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Community research

Long-term Performance of Engineered Barrier Systems

Long-term Performance of Engineered Barrier Systems PEBS

Engineered Barrier Emplacement Experiment in Opalinus Clay: "EB" Experiment

AS-BUILT OF DISMANTLING OPERATION

(DELIVERABLE-N°: D2.1-4)

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PU	Public	**PU**
RE	Restricted to a group specified by the partners of the [acronym] project	
CO	Confidential, only for partners of the [acronym] project	

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1 INTRODUCTION

1.1 THE EB PROJECT

The Engineered Barrier Emplacement Experiment in Opalinus Clay "EB" Experiment aimed the demonstration of a new concept for the construction of HLW repositories in horizontal drifts, in competent clay formations. The principle of the new construction method was based on the combined use of a lower bed made of compacted bentonite blocks, and an upper buffer made of granular bentonite material (GBM).

The project consisted on a real scale isothermal simulation of this construction method in the Opalinus Clay formation at the Mont Terri underground laboratory in Switzerland. A steel dummy canister, with the same dimensions and weight as the Spanish reference canister, was placed on top of a bed of bentonite blocks, and then the upper part of the drift was buffered with the GBM made of bentonite pellets (Figure 1). The drift was sealed with a concrete plug having a concrete retaining wall between the plug and the GBM. Since the end of the test installation the evolution of the different hydro-mechanical parameters were being monitored, both in the barrier and the rock (especially in the EDZ). Relative humidity and temperature in the rock and in the bentonite buffer, rock displacement, pore pressure and total pressure were registered by means of different types of sensors. Due to the short amount of free water available in this formation, an artificial hydration system was installed to accelerate the hydration process in the bentonite.

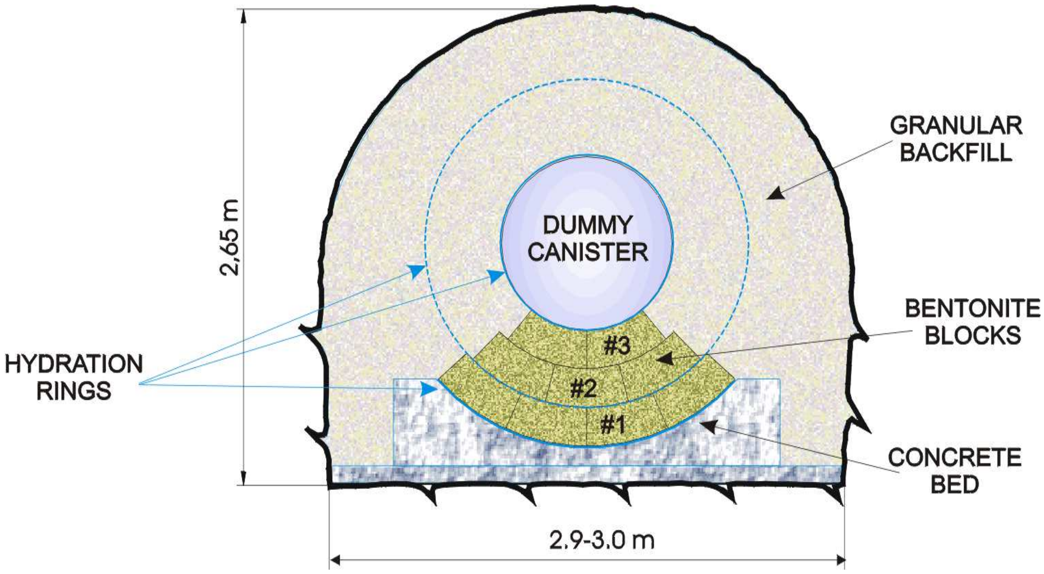


Figure 1: EB experimental layout

The basic objectives of the project were the following:

- o Definition of backfill material (composition, grain size distribution ...). Demonstration of the manufacturing process at semi-industrial scale.

- o Characterisation of the hydro-mechanical properties of the backfill material.
- o Design and demonstration of the emplacement and backfilling technique.
- o Quality Assessment of the clay barrier in terms of the achieved geomechanical parameters (homogeneity, dry density, voids distribution ...) after emplacement.
- o Characterisation of the Excavation Disturbed Zone (EDZ) in the Opalinus clay, and determination of its influence in the overall performance of the system.
- o Investigation of the evolution of the hydro-mechanical parameters in the clay barrier and the EDZ as a function of the progress of the hydration process.
- o Development of a hydro-mechanical model of the complete system adjusted and calibrated with the data resulting from the experiment.

After 11 years of operation, the experiment has been dismantled between the 19th of October 2012 and the 1st of February 2013. The aim of this document is to describe the processes, results and conclusions of the dismantling operation.

1.2 BACKGROUND

1.2.1 Funding

The first phase of the EB experiment -years 2000 to 2003–, devoted to the test design, installation and start-up of the operation, was co-financed by the European Commission (contract nº FIKW-CT-2000-00017), under the framework of the research and training programme (Euratom) in the field of nuclear energy, and ENRESA (Spain). Besides ENRESA, BRG (Germany) and NAGRA (Switzerland) were the principal contractors and AITEMIN (Spain) and CIMNE (Spain) the assistant contractors.

Between 2003 and 2009 the project operation continued under the support of the Mont Terri Consortium, project 32.015: EB, phases 10 to 14.

From 2010, the experiment is part of the PEBS[1] project, Work Package 2 Experimentation. The PEBS project is one of the “Small and Medium Projects” forming part of the FP7 Euratom programme. It is a multinational European research project that investigates processes affecting the engineered barrier performance of geological repositories for high-level waste disposal. The PEBS consortium consists of 17 leading nuclear research organisations, radioactive waste management agencies/implementing organisations, universities and companies.

1.2.2 Experiment development

After the preparation of the design document (AITEMIN 2001) and the components procurement, the installation of the experiment was carried out in several steps. The instrumentation was installed from November 2001 to February 2002: in-rock pore pressure sensors, rock displacement sensors and some rock relative humidity sensors, canister

[1] PEBS: Long-term Performance of the Engineered Barrier System

displacement sensors, relative humidity sensors in bentonite and total pressure cells. The artificial hydration system was installed in March 2002. The installation of the experiment was finished in April 2002, including the retaining wall, the concrete plug and the data acquisition system.

The artificial hydration of the bentonite started in May 2002 and ended in June 2007. There was an initial hydration phase with an important amount of water injected (6,700 litres in two days) that was stopped after several water stains appeared on the wall. After that, the hydration was restarted and from September 2002 to June 2007, there were different hydration phases with continuous water injection. The detailed record of effective water inflow for bentonite hydration is included in report SDR EB N19 (AITEMIN 2007).

After the end of the hydration phase, the monitoring of the experiment continued in order to follow the evolution of the bentonite.

The Engineered Barrier Emplacement Experiment test is described in detail in the "EB Experiment Test Plan", Project Deliverable 1, EC contract FIKW-CT2000-00017 (AITEMIN 2001), which includes the preliminary design, the emplacement and the operation.

1.3 CONCEPT OF THE DISMANTLING OPERATION

The main objective of the dismantling of the EB experiment has been to know about the real status of the GBM used after its artificial saturation: degree of saturation, permeability, density, aspect, homogeneity, etc. It has been also important to check the status of the bentonite blocks that support the canister, the rock in contact with the buffer, with especial interest in the EDZ, and the degree of saturation of the concrete in the vicinity of the buffer (plug and blocks support). Therefore, the activities of the dismantling have been coordinated with a sampling programme intended to analyse parameters such as dry density, water content, permeability… in the laboratories of the different organizations as well as in an on-site laboratory. The dismantling has been partial, as the last 120 cm of GBM was left on place, as well as the canister and the last 80 cm of the bed of bentonite blocks in order to show the way the experiment was done (demonstrator).

The Test Plan of the planned operation for the dismantling and sampling is described in the document "EB experiment TEST PLAN & SAMPLING BOOK" Deliverables n°:D2.1-2 and D2.1-3 (AITEMIN 2012).

AITEMIN has been the subcontractor to carry out the dismantling operation including the sampling and on site analyses.

ENRESA, AITEMIN & CIEMAT have been focused in the sampling and analysis of the buffer (GBM and the bentonite blocks), and other participant organizations (BGR, NAGRA and ANDRA) have taken care of the rest of components and interfaces (rock and concrete).

Additionally, the sampling and analysis of the used sensors, to be performed by ENRESA & AITEMIN, and the comparison of the on-site measurements with the last values provided for the installed sensors will help to assess the accuracy of acquired data. Besides, the data resulting from the dismantling will be used for the further adjustment of the H-M model of the complete system.

1.4 CONTENTS OF THE DOCUMENT

This document describes the dismantling and sampling activities carried out. It also shows the results of the dry density and water content obtained in the on site analyses carried out by AITEMIN and in the laboratory ones by the CIEMAT team. In section 2, it starts with a brief chronological description of all the activities that have been carried to accomplish the whole operation. Section 3 describes the dismantling of the concrete plug, the retaining wall and the bentonite removal including the methodology applied and the resources and tools that were used. It also explains the operation to support the canister and to dismantle the data acquisition system.

Section 4 is completely dedicated to the sampling and analysis operation. It describes the different sampling procedures applied depending on the different materials to be sampled, the samples that were taken for the analyses on site and the ones that were taken for the partner organizations. It also explains the analysis procedures carried out in the on-site laboratory, and the obtained results.

The document finishes with the conclusions and the used references.

2 SEQUENCE OF WORKS

The operation started with the partial dismantling of the concrete plug, followed by the sampling and bentonite removal, which were coordinated in order to reach even sections and to alter as minimum as possible the sampling areas. Previously to the dismantling works, the working area was set up.

The dismantling operation itself began on the 23rd of October 2012 with the drilling of a core in the concrete plug in order to have a free inner surface to start breaking it. The bentonite removal and sampling activities started on the 23rd of November 2012 and ended on the 29th of January 2013. The last days of the operation were used to dismantle the data acquisition system (DAS) as well as organizing the shipping of material. The operation was finished on the 1st of February 2013. A more detailed sequence of the whole operation is listed in Table 1.

Table 1. Detailed sequence of works

Date	Activity	Test Plan Phase
October 2012		
19/10/1012-20/10/2012	Preparation of the area of work	Phase 1
23/10/2012	Drilling a 200 mm in diameter core in the concrete plug	Phase 1
24/10/12-31/10/12	Drilling boreholes and use of the splitter to break the concrete plug	Phase 2
November 2012		
6/11/12-13/11/12	Drilling boreholes and use of the splitter to break the concrete plug using a mini-backhoe to help dismantling the plug	Phase 3, 4 and 5
	Taking concrete samples for water content on site analysis	Sampling Phase
14/11/12	The retaining wall and a small area of the bentonite are reached (window)	Phase 6
15/11/12	Testing with different tools to sample the bentonite	Sampling Phase
	Continuing with the plug dismantling works with both methods: splitter and backhoe	Phase 6
16/11/12	Preparation of a plastic cover to protect the bentonite from drying	-
	Testing how to sample concrete and bentonite with a drilling machine.	Sampling Phase
	Continuing with the plug dismantling works using the backhoe	Phase 6
20/11/12	Dismantling of cables box C	Phase 6
	Continuing with the plug dismantling works using the backhoe	Phase 6
21/11/12	Sampling concrete from the retaining wall/bentonite interface	Sampling Phase
22/11/12	Retaining wall/bentonite sampling	Sampling Phase
	Continuing with the plug removal works using the backhoe	Phase 6

Date	Activity	Test Plan Phase
23/11/12-26/11/12	Bentonite removal between retaining wall and the section where the face of the canister is	Bentonite removal
	Taking samples in the section where the face of the canister is for CIEMAT (Geochemical)	Sampling Phase
27/11/12	Testing bentonite sampling and on site dry density and water content analyses	Sampling Phase
28/11/12-30/11/12	Drilling boreholes and use of expansive cement to further break the concrete plug	Phase 6
	Testing bentonite sampling and on site dry density and water content analyses	Sampling Phase
	Continuation of bentonite removal	Bentonite removal
December 2012		
1/12/12-11/12/12	Bentonite removal up to section A1-25	Bentonite removal
12/12/12	Bentonite sampling. Water content and dry density on site analysis section A1-25	Sampling Phase
13/12/12	Sampling section CMT1	Sampling Phase
14/12/12-15/12/12	Sampling for dry density and water content on site analysis of section B1	Sampling Phase
17/12/12-19/12/12	Continuation of bentonite removal	Bentonite removal
	Drilling boreholes and use of expansive cement to further break the concrete plug	Phase 6
January 2013		
9/01/13	Continue bentonite removal	Bentonite removal
10/01/13	Sampling section CMT2	Sampling Phase
11/01/13	Continue bentonite removal	Bentonite removal
12/01/13	Sampling for dry density and water content on site analysis of section E	Sampling Phase
13/01/13-15/01/13	Continue bentonite removal	Bentonite removal
16/01/13	Sampling bentonite blocks from CMT2 section	Sampling Phase
	Nagra's sampling section CMT2	Sampling Phase
17/01/13-18/01/13	Continue bentonite removal	Bentonite removal
22/01/13	Sampling for dry density and water content on site analysis of section B2	Sampling Phase
23/01/13-24/01/13	Continue sampling for dry density and water content on site analysis of section B2 Welding beam to the canister. Canister support works	Canister support
25/01/13	Continue bentonite removal Sampling of blocks section E	Bentonite removal
26/01/13	Sampling for dry density and water content on site analysis of section A2	Sampling Phase
28/01/13-	Continue bentonite removal	Bentonite removal

Date	Activity	Test Plan Phase
29/01/13	DAS dismantling	DAS dismantling
29/01/13	Sampling section CMT3	Sampling Phase
30/01/13-01/02/13	Packing samples and tools	Sampling Phase
	Tiding and cleaning the area. Covering bentonite front with plastic	Closure

Figure 2 represents graphically the evolution of the experiment, taking into account the progress of the excavation, the days that every step took and the milestones of the project.

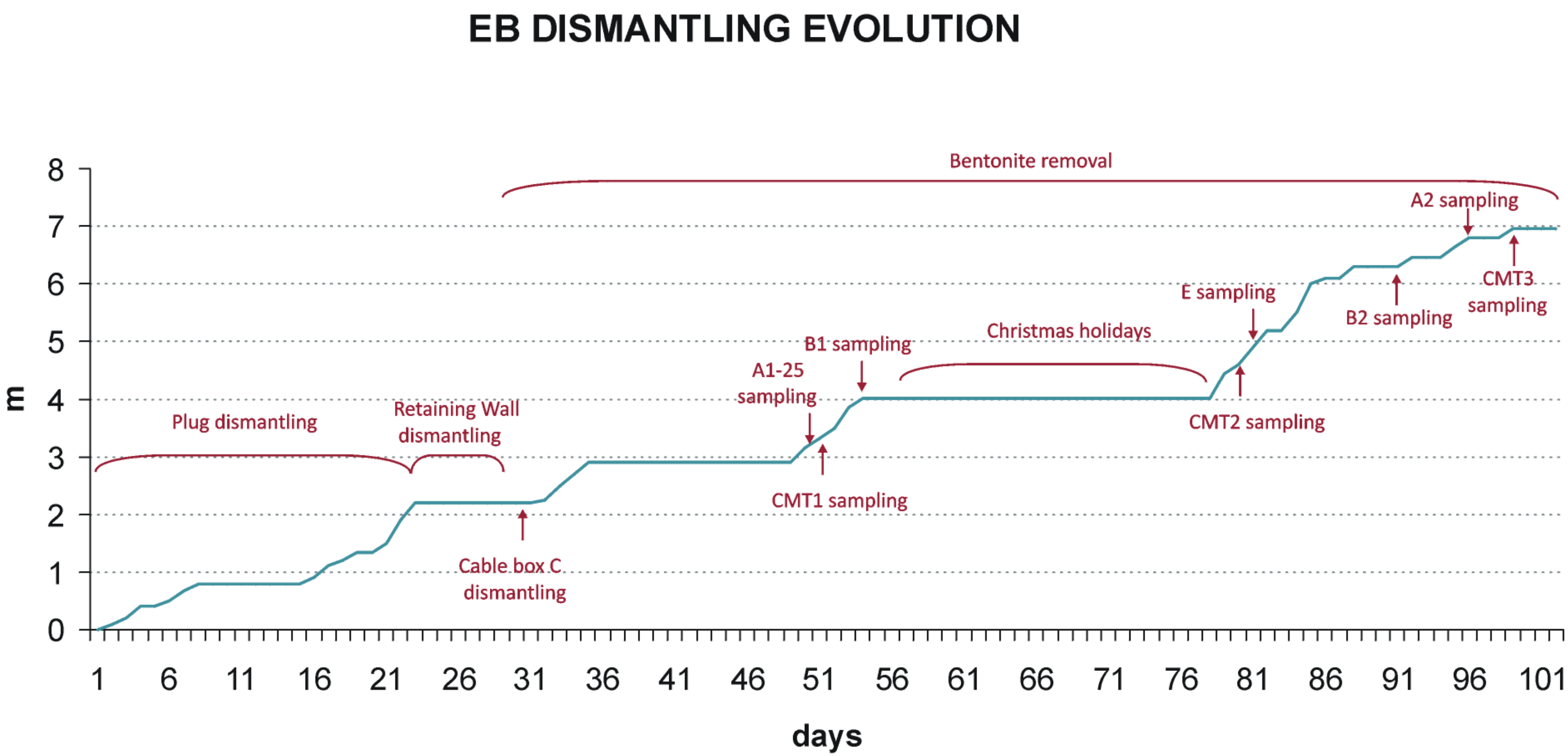


Figure 2: Evolution of the EB experiment. Duration in days of the whole operation (x axis) vs. progress in depth in the gallery (y axis)

3 DISMANTLING OPERATION

3.1 PREPARATION OF THE WORK AREA

On the 19th of October 2012, a team of two people from AITEMIN went on site to prepare the required area for the dismantling works. The purpose of this work was to protect both cables and the Data Acquisition System (DAS) from the dust and damage that the dismantling operations might cause.

The activities carried out were:

- Protection of the seismic cables with metallic tubing cut longitudinally in half. See Figure 3.
- Protection of the DAS cabinets with wooden boards and retro tactile plastic. See Figure 4.
- Positioning of the corresponding safety signs and fence. See Figure 5.
- Removal of the water tank used during the saturation phase.
- Supplying of auxiliary working tables and chairs.

Figure 3: Protection of seismic cables

Figure 4: Protection of the cabinets

Figure 5: Installation of safety signs

3.2 DRILLING OF THE INITIAL BOREHOLE IN THE PLUG

In order to have an inner free surface in the concrete plug to start its dismantling using the drilling/splitter method, it was planned to drill a horizontal borehole of 200 mm in diameter and 2.5 m long over the previous B1 borehole. See Figure 6.

According to the existing drawings*, the thickness of the plug was 2.2 m and of the retaining wall 0.3 m. So in total, the initial core was planned to be 2.5 m long to cover both plug and retaining wall.

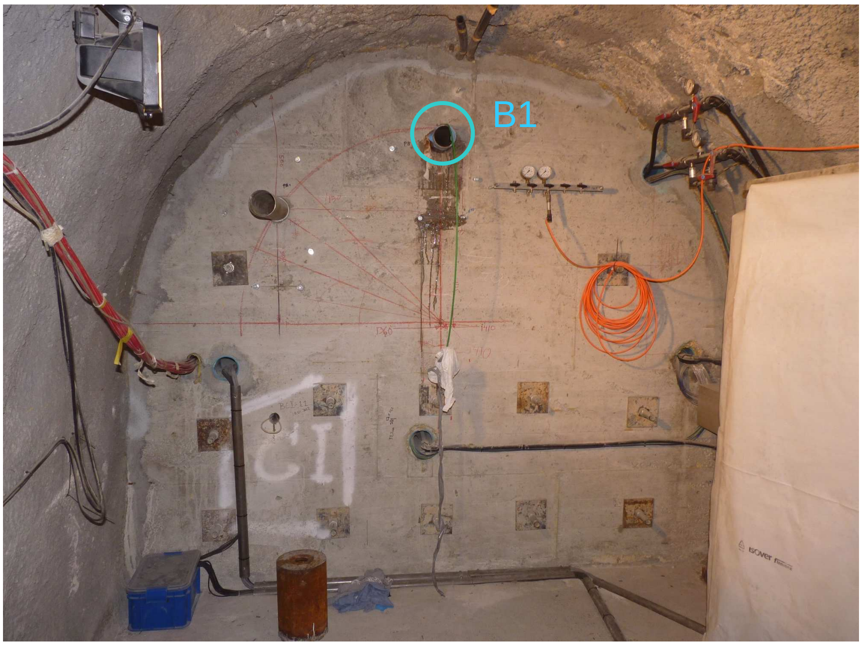


Figure 6: Location of Borehole B1 and planned over coring

The subcontractor company in charge of this operation was Schützeichel GmbH & Co. First of all, they measured the length of the iron pipe in the B1 borehole and it turned out to be 4.3 m long instead of the expected 2.5 m, so it was decided to move the location of the drill 15 cm below the planned one as the initial borehole had to be no longer than 2.5 m. See Figure 7.

* The information from the construction of the plug was very limited and somehow contradictory

Figure 7: Final location of the initial core

Restrictions about the use of water were specified in the Test Plan, but due to communication problems, the company did not bring tools to drill only with air as a refrigerator, so water had to be used during the first 2 m and then the drilling was continued with no water. In order to avoid introducing water in the bentonite everything was protected with plastics and the water was collected during the drilling process. See Figure 8.

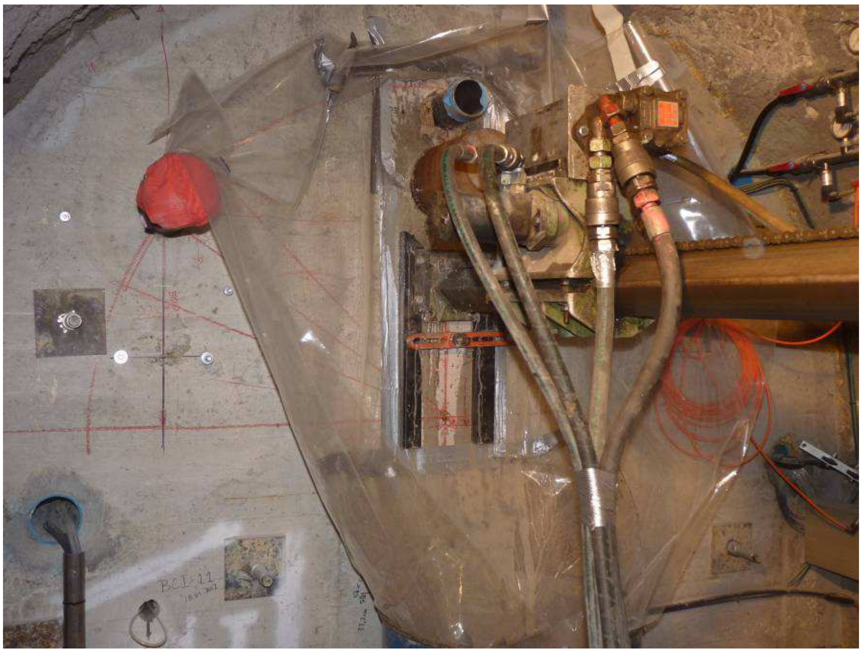


Figure 8: Protection of the experiment to collect the water during the drilling process

During the drilling process, about 30 cm of GBM were drilled because it was found that the plug thickness was 1.9 m and the retaining wall 0.3 m. See Figure 9.

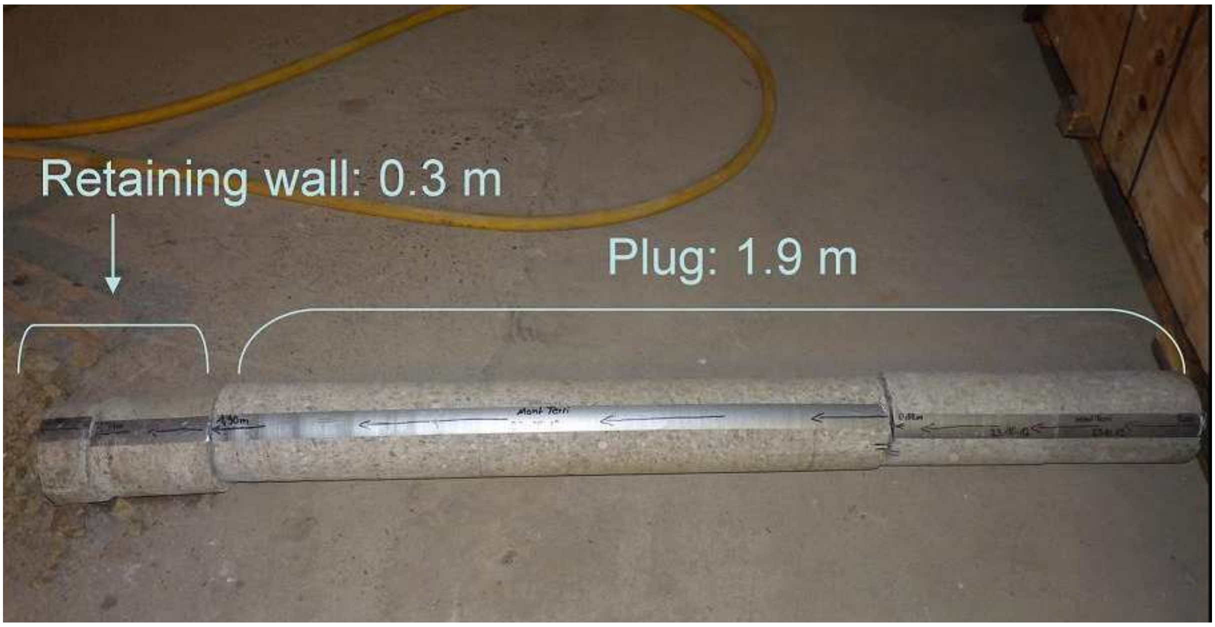


Figure 9: Core from the initial borehole.

3.3 DISMANTLING OF CONCRETE PLUG AND RETAINING WALL

3.3.1 Methodology and equipment

The dismantling of the plug had to be accomplished taking into account that the concrete plug had to be removed in steps in order not to alter the bentonite, not to damage the cables of the sensors and keep the operation as safe as possible. For this reason, the hydraulic splitter method was selected for the concrete dismantling. This method was also succesfully used in the demolition of the plug of the FEBEX experiment. This technique consists of drilling horizontal boreholes and introducing a hydraulic splitter to break the concrete towards an initial big-diameter hole. A pneumatic hammer (Model RH-571) was used to drill the boreholes and a DARDA hydraulic splitter to break the concrete. See technical data of the tools that were used in Appendix I.

The hydraulic splitter was fed by means of a hydraulic compressor. In the first phases, the hydraulic splitter used was the C9 model, which has a length of 30 cm. In the later phases the C12 model with a length of 45 cm was included to the process so both splitters were used in the same working face but not at the same time for safety reasons. See Figure 10.

Figure 10: Hydraulic splitter C9 and C12

A 48 mm in diameter and 800 and 1200 mm long drill bit was assembled to the pneumatic hammer to drill the plug, so the final diameter of the boreholes was around 55 mm. The air compressor supplying the hammer was located in another gallery next to the EB niche. In order to make the drilling activities easier, and due to the high weight of the tool, the pneumatic hammer was attached to a metallic extensible support. See Figure 11.

Figure 11: Pneumatic hammer and compressor (left/right)

The dust from the drilling was collected by means of an industrial vacuum cleaner. See Figure 12.

Figure 12: Vacuum cleaner

Due to the hard resistance of the concrete used to build the plug, this method (hammer+splitter) had to be supplemented with the use of a pneumatic hammer operated by a backhoe. See Figure 13.

Figure 13: Backhoe used for the plug dismantling

The dismantling operation of the plug was also helped with the use of other hand tools such as: a Hilti percussion hammer, a mallet, a pick… See Figure 14.

Figure 14: Handtools

The debris was collected in big bags by means of a shovel, and then it was transported with a forklift to a dump close to the main entrance to the Mont Terri site. See Figure 15.

Figure 15: Loading forklift with debris

3.3.2 Sequence of works

The dismantling of the plug started on the 23rd of October 2012 and it continued along the whole operation due to the difficulties related to the high strength of the concrete.

The plug was planned to be completely dismantled, but later it was decided to leave in place a third of it in the right side as part of the demonstrator.

As the concrete dismantling was moving forward, other components such as fibreglass bolts, metallic tubing… were also dismantled. Concrete samples were also collected and its water content measured on site. Any point regarding the sampling will be extended in section 4.

So the sequence of the works was the following:

1. Drilling the 200 mm diameter borehole so there would be an inner free surface to start with the Splitter breaking method.

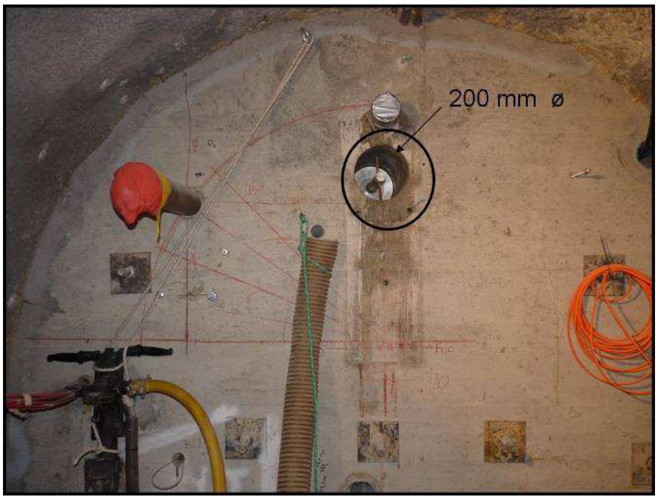


Figure 16: Initial borehole of 200 mm diameter

2. Drilling boreholes around the 200 mm one and use of the splitter to break the concrete. The distance between the boreholes was no longer than 30 cm. The aim was to get a bigger free surface to make breaking the concrete easier. As it was mentioned before, in order to speed up the dismantling, a backhoe was rented from the 6th of November. During this process, the cable box C was also dismantled. All the cables were cut after disconnecting the sensors from the DAS and the box was sent to AITEMIN laboratories to be studied. The following photos compiled in Figure 17 show the evolution of the concrete dismantling up to reaching the granular bentonite material (GBM).

Boreholes around the 200 mm diameter one

Use of the Darda

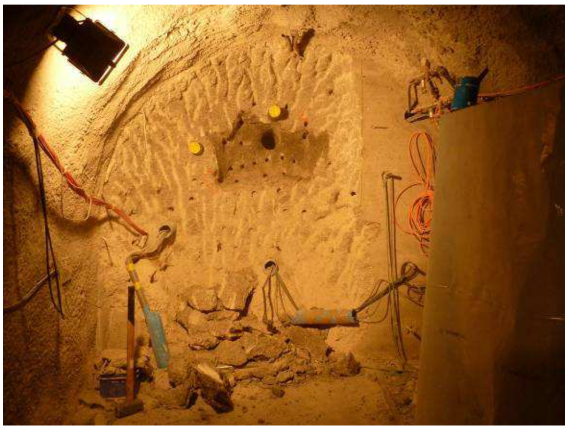
Holes around the main opening in the plug

Use of the Darda to break the concrete

Progress in breaking the concrete of the plug

Progress in breaking the concrete of the plug

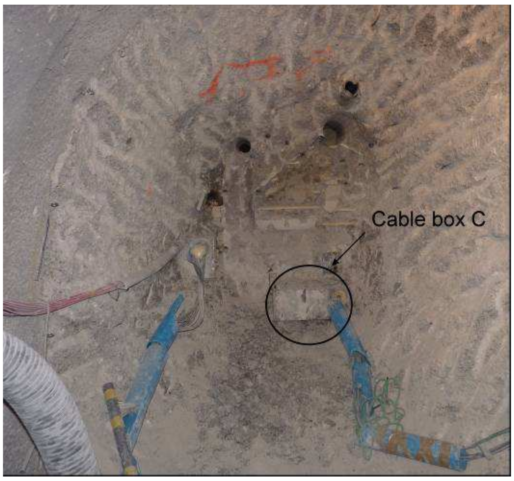
Backhoe working



Result of the use of the backhoe

Retaining wall reached

Retaining wall dismantling



Reaching the cable box C

Cable box C dismantling (I)

Cable box C dismantling (II)

Cable box C dismantling (III). Water spot

Retaining wall dismantling

Bentonite reached

Figure 17: Plug and retaining wall dismantling process

3. The last picture in Figure 17 shows the portion of plug and retaining wall that could be removed before starting to dig the bentonite. Having the inner part of the retaining wall as a free face would help with the dismantling of the remaining concrete. The plug/retaining wall dismantling activities stopped for a week until part of the bentonite behind the plug was removed. Then, the plug dismantling activities continued with the help of expansive cement that was poured in drills that were done for this purpose along the edge of the opening of the Plug/Retaining. The effects of the expansive cement were noticed 72 hours after its placing and part of the plug could be removed with the help of hand tools. The following photos compiled in Figure 18 show this process.

Drilling boreholes for the expansive cement (I)

Drilling boreholes for the expansive cement (II)

Preparation of the liquid expansive cement

Pouring of liquid expansive cement in the floor boreholes

Preparation of the solid expansive cement

Insertion of solid expansive cement in lateral and top boreholes

Use of hand tools to remove the concrete plug after the effect of the expansive cement (I)

Use of hand tools to remove the concrete plug after the effect of the expansive cement (II)

Figure 18. Use of expansive cement to break the plug

3.4 REMOVAL OF BENTONITE

3.4.1 Methodology and equipment

On the 14th of November 2012, the bentonite was reached and tests to find out the best way to remove and sample it were performed.

The conclusion was that the best way to remove the bentonite was with the use of a hammer (for instance a geologist one or an electric percussion hammer with a flat-end bit tool attached) to extract less-disturbed irregular pieces of GBM. See Figure 19.

Figure 19: Tools used for bentonite removal

For the removal of the bentonite blocks, the percussion hammer was provided with a pointy bit in order to separate the blocks between them and remove them in one whole piece. See Figure 20.

Figure 20: Tools for bentonite blocks removal

The removal of the bentonite was done in such way to keep the face of work as much parallel to the plug as possible. Initially the work was slower than expected, but as the team got used to the tools and the material, it went faster. From the moment the bentonite was reached, a fast drying process was observed in the bentonite front (see Figure 21), so after every day of work, the excavation was covered with a protection plastic (see Figure 22). If there were more than 2 days between working days, the team tried to keep the following sampling section as far as possible from the working face. There would be left at least 30 cm of not dismantled bentonite from the working face till the sampling section.

Figure 21: Bentonite front dryness after 5 days exposed

Figure 22: Plastic cover to avoid bentonite drying

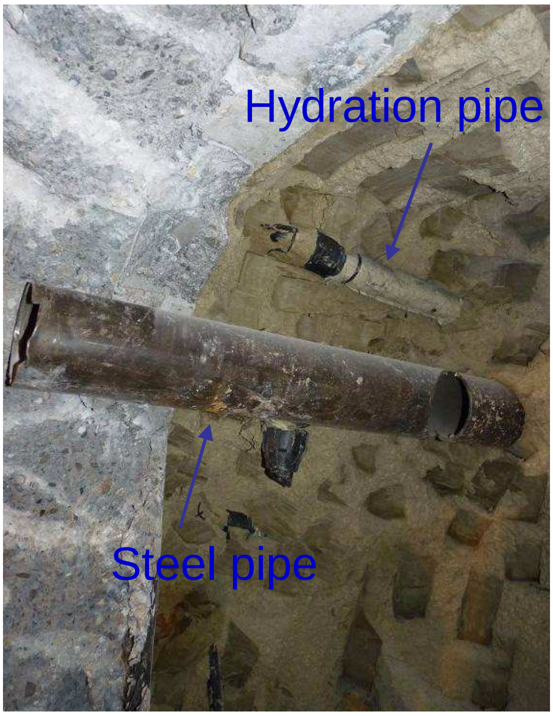
The debris was collected in big bags by means of a shovel, and then it was transported with a forklift to a dump close to the main entrance to the Mont Terri site. See Figure 23.

Figure 23: Big bags with bentonite for the dump

3.4.2 Sequence of works

First of all, once the bentonite was reached, a plastic cover was put at the beginning of the concrete plug in order to avoid the loss of humidity of the bentonite as much as possible. See Figure 22.

The removal of the bentonite was done with a team of two people. One of them working in the left side and the other in the right side when the available spaced allowed it. As the dismantling moved forward, all the elements such as hydration pipes, sensors or metallic piping from old boreholes were also dismantled. See Figure 24.



Cutting of the steel pipes located along the experiment

Figure 24: Embedded elements in the GBM

The progress of the bentonite removal was of about 25 cm per day. Pictures in the Figure 25 show its evolution.

Reaching retaining wall and bentonite

Bentonite in contact with the retaining wall

Front face of the canister. A layer of around 75 cm of bentonite already removed

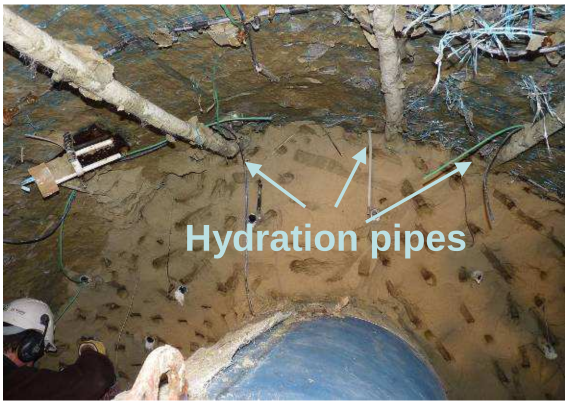
Front face of the canister and vertical extensometer uncovered. Section A1

Removal of the first layer of bentonite blocks

Section CMT2

General view from the gallery

Uncovered canister



Temporary support of the canister

Section B2

End of the bentonite removal. Z=695 for the GBM

Figure 25: Bentonite removal evolution

At the end, the front of the left bentonite was covered with a plastic in order to keep the humidity until the demonstrator was built. See Figure 26.

Figure 26: Front of the remaining bentonite covered with plastic

3.5 CANISTER SUPPORT OPERATION

As planned in the Test Plan, a custom-made metallic beam for this project was manufactured as the final support solution for the canister. Due to the large dimension of the beam and the narrow entrance initially available through the plug, it was decided it would be placed at the end of the dismantling works. In the mean time, other support works were carried out.

When the first metre of the canister was uncovered, an extensible metallic support was placed at the beginning of the canister. See Figure 27.

Figure 27: Metallic extensible support for canister

As the length of the uncovered canister increased, the metallic support was replaced by a metallic sawhorse able to support up to 10 t, and it was reinforced by two metallic extensible supports holding the left and right sides of the canister. See Figure 28.

Figure 28: Sawhorse support for canister

When the dismantling works finished, the planned final metallic beam was welded to the front face of the canister and fixed to the floor as well as to the concrete bed. As an extra safety measure, two metallic sawhorses were placed along the base of the canister. See representative pictures in Figure 29.

Welding of the beam to the front face of the canister

Metallic beam already welded to the canister front

Attachment of the bottom part of the beam to the floor

Attachment of the lateral part of the metallic beam to the concrete bed

Front view of the metallic beam

Sawhorses supporting the canister

Figure 29: Final support for the canister

3.6 REMOVAL OF THE DATA ACQUISITION SYSTEM (DAS)

The removal of the DAS was left until the very last moment of the dismantling operation as one of the aims was having as many sensors as possible running during the activities. All gathered data were compiled in a final data report that is included as Appendix III.

It consisted in first of all, cutting the cables of the sensors as close as possible to the data logger cabinet. Then, the cabinet containing the computer (PC) was also disconnected.

Finally, both cabinets were appropriately packed to be sent to Spain. See Figure 30.

Data logger cabinet

PC cabinet

DAS Cabinets packed

Figure 30: DAS dismantling

4 SAMPLING OPERATION

4.1 QUALITY DOCUMENTATION

The experiment was run under an internal Quality System. As a result, the following documents were released:

- Inspection Points Program. A log containing all the operations and the person in charge of them was filled in every day during the removal and sampling.
- All the samples taken during the operation were documented. For each sample, a Sample Log was filled in containing all the information regarding the sample: coordinates, sampling procedure, recipient organization, measurements, any relevant incidents… If the sample was also analysed on site, all the processes and results were recorded in the same log.
- For every sampling section, a Section Log was also produced, containing a list of the samples taken, as well as any relevant incidents.

As considered in the quality programme, relevant activity or event was also graphically documented.

The temperature and humidity of the EB niche as well as of the on site laboratory were registered by means of thermo-hygrometers placed in the gallery.

4.2 SAMPLING SECTIONS

There were planned several sampling sections along the experiment. The as built sections, shown in Figure 31, did not differed much from the planned ones in the Test Plan.

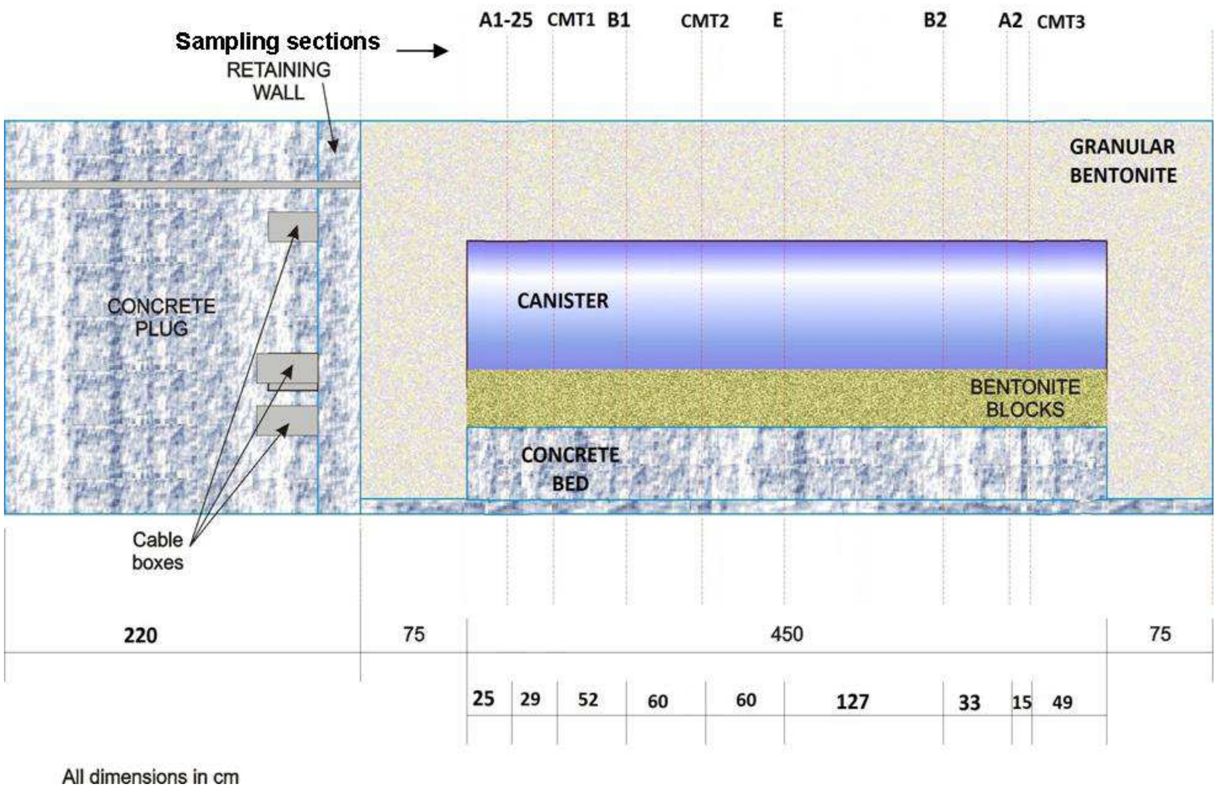


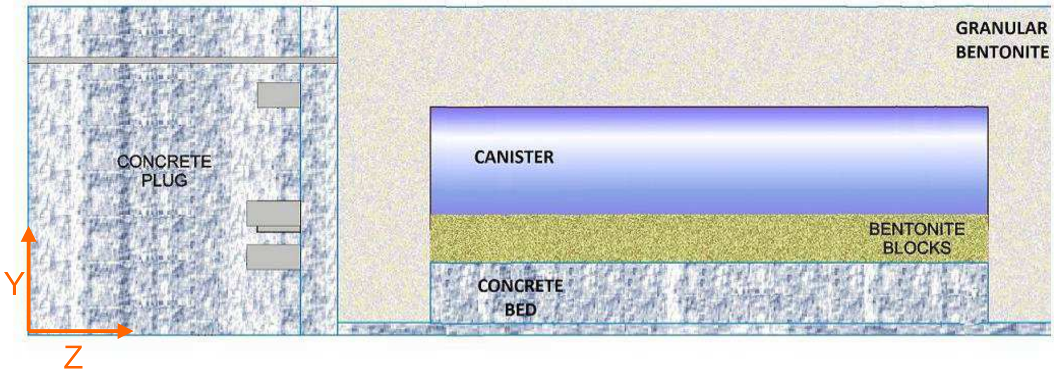
Figure 31: As built sampled sections

The main differences in relation to the Test Plan are:

- The first sampling section was called A1 and it was located in the front face of the canister. Section A1 was moved 25 cm backwards because the analysis method was still under test and the results obtained did not have the desired accuracy. This section has been called A1-25 and the same samples planned in Section A1 were taken.
- In order to leave part of the bentonite on place for the demonstrator, the removal work finished 49 cm before the rear end of the canister. For this reason, sections A2 and CMT3 had to be brought forward. See Figure 31.
- Due to a delay in the delivery of Al-coated paper for the packing of samples in section CMT3, the sampling had to be postponed, so section A2 was sampled before it.
- Due to safety reasons, it was decided not to remove all the bentonite blocks of the bed leaving the last 95 cm (see Figure 32), so the last bentonite blocks to be removed were those in section B2. Because some blocks in section CMT3 were required by the organizations, blocks from section B2 were provided in stead.

Figure 32: Blocks and bentonite left for demonstrator

The origin of coordinates for every section and sample is shown in Figure 33. It was located on the floor, in the centre of the outer face of the concrete plug.



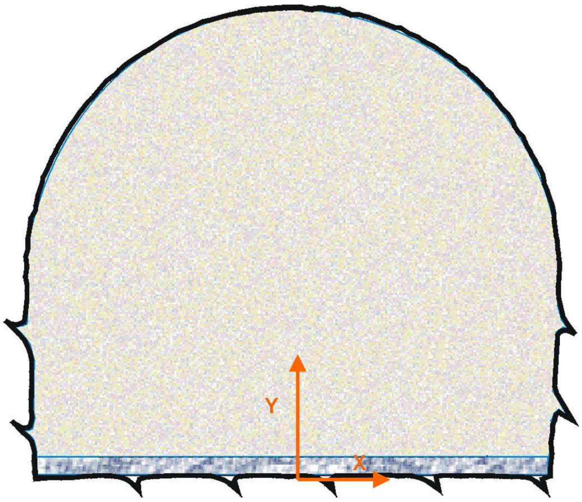


Figure 33: Origin of coordinates

4.3 SAMPLING PROCEDURES

There have been different kinds of samples to be taken. Depending on the sample or the purpose of the analysis to be done, the sampling procedure as well as the packing was adapted.

There were common practices such as:

- Registration of the location of the samples by means of filling the logs T-Y-NNNN-ZZZ (see section 4.3.8 for the codification). One log was filled per sample taken.
- If possible, the transparent film covering the samples was marked with permanent marker, so that their position and especially their orientation and rotation could be established afterwards.
- The sample was identified and the sample log completed as soon as possible. A copy of that file has been attached to the sample container.
- Samples were taken and handled gently to avoid any unnecessary mechanical disturbance.
- The samples were kept properly packed at 17 ºC, in a clean and chemical compounds-free area close to the EB niche. Samples of bentonite, concrete, or Opalinus Clay (OPA) were vacuum-packed in a double Al-coated polyethylene paper. Samples of any other material whose density or water content was not going to be analysed (i.e: sensors, geotextile…) were packed in the same type of paper without being vacuumed.

4.3.1 Samples taken

In total, almost 500 samples were taken. Around 210 of them were analysed on site and the rest was sent to the different partners in the project. Table 2 shows the detailed list of the number and the type of samples taken and the recipient organizations.

Table 2. Samples taken in total

PARTNER	CONCRETE	CONCRETE/ BENTONITE INTERFACE	OPA/BENTONITE INTERFACE	GBM(on site)	GBM(lab)	BENTONITE BLOCKS	SENSORS	WATER	OPA	ELEMENTS
CIEMAT	2	4	6	-	148	10	-	1	-	3
AITEMIN	12	-	-	209	-	-	16	-	-	14
BGR	-	-	-	-	-	-	4	-	-	-
CIEMAT/UAM	-	5	-	-	-	3	-	-	-	-
NAGRA	-	3	3	-	6	1	-	1	-	-
ANDRA	-	4	6	-	12	4	-	-	1	-
RESERVE	-	4	1	-	7	6	-	-	1	-

4.3.2 Concrete

Concrete samples were taken from the plug as well as from the concrete bed.

The samples from the plug were collected as the concrete dismantling was progressing. The demolition process itself generated pieces of concrete suitable for the sampling. The samples were irregular and between 75 and 150 cm3 in volume. See Figure 34.

Figure 34: Plug samples

Some of these samples were packed for the organizations but most of them were analysed on site (water content).

Samples from the concrete bed were taken by means of a circular saw. See Figure 35.

Figure 35: Concrete bed sampling

These samples were properly packed for the recipient organizations.

4.3.3 Concrete/Bentonite interface

Concrete/bentonite samples from the retaining wall and concrete bed were planned to be taken. Samples from the concrete bed in contact with the bentonite were physically impossible to take, so the only samples that were taken of this type were from the retaining wall.

The first samples were taken by means of rotating coring equipment for the concrete part and then a stainless steel pipe used in the bentonite part. See Figure 36.

Use of the rotating coring equipment for the concrete part

Use of a stainless steel pipe for the bentonite part

Figure 36: Retaining wall sampling I

Following samples were taken in blocks with the help of hand tools and then cut in pieces. This way the samples would be completely unaltered. See Figure 37.

Retaining wall. Concrete/bentonite interface

Sampling the concrete/bentonite interface of the retaining wall as a block

Preparing concrete/bentonite interface samples by cutting them

Figure 37: Retaining wall sampling II

4.3.4 OPA/Bentonite interface

Samples of the OPA/Bentonite interface were taken along the dismantling operation as requested by the organizations. For the bentonite, a stainless steel pipe was used to sample up to the OPA by pushing the pipe against the bentonite. Then the rotating coring device adapted with a crown of the same diameter than the stainless steel pipe was used to sample the OPA part (See Figure 38). Then each sample was packed as a whole one keeping the interface between the two materials in contact.

Figure 38: OPA/Bentonite sampling

Due to the difficulties found with the use of the rotating coring device without cooling water, the number of those samples was reduced.

4.3.5 GBM for on site and laboratory analyses

The procedure to sample GBM was the same for the on site analyses as for the laboratory ones (See section 4.4.1). The main difference between them was the size of the taken samples. For the on site analysis it was enough that the weight of the samples were approximately 300 g and for the organizations it was required that the samples weighed over 500 g if possible.

For the sampling, a first attempt was done using a stainless steel tube of 38 mm in diameter and 1.5 mm thickness which was dug into the bentonite by hammering the pipe and then pulled out by hand. This procedure was found not to be appropriate due to the plastic properties of the bentonite, showing a clear disturbance of the sample during the hammering as well as while taking the sample out form the pipe. In order to avoid this, a new attempt was done using the pipe with the help of the backhoe, but it did not work better. It was also tried to sample with a rotating crown attached to the Hilti but the rotation movement heated and dried the sample up. See Figure 39.

The final procedure adopted is described in Section 3.4.1.

Hammering the sampling pipe into the bentonite

Pushing the sampling pipe with the help of the backhoe into the bentonite

Bentonite sample inside the pipe

Sampling with a rotating crown

Figure 39: Testing how to sample GBM

4.3.6 Bentonite blocks

The procedure for sampling the bentonite blocks is the same as for their removal. It has been described in section 3.4.1.

Figure 40: Block of bentonite sample

4.3.7 Sensors

The sampling of the sensors was as expected. First of all, the sensor and cable were uncovered of bentonite and then the cable was cut as far as possible from the head of the sensor. During the sampling, it was observed some different colour in the bentonite surrounding the head of some of the sensors due to corrosion (not relevant). In the case that the sensor was covered with the geotextile (i.e. Total Pressure cells in Section E), the corrosion only affected clearly to the welding points used to attach the sensors to the canister. In this case, a corrosion stain could be observed in the geotextile too. See Figure 41.

Extensometers

Water content sensor

Total Pressure cell

Geotextile covering total pressure cells

Figure 41: Sensors sampling

4.3.8 Codification of samples

The samples were coded as explained in the Test Plan. The codification was as follows:

T-Y-NNNN-ZZZ

T refers to the material of the sample such as:

B: Bentonite

C: Concrete

C/B: Concrete/Bentonite

B/R: Bentonite/Rock

R: Rock

S: Sensor

O: Other

Y refers to the shape of the sample, such as:

B: Block

C: Cores

S: Any shape except blocks or cores. Sensors.

NNNN: Sampling section.

ZZZ: Correlative sample number for same type of samples in each section.

4.3.9 Analysis procedures used in on site laboratory

The procedures explained in this section are related with the on site analysis.

A laboratory in a niche close to the EB experiment was set. See Figure 42.

Figure 42: Laboratory

This laboratory was composed of the following elements.

- Oven
- Balances: One with a precision of 0.1 g and the other 0.01 g
- Density analysis tools: mercury, Pyrex vessels, pipette…
- Cutting tools: knife, cutter…
- Safety accessories: Gloves, masks…

Due to the use of mercury in the analysis procedure, the niche was placed in a ventilated place and the floor was covered with plastic.

Two different measurements were determined in the bentonite samples (blocks and GBM): Water content and dry density. It has been also calculated the degree of saturation of every sample. The specific weight used for these calculations has been 2.7 g/cm^3.

After collecting every GBM sample, it was cut and trimmed into 3 subsamples of between 6 and 12 cm^3 in volume each. The water content was obtained from all the subsamples and the dry density from only 2 of them.

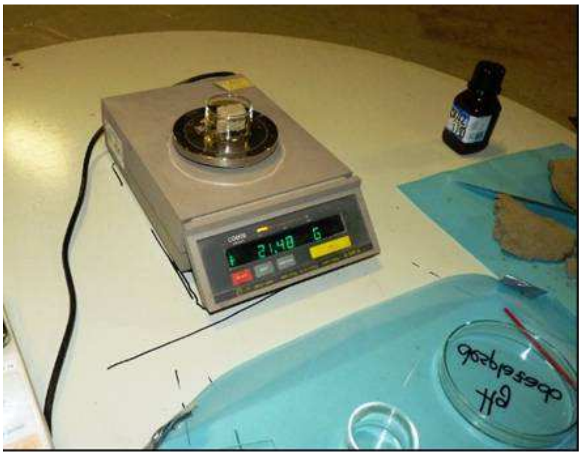
The gravimetric water content (w) is defined as the ratio between the weight of water and the weight of dry solid expressed as a percentage. The weight of water was determined as the difference between the weight of the sample and its weight after oven drying at 110°C for 48 h (weight of solid).

Dry density (ρ_d) is defined as the ratio between the weight of the dry sample and the volume occupied by it prior to drying. The volume of the specimens was determined by immersing them in a recipient containing mercury and by weighting the mercury displaced, as established in UNE Standard 7045 “Determination of soil porosity”. The same samples whose volumes had been determined were used for the water content determination.

Figure 43 shows the analysis procedure:

Original sample

Trimming the sample



Weighting of the subsamples

Use of mercury to determine the volume of the subsamples

Use of mercury to determine the volume of the subsamples

Drying of the samples in the oven

Figure 43: Analysis procedure

On site analysed samples were disposed of after the analysis.

4.3.10 Packing and transport

Every sample was immediately measured and weighed after the collection. Then the samples were vacuum packed in two successive Al-coated polyethylene sheets. See Figure 44.

Figure 44: Packing of samples

Each package was properly identified and stored in a niche close to the EB experiment until the shipping was organized.

Finally, the samples collected for the different organizations were packed in wooden boxes for its transport (see Figure 45). A copy of the sample logs was included in the parcel.

Figure 45: Transport of samples

4.4 SAMPLING SECTIONS.

4.4.1 Plug

The plug was considered a sampling section itself as a whole. It means that the z coordinate varies from z=0 to z=190 (in centimetres). In the Plug section, two types of samples were collected: concrete and water from the hydration pipes. The sample of water from the hydration pipes was located between the Plug and the Section A1, but it was decided to include it in this section.

Figure 46 shows the location of the samples and the recipient organizations. It also shows some samples of concrete that were taken for water content on site analysis.

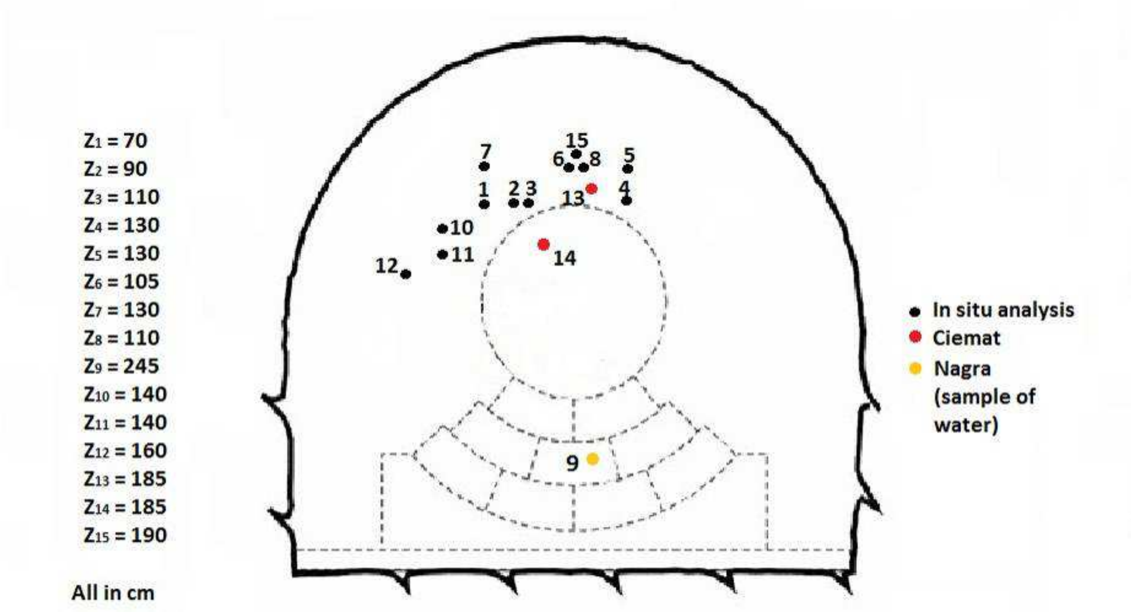


Figure 46: Plug section. Samples

Wet areas were observed while breaking the concrete (See Figure 47).

Figure 47: Wet concrete. Plug

The coordinates of the plug samples taken for on site analysis and the results of the water content obtained are listed below in the Table 3.

Table 3. Results of on site analyses of water content for PLUG samples

ID sample number	Sample	Coordinates			Water content (%)
		x	y	z	
1	C-S-PLUG-001	-20	170	70	3.9
2	C-S-PLUG-002	-10	170	90	4.1
3	C-S-PLUG-003	-10	170	110	3.9
4	C-S-PLUG-004	10	170	130	4.7
5	C-S-PLUG-005	10	175	130	4.7
6	C-S-PLUG-006	0	175	105	4.5
7	C-S-PLUG-007	-20	175	130	4.5
8	C-S-PLUG-008	0	175	110	4.3
9	C-S-PLUG-010	-30	160	140	4.1
10	C-S-PLUG-011	-30	170	140	4.5
11	C-S-PLUG-012	-40	140	160	4.5
12	C-S-PLUG-015	0	175	190	4.7

The values show a high saturation in the concrete, so it can be considered that the plug is practically saturated.

4.4.2 Retaining wall

In the Retaining Wall section, there were taken different types of samples: Bentonite in contact with the concrete, concrete/bentonite interface, and water. Figure 48 shows the location of the samples and the recipient organizations. Table 4 shows the list of the samples and their location coordinates.

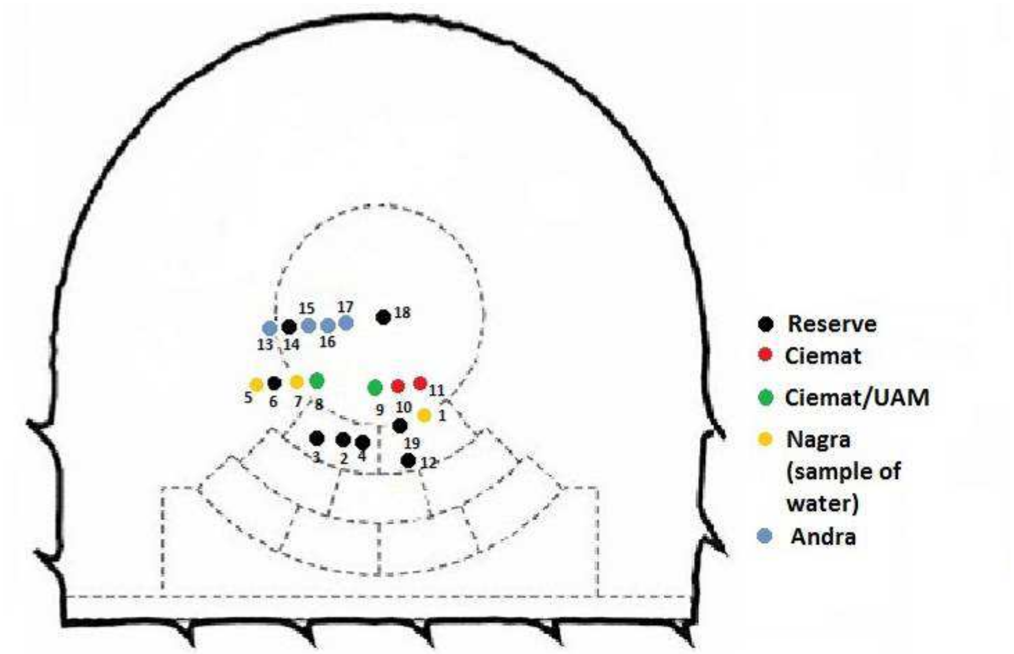


Figure 48: Location of samples in the Retaining Wall

Table 4. List of samples taken in the Retaining Wall

ID sample number	Sample	Coordinates	
		x	y
1	C/B-C-RW-001	20	85
2	C/B-C-RW-002	-25	70
3	C-C-RW-003	-30	75
4	C-C-RW-004	-20	80
5	C/B-S-RW-005	-60	90
6	C/B-S-RW-006	-55	90
7	C/B-S-RW-007	-50	90
8	C/B-S-RW-008	-40	90
9	C/B-S-RW-009	-10	90
10	C/B-S-RW-010	0	90
11	C/B-S-RW-011	10	90
12	C/B-S-RW-012	10	75

ID sample number	Sample	Coordinates	
		x	y
13	B-S-RW-001	-50	120
14	B-S-RW-002	-40	120
15	B-S-RW-003	-35	120
16	B-S-RW-004	-25	120
17	B-S-RW-005	-15	120
18	B-S-RW-006	0	120
19	B-S-RW-007	5	90

None of these samples were analysed on site.

4.4.3 A1-25

The location of the samples taken is shown in Figure 49.

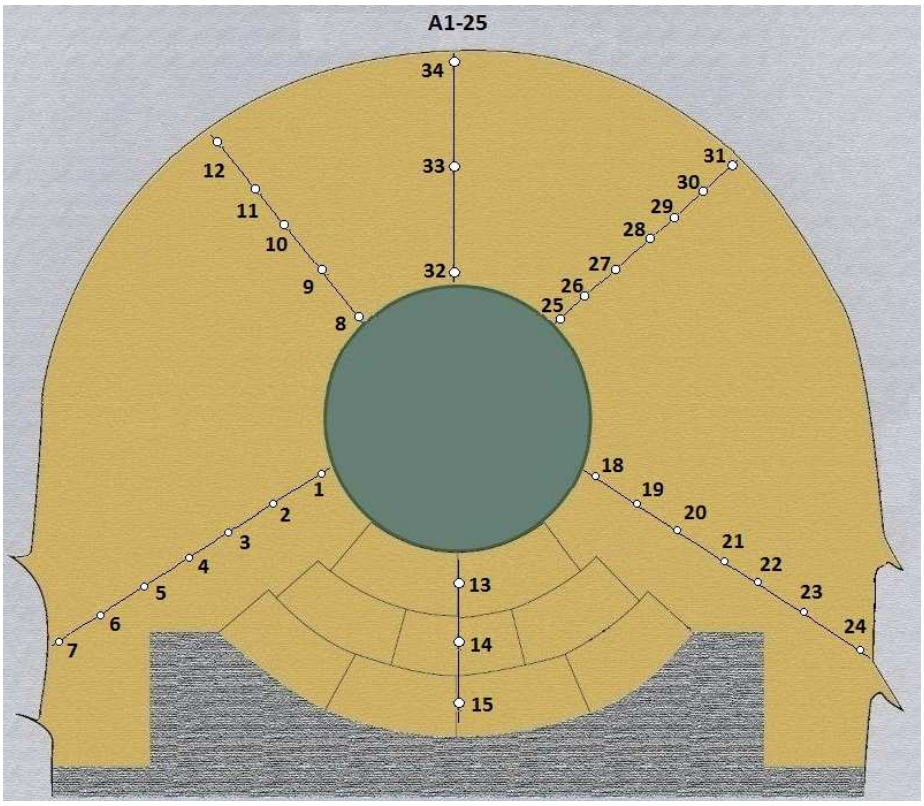


Figure 49: Location of samples in Section A1-25

Table 5 shows the coordinates of the samples and the results of the on site analysis.

Table 5. Water content and dry density obtained from on site analyses in Section A1-25

ID sample number	Sample	Coordinates		Water content (%) mean	Dry density (g/cm^3) mean	Degree of saturation %
		X	Y			
1	B-S-A1_25-001	-42	93	36.3	1.33	95
2	B-S-A1_25-002	-50	82	35.3	1.28	86
3	B-S-A1_25-003	-65	75	36.1	1.32	93
4	B-S-A1_25-004	-88	65	37.4	1.29	93
5	B-S-A1_25-005	-102	55	37.7	1.32	98
6	B-S-A1_25-006	-125	50	39.8	1.26	94
7	B-S-A1_25-007	-140	45	40.8	1.26	97
8	B-S-A1_25-008	-30	167	32.5	1.44	101
9	B-S-A1_25-009	-56	182	31.7	1.44	98
10	B-S-A1_25-010	-83	197	31.9	1.41	95
11	B-S-A1_25-011	-95	204	32.0	1.4	93
12	B-S-A1_25-012	-105	211	32.8	1.37	92
13	B-S-A1_25-013	0	70	33.4	1.36	92
14	B-S-A1_25-014	0	50	34.8	1.3	88
15	B-S-A1_25-015	0	30	34.9	1.33	91
18	B-S-A1_25-018	49	107	37.6	1.32	97
19	B-S-A1_25-019	57	100	35.6	1.36	97
20	B-S-A1_25-020	67	90	34.3	1.35	93
21	B-S-A1_25-021	83	80	34.9	1.39	100
22	B-S-A1_25-022	100	70	35.6	1.4	103
23	B-S-A1_25-023	125	60	35.8	1.37	99
24	B-S-A1_25-024	140	50	37.4	1.28	91
25	B-S-A1_25-025	38	174	32.6	1.42	97
26	B-S-A1_25-026	53	181	31.2	1.43	94
27	B-S-A1_25-027	69	188	31.6	1.43	97
28	B-S-A1_25-028	78	191	32.3	1.42	97
29	B-S-A1_25-029	86	195	31.3	1.42	94
30	B-S-A1_25-030	97	198	30.7	1.43	93
31	B-S-A1_25-031	109	207	32.5	1.39	93
32	B-S-A1_25-032	0	178	31.8	1.43	96
33	B-S-A1_25-033	0	211	30.9	1.46	98
34	B-S-A1_25-034	0	252	31.6	1.46	101

In order to check the reliability of the results obtained on site, some of the samples were taken bigger than the rest so they were divided in two parts: one for the on site laboratory and the other for the laboratory that CIEMAT has in Madrid.

Table 6 shows both results.

Table 6. Comparison of water content and dry density obtained from on site and laboratory analyses in Section A1-25

		Laboratory results			On site results		
ID sample number	Sample	Water content (%) mean	Dry density (g/cm^3) mean	Degree of saturation %	Water content (%) mean	Dry density (g/cm^3) mean	Degree of saturation %
18	B-S-A1_25-018	41.0	1.30	102	37.6	1.32	97
19	B-S-A1_25-019	36.5	1.35	98	35.5	1.36	97
20	B-S-A1_25-020	35.5	1.38	100	34.3	1.35	93
21	B-S-A1_25-021	35.9	1.35	97	34.9	1.39	100
22	B-S-A1_25-022	37.0	1.34	99	35.6	1.40	103
23	B-S-A1_25-023	36.7	1.34	97	35.8	1.37	99
24	B-S-A1_25-024	38.0	1.31	97	37.4	1.28	91

As it can be observed, the water content obtained in the laboratory was 3.8% higher than on site, and the dry density 1.1% lower. This difference is not very significant, and got smaller as the on site analysis progressed given that in this section the methodology was still being improved. See Appendix IV.

4.4.4 CMT1

The location and recipients of these samples are shown in Figure 50.

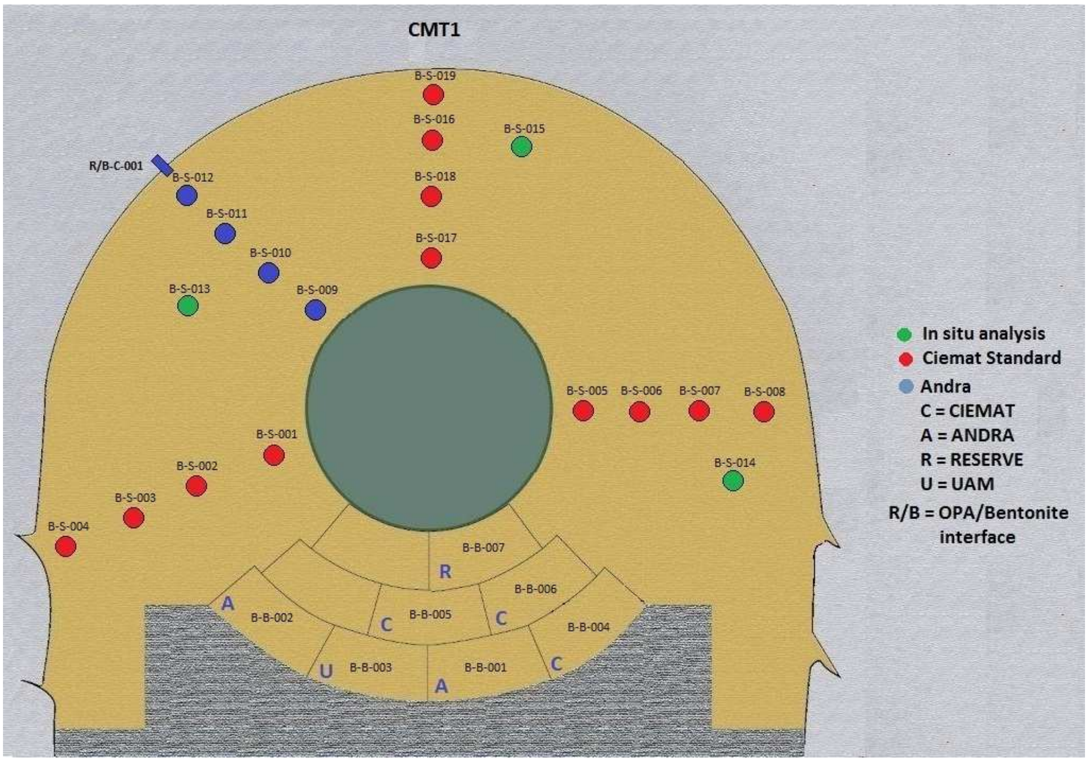


Figure 50: Location of samples in Section CMT1

There were taken few samples to be analysed in the on site laboratory and the rest was sent to the different organizations as requested. The results of the samples analysed on site as well as the ones analysed in the laboratory in CIEMAT facilities are listed below. See also Appendix IV.

Table 7. Water content and dry density on site and laboratory analyses. Section CMT1

Sample	Coordinates		Laboratory results			On site results		
	x	y	Water content (%) mean	Dry density (g/cm^3) mean	Degree of saturation %	Water content (%) mean	Dry density (g/cm^3) mean	Degree of saturation %
B-B-CMT1-007	-	-	34.2	1.39	98	-	-	-
B-B-CMT1-006	-	-	34.7	1.36	95	-	-	-
B-B-CMT1-004	-	0	37.2	1.34	99	-	-	-
B-S-CMT1-001	-58	105	37.3	1.35	100	-	-	-
B-S-CMT1-002	-78	95	36	1.35	97	-	-	-
B-S-CMT1-003	-105	81	37	1.33	97	-	-	-
B-S-CMT1-004	-130	68	39.8	1.3	100	-	-	-
B-S-CMT1-005	65	112	35.6	1.36	97	-	-	-
B-S-CMT1-006	84	113	36.3	1.36	99	-	-	-
B-S-CMT1-007	111	114	35.3	1.36	97	-	-	-
B-S-CMT1-008	132	114	36.3	1.36	99	-	-	-
B-S-CMT1-017	0	182	34.1	1.41	100	-	-	-

Sample	Coordinates x	Coordinates y	Laboratory results: Water content (%) mean	Laboratory results: Dry density (g/cm^3) mean	Laboratory results: Degree of saturation %	On site results: Water content (%) mean	On site results: Dry density (g/cm^3) mean	On site results: Degree of saturation %
B-S-CMT1-018	0	195	32.8	1.42	98	-	-	-
B-S-CMT1-016	0	235	32.3	1.43	98	-	-	-
B-S-CMT1-019	0	250	34.3	1.4	100	-	-	-
B-S-CMT1-013	-87	167	-	-	-	31.8	1.44	98
B-S-CMT1-014	100	110	-	-	-	31.9	1.45	100
B-S-CMT1-015	20	227	-	-	-	29.3	1.48	96

4.4.5 B1

The physical location of the samples in the section is shown in Figure 51.

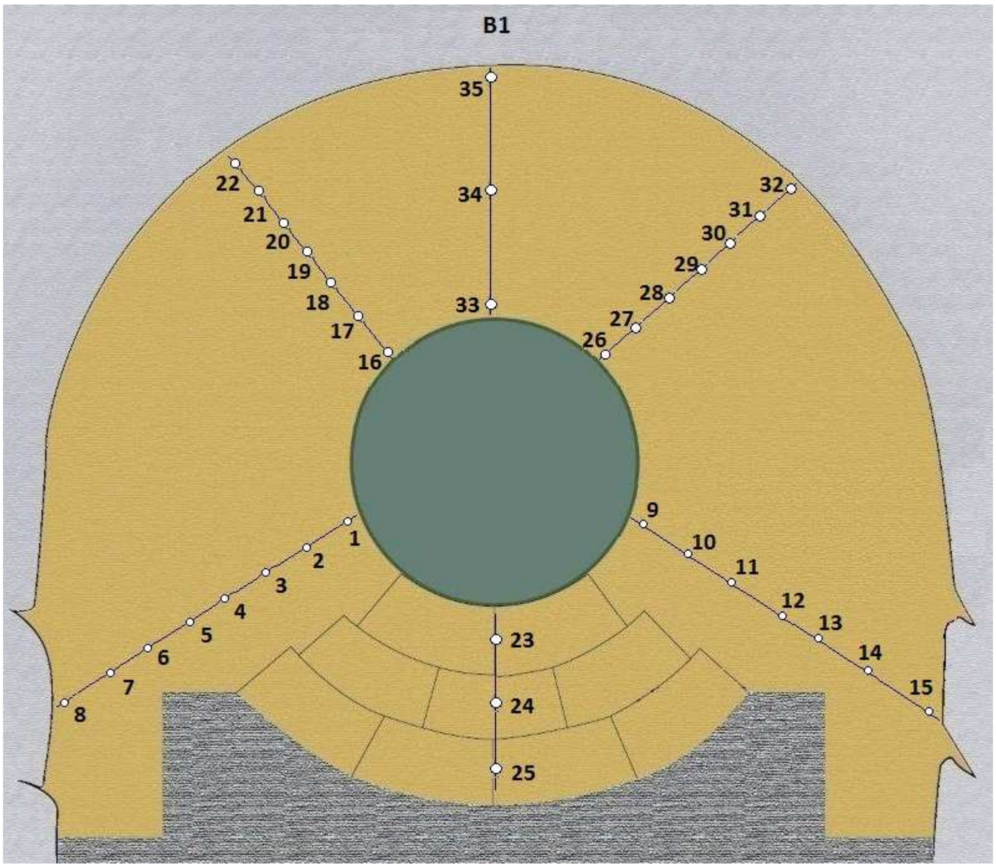


Figure 51: Location of samples in Section B1

Table 8 shows the coordinates of the samples and the results of the on site analysis.

Table 8. Water content and dry density of the on site analyses in Section B1

Sample	Coordinates		Water content (%) mean	Dry density (g/cm^3) mean	Degree of saturation %
	x	y			
B-S-B1-001	-37	92	37.4	1.36	102
B-S-B1-002	-49	86	38.3	1.29	95
B-S-B1-003	-64	77	37.1	1.32	96
B-S-B1-004	-80	66	37.7	1.31	96
B-S-B1-005	-96	57	40.3	1.27	96
B-S-B1-006	-110	49	43.5	1.20	95
B-S-B1-007	-123	45	45.7	1.19	98
B-S-B1-008	-139	43	46.4	1.18	97
B-S-B1-009	51	120	36.9	1.35	100
B-S-B1-010	63	110	36.5	1.32	94
B-S-B1-011	75	102	37.4	1.32	97
B-S-B1-012	91	90	39.4	1.28	96
B-S-B1-013	109	74	39.7	1.27	95
B-S-B1-014	129	61	41.5	1.25	97
B-S-B1-015	144	54	42.4	1.48	138
B-S-B1-016	-29	168	33.8	1.39	97
B-S-B1-017	-37	178	32.7	1.40	96
B-S-B1-018	-44	188	32.8	1.40	95
B-S-B1-019	-52	199	32.6	1.38	92
B-S-B1-020	-60	211	32.4	1.41	95
B-S-B1-021	-67	222	32.7	1.40	95
B-S-B1-022	-71	232	33.1	1.39	95
B-S-B1-023	0	67.5	33.6	1.39	96
B-S-B1-024	0	47.5	33.6	1.37	94
B-S-B1-025	0	25	34.6	1.38	98
B-S-B1-026	41	162	34.6	1.37	96
B-S-B1-027	50	173	33.1	1.35	90
B-S-B1-028	58	186	32.5	1.41	96
B-S-B1-029	68	196	32.3	1.40	94
B-S-B1-030	75	196	31.8	1.43	96
B-S-B1-031	81	214	31.9	1.43	97
B-S-B1-032	88	225	33.2	1.38	93
B-S-B1-033	0	176	33.3	1.43	102
B-S-B1-034	0	212	32.3	1.42	96
B-S-B1-035	0	246	32.5	1.43	98

4.4.6 CMT2

The location and recipients of the samples are shown in Figure 52.

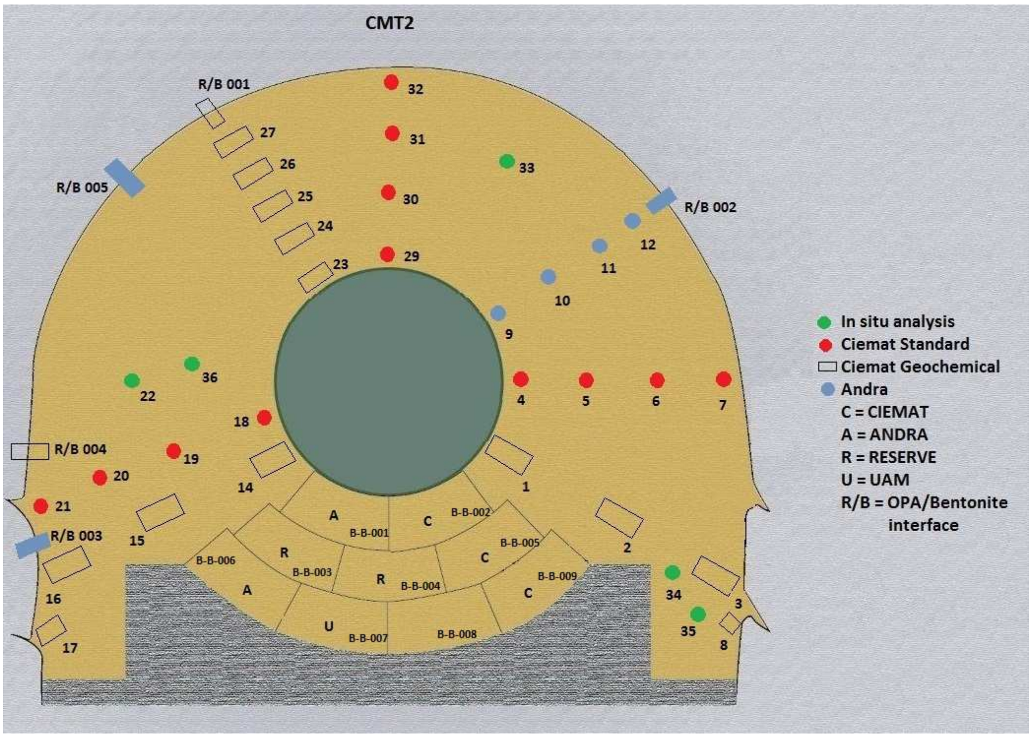


Figure 52: Location of samples in Section CMT2

There were taken few samples to be analysed on site and the rest was sent to the different organizations as requested. The results of the samples analysed on site as well as the ones analysed in the laboratory in CIEMAT facilities are listed in Table 9. See also Appendix IV.

Table 9. Water content and dry density obtained from on site and laboratory analyses in Section CMT2

ID sample number	Sample	Coordinates		Laboratory results			On site results		
		x	y	Water content (%) mean	Dry density (g/cm^3) mean	Degree of saturation %	Water content (%) mean	Dry density (g/cm^3) mean	Degree of saturation %
B-B-002	B-B-CMT2-002	-	-	33.2	1.39	95	-	-	-
B-B-005	B-B-CMT2-005	-	-	35.1	1.38	99	-	-	-
B-B-009	B-B-CMT2-009	-	-	35.7	1.37	99	-	-	-
4	B-S-CMT2-004	55	127	37.2	1.33	98	-	-	-
5	B-S-CMT2-005	81	127	37.4	1.33	98	-	-	-
7	B-S-CMT2-007	134	127	36.2	1.35	98	-	-	-
18	B-S-CMT2-018	-53	127	37.7	1.34	100	-	-	-
19	B-S-CMT2-019	-81	127	38.3	1.3	96	-	-	-

				Laboratory results			On site results		
ID sample number	Sample	Coordinates		Water content (%) mean	Dry density (g/cm^3) mean	Degree of saturation %	Water content (%) mean	Dry density (g/cm^3) mean	Degree of saturation %
		x	y						
20	B-S-CMT2-020	-111	103	39.2	1.29	97	-	-	-
21	B-S-CMT2-021	-120	95	46.2	1.18	97	-	-	-
29	B-S-CMT2-029	0	187	32	1.42	96	-	-	-
30	B-S-CMT2-030	0	207	33.3	1.39	95	-	-	-
31	B-S-CMT2-031	0	227	32.8	1.42	98	-	-	-
32	B-S-CMT2-032	0	250	33.5	1.42	100	-	-	-
26	B-S-CMT2-026	95	189	35.5	1.38	100	-	-	-
17	B-S-CMT2-017	-129	57	48.3	1.17	100	-	-	-
22	B-S-CMT2-022	-100	123	-	-	-	31.2	1.39	90
36	B-S-CMT2-036	-90	123	-	-	-	30.9	1.40	90
33	B-S-CMT2-033	75	195	-	-	-	30.8	1.39	89
34	B-S-CMT2-034	113	41	-	-	-	35.1	1.31	90
35	B-S-CMT2-035	113	30	-	-	-	35.4	1.33	93

4.4.7 E

The reference location of the samples is shown in Figure 53.

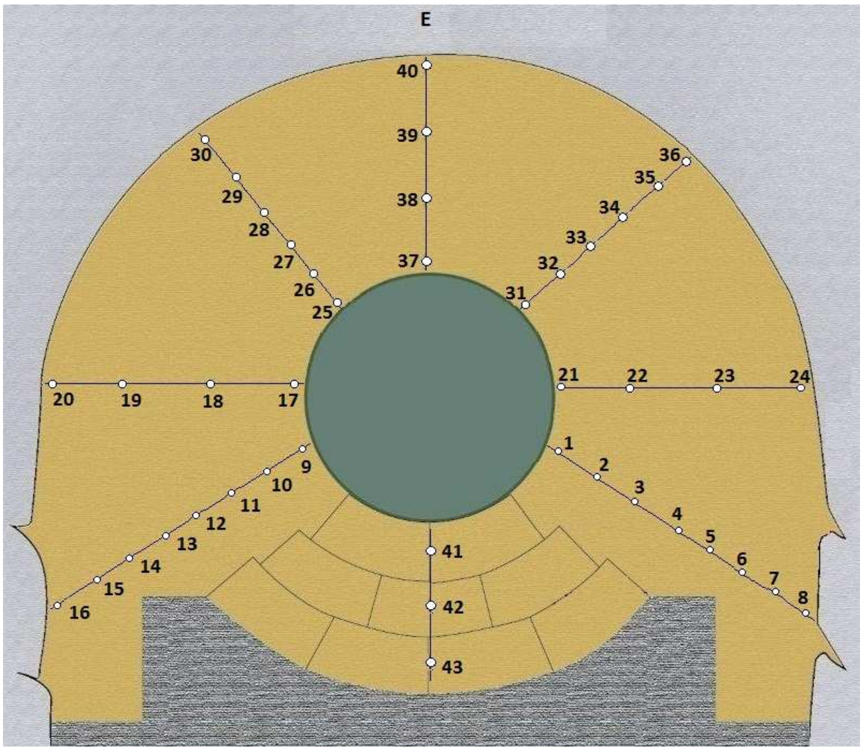


Figure 53: Location of samples in Section E

Table 10 shows the coordinates of the samples and the results of the on site analysis.

Table 10. Water content and dry density from on site analyses in Section E

ID sample number	Sample	Coordinates		Water content (%) mean	Dry density (g/cm^3) mean	Degree of saturation %
		x	y			
1	B-S-E-001	51	112	36.88	1.33	97.35
2	B-S-E-002	62	104	34.98	1.36	96.26
3	B-S-E-003	72	95	35.02	1.31	88.49
4	B-S-E-004	85	83	36.48	1.36	99.98
5	B-S-E-005	100	70	37.31	1.32	96.93
6	B-S-E-006	115	56	40.49	1.28	98.43
7	B-S-E-007	128	45	45.43	1.20	97.58
8	B-S-E-008	143	23	47.81	1.14	94.90
9	B-S-E-009	-54	111	37.30	1.28	91.45
10	B-S-E-010	-64.5	101	36.44	1.34	96.57
11	B-S-E-011	-76	92	35.52	1.33	92.96
12	B-S-E-012	-87	81	36.42	1.33	95.30
13	B-S-E-013	-96	73	39.64	1.25	92.85
14	B-S-E-014	-106	63	41.59	1.25	97.09
15	B-S-E-015	-117	46	45.05	1.20	97.57
16	B-S-E-016	-133	25	51.15	1.12	97.19
17	B-S-E-017	-67	128	36.90	1.36	100.47
18	B-S-E-018	-89	128	35.02	1.35	94.54
19	B-S-E-019	-112	127	34.98	1.34	93.05
20	B-S-E-020	-135	127	34.94	1.35	94.57
21	B-S-E-021	55	127	36.36	1.34	97.13
22	B-S-E-022	79.5	127.5	35.33	1.35	96.05
23	B-S-E-023	105	128	34.56	1.32	89.84
24	B-S-E-024	132	128.5	34.73	1.35	93.49
25	B-S-E-025	49	143	34.55	1.38	97.51
26	B-S-E-026	58	150	33.56	1.38	95.07
27	B-S-E-027	69	159	33.06	1.38	93.49
28	B-S-E-028	81	169	34.45	1.37	96.37
29	B-S-E-029	96	178	34.72	1.37	96.33
30	B-S-E-030	106	190	34.08	1.40	98.56
31	B-S-E-031	-45.5	159	34.18	1.43	103.26
32	B-S-E-032	-57	170	34.42	1.37	95.74
33	B-S-E-033	-71	185	34.22	1.37	94.82
34	B-S-E-034	-80	195	33.56	1.38	95.07
35	B-S-E-035	-89	202	33.78	1.40	97.73
36	B-S-E-036	-99	213	34.73	1.37	96.60
37	B-S-E-037	0	180	35.28	1.35	95.19
38	B-S-E-038	0	203	33.85	1.36	92.35
39	B-S-E-039	0	219	32.72	1.40	95.00
40	B-S-E-040	0	240	33.25	1.37	92.75

ID sample number	Sample	Coordinates		Water content (%) mean	Dry density (g/cm^3) mean	Degree of saturation %
		x	y			
41	B-S-E-041	0	67.5	31.84	1.42	95.86
42	B-S-E-042	0	47.5	32.64	1.33	85.41
43	B-S-E-043	0	25	34.40	1.38	96.82

In order to check the reliability of the results obtained on site, some of the samples were taken bigger than the rest so they could be divided in two parts and analysed two times: on site and in the laboratory that CIEMAT has in Madrid.

Table 11 shows both results.

Table 11. Comparison of water content and dry density results obtained from on site and laboratory analyses in Section E

		Laboratory results			On site results		
ID sample number	Sample	Water content (%) mean	Dry density (g/cm^3) mean	Degree of saturation %	Water content (%) mean	Dry density (g/cm^3) mean	Degree of saturation %
10	B-S-E-010	35.4	1.36	97	36.4	1.34	97
12	B-S-E-012	35.5	1.36	97	36.4	1.33	95
14	B-S-E-014	42.5	1.24	97	41.6	1.25	97
16	B-S-E-016	51.7	1.13	100	51.1	1.12	97
17	B-S-E-017	34.9	1.37	97	36.9	1.36	100
19	B-S-E-019	34.2	1.37	95	35.0	1.34	93
22	B-S-E-022	35.6	1.36	98	35.3	1.35	96
23	B-S-E-023	36	1.36	99	34.6	1.32	90
24	B-S-E-024	35.4	1.38	100	34.7	1.35	93
28	B-S-E-028	35.5	1.37	99	34.5	1.37	96
29	B-S-E-029	33.8	1.41	100	34.7	1.37	96
32	B-S-E-032	34.2	1.38	97	34.4	1.37	96
37	B-S-E-037	34.3	1.39	98	35.3	1.35	95
38	B-S-E-038	33.8	1.39	97	33.8	1.36	92
38	B-S-E-039	33.1	1.42	99	32.7	1.40	95
40	B-S-E-040	35.3	1.36	97	33.2	1.37	93

As the results show, the water contents obtained in the laboratory were on average the same as the on site results, and the dry densities 1.4 % higher. The differences are very small so they are not considered significant. See Appendix IV.

4.4.8 B2

The reference location of the samples is shown in Figure 54.

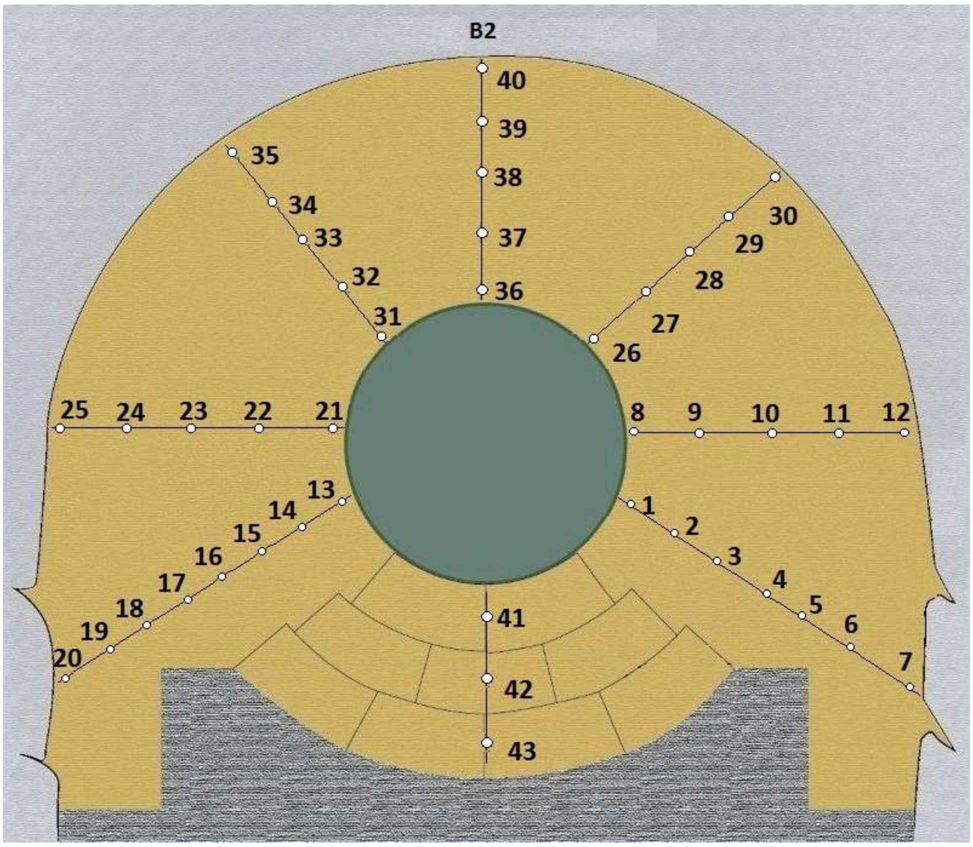


Figure 54: Location of samples in Section B2

Table 12 shows the coordinates of the samples and the results of the on site analysis.

Table 12. Water content and dry density obtained from on site analyses in Section B2

Sample	Coordinates		Water content (%) mean	Dry density (g/cm3) mean	Degree of saturation %
	x	y			
B-S-B2-001	48	101	39.0	1.27	93
B-S-B2-002	58	95	37.8	1.31	96
B-S-B2-003	67	85	37.8	1.31	96
B-S-B2-004	82	75	37.9	1.33	99
B-S-B2-005	102	62	40.8	1.27	97
B-S-B2-006	119	50	43.8	1.22	97
B-S-B2-007	129	40	44.9	1.18	95
B-S-B2-008	55	127	37.1	1.33	96
B-S-B2-009	70	127	35.7	1.33	94
B-S-B2-010	90	127	35.8	1.33	93
B-S-B2-011	115	127	37.5	1.29	93

Sample	Coordinates		Water content (%) mean	Dry density (g/cm3) mean	Degree of saturation %
	x	y			
B-S-B2-012	140	127	40.3	1.27	97
B-S-B2-013	-47	99	39.2	1.31	100
B-S-B2-014	-56	91	37.7	1.32	98
B-S-B2-015	-70	79	37.9	1.32	98
B-S-B2-016	-82	69	38.7	1.31	98
B-S-B2-017	-94	59	39.6	1.29	97
B-S-B2-018	-104	49	49.6	1.19	105
B-S-B2-019	-114	39	47.4	1.20	103
B-S-B2-020	-124	29	50.3	1.14	100
B-S-B2-021	-53	127.5	36.1	1.32	93
B-S-B2-022	-69	127	36.3	1.31	93
B-S-B2-023	-91	127	38.3	1.32	99
B-S-B2-024	-111	128	37.4	1.34	100
B-S-B2-025	-134	127	37.9	1.31	97
B-S-B2-026	46	166	34.2	1.37	95
B-S-B2-027	59	175	33.2	1.39	95
B-S-B2-028	71	185	32.8	1.39	94
B-S-B2-029	86	197	33.7	1.40	98
B-S-B2-030	99	212	32.9	1.38	93
B-S-B2-031	-35	168	35.5	1.38	100
B-S-B2-032	-45	176	34.8	1.36	95
B-S-B2-033	-55	186	34.7	1.36	96
B-S-B2-034	-65	199	35.3	1.35	95
B-S-B2-035	-75	214	35.2	1.36	96
B-S-B2-036	0	177	33.5	1.38	95
B-S-B2-037	0	197	33.0	1.39	95
B-S-B2-038	0	211	33.0	1.44	102
B-S-B2-039	0	229	32.9	1.45	104
B-S-B2-040	0	246	33.3	1.39	96
B-S-B2-041	0	67.5	34.1	1.36	94
B-S-B2-042	0	47.5	33.7	1.36	92
B-S-B2-043	0	25	35.3	1.35	95

As in sections A1-25 and E, some of the samples in section B2 were split in two so they were analysed on site as well as in the laboratory (CIEMAT) to check the consistency of the analysis.

Table 13 shows both results.

Table 13. Comparison of water content and dry density obtained from on site and laboratory analyses in Section B2

		Laboratory results			On site results		
ID sample number	**Sample**	**Water content (%) mean**	**Dry density (g/cm^3) mean**	**Degree of saturation %**	**Water content (%) mean**	**Dry density (g/cm^3) mean**	**Degree of saturation %**
31	B-S-B2-031	35.0	1.37	97	35.5	1.38	100
32	B-S-B2-032	35.2	1.36	96	34.8	1.36	95
33	B-S-B2-033	35.3	1.37	98	34.7	1.36	96
34	B-S-B2-034	35.0	1.37	97	35.3	1.35	95
35	B-S-B2-035	35.2	1.37	98	35.2	1.36	96
1	B-S-B2-001	39.6	1.29	98	39.0	1.27	93
2	B-S-B2-002	38.7	1.3	97	37.8	1.31	96
3	B-S-B2-003	38.8	1.31	99	37.8	1.31	96
4	B-S-B2-004	40.2	1.29	99	37.9	1.33	99
5	B-S-B2-005	39.6	1.29	98	40.8	1.27	97
6	B-S-B2-006	44.5	1.21	98	43.8	1.22	97
7	B-S-B2-007	45.6	1.19	97	44.9	1.18	95
20	B-S-B2-020	50.3	1.12	96	50.3	1.14	100

The values of the water content obtained in the laboratory are 0.7 % higher that the on site ones, and the dry densities are also higher in a 0.2 %. The differences are very small so they are not considered significant. See Appendix IV.

4.4.9 A2

No samples from the bentonite blocks were taken as explained in section 1.3.

The reference location of the samples is shown in Figure 55.

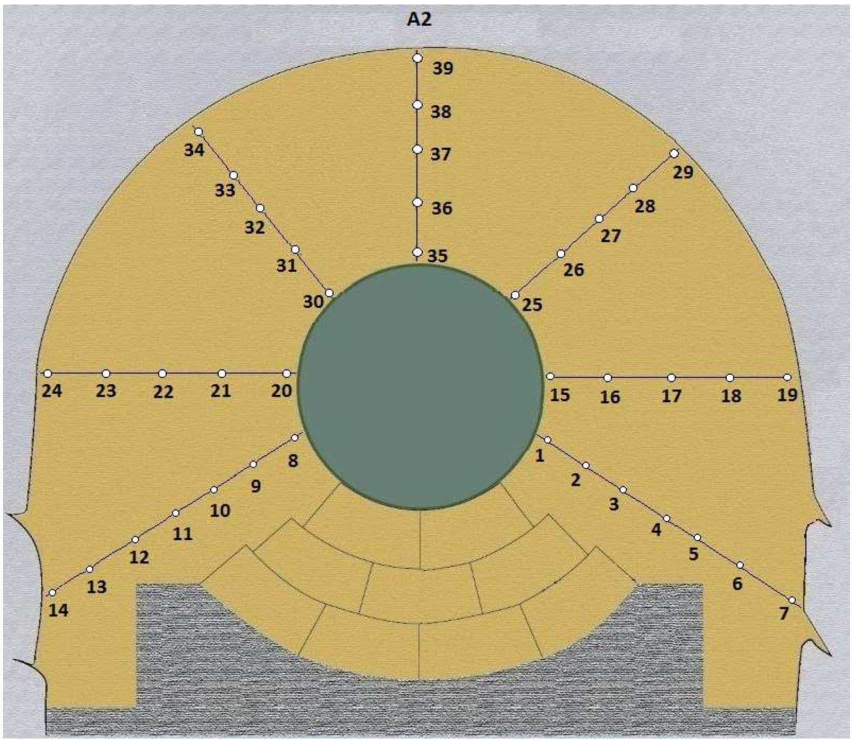


Figure 55: Location of samples in Section A2

Table 14 shows the coordinates of the samples and the results of the on site analysis.

Table 14. Water content and dry density obtained from on site analyses in Section A2

ID sample number	Sample	Coordinates		Water content (%) mean	Dry density (g/cm3) mean	Degree of saturation %
		x	y			
1	B-S-A2-001	49	113	40.3	1.28	98
2	B-S-A2-002	69	105	37.4	1.32	97
3	B-S-A2-003	89	95	38.5	1.29	95
4	B-S-A2-004	102	87	37.8	1.32	98
5	B-S-A2-005	115	79	40.6	1.26	96
6	B-S-A2-006	127	64	43.9	1.20	95
7	B-S-A2-007	147	44	46.8	1.17	97
8	B-S-A2-008	-48	113	41.0	1.23	93
9	B-S-A2-009	-66	105	38.8	1.28	95
10	B-S-A2-010	-82	95	38.9	1.28	94
11	B-S-A2-011	-95	86	39.6	1.27	94
12	B-S-A2-012	-111	75	46.0	1.19	98
13	B-S-A2-013	-126	63	48.3	1.14	95
14	B-S-A2-014	-141	52	49.2	1.13	96

ID sample number	Sample	Coordinates		Water content (%) mean	Dry density (g/cm3) mean	Degree of saturation %
		x	y			
15	B-S-A2-015	55	127	37.2	1.33	98
16	B-S-A2-016	72	127	36.1	1.36	99
17	B-S-A2-017	95	127	36.4	1.32	94
18	B-S-A2-018	115	127	38.4	1.27	92
19	B-S-A2-019	138	127	39.1	1.29	97
20	B-S-A2-020	-55	127	37.4	1.31	95
21	B-S-A2-021	-74	127	36.6	1.34	98
22	B-S-A2-022	-95	127	38.3	1.31	98
23	B-S-A2-023	-118	127	37.3	1.30	94
24	B-S-A2-024	-135	127	38.2	1.30	96
25	B-S-A2-025	35	165	34.7	1.37	97
26	B-S-A2-026	47	177	33.5	1.39	96
27	B-S-A2-027	63	187	34.3	1.38	97
28	B-S-A2-028	79	201	34.9	1.38	98
29	B-S-A2-029	95	211	35.7	1.36	98
30	B-S-A2-030	-32	169	35.0	1.37	97
31	B-S-A2-031	-42	179	34.5	1.37	96
32	B-S-A2-032	-52	190	33.5	1.39	96
33	B-S-A2-033	-65	201	34.0	1.38	96
34	B-S-A2-034	-77	211	35.6	1.35	96
35	B-S-A2-035	0	182	33.3	1.39	95
36	B-S-A2-036	0	196	32.3	1.38	91
37	B-S-A2-037	0	210	32.4	1.38	91
38	B-S-A2-038	0	228	32.5	1.41	97
39	B-S-A2-039	0	245	34.2	1.37	95

4.4.10 CMT3

Most of the samples taken in section CMT3 were for the organizations involved in the project. The location and recipients of these samples are shown in Figure 56.

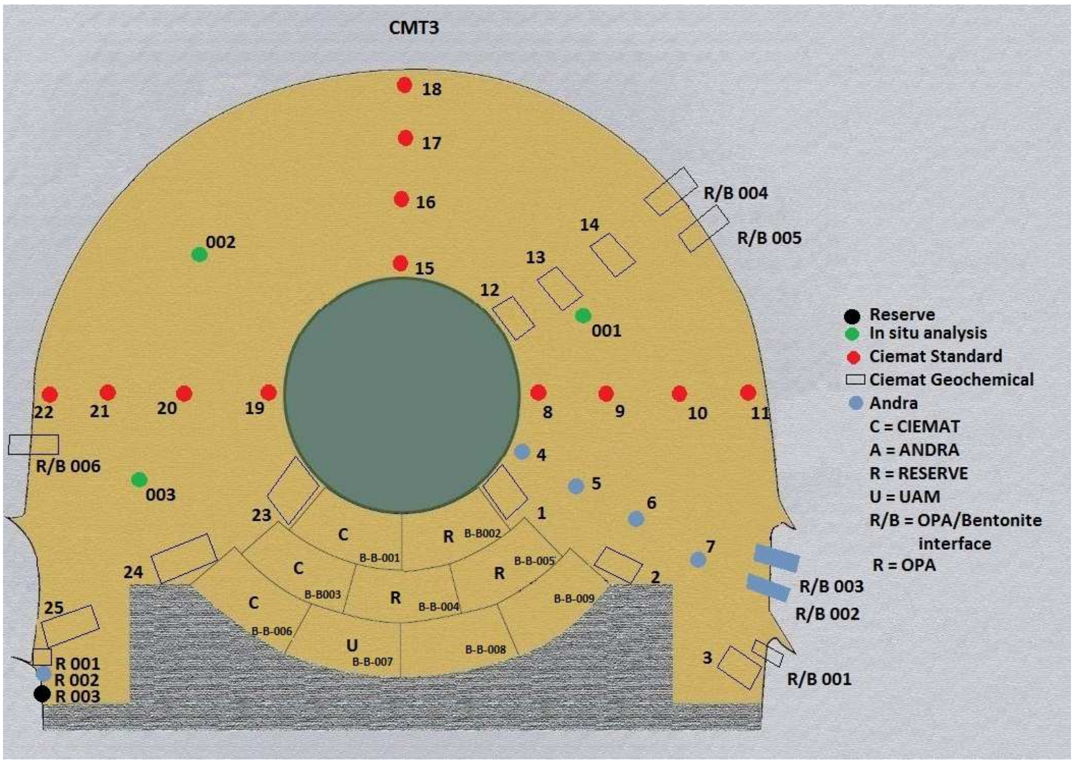


Figure 56: Location of samples in Section CMT3

There were taken few samples to be analysed on site. The rest was sent to the different organizations as requested. The results of the samples analysed on site as well as the ones analysed in the laboratory in CIEMAT facilities are listed in Table 15.

Table 15. Water content and dry density obtained from on site analyses in Section CMT3

ID sample number	Sample	Coordinates		Laboratory results			On site results		
		x	y	Water content (%) mean	Dry density (g/cm^3) mean	Degree of saturation %	Water content (%) mean	Dry density (g/cm^3) mean	Degree of saturation %
B-B-001	B-B-CMT3-001	-	-	35.5	1.36	97	-	-	-
B-B-003	B-B-CMT3-003	-	-	35.9	1.35	97	-	-	-
B-B-006	B-B-CMT3-006	-	-	35.1	1.36	96	-	-	-
8	B-S-CMT3-008	65	127	35.6	1.35	96	-	-	-
9	B-S-CMT3-009	90	127	36	1.34	96	-	-	-
10	B-S-CMT3-010	110	127	36	1.35	97	-	-	-
11	B-S-CMT3-011	125	127	35.6	1.34	95	-	-	-
14	B-S-CMT3-014	65	200	34.6	1.38	98	-	-	-
15	B-S-CMT3-015	0	180	35.7	1.38	101	-	-	-
16	B-S-CMT3-016	0	195	34.6	1.39	99	-	-	-
17	B-S-CMT3-017	0	215	34.7	1.39	99	-	-	-
18	B-S-CMT3-018	0	235	35.3	1.39	101	-	-	-

ID sample number	Sample	Coordinates		Laboratory results			On site results		
		X	Y	Water Content (%) mean	Dry Density (g/cm^3) mean	Degree of Saturation %	Water Content (%) mean	Dry Density (g/cm^3) mean	Degree of Saturation %
19	B-S-CMT3-019	-55	127	38.7	1.31	98	-	-	-
20	B-S-CMT3-020	-60	127	38	1.32	98	-	-	-
21	B-S-CMT3-021	-82	127	39.6	1.29	98	-	-	-
22	B-S-CMT3-022	-124	127	43.8	1.23	99	-	-	-
1	B-S-CMT3-001	41	90	41.3	1.3	104	-	-	-
2	B-S-CMT3-002	94	55	43.1	1.27	103	-	-	-
3	B-S-CMT3-003	129	30	47.8	1.17	99	-	-	-
23	B-S-CMT3-023	-40	105	41.4	1.26	98	-	-	-
24	B-S-CMT3-024	-95	70	40.9	1.27	98	-	-	-
25	B-S-CMT3-025	-135	35	50.1	1.14	99	-	-	-
001	BR-S-CMT3-001	50	185	-	-	-	34.7	1.37	97
002	BR-S-CMT3-002	-90	185	-	-	-	34.0	1.39	97
003	BR-S-CMT3-003	-100	100	-	-	-	44.5	1.22	99

4.5 ADDITIONAL TESTS, COMMENTS AND EVALUATION OF THE RESULTS

4.5.1 Test behavior of bentonite samples at air conditions

In order to evaluate the impact of the time spent handling the samples in the results, an expansion test was done. It consisted in taking a big sample and dividing it in 7 subsamples. Water content and dry density was measured in this subsamples after 2, 15, 30, 60 120, 240 and 360 minutes. Figure 57 and Figure 58 show the obtained results.

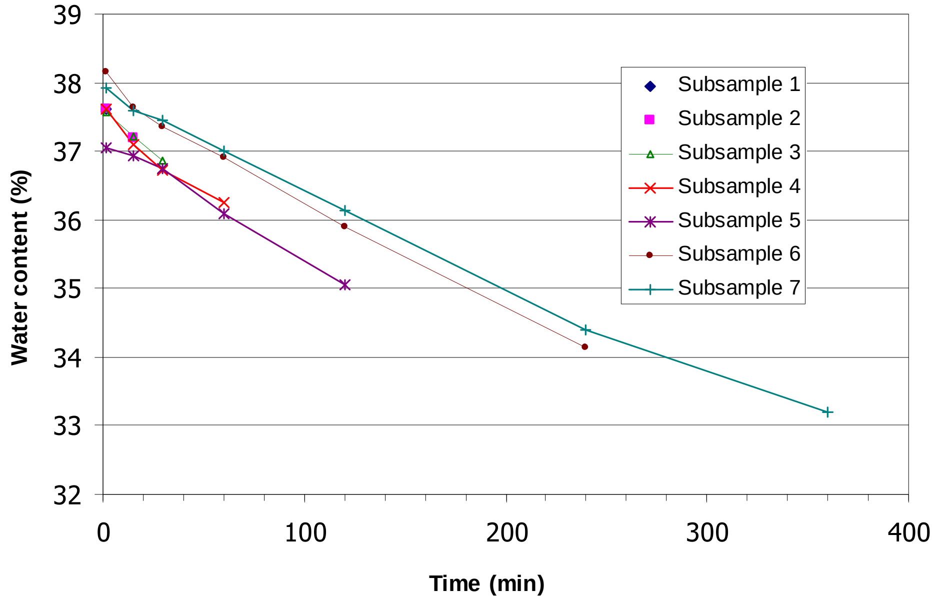


Figure 57: Evolution of the water content in the samples at air conditions in the on site laboratory

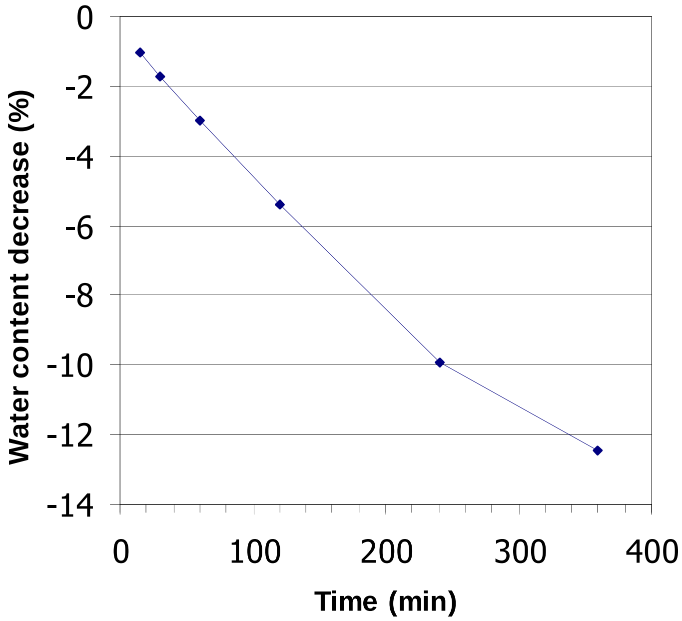


Figure 58: Evolution of the average water content loss

The results of this test show that there would be an average of a 1.2% decrease of the water content after 20 minutes of the sample being exposed to air conditions. 20 minutes is approximately the time spent trimming and handling the samples to be analysed. This would have an impact on the values of the degree of saturation, decreasing the percentage in approximately 3 points in most of the cases.

Apart from this, the expansion of the bentonite mass as a whole before the sampling should also be taken into account when calculating the degree of saturation. This would increase the porosity of the mass and therefore, the density would decrease and the degree of saturation. However, this effect can not be quantified with the expansion test it was carried out or by other tests.

4.5.2 Water content, dry density and degree of saturation

During the sampling campaigns of sections CMT1 CMT2 and CMT3, some samples were taken to be analysed on site in order to get reference values of water content and dry density for the future laboratory analyses. These samples were located in places between planned samples in order to cover as much as possible the surface of the section (See Figure 50, Figure 52 and Figure 56) as it was thought that the results would be homogeneous in every part of the section.

As the dismantling was moving forward and the on site analyses were being made, it was observed that the lower parts of the experiment were wetter than the upper ones and that the dry density was lower at the bottom than in the top. Table 16 shows the average values of water content, dry density and degree of saturation in every section and in every area of each section (upper, intermediate, lower and blocks). The total average in the experiment of water content is 36%, of dry density is 1.34 g/cm^3 and a 95.5% of degree of saturation.

Table 16. Average values of water content, dry density and degree of saturation in every section obtained from on site analysis.

Position		Amount of samples	Water content (%)	Dry density (g/cm^3)	Degree of Saturation (%)
A1_25	GBM Lower	14	36.8	1.32	95
	GBM Upper	15	31.8	1.42	96
	Blocks	3	34.4	1.33	90
B1	GBM Lower	15	40.0	1.29	99
	GBM Upper	17	32.8	1.40	96
	Blocks	3	34.0	1.38	96
E	GBM Lower	16	39.8	1.28	96
	GBM Intermediate	8	35.4	1.35	95
	GBM Upper	16	34.0	1.38	96
	Blocks	3	33.0	1.38	93
B2	GBM Lower	15	41.5	1.26	98
	GBM Intermediate	10	37.2	1.32	96
	GBM Upper	15	33.9	1.39	96
	Blocks	3	34.4	1.36	94
A2	GBM Lower	14	41.9	1.24	96
	GBM Intermediate	10	37.5	1.31	96
	GBM Upper	15	34.0	1.38	96

This results also show that the water content was higher and the dry density lower in the sections that are farther away from the concrete plug.

Regarding the degree of saturation, no differences were observed between areas in the same section or between sections. The values remain stable close to 96% in most of the cases.

These results are applicable to both the GBM and the blocks.

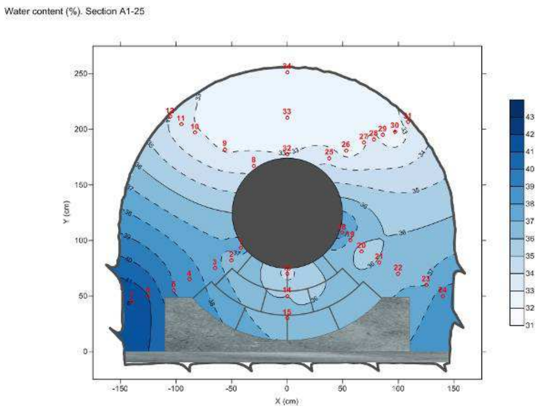
4.5.3 Tentative correction of the on site results

If the impact of the drying of the samples before they are analysed is taken into account (see section 4.5.1) in the final results of the experiment, then the actual water content of the samples could be about 1.2 % higher than the obtained results; and the degree of saturation would increase between 2 and 4 points in percentage.

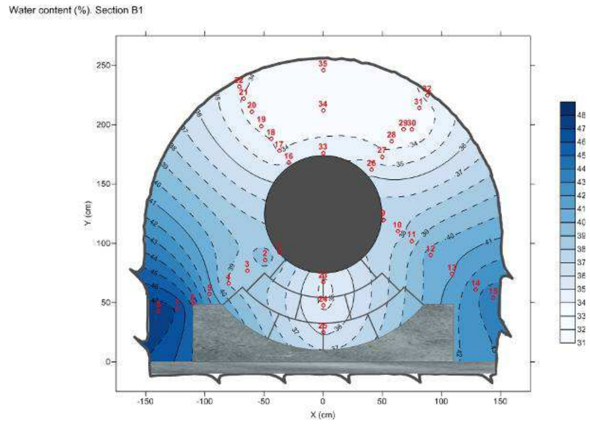
In order to show the results as real as possible, the values obtained in the on site laboratory have been tentatively corrected by means of rising 1.2 % more in the water content measurements and recalculating the degree of saturation. These values are gathered in Appendix II as well as the isoline graphs for every parameter in every cross section. Regarding the isoline graphs, note that the amount of data taken on the field should have been much higher in order to have a more accurate image so they show an approximate distribution but the general trends are representative.

To build the contour and shaded maps, Surfer 10 software has been used. Surfer is a grid-based mapping program that interpolates irregularly spaced XYZ data into a regularly spaced grid. This grid is used to produce different types of maps (contour, shaded relief, vector, image, 3D wireframe maps, 3D surface...). As gridding methods, Kriging has been used. Kriging produces visually appealing maps from irregularly spaced data, expressing trends suggested in the data.

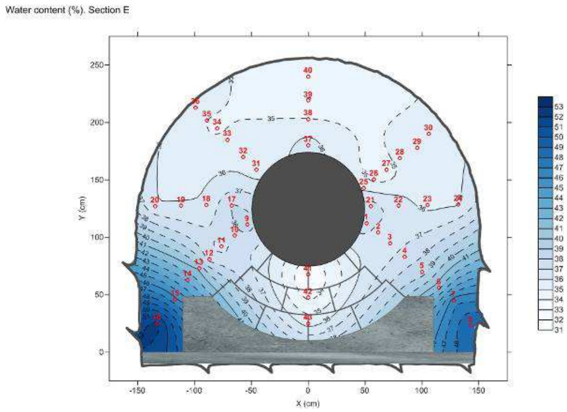
These maps are also shown in a smaller scale in Figures 60, 61 and 62. The red numbers in every chart refer to the identification number of the samples.



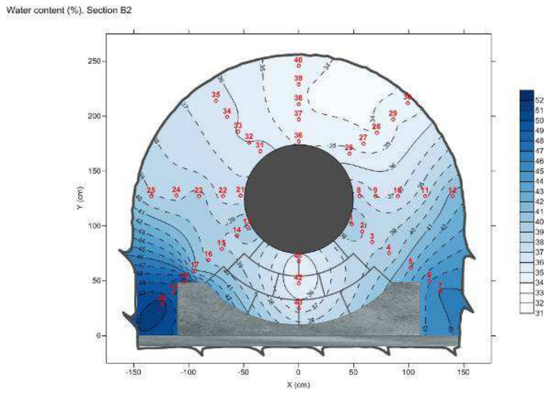
SECTION A1-25



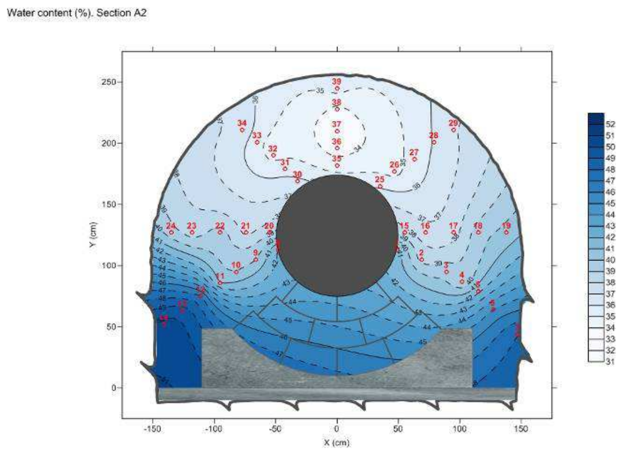
SECTION B1



SECTION E

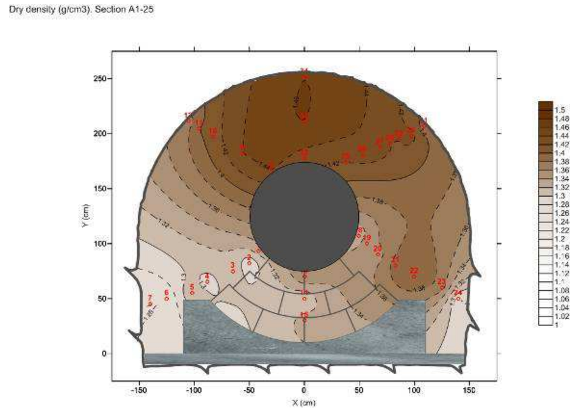


SECTION B2

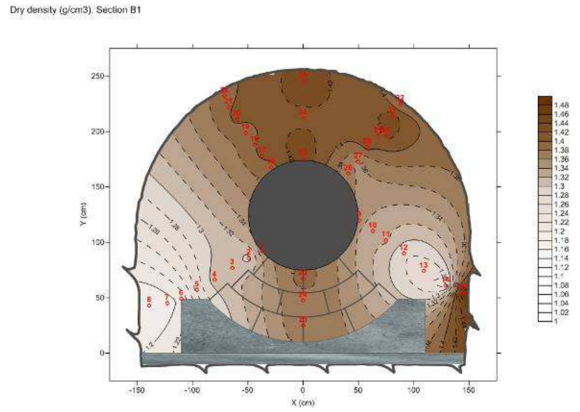


SECTION A2

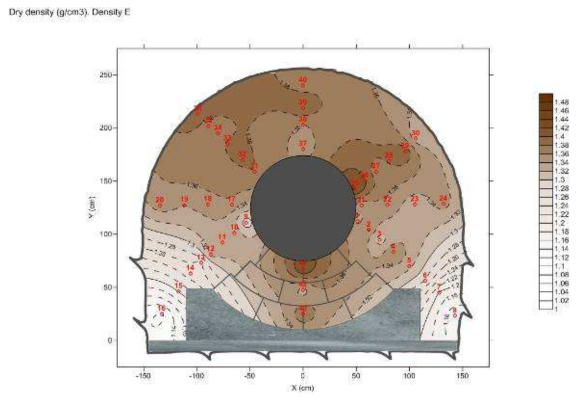
Figure 59: Evolution of the Water Content. Cross sections. Values corrected according to section 4.4.3.



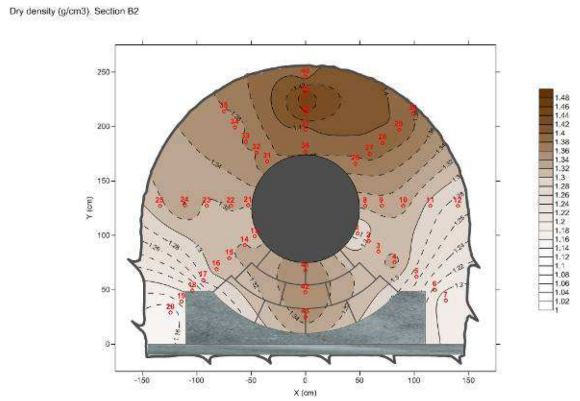
SECTION A1-25



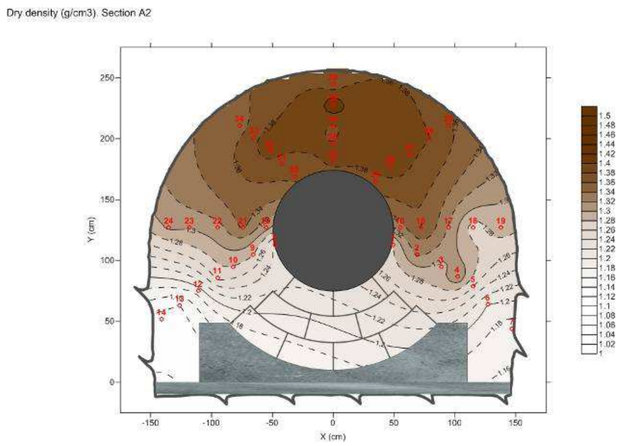
SECTION B1



SECTION E

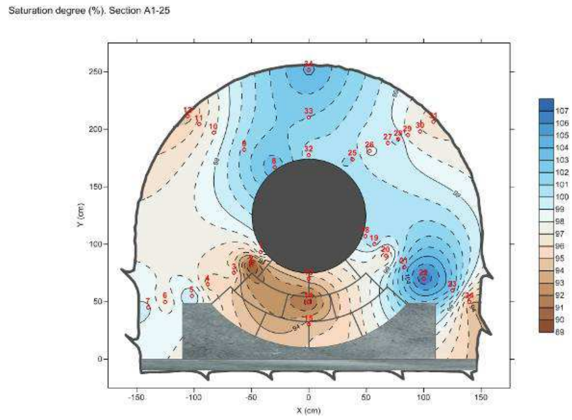


SECTION B2

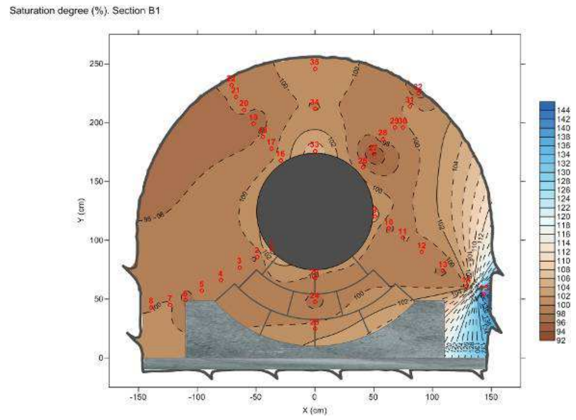


SECTION A2

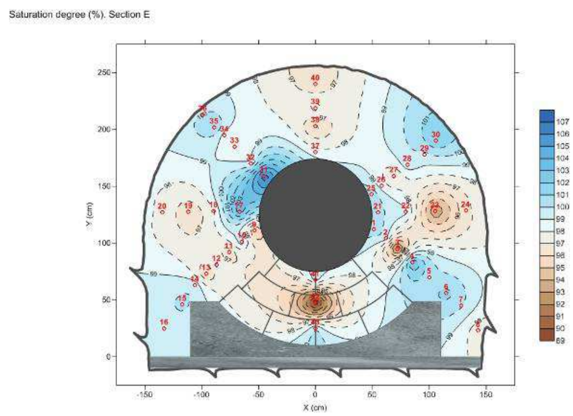
Figure 60: Evolution of the Dry Density. Cross sections. Values corrected according to section 4.4.3.



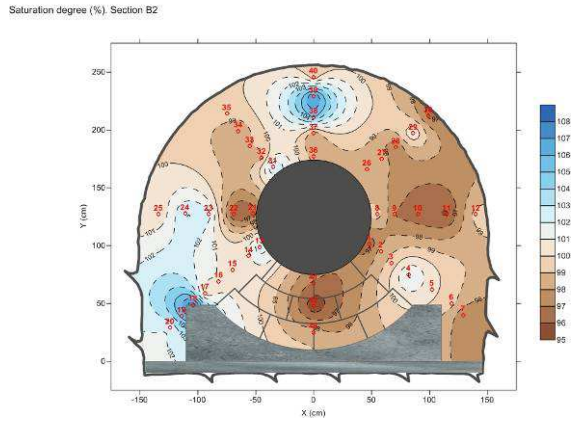
SECTION A1-25



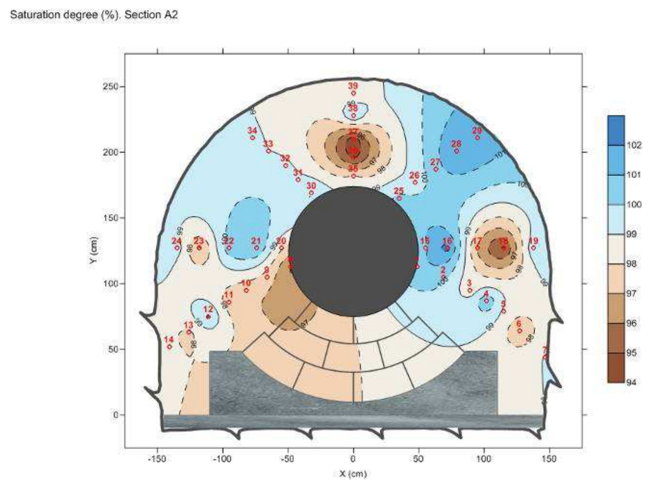
SECTION B1



SECTION E



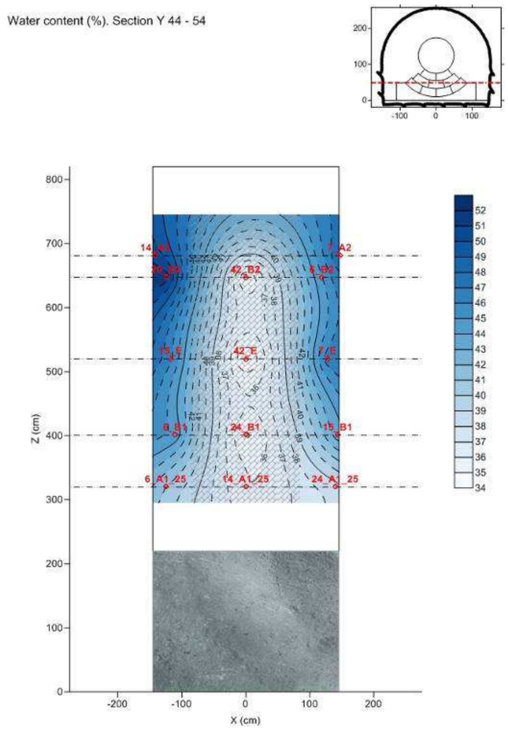
SECTION B2



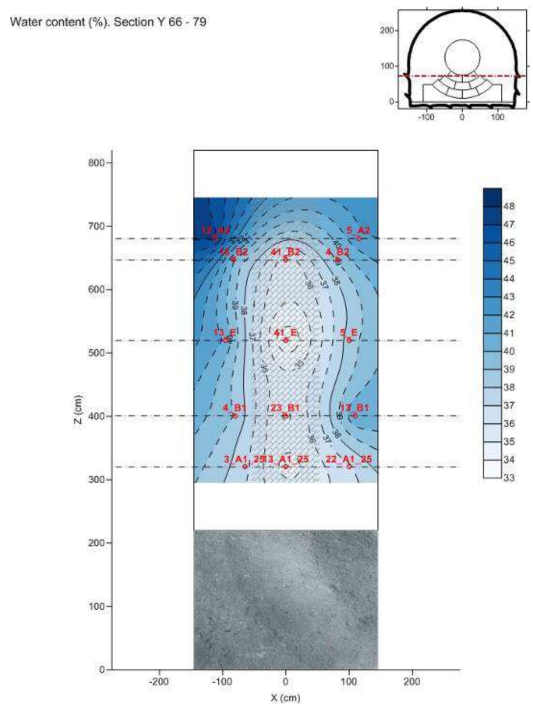
SECTION A2

Figure 61: Evolution of the degree of saturation. Cross sections. Values corrected according to section 4.4.3.

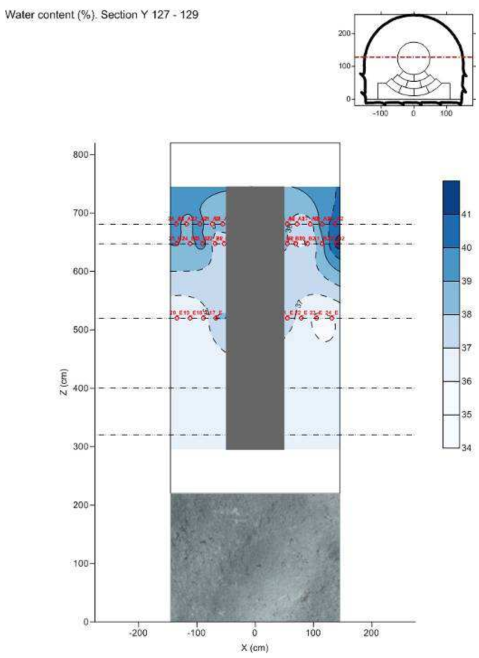
Since an increasing trend for the water content and decreasing trend for the dry density with the Y coordinate was observed, isoline maps corresponding to different longitudinal sections were also drawn. In order to have more data in the longitudinal sections, every section was defined to cover few cm thick (i.e. Y 44-54 represents a section of 10 cm thickness between z= 44cm and z=54 cm). See Appendix II and also Figures 63, 64 and 65.



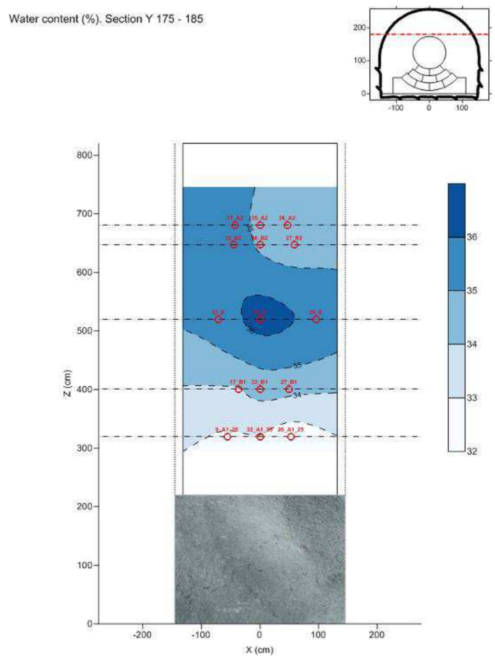
SECTION Y 44-54



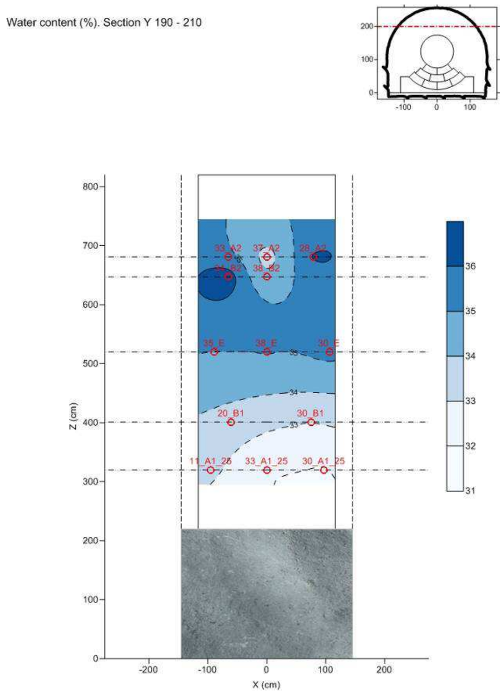
SECTION Y 66-79



SECTION Y 127-129

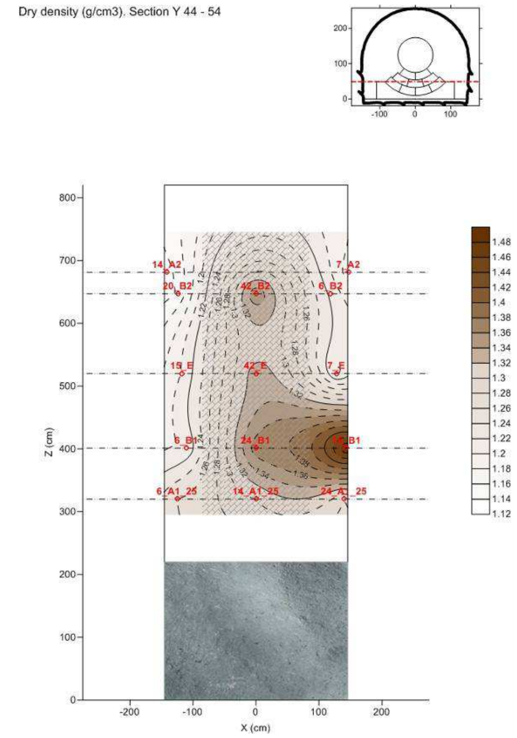


SECTION Y 175-185

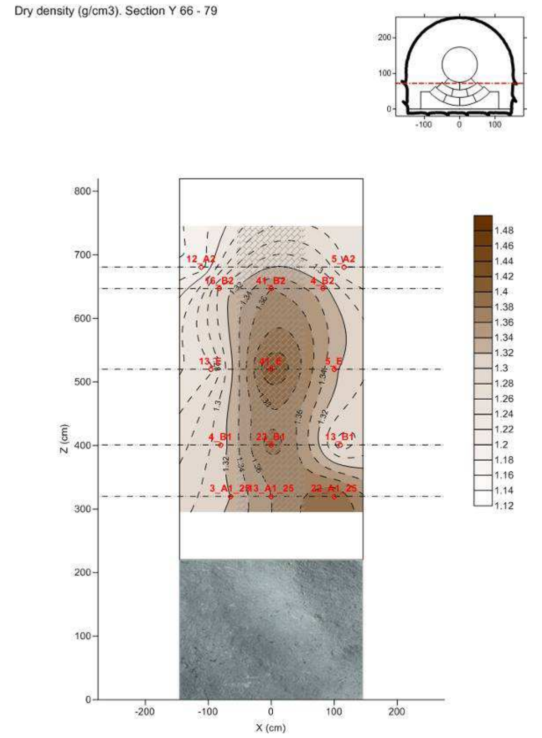


SECTION Y 190-210

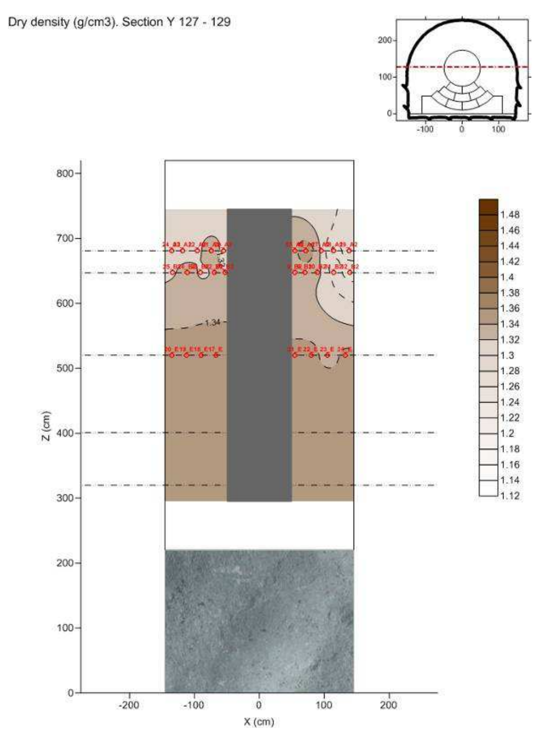
Figure 62: Evolution of the Water Content. Longitudinal sections. Values corrected according to section 4.4.3.



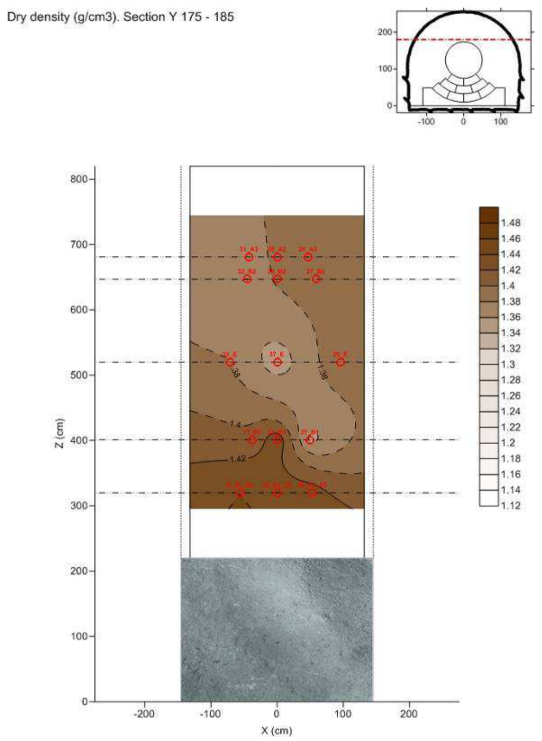
SECTION Y 44-54



SECTION Y 66-79



SECTION Y 127-129



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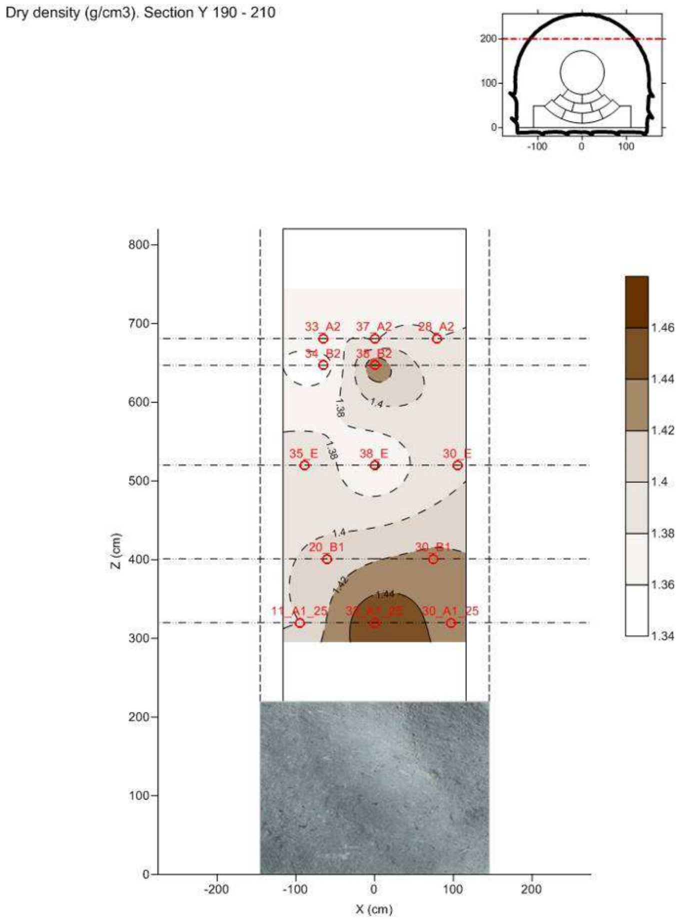
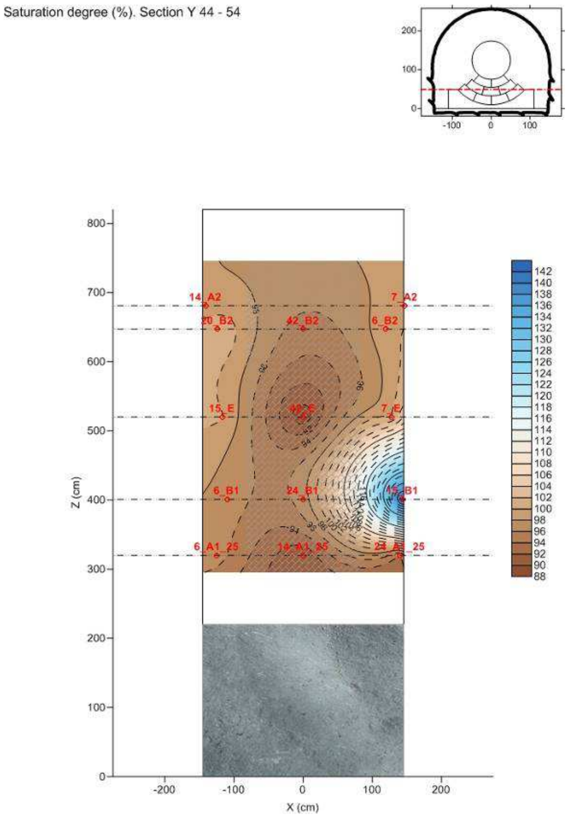
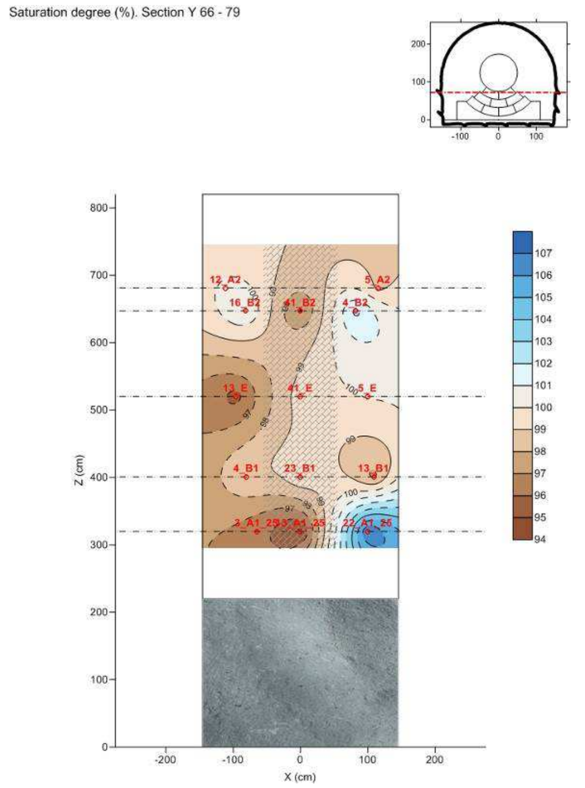


SECTION Y 190-210

Figure 63: Evolution of the Dry Density. Longitudinal sections. Values corrected according to section 4.4.3.



SECTION Y 44-54



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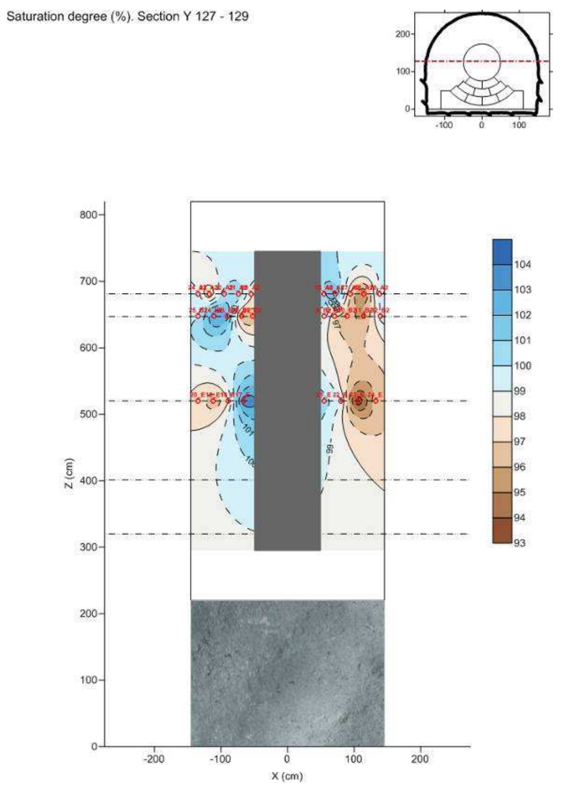
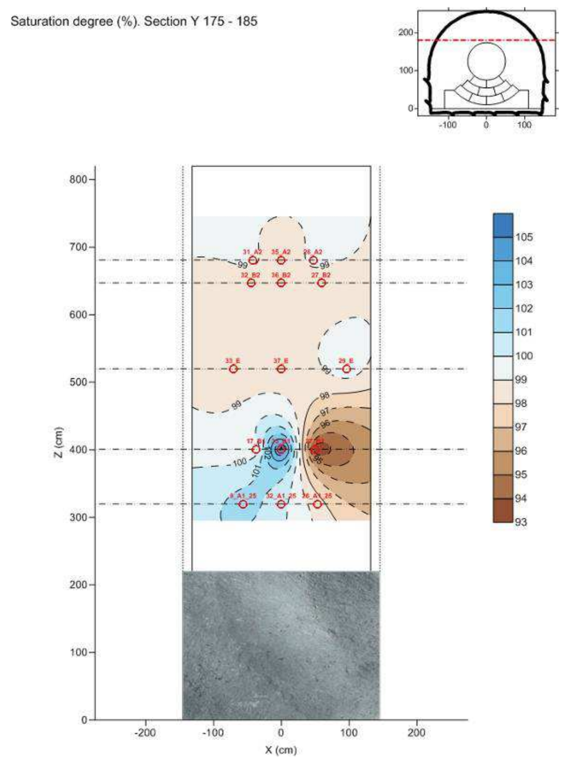
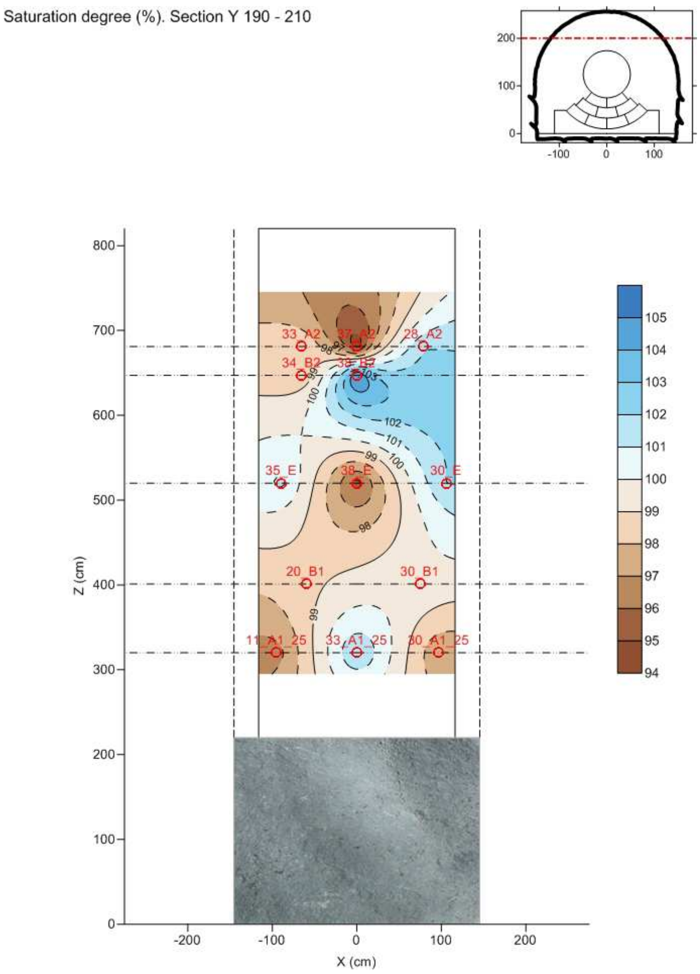


SECTION Y 127-129



SECTION Y 175-185



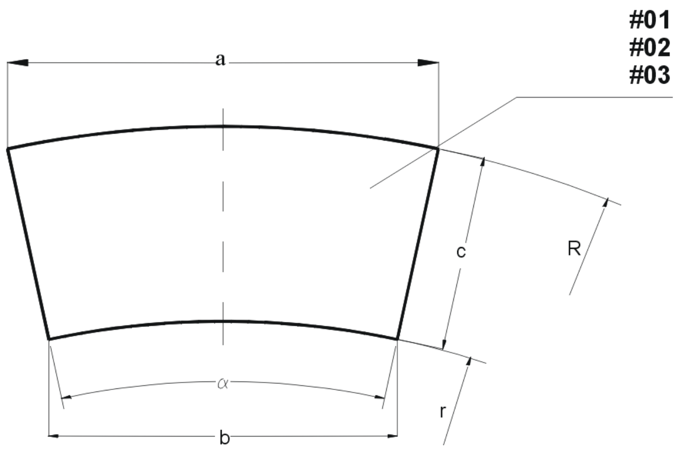
SECTION Y 190-210

Figure 64: Evolution of the degree of saturation. Longitudinal sections. Values corrected according to section 4.4.3.

4.5.4 Bentonite blocks and canister displacement

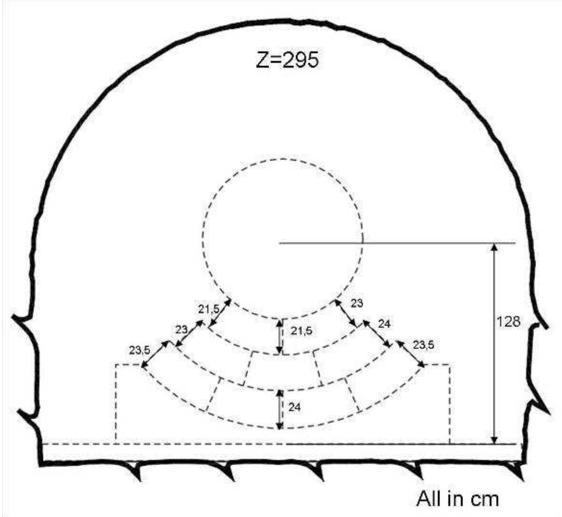
According to the results, the density of the bentonite blocks decreased from an initial value of 1.7 g/cm^3 in the installation phase to a value rating from 1.33 to 1.38 g/cm^3 (on site analyses). The lower densities corresponded to the sections closer to the concrete plug. This only can be explained by an expansion of the blocks.

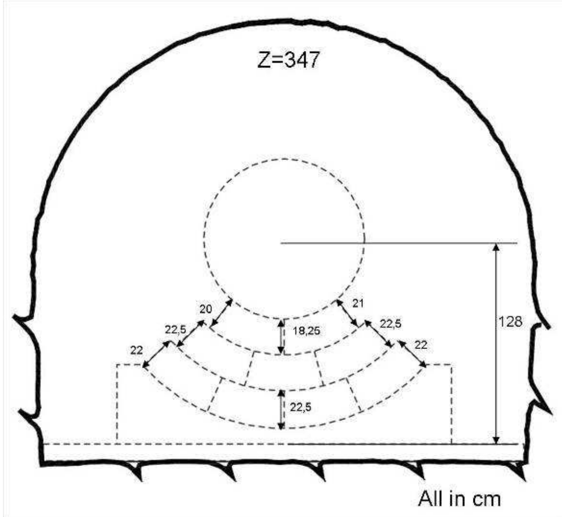
There were 3 different levels of bentonite blocks (#01, #02 and #03) and their dimensions measured on site as the dismantling was moving forward. The distance from the centre of the canister to the floor was also measured. Figure 65 shows the dimensions of the blocks when they were installed. Figure 66 shows the obtained measurements from blocks along different sections during the dismantling.

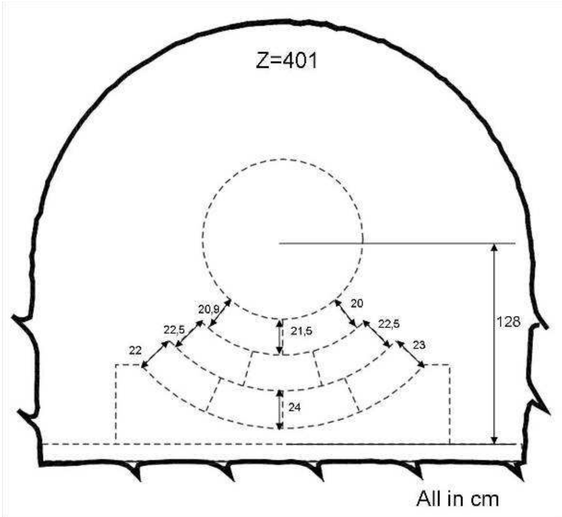


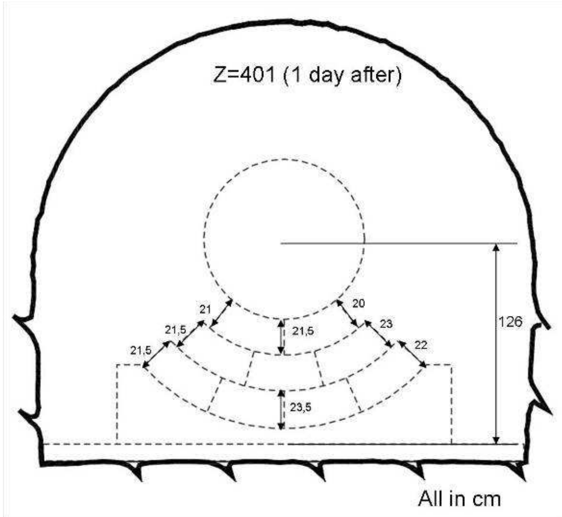
Block type	a (mm)	b (mm)	c (mm)	Thickness (mm)	External Radius R (mm)	Internal Radius r (mm)	α (°)	Weight (kg)
#01	$470.0^{+2,0}_{-5,0}$	$380.0^{+2,0}_{-4,0}$	$214.0^{+2,0}_{-3,0}$	$125.0^{+2,0}_{-2,0}$	1.133	919	24°	22.1
#02	$473.0^{+2,0}_{-5,0}$	$361.0^{+2,0}_{-4,0}$	$214.0^{+2,0}_{-3,0}$	$125.0^{+2,0}_{-2,0}$	917	703	30°	21.8
#03	$478.0^{+2,0}_{-5,0}$	$330.0^{+2,0}_{-4,0}$	$214.0^{+2,0}_{-3,0}$	$125.0^{+2,0}_{-2,0}$	701	487	40°	21.3

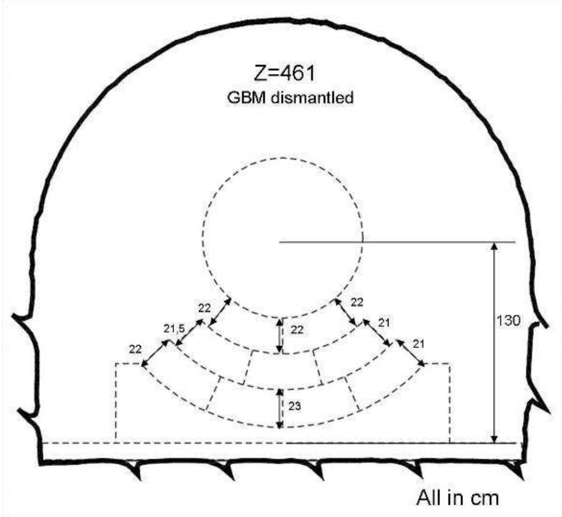
Figure 65: Original bentonite blocks dimensions

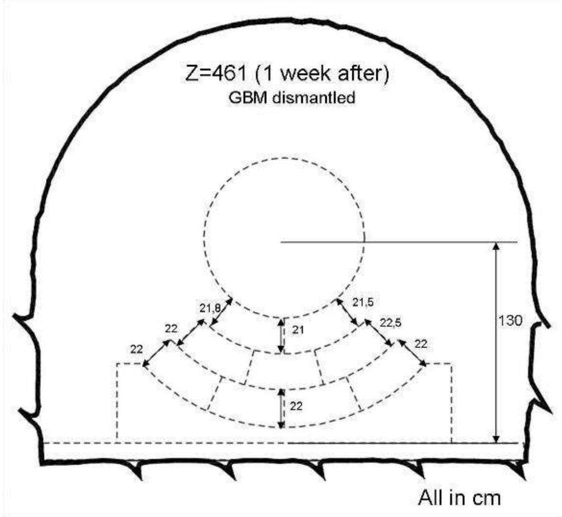

Z=295
21,5
23
23,5
21,5
23
24
23,5
24
128
All in cm


Z=347
20
22,5
22
18,25
21
22,5
22
22,5
128
All in cm


Z=401
20,9
22,5
22
21,5
20
22,5
23
24
128
All in cm


Z=401 (1 day after)
21
21,5
21,5
21,5
20
23
22
23,5
126
All in cm


Z=461
GBM dismantled
22
21,5
22
22
22
21
21
23
130
All in cm


Z=461 (1 week after)
GBM dismantled
21,8
22
22
21
21,5
22,5
22
22
130
All in cm

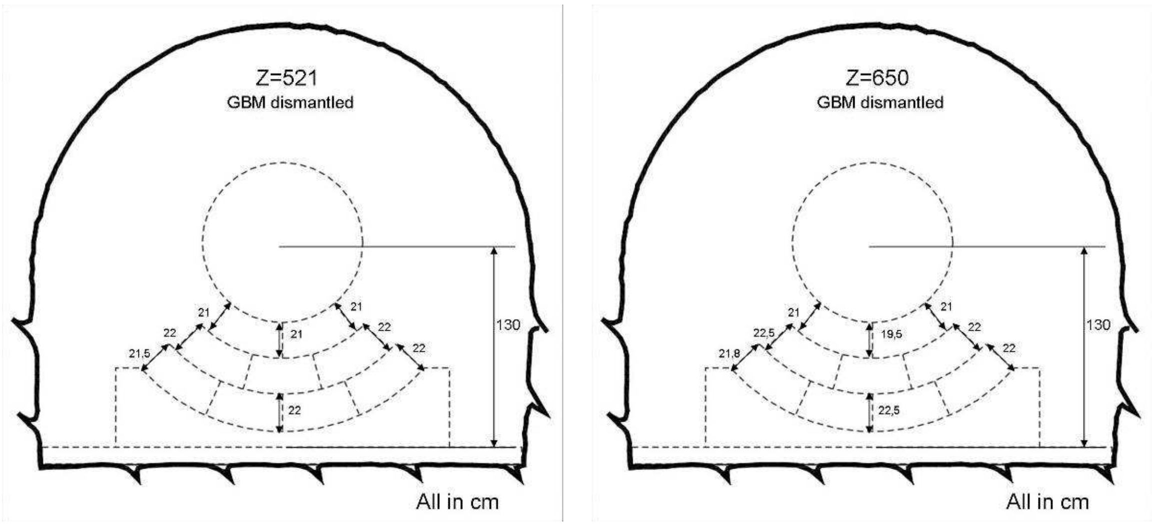


Figure 66: Bentonite blocks on site measurements

As seen in Figure 66 , the parameter measured in the blocks ('c' parameter in Figure 65) had an initial value of 21.4 cm, and in most of the cases this value increased showing that a vertical expansion (Y axis) of the block took place.

The expansion along the Y axis was also assessed by the evolution of the distance between the centre of the canister and the floor, which shows an uplift of the canister of approximately 3 cm from its original position. As it can be seen in Figure 66, this expansion took place from Z=461, when a complete section of bentonite was not dig at the same time because the bentonite blocks bed was left on place while the GBM front was being removed.

The expansion of the blocks along the Z axis was also proved by the evolution of the distance between the front face of the canister and the front face of the concrete bed. They were aligned when the EB experiment started and at the end of the dismantling operation there was a gap of around 4 cm between both. See Figure 67.

All these observations indicate that apart from the expansions developed in the bentonite blocks during the operational phase they had an additional expansion during the dismantling operation.

Figure 67: Longitudinal expansion of the bentonite

4.5.5 Other observations

In general, the aspect of the GBM was homogeneous and consistent along the whole operation. No risk of collapse was observed. This same observation can be applied to the Opalinus clay as it seemed to have kept all its physical properties intact. See Figure 68.

Figure 68: OPA after the dismantling operation

The rest of elements of the experiment such as hydration pipes, cables, geotextile…all of them were in perfect conditions. If any cable was damaged, it was during the bentonite removal operation as it was no possible to exactly predict the location of them after the swelling of the bentonite due to the hydration. The tools used to remove the bentonite were powerful and sharp and by the time the cables were reached, sometimes it was already too late to save them. See Figure 69.

Figure 69: Broken cables during the bentonite removal

The geotextile used for the hydration system always looked clean with no intrusions of bentonite. There were some corrosion stains from the welding points used to attach the total pressure cells to the canister in section E but in general the corrosion effects on metallic parts were negligible. See Figure 41.

5 SUMMARY AND CONCLUSIONS

Despite the initial delay due to the difficulties met to dismantle the concrete plug the operation as a whole went very well and it was concluded in a reasonable time, less than 100 working days.

The laboratory analyses show a clear trend of higher water contents from top to bottom in every section, and from sections closer to the plug to sections towards the end of the experiment. This trend was also followed by the dry density results but in a reverse way: the results showed lower densities at the bottom of every section. These trends can be explained by two events. One is the material segregation that probably happened during the construction of the experiment (NAGRA 2004, see Figure 70). The bigger pellets would lay at the bottom and the smaller ones filling the gaps, only on the top, so the initial values of density were lower at the bottom.

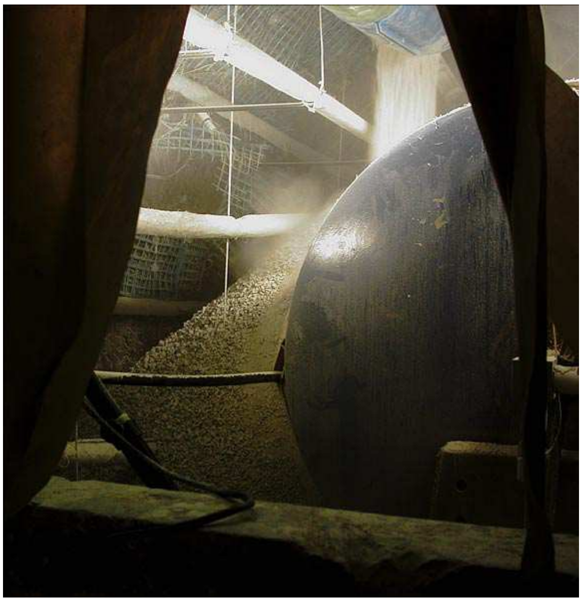


Figure 70: GBM emplacement with gravity fall from the auger during EB installation

The other fact is the gravity effect. During the hydration process, injected water would be affected by gravity and it might have accumulated preferentially at the bottom of the experiment. This explanation matches quite well with the up levelling recorded for the dummy canister during the operational phase and with the dry density distribution found, because the accumulation of the water at the bottom would have promoted the expansion of the blocks and GBM at the bottom increasing the initial heterogeneity due to the emplacement.

Observations indicated that the front of bentonite dried quickly, with a clear effect in 1-2 days after exposure. Besides, there was an expansion of the bentonite buffer along the Z axis, which correlates with the decreasing pressure trend of the total pressure cells recorded as the dismantling works were advancing. This expansion would have affected to the dry density of the bentonite in the experiment by dropping the results obtained in the laboratory, and therefore, the results of the degree of saturation. These laboratory results ranged from 90% to 99% and after applying a correction due to the handling of the samples, these results might range from 98 % to 100.5%. The decrease of the dry density due to the same reasons has not been possible to quantify, but taking the whole in consideration the values of the degree of saturation of the bentonite would probably show a complete saturation of it. This is in line with the operational results, which showed that no additional water could be introduced in the buffer after 5 years of artificial saturation.

In conclusion, the dismantling operation provided the information requested: it was possible to inspect and analyse “in-situ” the GBM in order to determine its properties. Despite the initial heterogeneity due to the emplacement its aspect and homogeneity were very good and the registered degree of saturation almost complete taking into account the uncertainties due to bentonite expansion and drying during the dismantling. Obtained dry density and most probably permeability (laboratory analyses are still on-going) are well correlated with the expected initial heterogeneity (not measured during the emplacement due to operational reasons) but the obtained values indicate that low enough buffer permeability was achieved everywhere and that higher than expected total pressures were developed. Furthermore, almost 300 samples more were taken and sent to the different partners in the project to carry out different laboratory analyses, which results will be reported in specific documents.

6 REFERENCES

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7 APPENDIX I TOOLS DATA SHEET

8 APPENDIX II TENTATIVE CORRECTION OF THE ON SITE ANALYSES DATA. ISOLINES GRAPHS

9 APPENDIX III FINAL SENSORS DATA REPORT SDR N30

10 APPENDIX IV EB EXPERIMENT. CONTRIBUTION OF CIEMAT