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Äspö Hard Rock Laboratory

Temperature Buffer test

Detailed design materials. Foundation and artificial saturation

Peder Thorsager

Scandiaconsult Sverige AB

October 2002

Svensk Kärnbränslehantering AB
Swedish Nuclear Fuel
and Waste Management Co
Box 5864
SE-102 40 Stockholm Sweden
Tel +46 8 459 84 00
Fax +46 8 661 57 19

Äspö Hard Rock
Laboratory

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Author	Date
Thorsager	02-10-01
Checked by	Date
Christer Svemar, Bertrand Vignal	02-11-28
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Abstract

The French organisation ANDRA is carrying out an experiment named "Temperature Buffer Test" (TBT) with international co-operation at Äspö Hard Rock Laboratory in Sweden.

The French repository concept, with temperatures above 100 °C, requires detailed information on temperature distribution in dimensioning of the clay engineered barriers. Two possible approaches have been investigated:

- allowing the temperature of the bentonite to exceed 100° C temporarily
- use of composite sand/bentonite engineered barriers.

Design and basic information regarding the following parts of the test installation is dealt with in the report:

- sand material
- bentonite buffer
- concrete foundation
- artificial saturation.

The slot between the compacted bentonite blocks and the rock surface of the deposition hole will be filled with sand for artificial wetting. The volume between the upper canister and the bentonite blocks will also be filled with sand (see Figure 3.1).
The sand has to fulfil three requirements, namely; resistant to temperatures >170° C, possible to compact at low water content and have high permeability during the saturation phase.

The bentonite buffer around the two canisters in the *Temperature Buffer Test* is planned to consist of highly compacted bentonite blocks. At the upper most part of the deposition hole (1 m) the outer slot will be filled with bentonite pellets. The bentonite used for the test will be MX-80 with a water content of 17-17,5% and will be compacted to a density of 2000 kg/m^3 for blocks or 2090 kg/m^3 for rings.

A concrete foundation will be cast in the deposition hole. The foundation will support the bentonite buffer and facilitate a vertical alignment of the stack. It will also facilitate drainage of the hole.

Artificial water supply will be used since the natural access to water from the rock is limited and is expected to delay the water saturation rate of the buffer. The water pressure during the saturation period should be able to be adjusted between 0-4 MPa to speed up the process.

Sammanfattning

Den franska organisationen ANDRA bedriver ett experiment benämnt ”Temperature Buffer Test” (TBT) i internationellt samarbete med Äspö Hard Rock Laboratory i Sverige.

Det franska djupförvaringskonceptet med temperaturer över 100º C kräver detaljerad information avseende temperaturspridning för dimensionering av bentonitbufferten.

Två möjliga tillvägagångssätt har undersökts:

- att tillåta bentonitens temperatur att tillfälligt överstiga 100º C
- att använda (”sammansatt”) sand/buffert tillverkad av bentonit.

Design och grundläggande information för test installationen enligt nedanstående punkter behandlas i denna rapport:

- sandmaterial
- bentonitbuffert
- betongfundament
- artificiell mätning.

Slitsen mellan de kompakterade bentonitblocken och bergväggen i deponeringshålet kommer att fyllas med sand för artificiell bevätning. Utrymmet mellan den övre behållaren och bentonit-blocken kommer också att fyllas med sand (se figur 3.1). Sanden skall uppfylla tre behov, nämligen; att vara resistent mot temperaturer >170º C, möjlig att packa vid litet vatteninnehåll samt att ha god genomtränglighet under mättnadsfasen.

Bentonitbufferten som omger de två behållarna i *Temperature Buffer Test* är tänkt att bestå av hårt packade bentonitblock. Vid den yttersta delen av deponeringshålet (1 m) kommer den yttre slitsen att fyllas med bentonitpellets. Bentoniten som kommer att används i detta experiment är MX–80 med ett vatteninnehåll på17-17,5% och kommer att packas till en densitet på 2000 kg/m³ för/gällande blocken eller motsvarande 2090 kg/m³ för bentonitringarna.

Ett betong fundament kommer att gjutas i deponeringshålet. Fundamentet skall stötta bentonitbufferten och underlätta en vertikala uppriktning av stapeln. Dessutom kommer fundamentet att underlätta dränering av deponeringshålet.

Då tillgång till naturlig vattenförsörjning från berget är begränsad och anses försena vatten-mättnaden i bufferten kommer man att använda sig av artificiell bevätning. Vattentrycket under mättnadsfasen skall vara möjlig att justera mellan 0-4 MPa för att kunna skynda på processen.

Contents

List of Figurs

List of Tables

1 Introduction

The French organisation ANDRA is carrying out an experiment named "Temperature Buffer Test" (TBT) with international co-operation at Äspö Hard Rock Laboratory in Sweden.

The scientific background to the project is as follows:

The Swedish design of a repository for spent fuel (KBS-3) and the Japanese design for vitrified waste ('H12' report) both limit the surface temperature of the packages to 100 °C.

The French repository concept, with temperatures above 100 °C, requires detailed information on temperature distribution in dimensioning of the clay engineered barriers. Two possible approaches have been investigated:

- allowing the temperature of the bentonite to exceed 100 °C temporarily
- use of composite sand / bentonite engineered barriers.

The TBT-test aims at evaluating the benefits of extending our current understanding of the behaviour of engineered barriers to include high temperatures above 100 °C and the experimental resources needed to achieve this.

2 Objective

The objective with this report is to account for and authenticate the principle design and basic information regarding the following parts of the test installation:

- sand material
- bentonite buffer
- concrete foundation
- artificial saturation.

The reports will also be used in conjunction with the Activity Plans (AP) for the actual installation and reporting of the site activities.

3 Sand material

3.1 Introduction

The slot between the compacted bentonite blocks and the rock surface of the deposition hole will be filled with sand for artificial wetting. The volume between the upper canister and the bentonite blocks will also be filled with sand (see Figure 3.1).

3.2 Choice of sand type

The sand should have the following properties:

- be chemically stable and inert at high temperature and other conditions that prevail in the experiment

- be possible to compact into the slot in layers at low water content in order to minimise the risk of water to be taken up by the buffer during the installation as well as the risk of corroding the heater

- withstand the swelling pressure of the buffer in the outer slot with an average compression of about 30% and at the heater with a compression of about 10%

- the sand in the outer slot must have a sufficient high hydraulic conductivity during the whole saturation phase of the buffer in order to function as a filter during the artificial saturation of the buffer.

Due to the high temperature and the limited time the TBT test is planned to run, the sand in the inner slot is expected to be kept dry. This means that the first demand listed above is fulfilled in spite of the problem a water saturated quartz sand may yield at high temperatures. Therefore, a sand with quartz, is judged to be suitable for the test. Three types of sands have been tested in the laboratory. One sand is a natural well graded sand (Ilstorp sand) one sand is sewed to a grain size between 0,25 and 1 mm (golf bunker sand) and one is a sand of crushed rock (Dalby sand). The sands have been filled loosely in an oedometer and the compressibility was tested up to a stress of 10 MPa. The results from the test are shown in Figure 3.2. Furthermore the density at loose filling and the density after proctor compaction were determined. The results from these tests are shown in Table 3.1.

It is expected that all three of the sands can be used as filling both in the outer and inner slot in the TBT test.

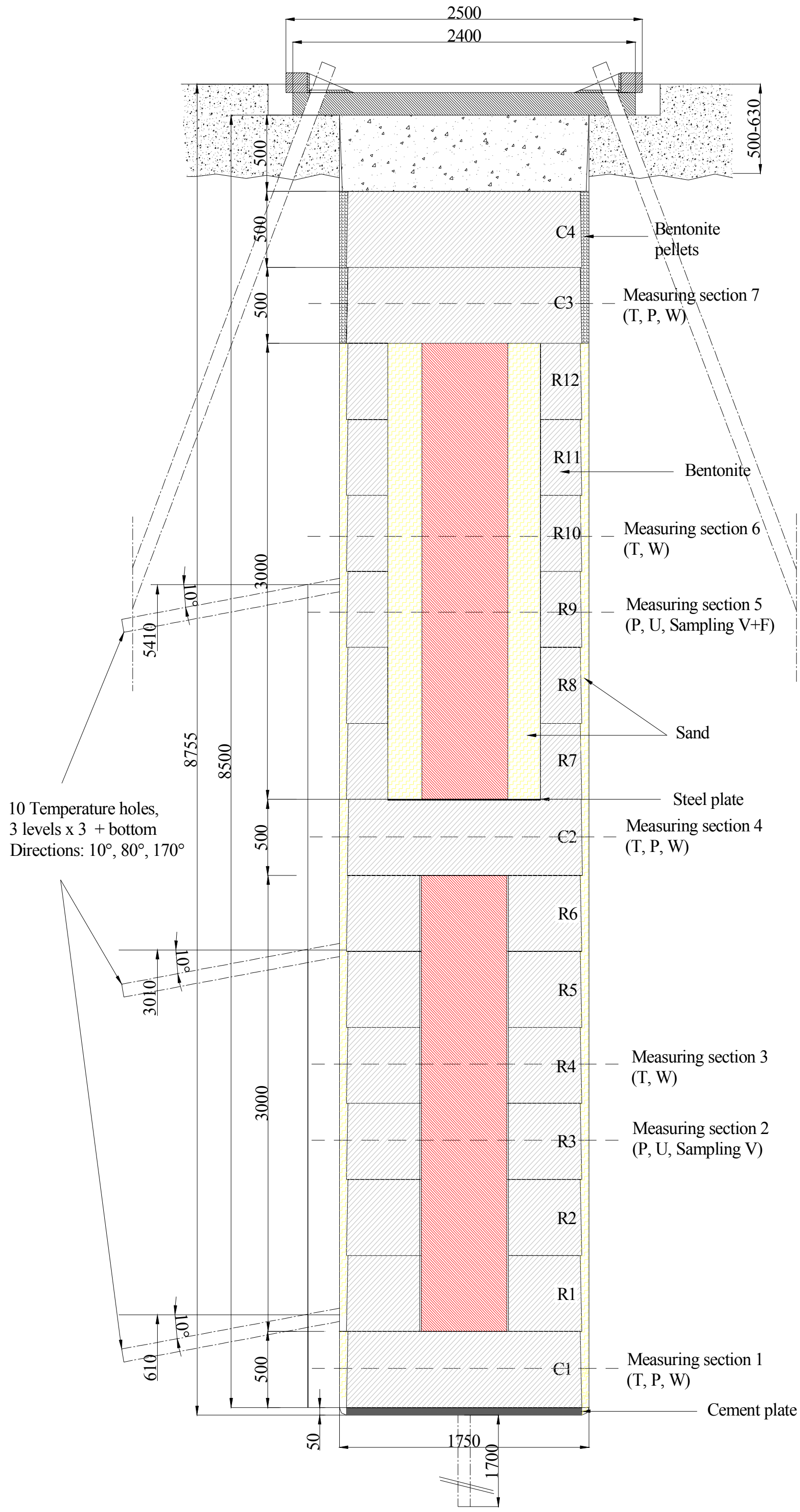

Figure 3-1. *The deposition hole for the TBT.*

Table 3.1 Density and water ratio for three types of sands.

Type	Water ratio (%)	Loose dry density (kg/m^3)	Dry density after proctor (kg/m^3)
Dalby sand	2,4	1170	2020
Ilstorp sand	2,5	1270	1840
Bunker sand	2,2	1260	1690

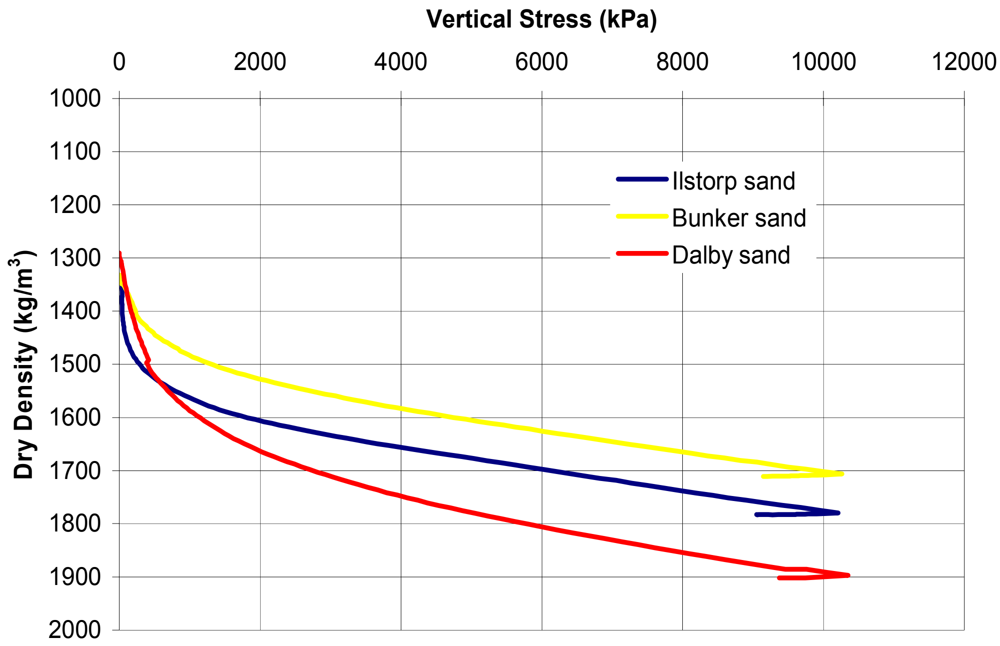

Figure 3-2. *Oedometer tests performed on three types of sands.*

4 Bentonite buffer

4.1 Introduction

The bentonite buffer around the two canisters in the *Temperature Buffer Test* is planned to consist of highly compacted bentonite blocks. The bentonite used for the test will be MX-80 with a water content of 17-17,5%. Since the natural water content of MX-80 is about 10% water must be added to the bentonite. At the upper most part of the deposition hole (1 m) the outer slot will be filled with pellets of bentonite.

A form has been constructed and manufactured where ring-shaped and cylindrical blocks can be compacted with a maximum diameter of 1650 mm. The form will be used for producing the blocks for the *Temperature Buffer Test*. A schematic drawing of a deposition hole with bentonite blocks is shown in Figure 4-1. The figure shows that the total amount of blocks needed for the deposition hole is 12 ring-shaped blocks and 4 cylindrical blocks. The blocks around the upper canister will have an inner diameter of 1070 mm. These blocks can be compacted with the existing form. The ring-shaped blocks around the lower canister will be machined out from cylindrical blocks to its final inner diameter of 620 mm. The total weight of the bentonite blocks needed for the deposition hole is about 25,5 tons (after machining of the blocks).

The production of the buffer (blocks and pellets) can be divided in to the following items:

- delivery control of the bentonite
- mixing of the bentonite with water
- compaction of the blocks
- investigation of the blocks immediately after compaction
- machining of the blocks to their final shape and dimensions
- manufacturing of pellets.

In the following sections the items are described in detail except for the production of pellets. The pellets that will be used for the tests (about 500 kg) have already been manufactured (a part of the pellets produced for the Prototype Repository Test).

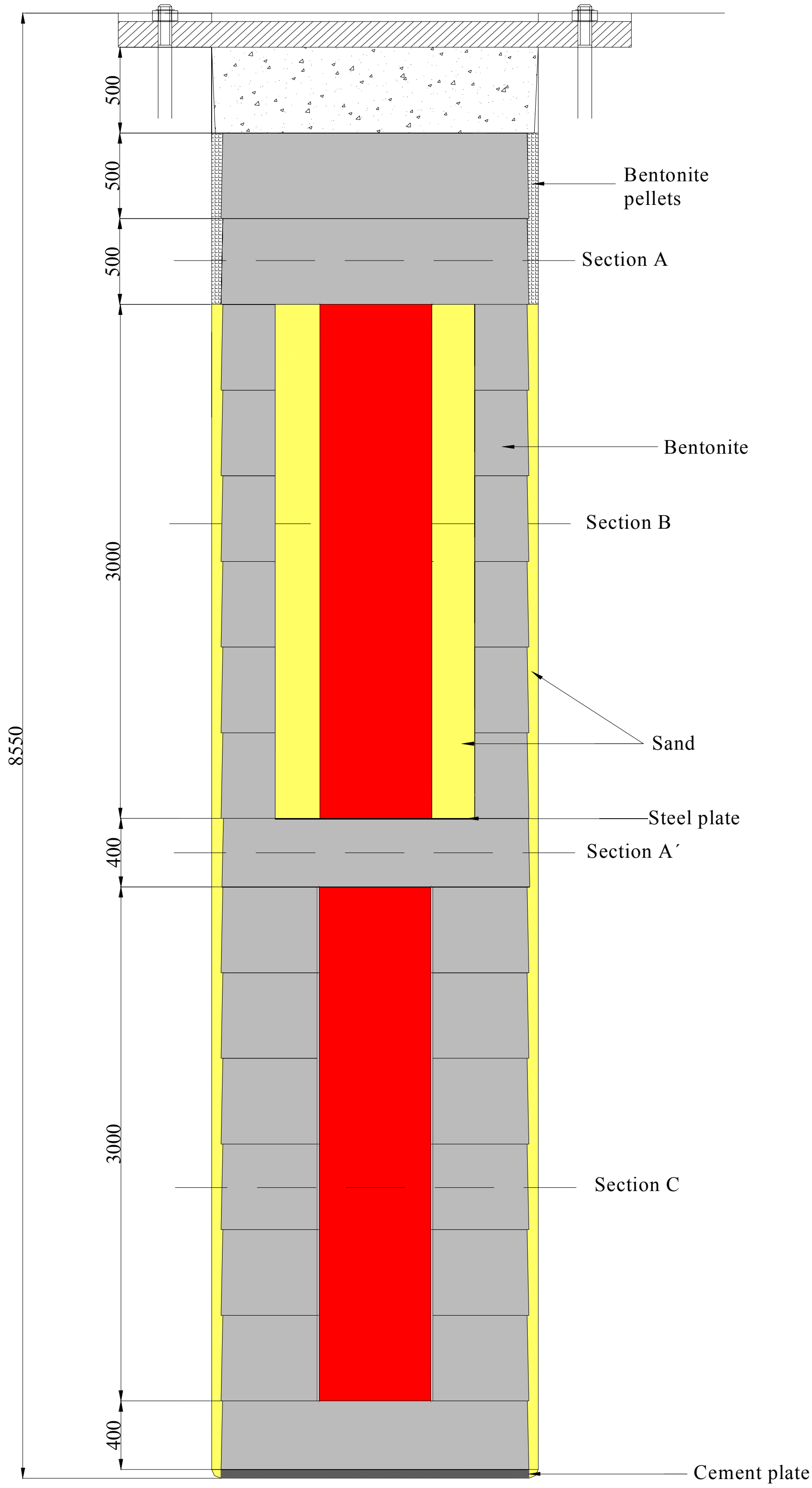

Figure 4-1. *Skeleton drawing of the deposition hole for the TBT.*

4.2 Delivery control of the bentonite material

The quality control of the bentonite is made when the bentonite is delivered to the site for mixing at Hackman-Rörstrand AB in Lidköping. The bentonite will be delivered in Big-Bags. The Big-Bags will be weighted and a sample will be taken from each Big-Bag. The samples will be used for the delivery control of the bentonite.

The delivery control is described in a quality plan with the title *Acceptance control of bentonite material* (QP TD S63-99-064). The control consists of the following tests:

- The natural water content
- Free swelling
- Liquid Limit
- Grain size distribution

The water content of the delivered bentonite varies between 8 and 13%. The water content is very much depending on when the bentonite is filled in the Big-Bags. The lowest water content is expected during the winter season when the Relative Humidity in the air outdoors is low. The variation in water content of the bentonite within one delivery is normally very small.

In the free swelling tests 1.1 g bentonite is carefully poured in a 100 ml measuring glass filled with de-ionized water. After 24 h the volume of the swollen sample is determined. The expected value for MX-80 is 15-20 ml.

The definition of the liquid limit (w_L) of a soil is the water content where the soil is going from a plastic consistency to a semi liquid/liquid state. This parameter is correlated to parameters as swelling pressure and hydraulic conductivity for a bentonite. The liquid limit is determined with the fall-cone method. The method is described in the "Consistency Limits" part of the Laboratory manual series of the Swedish Geotechnical Society (SGF). The expected liquid limit for MX-80 is 450-500 %.

The granule size distribution of the bentonite is determined by sieving the bentonite. Since the bentonite consists of granules of clay particles the sewing itself can affect the result (by crushing the granules). This test is made in order to avoid deliveries with very fine powder, which might be hard to both mix and compact.

When the bentonite is accepted according to the quality plan it is filled in a silo placed close to the mixing device.

4.3 Mixing of bentonite

The mixing of the bentonite will be performed at Hackman-Rörstrand AB in Lidköping in a mixer used for mixing clays for porcelain ware. The mixer, see Figure 4-2, is an Eirich mixer with a built-in weighing-machine. The maximum batch that can be handled using this mixer is about 1.5 tons.

The bentonite, of type MX-80, will be filled into a silo placed above the mixer and then transported to the mixer. About 1 ton of bentonite will be mixed in each batch. A small sample will be taken from the bentonite filled into the mixer and the initial water content will be determined by weighting a piece of the sample before and after drying in a microwave oven. This water content and the total amount of bentonite will be used for calculating the amount of water needed in order to get a final water ratio of 17-17,5%. After mixing, another sample will be taken and the final water ratio determined (also in a microwave oven). A sample from each batch is saved for further investigations of the bentonite. The bentonite is then filled in Big-Bags. The Big-Bags are placed in a plastic bag to avoid any desiccation of the bentonite during transportation and storage. In all 35 batches will be mixed. The Big-Bags and the samples taken from the batches will be numbered and marked with the date of mixing.

After the mixing the final water content will be determined, by drying a sample for 24 h at a temperature of 105º C.

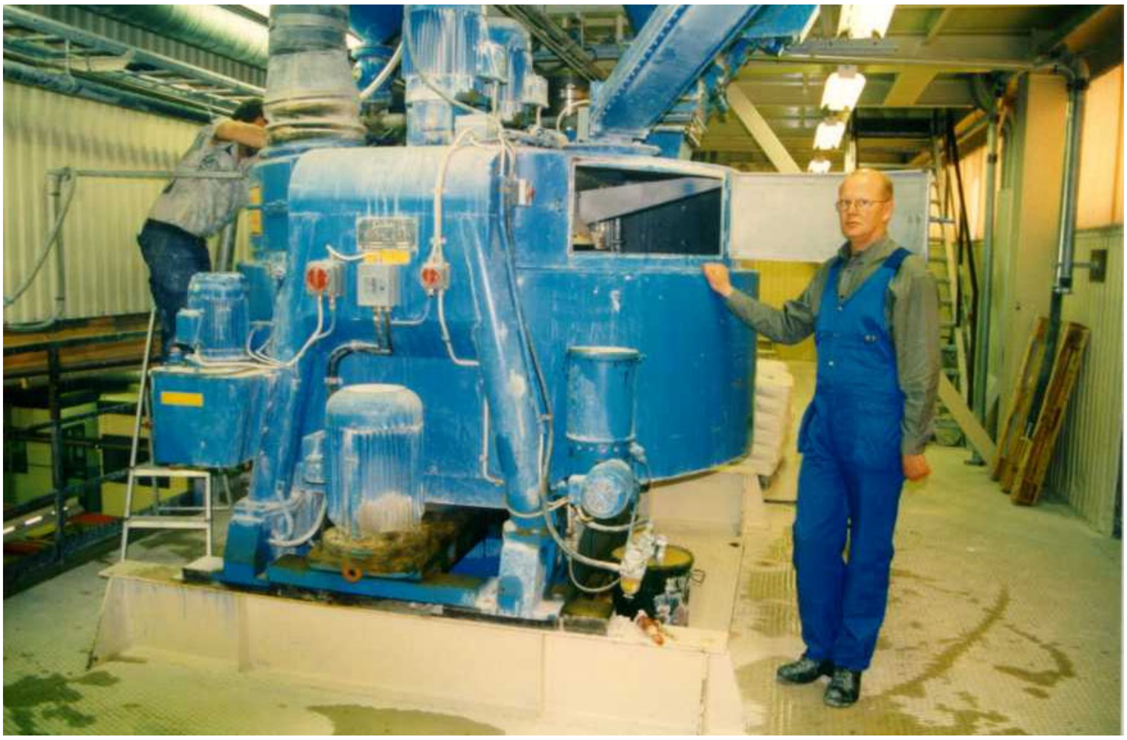

Figure 4-2. *The Eirich mixer placed at Hackman-Rörstrand AB.*

4.4 Block compaction

The mixed bentonite will be transported in Big-Bags to HYDROWELD AB in Ystad where the press is situated. The bentonite is there filled into a silo, which is a part of the filling equipment. The required amount of bentonite is then filled into the form and the form is placed in the press with a subsequent compaction of the bentonite. After removing the block from the form it will be placed on a pallet using specially designed lifting equipment, and a plastic bag is placed over the block in order to prevent the block from drying. The lifting equipment is described in detail by Johannesson (1999). Table 4-1 shows the programme for compacting altogether 18 blocks. In order to get a buffer with a homogenous density after saturation the blocks placed at different sections have to be compacted to various densities. Three types of blocks, related to the type sections A, B and C, shown in Figure 4-1, will be compacted.

Table 4-1 Programme for compacting blocks for the Temperature Buffer Test in the Äspö HRL.

No.	Shape of block	Section	Comp. Pressure (MPa)	Water ratio (%)	Bulk density (kg/m^3)	Weight (kg)	Density at satur. (kg/m^3)
TBTA1 – TBTA4	Cylinder	A	40	17,5	2000	2110	2038*)
TBTB1 – TBTB7	Ring.	B	100	17,5	2090	1270	2014
TBTC1 – TBTC7	Cylinder	C	40	17,5	2000	2110	2029

*) The section A´ where the outer slot will be filled with sand the density at saturation will be 2046 kg/m^3.

All the compacted blocks will have a height between 495-510 mm. The maximum outer diameter will be about 1650mm while the inner diameter of the ring-shaped blocks will be about 1070 mm. With an assumption of the compression of the sand filling in the slots the densities at saturation of the buffer in the three type sections (A, B and C) can be calculated. In Table 4-1 the expected densities of the buffer after saturation are shown. The calculations are made with the following assumptions:

- the diameter of the deposition hole is 1750 mm
- the compression of the sand in the outer slot will be 30%
- the compression of the sand in the inner slot will be10% (valid for the upper canister)
- no axial swelling of the buffer.

The expected average density of the buffer can also be calculated to about 2030 kg/m^3. The calculations are made with the assumption that no axial swelling of the buffer will occur during the water uptake. Since it is likely there will be some swelling of the buffer, the densities can be seen as the absolute maximum density of the buffer.

The compaction will be made in a press with a maximum capacity of 30.000 tonnes. The compaction will be made in the following sequence:

- Material delivered in Big-Bags is filled into the silo, which is an integrated part of the filling equipment.

- The form is mounted outside the press and lubricated with MOLYKOTE BR 2 plus®, which is a lubricant for lubricating at high pressure.

- With the built-in weighing machine material is portioned into the form with an accuracy of about ±50 kg (see Figure 4-3).

- A sample (about 5 kg) is taken from the material in the form. The sample will be marked with the same number as the compacted block and the date of compaction (see Table 4-1). This material will be further investigated with respect to chemical composition and mechanical properties. These investigations will be described in a separate Activity Plan.

- Since the gap in the press is small (see Figure 4-4) the compaction has to be made in three steps by placing small pistons on top of each other after each step. The first piston is placed on top of the bentonite in the form and the form is placed in the press (see Figure 4-3). The tubes from the filters are connected to a vacuum pump and air is evacuated from the bentonite in the form. The evacuation is retained through the whole compaction sequence. The bentonite is then compacted with the press as far as possible, after that the second piston is placed on top of the first piston and the compaction continued. The same procedure is repeated for the third piston. The total time for the compaction will be about 10 minutes. The maximum load will then be left on the piston for another 10 minutes (hold time 10 minutes).

- The reloading of the block takes about 10 minutes. The form with bentonite and the pistons are then lifted with jackets. Steel plates are placed between the form and the bottom plate and the block is pushed out of the form with the press.

- The form and the block are then removed out from the press and the ring and pistons lifted off the block (see Figure 4-5). With the lifting equipment the block is lifted of the bottom plate of the form and placed on a pallet (see Figure 4-6).

Figure 4-3. *Bentonite filled into the form.*

Figure 4-4. *The form with the first piston placed in the press.*

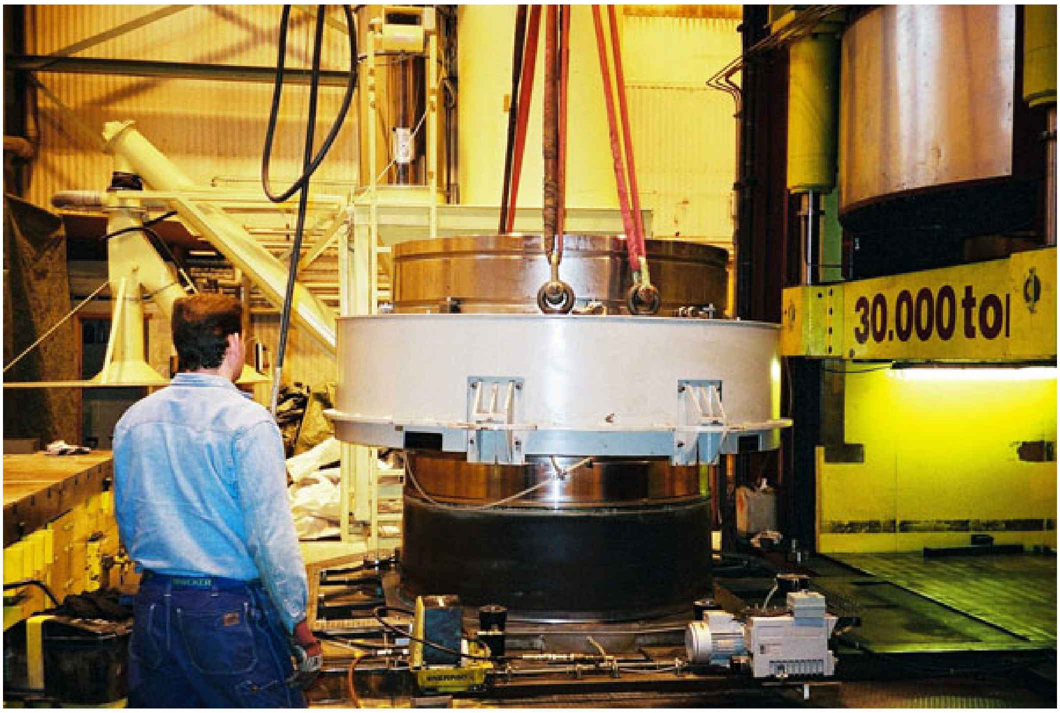

Figure 4-5. *The bentonite block placed on the bottom plate while the form is removed.*

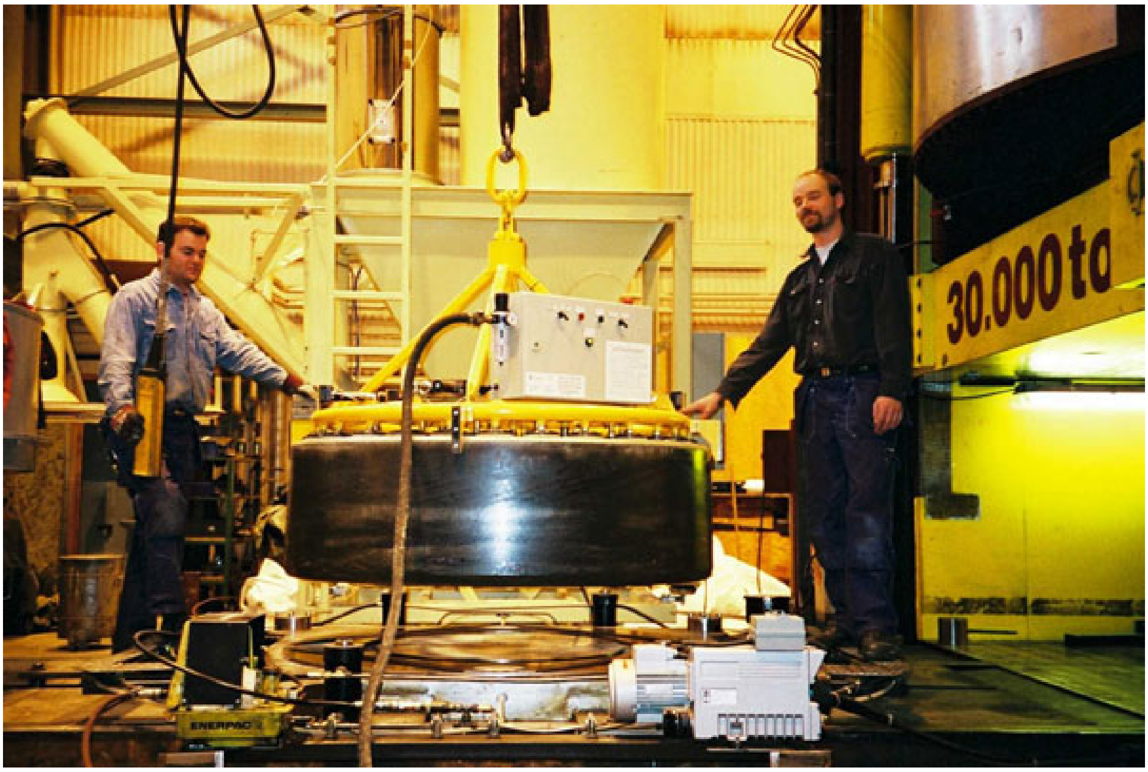

Figure 4-6. *The bentonite block lifted from the bottom plate with the lifting equipment.*

4.5 Investigation of the compacted blocks

A protocol will be filled in for each block. It will contain the weight of bentonite used for the blocks, the time for compaction, the maximum compaction force, the time at the maximum load (hold time) and the time for reloading. The blocks are examined by eye. Any notable damages on the blocks are noted in the protocols.
After compaction, the dimensions (height and diameters) of each block will be measured (see Figure 4-7). The height of the blocks will be measured at 12 locations around the block. The highest measured point of each block will be marked. The weight of the blocks will also be determined with an accuracy of ±2 kg using a weighing machine hanging from an overhead crane. All these parameters are also noted in the protocol.
On a small part of the sample taken from the filled bentonite in the form the water ratio of the bentonite in each block is will be determined and noted in the protocol.

Figure 4-7. *The height of the bentonite block is measured.*

4.6 Machining of the blocks

The block at the bottom of the deposition hole and the block between the two canisters will be machined to a final height of 400 mm. The machining will be made with a saw and a grinding machine after placing the block on a pallet. By sawing small tracks in the blocks to a defined depth it is possible to break loose pieces of the blocks so the blocks get the final height.
The upper part of the block is then ground to get a smooth surface. The ring-shaped blocks surrounding the lower canister will be manufactured by machining cylindrical blocks. The final inner diameter of the block will be about 620 mm. By drilling a slot using a drill with a diameter of 40 mm the inner part can be removed from the rest of the block. This inner part will have a weight of about 350 kg. It will be lifted of the pallet by attaching several lifting eye bolts and then use an overhead crane. The surface at the inner diameter will then be ground.

After the machining the dimensions and weight of the each block will be determined and noted in a protocol.

5 Concrete foundation

5.1 Introduction

Bottom slabs have been cast in all full-scale deposition holes used in experiments at Äspö. The bottom slabs made of concrete will be the foundation for the placement of bentonite blocks, see Figure 5.1. The slab will support the bentonite buffer. It will also facilitate drainage of the hole during placement of bentonite blocks and deposition of canister. Before the buffer installation takes place, a thin copper plate will be placed on the top of the bottom slab in order to prevent the buffer from taking up water from the concrete/rock.

5.2 Design

To reduce the risk of tilting the pile of bentonite blocks after placement and to ensure that the centre point of each ring does not deviate from the theoretical point, the bottom slab should be as horizontal as possible. The slab may have a maximum deviation between opposite sides of 1 mm. One millimetre deviation gives a horizontal displacement of the top ring of approximately 4 mm. The cast of the bottom slab is divided into two steps. The two castings differ in compounds to fulfil the requirement of the bottom slab for the bentonite blocks. The first coarse casting is to create a slot between the deposition hole wall and the first bentonite block where water can be transported from the surrounding wall to the sump without affecting the bentonite. The second fine casting is to create the horizontal, flat surface for the pile of bentonite blocks.

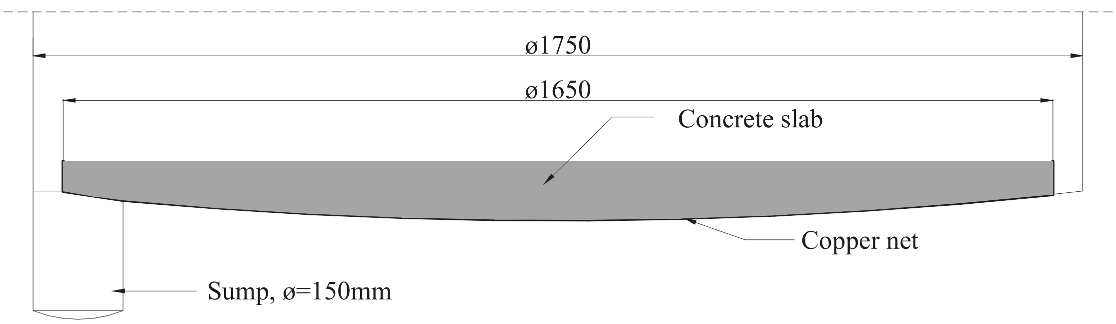

Figure 5-1. *Layout of bottom slab with copper net and sump.*

A copper net is mounted between the bottom of the hole and the concrete slab in order to create a waterway. The net will also prevent ballast to flow into the sump. The net will be pressed against the bottom of the borehole and follow the inside of the mould to its upper edge. The net consists of copper with a mesh size of 0.15 mm. The net will also be mounted in the part of the sump that is inside the mould. It is of outmost importance that the net has no "bubbles" and is flat against the mould. Bubbles can create transporting openings for concrete to flow out from the mould during the second casting.

5.3 Surveying

After hardening and removal of the mould the slab will be surveyed in order to control the result of the final casting.

6 Artificial saturation

6.1 Introduction

The access to water is important. The slot between the bentonite and the rock will be filled with sand that will work as a filter and distribute the water to the bentonite surface. Since the natural access to water from the rock is limited and is expected to delay the water saturation rate, the buffer will be artificially saturated.

6.2 Design

The design of the artificial water saturation system will be done with respect to the following demands:

- The system will consist of a low-pressure part and a high-pressure part. The low- pressure part will be used for filling up the pore volume in the sand, which is about 1 m^3.
- The high-pressure part will be used during the saturation of the bentonite.
- The wet parts of the system should be constructed of either inert material or stainless steel.
- The water pressure during the saturation period should be able to be adjusted between 0-4 MPa.
- The amount of water filled up/injected will be measured.
- The water should be taken from the formation, the same source as the canister retrieval test can be used.

The water will be led in to the filter sand by use of titanium tubes placed in the sand. The tubes will be equipped with filter tips in the ends. In order to de-air the sand volume during the filling, the tubes will be placed at different levels. The filling will start from the bottom and will continue until water comes out from the tubes placed in the top of the sand.

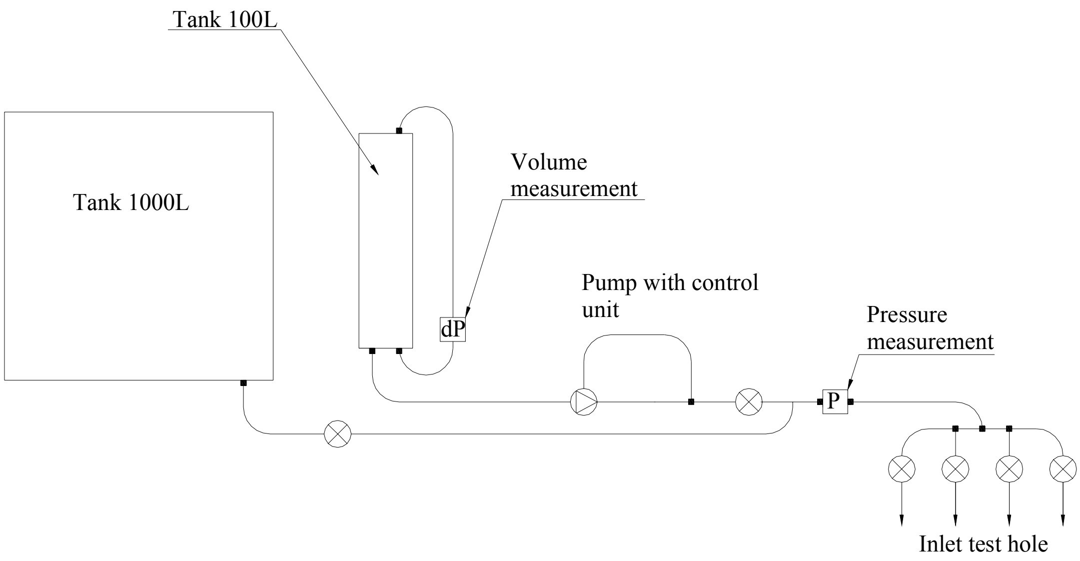

Figure 6-1. *Principal design of saturation equipment.*