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Äspö Hard Rock Laboratory

Prototype Repository

Installation of buffer, canisters, backfill, plug and instruments in Section II

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PROTOTYPE REPOSITORY

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D15 & D17

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Abstract

During 2003 Section II of the Prototype Repository has been installed in Äspö Hard Rock Laboratory. Section II consists of two full-scale deposition holes, copper canisters equipped with electrical heaters, bentonite blocks (cylindrical and ring shaped) and a deposition tunnel backfilled with a mixture of bentonite and crushed rock and ends with a concrete plug. Temperature, water pressure, relative humidity, total pressure and displacements etc. are measured in numerous points in the test. Most of the cables from the transducers are led through the rock in watertight tubes to the data collection systems in the adjacent G-tunnel. Some cables are led through the outer concrete plug.

This report describes the work with the installations of the buffer, canisters, backfill plug and instruments and yields a description of the final location of all instruments. The report also contains a description of the materials that were installed and the densities yielded after placement.

Sammanfattning

Under år 2003 har Sektion II av Prototypförvaret installerats i Äspö Hard Rock Laboratory. Sektion II består av två fullskaliga deponeringshål, två kopparkapslar utrustade med elektriska värmare, buffert av bentonitblock (cylindar och ringar) och en deponeringstunnel som är återfylld med en blandning av bentonit och krossat berg. Sektion II avslutas med en betongplugg. Temperatur, vattentryck, relativa fuktigheten, totaltryck och förskjutningar mm mäts i ett stort antal punkter. De flesta kablarna från givarna leds genom berget i vattentäta rör fram till datainsamlingssytemen i den intilliggande G-tunneln. Kablar från en del givare leds genom betongpluggen.

Rapporten beskriver arbetet med installation av buffert, kapslar, återfyllning, plugg och instrumentering och ger en beskrivning av de slutliga lägena för alla instrument. Rapporten innehåller också en beskrivning av de installerade materialen och de densiteter som uppnåddes efter inplacering.

Contents

1 Introduction

The Prototype Repository is located in the innermost part of the TBM-tunnel. Figure 1-1 shows the layout of the test. The test is divided into two sections and this report deals with the installation of the buffer, canisters, backfill, instruments and cables and the plug in Section 2. The different type of instruments used in Section 2 for measuring the THM processes of the buffer and the backfill are described in detail in /1-1/. The instrumentation of the outer plug is described in /1-2/. Resistivity measurements both in the buffer, rock and the backfill are described in /1-3/. The installation of stress and strain measurements in the rock is described in /1-4/. Some instruments for gas and water sampling in the buffer and the backfill have also been installed. This work is described in /1-5/. Transducers for measuring the displacement of the canisters were installed in deposition hole 6. This work is described in /1-6/.

Section 2 consists of two full-scale deposition holes, copper canisters equipped with electrical heaters, bentonite blocks (cylindrical and ring shaped) and a deposition tunnel backfilled with a mixture of bentonite and crushed rock and ends with a concrete plug. Temperature, water pressure, relative humidity, total pressure and displacements etc. are measured in numerous points in the test. Most of the cables from the transducers are led through the rock in watertight tubes to the data collection systems in the adjacent G-tunnel. Some cables from transducers are led through the outer concrete plug. The work in Section 2 was finished, by casting the plug, in the middle of September 2003.

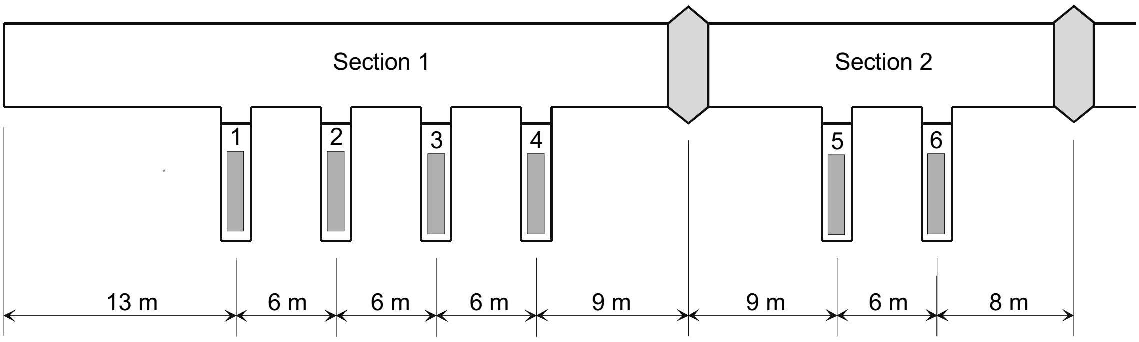


Figure 1-1. *Layout of the Prototype Repository.*

2 Handling of cables and tubes

2.1 Design of lead throughs

Cables and tubes from the different measuring points must be led through the rock into the adjacent tunnel (the G-tunnel), where a measuring house with data collection system is placed. 27 lead through holes, 16 holes from section 1 and 11 from section 2, were drilled through the rock in to the adjacent G-tunnel (see Figure 2-1) for this purpose. Beside these lead throughs two additional lead throughs were made through the out concrete plug. The construction of these was similar to those led through the rock.

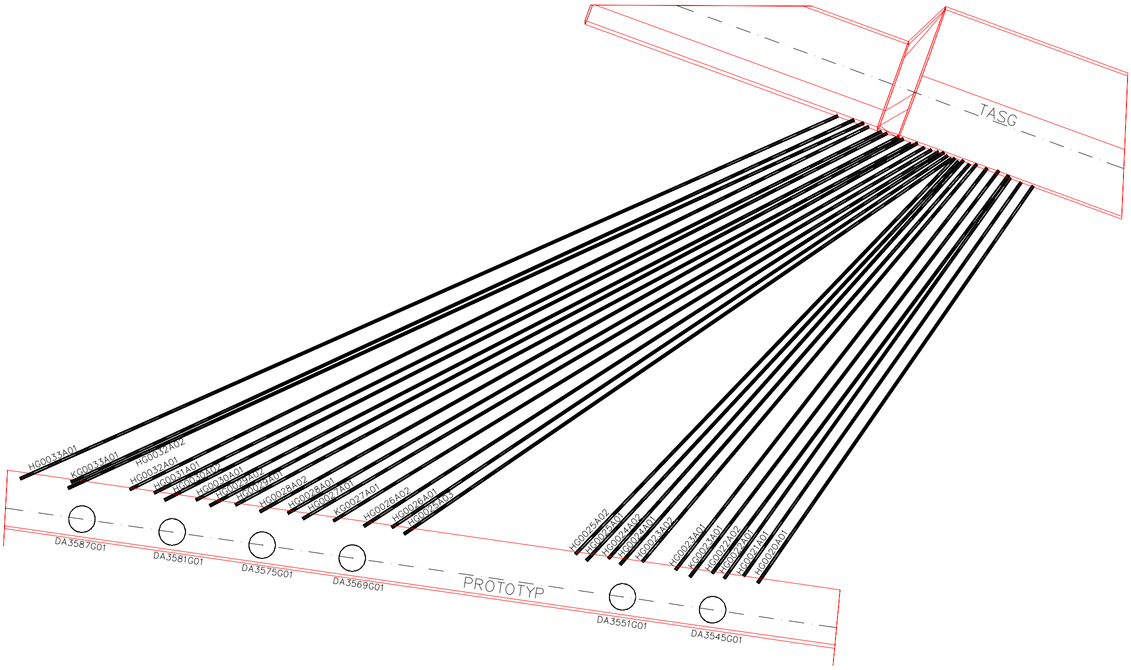


***Figure 2-1**. The lead through holes drilled between the Prototype Repository and the G-tunnel.*

The demands on the lead throughs are very high:

- They should be so watertight that they do not have a significant influence on the water pressure in the backfill.
- They should withstand a water pressure of 5 MPa.
- The long-term stability of the included materials must be high. They will be exposed to water with high salinity for about twenty years. The gauges, placed in the bentonite, will in addition also be exposed to a temperature of about 90° C.

The lead throughs in the rock are similar to those used in the Backfill and Plug Test. The number of cables and tubes that is led out is, however, more than twice as many. The variation of types and dimensions of the cables and tubes also made the work complicated. The distances through the rock are in some cases about twice as long as in the Backfill and Plug Test, i.e. 60 m instead of 30 m.

The principle is that a certain number of cables and tubes are collected and led through a steel flange and then further on through a steel pipe, which is placed in a borehole in the rock. The sealing of the cables and tubes in the flange is mainly done with ferrule connections of Swagelok type. For some of the cables, for example the power cables to the heaters, special lead throughs of submarine type were manufactured. The space between the steel pipes, leading cables and tubes, and the rock was sealed with bentonite rings at a length of about 1 meter at both ends. The bentonite is supported with steel flanges and rubber sealings as well as cement plugs. The rest of the empty space between the pipes and the rock was grouted with cement. Totally 27 bore holes, 16 in section 1 and 11 in section 2, were drilled in order to lead about 500 cables and tubes out. The diameter of the drilled holes is 200 mm and the outer diameter of the steel tubes is 139,7 mm with a thickness of 5 mm.

The final design and the installation of the lead throughs in the rock are shown in Figures 2-2 and 2-3.

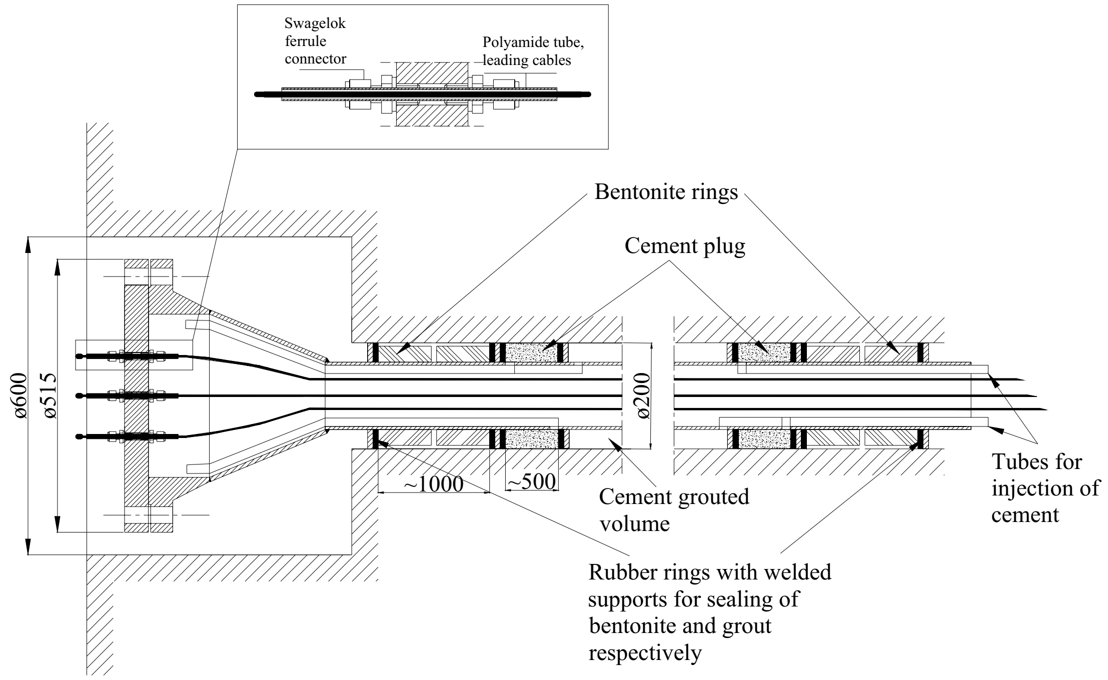


Figure 2-2. Schematic view of a lead through.

Figure 2-3. *Photos showing the installation of steel tubes in the rock (upper) and one completed lead through installed in the rock (without steel flange and cables).*

The principal design of the lead throughs in the concrete plug is shown in Figure 2-4. The lead throughs are used for cables coming from Wescor soil psychrometers placed in the buffer and cables from transducers for measuring stresses in the rock mass around the deposition holes. The demands on these lead throughs are the same as the lead throughs in the rock. The installation was made in the following steps:

- The tubes and the cables coming from the transducers were placed on the north side of the tunnel and embedded in the backfill material.

- The cables were placed in two steel pipes. In order to create the volume for the compacted bentonite in the concrete plug a somewhat conical steel pipe with a length of about 1 m was screwed on outside the longer pipe.

- The mould for the plug was built and the plug was cast with the two pipes led through it.

- After the concrete was hardened and the mould was removed the outer steel pipes were unscrewed.

- The space between the steel pipes, leading cables and tubes, and the concrete plug was sealed with rings of highly compacted bentonite. The bentonite is supported with rubber sealings and steel flanges.

- The outer part of the lead through was screwed on the pipe and the cables and tubes were led through the bulk head (see also Section 2.4). The sealing of the cables and tubes in the bulk head is done with ferrule connections of Swagelok type. Finally the steel flange was screwed on to the pipe.

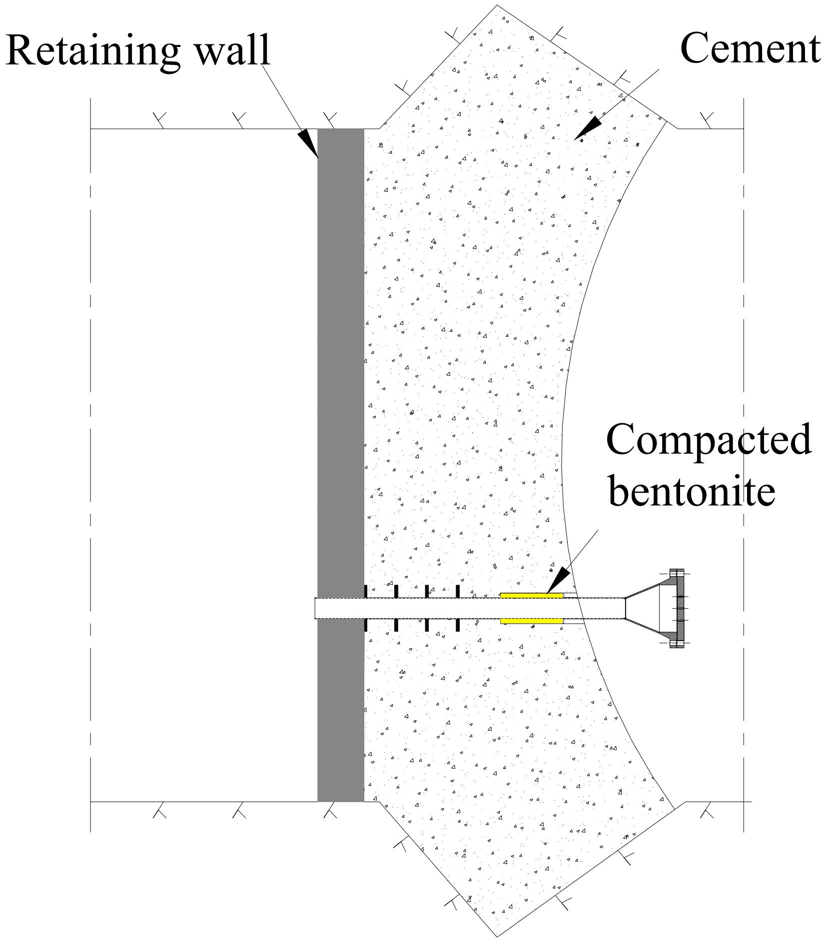


Figure 2-4. *Schematic view of a lead through in the plug.*

2.1.1 Quantity and distribution of cables and tubes

The total number of cables and tubes that were led through the rock and the outer concrete plug from Section 2 to the adjacent tunnel were as follows (see also Table 2-1):

Canisters (2 pcs.)

- 6 power cables with a diameter of 32 mm (PE-PUR).
- 8 fiber optic temperature cables with a diameter of 2 mm led in tubes of polyamide with a diameter of 6 mm.
- 6 tubes leading fiber optic cables from gauges measuring displacement of the canisters (canister 6) with a diameter of 8 mm (Polyamide)

Bentonite (2 instrumented deposition holes)

- 54 tubes with a diameter of 8 mm from total pressure gauges (Titanium/Polyamide)
- 28 tubes with a diameter of 8 mm from pore pressure gauges (Titanium/Polyamide)
- 98 tubes with diameters of 10 mm and 8 mm from relative humidity sensors (Titanium/Polyamide). 20 of the cables are supporting 2 sensors each
- 64 thermocouples with a diameter of 4.0 mm for temperature measurements (Cupronickel)
- 6 tubes with a diameter of 10 mm from copper electrodes for measuring the corrosion rate (Polyamide)
- 4 tubes with a diameter of 8 mm for taking water samples in the bentonite.
- 6 tubes with a diameter of 8 mm from transducers (one in each deposition hole) for measuring the displacement of the upper surface of the bentonite.

Backfill (2 sections type E (see Chapter 5) with 30 gauges, 3 sections type F with 12 gauges and 12 gauges in the rest of the backfill)

- 16 tubes with a diameter of 8 mm from total pressure gauges (Polyamide)
- 18 tubes with a diameter of 8 mm from pore pressure gauges (Polyamide)
- 32 tubes with a diameter of 8 mm from relative humidity gauges (Polyamide)
- 16 thermocouples with a diameter of 4.0 mm for temperature measurements. (Cupronickel)
- 1 cable with a diameter of 25.7 mm for resistivity measurements (Polyether-Polyurethane).

Rock

- 89 tubes with a diameter of 4/6” from packers in the rock (Polyamide/Peek)
- 20 tubes with a diameter of 10 mm for hydraulic measurement (Polyamide)
- 8 tubes with a diameter of 1/8” from sampling of water and gas (PEEK).
- 4 cable with a diameter of 25.7 mm for resistivity measurements
- 48 thermocouples with a diameter of 4.0 mm (Cupronickel)
- 24 cables with a diameter of 1/4” from Acoustic emission measurement (PE-PUR)
- 15 multicables with a diameter of 19 mm from rock stress measurement
- 2 tubes used for water drainage with a diameter of 8 mm (Polyamid)

Table 2-1. Table showing how the different cables and tubes were distributed in the lead through holes for Section 2.

Prototype Repository				**Deposition hole DA3551G01**					**Deposition hole DA3545G01**							
Measuring place	Tube d mm	Lead through type	Material	Number of tubes/cables					Number of tubes/cables							
				HG0025A02	HG0025A01	HG0024A02	HG0024A01	HG0023A02	HG0023A01	KG0023A01	HG0022A02	HG0022A01	HG0021A01	HG0020A01	Through plug	Sum
Canister																
Power cables	32	Flange receptacle	PE-PUR				3					3				6
Optic fiber	2	Swagelok	Inconel				4					4				8
Displacement	8	Swagelok	Titanium									6				6
Bentonite																
Total pressure	8	Swagelok	Titanium/Polyamid		27					27						54
Pore pressure	8	Swagelok	Titanium/Polyamid		14					14						28
Relative humidity R	10	Swagelok	Titanium/Polyamid			17							17			34
Relative humidity V	10	Swagelok	Titanium/Polyamid						20							20
Relative humidity W	8	Swagelok	Cupronickel												44	44
Temperature	4	Swagelok	Cupronickel		32					32						64
Backfill																
Total pressure	8	Swagelok	Polyamid			7		9								16
Pore pressure	8	Swagelok	Polyamid			8							10			18
Relative humidity W	8	Swagelok	Polyamid			13							19			32
Temperature	4	Swagelok	Cupronickel			7				9						16
Resistivity	25,7	Flange receptacle	Multicable										1			1
Rock																
Hydro	4/6	Swagelok	Tecalan/PEEK	49							40					89
Sampling	1/8"	Swagelok	PEEK												8	8
Resistivity	25,7	Flange receptacle	Multicable					4								4
Temperature	4	Swagelok	Cupronickel	24							24					48
Rock mechanical	19	Swagelok	Multicable											15		15
Acoustic emission	1/4"	Swagelok	PE-PUR						24							24
Water drainage	8	Swagelok	Polyamid					2								2
Hydro	10	Swagelok	Polyamid											20		20
Additional meas.																
Bentonite displ.	8	Swagelok	Polyamid					4								4
Copper corrosion	8	Swagelok	Polyamid					6								6
Sum				73	73	52	7	25	44	82	64	13	47	35	52	567

2.2 Encapsulation of instruments and cables

2.2.1 Relative humidity sensors

The instruments measuring relative humidity were encapsulated in titanium.

The instruments are delivered from three suppliers (Rotronic, Wescor and Vaisala). The principle of the Vaisala and Rotronic instruments is measurement of capacitance, while the Wescor instruments are psychrometers. A difference between Rotronic and Vaisala is that the Vaisala instruments have a maximum allowed length of the cable from the sensor to an electronic box (10 m). This means that the electronic box must be built into a vessel and be left in the backfill. Rotronic have built in the required electronics in the sensor body and the rest can be placed at any distance from the sensor. Hence, these sensors had to be handled in different ways. A more detailed description of the instruments is given in /2-1/.

Rotronic

The sensor bodies were built into titanium cases, consisting of a house for the sensor body and a titanium tube for the cable. The titanium tubes were welded to the sensor houses. On top of the sensor houses, titanium filters were placed. The connections between the sensor bodies and the titanium were sealed with O-rings. In order to prevent water leakage through the sensor, after saturation of the bentonite, the bottom of the sensor houses was filled with epoxy and will withstand a water pressure of about 5 MPa. The length of the titanium tubes depends on the position of the sensors in the deposition holes.

The rest of the cables placed in the backfill were protected by polyamide tubes with an outer diameter of 10 mm and an inner diameter of 6 mm. Polyamide tubes of suitable lengths were thread over the electrical cables and connected to the titanium tubes with Swagelok ferrule connections. The gauges were then ready for installation on the intended flange. Ferrule connections were mounted on the flanges in advance (see Figure 2-4). The polyamide tubes were pulled through these to specified lengths in order to have suitable lengths left in the test tunnel together with the sensors. Before mounting the head flange on the cone, the ferrule connections were tightened.

Vaisala

The Vaisala gauges were delivered with 10 m long electrical cables, connecting the sensors to a box containing electronics. 10 m was the maximum lengths of each cable, which means that the electronic boxes had to be left in the test tunnel. The boxes were built in to special containers in pairs and the cables and sensor bodies were protected by titanium tubes. The work was done as follows:

1. The electrical cables were released from the electronic box by soldering.
2. The sensors were built in to titanium cases, consisting of houses for the sensor bodies and titanium tubes for the cables. The titanium tubes were welded to the sensor houses. On top of the sensor houses, titanium filters were positioned. The sensor bodies were sealed against the titanium with O-rings. In order to prevent water leakage through the sensors, after saturation of the bentonite, the bottom of the sensor houses was filled with epoxy. The length of each titanium tube before changing to polyamide tube depends on the position of the sensor in the deposition holes.

3. Polyamide tubes were pulled over the rest of the cable, leaving about 30 cm free. Swagelok ferrule connectors were used to connect the titanium tubes and the polyamide tubes.
4. Swagelok ferrule connectors were mounted on the cap of the electronic box. The free ends of the electric cables were then pulled through these and connected to the electronic box. The ferrule connections were fastened.
5. Function tests and calibrations of the sensors were done after soldering.
6. Titanium filters were positioned on the top of the encapsulation.
7. The tubes containing multi wire cables, for voltage supply and output signals were pulled through a flange. They were pulled through from the low-pressure side in order to minimize the pulling length. One tube was connected to each vessel containing the electronic boxes. This was done after installation of the sensors.

Wescor

The sensors were built into titanium cases, consisting of houses for the sensor bodies and titanium tubes for the cables. The titanium tubes were welded to the sensor houses. On top of the sensor houses, titanium filters were positioned. In order to prevent water leakage through the sensor after saturation of the bentonite, the bottom of the sensor houses was filled with epoxy. Before installation, the cable was split, exposing the leaders. Epoxy was then injected, sealing the leaders and the volume in the tube. Laboratory tests have shown that the sealing can withstand a water pressure of 5 MPa.

2.2.2 Encapsulation of other sensors

The sensors from Geokon and Kulite were manufactured in titanium. The electrical cables from the sensors were protected by titanium tubes of different lengths in order to protect the cables the entire way through the bentonite. The titanium tubes were welded to the sensor bodies. When entering the backfill, the tubes were converted to polyamide tubes (see next chapter).

The thermocouples were manufactured in cupro nickel and did not need any additional protection.

2.3 Leading sensor cables in polyamide tubes

All sensor cables were led in polyamide tubes in order to protect the cables and to make a secure sealing when they pass through the head flange. The following types of polyamide tubes were used:

1. Outer diameter 10 mm and inner diameter 6 mm. This tube was used for cables from Vaisala (20 pcs) and Rotronics (34 pcs).
2. Outer diameter 8 mm and inner diameter 5 mm. This tube was used for cables from Kulite (51 pcs), Geokon (65 pcs), Wescor (44+32 pcs) and displacement transducers (6 pct).
3. Outer diameter 6 mm and inner diameter 3 mm. This tube was used for the optical cables for measuring the temperature on the canisters (8 pct)

The work leading a cable through a polyamide tube was done as follows:

- A polyamide tube was uncoiled in its whole length, i.e. 80 m.
- A thin string was sucked through the polyamide tube by use of a vacuum pump.
- A Swagelok ferrule connector was mounted on the tube end in order to connect the polyamide tube to the sensor.
- The string was then connected to the cable with the sensor and pulled through.
- The Swagelok connector was fastened, connecting the polyamide tube to the sensor.

The tube with the connected sensor was then coiled and stored.

2.4 Preparation and mounting of "cable parcels"

2.4.1 Assembling of cable parcels

All cable/tube parcels, except for the one leading out cables from the canisters, were prepared in advance. The mounting was done in the A-tunnel, outside the Prototype tunnel. The parcels leading out cables from the canister could not be prepared in advance since the optic fiber cables was already fixed to the canister surface. This meant that these cable parcels had to be assembled when the canisters were installed.

Function testing of all instruments was done before mounting them on the flange except for the Rotronic relative humidity sensors and the Geokon pressure sensors. These sensors were tested after installation of the cable parcels.

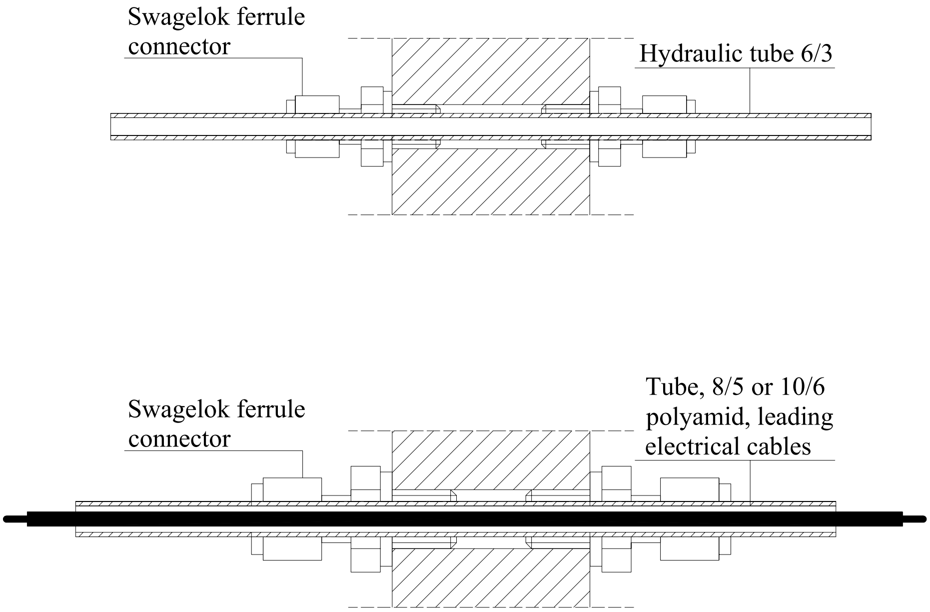


Figure 2-5. *Schematic view, showing how the hydraulic tubes (upper) and electrical cables were sealed on their way through the head flanges.*

2.4.2 Parcels including cables from the canister

Each flange containing cables from the canister was mounted on a wagon with wheels designed for the purpose. The wagon with the cables was placed close to the deposition hole. Two types of cables were led in these parcels:

1. **Fiber optic cables, measuring temperature and displacement.** The fiber optical cables were protected with a tube of polyamide. All tube fittings, for the fiber optic cables, were mounted on the flange. The cables were then pulled through the tube fittings, until a specified length remained.

2. **Electric power cables.** Flange receptacles were mounted on these cables in advance, which mean that the cables were pulled through holes in the head flange until the pre mounted flanges reached the head flange. They were then fixed to the head flange by bolts. Gaskets were mounted before pulling the cables through the head flange.

The cables were ID-marked in both ends and gathered by strings every meter. Depending on the cable lengths and the limited space in the tunnel, the tube parcels were led out from the TBM-tunnel and then back again to the specified lead through hole before the installation.

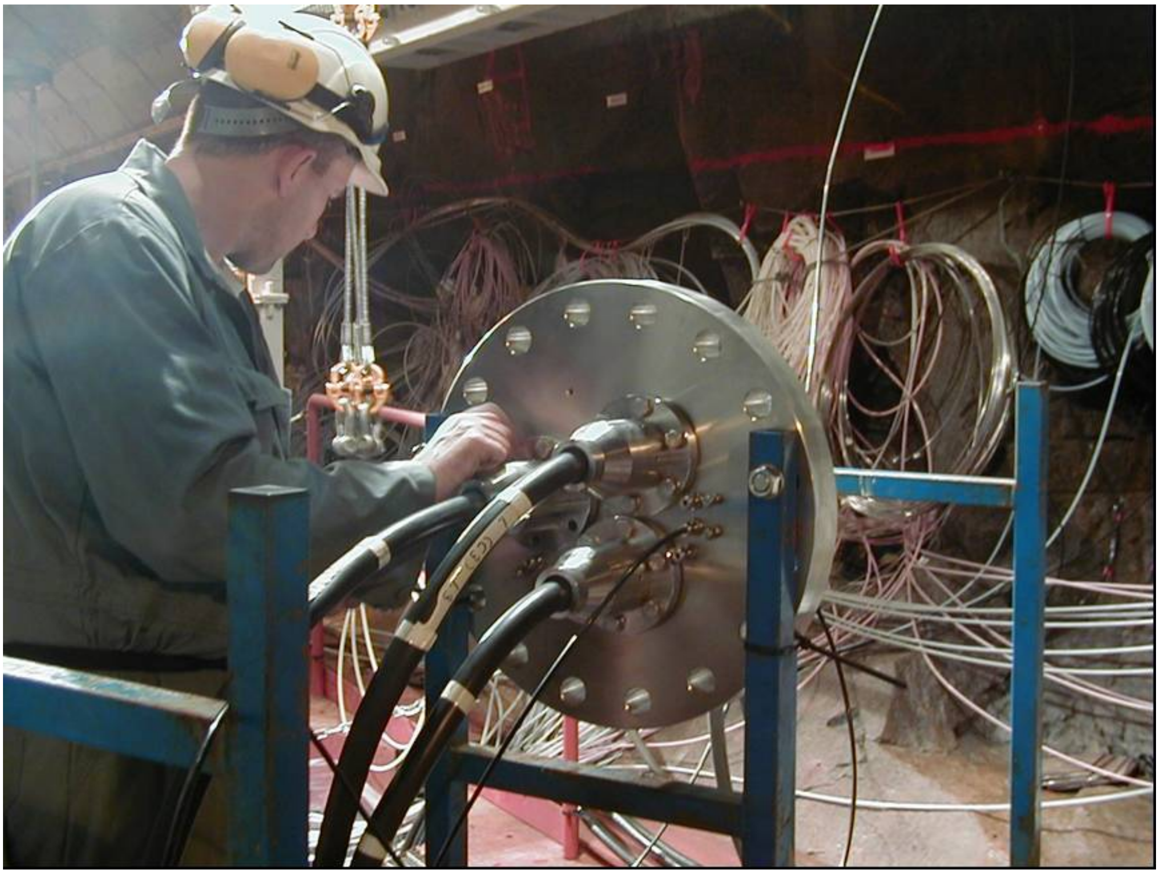


***Figure 2-6**. Photo showing the assembling of a cable parcel with cables from canisters.*

2.4.3 Parcels including cables from bentonite, backfill and rock

These parcels were installed in advance i.e. before the deposition of the bentonite blocks. The procedure was the same as described for the cables from the canisters except that the wagon with the flange was placed outside the Prototype tunnel where the assembling was done. The work was done as follows:

1. Each flange was mounted on the wagon. The flanges were fixed during mounting of the tube fittings and installation of the tubes. All tube fittings were mounted on the flange according to directions.

2. The tubes were pulled through the tube fittings. They were handled somewhat different depending on the type of tube as follows:

   Kulite, Geocon, Wescor and Rotronic:

   The tubes, with the sensors in one end and the electric cables covered with polyamide tubes in the other, were pushed through the flange from the high-pressure side. This means that about 90 m had to be pushed through.

   Vaisala

   The tubes containing the electric cables (which were later connected to the vessels, containing the electronic boxes from two sensors) were pushed through the tube fittings from the low-pressure side, which means that about 15 m had to be pushed through.

   Thermocouples

   The thermocouples were pulled through the tube fittings from the low-pressure side, which means that about 15 m had to be pushed through.

   Hydraulic tubes, sampling and hydro-chemical tubes

   The hydraulic tubes were handled like the thermocouples i.e. they were pushed through from the low-pressure side to a specified length.

3. Each tube installed was marked with a special ID number in both ends.

4. When all tubes were mounted and the lengths on the high-pressure side had been controlled, the tube fittings on the flange were fastened.

5. The tubes on the low pressure side i.e. the tubes that later were pulled through the rock, were collected in a parcel by strings placed every meter. This facilitated the installation. The tubes on the high-pressure side were rolled together and locked with strings. These cable rolls were then hung on the rock wall until the sensors were installed in the bentonite, backfill or rock.

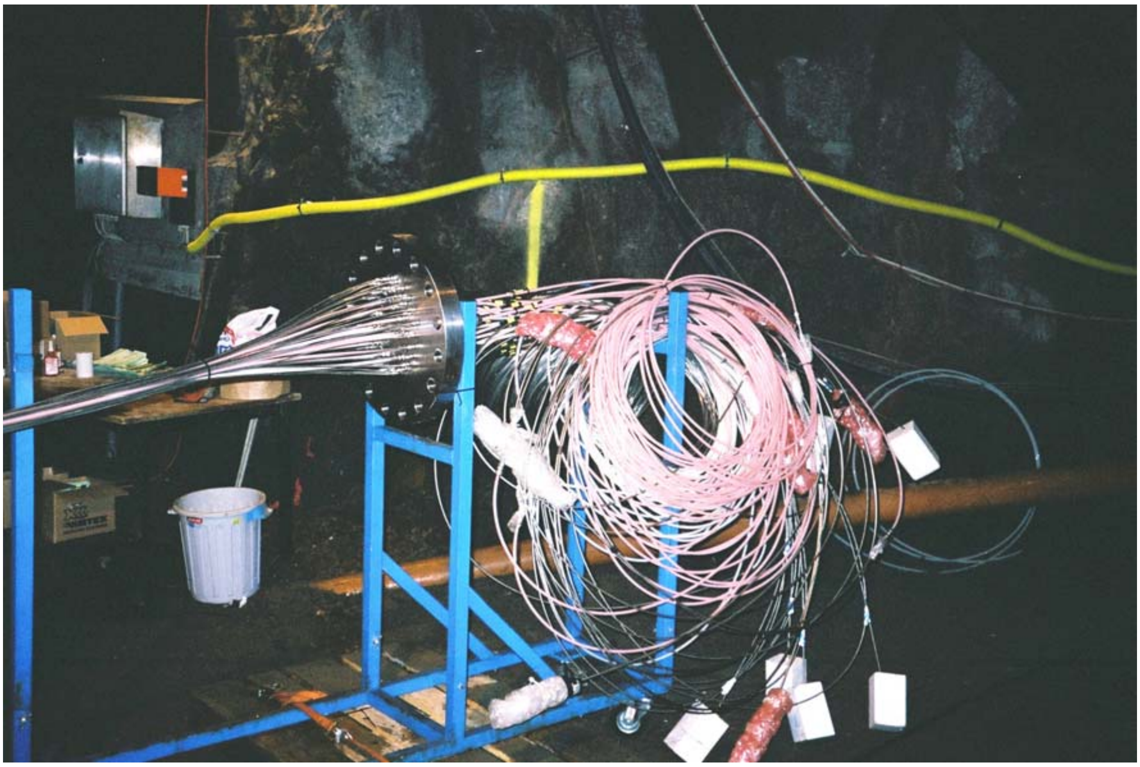


Figure 2-7. *A photo showing the assembling of a cable parcel including cables from the buffer and backfill.*

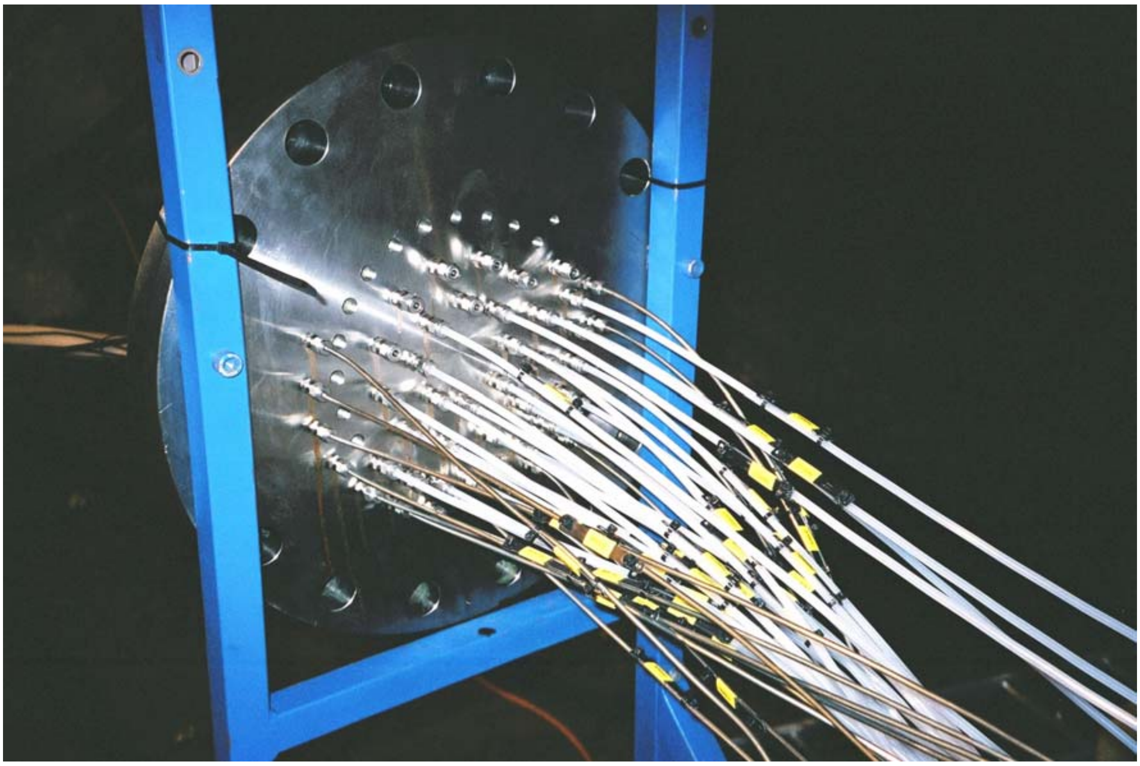


Figure 2-8. *A photo showing the assembling of a cable parcel, including cables from the buffer and backfill. Every tube was marked in several positions on both sides of the flange.*

2.4.4 Procedure for installing a cable parcel

1. All tube fittings on the flange were checked and fastened.

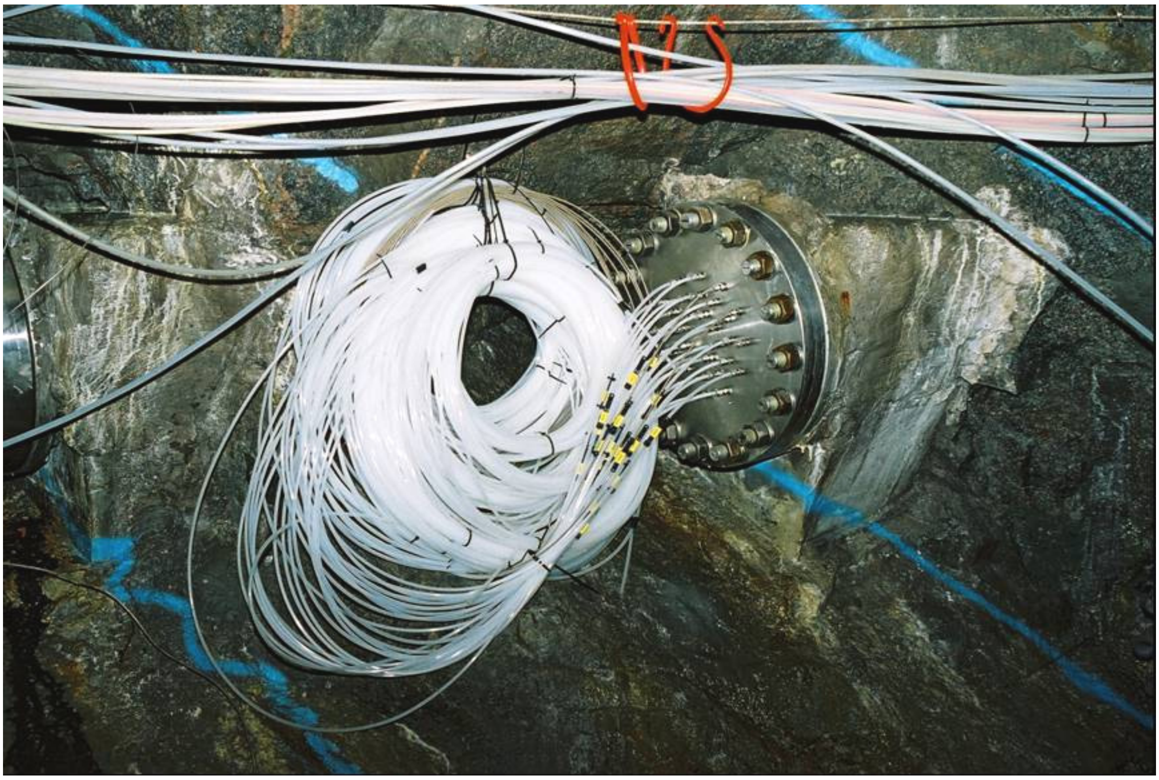
2. A steel wire was pushed through the lead through hole from the G-tunnel.

3. A gasket was mounted on the steel collar in the Prototype tunnel.

4. The end of the cable parcel was fastened to the steel wire.

5. The cable parcel could then be pulled through the borehole. One man pulled the wire from the G-tunnel and one guided the tubes when they were entering the borehole. Two or three men lifted and guided the cables in the Prototype tunnel.

6. When only a few meters remained, the head flange was released from the wagon and lifted by hand the final meters to the steel collar. The flange was then fastened to the collar by bolts.



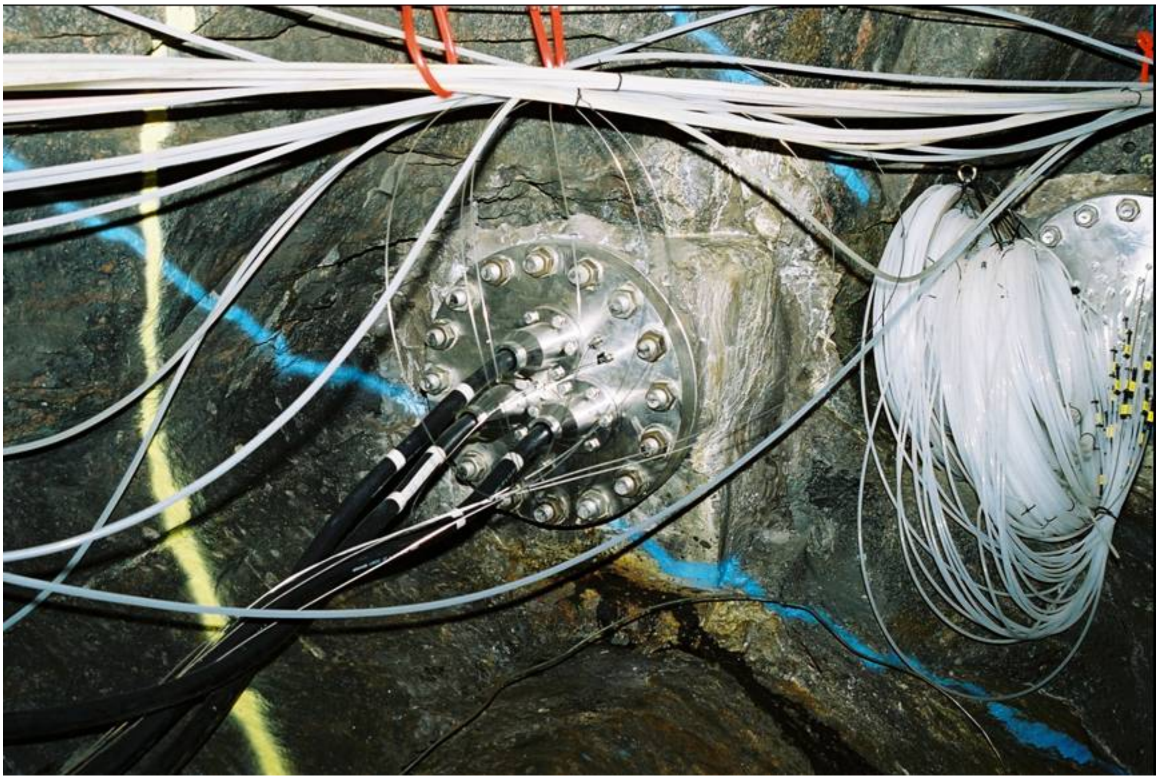


***Figure 2-9**. Photos showing cable parcels installed in the rock. The upper photo shows a cable parcel containing tubes that are intended for rock measurements. The lower shows a parcel containing cables from a canister.*

3 Preparation of bentonite blocks for instruments and cables

3.1 General

The main preparation of the bentonite blocks was done at Hydroweld in Ystad i.e. at the same place as where the blocks were manufactured. The activity required access to a large hall of about 100 m² and a truck in order to facilitate the lifting and covering of the blocks.

The work on the block was done with the following equipment:

- A core-drilling machine (Hilti)
- A hand hold drilling machine
- A large vertical drilling machine
- A hand hold cutter
- Different rulers and a pair of compasses

3.2 Location of instruments in the bentonite

3.2.1 Brief description of the instruments

The different instruments that were used in the experiment are briefly described in this section. A more detailed description is given in /2-1/.

Measurements of temperature

Thermocouples from Pentronic were used to measure temperature. Measurements are done in 32 points in each instrumented deposition hole. In addition, temperature gauges are built into the relative humidity sensors and the pressure gauges of vibrating wire type. Temperature is also measured on the surface of the canisters with optical fiber cables /2-1/.

Measurement of total pressure

Total pressure is the sum of the effective stress and the pore water pressure. It is measured in totally 27 points in each test hole with the following instrument types:

- Geokon total pressure cells with vibrating wire transducers. 18 cells of this type were installed in Dh 5 and 13 were installed Dh 6.
- Kulite total pressure cells with piezo resistive transducers. 9 cells of this type were installed in Dh 5 and 14 were installed in Dh 6.

Measurement of pore water pressure

The pore water pressure is measured in totally 14 points in each test hole with the following instrument types:

- Geokon pore pressure cells with vibrating wire transducers. 6 cells of this type were installed in each deposition hole.
- Kulite pore pressure cells with piezo resistive transducers. 8 cells of this type were installed in each deposition hole.

Measurement of the water saturation process

The water saturation process is measured in totally 37 points in each instrumented test hole with the following techniques:

- Vaisala relative humidity sensors of capacitive type. 20 cells of this type were installed in each deposition hole.
- Rotronic relative humidity sensors of capacitive type. 17 cells of this type were installed in each deposition hole.
- Wescor soil psychrometers : 10 cells were installed in Dh 5 and 28 cells were installed in Dh 6.

3.2.2 Strategy for describing the position of each device

The instrumented deposition holes in Section 2 are termed DA3551G01 (hole 5) and DA3545G01 (hole 6). Measurements in deposition hole 5 are done in four vertical sections A, B, C and D according to Figure 3-1 and 3-2. Direction A - C correspond to the direction of the tunnel axis with A headed against the end of the tunnel i.e. almost west. Deposition hole 6 has, however, been instrumented according to another strategy. The instruments have been placed in eight directions, where four directions are represented in each instrumented block, see Figure 3-3.

Every instrument is named with a unique name consisting of 1 letter describing the type of measurement, 2 letters describing where the measurement takes place (buffer, backfill, rock or canister), 1 figure denoting the deposition hole (5-6) and 2 figures specifying the instrument according to a separate list. Every instrument position is then described with three coordinates according to Figure 3-1.

The r-coordinate is the horizontal distance from the center of the hole and the z-coordinate is the height from the surface of the bottom casting of the hole (the block height is set to 500mm). The α–coordinate is the angle from the vertical direction A (almost West).

The bentonite blocks are called cylinders and rings. The cylinders are numbered C1-C4 and the rings R1-R10 respectively (Figure 3-2).

The final position of each instrument in the deposition holes is presented in Chapter 4.4 and Appendix I.

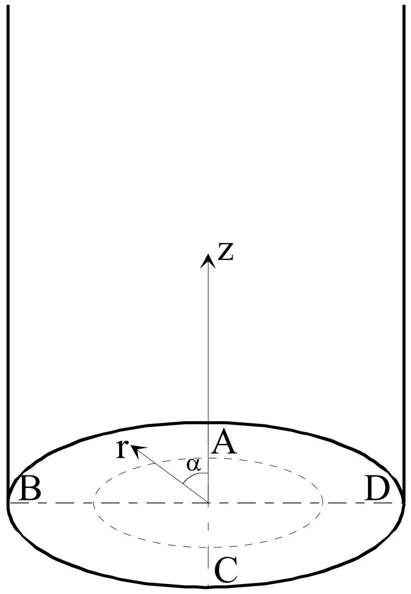


Figure 3-1. *The coordinate system used when describing the instrument positions in the deposition holes.*

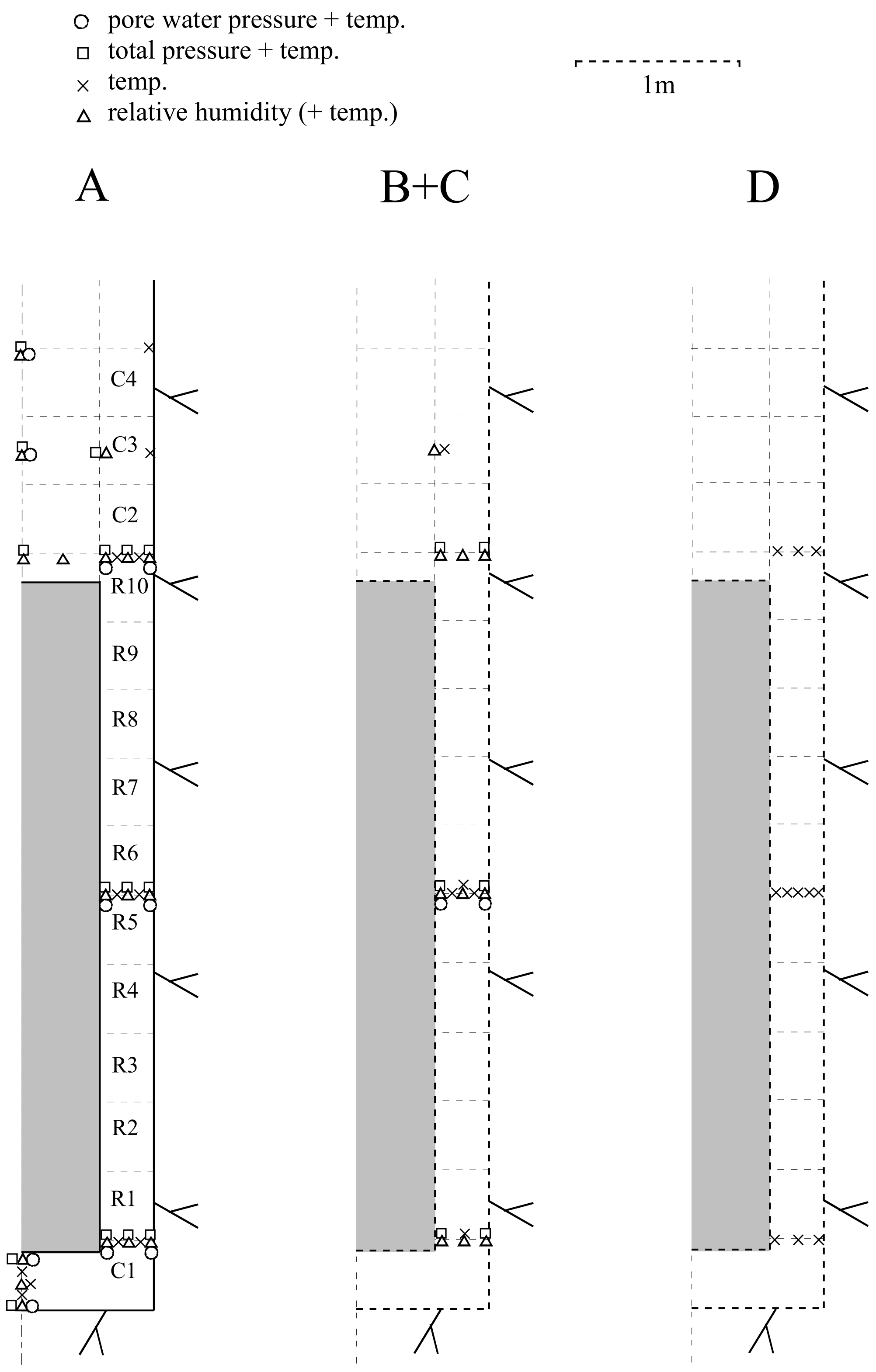


Figure 3-2. *Schematic view of the instrument positions in deposition hole 5 and the used block designation. The instruments are placed in four vertical sections.*

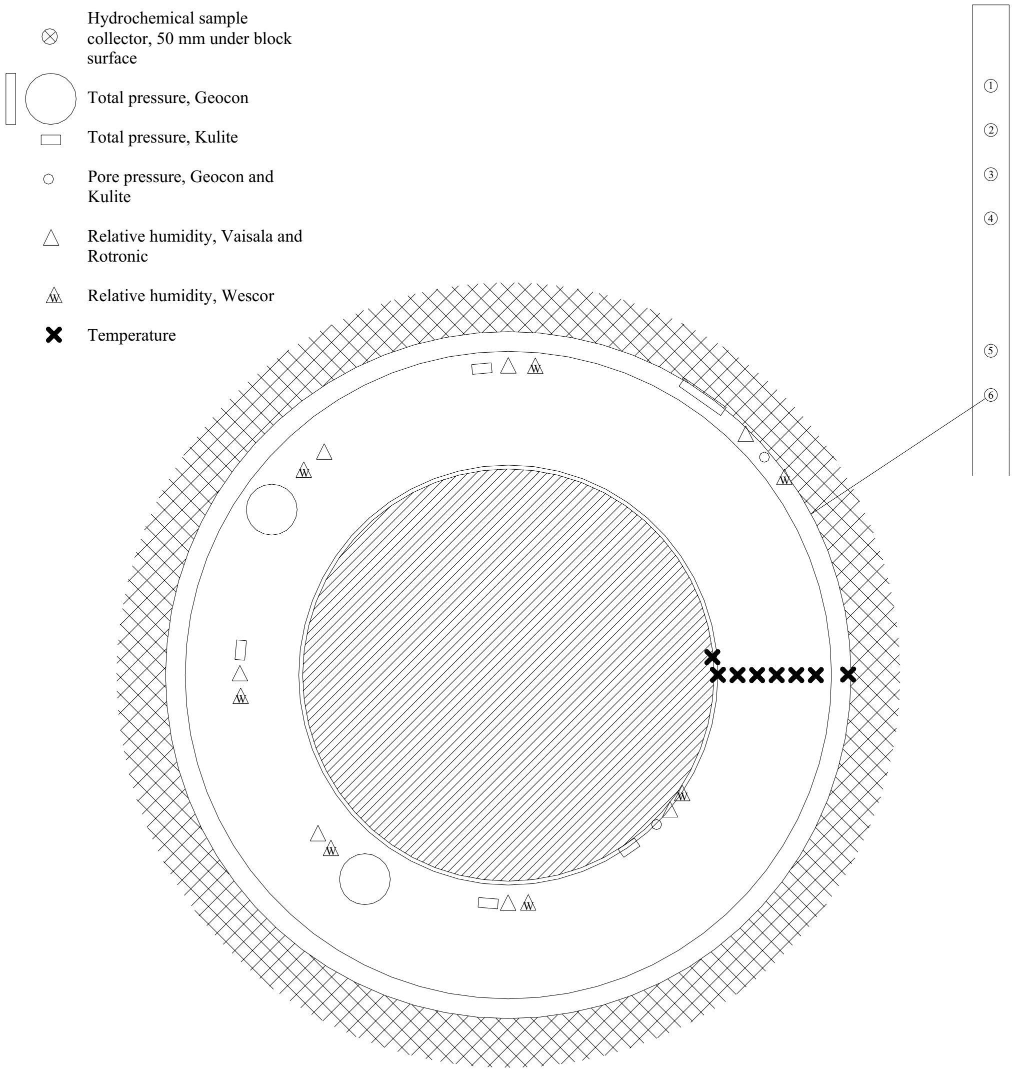


Figure 3-3. *Schematic view over the instruments positions in deposition hole 6. The instruments are placed in eight vertical sections, where four sections are represented in each instrumented block.*

3.3 Position of each cable and tube on the bentonite block periphery

All cables and tubes from the instruments in the bentonite blocks, the four optic cables the three power cables from the canister were planned to be led out of the hole along the bentonite block periphery surface.

Since the cables and tubes were led in the gap between rock and bentonite in the deposition holes it was important to distribute them on the block periphery in a prescribed order. Every cable or tube was assigned an α−coordinate, which is the angle from direction A (Figure 3-1). The cables were led from the sensor in this direction in pre-manufactured tracks on the block surface.

3.3.1 Cables and tubes from instruments in the bentonite

All instrument cables were led in titanium tubes (Ø 8 mm or Ø 6 mm) except for the thermocouples (Ø 4 mm), which are made of cupro nickel. Tracks were made on the block surface from the instrument position in the bentonite block to the specified position on the bentonite block periphery, where they were bent and led vertically along the bentonite blocks. Expandable strings were placed on about every third block in order to fix the cables.

3.3.2 Cables from the canister

The following cables are coming from the canisters:

- 3 x 32 mm power cables from the electrical heaters
- 4 x 2 mm fiber optic cables (two loops) from the temperature measurements on the canister surface

The directions of the cables are shown in Figure 3-4.

The cables were led from the canister through the bentonite in slots sawed in advance in block no R10 (see Figure 3-4). The cables were then led out from the hole along the slot between the bentonite blocks and the rock surface.

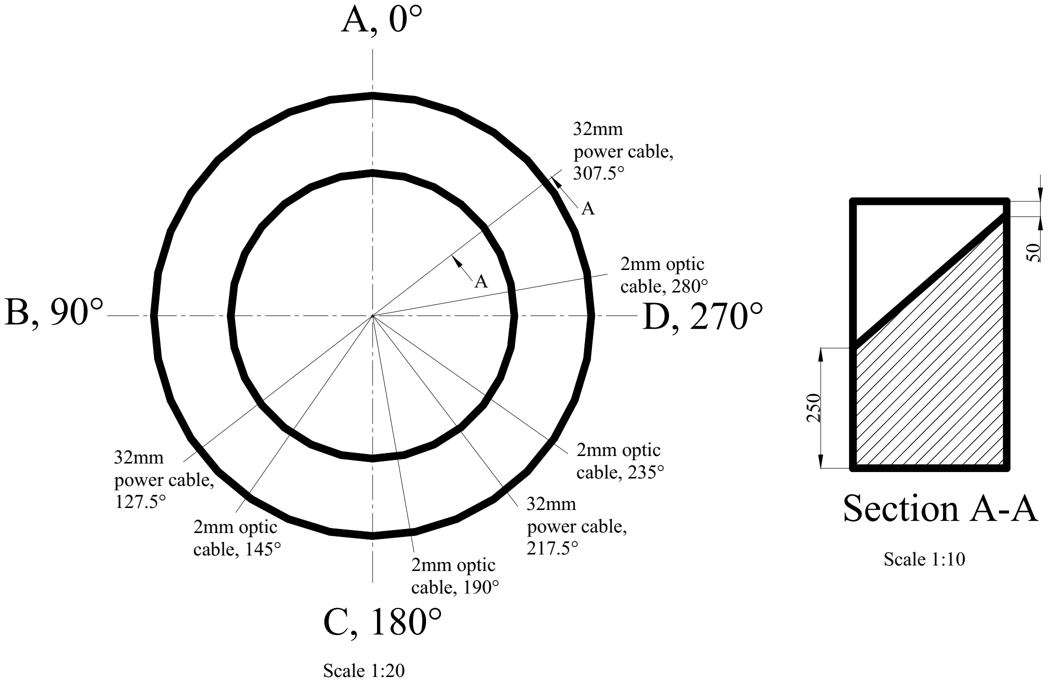


Figure 3-4. Figure showing the directions of cables from the canister relative the instrument directions A, B, C and D in block R10. In this block slots were sawed in order to let the cables from the canister pass through the bentonite and out to the rock. The widths of the slots are about 40 mm for the power cables and about 5 to 10 mm for the optic cables.

3.4 Preparation of the bentonite blocks

3.4.1 Clearances for instruments

Every instrumented block was prepared in advance. The preparation was somewhat different depending on instrument type.

Thermocouples

- The thermocouples have an outer diameter of 4.0 mm. A handhold boring-machine was used at installation. *Working:* Borehole Ø 5 mm; depth 50-450 mm.

Total pressure

- **Geokon.** The transducers are shaped as ice hockey pucks with a diameter of 125 mm and a thickness of 22 mm. The instruments were countersunk in the bentonite block surface by use of a handhold cutter. *Working:* Borehole Ø 126-130 mm; depth 25 mm.

- **Kulite.** The transducers are shaped as ice hockey pucks with a diameter of 55 mm and a thickness of 23 mm. All instruments were placed vertically, which means that an almost rectangular hole is needed. The clearances were done by drilling 2-3 holes with a diameter of 25 mm in a row and then form the hole with a chisel. *Working:* Borehole Ø 25mm; depth 160-250 mm. The shape of the rectangular hole was cut with a chisel.

Pore pressure

- **Geokon.** Shaped as cylindrical tubes with 25 mm outer diameter and 127 mm length. The holes for these gauges were bored with a drilling machine of Hilti-type fixed with a vacuum plate. *Working:* Borehole Ø 27mm; depth 250mm.

- **Kulite.** Shaped as a cylindrical tube with 19 mm outer diameter and 55 mm length. The holes for these gauges were bored with a drilling machine of Hilti-type fixed with a vacuum plate. *Working:* Borehole Ø 20mm; depth 160-250 mm.

Relative humidity

- Vaisala. Shaped as cylindrical tubes with 22 mm outer diameter and 63 mm length. The holes for these gauges were bored with a drilling machine of Hilti-type fixed with a vacuum plate. *Working:* Borehole Ø 23 mm; depth 160-250 mm.

- **Rotronic.** Shaped as cylindrical tubes with 22 mm outer diameter and 135 mm length. The holes for these gauges were bored with a drilling machine of Hilti-type fixed with a vacuum plate. *Working:* Borehole Ø 23mm; depth 250 mm.

- **Wescor.** Shaped as a cylindrical tube with 22 mm outer diameter and 70 mm length. The holes for these gauges were bored with a drilling machine of Hilti-type fixed with a vacuum plate. *Working:* Borehole Ø 23mm; depth 160-250 mm.

Other measurements

- **Aitemin.** Aitemin are measuring canister displacements. The instruments are located in deposition hole 6, in blocks C1 and R10. Most of the preparation was done during installation. Three vertical holes were drilled in advance. *Working:* Borehole Ø 40 mm, through the block.

3.4.2 Tracks for cables and tubes on the bentonite blocks surface

Tracks for the cables from each instrument to the block periphery were made on the block surface. The tracks were made by a handhold cutter.

Working: For all tubes from the instruments, except for the thermocouples, tracks with the dimension 10 x 10 mm were made. For the thermocouples tracks with the dimension 6 x 6 mm were made. Close to the sensor holes, the tracks were made deeper in order to let the tube have a smooth bend (Figure 3-5).

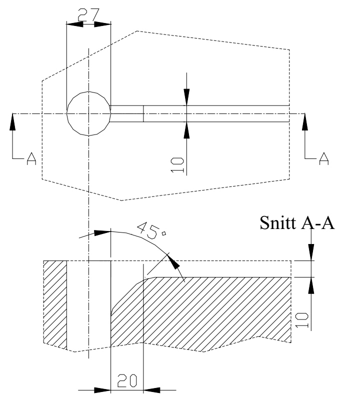


Figure 3-5. *Schematic view showing an example of how the tracks on the bentonite block surface were connected to the sensor holes.*

3.4.3 Clearances for cables through block R10

The cables from the canisters were led through the bentonite in block R10 by sawing slots in the bentonite block in advance (see Figure 3-4). The slots have different width depending on the cable type. They were sawed with an alligator-type of saw.

Working: The depth and shape of the slots are shown in Figure 3-3. The widths of the slots are about 40 mm for the power cables and 5 mm for the fiber optic cables.

3.4.4 Clearances for the bottom of the canister in block C1

The canisters are standing on the cylindrical bottom block. The canisters are by design equipped with a skirt on the bottom (see Figure 3-6). A corresponding track was drilled with a drilling machine of Hilti-type fixed with a vacuum plate.

Working: Holes with a diameter of 120 mm were seam-drilled to a depth of 85 mm. The track was then worked out by cutting with chisels.

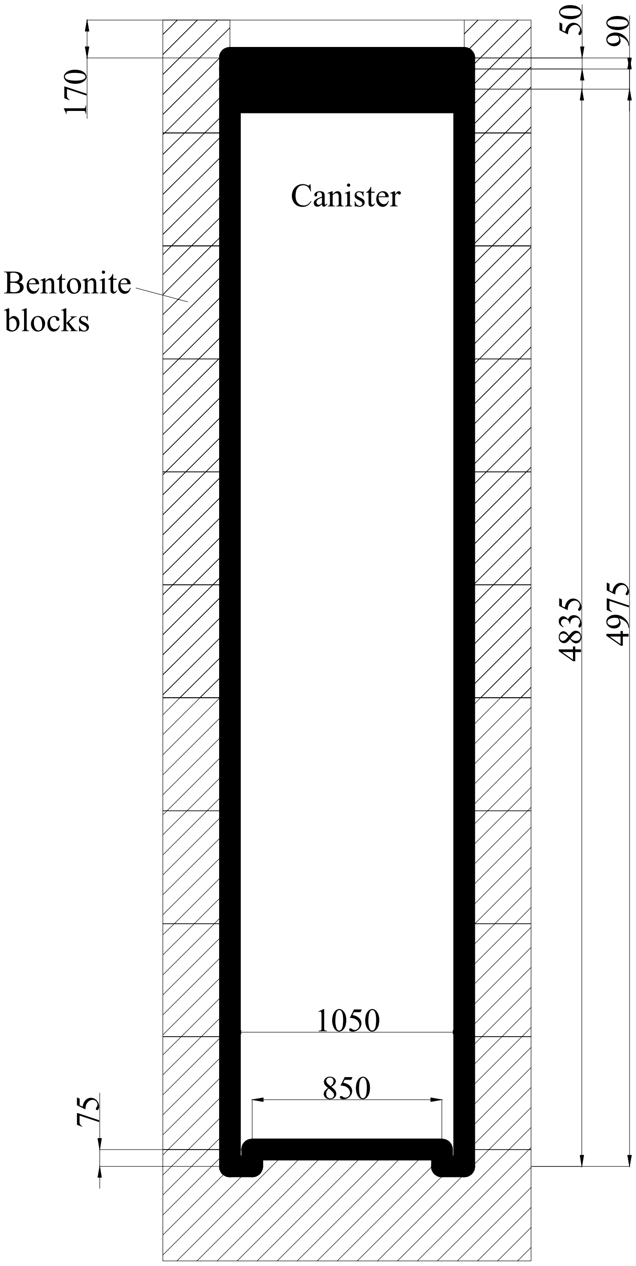


Figure 3-6. *Schematic view of a canisters position in relation to the position of the bentonite blocks.*

4 Installation of the buffer and the canisters

4.1 General

The blocks used for buffer material in the Prototype Repository were made of Na-bentonite MX-80 mixed with tap water and were compacted to two different shapes; ring shaped blocks, which are placed around the canister and massive cylindrical blocks, which are placed above and under the canister. The blocks were uniaxially compacted in a rigid form to an outer diameter of about 1650 mm and a height of about 500 mm. The inner diameter of the ring shaped blocks is about 1070 mm. In order to have similar average density everywhere (including the slots), the two types of blocks were compacted to different densities (see Chapter 4.4 in this report). The initial average weight, water ratio, density and void ratio of the two types of block are listed in Table 4-1. The table also shows the load and compaction pressure used at the compaction. The technique for compacting the blocks is described in detail in /4-1/.

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

Block type	Weight (kg)	Water ratio (%)	Density (kg/m^3)	Degree of saturation	Void ratio	Compact. load (MN)	Compact. pressure (MPa)
Ring	1264	17.3	2075	0.841	0.571	121	100
Cylinder	2126	17.4	2012	0.778	0.623	84	40

The buffer material and canisters have been installed in DA3551G01 (Deposition hole 5, Dh 5) and DA3545G01 (Dh 6). Transducers were installed in the buffer in both of the deposition holes. During preparation and installation the blocks were designated according to Figure 4-1. The activities carried out during the installation of the buffer in Dh 5 are listed in Table 4-2. The activities are described in detail in Chapter 4.2. The same types of activities were carried out for Dh 6 although more blocks where instrumented.

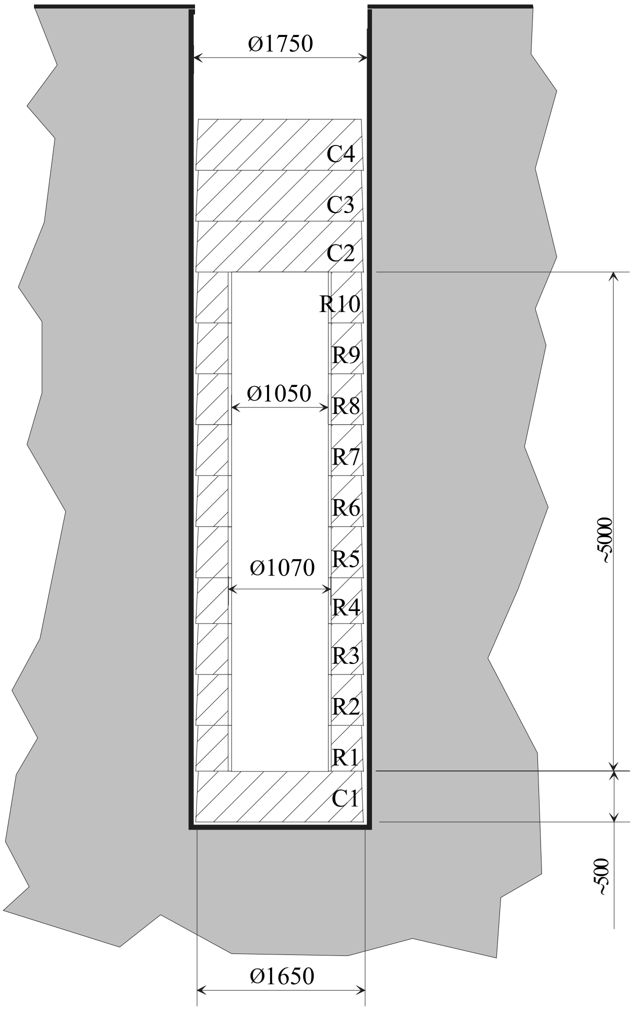


Figure 4-1. *Designation of blocks in the deposition hole (prefix Dh 5 and Dh 6for the two deposition holes).*

Table 4-2. List of activities performed during the installation of the buffer in Dh 5.

ID	Activity	Note
1	Preparation of the deposition hole	See Section 4.2.1
2	Mounting of gantry-crane	See Section 4.2.2
3	Installation of water protection sheet in the deposition hole	See Section 4.2.3
4	Deposition of bentonite block C1.	See Section 4.2.4
5	Instrumentation of bentonite block C1	See Section 4.2.5
6	Deposition of bentonite blocks R1-R5.	See Section 4.2.4
7	Instrumentation of bentonite block R5	See Section 4.2.5
8	Deposition of bentonite blocks R6-R10.	See Section 4.2.4
9	Instrumentation of bentonite block R10	See Section 4.2.5
10	Transportation of canister	See Section 4.2.6
11	Mounting of the deposition crane	See Section 4.2.7
12	Deposition of canister	See Section 4.2.8
13	Connecting heaters and cables	See Section 4.2.9
14	Installation of small blocks on the lid of the canister	See Section 4.2.10
15	Deposition of bentonite blocks C2 and C3	See Section 4.2.4
16	Instrumentation of bentonite block C3	See Section 4.2.5
17	Deposition of bentonite block C4	See Section 4.2.4
18	Instrumentation of bentonite block C4	See Section 4.2.5
19	A plastic sheet was placed over the uppermost block C4	See Section 4.2.11
20	Installation of displacement and moisture transducers	See Section 4.2.12
21	Restoring the road bed	
22	Continuous registration of displacement and moister	See Section 4.2.13
23	Filling bentonite pellets	See Section 4.2.14

4.2 Procedures for deposition of buffer and canisters

4.2.1 Preparation of the deposition holes

The following preparations of the deposition holes were done before start deposition:

Cleaning of the deposition holes

The deposition holes were cleaned before the installation of the buffer. This work was done with a vacuum cleaner.

Mounting of pumps in the deposition holes

One pump was temporarily installed in each of the deposition holes 5 and 6. The pipes used for pumping up water had an inner diameter of 21 mm. The length of the pipes was about 7.5 m. The pipes were cut in 45º at one end. The pipes were placed standing in the sump with the 45º end in the sump and the other end attached to the surface of the deposition hole. A hose leading from the drainage pipe to the pump and from the pump to the spillway was mounted.

A separate float switch was placed together with the drainage pipes in the sump to secure that the water level never exceeded the top of the concrete slab.

4.2.2 Mounting of gantry-crane

The mounting of the gantry-crane over the deposition hole was done in the following steps:

- The gantry-crane was transported to the Prototype tunnel with a front loader.
- The position of the gantry-crane in the tunnel during deposition was determined (input for the calculation is the co-ordinates of the centre of the deposition hole and the dimensions of the gantry-crane)
- A surveyor's assistant marked the positions of the four feet of the gantry-crane on the tunnel floor.
- The gantry-crane was placed over the deposition hole with its feet placed in the marked positions.
- A check was made that the gantry-crane was placed in a horizontal position (with a spirit level)
- The gantry-crane was operated according to the manual for the crane.

4.2.3 Installation of water protection sheets in the deposition hole

A plastic sheet formed as a large tube with a diameter of 1910 mm was attached to the rock surface of the deposition hole in order to prevent wetting of the bentonite buffer during the installation phase. The sheet was attached to the concrete slab with an O-ring. The O-ring was removed after the installation of the buffer and the canister and the plastic sheet was pulled up from the deposition hole before the slot between the compacted bentonite blocks and the rock surface was filled with pellets of bentonite.

4.2.4 Deposition of bentonite block C1 and R1-R10

The deposition of the bentonite blocks was made in the following steps:

- The bentonite block was transported to the gantry-crane in its case with a loader.
- The cap of the case was removed with the loader.
- The number on the case was noted and the height of the blocks measured in four positions. The diameter of the block was also measured and noted.
- The block was examined by eye. Any observed damages on the blocks were noted
- The block was attached to the lifting equipment with four straps and moved in position and lowered in the deposition hole with a gantry-crane (see Figure 4-2).
- The block was centred in the deposition hole. The final adjustment of the position of the block was made just before the block was put in place in the deposition hole.
- After placement, the four straps were released from the block and the lifting equipment was removed from the deposition hole.
- The depth from the upper part of the deposition hole to the upper surface of the block was measured with a laser in four positions and noted in a protocol. Also the radial distance from the rock surface to the outer diameter of the block was measured in four points.
- The final height of the bentonite buffer was measured by levelling the uppermost block.

Figure 4-2. A bentonite block attached to the lifting equipment with four straps.

4.2.5 Instrumentation of bentonite blocks

The preparation of the bentonite blocks for the instrumentation is described in Chapter 3 in this report. The installation of each instrument was done in the following steps:

- The tube with the transducer was taken from the packages hanging on the tunnel wall. The mark on the transducer was checked against the list in protocols.
- The tube with the transducer was lowered in the deposition hole.
- The position of the transducer was checked and noted.
- The tube was bent to fit the holes and the grooves in the block and the transducer was installed.

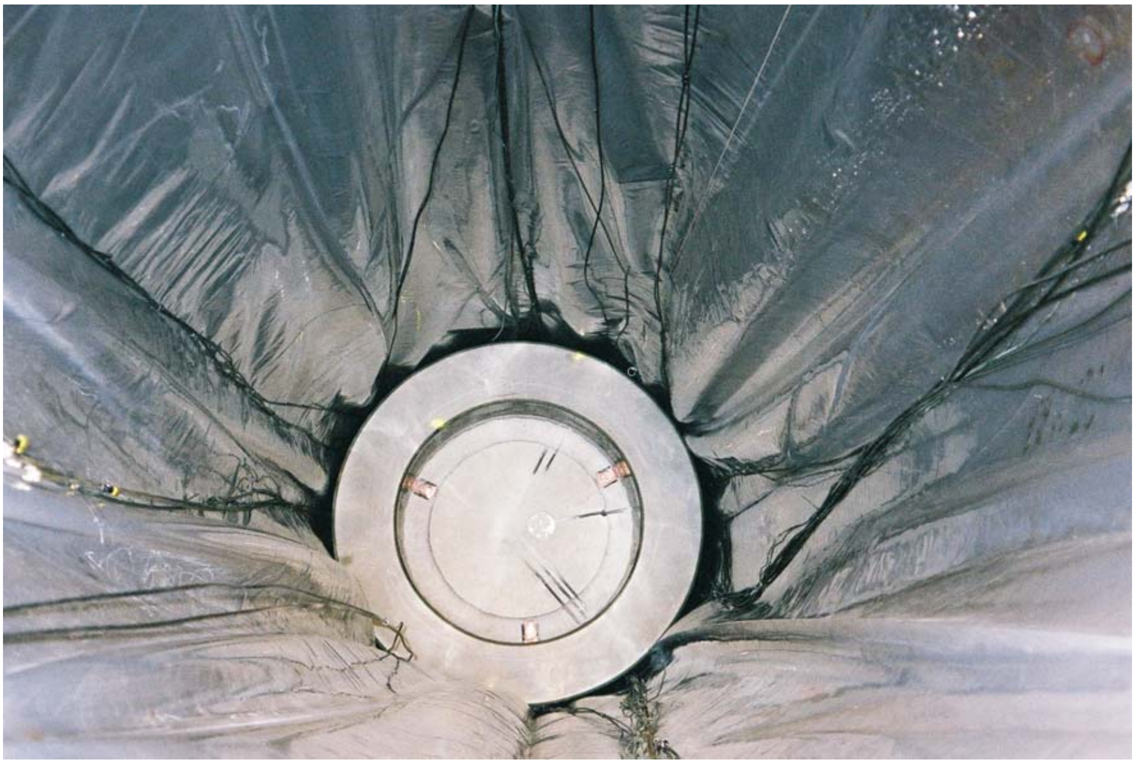


Figure 4-3. *A photo taken after installation of the bottom block and the first bentonite ring, showing also the plastic sheet and several transducers installed in the bottom block.*

4.2.6 Transportation of the canisters

The canisters were transported in to the tunnel placed on the deposition-machine in a horizontal position. A trailer has been constructed for the transportation of the machine. The deposition-machine with the canister was placed on the trailer, which was attached to a heavy vehicle and transported down the Äspö tunnel to the level -420 m. During transportation a front loader had to be connected to the back of the trailer in order to keep the trailer in the right position. Finally, a small truck of type SISU was used for transportation of the trailer with the canister from level -420 to the Prototype Tunnel. It was found out that during the transportation and the handling of the canister for deposition hole 5 one of the optical cables was broken. The cable was fixed and the joint was protected with a steel tube placed on the surface of the canister (see Figure 4-4). Some preparing of the bentonite block R10 was done for fitting the joint of the optical cable.

Figure 4-4. *The tube with the fixed optical cable placed on the surface of the canister with tape. The tape was removed before the deposition of the canister.*

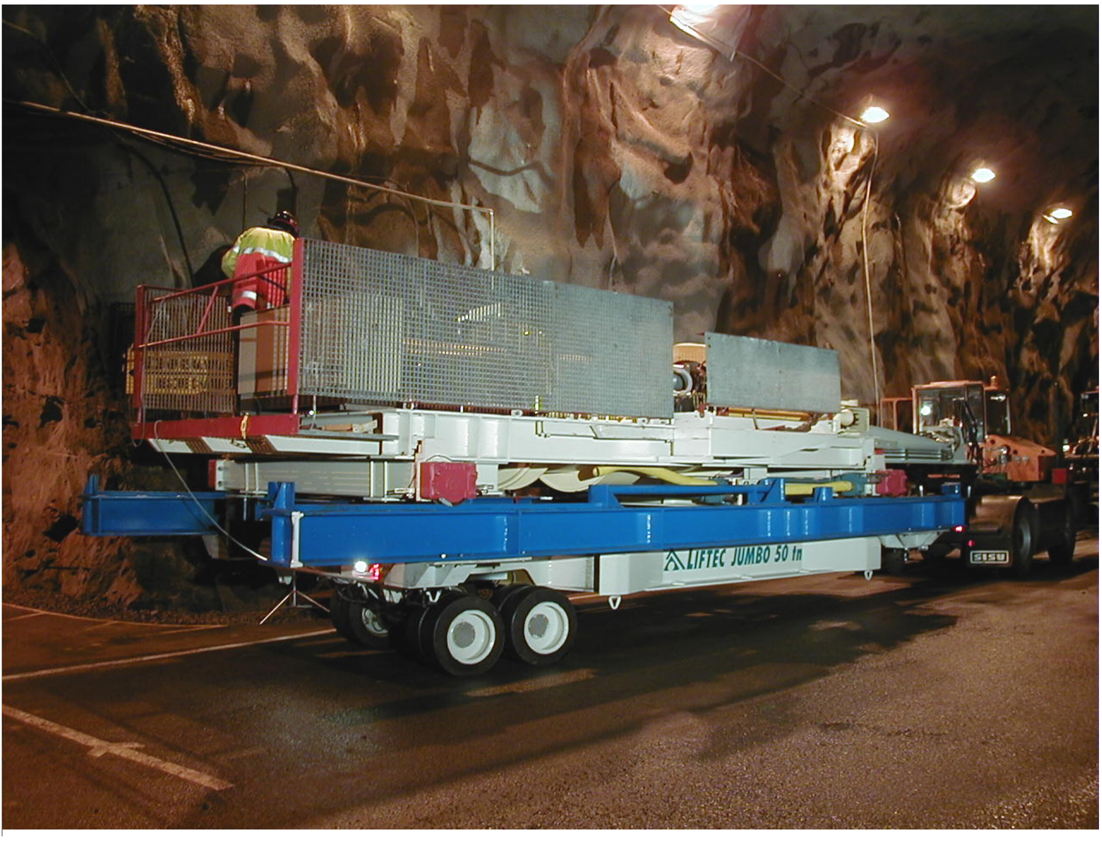


Figure 4-5. *The canister and deposition-machine placed on a trailer.*

4.2.7 Mounting of the deposition machine

The trailer with the deposition-machine was placed over the deposition hole with the SISU truck. The position of the adjustable four legs of the deposition machine was marked on the roadbed by a surveyor's assistant in advance. Small adjustments of the trailer were made in order to get the legs over the marked positions. The deposition machine was then lifted with the adjustable legs and the trailer was pulled out from the tunnel. The deposition machine was levelled, the sidewalks were mounted and the transport locking devices of the canister were removed.

4.2.8 Deposition of the canister

The canister was placed horizontally on the deposition machine in a frame which could be moved both horizontally and vertically relative the rest of the machine. A lifting plate with two large chains was attached to the lid of the canister. The chains were used for lifting the canister into the deposition hole. The work was done in the following steps:

- The canister was placed in a vertical position over the deposition hole by tilting the canister and at the same time move the frame both in horizontal and vertical direction.

- By using the chains the canister was moved vertically in to the deposition hole in steps.

- The lifting plate was unscrewed from the lid of the canister and lifted from the deposition hole with the chains in steps.

- The frame was tilted to a horizontal position. The sidewalks on the sides were removed and the transport locking devices were put in place.

- The trailer was placed under the deposition-machine with the SISU truck and the deposition machine was placed on the trailer by shorten the adjustable legs. The trailer was then pulled out from the tunnel.

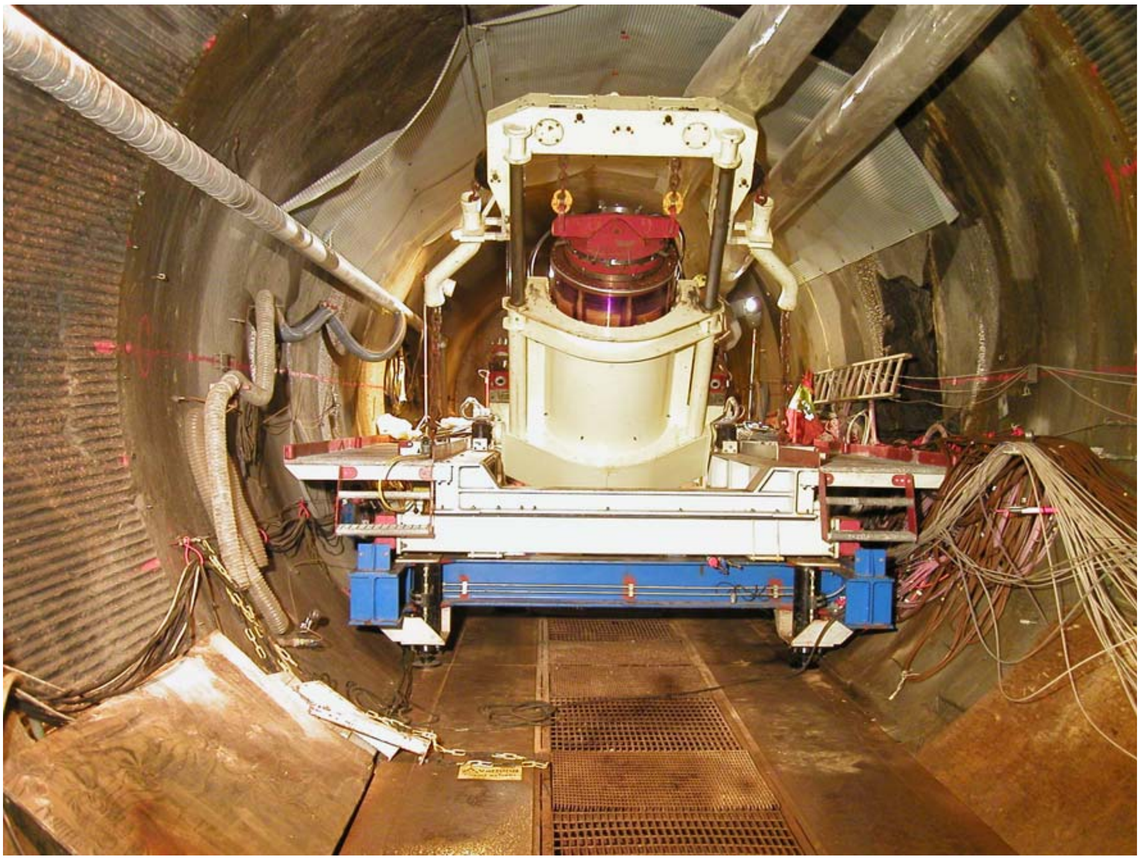


Figure 4-6. *The canister tilted into the deposition hole.*

Figure 4-7. *The canister placed in the deposition hole.*

4.2.9 Connecting heaters and cables on the canister

The cables from the heaters were connected to the system for generating power. Furthermore the optical cables for measuring the temperature on the surface of the canister were connected to the data acquisition equipment. This work was done as follows:

- When the canister was placed in the deposition hole the lifting oak was demounted from the canister and removed from the deposition hole.
- A surveyor's assistant checked the position of the canister.
- 12 bolts were unscrewed from the canister lid and 2 guide taps were attached to the boltholes.
- A ring of copper was mounted on the top of the canister and several intermediate partitions were attached to the lid of the canister.
- The cables from the heaters were lead through the intermediate partitions and out from the canister. The cables were sealed to the ring with silicon.
- The lid of the canister was cleaned with a vacuum cleaner
- The volume between the ring, the lid of the canister and the intermediate partitions was filled with a mixture of 30% bentonite and 70% sand.
- An upper lid was fastened to the canister with 12 bolts.
- Both the power cables and the optical cables were checked after the installation. The results from the measurements were noted in a protocol.

4.2.10 Installation of small blocks on the lid of the canister

Highly compacted ring-shaped bentonite blocks will, after installation, surround the canister. The rings have 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 233x114x65 mm^3). The average height of 10 ring shaped blocks is about 5085 mm and the length of the canister 4900 mm. The height of the volume filled with small bentonite blocks was thus 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 1950 kg/m^3.

The bricks were made of MX-80 bentonite with a water ratio of 17% at Höganäs Bjuf AB in Bjuv. They were made by uniaxial compaction of MX-80 bentonite with a water content of about 17%. Each block had a dry density of 1700 kg/m^3 and a weight of about 4 kg.

The placement of the small bentonite blocks was made as follows:

- The blocks were lowered in a basket to the top of the canister in the deposition hole.
- The placement was made by hand.
- In order to fill the volume above the canister some of the blocks were cut in smaller pieces. This was made with a saw.
- The weight of all the blocks installed was noted in a protocol for the purpose of calculating of the final bulk density. The slots between the blocks were filled with bentonite pellets and powder. The weight of the powder and the pellets was also noted in a protocol.

Figure 4-8. *Bricks of bentonite placed on top of the lid of the canister.*

4.2.11 Covering of bentonite block C4 with plastic

A plastic sheet was placed over the uppermost bentonite block (C4) and attached to the plastic sheet on the wall of the deposition hole with tape.

4.2.12 Installation of temporary displacement and moisture transducers

Two types of transducers were installed in order to measure the condition of the blocks during the time between the deposition of the bentonite blocks and the installation of the pellets. One transducer (Solartron B.I.C.M) for measuring the temporary deformation of the buffer was installed on top of the plastic sheet. The transducer was placed in a holder attached to the surface of the deposition hole. Another transducer was installed for measuring relative humidity (Vaisala RH transducer HPM 237) in the slot between the bentonite blocks and the rock surface inside the plastic sheet. The cables from the transducers were led through the A-tunnel to the G-tunnel and connected to the data acquisition equipment.

4.2.13 Continuous registration of displacement and moisture

RH in the deposition hole and displacements of block C4 were recorded every hour with the data acquisition equipment.

4.2.14 Filling bentonite pellets

In order to get a buffer with a sufficiently high density the slot between the bentonite blocks and the rock surface was filled with pellets of bentonite. The bentonite pellets had the width and length of 16.3 mm and a maximum thickness of 8.3 mm. The bulk density of the separate pellets varied between 1970 and 2110 kg/m^3. The expected bulk density of the filling was between 1100 and 1300 kg/m^3. The pellets were placed just before backfilling the uppermost part of the deposition hole.

The sequence was as follows:

- The plastic sheet on top of the bentonite block C4 was removed and the plastic sheet between the bentonite blocks and the wall of the deposition hole was pulled out of the hole.
- The pellets were delivered in big bags containing about 1 ton. The weight of all bentonite pellets used for the filling was noted.
- Several large tubes were attached to a vacuum cleaner and applied close to the slot between the bentonite blocks and the rock surface. With this arrangement it was possible to minimize the dust in the tunnel during the filling.
- The pellets blowing machine was filled with pellets. From the top of the last installed bentonite block the pellets were blown into the slot through a nozzle. The pellets blowing machine is described in /4-2/.

The installation of the buffer and the deposition of the canisters were carried out during the period 2003-01-10--04-17. The pellets filling in the slots of the deposition holes was carried out when the backfilling hade reached the edge of the different holes during the period 2003-05-08--05-22.

4.3 Density of the installed buffer

As described in previous chapters, the buffer of bentonite consists of highly compacted large blocks, small bricks of bentonite on top of the canister lid and pellets of bentonite in the outer slot between the bentonite blocks and the surface of the deposition hole. In Table 4-3 the weights and the water ratios of the different parts of the installed bentonite buffer are listed. About 21100 kg bentonite was used in each deposition hole for the large blocks. The weight of the pellets varied from 2900 kg to about 3000 kg. The weight of the installed small bricks was about 330 kg. Using the weight and water ratio of the bentonite together with the measured dimensions of the deposition holes it is possible to calculate the average density of the buffer (or the void ratio). These parameters are also listed in Table 4-3. The calculations are made with the assumption that no axial swelling of the buffer will occur during the water uptake. The calculated average density at saturation varies between 2020-2030 kg/m^3.

The large bentonite blocks were compacted to different densities, in order to get as homogeneous buffer as possible after the installation. The blocks placed underneath and above the canister (cylindrical blocks) were compacted to a bulk density of about 2010 kg/m^3 while the ring shaped blocks, placed in the canister sections, were compacted to a density of about 2075 kg/m^3. In Table 4-4 the densities and void ratio for the buffer calculated at three different sections in the deposition holes are listed. These three sections correspond to underneath the canister (Section A), between the canister and the rock (Section B) and just above the lid of the canister, where the bricks of bentonite were placed (Section C). The largest variation in density was yielded in deposition hole DA3545G01 (Dh6), where the calculated density varied between 2012 and 2067 kg/m^3. Also these calculations are made with the assumption that no axial swelling of the buffer will occur.

Table 4-3. The weight and water ratio of the blocks and pellets installed in the deposition holes and the average density of the buffer

Deposition hole	Blocks Weight (kg)	 Water ratio (%)	Bricks Weight (kg)	 Water ratio (%)	Pellets Weight (kg)	 Water ratio (%)	Average Density at sat. (kg/m^3)	 Void ratio
DA3551G01 (Dh5)	21118	17,3	330	15,1	3000	13,1$^{*)}$	2027	0,734
DA3545G01 (Dh6)	21168	17,4	335	13,7	2870	13,1$^{*)}$	2022	0,742

$^{*)}$ Measured at the delivery of the pellets

Table 4-4. Calculated density at saturation and void ratio for different parts of the buffer in the two deposition holes

Deposition hole	Section A Density at sat. (kg/m^3)	 Void ratio	Section B Density at sat. (kg/m^3)	 Void ratio	Section C Density at sat. (kg/m^3)	 Void ratio
DA3551G01 (Dh5)	2039	0,713	2017	0,750	2053	0,690
DA3545G01 (Dh6)	2034	0,722	2012	0,759	2067	0,668

4.4 Installation of instruments

220 instruments were installed in the buffer. They are described in detail in Chapter 3. Five of the transducers were spoilt during the installation. Two of these transducers were pore pressure transducers in deposition hole DA3551G01 (Dh5). They were broken during the bending of the titanium tube for the cables.

Sample collectors for collecting pore water from the buffer were also installed (totally 27 of them). A sample collector consists of a cup of titanium with a titanium filter on its top. After the buffer is saturated the cup will be filled with water. When the test is over and the excavation of the buffer has started, the cups will be located and the water analyzed. At the bottom of four of the cups there are tubes of PEEK going from the collector's through the rock to the G-tunnel with the purpose to take in situ samples of the pore water during the test period.

All the instruments and their coordinates are listed in Appendix I. Two types of coordinates are used for describing the position of the transducers. With the first type of coordinates the position of the instruments are described with a radius and an angle together with a depth coordinate (z-coordinate) as described in Chapter 3.2.2 and Figure 3-1. The second type of coordinates describes the positions of the instruments with the ÄSPÖ 96 coordinate system (X-, Y-, Z-coordinates).

5 Backfilling and instrumentation of the tunnel

5.1 Description of the backfilling of the tunnel

5.1.1 Overview of the backfilling

The tunnel was backfilled with 20 cm thick layers given the inclination 35°. An overview of the backfill layers is presented in Fig. 5-1.

The backfilling started from the plug of section 1 and continued until about 30 cm from the first deposition hole, DA3551. The plastic protecting the bentonite buffer in the deposition holes was removed and the slot between the blocks and the rock was filled with bentonite pellets. When the pellet filling was complete the remaining upper part of the deposition hole was backfilled and instrumented. When the last backfill layer in the hole had been compacted the backfilling of the tunnel started again. There were minor problems with removing the plastic and a small piece (about 0,25 m^2) could not be removed since it was stuck between the power cable and the rock in-between 1.5 and 1.7 meters below the top bentonite block.

The same procedure was repeated for the second deposition hole (DA3545G01). The same problem with the plastic as for the previous deposition hole was encountered and a 0.5 – 1 m^2 piece of plastic was caught between the power cables and the rock 1.5 – 1.7 m from the top bentonite block.

When the backfilling had progressed to the position of the plug the first prefabricated concrete beam was put in place. The beams are held in place with angle-irons bolted to the walls of the tunnel. The backfilling continued with 20 cm thick layers until the edge of the beam was reached and then the second beam was put in place. This procedure was repeated until it was not possible to reach with the compaction equipment. The remaining volume was filled with bentonite pellets and blocks containing 20 % bentonite and 80 % sand. When the last beam was in place the construction of the plug could start.

Instruments in the backfill and in the rock were installed as the backfilling progressed. Ventilation and lamps were also dismantled during the course of the backfilling. The roadbed was left in the tunnel as long as possible for the carrier to drive on. The carrier needed to be able to come close to the backfill layer in order to compact it. A special telescopic roadbed segment was used for making this possible. When the backfilling front came close to a roadbed segment, it was moved out of the tunnel and replaced by the telescopic roadbed.

The density was measured in every second layer. The position of each layer was determined. The length co-ordinates for the layer were determined at the roof, floor and walls. The backfilled material was weighed when it was transported into the tunnel.

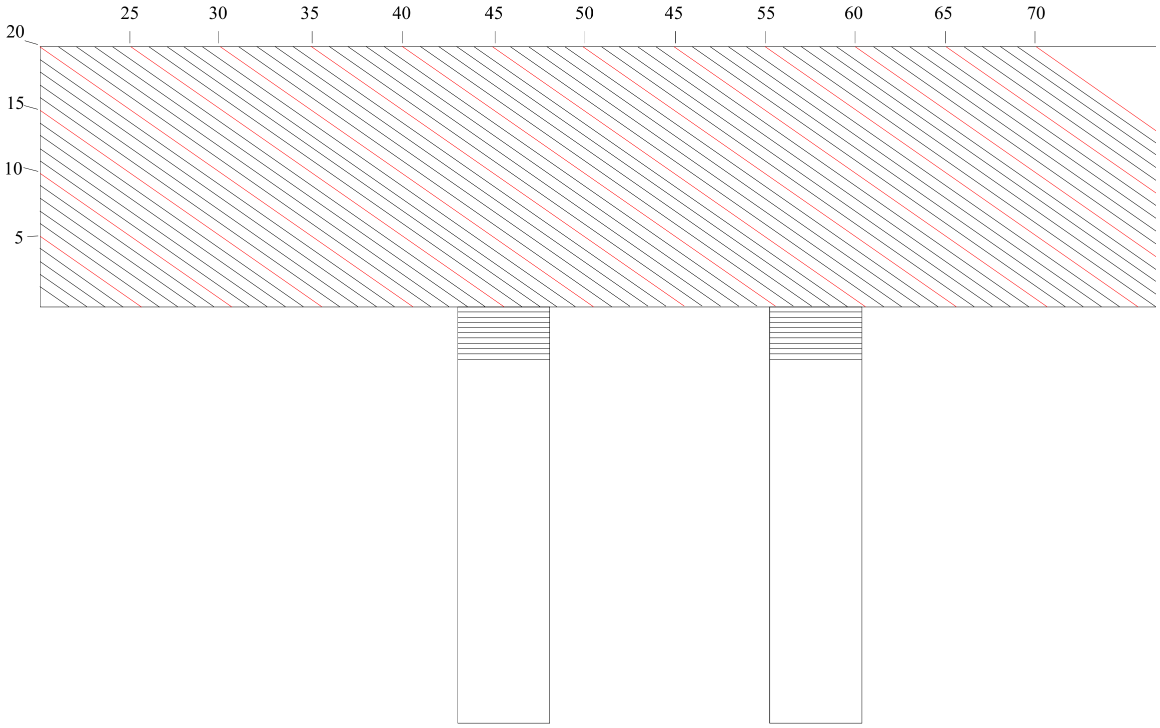


***Figure 5-1**. Overview of the backfill layers and their numbering in section 2*

5.1.2 Backfilling and instrumentation of the individual layers

The backfilling of one layer is described below and in Figure 5-2 and 5-3, a photo of the roof compactor is shown in Figure 5-4 and a photo of the slope compactor is shown in Figure 5-5.

1. 30/70 material for one layer was transported to the backfilling front. The mass of one layer was about 12 tons.

2. The material is pushed in place with the pushing tool. The layer was given a slightly concave shape.

3. The roof compactor was then used for compacting the material close to the roof. The purpose of this is to achieve a high density at the roof and to ensure a good contact between the backfill and the rock.

4. The rest of the layer was then compacted with the slope compactor. The compactor was placed 1.5 m from the floor and was then moved sideways over the layer. The compactor was moved from side to side over the layer and after each sweep the compactor was moved up the slope some 30 –50 cm and the sweeping motion was repeated. This was repeated as high up as the carrier / compactor could reach and then the compactor was moved down the layer with horizontal sweeps. This was repeated until the density was high enough. The last step was to compact the material close to the tunnel floor. In order to do this the compactor was turned 180 degrees.

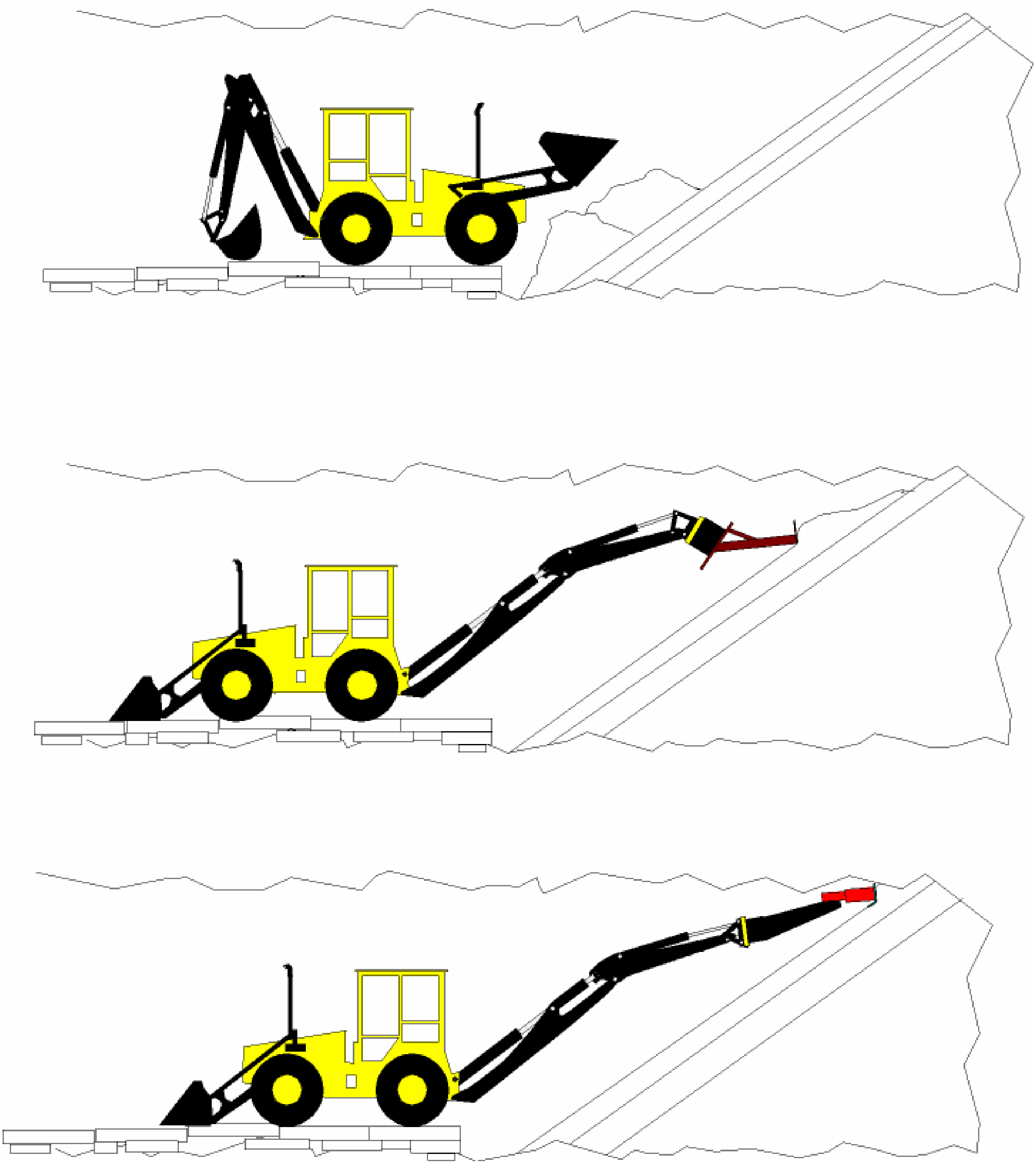


Figure 5-2. *The backfilling sequence for one layer*

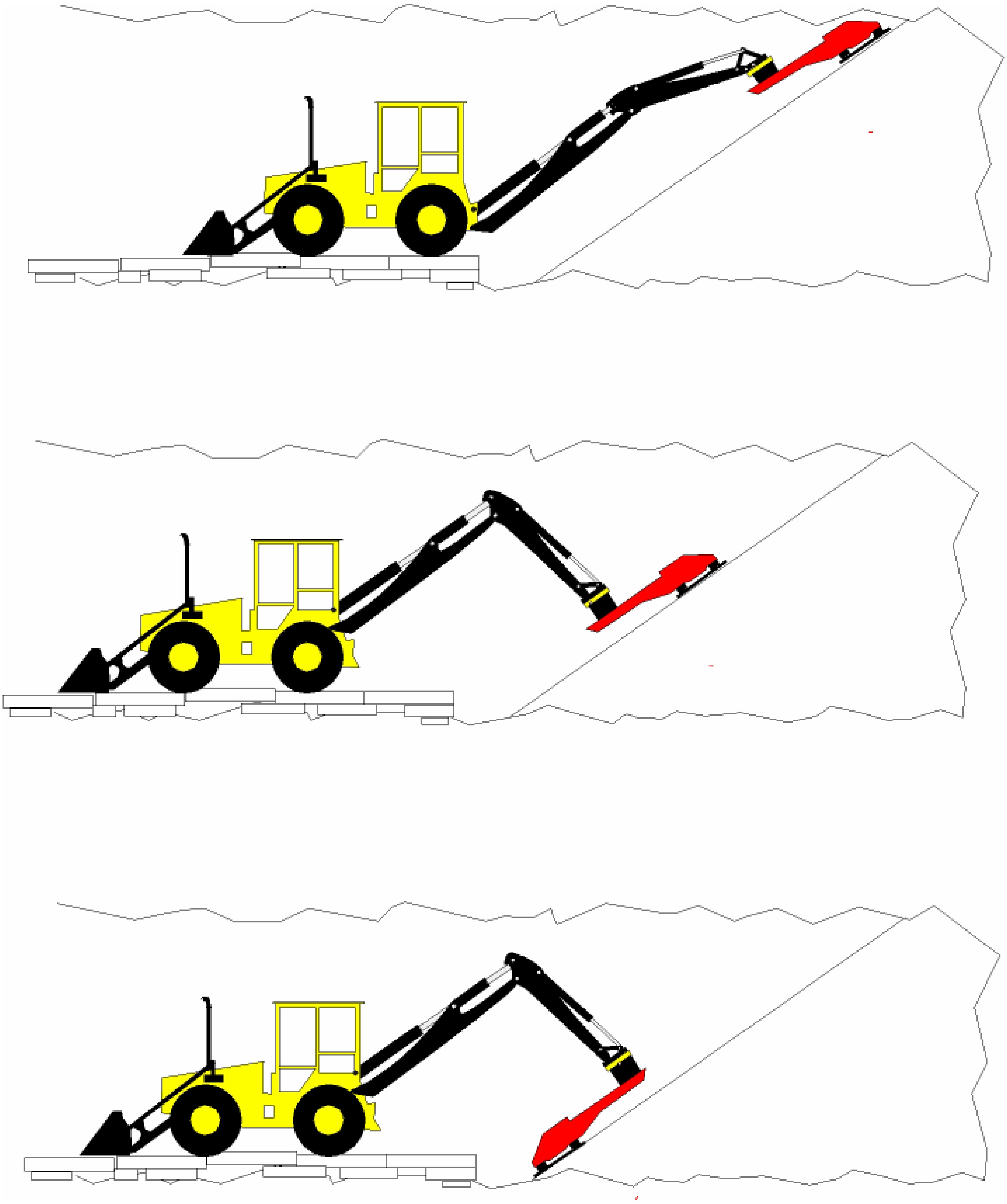


Figure 5-3. *The backfilling sequence for one layer.*

Figure 5-4. *The roof compactor.*

Figure 5-5. *The slope compactor.*

The locations of the sensors in the backfill are described in Appendix B1. Before the backfilling of the tunnel the cables and tubes for the instrumentation had been installed in lead-through holes leading to a neighbouring tunnel, see Figure 5-6.

Figure 5-6. *Cable package in place.*

The sensors and the length of the cables and tubes needed in the prototype tunnel had been made into bundles and hung on the walls of the tunnel. Each sensor was installed when the backfilling had progressed to the location intended for the sensor. To create as little disturbance in the backfill as possible the tubes and sensors were put in about 3 cm deep ditches in the backfill, see Figure 5-7.

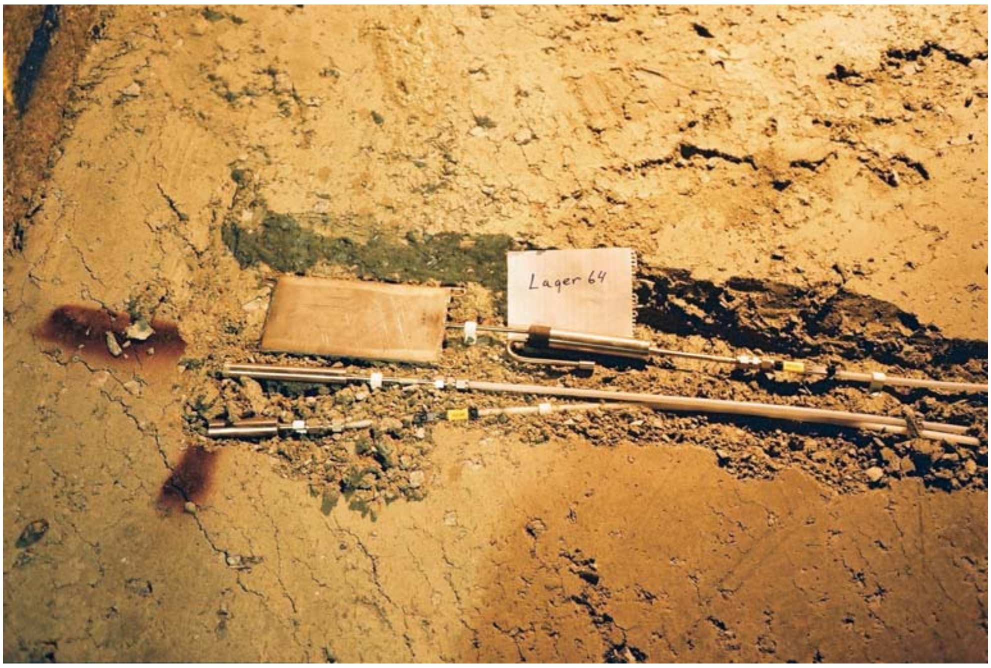


Figure 5-7. *Installation of sensors in the backfill.*

Bentonite powder was placed on and between the cables. The ditches were then filled with backfill material before the next backfill layer was compacted. The cables were lead in assigned cable corridors on the surface of the compacted layers (Figure 5-8). This was made to keep the areas where density measurements were made free from cables and tubes.

For the for measuring the position of the instruments and layers one line was drawn along the centre of the roof and two lines were drawn along the walls 2.5 m from the roof. The tunnel length was marked on the lines. Every fourth layer position had also been marked on the walls. The position of each backfilled layer was measured in the three points where the layers intersect the lines and in the centre of the tunnel.

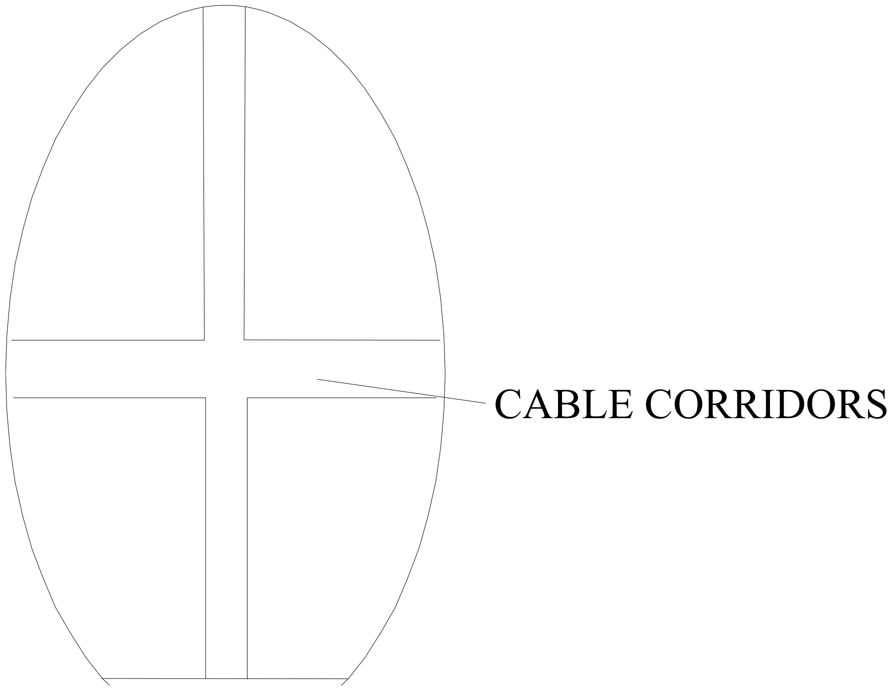


Figure 5-8. *Principle drawing showing the areas where cables and tubes were lead on the surface of the compacted layer.*

5.1.3 Backfilling of the upper part of the deposition holes

Ten 10 cm thick backfill layers were compacted in each deposition hole. For the first layer 30/70 the water ratio was low (about 5 %) in order to avoid that the top bentonite block adsorbed water and started to swell. A high number of tubes were led out from the slot between the bentonite blocks and the rock. The other end of the tubes was fixed in the lead-through plates. Each instrument had from 5 to 15 meters of excess tube. These tubes were taken care of in the upper part of the deposition holes and in the tunnel. Apart from the excess tube about ten sensors in each instrumented hole had an amplifier box ten meters from the sensor. The boxes were placed in the excavations at the lead-through and at the inner side of the deposition holes, see Figure 5-9.

Figure 5-9. *The Vaisala amplifier boxes.*

When the plastic had been removed and the bentonite pellets had been poured into the slot the tubes from the blocks were led in the periphery of the holes to the slot in the rock leading to the lead through, see Figure 5-10.

Figure 5-10. *The backfilling and instrumentation of the top of a deposition hole.*

The aim was to cross as few cables as possible. The excess tubes were made into bundles close to the lead-through plate, see Figure 5-11.

Figure 5-11. *Handling of cables and tubes.*

The backfill in the deposition holes had to be compacted to a high density. At the same time it was very important not to harm the tubes from the sensors. To accomplish this, a hand held compaction device was used for the compaction and the compacted layer thickness was decreased to 10 cm.

The layers were given a concave shape so that it was possible to compact the material against the rock wall. This way the material was pushed against and in-between the cables and tubes without coming in contact with the vibrating part of the compactor. The density was measured in eight points every other layer. The instrumentation was installed in the same way as in the backfill in the tunnel. The sensors and the tubes were placed in 4 cm deep ditches, bentonite powder was placed on and in-between the tubes and backfill material was then used for keeping the cables down in the ditches.

The 30/70 backfill material used for the first layer that was compacted directly on the top bentonite block had a low water ratio, approximately 5 %. The reason for this was to prevent the top bentonite block from taking up water from the backfill and start to swell.

5.1.4 Backfilling against the retaining wall

The emplacement of the retaining wall and the backfilling against it generally worked well and it was possible to compact backfill material as high as to the 7th out of totally 9 beams. The remaining volume was filled with blocks containing 20% bentonite and 80% sand and bentonite pellets. Two lead-throughs for instrument cables were installed in this outer plug of the Prototype Repository. During the emplacement of the concrete beams only the instrument cables were lead through the holes made in the 3^{d} and 4th beam (See Figure 5-12). Some water coming from the slot for the plug trickled out between the concrete beams. The installation procedure had to be changed since it was not possible to get the angle-irons and prefabricated concrete beams in place in the upper part of the tunnel. These angle-irons had to be welded in place. Pictures from the installation are shown in Figure 5-12 to 5-15.

A permeable section consisting of three layers of fibre mats was installed on the inside of the concrete beams. Tubes leading from the top and bottom were installed so that the pressure behind the plug can be controlled from the outside.

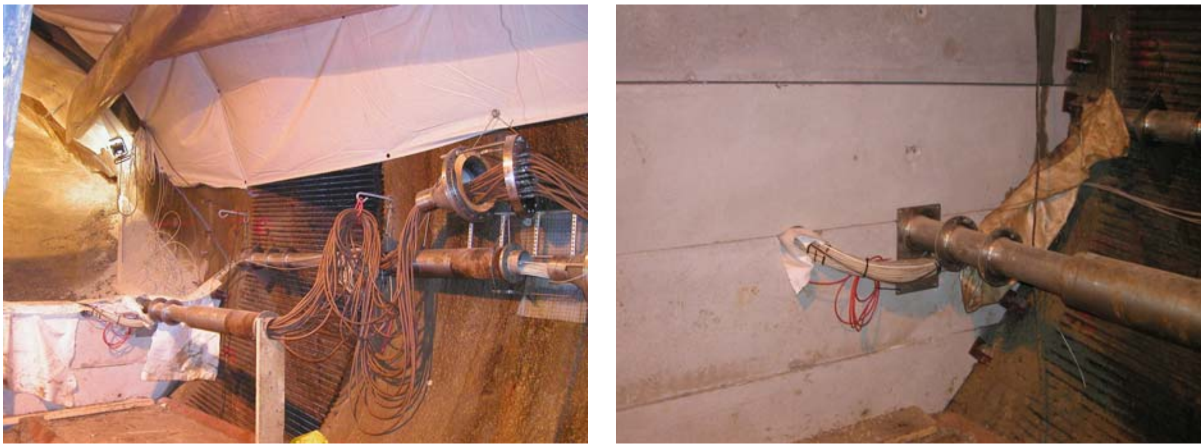


Figure 5-12. *Cable lead-through installation.*

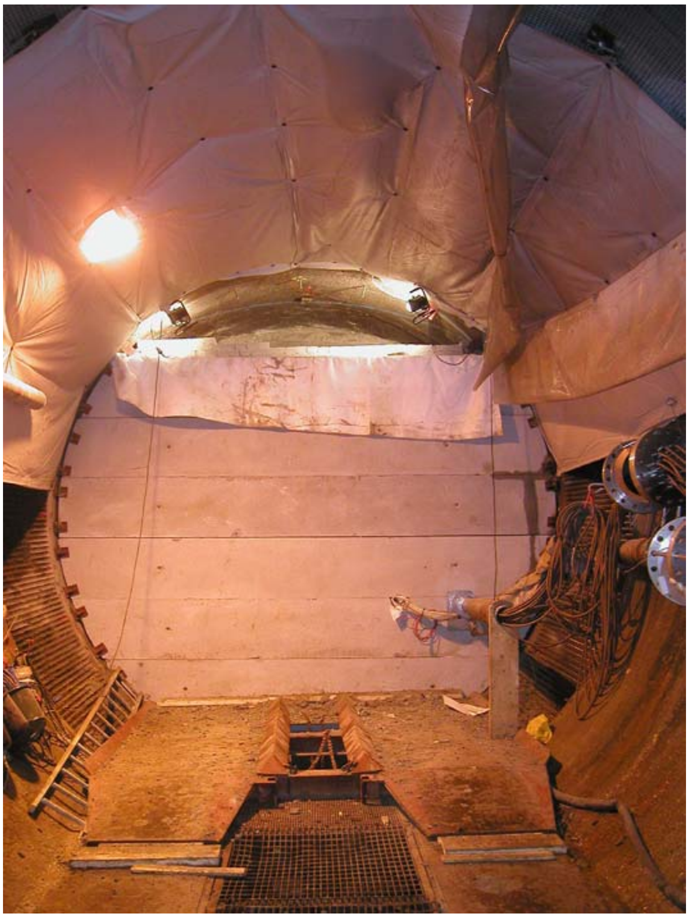


Figure 5-13. *Installation of the concrete beams.*

Figure 5-14. *Placing blocks and pellets in the volume at the roof.*

Figure 5-15. *All nine concrete beams and the two lead through pipes in place.*

5.2 Measurement of density and water ratio

5.2.1 Scope of measurements

The density and water ratio of every other 30/70 layer from layer were measured (with a few exceptions for practical reasons). Samples for determining water ratio were taken in the points where density meter A was used for determining density. Two types of measuring principles were used for determining the density. Equipment, technique and results from the measurements are presented in this chapter.

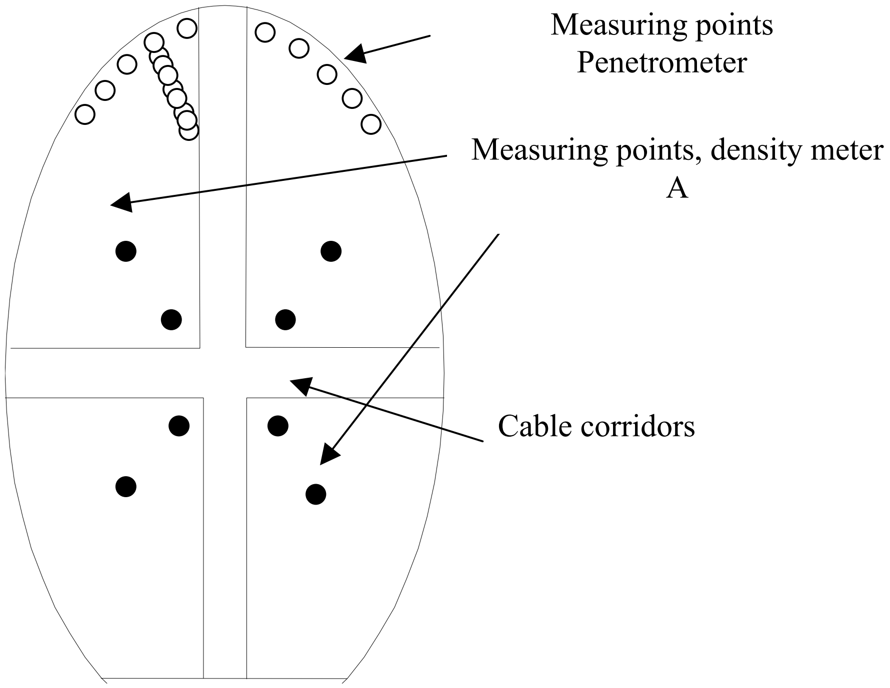
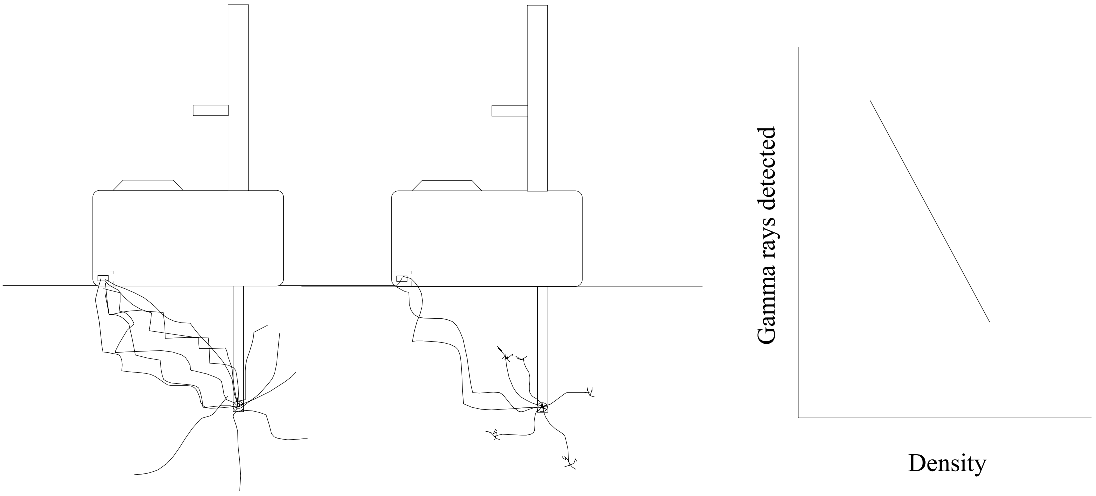


Figure 5-16. Standardised pattern of density measurements in the backfill layers.

5.2.2 Equipment and Technique

Nuclear gauge

The performance of the Campel Pacific MC-3 Port probe (referred to as density meter A) is based on the use of radio physics. A gamma source emits radiation that passes through the soil. The density is calculated on the basis of the amount of radiation that is absorbed by the soil. Schematic drawings of the gauge are shown in Figures 5-17.



Low density material High density material Density calibration curve

Figure 5-17. *Pacific MC-3 Portaprobe (density meter A)*

A slide hammer and a plate were used for making a hole perpendicular to the compacted surface and the rod with the gamma source was pushed down into it. The recording time was 1 minute. Density meter A measures an average density between the source and the soil surface. The gauge is described in detail in /5-1/.

Penetrometer

A penetrometer was used where it was not possible to use the nuclear gauges, i.e. close to the roof and walls of the tunnel.

The principle of the penetrometer is to measure the resistance when a steel rod is pushed into the material. The average resistance for different densities of a certain material with a certain water ratio can be calibrated. This is a rough method and it is used for estimating the density of the backfill.

Water ratio

One sample was taken in every place where density was measured. The samples were weighed, dried at 105°C for 24 hours and then weighed again for determining the loss of water. The water ratio was calculated as the weight of water divided by the dry weight of the sample.

5.2.3 Results from the density measurements

In Figure 5-18 the average dry density per layer measured with the nuclear gauge and the average measured water ratio per layer are presented. The measurements were made according to Figure 5-16, i.e. in the central area of the tunnel. The average dry density measured with nuclear gauge A on all of the layers was 1.75 g/cm^3 and the average measured water ratio was 13.7%.

The results from the penetrometer measurements indicate that the densities at the roof have been higher than 1,45 g/cm^3 for most of the test, i.e. the density has been out of the measuring range of the penetrometer. It has not been possible to penetrate the material.

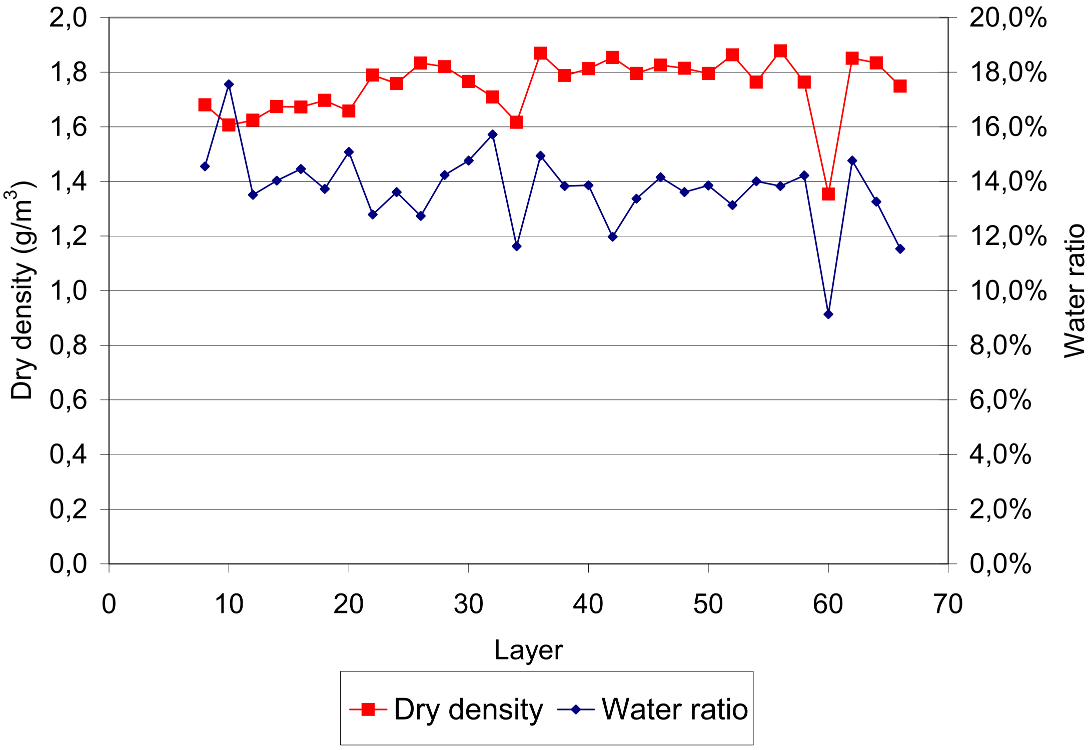


Figure 5-18. The average measured water ratio and dry density.

A mass volume estimation, where the mass of backfill moved into the tunnel was divided by the volume of the tunnel, was made and this resulted in a density of 1.63 tons per m^3.

On layer 48 a series of measurements were made to investigate how the density varies over the tunnel cross-section. The positions of the measurement points are shown in Figure 5-19. Four measurements in different directions were made in each measuring point as shown in the figure.

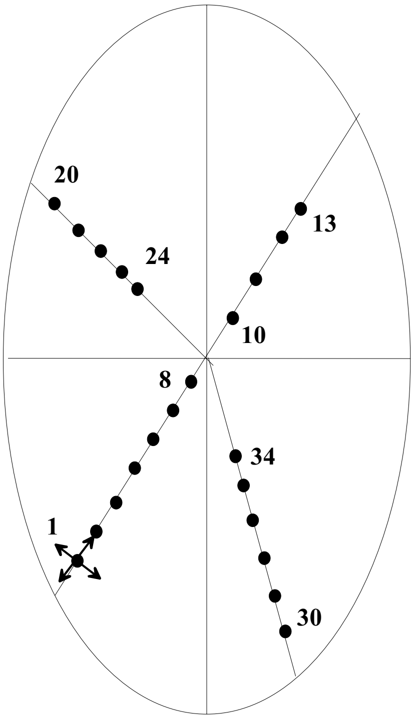


Figure 5-19. *Positions of the extra density measurements made in layer 48. In each measuring point measurements were made in the 4 directions represented by arrows in measuring position 1.*

The results from the extra measurements made in layer 48 are plotted against the distance from the rock in Figures 5-20 to 5-23. Measurements made in points 1 to 8 are presented in Figure 5-20, measurements in points 10 to 13 in Figure 5-21, measurements in points 20 to 24 in Figure 5-22 and measurements made in points 30 to 34 in Figure 5-23.

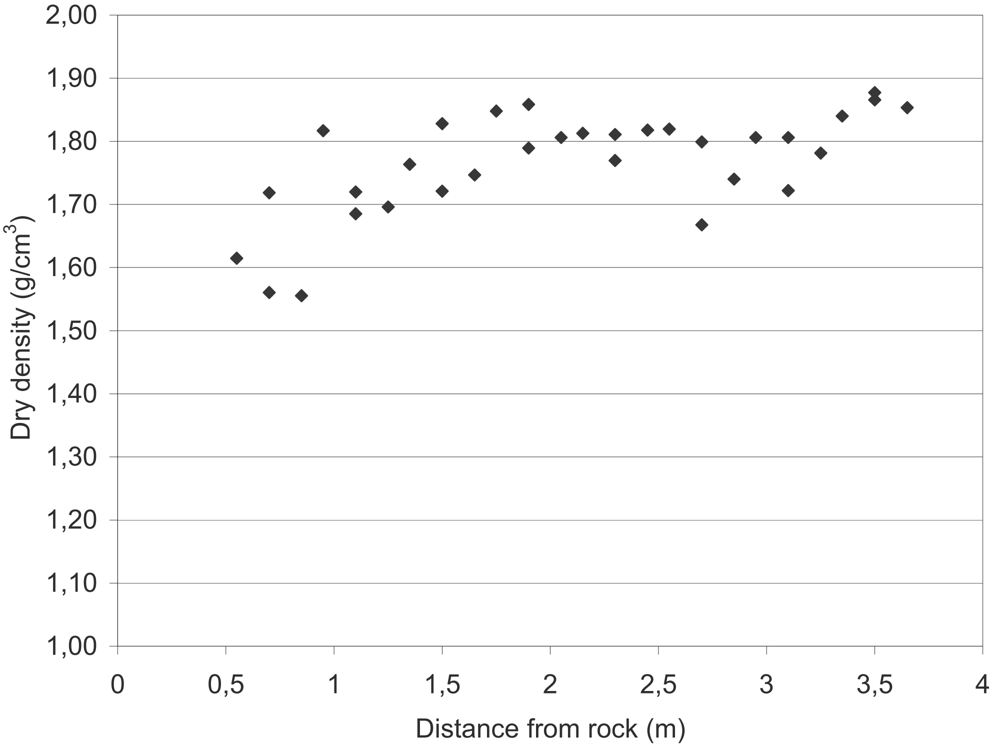


Figure 5-20. *Dry densities measured in points 1 to 8.*

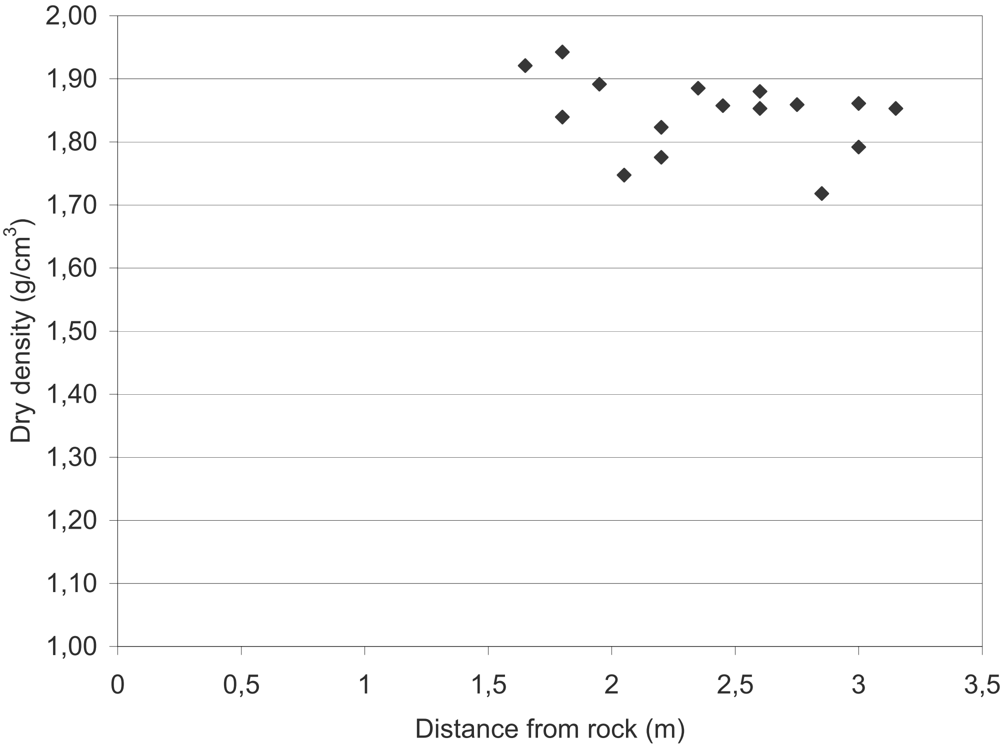


Figure 5-21. *Dry densities measured in points 10 to 13.*

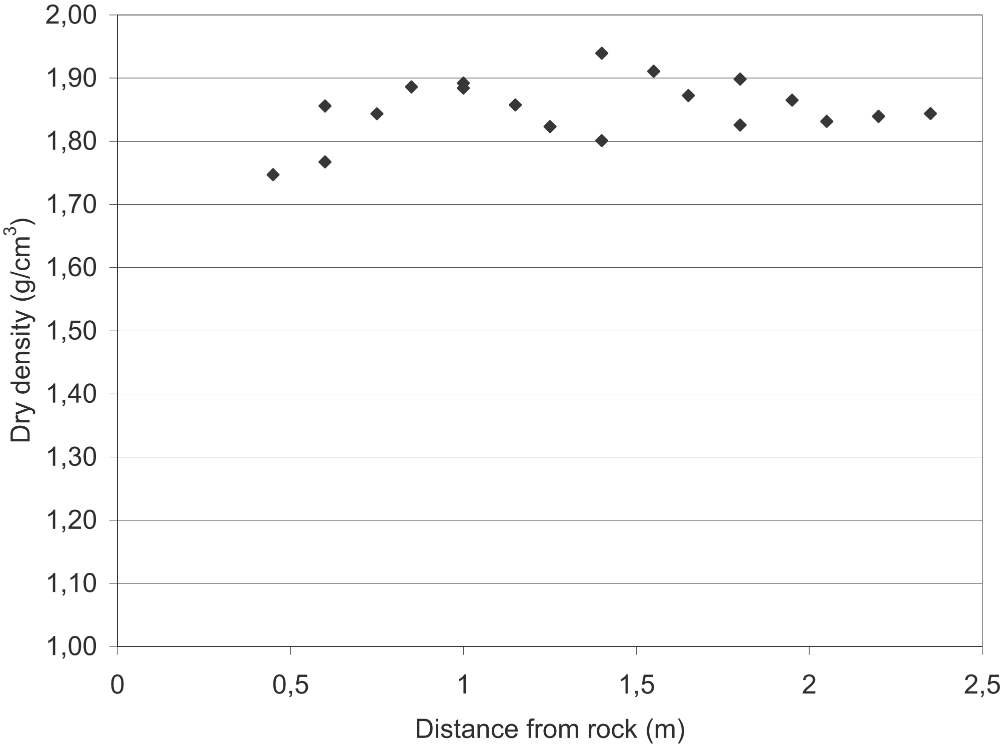


__Figure 5-22.__ Dry densities measured in points 20 to 24.

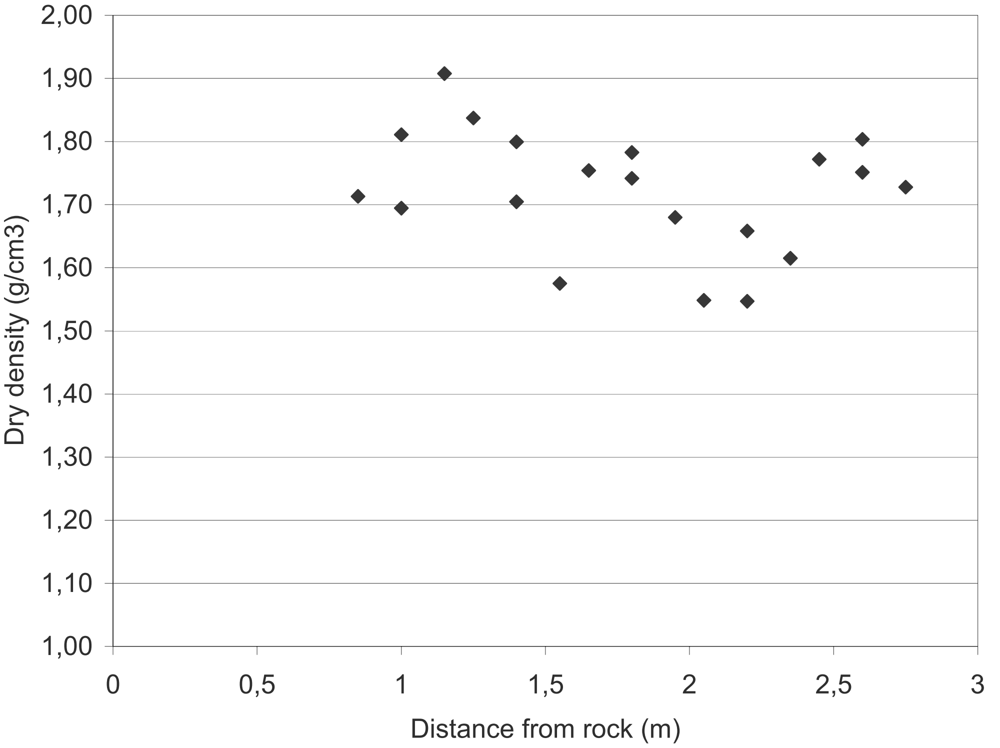


__Figure 5-23.__ Dry densities measured in points 30 to 34.

Figures 5-20 to 5-23 give a good indication on the variation in density in a layer that in general is between 1.7 g/cm^3 and 1.9 g/cm^3. It is difficult to make the measurements close enough to the rock to describe the assumed decrease in density towards the rock with the nuclear density meter. In Figure 5-20 a decrease in density can be observed in the measurements made within a meter from the rock wall. This decrease in density can, however, not be seen in the other density profiles.

The measurements made with the penetrometer indicate that the dry density is higher than 1.45 g/cm3 which is the upper measuring limit for the penetrometer.

The measured dry densities in deposition hole DA3551G01 was 1.83 g/cm^3 and the water ratio was 12,8 %. In deposition hole DA3545G01 the average dry measured density was 1.77 g/cm^3 and the water ratio was 15.0 %. Each 10 cm layer in the deposition holes were compacted for 30 minutes. This was based on experience from Section 1.

5.3 Instrumentation in the backfill

5.3.1 Installations made during backfilling

A total of 86 sensors (excluding GRS electrodes) were planned to be installed in the backfill. One sensor for monitoring water saturation was lost during backfilling. The positions of 10 sensors were changed compared to the original plan.

The following sensors were installed in the backfill:

• Sensors for monitoring water saturation	31
• Sensors for measuring pore water pressure	18
• Titanium cups for sampling	4
• Thermocouples	16
• Sensors for measuring total pressure	16

The following installations were also made during the backfilling:

- 20 concrete parcels containing cellulose were installed in the backfill
- Two titanium cups were installed in the pellet filled gap between the top bentonite ring and the rock one in each instrumented deposition holes.
- Two sensors for measuring the horizontal displacement of the top bentonite block were installed.
- GRS installed 36 electrodes for measuring the water content of the backfill in layer 65.

5.3.2 Co-ordinate system and measurement of sensor positions

Before the start of the backfilling three lines were drawn on the walls and roof along the tunnel. One line was drawn along the top position of the roof and two lines were drawn along the tunnel walls 2,5 m from the floor, i.e. at the tunnel mid height. Two laser planes were established. One intersected the two lines drawn on the walls and thus created a sub horizontal plane at mid height in the tunnel. The other created a vertical plane that intersected the line drawn in the roof. The laser planes were thus placed in the axes of the coordinate system as shown in Figure 5-24. The laser planes marked the X and Z-axis on the backfill layers, which made it easy to place and measure the positions of the sensors.

The co-ordinates were measured in the local co-ordinate system presented above and then transformed into Äspö 96 co-ordinates that were given to SICADA. The co-ordinates are presented in Appendix B1.

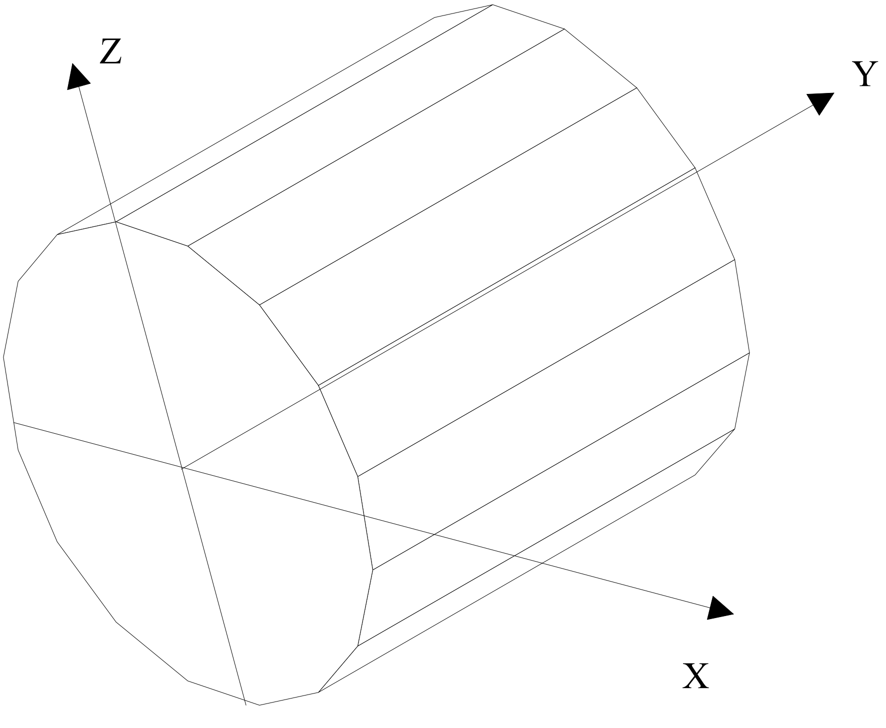


Figure 5-24. *The co-ordinate system*

6 Plug construction

6.1 Introduction

As a part of the Prototype Repository two plugs have been constructed that separate the two test sections and seal off the experiment from the tunnel system.

These plugs are intended to provide a sealing of axial water flow out from the Prototype Repository, so that sufficiently high water pressure may develop in the surrounding rock, the backfilled deposition holes and tunnel. This function requires that the plug has a low hydraulic conductivity and that the interface between the concrete and rock is sufficiently sealed and that unfavourable orientated water-bearing structures near the plug location are grouted.

The plugs are designed to withstand a pressure of 4.5 MPa.

The plugs are inserted in slots that have been cut by seam drilling at section 3/560 (Plug 1) and 3/537 (Plug 2). Both plugs are in principle designed and constructed in the same way.

Both plugs where equipped with instrument to monitoring temperatures. Plug 2 is equipped with a lead-through system and is further equipped with instruments for monitoring mechanical response to acting loads during operation. Both plugs are cast with self-compacting concrete (SCC).The reason way SCC were used, was the working environment, and that tubes for ventilation and vibrating equipment were not needed.

A compilation of the plug design is shown in Figure 6-1.

The concrete plugs were constructed after backfilling test section 1 and 2, respectively, and serve as a support of the backfill material during backfilling, which required an inner retaining wall before construction of the plug.

6.2 Retaining walls

The retaining walls are made of prefabricated concrete planks.

(Construction drawings R PT-113, Pro.type-213A)

Prefab data:

Concrete: 5,9 m^3 with a total weight of 13 500 kg

Reinforcement: Ø 25 mm with at total weight of 500 kg

Ø 16 mm with a total weight of 1100 kg

The retaining walls are designed to withstand the developed earth pressure and compaction pressures (100 kPa).

In order to save time for the backfilling, simplify handling during installation and to make sure that full resistance were achieved for the rock bolts holding the planks, the latter where installed before the backfilling started.

The walls were made in nine different pieces and were installed in parallel to the backfill because of the inclined (35 degrees) backfill of the tunnel (see chapter 5.4).

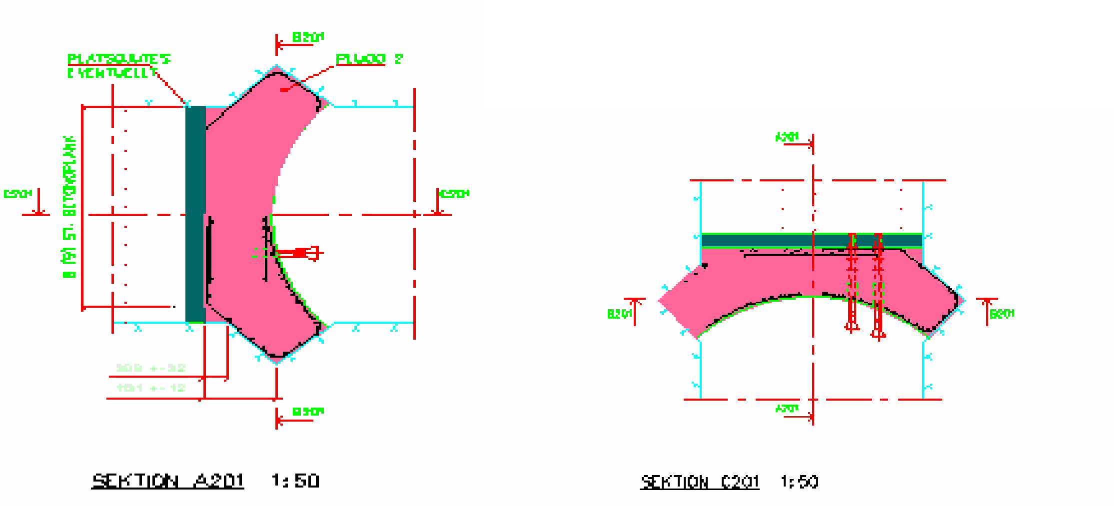


Figure 6-1. The outer plug.

6.3 Preparation work

Before any work at the plug location started, the plug seat was investigated to localise potential water bearing structures that may require grouting. Plug 1 in section 3/560 had low inflow. Therefore, no grouting was required. Plug 2 in section 3/537 had an inflow about 48-50 lit/h. Therefore, it was decided to drill nine drainage holes around the slot, three from the inside and six from the outside. The inflow decreased to 7 lit/h.

To perform contact grouting between rock and concrete after the casting of plug, minor slots where produced to enable the grouting tube to be installed against the rock at all time in both plugs.

Slots for instruments (Geokon, Model 4400) for monitoring mechanical response in the plug were also made. The first response from these instruments is expected to appear six months after casting and it is calculated that 70% of the changes in the plug are achieved after one year.

6.4 Formwork

The inner part of the reinforcement was installed at first. Then the instruments for monitoring of mechanical response (Plug 2) were installed in the slot and on the reinforcement, see Figure 6-1. Thirdly the cooling system was installed to control the heat release during the curing of the concrete.

Instrument for monitoring of mechanical response (Plug 2) where located as shown in Figure 6-2. A picture of some of the installed transducers is shown in Figure 6-3.

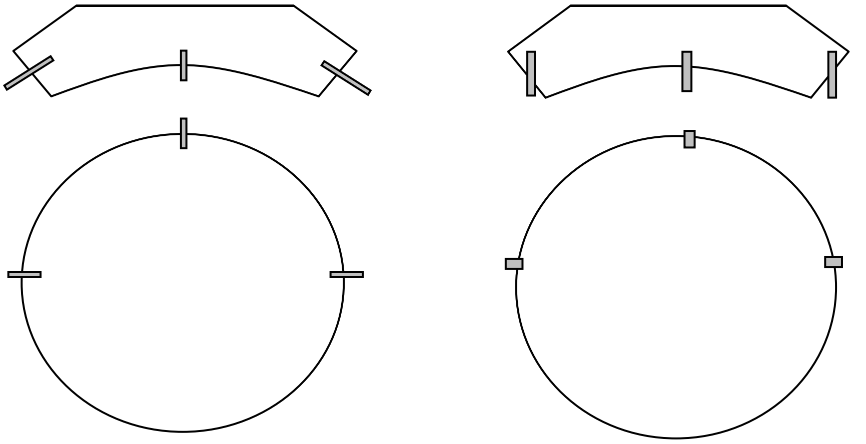


Figure 6-2. *Location of instruments for measuring the mechanical response.*

The work went on with the outer reinforcement and finished with instruments to monitor temperatures. In Figure 6-4 the outer reinforcement is shown.

The steel mould was put together on the surface and the framework was made of plywood and plexiglass. The function of the plexiglass is to have ocular control during the casting. After the framework, the mould was disassembled and transported to the Prototype tunnel for construction. The construction work started with five pieces that were put together and installed. Then, two pieces were placed at the same time until finally the top piece finished the work (see Figure 6-5).

Figure 6-3. *Installed instruments for monitoring the mechanical response.*

Figure 8-4. *The outer reinforcement of the plug.*

Figure 6-5. *The framework of plywood and plexiglass.*

Figure 6-6. *The reinforcement and part of the framework put in place.*

6.5 Casting of plug

The contractor had to follow a control system during the casting. A quality control program for the concrete included several parameters. The parameters were checked at the factory, before entering the tunnel and before concrete pumping started. The following checking controls were done:

1. Control of concrete temperature. Maximum temperatures were 15 °C (plug 1) 20 °C (plug 2).

2. Flowrate /viscous/separation and the propagate diameter; 720 +30/ -20mm and T50 4 +2/-2 sek.

3. Samples for test cubes

4. Allowed concrete rate of climb in mould where 25cm/15 min during casting.

5. Measure changes in temperature during hardening time.

Table 8-1 Formula for SCC plug 2, Äspö.

Components	Weight (kg)
ANLÄGGNINGS CEM[*)]	400
Gravel	746
8-16 Natur	668
Filler	289
Limus 40	100
Water	192
VCT	0,48

[*)] (CEM I 42,5 BV/SR/LA)

Table 8-2 Resistance of the concrete after 28 day, Plug 2.

Density (ton/m^3)	Cubic strength (MPa)
2,41	76,4
2,39	76,0
2,40	73,6

The experience from the casting of the first plug resulted in a change of the formula for the concrete. In order to minimise the expansion of the concrete and the pressure against rock / slot it was decided to use more *anläggningscement* (CEM I 42,5 BV/SR/LA). In that way, remaining deformation cracks (plastic cracks) will decrease.

Plug data

The composition of the used concrete is shown in Table 8-1. The determined cubic strength of the used concrete is shown I Table 8-2. The plug consists of following components:

Concrete (SCC): V=52,5 m^3, W=120 750 kg, $pH_{concrete}$ =11,5

Reinforcement: $W_{Ø25mm}$=4800 kg and $W_{Ø10mm}$ =500 kg

Cooling pipes: L=194 m

The mould was allowed to be dismounted when sufficient strength 37,5 MPa were achieved, based on temperature monitoring with Con Reg.

Before the planned contact grouting, the natural cooling process will continue until the plug has reached the ambient temperature. The final cooling process to get the plug to shrink before contact grouting, will start after the concrete has reached the required strength and continue as long as allowed according to the project time schedule. Preferably the cooling process will continue for 2-4 weeks before grouting to get the plug to shrink. This work are planned to do in the end of 2004.

Temperature measurement in plug 2.

At first there were some problems with the cooling system. In the initial stage the temperature in the concrete could run freely. This caused the temperature to be approximately 5 degrees over the limit of 27 degrees. Figure 6-7 shows the measured temperatures in the plug during the first 24 hours while Figure 6-8 shows the temperature during the first six days. K1, K2 and K3 were placed in the middle of the plug. K4 is the temperature in the tunnel outside the plug. K6 is the temperature of the cooling water entering the plug while K5 is the temperature of the cooling water coming out from the plug. Figure 6-9 shows the development of strength of the concrete calculated from the measured temperatures.

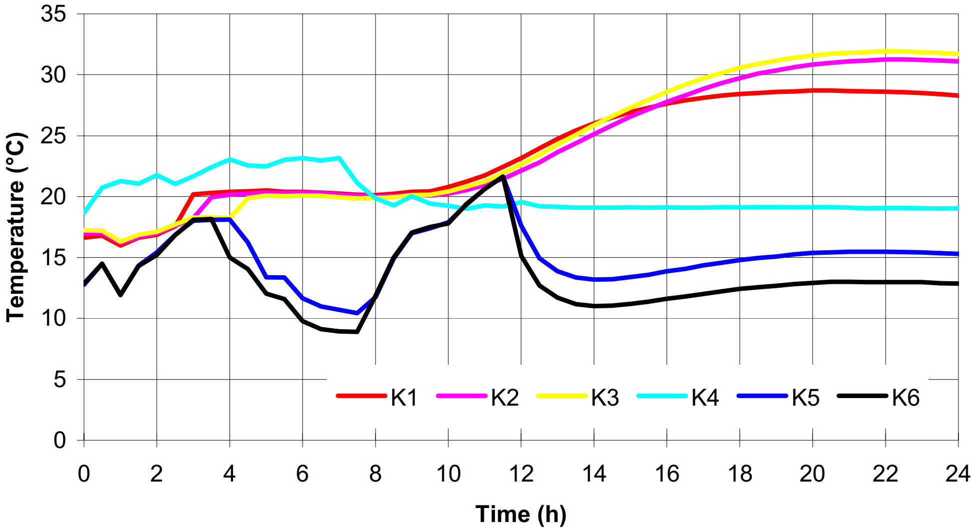


Figure 6-7. *The measured temperature of the plug during the first 24 hours after the casting.*

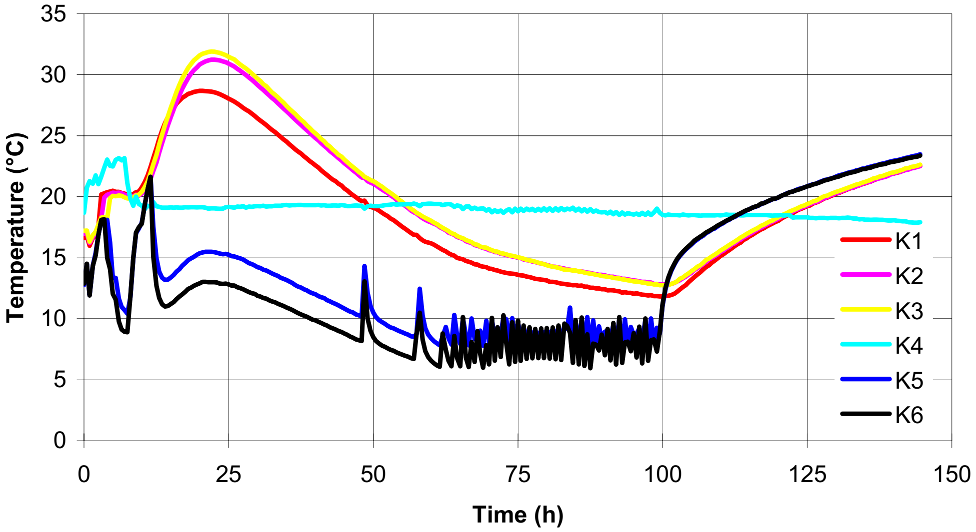


Figure 6-8. *The measured temperature of the plug during the first 6 days after the casting.*

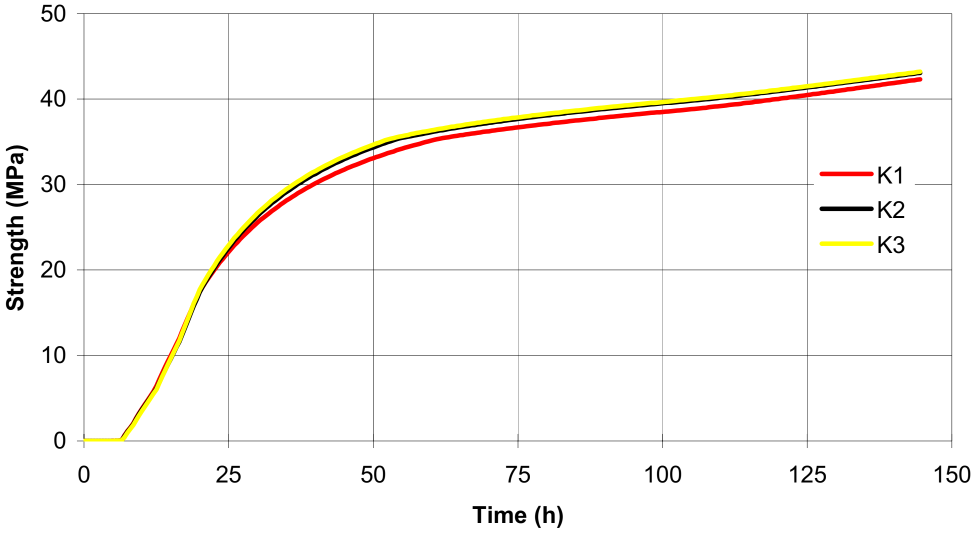


Figure 6-9. *The strength of the concrete calculated from the measured temperatures.*

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Appendix I

Final position of the instruments in the buffer material

Table AI:1 Temperature sensors in Dh 5

Dh5 (DA3551G01) Measurement of temperature						
	Local coordinate system			Äspö 96 coordinate system		
ID CODE	Z	alfa	r	X	Y	Z
TB501	0,080	270	0,050	7 270,435	1 914,562	-456,928
TB502	0,250	270	0,060	7 270,445	1 914,563	-456,758
TB503	0,450	270	0,070	7 270,455	1 914,565	-456,558
TB504	0,450	355	0,525	7 270,505	1 914,044	-456,558
TB505	0,450	355	0,685	7 270,541	1 913,888	-456,558
TB506	0,450	85	0,685	7 269,719	1 914,400	-456,558
TB507	0,450	175	0,685	7 270,231	1 915,222	-456,558
TB508	0,450	270	0,585	7 270,965	1 914,638	-456,558
TB509	0,450	270	0,685	7 271,064	1 914,652	-456,558
TB510	0,450	270	0,785	7 271,163	1 914,666	-456,558
TB511	2,950	0	0,525	7 270,460	1 914,035	-454,058
TB512	2,986	0	0,685	7 270,483	1 913,877	-454,022
TB513	2,986	85	0,585	7 269,816	1 914,422	-454,022
TB514	2,986	85	0,685	7 269,719	1 914,400	-454,022
TB515	2,986	85	0,785	7 269,621	1 914,377	-454,022
TB516	2,986	175	0,585	7 270,253	1 915,125	-454,022
TB517	2,986	175	0,685	7 270,231	1 915,222	-454,022
TB518	2,986	175	0,735	7 270,219	1 915,271	-454,022
TB519	2,986	270	0,585	7 270,965	1 914,638	-454,022
TB520	2,986	270	0,635	7 271,015	1 914,645	-454,022
TB521	2,986	270	0,685	7 271,064	1 914,652	-454,022
TB522	2,986	270	0,735	7 271,114	1 914,659	-454,022
TB523	2,986	270	0,785	7 271,163	1 914,666	-454,022
TB524	5,150	0	0,525	7 270,460	1 914,035	-451,858
TB525	5,543	0	0,685	7 270,483	1 913,877	-451,465
TB526	5,543	270	0,585	7 270,965	1 914,638	-451,465
TB527	5,543	270	0,685	7 271,064	1 914,652	-451,465
TB528	5,543	270	0,785	7 271,163	1 914,666	-451,465
TB529	6,353	0	0,785	7 270,497	1 913,778	-450,655
TB530	6,353	95	0,585	7 269,802	1 914,523	-450,655
TB531	6,353	185	0,585	7 270,354	1 915,139	-450,655
TB532	7,060	0	0,785	7 270,497	1 913,778	-449,948

Table AI:2 Total pressure cells in Dh 5

Dh5 (DA3551G01) Measurement of total pressure						
	Local coordinate system			Äspö 96 coordinate system		
ID CODE	Z	alfa	r	X	Y	Z
PB501	0,000	0	0,000	7 270,386	1 914,555	-457,008
PB502	0,500	0	0,100	7 270,400	1 914,456	-456,508
PB503	0,340	5	0,585	7 270,418	1 913,971	-456,668
PB504	0,340	5	0,685	7 270,423	1 913,871	-456,668
PB505	0,340	5	0,785	7 270,429	1 913,771	-456,668
PB506	0,500	95	0,635	7 269,752	1 914,520	-456,508
PB507	0,500	105	0,735	7 269,656	1 914,643	-456,508
PB508	0,500	185	0,635	7 270,351	1 915,189	-456,508
PB509	0,500	195	0,735	7 270,474	1 915,285	-456,508
PB510	2,876	10	0,535	7 270,368	1 914,020	-454,132
PB511	3,036	10	0,685	7 270,364	1 913,870	-453,972
PB512	2,876	5	0,825	7 270,431	1 913,731	-454,132
PB513	3,036	95	0,635	7 269,752	1 914,520	-453,972
PB514	3,036	105	0,785	7 269,607	1 914,649	-453,972
PB515	3,036	190	0,635	7 270,407	1 915,190	-453,972
PB516	2,876	190	0,825	7 270,413	1 915,380	-454,132
PB517	5,593	0	0,050	7 270,393	1 914,506	-451,415
PB518	5,433	10	0,585	7 270,367	1 913,970	-451,575
PB519	5,433	10	0,685	7 270,364	1 913,870	-451,575
PB520	5,433	10	0,785	7 270,360	1 913,770	-451,575
PB521	5,593	95	0,635	7 269,752	1 914,520	-451,415
PB522	5,593	105	0,735	7 269,656	1 914,643	-451,415
PB523	5,593	180	0,635	7 270,296	1 915,184	-451,415
PB524	5,593	190	0,735	7 270,410	1 915,290	-451,415
PB629	5,593	30	0,685	7 270,131	1 913,919	-451,415
PB525	6,603	0	0,100	7 270,400	1 914,456	-450,405
PB526	6,603	5	0,585	7 270,418	1 913,971	-450,405
PB527	7,110	0	0,100	7 270,400	1 914,456	-449,898

Table AI:3 Pore water pressure gauges in Dh 5

Dh5 (DA3551G01) Measurement of pore water pressure						
	Local coordinate system			Äspö 96 coordinate system		
ID CODE	Z	alfa	r	X	Y	Z
UB501	0,251	90	0,050	7 270,337	1914,548	-456,758
UB502	0,051	90	0,100	7 270,287	1914,541	-456,958
UB503	0,251	355	0,585	7 270,519	1913,985	-456,758
UB504	0,341	355	0,785	7 270,564	1913,790	-456,668
UB505	2,786	355	0,585	7 270,519	1913,985	-454,222
UB506	2,876	355	0,785	7 270,564	1913,790	-454,132
UB507	2,876	85	0,535	7 269,865	1914,434	-454,132
UB508	Not installed					
UB509	2,786	175	0,535	7 270,265	1915,076	-454,222
UB510	2,786	175	0,825	7 270,199	1915,358	-454,222
UB511	5,433	355	0,585	7 270,519	1913,985	-451,575
UB512	5,433	355	0,785	7 270,564	1913,790	-451,575
UB515	5,283	330	0,585	7 270,747	1914,095	-451,725
UB513	Not installed					
UB514	6,860	90	0,100	7 270,287	1914,541	-450,148

Table AI:4 Relative humidity sensors in Dh 5

Dh5 (DA3551G01) Measurement of the water saturation process						
	Local coordinate system			Äspö 96 coordinate system		
ID CODE	Z	alfa	r	X	Y	Z
WB501	0,250	180	0,050	7 270,379	1 914,604	-456,7575
WB502	0,050	180	0,100	7 270,372	1 914,654	-456,9575
WB503	0,250	0	0,400	7 270,442	1 914,159	-456,7575
WB504	0,340	350	0,585	7 270,568	1 913,999	-456,6675
WB505	0,340	350	0,685	7 270,599	1 913,904	-456,6675
WB506	0,340	350	0,785	7 270,630	1 913,809	-456,6675
WB507	0,340	80	0,585	7 269,830	1 914,373	-456,6675
WB508	0,250	80	0,685	7 269,735	1 914,342	-456,7575
WB509	0,250	80	0,785	7 269,640	1 914,311	-456,7575
WB510	0,250	170	0,585	7 270,204	1 915,111	-456,7575
WB511	0,250	170	0,685	7 270,173	1 915,206	-456,7575
WB512	0,250	170	0,785	7 270,142	1 915,301	-456,7575
WB538	1,624	225	0,775	7 270,851	1 915,175	-455,3845
WB539	1,624	235	0,680	7 270,882	1 915,020	-455,3845
WB540	1,624	245	0,585	7 270,876	1 914,875	-455,3845
WB541	1,624	255	0,680	7 271,011	1 914,822	-455,3845
WB542	1,624	265	0,775	7 271,141	1 914,731	-455,3845
WB513	2,876	350	0,585	7 270,568	1 913,999	-454,1318
WB514	2,876	350	0,685	7 270,599	1 913,904	-454,1318
WB515	2,876	350	0,785	7 270,630	1 913,809	-454,1318
WB516	2,786	80	0,535	7 269,878	1 914,389	-454,2218
WB517	2,786	80	0,685	7 269,735	1 914,342	-454,2218
WB518	2,786	80	0,785	7 269,640	1 914,311	-454,2218
WB519	2,876	180	0,535	7 270,310	1 915,085	-454,1318
WB520	2,876	180	0,685	7 270,289	1 915,233	-454,1318
WB521	2,786	180	0,785	7 270,275	1 915,332	-454,2218
WB543	4,173	225	0,775	7 270,851	1 915,175	-452,8348
WB544	4,173	235	0,680	7 270,882	1 915,020	-452,8348
WB545	4,173	245	0,585	7 270,876	1 914,875	-452,8348
WB546	4,173	255	0,680	7 271,011	1 914,822	-452,8348
WB547	4,173	265	0,775	7 271,141	1 914,731	-452,8348

Table AI:4 Cont. Relative humidity sensors in Dh 5

Dh5 (DA3551G01) Measurement of the water saturation process						
	Local coordinate system			Äspö 96 coordinate system		
ID CODE	Z	alfa	r	X	Y	Z
WB522	5,433	180	0,050	7 270,379	1 914,604	-451,5747
WB523	5,433	0	0,262	7 270,423	1 914,296	-451,5747
WB524	5,433	350	0,585	7 270,568	1 913,999	-451,5747
WB525	5,433	350	0,685	7 270,599	1 913,904	-451,5747
WB526	5,433	350	0,785	7 270,630	1 913,809	-451,5747
WB527	5,343	80	0,585	7 269,830	1 914,373	-451,6647
WB528	5,343	80	0,685	7 269,735	1 914,342	-451,6647
WB529	5,343	80	0,785	7 269,640	1 914,311	-451,6647
WB530	5,433	170	0,585	7 270,204	1 915,111	-451,5747
WB531	5,343	170	0,785	7 270,142	1 915,301	-451,6647
WB532	6,353	270	0,100	7 270,485	1 914,569	-450,6548
WB533	6,353	350	0,585	7 270,568	1 913,999	-450,6548
WB534	6,353	90	0,585	7 269,807	1 914,472	-450,6548
WB535	6,353	180	0,585	7 270,303	1 915,134	-450,6548
WB536	6,790	180	0,100	7 270,372	1 914,654	-450,2179
WB537	6,950	270	0,100	7 270,485	1 914,569	-450,0579

Table AI:5 Water sampler in Dh 5

Dh5 (DA3551G01) Water sampler in the bentonitee						
	Local coordinate system			Äspö 96 coordinate system		
ID CODE	Z	alfa	r	X	Y	Z
KB501	0,450	0	0,262	7 270,423	1 914,296	-456,5575
KB502	0,450	180	0,262	7 270,349	1 914,814	-456,5575
KB503	1,466	0	0,685	7 270,483	1 913,877	-455,5423
KB504	1,466	90	0,685	7 269,708	1 914,458	-455,5423
KB505	1,466	180	0,685	7 270,289	1 915,233	-455,5423
KB506	1,466	270	0,685	7 271,064	1 914,652	-455,5423
KB507	4,523	0	0,685	7 270,483	1 913,877	-452,4848
KB508	4,523	90	0,685	7 269,708	1 914,458	-452,4848
KB509	4,523	180	0,685	7 270,289	1 915,233	-452,4848
KB510	4,523	270	0,685	7 271,064	1 914,652	-452,4848
KB511	5,543	0	0,262	7 270,423	1 914,296	-451,4647
KB512	5,543	180	0,262	7 270,349	1 914,814	-451,4647
KB513	7,060	0	0,875	7 270,510	1 913,689	-449,9479
KB514	7,060	180	0,875	7 270,262	1 915,421	-449,9479

Table AI:6 Temperature sensors in Dh 6

Dh6 (DA3545G01) Measurement of temperature						
	Local coordinate system			Äspö 96 coordinate system		
ID CODE	Z	alfa	r	X	Y	Z
TB601	0,385	45	0,050	7 269,509	1 920,452	-456,748
TB602	0,260	315	0,050	7 269,579	1 920,462	-456,873
TB603	0,135	0	0,050	7 269,546	1 920,443	-456,998
TB604	0,770	270	0,535	7 270,069	1 920,568	-456,363
TB605	0,770	270	0,585	7 270,118	1 920,575	-456,363
TB606	0,770	270	0,635	7 270,168	1 920,582	-456,363
TB607	0,770	270	0,685	7 270,217	1 920,589	-456,363
TB608	0,770	270	0,735	7 270,267	1 920,596	-456,363
TB609	0,770	270	0,785	7 270,316	1 920,603	-456,363
TB610	0,753	270	0,875	7 270,356	1 920,609	-456,380
TB611	0,753	0	0,525	7 269,613	1 919,972	-456,380
TB612	2,795	270	0,535	7 270,069	1 920,568	-454,338
TB613	2,795	270	0,585	7 270,118	1 920,575	-454,338
TB614	2,795	270	0,635	7 270,168	1 920,582	-454,338
TB615	2,795	270	0,685	7 270,217	1 920,589	-454,338
TB616	2,795	270	0,735	7 270,267	1 920,596	-454,338
TB617	2,795	270	0,785	7 270,316	1 920,603	-454,338
TB618	2,753	270	0,875	7 270,356	1 920,609	-454,380
TB619	2,753	0	0,525	7 269,613	1 919,972	-454,380
TB620	4,324	270	0,535	7 270,069	1 920,568	-452,809
TB621	4,324	270	0,585	7 270,118	1 920,575	-452,809
TB622	4,324	270	0,635	7 270,168	1 920,582	-452,809
TB623	4,324	270	0,685	7 270,217	1 920,589	-452,809
TB624	4,324	270	0,735	7 270,267	1 920,596	-452,809
TB625	4,324	270	0,785	7 270,316	1 920,603	-452,809
TB626	4,253	270	0,875	7 270,356	1 920,609	-452,880
TB627	4,253	0	0,525	7 269,613	1 919,972	-452,880
TB628	6,366	0	0,785	7 269,650	1 919,715	-450,768
TB629	6,366	95	0,585	7 268,955	1 920,460	-450,768
TB630	6,366	185	0,585	7 269,507	1 921,076	-450,768
TB631	7,071	225	0,100	7 269,599	1 920,572	-450,063
TB632	7,071	0	0,785	7 269,650	1 919,715	-450,063

Table AI:7 Total pressure cells in Dh 6

Dh6 (DA3545G01) Measurement of total pressure						
	Local coordinate system			Äspö 96 coordinate system		
ID CODE	Z	alfa	r	X	Y	Z
PB601	0,510	315	0,210	7 269,707	1 920,366	-456,623
PB602	0,260	80	0,685	7 268,888	1 920,279	-456,873
PB603	0,770	10	0,785	7 269,513	1 919,707	-456,363
PB604	0,770	80	0,685	7 268,888	1 920,279	-456,363
PB605	0,770	170	0,585	7 269,357	1 921,048	-456,363
PB606	1,534	55	0,735	7 269,002	1 919,990	-455,600
PB607	1,534	145	0,635	7 269,105	1 920,956	-455,600
PB608	1,284	215	0,535	7 269,781	1 920,969	-455,850
PB609	1,253	325	0,875	7 270,137	1 919,853	-455,880
PB610	2,795	10	0,785	7 269,513	1 919,707	-454,338
PB611	2,795	80	0,685	7 268,888	1 920,279	-454,338
PB612	2,795	170	0,585	7 269,357	1 921,048	-454,338
PB613	3,550	55	0,785	7 268,966	1 919,955	-453,583
PB614	3,550	145	0,635	7 269,105	1 920,956	-453,583
PB615	3,300	215	0,535	7 269,781	1 920,969	-453,833
PB616	3,253	325	0,875	7 270,137	1 919,853	-453,880
PB617	4,324	10	0,785	7 269,513	1 919,707	-452,809
PB618	4,324	80	0,685	7 268,888	1 920,279	-452,809
PB619	4,324	170	0,585	7 269,357	1 921,048	-452,809
PB620	5,084	55	0,735	7 269,002	1 919,990	-452,049
PB621	5,084	145	0,635	7 269,105	1 920,956	-452,049
PB622	4,834	215	0,535	7 269,781	1 920,969	-452,299
PB623	4,753	325	0,875	7 270,137	1 919,853	-452,380
PB625	6,616	0	0,100	7 269,553	1 920,393	-450,518
PB626	6,616	5	0,585	7 269,571	1 919,908	-450,518
PB627	7,121	0	0,100	7 269,553	1 920,393	-450,013
PB624	7,121	135	0,585	7 269,071	1 920,843	-450,013

Table AI:8 Pore water pressure gauges in Dh 6

Dh6 (DA3545G01) Measurement of pore water pressure						
	Local coordinate system			Äspö 96 coordinate system		
ID CODE	Z	alfa	r	X	Y	Z
UB601	0,260	280	0,210	7 269,749	1 920,485	-456,873
UB602	0,260	95	0,685	7 268,855	1 920,455	-456,873
UB603	1,284	225	0,535	7 269,860	1 920,920	-455,850
UB604	1,253	310	0,875	7 270,282	1 920,030	-455,880
UB605	2,795	190	0,585	7 269,558	1 921,077	-454,338
UB606	2,795	350	0,785	7 269,783	1 919,746	-454,338
UB607	3,300	35	0,735	7 269,207	1 919,836	-453,833
UB608	3,300	125	0,635	7 268,973	1 920,779	-453,833
UB609	3,300	225	0,535	7 269,860	1 920,920	-453,833
UB610	3,253	310	0,875	7 270,282	1 920,030	-453,880
UB611	4,834	225	0,535	7 269,860	1 920,920	-452,299
UB612	4,753	310	0,875	7 270,282	1 920,030	-452,380
UB613	6,366	135	0,100	7 269,459	1 920,552	-450,768
UB614	6,961	90	0,100	7 269,440	1 920,478	-450,173

Table AI:9 Relative humidity sensors in Dh 6

Dh6 (DA3545G01) Measurement of the water saturation process						
	Local coordinate system			Äspö 96 coordinate system		
ID CODE	Z	alfa	r	X	Y	Z
WB601	0,260	135	0,050	7 269,499	1 920,522	-456,873
WB602	0,260	225	0,050	7 269,569	1 920,532	-456,873
WB603	0,260	260	0,210	7 269,739	1 920,557	-456,873
WB604	0,260	270	0,210	7 269,747	1 920,522	-456,873
WB605	0,260	90	0,685	7 268,861	1 920,395	-456,873
WB606	0,260	100	0,685	7 268,854	1 920,514	-456,873
WB667	0,260	280	0,685	7 270,224	1 920,470	-456,873
WB607	0,770	90	0,685	7 268,861	1 920,395	-456,363
WB608	0,770	95	0,685	7 268,855	1 920,455	-456,363
WB609	0,770	180	0,585	7 269,456	1 921,071	-456,363
WB610	0,770	185	0,585	7 269,507	1 921,076	-456,363
WB611	0,770	355	0,785	7 269,717	1 919,727	-456,363
WB612	0,770	360	0,785	7 269,650	1 919,715	-456,363
WB613	1,284	40	0,735	7 269,151	1 919,868	-455,850
WB614	1,284	45	0,735	7 269,098	1 919,904	-455,850
WB615	1,284	130	0,635	7 269,000	1 920,827	-455,850
WB616	1,284	135	0,635	7 269,031	1 920,873	-455,850
WB617	1,284	230	0,535	7 269,896	1 920,890	-455,850
WB618	1,284	235	0,535	7 269,930	1 920,858	-455,850
WB619	1,253	305	0,875	7 270,319	1 920,096	-455,880
WB620	1,253	315	0,875	7 270,239	1 919,967	-455,880
WB621	2,795	90	0,685	7 268,861	1 920,395	-454,338
WB622	2,795	95	0,685	7 268,855	1 920,455	-454,338
WB623	2,795	180	0,585	7 269,456	1 921,071	-454,338
WB624	2,795	185	0,585	7 269,507	1 921,076	-454,338
WB625	2,795	355	0,785	7 269,717	1 919,727	-454,338
WB626	2,795	360	0,785	7 269,650	1 919,715	-454,338
WB627	3,300	40	0,735	7 269,151	1 919,868	-453,833
WB628	3,300	45	0,735	7 269,098	1 919,904	-453,833
WB629	3,300	130	0,635	7 269,000	1 920,827	-453,833
WB630	3,300	135	0,635	7 269,031	1 920,873	-453,833
WB631	3,300	230	0,535	7 269,896	1 920,890	-453,833
WB632	3,300	235	0,535	7 269,930	1 920,858	-453,833

Table AI:9 Cont. Relative humidity sensors in Dh 6

Dh6 (DA3545G01) Measurement of the water saturation process						
	Local coordinate system			Äspö 96 coordinate system		
ID CODE	Z	alfa	r	X	Y	Z
WB633	3,253	305	0,875	7 270,319	1 920,096	-453,880
WB634	3,253	315	0,875	7 270,239	1 919,967	-453,880
WB657	3,300	190	0,625	7 269,560	1 921,117	-453,833
WB658	3,300	190	0,725	7 269,563	1 921,217	-453,833
WB668	3,300	200	0,625	7 269,668	1 921,104	-453,833
WB669	3,300	200	0,725	7 269,688	1 921,201	-453,833
WB635	4,324	90	0,685	7 268,861	1 920,395	-452,809
WB636	4,324	95	0,685	7 268,855	1 920,455	-452,809
WB637	4,324	180	0,585	7 269,456	1 921,071	-452,809
WB638	4,324	185	0,585	7 269,507	1 921,076	-452,809
WB639	4,324	355	0,785	7 269,717	1 919,727	-452,809
WB640	4,324	360	0,785	7 269,650	1 919,715	-452,809
WB662	4,324	280	0,625	7 270,164	1 920,471	-452,809
WB663	4,324	280	0,725	7 270,264	1 920,468	-452,809
WB670	4,324	290	0,625	7 270,151	1 920,363	-452,809
WB671	4,324	290	0,725	7 270,248	1 920,343	-452,809
WB641	4,834	40	0,735	7 269,151	1 919,868	-452,299
WB642	4,834	45	0,735	7 269,098	1 919,904	-452,299
WB643	4,834	130	0,635	7 269,000	1 920,827	-452,299
WB644	4,834	135	0,635	7 269,031	1 920,873	-452,299
WB645	4,834	230	0,535	7 269,896	1 920,890	-452,299
WB646	4,834	235	0,535	7 269,930	1 920,858	-452,299
WB647	4,753	305	0,875	7 270,319	1 920,096	-452,380
WB648	4,753	315	0,875	7 270,239	1 919,967	-452,380
WB649	5,439	90	0,050	7 269,490	1 920,485	-451,695
WB650	5,439	270	0,210	7 269,747	1 920,522	-451,695
WB651	6,366	225	0,100	7 269,599	1 920,572	-450,768
WB652	6,366	90	0,585	7 268,960	1 920,409	-450,768
WB653	6,366	180	0,585	7 269,456	1 921,071	-450,768
WB654	6,366	350	0,585	7 269,721	1 919,936	-450,768
WB655	6,801	180	0,100	7 269,525	1 920,591	-450,333
WB656	6,961	270	0,100	7 269,638	1 920,506	-450,173

Table AI:10 Water sampler in Dh 6

Dh6 (DA3545G01) Water sampler in the bentonitee						
	Local coordinate system			Äspö 96 coordinate system		
ID CODE	Z	alfa	r	X	Y	Z
KB601	0,460	0	0,262	7 269,576	1 920,233	-456,673
KB602	0,460	180	0,262	7 269,502	1 920,751	-456,673
KB603	1,484	0	0,685	7 269,636	1 919,814	-455,65
KB604	1,484	90	0,685	7 268,861	1 920,395	-455,65
KB605	1,484	180	0,685	7 269,442	1 921,170	-455,65
KB606	1,484	270	0,685	7 270,217	1 920,589	-455,65
KB607	5,034	0	0,685	7 269,636	1 919,814	-452,099
KB608	5,034	90	0,685	7 268,861	1 920,395	-452,099
KB609	5,034	180	0,685	7 269,442	1 921,170	-452,099
KB610	5,034	270	0,685	7 270,217	1 920,589	-452,099
KB611	5,549	0	0,262	7 269,576	1 920,233	-451,585
KB612	5,549	180	0,262	7 269,502	1 920,751	-451,585
KB613	7,071	0	0,875	7 269,663	1 919,626	-450,063
KB614	7,071	180	0,875	7 269,415	1 921,358	-450,063

Appendix II

Final position of all instruments in the backfill

Table AII:1 Concrete parcels containing cellulose

			Local coordinate system			Äspö 96 coordinate system		
ID CODE	Layer	Installed	X	Z	Y	X	Y	Z
CBU1001C	13	03-05-05	0,000	1,250	3559,000	7 271,519	1 906,641	-445,012
CBU1002D	5	03-04-29	0,000	-1,250	3559,000	7 271,519	1 906,641	-447,512
CBU1002C	9	03-04-29	1,250	0,000	3559,000	7 272,756	1 906,819	-446,262
CBU1001D	9	03-04-29	-1,250	0,000	3559,000	7 270,281	1 906,464	-446,262
CBU1003C	9	03-04-29	0,000	0,000	3559,000	7 271,519	1 906,641	-446,262
CBU1003D	16	03-05-06	0,000	1,250	3558,000	7 271,376	1 907,631	-445,032
CBU1004C	7	03-04-29	0,000	-1,250	3558,000	7 271,376	1 907,631	-447,532
CBU1004D	12	03-05-05	1,250	0,000	3558,000	7 272,614	1 907,809	-446,282
CBU1005C	12	03-05-05	-1,250	0,000	3558,000	7 270,139	1 907,454	-446,282
CBU1005D	12	03-05-05	0,000	0,000	3558,000	7 271,376	1 907,631	-446,282
CBU1006C	18	03-05-12	0,000	1,250	3557,000	7 271,234	1 908,621	-445,052
CBU1006D	10	03-04-30	0,000	-1,250	3557,000	7 271,234	1 908,621	-447,552
CBU1007C	14	03-05-05	1,250	0,000	3557,000	7 272,472	1 908,799	-446,302
CBU1007D	14	03-05-05	-1,250	0,000	3557,000	7 269,997	1 908,443	-446,302

Table AII:2 Devices for measuring horizontal displacements

			Local coordinate system			Äspö 96 coordinate system		
ID CODE	Layer	Installed	X	Z	Y	X	Y	Z
DB501	Dh 5	03-05-06	0,000	-3,547	3 551,000	7 270,386	1 914,555	-449,898
DB502	Dh 5	03-05-06	0,000	-3,505	3 551,000	7 270,386	1 914,555	-449,898
DB503	Dh 6	03-05-20	0,000	-3,520	3 545,000	7 269,539	1 920,492	-450,012
DB504	Dh 6	03-05-20	0,000	-3,515	3 545,000	7 269,539	1 920,492	-450,012

Table AII:3 Titanium cups for water sampling

			Local coordinate system			Äspö 96 coordiante system		
ID CODE	Layer	Installed	X	Z	Y	X	Y	Z
KFA01		03-05-15	0,000	2,400	3556,000	7 271,092	1 909,611	-443,922
KFA02		03-05-12	-1,000	-2,500	3552,500	7 269,605	1 912,933	-448,892
KFA03		03-06-24	1,350	2,000	3541,900	7 270,425	1 923,760	-444,603
KFA04		03-05-16	0,000	-2,400	3548,000	7 269,956	1 917,530	-448,881
KB513		03-05-08	0,000	-3,550	3551,900	7 270,510	1 913,669	-449,954
KB514		03-05-08	0,000	-3,550	3550,100	7 270,254	1 915,451	-449,989
KB613		03-05-22	0,000	-3,550	3545,900	7 269,657	1 919,608	-450,073
KB614		03-05-22	0,000	-3,550	3544,100	7 269,402	1 921,390	-450,109

Table AII:4 Total pressure sensors

			Local coordinate system			Äspö 96 coordinate system		
ID CODE	Layer	Installed	X	Z	Y	X	Y	Z
PFA01	17	03-05-12	0,000	0,000	3555,800	7 271,064	1 909,809	-446,326
PFA02	29	03-05-16	0,000	0,000	3551,000	7 270,382	1 914,560	-446,422
PFA03	21	03-05-13	0,000	-1,750	3551,000	7 270,382	1 914,560	-448,172
PFA04	8	03-05-12	0,000	-2,600	3551,000	7 270,382	1 914,560	-449,022
PFA05	3	03-05-08	0,000	-3,150	3551,000	7 270,382	1 914,560	-449,572
PFA06	29	03-05-16	-2,300	0,000	3551,000	7 268,105	1 914,233	-446,422
PFA07	38	03-05-28	0,000	2,300	3551,000	7 270,382	1 914,560	-444,122
PFA08	37	03-05-28	0,000	0,000	3548,000	7 269,956	1 917,530	-446,481
PFA09	29	03-05-19	0,000	-2,000	3548,000	7 269,956	1 917,530	-448,481
PFA10	45	03-06-03	0,000	0,000	3545,000	7 269,530	1 920,499	-446,541
PFA11	36	03-05-27	0,000	-1,750	3545,000	7 269,530	1 920,499	-448,291
PFA12	8dh	03-05-26	0,000	-2,600	3545,000	7 269,530	1 920,499	-449,141
PFA13	3dh	03-05-23	0,000	-3,150	3545,000	7 269,530	1 920,499	-449,691
PFA14	45	03-06-03	-2,300	0,000	3545,000	7 267,253	1 920,172	-446,541

Table AII:5 Thermocouples

			Local coordinate system			Äspö 96 coordinate system		
ID CODE	Layer	Installed	X	Z	Y	X	Y	Z
TFA01	38	03-05-28	0,000	2,300	3551,000	7 270,386	1 914,555	-444,122
TFA02	35	03-05-27	0,000	1,250	3551,000	7 270,386	1 914,555	-445,172
TFA03	26	03-05-15	0,000	-0,800	3551,000	7 270,386	1 914,555	-447,222
TFA04	8	03-05-12	-0,500	-2,600	3551,000	7 269,891	1 914,484	-449,022
TFA05	8	03-05-12	0,500	-2,600	3551,000	7 270,881	1 914,626	-449,022
TFA06	29	03-05-16	-1,250	0,000	3551,000	7 269,149	1 914,378	-446,422
TFA07	29	03-05-16	1,250	0,000	3551,000	7 271,623	1 914,732	-446,422
TFA08	43	03-06-03	0,000	1,000	3548,000	7 269,956	1 917,530	-445,481
TFA09	32	03-05-16	0,000	-1,250	3548,000	7 269,956	1 917,530	-447,731
TFA10	53	03-06-17	0,000	2,300	3545,000	7 269,530	1 920,499	-444,241
TFA11	50	03-06-16	0,000	1,250	3545,000	7 269,530	1 920,499	-445,291
TFA12	41	03-06-02	0,000	-0,800	3545,000	7 269,530	1 920,499	-447,341
TFA13	8dh	03-05-26	-0,500	-2,600	3545,000	7 269,035	1 920,428	-449,141
TFA14	8dh	03-05-26	0,500	-2,600	3545,000	7 270,025	1 920,570	-449,141
TFA15	45	03-06-03	-1,250	0,000	3545,000	7 268,292	1 920,322	-446,541
TFA16	45	03-06-03	1,250	0,000	3545,000	7 270,767	1 920,677	-446,541

Table AII:6 Pore water pressure sensors

			Local coordinate system			Äspö coordinate system		
ID CODE	Layer	Installed	X	Z	Y	X	Y	Z
UFA01	17	03-05-12	0,000	0,000	3555,800	7 271,064	1 909,809	-446,326
UFA02	21	03-05-13	0,000	0,000	3554,100	7 270,822	1 911,492	-446,360
UFA03	29	03-05-16	0,000	0,000	3551,000	7 270,382	1 914,560	-446,422
UFA04	21	03-05-13	0,000	-1,750	3551,000	7 270,382	1 914,560	-448,172
UFA05	8	03-05-12	0,000	-2,600	3551,100	7 270,396	1 914,461	-449,020
UFA06	3	03-05-08	0,000	-3,150	3551,000	7 270,382	1 914,560	-449,572
UFA07	21	03-05-13	0,000	-1,750	3551,000	7 270,382	1 914,560	-448,172
UFA08	38	03-05-28	0,000	2,300	3551,000	7 270,382	1 914,560	-444,122
UFA09	37	03-05-28	0,000	0,000	3548,000	7 269,956	1 917,530	-446,481
UFA10	29	03-05-19	0,000	-2,000	3548,000	7 269,956	1 917,530	-448,481
UFA11	45	03-06-03	0,000	0,000	3545,000	7 269,530	1 920,499	-446,541
UFA12	36	03-05-27	0,000	-1,750	3545,000	7 269,530	1 920,499	-448,291
UFA13	8dh	03-05-26	0,000	-2,600	3545,000	7 269,530	1 920,499	-449,141
UFA14	3dh	03-05-23	0,000	-3,150	3545,000	7 269,530	1 920,499	-449,691
UFA15	45	03-06-03	-2,300	0,000	3545,000	7 267,253	1 920,172	-446,541
UFA16	53	03-06-17	0,000	2,300	3545,000	7 269,530	1 920,499	-444,241
UFA17	29	03-05-16	-2,300	0,000	3551,000	7 268,105	1 914,233	-446,422
UFA18	62	03-06-24	0,000	0,000	3539,000	7 268,677	1 926,438	-446,661

Table AII:7 Wescor psychrometers for measuring the relative humidity

			Local coordinate system			Äspö coordinate system		
ID CODE	Layer	Installed	X	Z	Y	X	Y	Z
WFA01	17	03-05-12	0,000	0,000	3555,800	7 271,064	1 909,809	-446,326
WFA02	21	03-05-13	0,000	0,000	3554,100	7 270,822	1 911,492	-446,360
WFA03	38	03-05-28	0,000	2,300	3551,000	7 270,382	1 914,560	-444,122
WFA04	35	03-05-27	0,000	1,250	3551,000	7 270,382	1 914,560	-445,172
WFA05	29	03-05-16	0,000	0,000	3551,000	7 270,382	1 914,560	-446,422
WFA06	26	03-05-15	0,000	-0,800	3551,000	7 270,382	1 914,560	-447,222
WFA07	45		2,300	0,000	3545,000	7 271,806	1 920,826	-446,541
WFA08	8	03-05-12	0,000	-2,600	3550,900	7 270,368	1 914,659	-449,024
WFA09	3	03-05-12	0,000	-3,150	3551,000	7 270,382	1 914,560	-449,572
WFA10	29	03-05-16	-2,300	0,000	3551,000	7 268,105	1 914,233	-446,422
WFA11	29	03-05-16	-1,250	0,000	3551,000	7 269,145	1 914,383	-446,422
WFA12	29	03-05-16	1,250	0,000	3551,000	7 271,619	1 914,738	-446,422
WFA13	29	03-05-16	2,300	0,000	3551,000	7 272,659	1 914,887	-446,422
WFA14					Not installed			
WFA15	43	03-06-02	0,000	1,000	3548,000	7 269,956	1 917,530	-445,481
WFA16	37	03-05-28	0,000	0,000	3548,000	7 269,956	1 917,530	-446,481
WFA17	35	03-05-27	0,000	-0,550	3548,000	7 269,956	1 917,530	-447,031
WFA18	37	03-05-28	-1,250	0,000	3548,000	7 268,718	1 917,352	-446,481
WFA19	37	03-05-28	1,250	0,000	3548,000	7 271,193	1 917,707	-446,481
WFA20	53	03-06-17	0,000	2,300	3545,000	7 269,530	1 920,499	-444,241
WFA21	50	03-06-16	0,000	1,250	3545,000	7 269,530	1 920,499	-445,291
WFA22	45	03-06-03	0,000	0,000	3545,000	7 269,530	1 920,499	-446,541
WFA23	41	03-06-02	0,000	-0,800	3545,000	7 269,530	1 920,499	-447,341
WFA24	36	03-05-27	0,000	-1,750	3545,000	7 269,530	1 920,499	-448,291
WFA25	8dh	03-05-26	0,000	-2,600	3545,000	7 269,530	1 920,499	-449,141
WFA26	3dh	03-05-23	0,000	-3,150	3545,000	7 269,530	1 920,499	-449,691
WFA27	45	03-06-03	-2,300	0,000	3545,000	7 267,253	1 920,172	-446,541