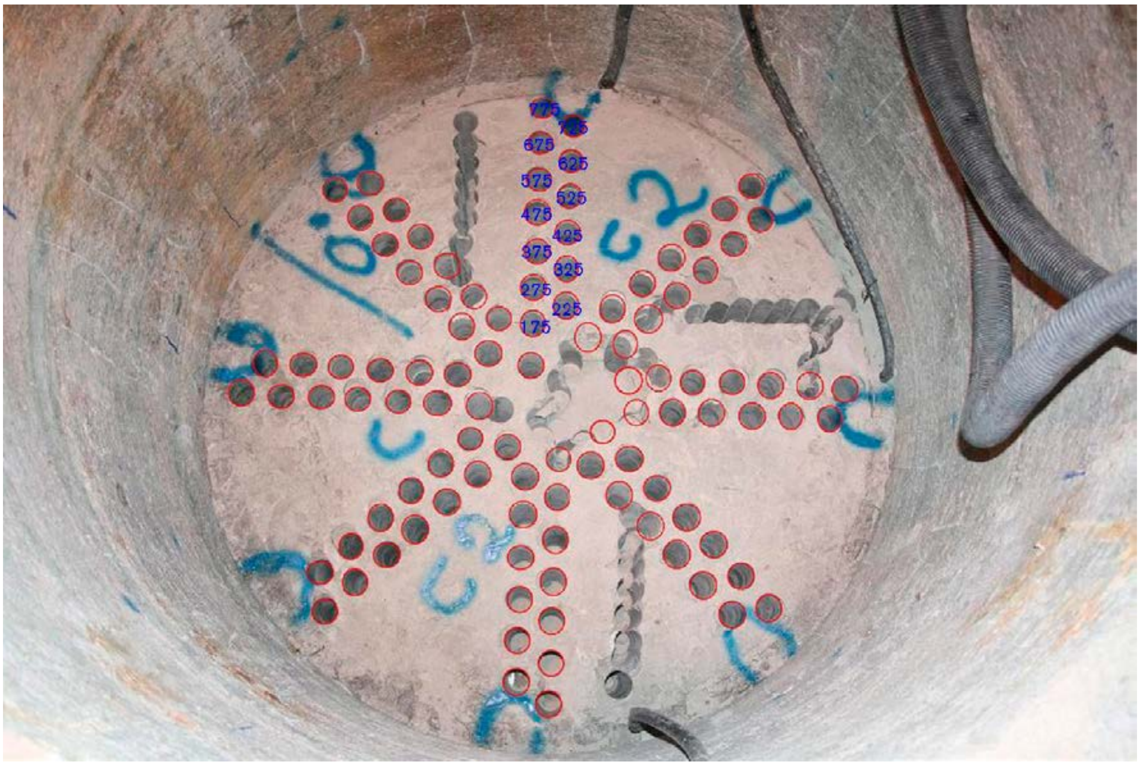

Figure A2-8. *Block No C2 deposition hole 5.*

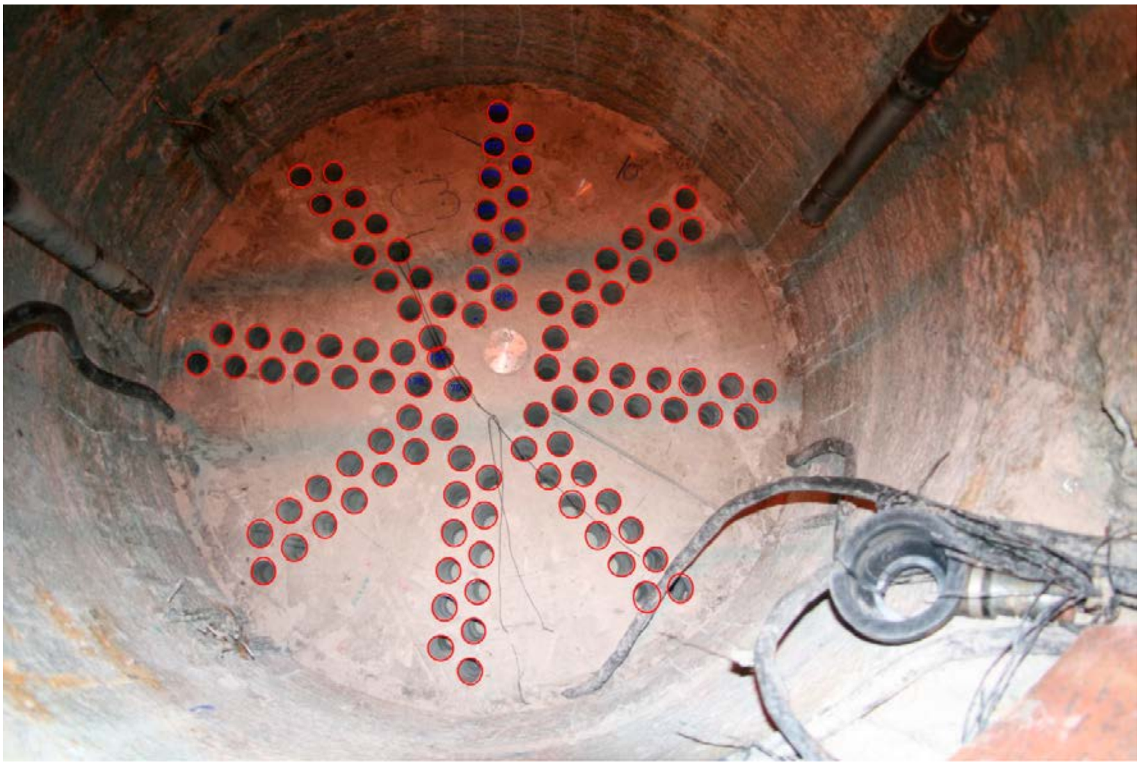

Figure A2-9. *Block No C3 deposition hole 5.*