Contract Number: 622177

Deliverable n°4.3

Long Term Rock Buffer Monitoring (As-built)

Work Package 4

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RE	Restricted to a group specified by the partners of the Modern2020 project	
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This report has been reviewed according to the Modern2020 Quality Plan and the Deliverables Review Procedure therein. Formal review according to a Review Plan has been undertaken by Jan Verstricht (WP4 leader) and documented in Review Statements

Approved by

This report has been approved by:

- Jan Verstricht, Work Package 4 Leader, *08.08.2019*
- Johan Bertrand, the Modern2020 Project Co-ordinator (on behalf of the Modern2020 Project Executive Board), *19.08.2019*

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Glossary

Backfilling: Process of emplacing the granular bentonite.
CHEH: Chemical Eh sensor
CHCL: Chemical -Cl sensor
CHPH: Chemical Ph sensor
DAS: Data Acquisition System
DSCO: Displacemeent conventional sensor
EBS: Engineering Barriers System
EDZ: Excavation Damage Zone
ELAR: Electrode array
ERT-IP: Electrical Resistivity Tomography and Inversion Polarisation
FFCO: Fluid flow conventional sensor
FPCO: Fluid pressure conventional sensor
GM: Granular Material
GBM: Granular Bentonite Material
LTRBM: Long Term Rock Buffer Monitoring
MVCO: Mass/Volume conventional sensor
O.D.: Outer Diameter
PPCO: Pore Pressure conventional sensor
PPFO: Pore Pressure fiber optique sensor
PPWL: Pore Pressure wireless sensor
Q.C: Quality Control
RHCO: Relative Humidity conventional sensor
RHDP: Relative Humidity dew point sensor
RHFR: Relative Humidity FDR (Frequency Domain Reflectometry) sensor
RHTN: Relative Humidity tensiometer sensor
RHPS: Relative Humidity psycrometer sensor
NRG: Nuclear Research and Consultancy Group
VTT : Technical Research Centre of Finland
CTU: Czech Technical University in Prague
IRSN: Institut de radioprotection et de sûreté nucléaire
ENRESA: Empresa Nacional de Residuo Radiactivo
PVC: Polyvinyl chloride
MB: Main Borehole
FO: Fibre Optic
WP: Work Package
SCADA: Supervisory Control and Data Acquisition
SEALEX: In situ sealing experiment (performance assessment tests of bentonite seals)
THMC: Total Pressure + Pore Pressure + RH + Temperature probe
TPCO: Total Pressure conventional sensor

TPFO: Total Pressure fiber optique sensor

TTCO: Total temperature conventional sensor

URL: Underground Research Laboratory

WLR: Wireless Long Range

WSR: Wireless Short Range

WTB: Wireless Test Bench

WP: Work Package

1. Introduction

The Long Term Rock Buffer Monitoring in situ test (LTRBM) is one of the field demonstrators in WP4 of the Modern2020 project. It has been installed with part of the new monitoring devices developed in WP3. The LTRBM installation is based on the document "*Milestone M4.2 Design of Long Term Rock Buffer Monitoring demonstrator*".

1.1 Objectives

The main objective of LTRBM is to house prototypes made in WP3, with conditions as close as possible to the expected ones in the repository. The objective of the present document is to detail the design of this demonstrator in order to proceed with the procurement and installation phases.

1.2 Internal organization and roles

The main participants were IRSN, ENRESA, ARQUIMEA, AMBERG. ANDRA, VTT, CTU and U. Strathclyde aslo participated by providing new monitoring instrumentations that were incorporated in LTRBM.

The development of the demonstrator was done according to the following program:

1. Definition of the objectives and time plan for the demonstrator: IRSN, ENRESA, NRG and AMBERG.
2. Determination of the status of the new technologies that could be incorporated in the demonstrator: AMBERG with the help of the potential additional partners developing new solutions in WP3.
3. Development of the Test Plan for the Demonstrator (Design): AMBERG and ARQUIMEA with the supervision of IRSN, ENRESA and NRG.
4. Construction of the LTRBM
   - Leader, infrastructure, location and general coordination of Tournemire activities: IRSN
   - Interlocutor with IRSN, coordination and quality control of in-situ activities: AMBERG
   - ARQUIMEA carried out the activities related with short range wireless solutions with the exception of the support provided by AMBERG for the interface between ARQUIMEA and NRG, required for the integration between short and long range wireless solutions. Thus, AMBERG was in charge to link the short and long distance wireless data transmissions.

   4.1.Drilling and buffer procurement: IRSN

   4.2. Other procurements

   4.2.1. Procurement of Wireless Long-Range (WLR) equipment: NRG.

   4.2.2. Procurement of the Wireless Short-Range (WSR) equipment adapted to the required monitoring instrumentation and of the associated DAS devices: ARQUIMEA.

   4.2.3. Procurement of hydration system, confining system and additional equipment/ additional instrumentation: AMBERG.

   4.2.4. Procurement of prototypes of the developments made in WP3: interested partners.

   4.3. Installation

   4.3.1. Installation of the engineered materials (bentonite and cement) and quality control (QC): AMBERG

   4.3.2. Installation of the instrumentation: AMBERG with the help from ARQUIMEA for the WSR equipment and the related DAS, NRG for WLR equipment and partners providing prototypes.

   4.3.3. Supervision of installation has been made by IRSN.
5. As-built document: AMBERG with the supervision of IRSN and ENRESA.

1.3 Applicable documents and references

- *GRANT AGREEMENT No. 662177 of Modern2020 dated 11/05/2015*
- *Written agreement between Amberg Infraestructuras and Arquimea Ingeniería (Reviewed version) dated 7th November 2016*
- *AMENDMENT Reference No AMD-662177-15*
- *MS10: As-built report: Wireless Testing Bench*
- *MS10: As-built report: Wireless Testing Bench*
- *Note on LTRBM to WP3 partners distributed 29.05.2017*
- *Inputs received from WP3 partners to the template about the current status of technology, which was discussed during the parallel session for LRTBM during GA#3 held in Montpellier June 2017.*
- *Regulations applicable to IRSN's facility at which the services are to be provided,*
- *Mokni, N., Barnichon, J.D., 2016. Hydro-mechanical analysis of SEALEX in situ tests —impact of technological gaps on long term performance of repository seals. Eng. Geol. 205, 81–92*
- *Barnichon, J.D., Dick, P., Bauer, C., 2012. The SEALEX in situ experiments: performance tests of repository seals. In: Qian, Zhou (Eds.), Harmonising Rock Engineering and the Environment. Taylor and Francis Group, London, pp. 1391–1394.*
- *Dick, P. Feedback from the SEALEX tests installations (2010-2013) and monitoring results until end 2015. IRSN Rapport RT/PRP-DGE/2016-00017.*
- *Test Plan. Design of Long Term Rock Buffer Monitoring demonstrator. Milestone M4.2. Contract Number: 622177.*

2. LTRBM demonstrator description

2.1 Location

This experiment was conducted in the Tournemire URL, located in the Aveyron Département, 15 km SSE of Millau. The Tournemire tunnel has its main entry point on the south side, in the Commune of Roquefort sur Soulzon. This entrance is connected to Departmental Highway D23 by a paved road about 1 km in length. The tunnel, which is 1,885 km long, has a fully concreted foundation. The SEALEX tests are located in the Gallery South_08 (see Figure 1). This area is accessible from the south via the paved road (in the tunnel) on the old railway sleepers.

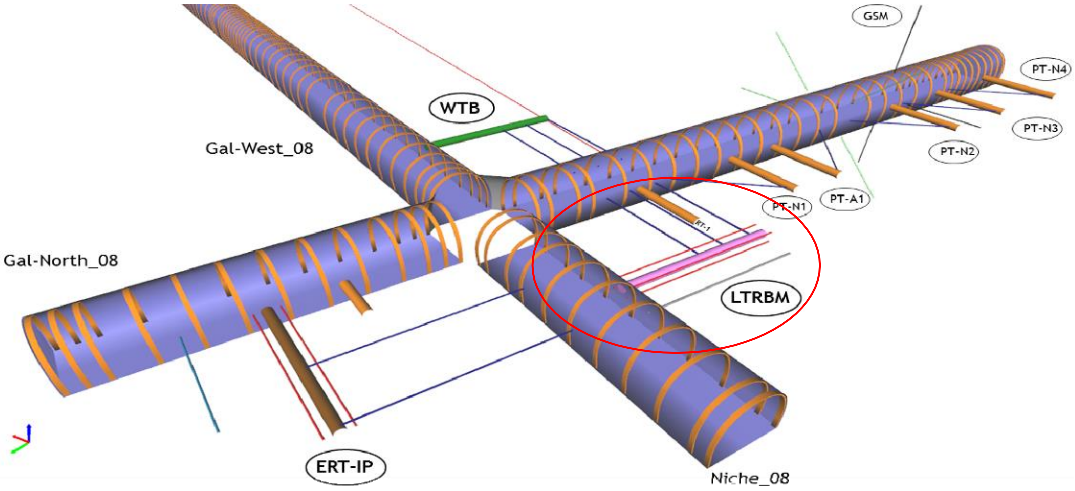


Figure 1. Overall view of the structures of the Tournemire URL and the area where the LTRBM demonstrator will be located (red circle)

The LTRBM is located close to the WTB of Modern 2020 (WP3), the electrical tomography test (ERT-IP) and the SEALEX experiments of Tournemire, see Figure 2, in order to take advantage of the services already available there: power supply, communications and the data acquisition system.

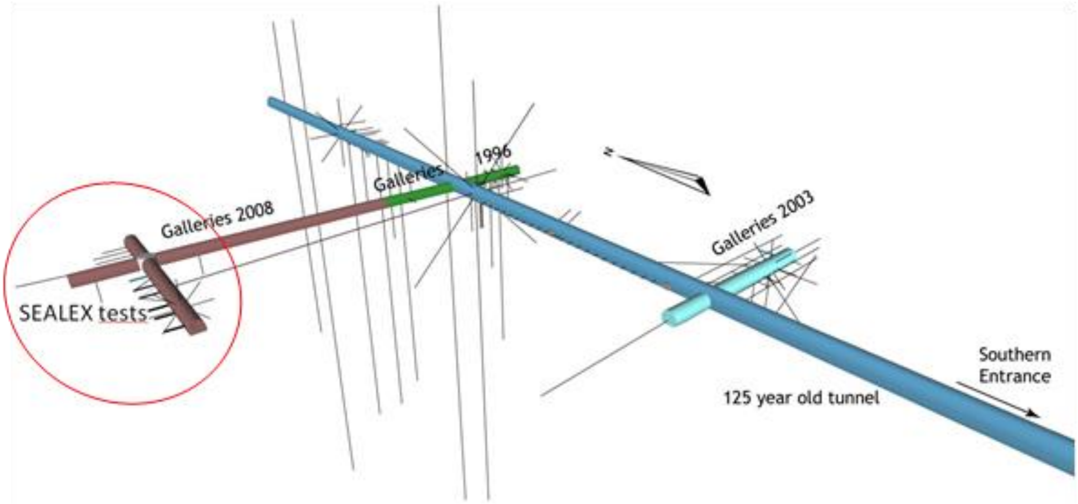


Figure 2. Location of LTRBM in Tournemire (source IRSN)

Several excavation damage zone (EDZ) features can clearly been see all around and along the MB. These features are associated with the construction of the borehole and more particularly to the natural ventilation of the galleries causing the development of desaturation fractures. These structures are oriented parallel to the bedding and have a radial extension of ~7 cm. A water injection experiment (located next to LTRBM) combined with numerical modelling has shown that these cracks when artificially saturated tend to seal after a few years thus enabling the permeability of the EDZ zone to decrease and eventually reach the low permeability values of the undeformed host rock (Thatcher et al., 2016).

2.2 In situ rock geology

The LTRBM boreholes were drilled in the Upper Toarcian shale formation of the Mesozoic sedimentary Causse basin (SW France). The shale features typical anisotropic textures induced by compaction and presents an average dip of the bedding of 10° with a dip-direction in the N330° direction.

The mineral composition of the host rock around the test is relatively homogenous a part from 5-10 cm thick layer formed by an ammonite-rich layer and a diagenetic carbonate rich nodule layer.

The mineral composition of the rock contains:

- 50% of clay minerals (illite and illite/smectite),
- mixed layers rich in illite (with 50 to 90% of illite (Tremosa 2010),
- 10% kaolinite,
- 5% chlorite and non-negligible amounts of quartz and carbonates (~15% each) mainly calcite but also dolomite and siderite as well as
- 5% of accessory minerals (pyrite, K-feldspar and organic matter).

The host rock exhibits very low permeability to saturated water flow (~10^{-22} – 10^{-21} m^2), significant porosity values ~11% (Dick et al. 2015) and post-excavation self-sealing characteristics (Thatcher et al., 2016).

The stress field in the vicinity of the test was defined with a series of leak off tests performed in a vertical borehole at 125 m from the current experiment. The stress regime is characterized with:

- σ_1=4 ±2 MPa, horizontal and oriented N162° ±15°,
- σ_2=3.8 ±0.4 MPa 7-8° inclined from the vertical in the N72° direction and
- σ_3=2.1 ±1 MPa 7-8° inclined from the horizontal in the N72° direction.

The pore water pressure in the vicinity of the newly excavated gallery varies between 840 and 860 kPa, the fluctuations coincide with seasonal variations (higher pressure in the summer and lower at winter).

2.3 Working conditions

The Tournemire URL galleries have the following environmental conditions:

- Humidity from 30% to 100% RH.
- Temperature between 10 °C and 17 °C (ambient temperature).

The sensors installed in the swelling core will have to withstand the following expected conditions:

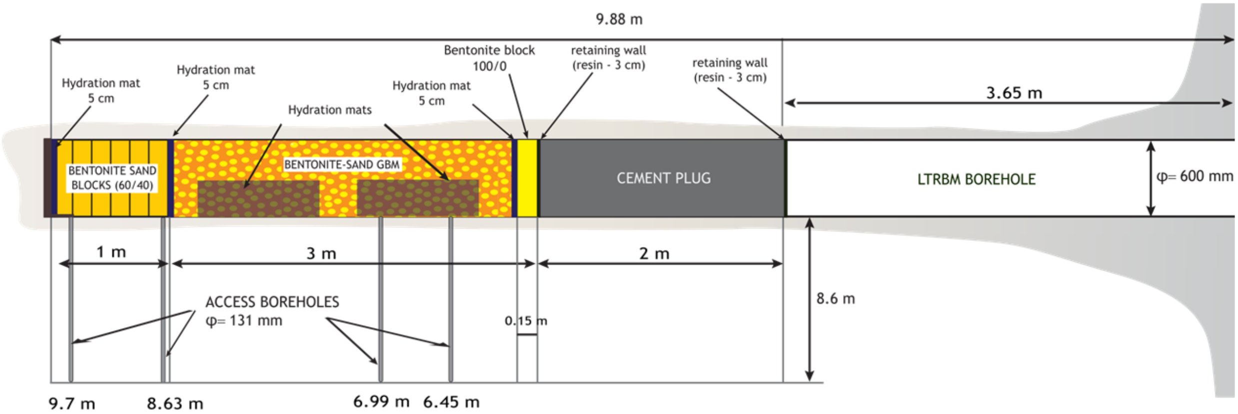
- A humidity of up to 100% RH (condensing) with presence of free salty water with time.
- A stress state of up to 2-3 MPa due to the bentonite swelling.
- A temperature of around 13 to 25 °C (Isothermal test).
- A pore pressure up to 0.15 MPa due to the hydration system.
- Duration of at least 5 years or up to their complete flooding (only for RH type humidity sensors).

2.4 General experiment layout

The general layout of the experiment,

Figure 3, consist of a main horizontal borehole (MB) measuring 60 cm in diameter and up to 10 m in length. The MB is parallel to the Gallery-South_08 and located 10m from the gallery's entrance. The MB was drilled from the Niche_08 (Figure 1) with an excavation direction towards 197°, the axis of the main LTRBM borehole is oriented obliquely (55°) to the strike of the bedding. The MB was backfilled with 4 m of bentonite-sand buffer, highly compacted bentonite-sand blocks and granular material based on bentonite, confined by means of 2 m long bentonite-concrete plug. The buffer was equipped with an independent artificial saturation system, composed by 5 hydration mats inside the MB connected to a water injection system, to accelerate the saturation of the buffer.

All the bentonite used was natural sodic Wyoming bentonite MX-80 type. The ratio Bentonite/sand was 60/40 at the blocks.



Granular Based Bentonite-Sand Material (GBM)

- Length 3 m, composition: 75% bentonite (MX 80-Expangel SP7) pellets and 25% sand. Target dry density pellets + sand:1.4 g/cm³

Cement plug

- 55% cement (Portland type IV) + 40% water + 5% bentonite (sodic)

Bentonite-Sand compacted blocks (moulds from SEALEX PT-N2)

- Diameter φ=560 mm, divided in 4 sections, length 1 meter
- Composition: 60% bentonite (MX 80) and 40% sand. Dry density 1.88
- 1 block 100% bentonite with a dry density of 1.5 g/cm3

Figure 3. General layout of LTRBM demonstrator

2.5 Bentonite buffer production

Bentonite is widely considered as a potential buffer material in most concepts for geological disposal of radioactive waste (Finland, France, Sweden and Switzerland). For industrial purposes two main bentonites exist: (i) the sodium bentonite which has the property to expand by absorbing as much as several times its dry mass in weight and (ii) the calcium bentonite which has the property to absorb ions in solution and has been widely used in industry as a cleaning agent. In this study, the widely used 'LAVIOSA BENTOSUND A100' natural sodium-rich bentonite was chosen as raw material for the LTBRM experiment.

2.6 Bentonite blocks

28 bentonite blocks were produced by Laviosa MPC using moulds from the PT-N2 SEALEX test (Barnichon et al., 2012), Figure 4. These moulds were ¼ disks designed with a groove and tongue (Figure 3A) to facilitate the emplacement and stability of the blocks inside the horizontal borehole. The discs dimensions are: 560 mm in diameter and 150 mm in width.

The blocks were compacted at Saint Etienne using a LAEIS HPF 1600 presse and were produced on June 6th, 2018. In order to ensure a fast hydration and a swelling pressure of at least 1 MPa, 24 highly compacted blocks were made from a bentonite/sand mixture in a ratio of 60/40 (in dry mass). In addition to these blocks, 4 blocks were made from pure bentonite (ratio of 100/0).

Figure 4. Bentonite buffer (Highly compacted ¼ blocks of bentonite and sand) used in LTRBM

The chosen production parameters were a water content (wc) of 11% and a compaction pressure of 28 MPa for the 60/40 mixture, and a wc of 15.7% and a compaction pressure of 13.3 MPa for the 100/0 mixture. The selected compaction pressure and wc for the 60/40 mixture resulted in an average dry density (dd) of 1.875 g/cm^3, whereas for the 100/0 mixture the average dd was 1.517 g/cm^3. Information about the different manufactured bentonite blocks is shown in Annex III.

After production, the blocks were stocked and wrapped tightly with plastic foil to prevent water absorption from the environment, which could have caused damaged. The blocks were then stored on June 25th 2018 in the Tournemire URL.

2.7 Granulated bentonite mixture

The granular bentonite mixture (GBM) was made from granular bentonite (75%) and sand (25%). The granular bentonite produced by Laviosa MPC under the commercial name Expangel SP7 consists of pellets of pure bentonite (each pellet has a 7 mm diameter).

The pellets, Figure 5, were industrially produced by instantaneously compacting a powder of the BENTOSUND A100 bentonite in a mould of 7 mm of diameter and 7 mm of height. The fabrication was done with a wc= 5% - 7% and at dd =1.998 g/m^3 - 2.12 Mg/m^3. The pellets were received in packages of 25 kg and wrapped with plastic foil to prevent any hydric absorption.

Figure 5. Bentonite buffer (Pure bentonite pellets) used in LTRBM

2.8 Main borehole

The test was emplaced directly in the host rock by means of a main borehole (Figure 6). As it was mentioned before, this borehole is horizontal (0 ± 2º), with a circular section of 60 cm in diameter (ϕ) and a maximum length (L) of 10 m. The rear end was not completely flat and some concrete was needed flatten the rear of the borehole (see chapter 4).

Figure 6: Photo of main LTRBM borehole

2.9 Auxiliary boreholes

In order to install the different wireless receptors, as well as to take out the cables of the wired sensors for connection to the DAS and to take in/out water tubes from the hydration system, it was necessary to drill nine auxiliary boreholes around the main one, parallel and perpendicularly to the MB, as is shown in Figure 7.

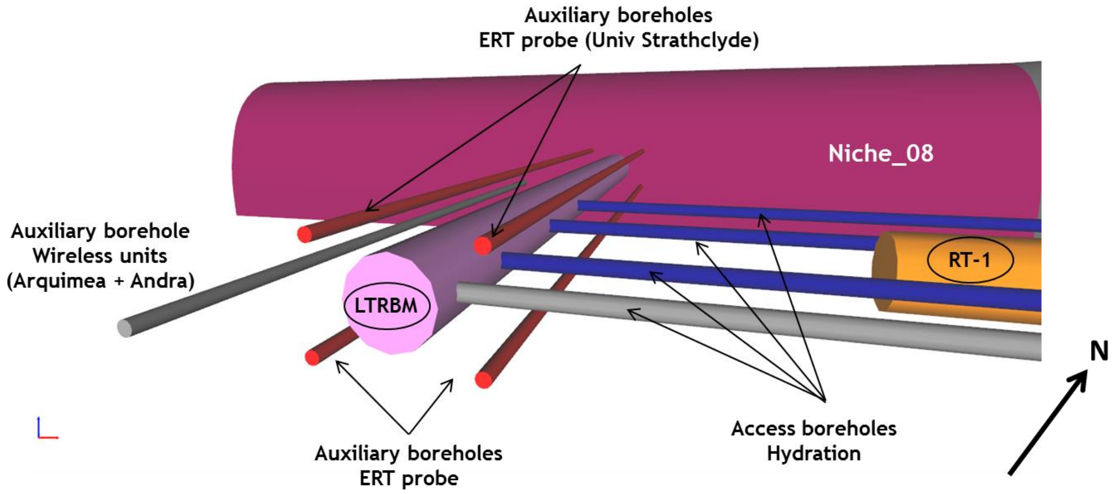


Figure 7. Overview of the auxiliary boreholes (source IRSN)

Four of these auxiliary boreholes were drilled concentrically at 50 cm, parallel to the MB, and were used to house 4 geophysical streamers for electrical resistivity tomography (ERT), Figure 8. Another auxiliary borehole was drilled parallel to the MB at a distance of 1.5 m to house wireless receivers.

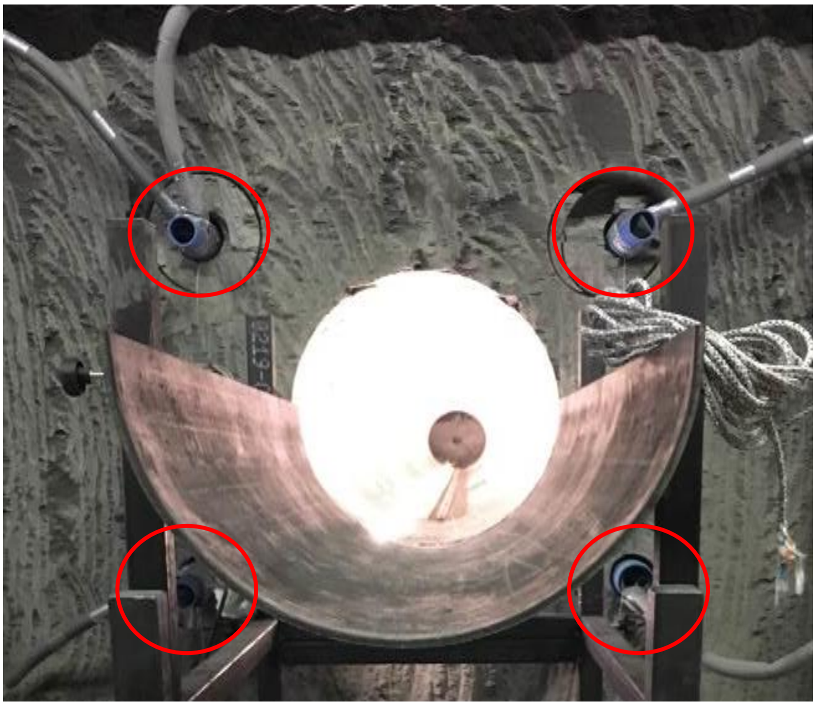


Figure 8. View of the four of the auxiliary boreholes drilled parallel to main borehole

The other four auxiliary boreholes were drilled perpendicularly to the MB and used to pass the hydration lines and sensors wired cables from the buffer to the hydration panel and data acquisition system, thus avoiding having the cables running through the buffer. The boreholes were PVC cased and cemented with a high performance resin to avoid any water flow inside the boreholes, Figure 9.

Figure 9. View of the access boreholes of the LTRBM drilled perpendicular to main borehole

2.10 Drilling chronology

The LTRBM boreholes were drilled between December 2017 and June 2018. The boreholes were drilled with a Hilti DD-780 and 600, 100 and 130 mm diamond core bits. The drilling sequence is as follows:

- Drilling of auxiliary boreholes (ERT) December 4th to December 15th 2017
- Drilling of main borehole (MB) from March 27th to April 27th 2018
- Drilling of access boreholes from May 14th to June 6th 2018

The drilling procedures for the MB consisted in:

(i) the drilling of a horizontal, 10m long and 101 mm diameter pilot borehole,

(ii) the overcoring of the pilot borehole with a 600 mm core bit,

(iii) after 40-45 cm of orovercoring, a hydraulic splinter was inserted in the pilot borehole and inflated to break the rock, (iv) the rock could then be removed from the borehole.

These successive operations enabled the drilling of a 10 m long 600 mm diameter borehole in 2 weeks. Once the drilling operations finished, the borehole was sealed from the gallery to prevent the development of hydric fracturing along the borehole.

2.11 Borehole casing

Inside the auxiliary boreholes, PVC tubes of 114 mm inner diameter and 3 m long were introduced, Figure 10. These tubes were coupled at the access gallery and pushed by hand one by one until the borehole was reached. The coupling of the tube was done with a special glue for PVC.

Figure 10. One PVC tube protruding from the access boreholes at SEALEX gallery side.

Caps were prepared and located at the end of PVC blue tubes, Figure 11, by the main borehole side with cable glands for the insertion and isolation of hydration tubes and sensor cables. With these plugs, the access boreholes should remain isolated from the main borehole that was filled with bentonite and water. The prepared plugs did not fit properly in the boreholes and they had to be changed in situ, the holes for the cable glands were made again.

At the section occupied by the bentonite blocks the caps were different from the one showed in Figure 11-A because they had to be installed inside the access borehole to enable the block package installation, see Figure 11-B.

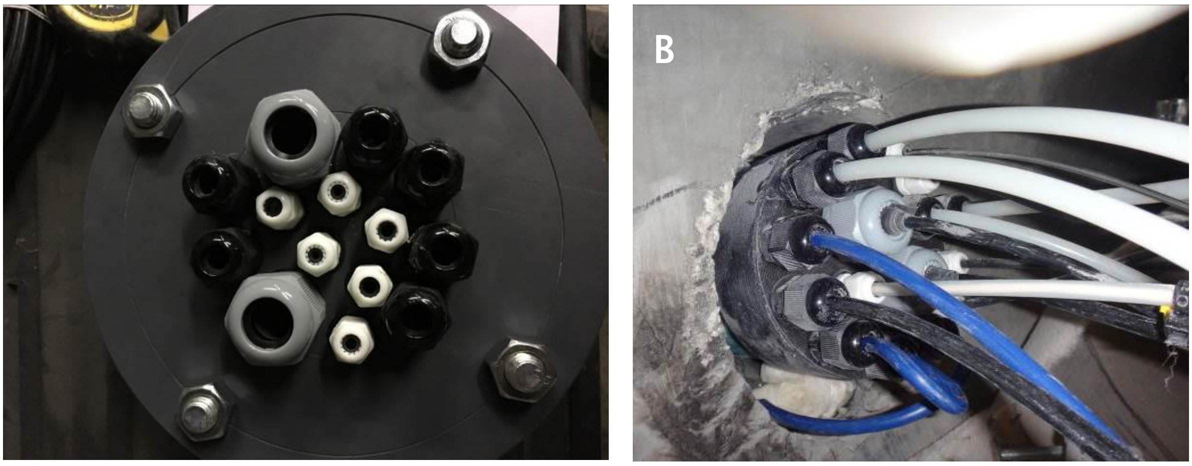


Figure 11.Different plugs for the access boreholes PVC tubes

When the total length of the PVC tube was inside the boreholes the caps installed and the cables passed by the glands, the gap between the rock and the tube was then filled with resin injected from the side of the MB, for a length of around 2-3m in length. The resin mixture was “Sikadur®-52 Injection Type LP”, with these characteristics:

- Solvent-free,
- Low viscosity injection-liquid,
- Based on high strength epoxy resins,
- Type LP (= Long Potlife) is used for substrate temperatures between +25˚C and +40˚C.

This mixture was prepared «in situ», Figure 12.

Figure 12. View of the resine mixture preparation

2.12 Hydration system

Two types of hydration “surfaces” or “mats” were installed inside the test. All of them were based on synthetic geotextile. The first type was a circular disk and three units were located in perpendicular to the borehole axis, two at both sides of the swelling core and one between the two types of bentonite material (blocks and GBM) close to the concrete plug. These mats were denominated MAT1, MAT2 and MAT5.

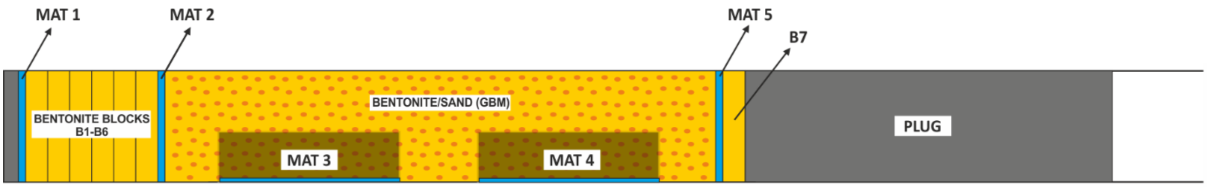


Figure 13. Location of MATS

The circular disk mats were fed with two perforated rigid plastic water distribution tubes (inflow and outflow ones) inside a rigid plastic grid, which were located within a geotextile coverage to avoid the intrusion of the bentonite inside. The total thickness of the “mats” was around 5 cm each, Figure 14. The rigid plastic grid allows each mat to contain around 10 l of water, thus enabling a substantial amount of water to be available within the buffer and therefore facilitating a quicker hydration of the buffer.

Figure 14. Photo of hydration mats used to hydrate the pre-compacted blocks
A- Hydration Mat 1 with 4 tube inlets (2 on top, 2 at the bottom). B- Rigid plastic mesh placed inside the geotextile mat.

The second type of hydration surfaces consists of two layers of geotextyle sandwiching the two perforated rigid plastic water distribution tubes (inflow and outflow ones) inside, MAT3 and MAT4, each one 1-m long,

Figure 13.

At the gallery, the hydration "mats" were connected to a water distribution panel, located on the gallery wall next to the main borehole mouth. Each MAT can be managed separately from the others, Figure 15.

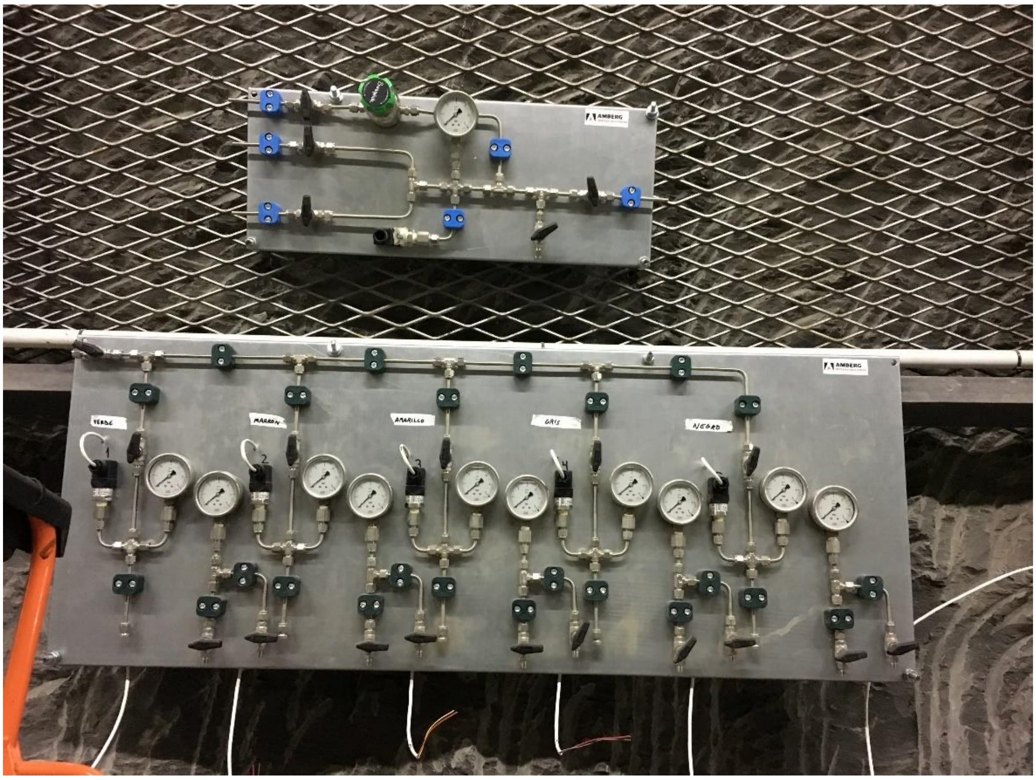


Figure 15. Hydration panel view

In this general hydration panel, the inlet/outlet water to the different mats is controlled with manual valves and the fluid pressure of the main line and the different inlet fluid pressures of the mats, denominated as "injection pressure" and "hydration pressures" respectively, are measured and stored in the DAS of the LTRBM system. This panel also contains valves to drain the air from the different mats. Figure 16 shows a basic scheme of the hydration system.

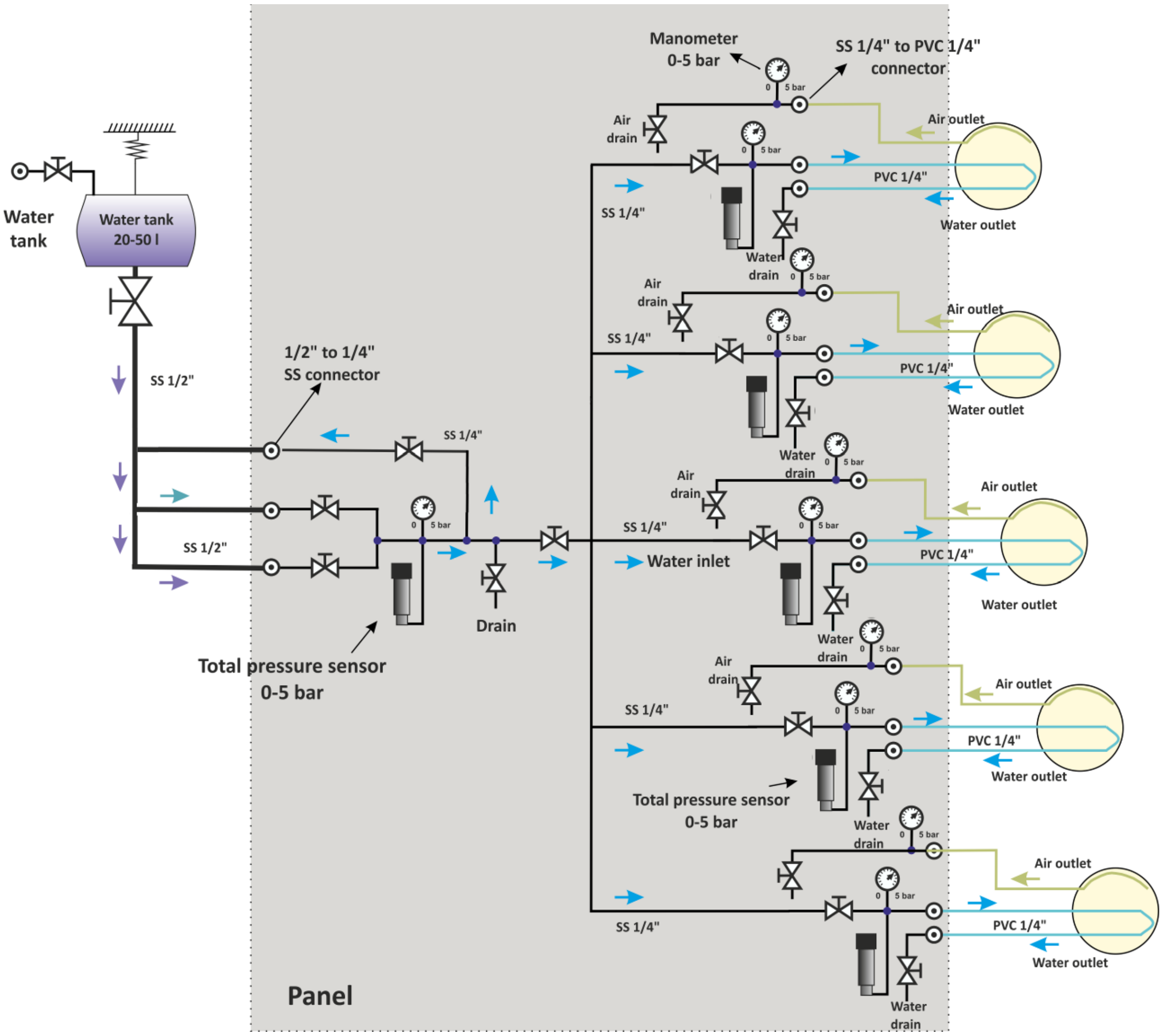


Figure 16. Scheme of the LTRBM hydration panel

The swelling core is being hydrated with synthetic water representative of the Callovo-Oxfordian argillite at Bure, already used for SEALEX tests, whose chemical composition is given in Table 1.

Table 1. Chemical composition of pore water used in SEALEX tests

Salt	Molar mass [g/mol]	Concentration [mol/l]
CaSO4 2H2O	169.17	7.60E-03
NaHCO3	84.01	4,20E-03
MgSO4 7H20	246.47	5,90E-03
KCl	74.56	8,99E-04
Na2SO4	142.04	5,50E-03
NaCl	58.44	4.00E-03

2.13 Cement plug

The bentonite buffer section was confined by the rock at the rear side and by a concrete plug at the entry. However, the rear end of the main borehole was flattened with a thin layer of cement, about 2 cm thick (upstream). At the entry side (downstream) a 2 m long cement-bentonite frictional plug was built, intended to keep the bentonite mechanically confined and avoid the saturation water to excape from inside.

To build the concrete plug two retaining walls, made of high-density polyethylene, were emplaced at both sides as forms to keep the concrete during the curing/hardening phase

3. DESCRIPTION OF THE INSTRUMENTATION INSTALLED

3.1 Non FO instrumentation from WP3

3.1.1 Chemical sensors (VTT)

In general, the ion-selective electrodes are based on measurements of potential difference between an ion-selective electrode and a reference electrode. Potential difference is measured by voltimeter (input resistance ~1 Tera Ohm, input Bias current lower ~0.1 Pico amperes).

A resistent plastic probe which included the three measuring electrodes (pH, Eh and Cl), and the same reference electrode was installed (CHPH, CHEH, CHCL). The length of each electrode is 50 mm and diameter about 1 mm. The maximum length between sensors and reading unit have to be about 1.5 m. This probe was installed in the bentonite block 1, Figure 17.

The signals from these three electrodes (pH, Eh and Cl), in mV, were connected to a conventional datalogger, the same used for the reading of the conventional sensors installed for comparison.

Figure 17. View of the probe installed with the three electrodes from VTT

3.1.2 THMC smart sensor (CTU)

A Smart Cell probe (THMC) which included: Total pressure, Pore Pressure, RH and Temperature signals, developed by CTU was installed in bentonite block 7. The ranges of the different sensors were adjusted in function of expected conventional sensors placed nearby.

The main characteristics of this sensor are given in Table 2.

Table 2. Characteristics of FO total pressure sensor

Pressure Range	Up to 7 MPa
Accuracy	± 0.1% F.S
Temperature Range	−20 to +85 ℃
Dimensions	Outer diameter: 80 mm, Height: 30 mm Length of metal connection: 360mm
Power supply	7-16V DC with a load of 100 mA (250 mA of peak value)
Cable	5-6 mm O.D. Maximum cable length should be 50 m at least. It depends mostly on interface used (SDI-12 should work for 50m while RS-485 with around 100m).
Communication	RS485->ETHERNET

The communication between the control PC and this device was RS-485/Ethernet, a program provided by CTU will collect the data obtained dron this communication line.

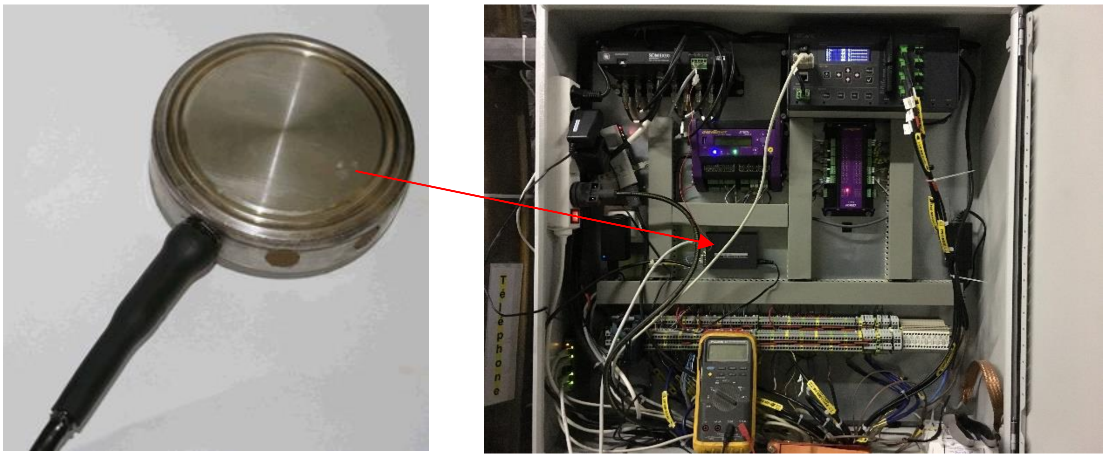


Figure 18. View of the Smart Cell (THMC) and the communication RS-485/Ethernet device installed

3.1.3 New Thermocouple Psychrometers (ARQUIMEA)

The suction of the bentonite is being measured by a new thermocouple type psychrometers using dew point method, this sensor (RHPD) has been developed by Arquimea and there were installed four units in Block 2 and MAT4, Figure 19.

The dimensions of these sensors were 18 to 20 mm in diameter and 60 mm in length.

Figure 19. View of two of the new Thermocouple psycrometer (RHPD) sensor installed

3.1.4 Electrodes for ERT/IP measures (U. Strathclyde)

Geophysical electrical monitoring measurements were used to measure in a non-intrusive way the changes in water content within the bentonite buffer. These measurements were conducted using four elctrical resistivity probes developped and installed by IRSN, Figure 19. Each probe measures 9 meters in length and contains 32 copper electrodes.

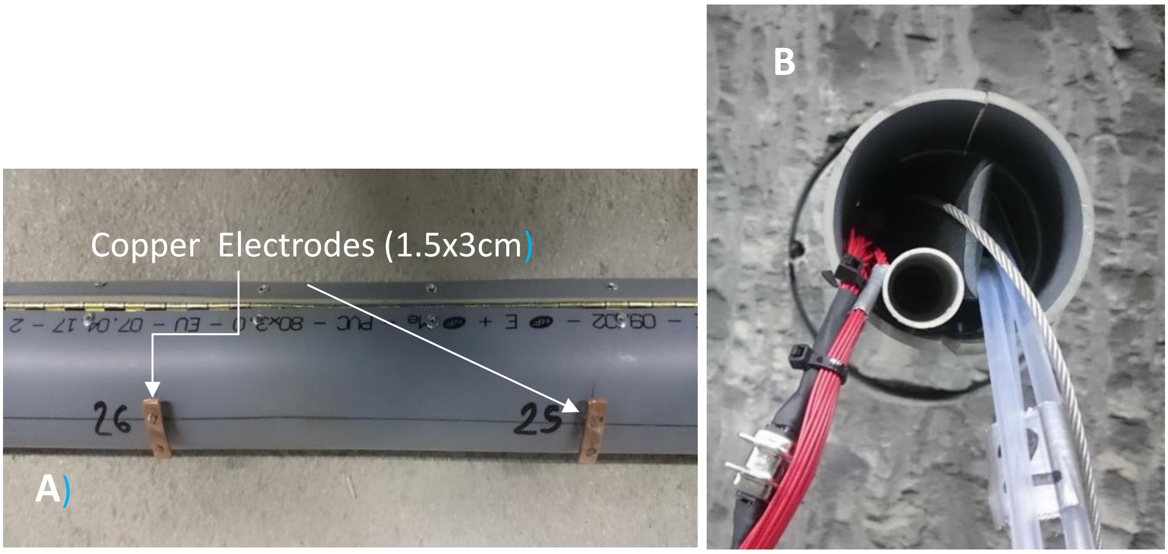


Figure 20. View of the electrical resistivity probe. A- shows two copper electrodes attached to a PVC tube. B- The PVC tube is cut in half and is maintained together with rivets, three 3-meter long bladders were implaced in the PVC tube and inflated allowig a good and continuous contact between the electrode and the rock.

3.2 FO instrumentation from WP3 (PARTNERS)

3.2.1 Total pressure (ANDRA)

Total pressure sensors based on fibre optic technology (white light) manufactured by Opsens and adaptated for this installation were installed in the bentonite blocks 0 and 4, Figure 21. The sensor was developed to be embedded into concrete, never was used with bentonite before this experiment. The range is higher than expected pressure in the test, so sensitivity will decrease.

The main characteristics of this sensor are given in Table 3.

Table 3. Characteristics of FO total pressure sensor

Pressure Range	Up to 7 MPa
Accuracy	± 0.1% F.S
Temperature Range	-20 to +85 °C
Dimensions	Outer diameter: 60 mm, Thickness: 20 mm Length of metal connection: 360mm
Material	Invar
Cable	4mm O.D. rugged tight-buffered fiber optic cable with aramid strength member and polyurethane jacket

Figure 21. View of the FO Total Pressure sensor, TPFO, installed

3.2.2 Deformation and temperature (IRSN)

A fibre optic sensor (strain) was installed along the cement plug, Figure 22.

The main characteristics of this sensor are given in Table 4.

Table 4. Characteristics of FO total pressure sensor

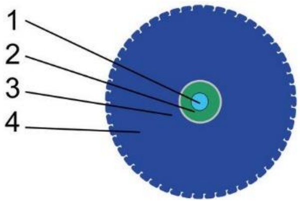
Manufacturer/Model	BRUGG, Brusens v9
Strain Range	Strain range up to 1% (10000 µstrain)
Temperature Range	-30°C to 70°C
Specifications / dimensions 	(1)The cable (1) contains a bending loss insensitive single mode fibre with a multilayer buffer and strain transfer layer with interlocking system, which is embedded inside a low carbon steel tube (2) for protection and hermetic seal (external diameter approx. 0.9 mm). The tube is encapsulated in a polyamide outer sheath with a nominal external diameter of 3.2 mm (3): the external surface is characterized by 0.7 mm deep indentations with a regular interspace of about 5 mm, to assure a good grip with the materials in which it is buried.
Cable	1 single mode, bonded core, 3.2mm O.D. Minimum Operational Bend Radius: 4.8cm
Weight	10,5 kg/km
Max. tensile strength	260N
Typical Load at 1% elongation	470 N

Figure 22. View of the FO strain installed

3.3 Wireless units

3.3.1 Pore water and SAKATA transmitter (ANDRA)

There were 2 pore water pressure sensors, PPWL; based on vibrating wire extensometer linked to a wireless transmission system manufactured by Sakata Denki (Japan). They were tested in Andra´s URL up to 20m in borehole with success. These sensors and transmitters were installed in the bentonite block 1 and inside the GBM, Figure 23.

The main characteristics of these sensors are given in Table 5.

Table 5. Characteristics of WL pore pressure sensor

Model	Based on EPZ, Vibrating Wire type
Pressure Range	0-300, 0-500, 0-1000, 0-2000, 0-3000, 0-5000 kPa (abs)
Accuracy	2 x 10^{-3} FS
Dimensions	Outer Diameter: ~50 mm Lenght: 190 mm
Material	Bronze
Filter	10^{-3} cm/s (bronze) 10^{-7} cm/s (ceramic)

The wireless transmitter was placed nearby the sensor, Figure 23.

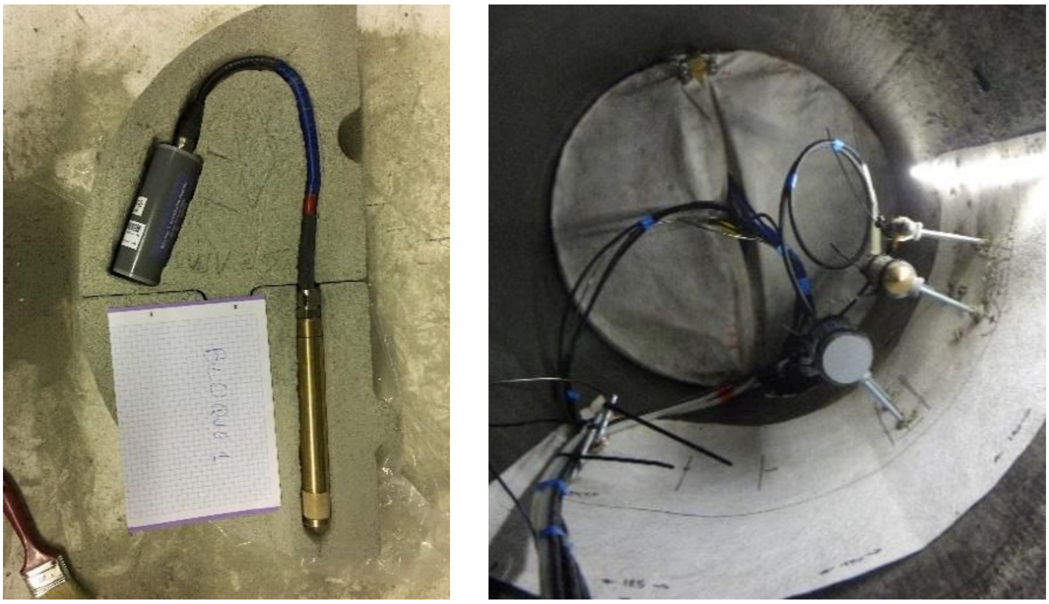


Figure 23. View of the Pore Pressure sensors and SAKAKI wireless transmitters installed

3.3.2 Short range (ARQUIMEA)

Two wireless units manufactured by Arquimea were installed inside the main borehole, one in the bentonite block 2 and the second unit inside the GBM, Figure 24, a wireless receptor was installed outside the main LTRBM borehole.

Four different conventional sensors were connected to each WL units installed in block 2 and GBM: two conventional Relative Humidity sensor RHPD, one conventional Pore Pressure sensor PPCO and one capacitive conventional Relative Humidity sensor RHCO.

The main characteristics of these wireless units are given in Table 6.

Table 6. Characteristics of Arquimea WL units

Analoge input ranges	Up to three inputs I2C type and adapted to Temp/RH Sensirion type sensors – 20 mA max Up to four V/I (0.4-2 V//4…20 mA) analogic inputs - supplied power not yet fixed.
Dimensions	76 mm in diameter, 320 mm in length
weight	2,5 kg

Figure 24. View of the Arquimea wireless transmitters installed

Figure 25. View of the Arquimea&SAKATA wireless receptors installed

3.3.3 Long Range (NRG)

This system will be used to transmit different data stored in a computer to the outside. The system consists of:

- A wireless transmitter unit to be place in the northern part of the main tunnel of Tournemire URL, ±1230 m from southern entrance, ±660 m from northern entrance, at 524.65 m a.s.l.
- A wireless receiver unit to be place on top of the transmitter, next to road/track, at about 795 m a.s.l.
- Estimated transmission distance: 270 m

The plan is to install the system in Tournemire temporaly and desinstall when the system had been tested.

The transmitter antenna will be placed in the northern part of the tunnel, ±1230 m from southern entrance, at about 525 m a.s.l. The receiver antenna will be situated on top of the transmitter, 13 m north of a track, at about 795 m a.s.l. (GPS coordinate: 43˚59.312' N, 3˚00.920' E). Estimated transmission distance is 270 m.

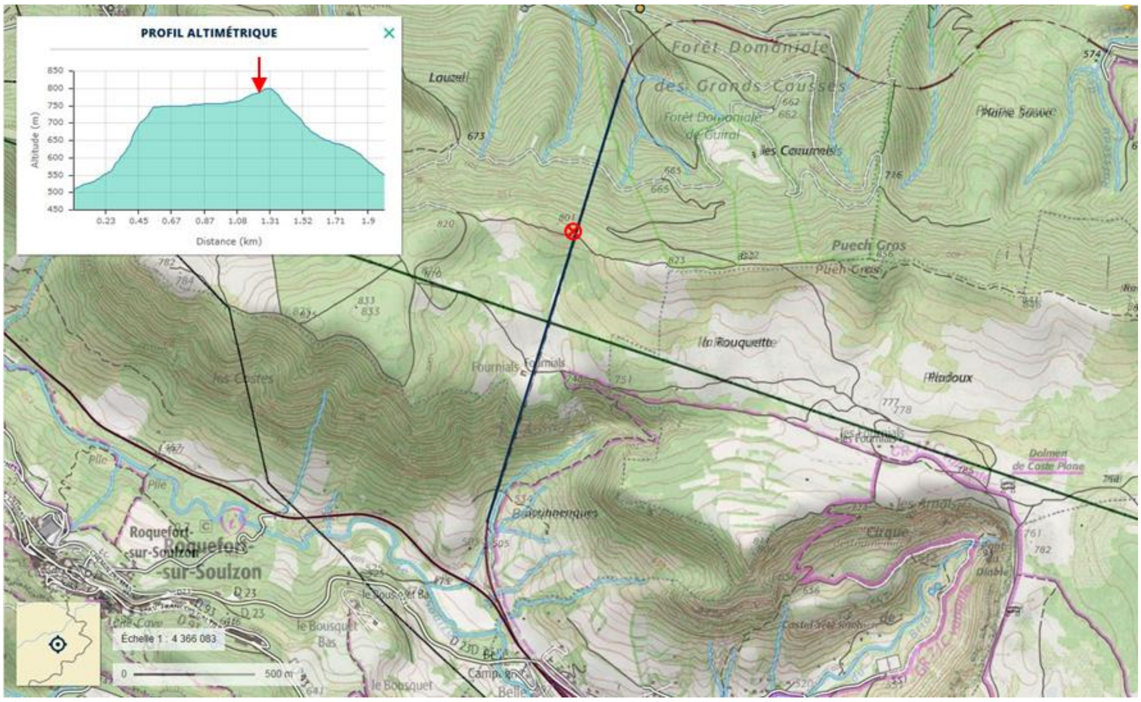


Figure 26. Top-down view of the transmitter and receiver locations and the cross-section along the tunnel

NRG performed measurements on 4th of July 2017 that confirmed the suitability of the surface (and subsurface) suggested locations despite the abundance of some (subsurface and surface) power lines.

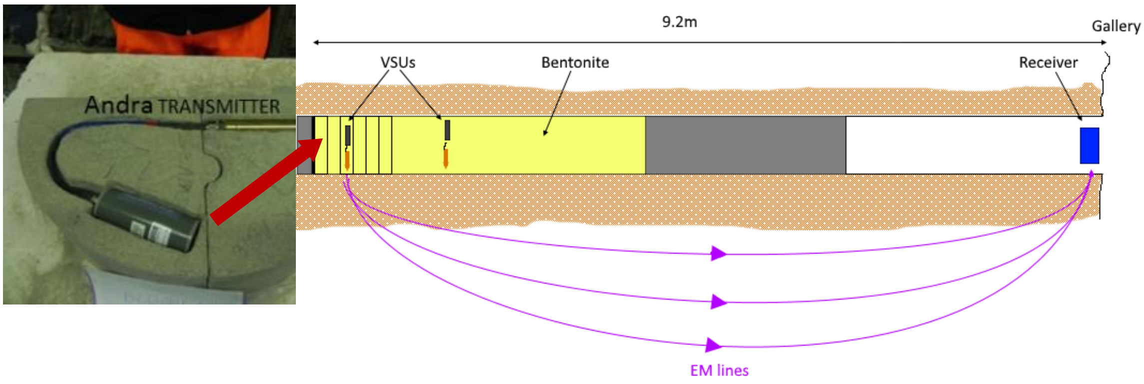


Figure 27. Andra's vibration sensor node and its location in the LTRBM borehole

3.3.4 Combined system (AMBERG, ARQUIMEA & NRG)

The data gathered by the short-range wireless system will be transferred, directly to the local DAS an when needed the data will be shared with the transmitter of the long-range wireless system to make them available at the surface, Figure 28.

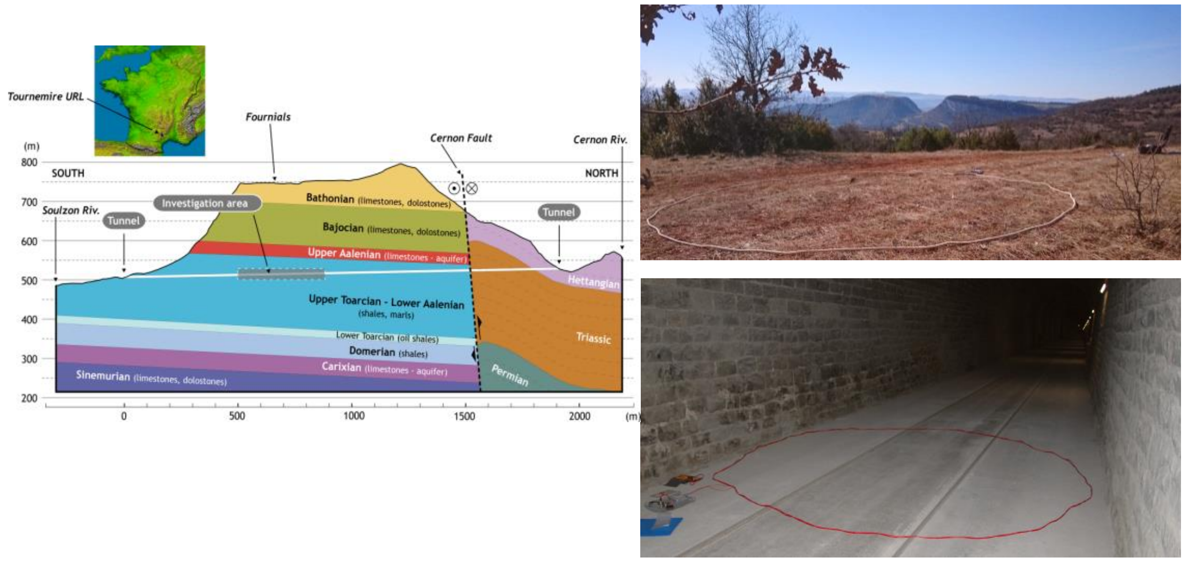


Figure 28. Cross section of the Tournemire tunnel and location of NRG's long range transmission system

3.1 Other wired instruments

3.1.1 Miniature piezoresistive pore pressure sensors

Three conventional absolute pressure type transducers, PPCO, were installed to measure the pore water pressure in different locations of the swelling buffer and in particular nearby the new pore pressure sensors. They were installed in Block 2 and inside the two sensors zones of the GBM, Figure 29.

The main characteristics of these sensors are shown in Table 7.

Table 7. Characteristics of water pressure sensor for pore pressure

Pressure Range	0 to 0.5 MPa (abs)
Accuracy	± 0.25% FS

Dimensions	OD. 20 mm; 73 mm length
Excitation	8…32 V DC
Output	4 -20 mA/ 2 wire
Material	Stainless steel 316
Operating Temperature	-40 to 80 °C
Comp. Temp. Range	-10 to 80°C
Cable	PE jacketed O.D. 5.8 mm
Filter	TBC

Figure 29. View of one of the conventional pore pressure sensors, PPCO, installed

3.1.2 Piezoresistive total pressure cells

Five conventional total pressure sensors, TPCO, were installed to measure the swelling pressure of the bentonite core in the different points of the buffer and in particular nearby the new total pressure cells to test. They were installed in Block 0, Block 3 and Block 7, Figure 30.

The main characteristics of these sensors are shown in Table 8.

Table 8. Characteristics of total pressure cell

Measurement principle	Semiconductor transducer
Range	0 to 3 MPa
Over range capacity	150% FS (max)
Output	Vibrating wire (Hz)
Accuracy	+/- 0.5 % FS
Excitation Supply	10 V DC maximum

Case material	AISI 316 Stainless steel
Dimensions	Diameter: 66,7 mm; Thickness: 12.5 mm
Transducer Dimensions	170x16 mm (LxØ)
Cable	Mineral insulated up to 5m in length maximum and transition to PVC jacketed cable. Outer diameter: 4.7 mm

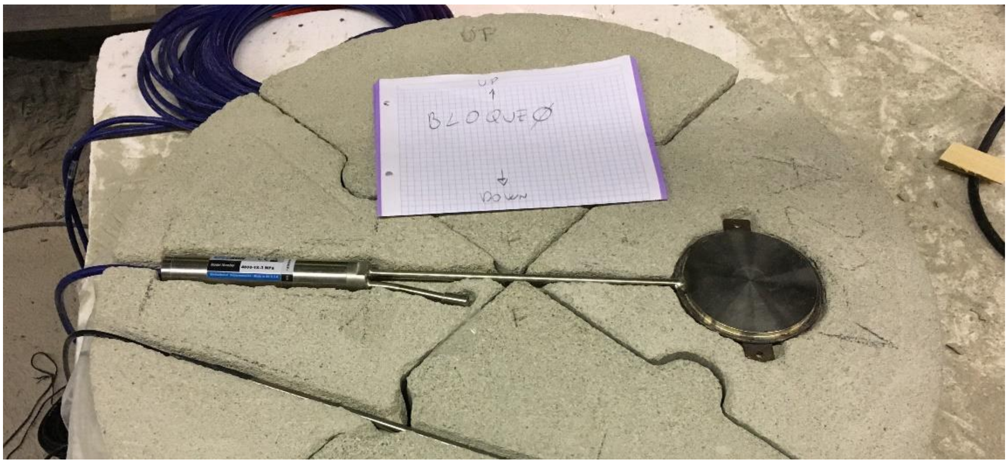


Figure 30. View of one of the conventional total pressure sensors, TPCO, installed

3.1.3 Capacitive type hygrometers

Two custom made sensors based on a commercial chip were installed, measuring both relative humidity and temperature, in block 2 and MAT4.

The electronic circuit of the sensing element is located in a stainless steel body and protected from humidity by means of epoxy resin. The sensing element is mechanically protected with a steel filter, Figure 31.

The characteristics of these sensors are listed in Table 9.

Table 9. Characteristics of relative humidity sensors

Measurement principle	Capacitive
Relative humidity range	0 % to 100% R.H.
Temperature range	-40 °C to 124 °C
Output	digital 12 bit/14 bit
Resolution	0.03% R.H. /0.01 °C
Dimensions	Diameter: 12 mm; Length: 87 mm

Construction	Stainless steel with steel filter
N° of wires	4 x 0.5 mm2
Cable sheat	Teflon jacketed. Screen threaded cable
Cable characteristics	4x0.3 mm2, Ø2.2mm ,Teflon insulated
Cable entry	Epoxy potted. Tight up to 35 barg (up to 155 °C)

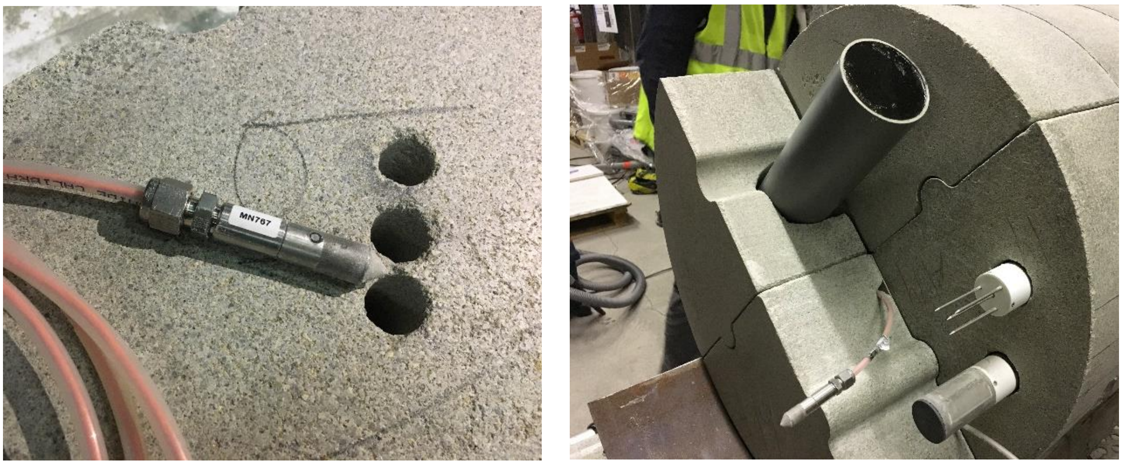


Figure 31. View of one of the conventional Relative Humidity sensors, RHCO, installed

3.1.4 Soil water potential sensors (automatic tensiometers)

Three sensors were installed to measure the evolution of bentonite suction, RHTN. These sensors were installed in bentonite blocks 2 and 6 and inside the GBM, Figure 32.

The main characteristics of these sensors are shown in Table 10.

Table 10. Characteristics of Automatic tensiometers

Type	Soil water potential (matric potential)
Model	EQ3
Range	0 to −1000kPa
Accuracy	± 10 kPa over 0 to -100 kPa 10% of reading over -100 to -1000 kPa
Power	5–14 V DC, 18 mA for 1s
Output	0–1 V DC
Sensor dimensions	181 x 40,5 mm lxØ
Cable connection	Epoxy potted output

Case material	PVC protected with SS316L casing. IP68
Diameter of cable	3 mm Teflon jacketed
Cable protection	SS316L or PEEK tubing ¼" OD if required

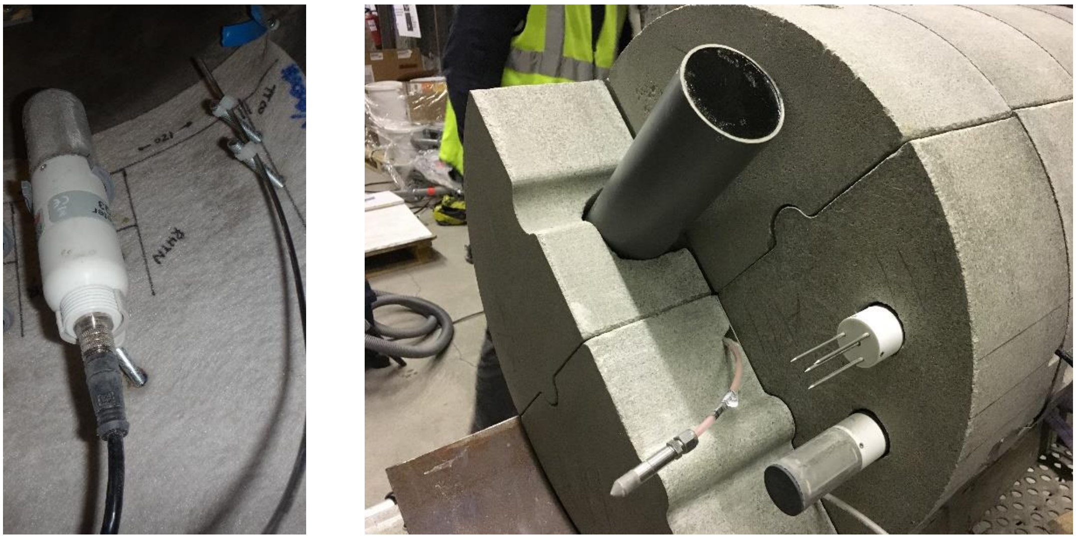


Figure 32. View of one of the conventional soil water potential sensors, RHTN, installed

3.1.5 FDR type water content sensors

Three sensors were installed to measure the volumetric water content in the bentonite is based on the FDR (Frequency domain reflectometry) technique, RHFR. These sensors were installed in bentonite blocks 2 and 6 and inside the GBM,

Figure 33.

The main characteristics of these sensors are shown in Table 11.

Table 11. Characteristics of Soil Moisture sensors (FDR)

Type	Volumetric water content
Model	ML3
Range	0–1000 kPa
Accuracy	± 0.01 $m^3.m^{-3}$ (1%) with soil-specific calibration
Power	5-14 V DC, 18 mA for 1s
Output	0-1 V DC
Accuracy	+/-1%
Sensor dimensions	172 x 40 mm lxØ
Cable connection	Epoxy potted output
Case material	PVC protected with SS316L casing. IP68

Diameter of cable	3 mm Teflon jacketed
Cable protection	SS316L or PEEK tubing ¼" OD if required

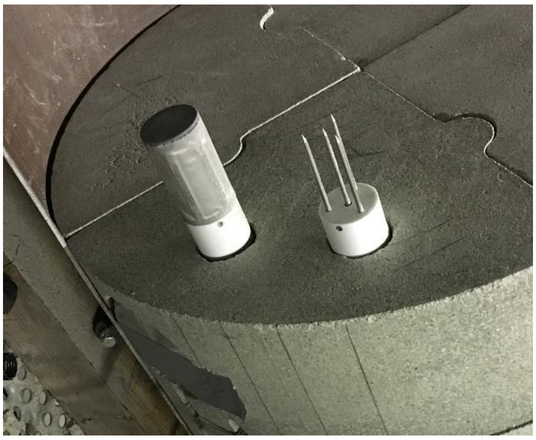



Figure 33. . View of one of the conventional FDR sensors, RHFR, installed

3.1.6 Wescor psycrometers

The suction of the bentonite given by the new psychrometers using dew point method will be compared with standard thermocouple psychrometers measuring by psychrometric method. Two of these sensors type were installed in Block 2 and MAT 4.

The characteristics of these sensors are listed in Table 12.

Table 12. Characteristics of psychrometers

Temperature range	-200/350 °C
Humidity range	95 % RH to 99.96 % RH
Suction range	50 to 7000 kPa
Output signal	Two analogue outputs (μV). 0.47 μV/bar
Filter	Ceramic filter
Probe material	Teflon-vinyl
Cable connection	Welded and epoxy sealed
N° of wires	1 cable with 3 conductors, PVC insulation
Diameter of cable	3.8 mm
Sensor dimensions	Diameter 6 mm, length 30 mm

Figure 34. View of one of the conventional Relative Humidity sensors, RHPS, installed

3.1.7 Displacement sensors

Two conventional LVDT displacement sensors, Figure 35, were installed at the concrete plug face, in perpendicular position, in order to measure the potential movements of the plug in this direction.

The main characteristics of these sensors are shown in Table 13.

Table 13. Characteristics of displacement sensors

Measuring Principle	LVDT
Range	± 5mm
Accuracy	<±0.25% FS (0.04 mm)
Excitation	5V rms, 5kHz (sinusoidal)
Operating temperature	-40ºC to 125ºC
Dimensions	253 mm long, Ø20.6 mm
Casing	SS316L
Cable	Polyurethane

Figure 35. View of one of the conventional LVDT sensors, DSCO, installed

3.1.8 Hydraulic pressure sensors (Fluid pressure)

Five conventional absolute pressure type transducers were installed to measure the water pressure in the different lines of the hydration system, Figure 36.

The main characteristics of the pressure transducers installed are shown in Table 14.

Table 14. Characteristics of water pressure sensor for Hydration system

Pressure Range	0 to 5 bar (rel)
Linearity + Hysteresis + Repeatability	typ. ± 0.01 bar, max. ± 0.025 bar
Stability Range> 2 bar	typ. 0.05 bar, max. 0.01 bar
Stability, Range < 2 bar	typ. 0.001 bar, max. 0.002 bar
Output	4 - 20 mA / 2 wire
Material	Stainless steel
Operating Temperature	-40 ºC to100 ºC
Comp. Temp. Range	-10 to 80 ºC

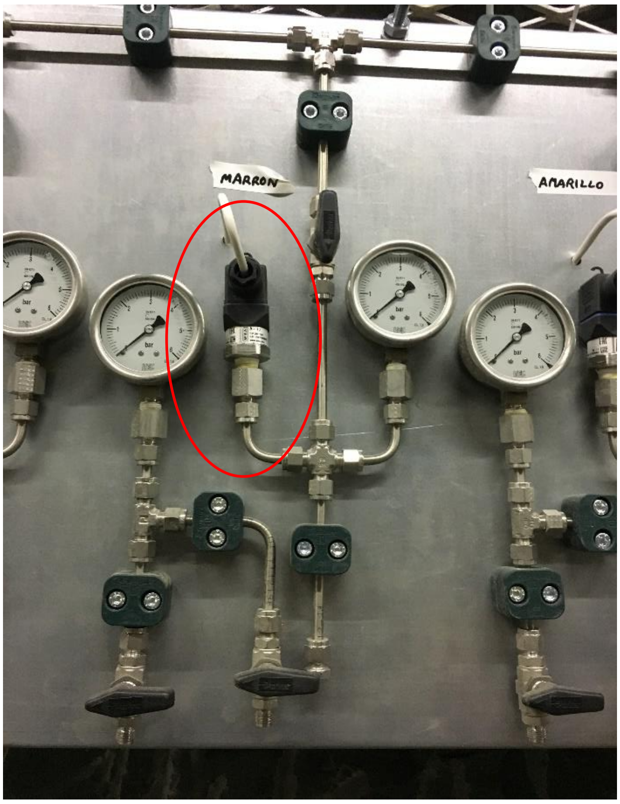


Figure 36. View of one the conventional fluid flow sensors, FFCO, installed in the hydration panel

3.1.9 Weight/Volume sensor

The tank level and water flow is monitored using a weight transducer conected to an industrial weighing machine, Figure 37. This system was used also to measure the weight of the bentonite blocks installed, before and after the machining. This weight transducer includes display and one output to communicate with the control PC via RS-232.

The main characteristics of these devices are shown in Table 15.

Table 15. Characteristics of weighing machine and weight transducer

Weighing machine model	**Baxtran BMM**
Nominal load	Up to 150 kg
Accuracy class	C6 (6000d)
Accuracy	10 gr
Approvals	OIML, NTEP, Ex
Tolerance on sensitivity	± 0.05 %
Output	RS-232
Protection class	EMC approved. IP 54
Material	Stainless steel
Display model	**Baxtran BR15**
Protection	IP54
Units	Configurable: lb, gr, lboz
Output	RS-232
Power supply	230 VAC adapter

Figure 37. View of the weighing system (left), MVCO (right), installed

3.1.10 Temperature sensors

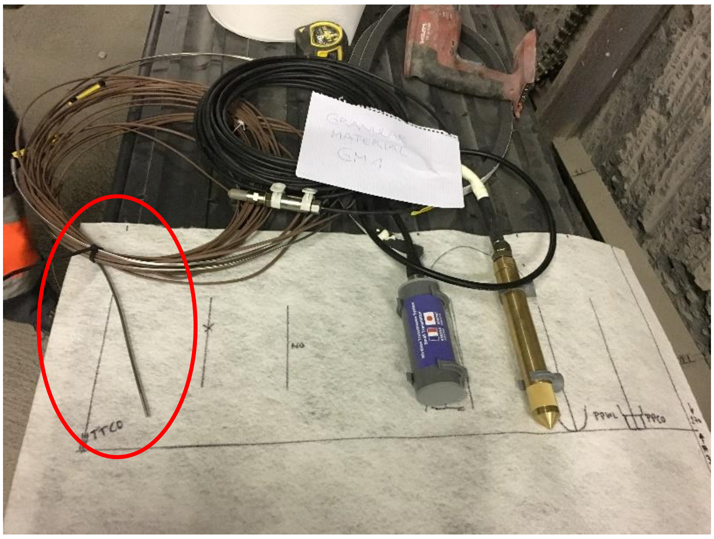
Four thermocouples, T type, were installed at different locations of the betnite buffer: Block2, Block 6, MAT 3 and MAT4,

The main characteristics of these sensors are shown in Table 16.

Table 16. Characteristics of temperature sensors

Measuring Principle	Thermocouple type T
Range	-200 to 400 ºC
Accuracy	0,5ºC
Dimensions	Ø 3 mm, length to be determined
Casing	SS316L
Cable	Mineral insulated and transition to plastic cable

Figure 38. View of one of the thermocouples installed



3.2 Geophysical systems (IRSN & U. Strat)

This technique does not require the installation of any sensor inside the main borehole. It is a non-intrusive technique that requires four boreholes, as illustrated in Figure 39 and detailed in Table 17. Each borehole was equipped with 32 copper electrodes spaced at 0.27m within an inflatable PVC tube (Figure 40), designed and manufactured by IRSN team. The inflatable system ensures contact between the electrodes and the borehole wall, as the injection of water into the boreholes would potentially disturb the resistivity of the study area and would, hence, be out of the question for this experiment.

It is important that metallic materials are kept to a minimum within the experiment area to avoid significant interferences with the electrical field.

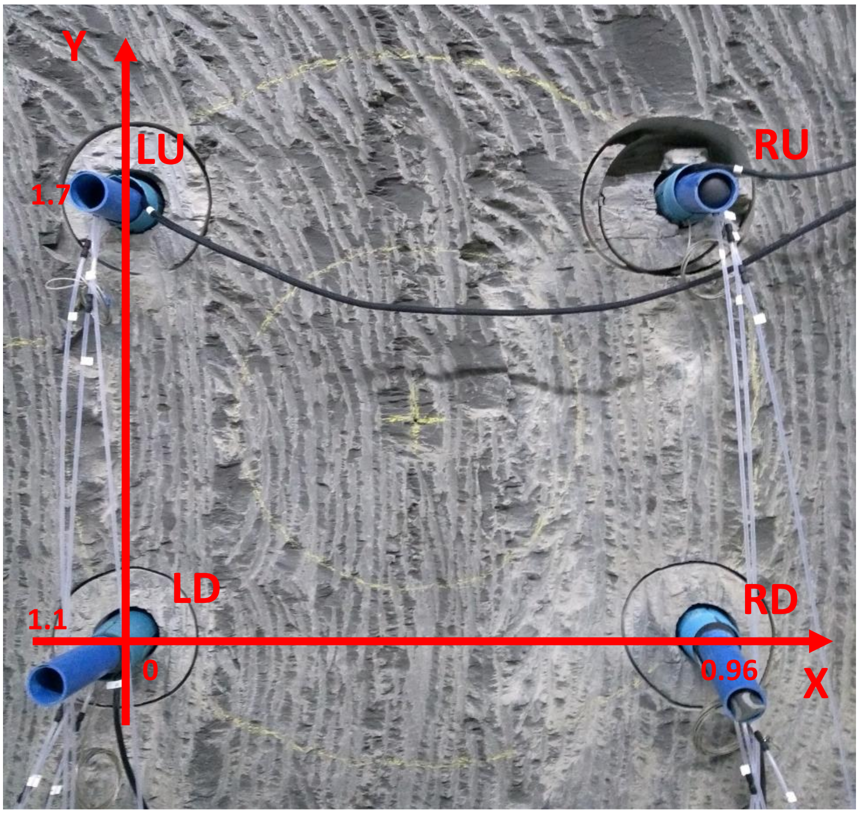


Figure 39. Layout for geophysical boreholes (Auxiliary boreholes)

Table 17: Geophysical boreholes characteristics

Borehole ID	LU	RU	LD	RD
Diameter [m]	0.10	0.10	0.10	0.10
Position, X [m] from left to right	0.00	0.96	0.00	0.96
Height, Y [m] from floor slab	1.70	1.70	1.10	1.10
Length, Z [m]	9.19	9.19	9.08	9.09
Distance from gallery wall to the 1st electrode [m]	0.117	0.097	0.077	0.074
Number of electrodes installed	32	32	32	32
Spacing between electrodes Z [m]	0.27	0.27	0.27	0.27

LU = Left Up; RU = Right Up; LD = Left Down; RD = Right Down.

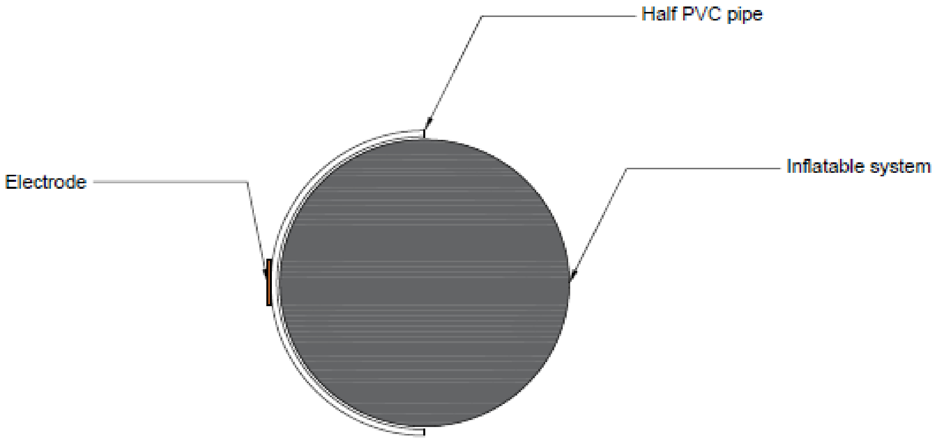


Figure 40. Scheme of the electrode set-up developed by IRSN.

Seven TDR soil probes produced by Campbell Scientific were installed within the GBM. They consisted of 7.5 cm long stainless-steel rods connected to a printed circuit board. The circuit board was encapsulated in epoxy and a shielded cable was attached to the circuit board for datalogger connection. The cable length is 15 m. A radial coordinate system has been adopted as reference to the 3D positions of the sensors inside the MB, as showed in Figure 41. Table 18 shows the location of the sensors according to the reference system.

Figure 41: Reference coordinate system, where the origin (O) of the coordinate system is located at the intersection of the MB axis with the plane containing the borehole entry, Radius (r): Radial distance from the sensor centre to the axis of the MB, Angle (α): Clockwise angle from the vertical diameter and Depth (d): Distance from the origin of the coordinate system along the axis.

Table 18: Theoretical location of TDR sensors

Sensor name	r (m)	α (°)	d (m)
TDR1	0.3	90	8.88
TDR2	0.3	270	8.67
TDR3	0.3	90	8.46
TDR4	0.3	270	8.25
TDR5	0.3	90	8.04
TDR6	0.3	270	7.83
TDR7	0.3	90	7.62

4. LTRBM installation

All sensors and instruments were installed gently at the bentonite blocks or the GM skeleton following the instructions given by the reference partner.

Special care was taken to minimize the buffer alteration, to properly seal the preferential paths created during the sensors installation and to lay out the cables when existing.

All sensors were controlled before and after being installed to guarantee their proper functioning and the final location in the test.

The different sensors installed (except for the TDRs) and their symbols are summarized in Table 19.

Table 19. Codes for types of sensors installed

Code	Instrument	Symbol
CHCL	Chemical electrode (Cl)	
CHpH	Chemical electrode (pH)	
CHEh	Chemical electrode (Eh)	
DSCO	Displacement conventional	
ELAR	Electrode Array	∞
FFCO	Fluid Flow conventional	F
FPCO	Fluid pressure conventional	P
MVCO	Weight/Volume of water conventional	
PPCO	Pore Pressure conventional	
PPFO	Pore Pressure Fiber Optic	
PPWL	Pore Pressure Wireless	
RHFR	Relative Humidity (FDR)	
RHCA	Relative Humidity (capacitive)	
RHPD	Relative Humidity (psychrometer dew point)	
RHPS	Relative Humidity (psychrometer conventional)	
RHTN	Relative Humidity (tensiometer)	
THMC	THMC Smart sensor	
TPCO	Total pressure conventional	
TPFO	Total pressure Fiber Optic	
TTCO	Temperature conventional	

The first work step carried out inside the MB was the installation of the cement layer at the rear to flaten the rock surface, Figure 42. Some manual drilling was needed first to remove loose pieces of rock.

Figure 42. View of the MB rear end flaten with concrete

Once the flattening was finished the different bentonite blocks were machined in situ to house the sensors and cables, Figure 43. As soon as each block was finished, formed by four coupled pieces, it was wrapped, piece by piece, in plastic material to preserve their properties and keep the exposition to laboratory moisture at a minimum. A table with the different installed bentonite blocks is shown in Annex III.

Figure 43. View of the work area for the machining of the bentonite blocks

The first bentonite block was prepared, Figure 44, it contained two different total pressure sensors:

- 1 standard wired total pressure sensor (TPCO)
- 1 Fiber Optique total pressure sensor (TPFO)

Note that initially it was planned to install the sensors on the rear concrete surface but it was changed to facilitate their emplacement.

Two small holes were drilled to drive the water tubings for MAT 1 too. This block 0, made of half thickness of one estandard block, was installed with the first hydration section (MAT 1), Figure 44. The Block 0 & MAT 1 were inserted inside the main LTRBM borehole manually, Figure 45.

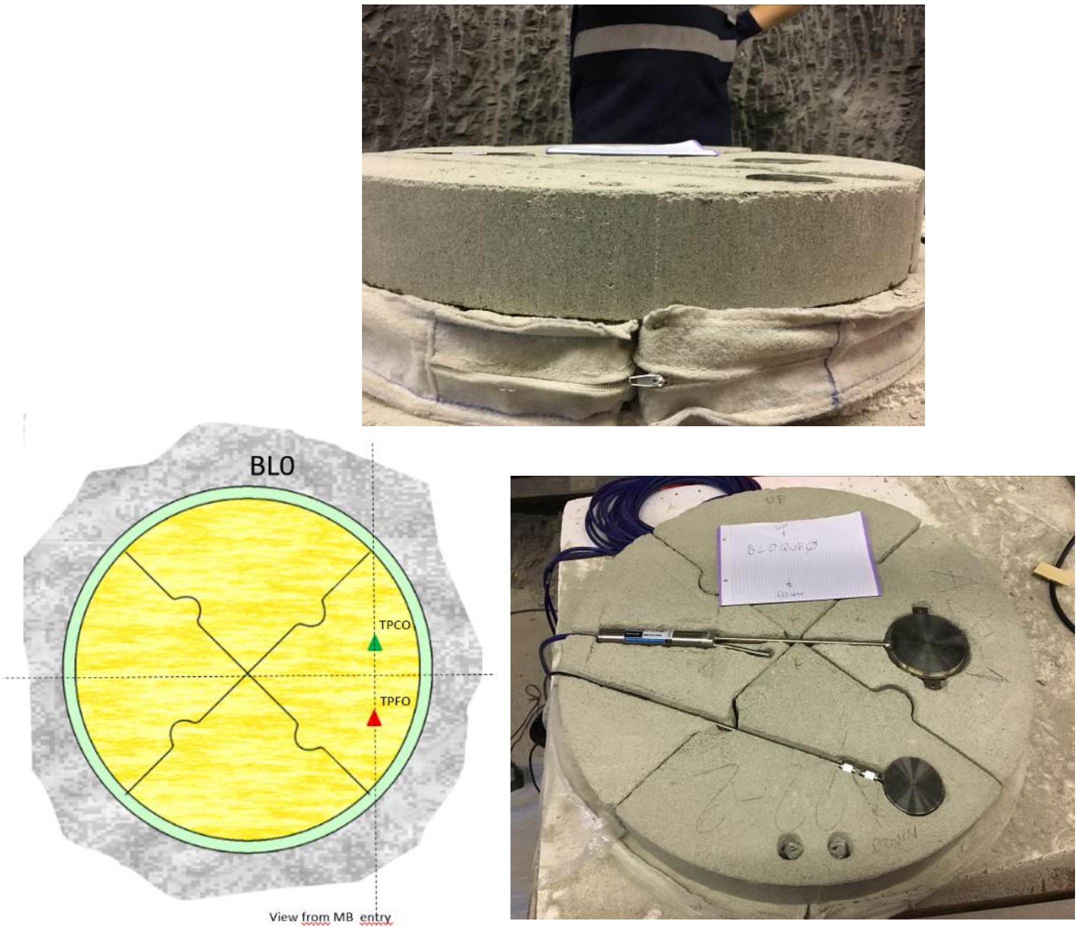


Figure 44. View of Block 0 and Mat 1 before the installation, sensors were located towards MB entry

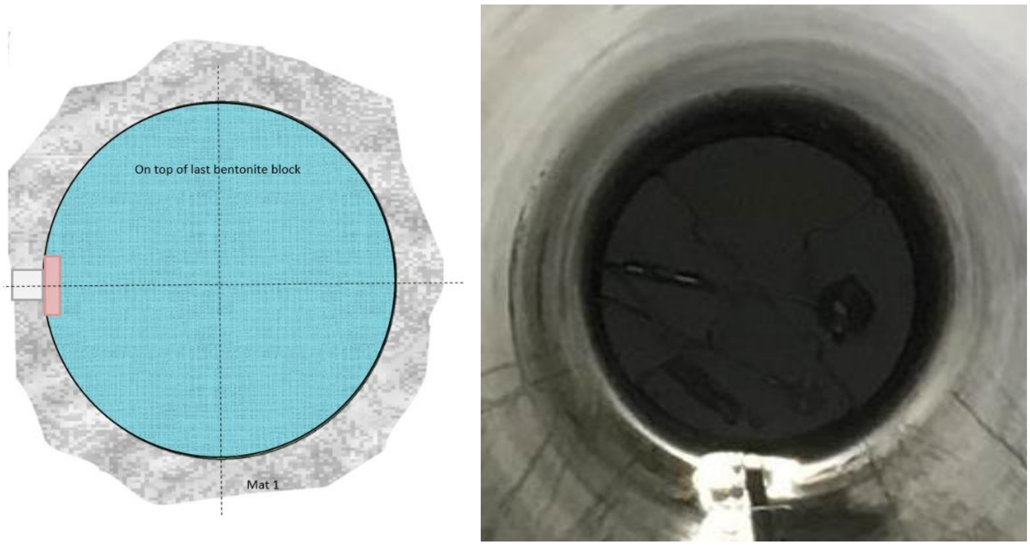


Figure 45. Mat 1 and Block 0 installed inside MB

The hydration system panels and the water tank were installed while the bentonite blocks mechanization was being done.

The hydration system components were located at the SEALEX gallery, perpendicular to the main LTRBM borehole, Figure 46. It consists of:

- Five different hydration sections (MATS 1 to 5) located inside the MB,
- A water tank and a weighting machine were suspended from the roof of the gallery. The tank has 50 liters of capacity and is capable os sustain a maximum internal pressure of 8,5 bar,
- The weighting machine includes a display connected to the LTRBM DAS,
- Two hydration panels, one of them with the main line and the second to control the injection of water to the different mats. These panels contains manometers, valves and fluid pressure sensors connected to the LTRBM DAS
- Plastic tubes were used to connect the water tank with the hydraulic panel and with the MATS installed inside the bentonite buffer.

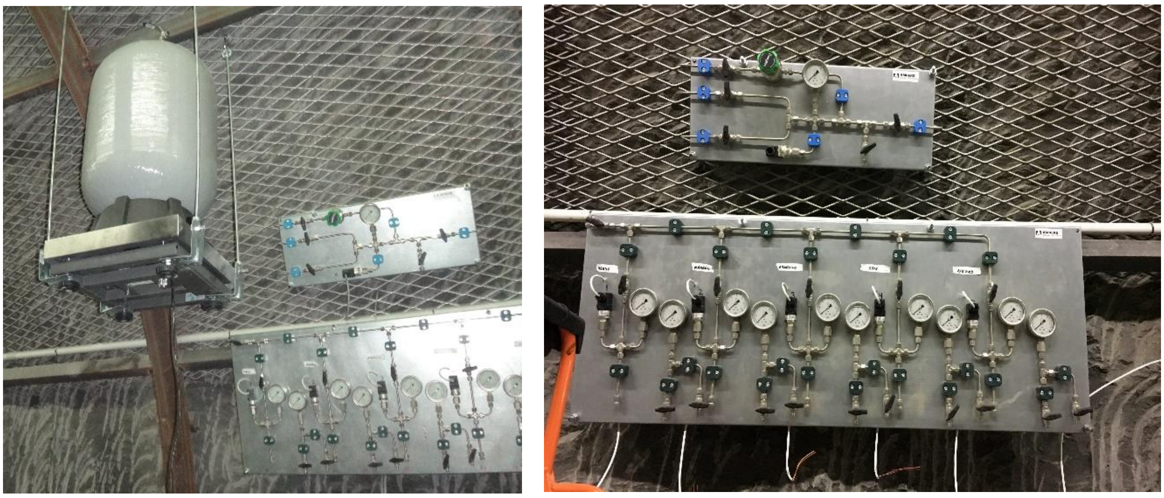


Figure 46. Hydration system

The bentonite blocks 1 to 6 were machined one by one with the shape of the different sensors which were going to be placed, Figure 47. It was important for the sensor to be placed embedded inside the bentonite block but just on the surface level and well fitted to avoid extra gaps around. This work was very time consuming.

Figure 47. Holes prepared for sensors (left) and sensors installed on the bentonite blocks (right)

The bentonite block 1, Figure 48, was machined to contain two different sensor types:

- 3 chemical electrodes located inside a single metallic probe (CHPH, CHEH, CHCL). This probe was installed inside the side of the block
- 1 Pore pressure sensor (PPWL) connected to the SAKATA wireless transmitter
- 1 wireless SAKATA transmitter

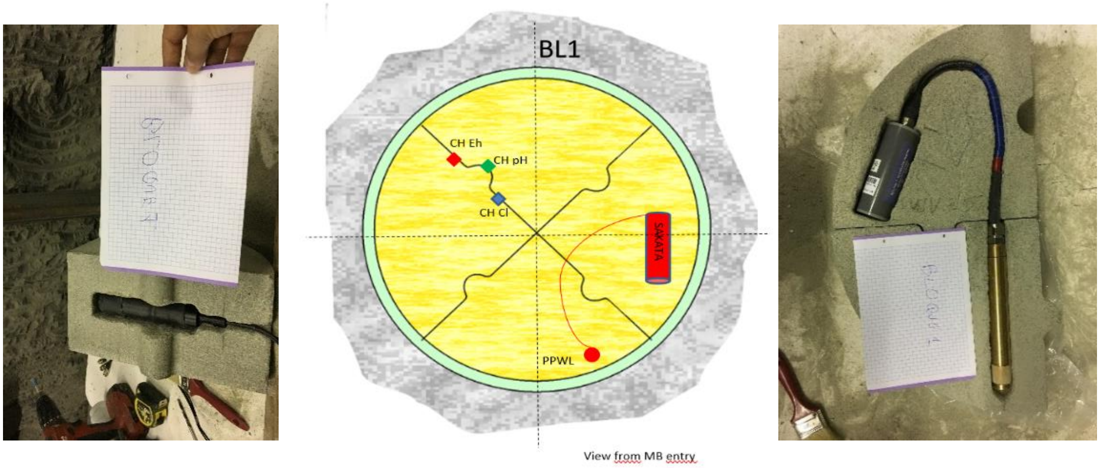


Figure 48. Block1 view

The bentonite block 2, Figure 49, was machined to contain seven different sensor types:

- 1 conventional Type T thermocouple (TTCO),
- 1 conventional Relative humidity sensor (RHCO),
- 1 FDR type Relative Humidity sensor, (RHFR), connected to Arquimea wireless transmitter,
- 1 Tensiometer type Relative Humidity sensor, (RHTN), connected to Arqimea wireless transmitter,
- 2 type Relative Humidity sensor, (RHPD), connected to Arquimea wireless transmitter,
- 1 type Relative Humidity sensor, (RHPS), connected to Arquimea wireless transmitter,
- 1 Pore pressure sensor (PPWL) conected to Arquimea wireless transmitter
- 1 Arquimea wireless transmitter

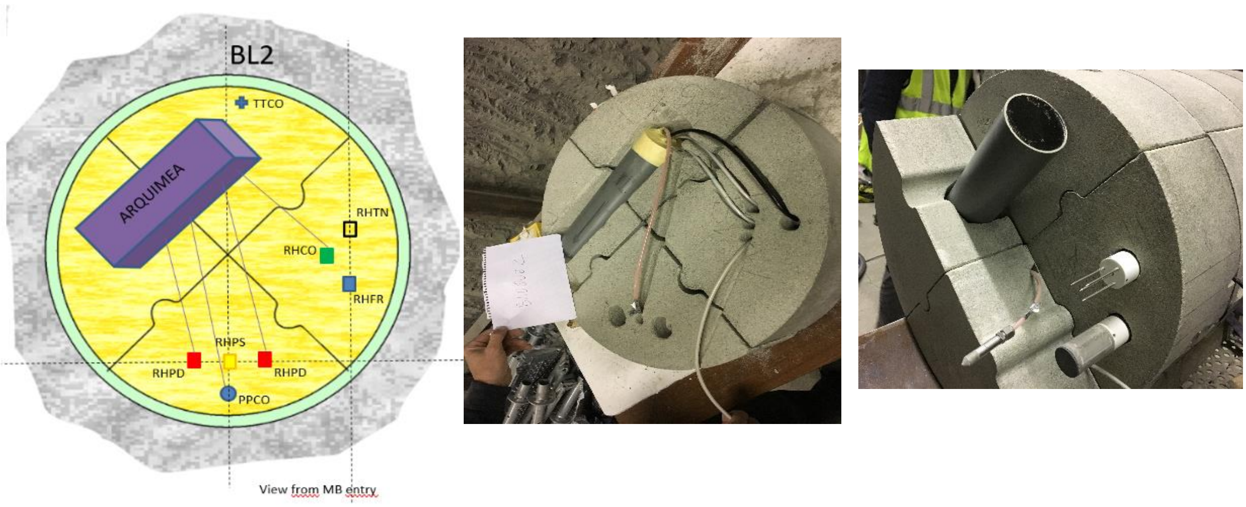


Figure 49. Block 2 view

The bentonite block 3, Figure 50, was prepared to contain only one sensor type:

- 3 conventional Total Pressure sensors (TPCO), installed on the block side, around it.

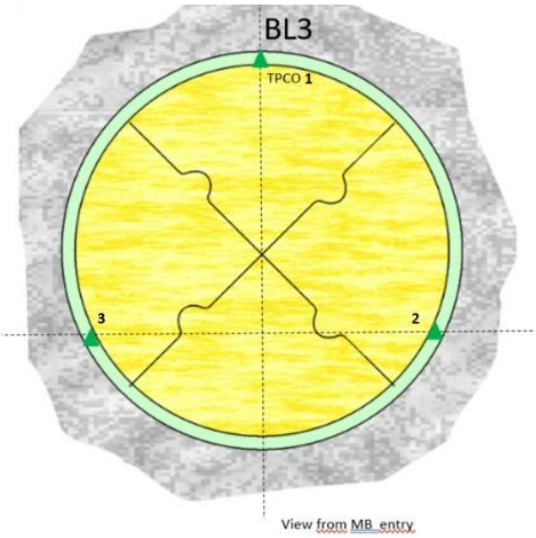
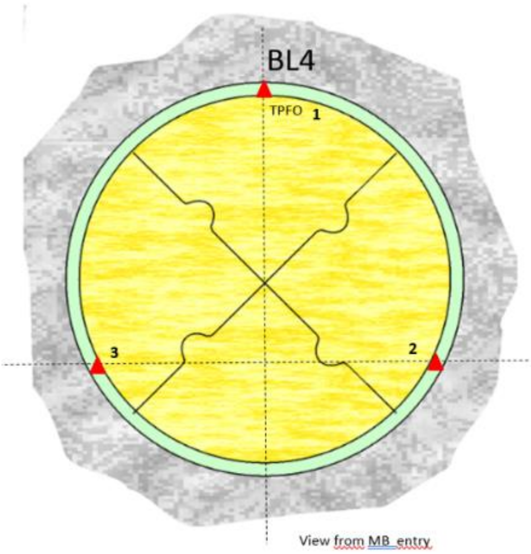


Figure 50. Block 3 view

The bentonite block 4, Figure 51, was machined to contain only one sensor type:

- 3 Fiber Optique Total Pressure sensors (TPFO), installed on the block side, around it.



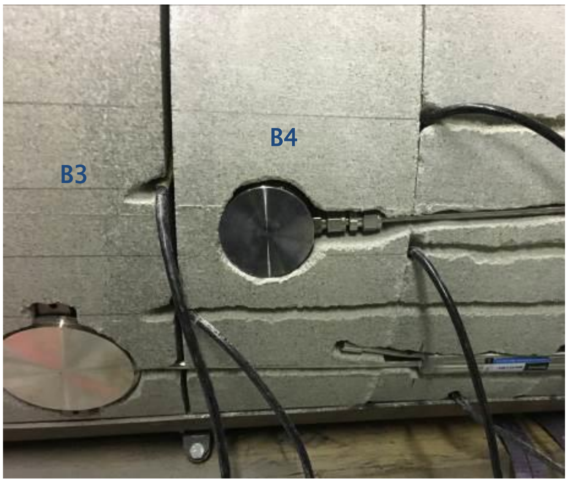


Figure 51. Block 4 view

The bentonite block 5, Figure 52, does not contain any sensor, with the exception of part of the bodies of the sensors located inside block 6: one RHTN and one RHFR.

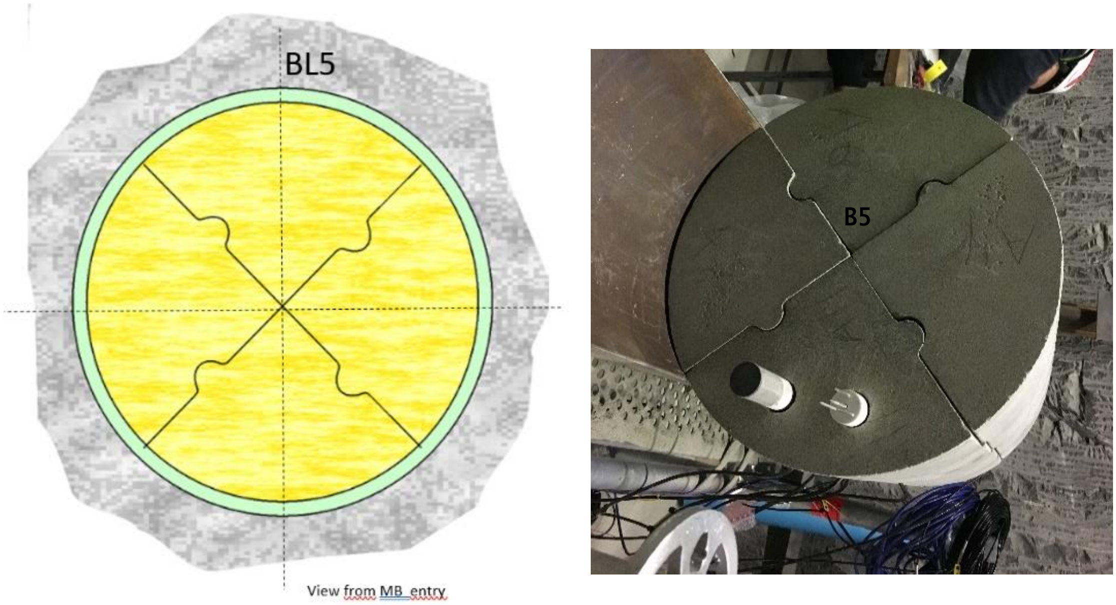


Figure 52. Block 5 view

The bentonite block 6, Figure 53, contains three different sensor types:

- 1 conventional Type T thermocouple (TTCO),
- 1 FDR type Relative Humidity sensor, (RHFR),
- 1 Tensiometer type Relative Humidity sensor, (RHTN),

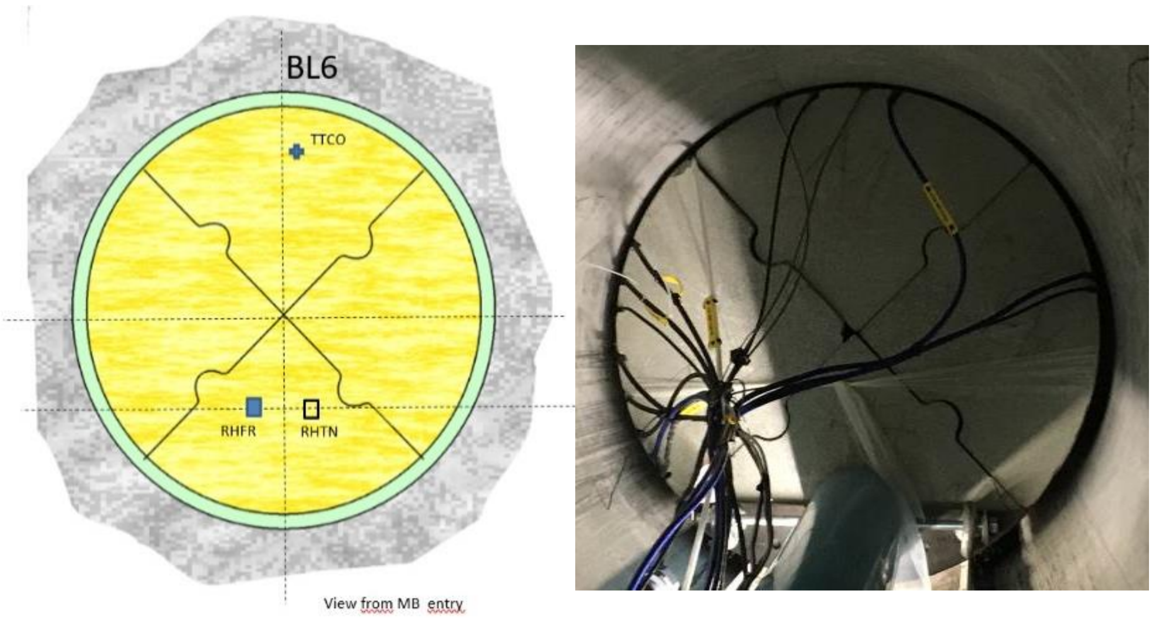


Figure 53. Block 6 back side view when already installed inside de main borehole

Once all sensors holes were prepared, the different blocks, from 1 to 6, and their sensors were placed all toguether on top of a metallic sliding/rolling bed, forming a single body or package in order to insert them inside the main LTRBM borehole at once. The blocks set with the metallic «bed» was placed on a scaffold with wheels for an easier transport from the work area to the entry of the LTRBM borehole, Figure 54.

Figure 54. Block 1-6 located on the transport scafold

Then the package was downloaded over the metallic structure («bed») previously installed at the MB entry to be inserted inside the LTRBM main borehole. This was done by pushing it by hand to the end of the borehole with the same type of blue tubes used for the access auxiliary boreholes, Figure 55. This vas a difficult task due to the tight space available around the package, some pieces of rock were removed at the upper part of the borehole to enable the package introduction.

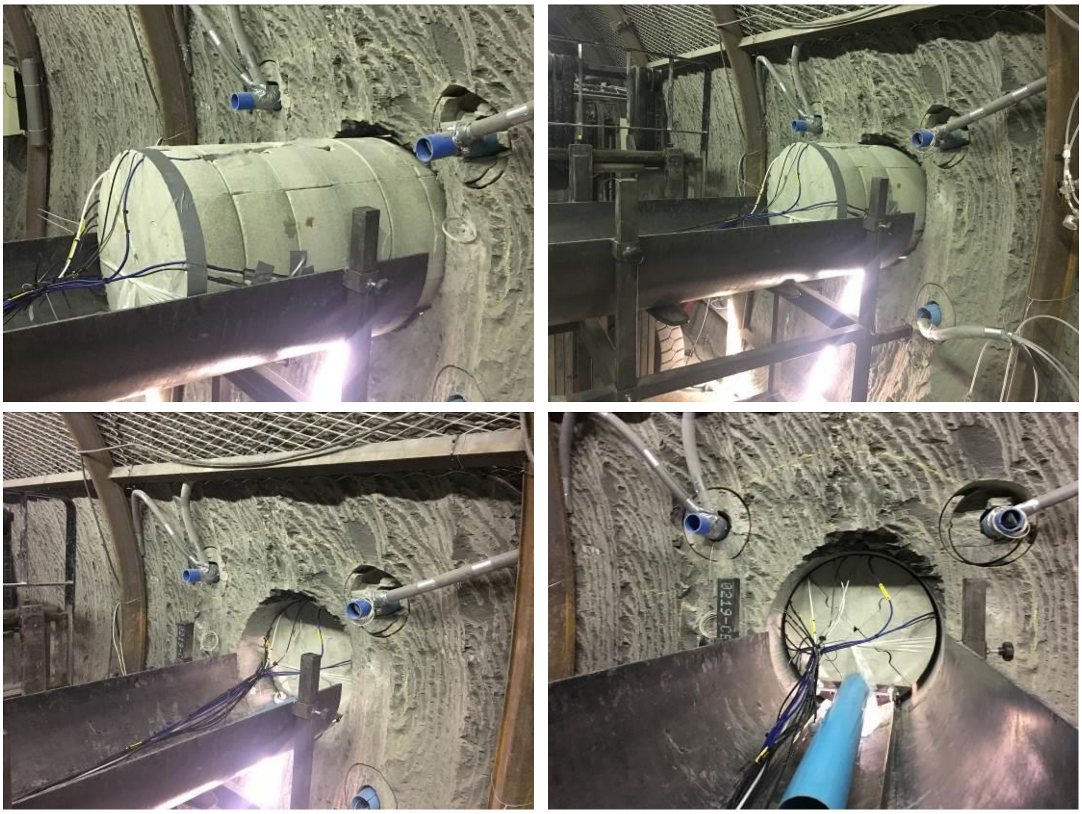


Figure 55. Block package: sequence of the insertion

When the block package was placed into the main LTRBM borehole, the cables of the sensors were passed by the caps of the auxiliary boreholes. Then the next hydration surfaces, MAT 2 and MAT3 were placed, MAT2 next to block 6 and MAT3 at 25 cm from MAT2, at te floor of the borehole and in the granular benonite material zone.

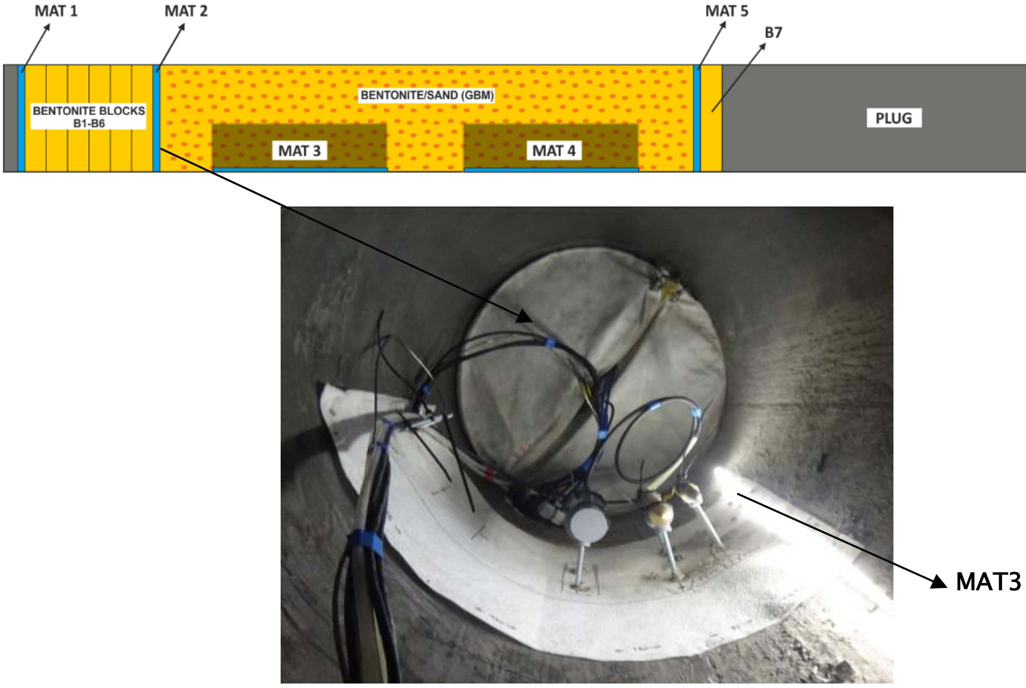


Figure 56. MAT2 and MAT3 position inside the borehole

Two different sensors groups were installed in the granular benonite material zone, one of them on the middle of MAT 3 area and the other in the middle of MAT 4 area.

The first group, located on MAT3, included three different sensors types, :

- 1 Type T thermocouple (TTCO),
- 1 Pore pressure sensor (PPWL) conected to Sakaki transmitter (PPWL)
- 1 conventional Pore Poressure sensor (PPCO)

The plug of the access borehole 1 was installed at the side of the main LTRBM borehole, Figure 57.

Figure 57. View of Acces borehole 1 sensor cables plug

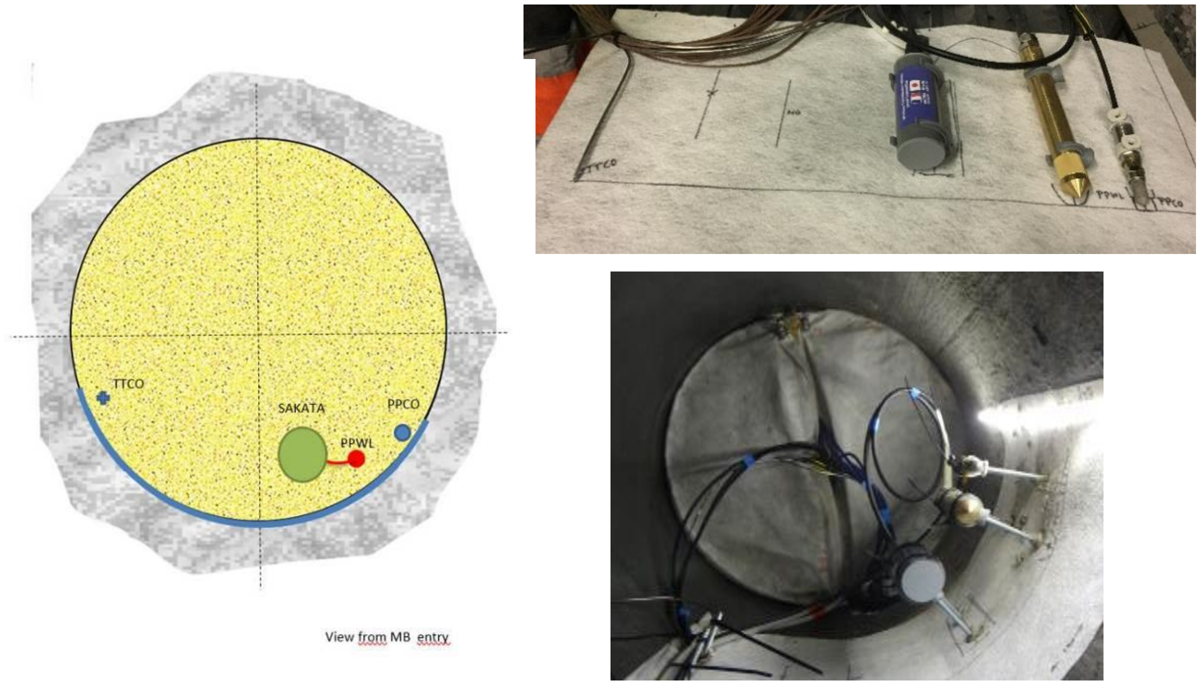


Figure 58. View of Mat 3 and sensors in granular bentonite material zone

As soon as MAT 3 and sensors were instaled, part of the TDRs were located at the rock walls and then the first insertion of bentonite/sand granular material was done.

For the GBM insertion an auger system was used, Figure 59 and Figure 60. This system was designed by Amberg Infraestructuras for the insertion of granular material in deep and narrow boreholes. The system consists on two augers coupled toguether. First auger consists of one hopper, located at the entry gallery, in which the material to be introduced is poured. The material goes through the tube with a worm screw. Then, it reaches a second and smaller hopper, located several meters inside the borehole, and the process is repeated to carry the material to the bottom of the borehole. Both hoppers have an electric motor for the operation of the worm screw, different drawings are shown in Annex I.

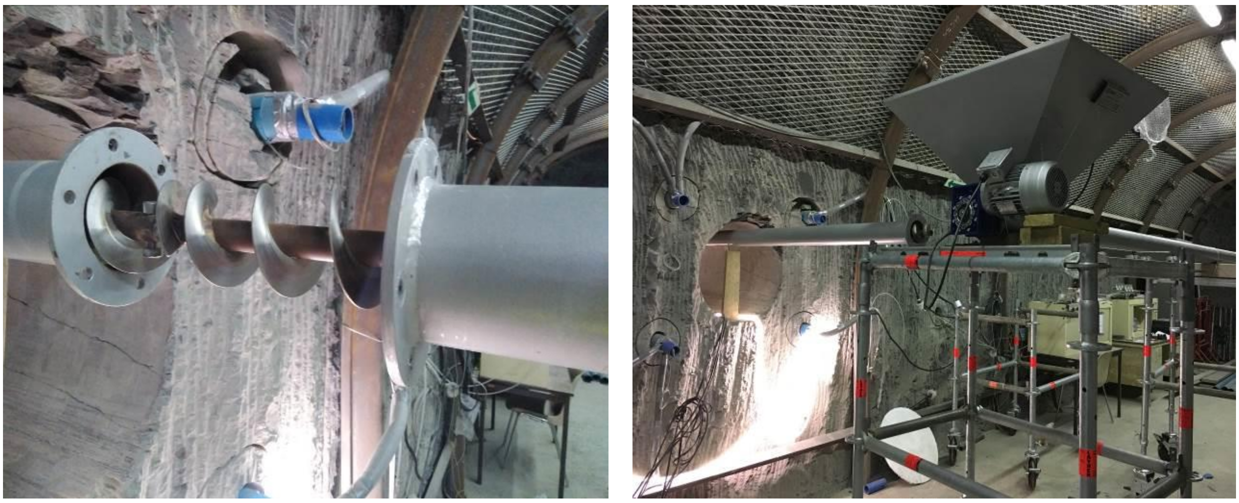


Figure 59. View of the auger used for the GBM insertion inside the main borehole: tube with worm screw and hoppers

Figure 60. View of the auger installed inisde the LTRBM borehole

Afterwards the GBM insertion was stopped and the second sensors group, located on MAT4 and the remaining TDRs, were installed. This sensors section included seven different sensors types, Figure 61:

- 1 conventional Type T thermocouple (TTCO),
- 1 conventional Relative humidity sensor (RHCO),
- 1 FDR type Relative Humidity sensor, (RHFR), connected to Arqimea wireless transmitter,
- 1 Tensiometer type Relative Humidity sensor, (RHTN), connected to Arqimea wireless transmitter,
- 2 type Relative Humidity sensor, (RHPD), connected to Arqimea wireless transmitter,
- 1 type Relative Humidity sensor, (RHPS), connected to Arqimea wireless transmitter,
- 1 Pore pressure sensor (PPWL) conected to Arquimea wireless transmitter
- 1 Arquimea wireless transmitter

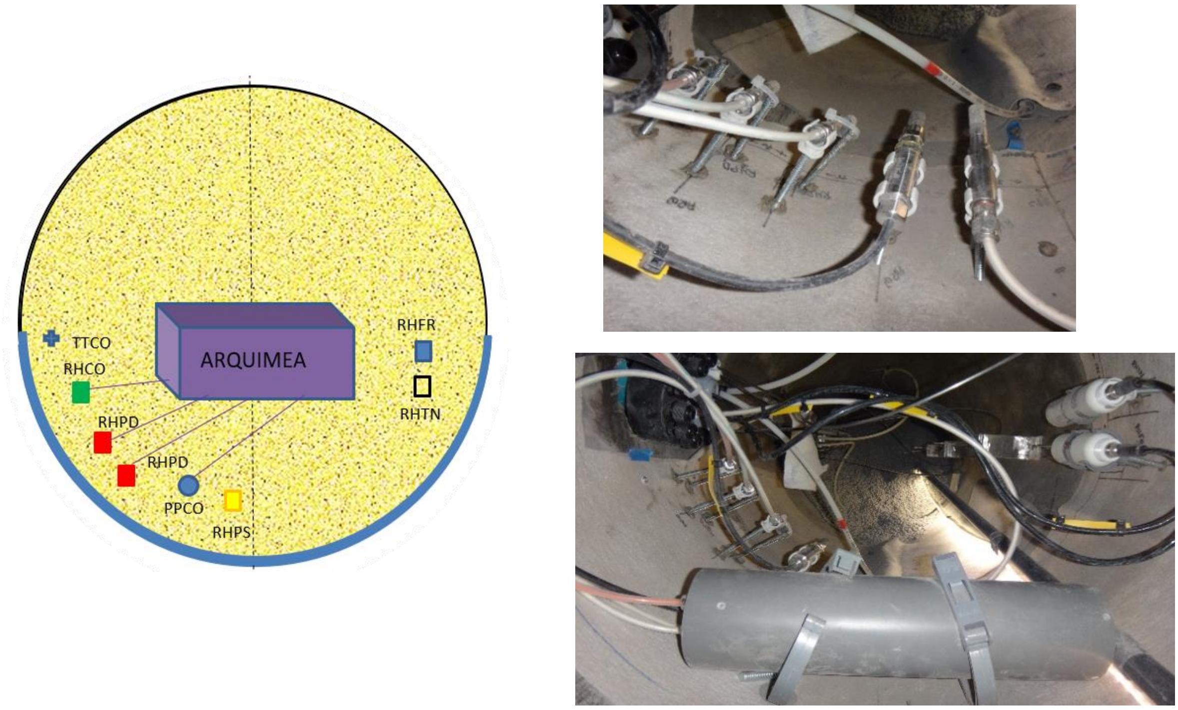


Figure 61. View of Mat 4 and sensors in granular bentonite material zone

Then a second GBM emplacement was made until reaching the location for Block 7. The last hydration section, MAT5, and the last bentonite block, B7, were installed after the previous step. Both, hydration section and block 7, have a channel, located at the top of the section, Figure 62, to enable passing the auger that introduced the granular material into the main borehole. The third insertion of GBM was then done untill filling the inner space completely. Some pieces of blocks were then installed at the gap of block 7 to close it.

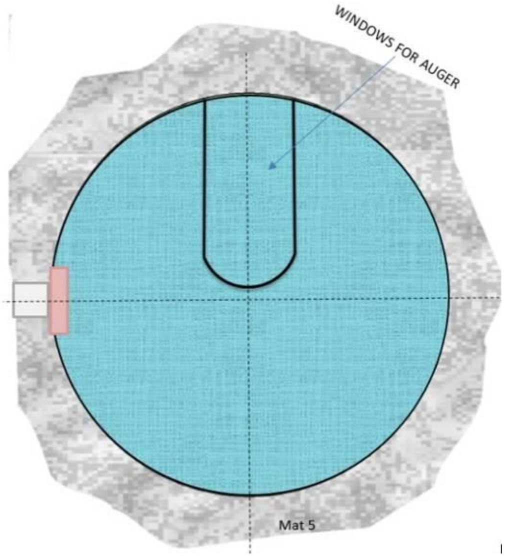


Figure 62. View of Mat 5 and bentonite block B7

Finally, the upper part of rear confining plate for cement plug and the lower half of that at the entry of the main borehole (downstream), were installed.

The characteristics of the mixture are shown in Table 20.

Table 20. Percentages of the cement mixture used in the plug

Component	Planned composition (% weight)	Type	Weight (kg)	Actual composition (% weight)
Cement	55	Portland Cement type IV	577.5	54.4
Water	40	Tournemire tap water	431.625	40.65
Bentonite	5	Sodic type	52.5	4.95
Total			1061.625	

The cement mixture for the plug was poured through a retaining wall installed at 3.65 meters from the borehole mouth. This mixture was prepared in situ, Figure 63.

Figure 63. View of the cement mixture preparation

In order to avoid the pouring of cement inside the buffer another retaining wall was placed between the GBM and the cement plug, Figure 64.. The contact area of the rock was resined around both retaining sections to minimise potential leaks by rock fractures. The bottom plate (nearest to the borehole mouth) was cut in half to allow a two-step installation of the cement plug. The retaining walls were attached to the rock walls using L type supports, screws and a flexible join between the plastic material and the rock. The first step enabled the filling of the lower half of the retaining plug.

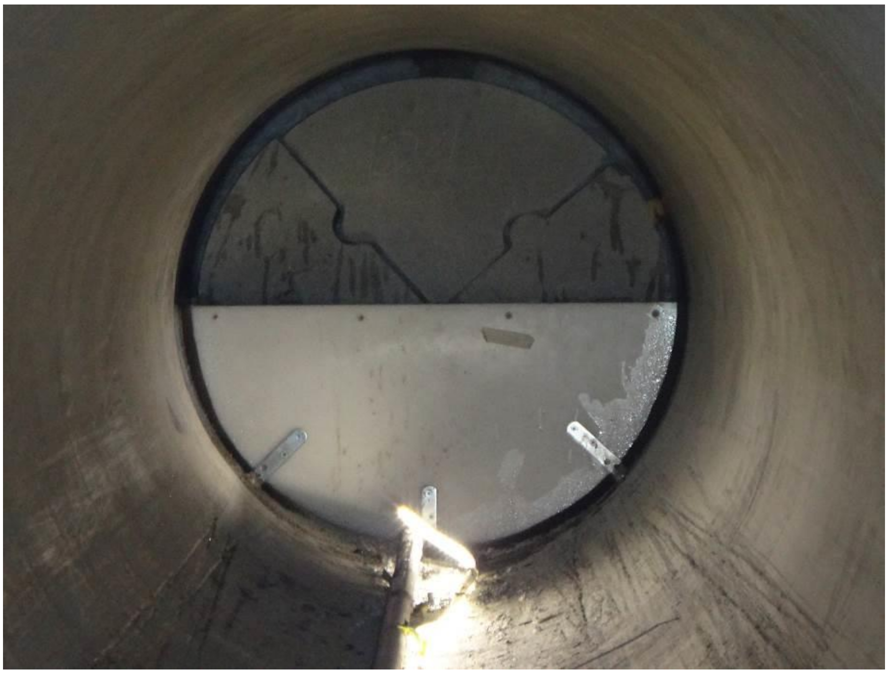


Figure 64. View of the installed retaining wall

The confining plate at the entry side was provided with one conecction for the inflow concrete-bentonite mixture and another for air draining. The filling was made in three steps:

- Phase 1: 17 July 2018 was inserted 452.15 kg
- Phase 2: 18 July 2018 was inserted 266.93 kg
- Phase 3: 19 July 2018 was inserted 394.23 kg

The dry density iof the granular bentonite material is shown in Table 21.

Table 21. GBM dry density

Actual Vol Total (l)	**766,55**
Actual mass (kg)	**1.113,31**
Actual apparent density (kg/l)	**1,45**
Actual Humid Mass (kg) in pellets (5%)	**42,36**
Actual dry mass (kg)	**1.070,95**
Actual Dry Density (kg/l)	**1,40**

Once completed an optical fiber was placed on top of the fresh cement. The upper part of the retaining wall was then installed and cement was poured into the borehole. This operation was done to permit the optical fiber cable to be situated in the middle of the cement plug without being attached to any other device.

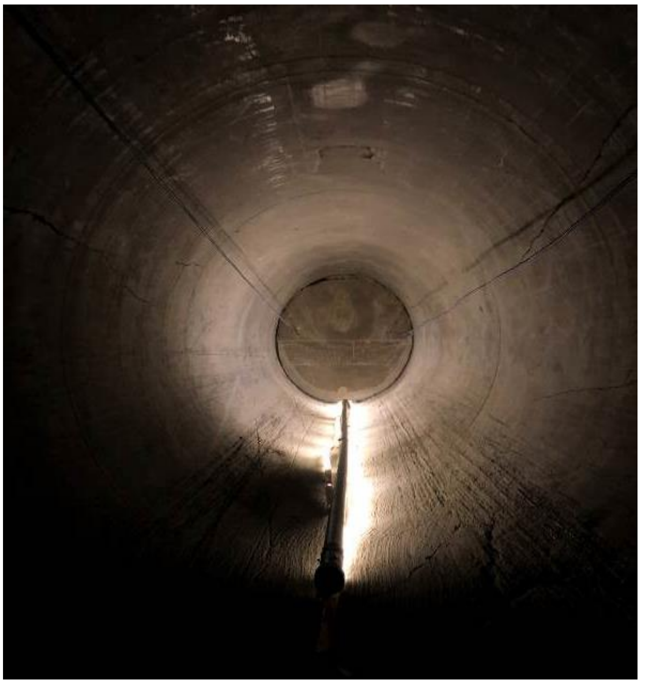


Figure 65. View of the installed cement plug

After 24-48h of curing the plastic plate was removed and the extensometers were installed at the plug front. With that the LTRBM installation was concluded.

4.1 Summary of the instrumentation installed

The installed instrumentation was composed by:

a) New measuring instruments to be tested (produced in WP3 of Modern 2020)
b) Standard measuring instruments to cross check the performance of the new ones
c) Instrumentation required to control and follow the test evolution

a) The new measuring instruments that have been installed were:

1. Pore water sensors (VW based) attached to a wireless transmitter provided by ANDRA, PPWL, (2 units)
2. Total pressure (FO based) provided by ANDRA, TPFO, (4 unit)
3. A fibre optic cable (measuring deformation and temperature) in the cement plug, provided by IRSN (2 cables).
4. Chemical sensors based on IrOx (pH, Eh & CL-) provided by VTT, CHPH+CHEH+CHCL, (1 unit)
5. New Thermocouple Psychrometers provided by ARQUIMEA, RHPD, (4 units)
6. A Smart sensor provided by CTU, THMC (1 unit).
7. Four arrays of electrodes for developing ERT measures and provided by IRSN.

b) The instruments that were installed for cross-checking the performance and controlling the test were these:

1. Miniature piezoresistive pore pressure sensors, PPCO, (3 units)
2. Piezoresistive total pressure cells, TPCO, (5 units)
3. Capacitive type hygrometers RHCO (2 units)
4. Automatic tensiometers, RHTN, (3 units)
5. FDR type water content sensors, RHFR, (3 units)
6. Wescor Psychrometers, RHPS, (2 units)
7. TDRs in the buffer, ELAR, (up to 12 units) provided by U. Strathclyde.

c) Other instruments installed to control and follow the test evolution were:

1. Displacement sensors, DSCO, (2 units)
2. Hydraulic pressure sensors, FPCO, (6 units)
3. Weight sensor,WVCO, (1 unit)
4. Temperature sensors,TTCO, (4 units)

4.2 Reference coordinate system

A cylindrical coordinate system was used for referring three-dimension spatial positions of sensors in the test area. The origin of the coordinate system was located at the axis of the main borehole at Niche_08 gallery wall, as shown in Figure 66.

The three coordinates identifying a specific point are:

- "radius" (r) Radial distance from the sensor centre to the axis of the main borehole (maximum 300 mm),
- "angle" (α) Clockwise angle from the borehole axis, with origin in the vertical diameter at the bottom of the borehole,
- "depth" (d) Distance from the Niche_08 gallery wall surface to the bottom of the borehole.

This is a relative coordinate system, referred to the main borehole axis when crossing the Niche_08 gallery wall. The relation with the absolute (topographic) coordinate system is given by the position of such borehole in the Niche_08 gallery and in the Tournemire laboratory.

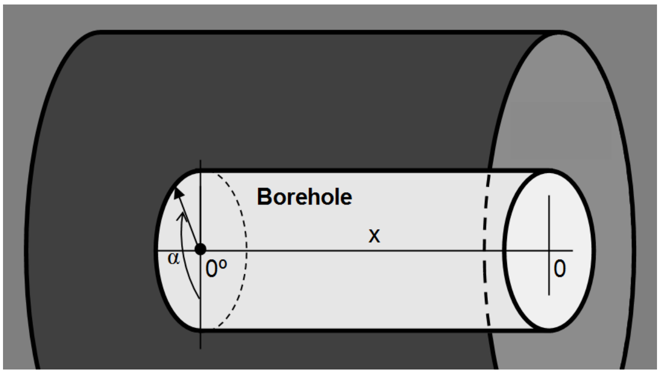


Figure 66. Reference coordinate system.

4.3 Coding system

The instruments were identified according to a code of the type: *SSSS_PP_D.DD/N*

Where:

SSSS: is the sensor type (see Table 19)
PP: represents the positioning zone:
- Boreholes: borehole code (MB, A1, A2, A3, A4, etc)
- Hydration system: *HY*
- Gallery*: GA*

D.DD: is the depth in meters, with a maximum of two decimal digits.
N: is an order number, only necessary in case that more than one sensor of the same type is installed in the same zone and at the same depth. It starts by 1 and increases with the radius *r*. For the same radius, it increases with the value of angle α.

4.4 Wireless data acquisition system

There were two different wireless data acquisition system to extract part of the sensors signals from the test section, .

This system was composed by:

a) Within the sealed test section:

1. Short range wireless transmitters for the VW (vibrating wire) pore pressure sensors (2 units) provided by ANDRA (Sakata Denki),
2. Short range wireless transmitters for the new Thermocouple Psychrometers provided by ARQUIMEA (2 units).

b) Within parallel boreholes to the main one:

1. A wireless receptor for the VW (vibrating wire) pore pressure sensors provided by ANDRA (Sakata Denki)
2. A wireless receptor provided by ARQUIMEA

c) At the gallery:

1. An interface to the DAS for the wireless receptor of sensors provided by ANDRA (Sakata Denki)
2. An interface to the DAS for the wireless receptor of sensors provided by ARQUIMEA
3. An interface between the DAS and the long range wireless data transmission system
4. A long range wireless data transmitter provided by NRG

d) At the surface

1. A long range wireless data receiver will be provided by NRG.
Note: it is not foreseen to provide a permanent receiver, it will include demodulation, decoding & data storage. It will be possible make some claims, at the end on, the performance of the set-up in terms of bit-error-rates by comparing received data with the 'original' data as present in the DAS.

4.5 Other components of the data acquisition system

The Data Acquisition System (DAS) implemented for SEALEX experiment in 2005 has been used for recording all LTRBM data. However, apart from the indicated interfaces of the wireless devices, additional components were required for:

1-Reading the FO sensors and convert them into digital values to be transmitted to the DAS

3-Reading and power supply all the wired sensors

4-Share all recorded data with the partners

4.1 Chronology and participants from AMBERG

The LTRBM installation was performed between the 25/06/2018 and 20/07/2018.

The Amberg Infraestructuras team was composed by:

- José Luis García-Siñeriz (JLGS) 25/06/2018 to 20/07/2018
- Susana Tuñón Valladares (STV) 25/06/2018 to 13/07/2018
- María Rey Mazón (MRM) 02/06/2018 to 13/07/2018
- Oualid Harti (OH) 25/06/2018 to 29/06/2018 and 16/07/2018 to 20/07/2018
- Mariano Rivas Guayerbas (MRG) 25/06/2018 to 20/07/2018
- David Esteban Fuentes (DEF) 25/06/2018 to 20/07/2018

Main activities realized per day are summarized in the following table:

Date	Participants	Main works
25/06/2018	JLGS/STV/OH/MRG/DEF	-Supervision of material downloading from the truck at the gallery entry
26/06/2018	JLGS/STV/OH/MRG/DEF	-The installation material was placed inside the tunnel -The led lights were fixed on the top of main borehole -The hydration panels and water tank were installed
27/06/2018	JLGS/STV/OH/MRG/DEF	-Cementation of the end of LTRBM borehole -The DAS box was installed on the rock, it was wired and cabled to the general power supply of the laboratory, new devices of the DAS were introduced in the SEALEX PC network and tested before the sensors wiring -Testing of block machining -Identification of available sensors
28/06/2018	JLGS/STV/OH/MRG/DEF	-Machining of blocks started -Continue with DAS installation: new communication devices and drivers -Preparation of acces to borehole
29/06/2018	JLGS/STV/OH/MRG/DEF	-Machining of Block 1 -The rest of the material was placed inside the tunnel
02/07/2018	JLGS/STV/MRM/MRG/DEF	-Resine injected in the auxiliary boreholes -Sensors of hidration system wired and tested to the DAS -The water tank was placed at the top of the gallery -The machining of the blocks continues
03/07/2018	JLGS/STV/MRM/MRG/DEF	-The plastic casing of access boreholes 0&1 was filled and fixed to the rock with resin -DAS communications with SEALEX computer tested, Datalogger re-configured with new signals and new communication program -The machining of the blocks continues
04/07/2018	JLGS/STV/MRM/MRG/DEF	-The plastic casing of access boreholes 2&3 was filled and fixed to the rock with resin -The borehole 0 was cleaned -The machining of the blocks was finished -DAS MODBUS communication established with datalogger

		-The the blocks set (B1 to B4) was prepared to be inserted
05/07/2018	JLGS/STV/MRM/MRG/DEF	-Block 0 was placed inside main borehole -The sensors for GM were prepared -The wires from Block 0 sensors were passed through acces borehole 0 - Communication tests with weighing machine and communicatio driver with PC, testing of communicactions with THMC sensors -The hydration MAT 1 was installed -The transmitter radio from Arquimea was filled «insitu» with resin -The plug of the access borehole 0 was installed inside main LTRBM borehole
06/07/2018	JLGS/STV/MRM/MRG/DEF	-The machining of blocks was finished -The Fiber Optique datalogger and the RS-232/Ethernet converted from Strarhclyde University were installed inside the DAS box -Installation of the blocks set on the metallic bed, before the insertion
09/07/2018	JLGS/STV/MRM /MRG/DEF	-The blocks set on the metallic bed and wires were located in a better position before the starting of the insertion. The operation was re-designed - Testing of communicactions with THMC sensors
10/07/2018	JLGS/STV/MRM /MRG/DEF	-The lanes of the main LTRBM borehole were prepared for the insertion of the blocks set - SCADA updated with LTRBM graphs and view screen -The blocks set with the sensors were inserted inside the main LTRBM borehole
11/07/2018	JLGS/STV/MRM /MRG/DEF	-The sensor wires connection to the DAS was started and the wiring table was being updated -The hydration MAT 2 was installed and connected to the hydration panel -The lanes of the main LTRBM borehole were removed -The preparation of sensors that were going to be located inside the granular material zone was started
12/07/2018	JLGS/STV/MRM /MRG/DEF	-The sensors of the first granular material (GM) zone were installed -The plug of the access borehole 1 was installed inside main LTRBM borehole –connection of cables to DAS -The preparation of TDRs sensors was started - Last testing of communicactions with THMC sensors -The piezometers were filled with vaseline and silicone oil -The FO and TDRs sensores were connected to the DAS
13/07/2018	JLGS/STV/MRM /MRG/DEF	-4 TDRs sensors were installed -The sensor cables were passed through the access borehole -The sensor connection to the DAS system was finished -The preparation of the auger to be used for the granular bentonite material (GBM) insertion was started
16/07/2018	JLGS/OH/MRG/DEF	-The auger was placed at the entry of the LTRBM borehole
17/07/2018	JLGS/OH/MRG/DEF	-The first GBM insertion in the main borehole with the auger was done -The hydration system water tank was placed -The hydration MAT 3 was placed inisde the main LTRBM borehole -The rest of TDRs sensors were installed
18/07/2018	JLGS/OH/MRG/DEF	-The hydration MAT 4 was placed inside the main LTRBM borehole -The sensors of the second granular material (GM) zone were installed

		-The sensor cables were passed through the access borehole -The second GBM insertion in the main borehole with the auger was done -The auger was removed and cleaned the area -The hydration MAT 5 and block 7 were prepared
19/07/2018	JLGS/OH/MRG/DEF	-The filling of the GBM inside the main LTRBM borehole with the auger was finished -The hydration MAT 5 was installed -The last block 7 was installed -The Retaining Wall 1 was placed
20/07/2018	JLGS/OH/MRG/DEF	-The Retaining Wall 2 was placed -The cement Plug for LTRBM was done - FO from IRSN installation

5. Data Acquisition and Control system

5.1 General description

The Data Acquisition and control System (DAS) was used to read and store the data obtained from the conventional instrumentation installed in the LTRBM experiment. This information will be used to compare with the data obtained with the new sensors developed in WP3.

The main system used was the installed for the SEALEX experiment in 2011, Figure 67. It basically consisted of

- A computer where the differeny drivers and programs were installed
- A DAS box, the same used for the computer, with 230 V AC bornes, 24 V DC power supplies and network switches,
- An iFIX v4.5 HMI SCADA to control and store the data obtained from the experiment.

Figure 67. View of SEALEX computer&gallery

5.2 Instrumentation box

It was installed an instrumentation box to connect the different conventional sensors, and feed them if necessary. An intermediate bornes were installed to connect the wires, they act as barrier if some of the sensors brings water from the interior of the experiment. It included these elements:

- A Datalogger, DATATAKER DT80G model, was installed and configured. This datalogger read mA, V, mV Hz, etc. A few sensors were connected to this unit: three TPCO sensors,
- A Datalogger extension, CEM20 model, was installed. Almost all the wired sensors were connected to this unit: TPCO, PPCO, RHCO, DSCO, TTCO, CHCL, CHEH, CHPH and FPCO,
- An Ethernet switch was installed to include the new devices to the computer network,
- Two RS-232/Ethernet converters were installed, configured and included in the SEALEX computer network, one to be connected with the THMC unit and the other to be connected to the output of the weighing machine
- A power supply of 12 V DC was installed
- Power supply bornes, cabled to the 220 V AC and 24 V DC power supplies bornes from SEALEX experiment
- Bornes for the connection of conventional sensors: V, mV and mA
- Temperature compensation bornes that were used for the thermocouples connections

Once, the new LTRBM box was installed, it was used to include two new devices:

- The FO data logger from Andra, it was also connected to the power supply of the box
- The TDR connection device, with RS-485 output. It was an extension of the main Campbell Scienfitic data logger from U. Strathclyde. It was also connected to the power supply of the box.

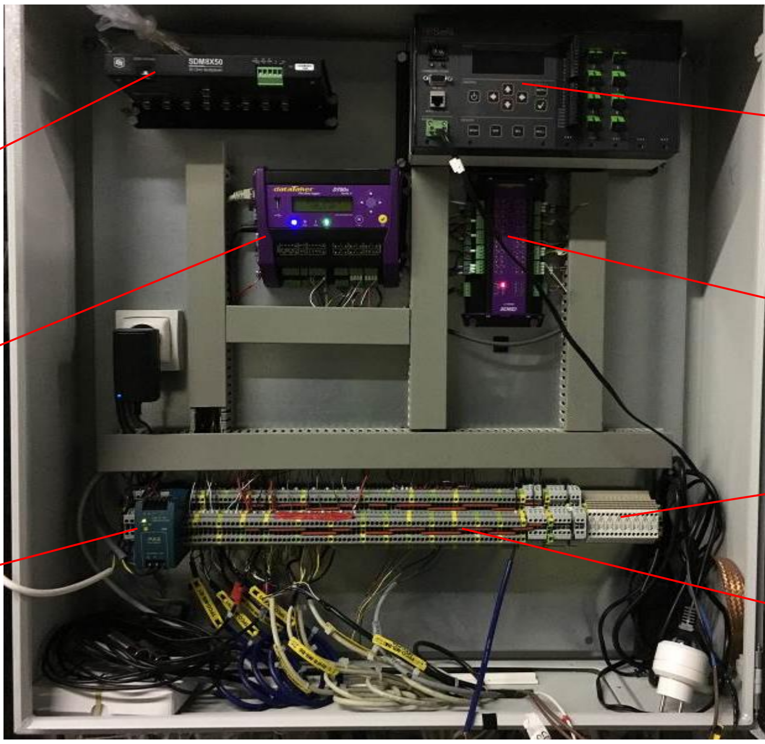


Figure 68. View of LTRBM DAS box

5.3 Communications layout

The MODBUS communication was implemented in the SEALEX PC to communicate with the devices and with the SCADA, it allowed an easy configuration of the new data logger. Modbus enables communication among many devices connected to the same network, it is openly published and royalty-free and easy to deploy and maintain.

The communication protocol used for the data transmission between the DATATAKER and the computer was MODBUS/Ethernet TCP-IP, over port 502.

Two new drivers were installed in the SEALEX computer to obtain data from the THMC unit, through RS-232, one of them developed by CTU and the other one by AMBERG, but the communication with the sensor was not possible with either of the two programs.

The weighing machine had an specific communication protocol via RS-232. A program was developed to communicate with this device, it is working also as Modbus server to communicate with the SCADA.

5.4 Scada software

A general purpose SCADA (Supervisory Control And Data Acquisition) of General Electric (GE), iFIX 4.5 version, was used to perform the following functions:

- Continuous data acquisition from the signal conditioning and data logging units (raw data).
- Data conversion into physical units
- Adaptation of conversion functions and calibration curves
- Data presentation
- Data storage into internal data base (raw and converted data)
- Trend graph views
- Exportation of the data to csv data files

It was necessary to updated the SCADA installed for the new LTRBM requirements, these were the different updatings:

- data base
- historical data
- Modbus driver
- csv data files exportation programs
- visualizaton screens (Figure 69)
- graphs
- etc

Remote access to the control computers is possible via network using an internet connection and a well proven dedicated communications firmware. This enables to perform the heater control remote supervision, to dump stored data, and to modify the power control strategy, if necessary.

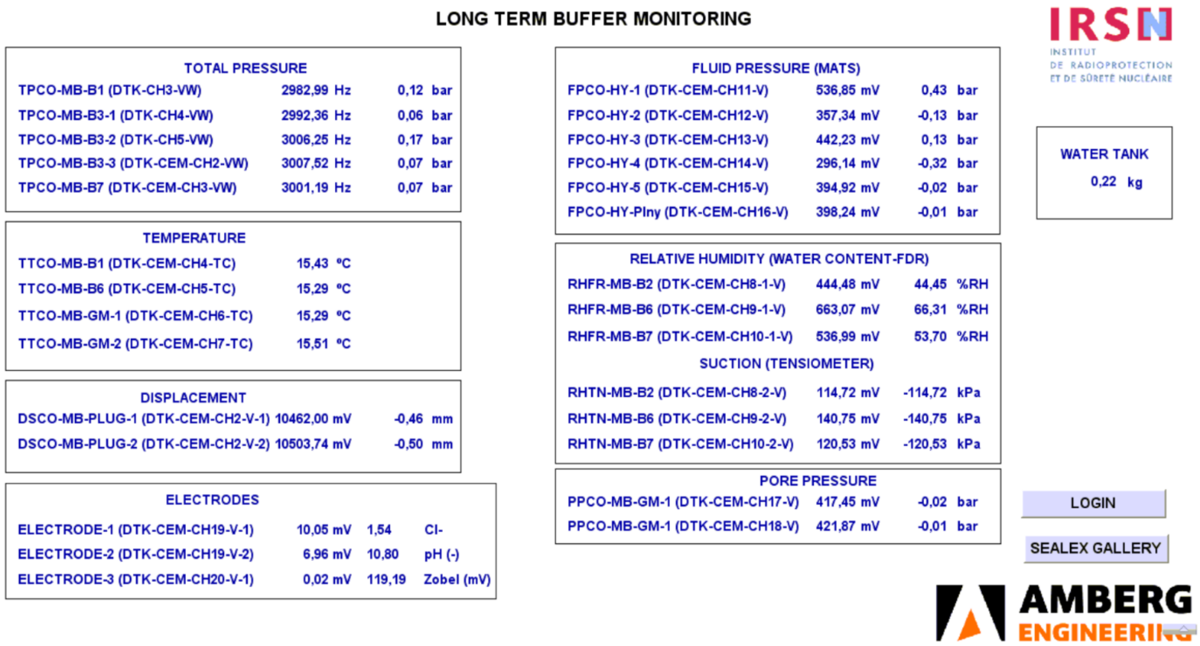
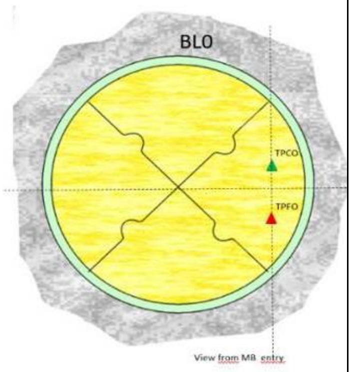
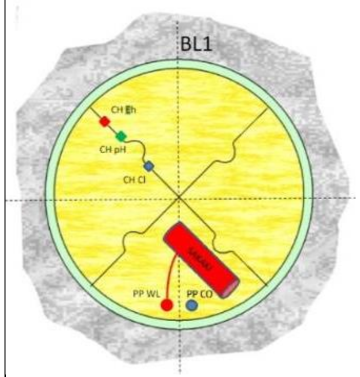
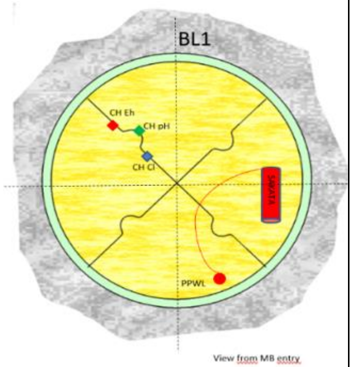


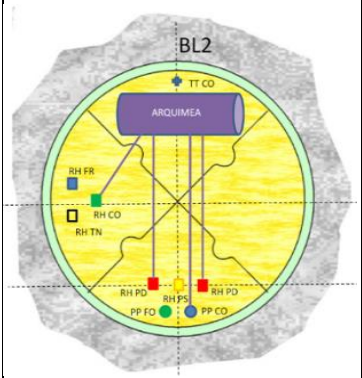
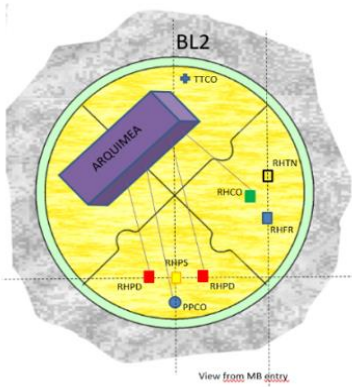
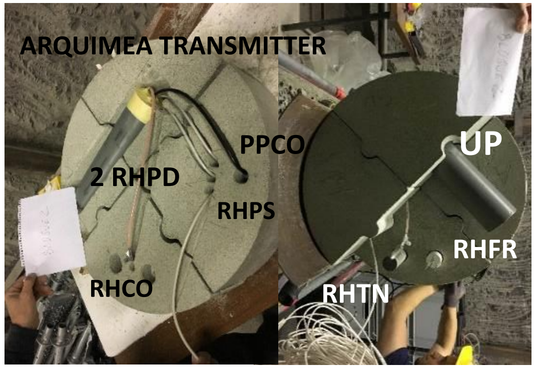
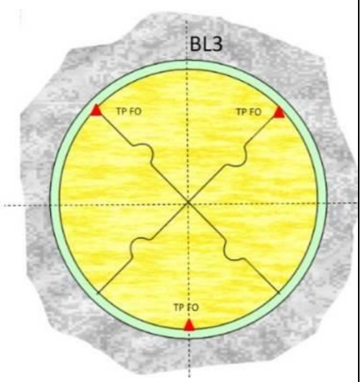
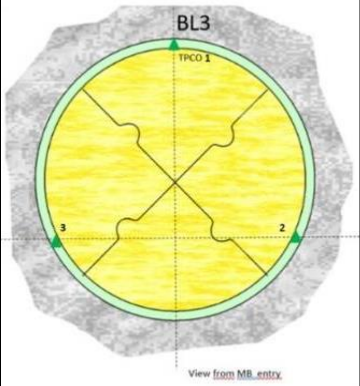
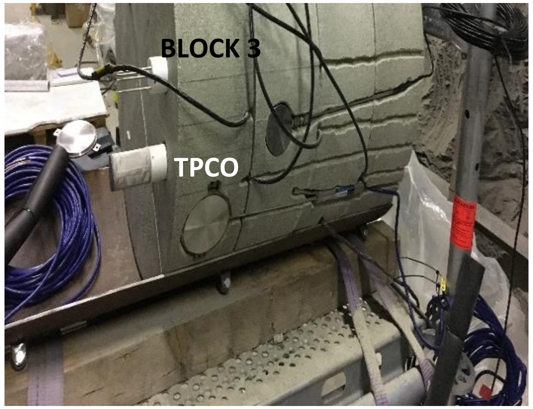
Figure 69. View of SCADA data in real time

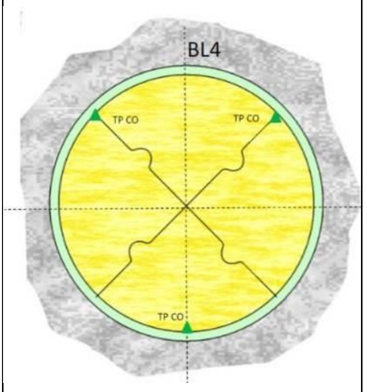
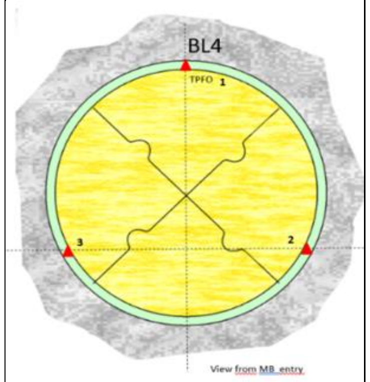
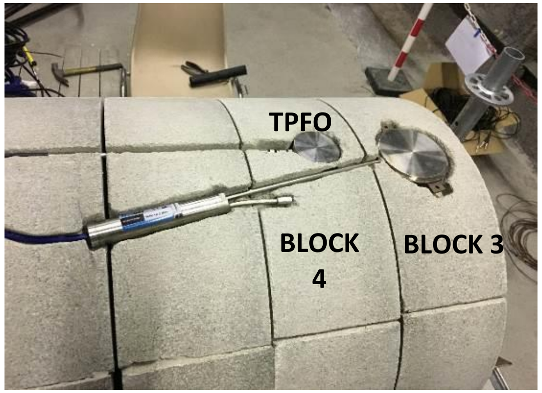
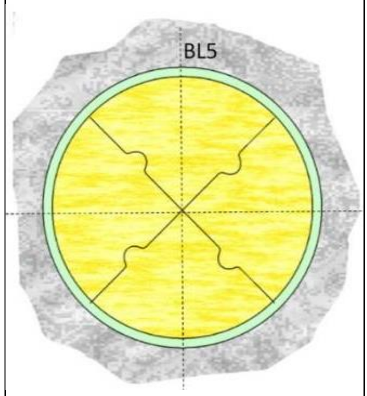
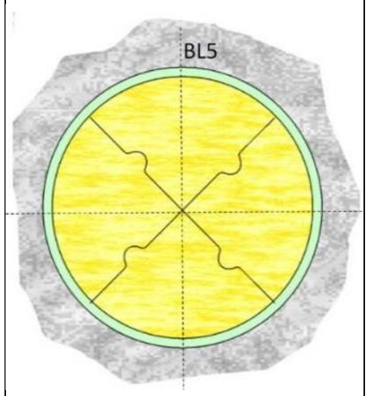
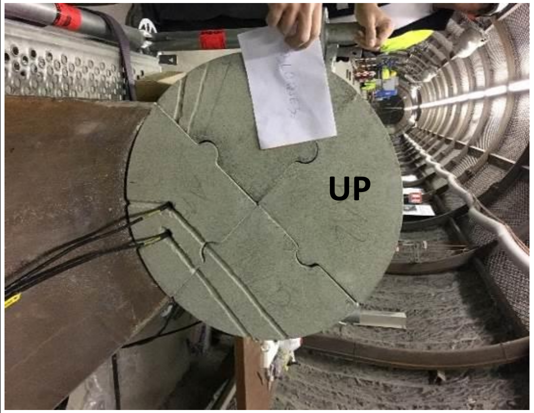
6. Annex

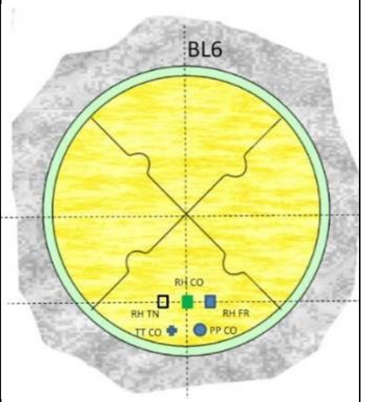
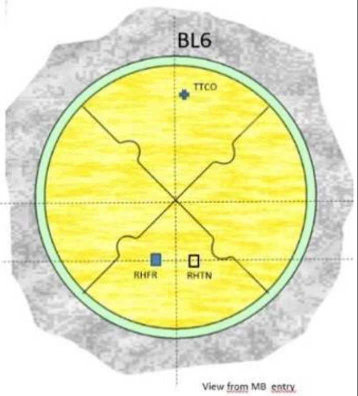
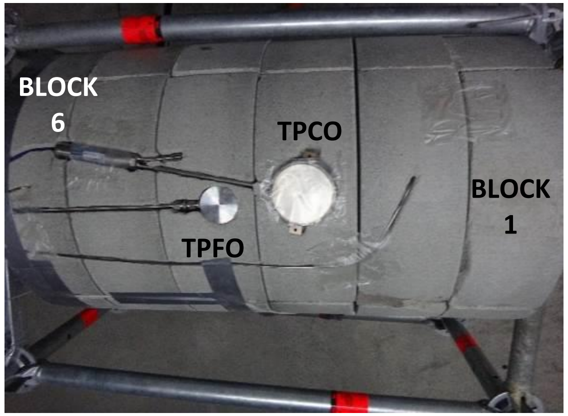
ANNEX I

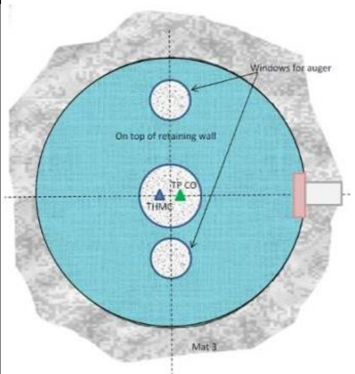
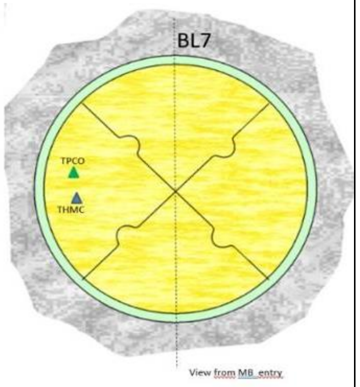
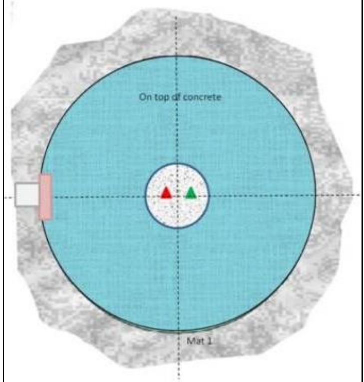
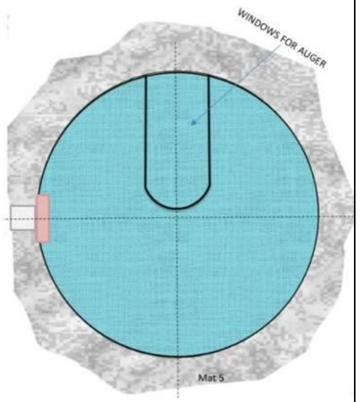
LTRBM BLOCKS & SENSORS &MATs

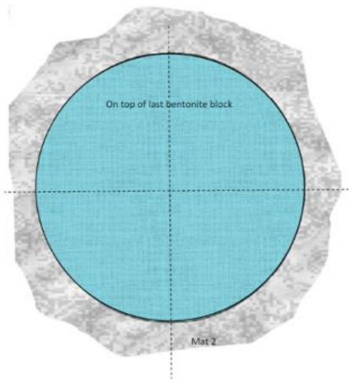
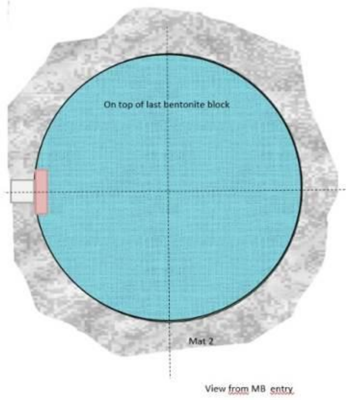
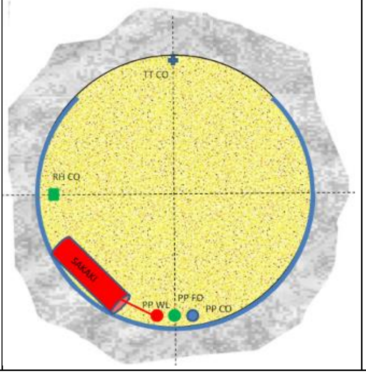
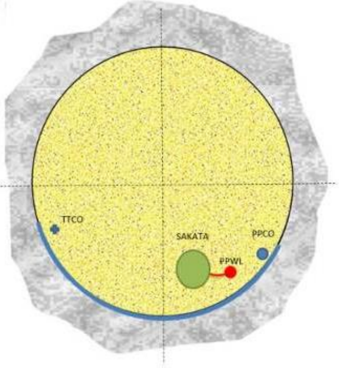
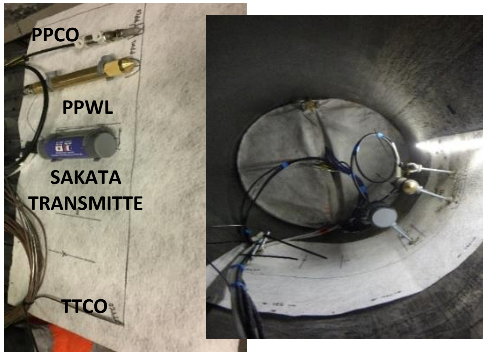
TEST PLAN/INSTALLATION DESIGN			AS BUILT/FINAL INSTALLATION				
BLOCK OR MAT	SENSOR TYPE	TEST PLAN DRAWING	SENSORS NUMBER	SENSOR TYPE	AS BUILT DRAWING	PHOTO	COMMENTS
B0	NONE		2	TPFO AND TPCO			View from MB entry. Beside the total pressure sensors the holes for the tubing of the MAT1 can be seen.
B1	CHEH CHPH CHCL PPWL SAKATA WIRELESS TRANSM.		2	CHEH, CHPH CHCL PPWL SAKATA WIRELESS TRANSM.			On the right, the 3 electrodes in a single capsule. On the left the PPWL sensor from Andra with the Sakata transmitter.

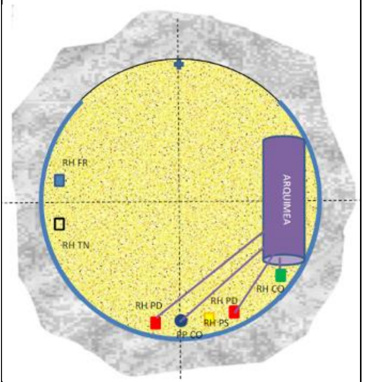
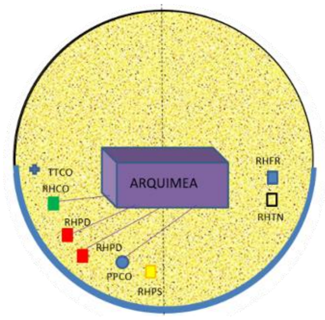
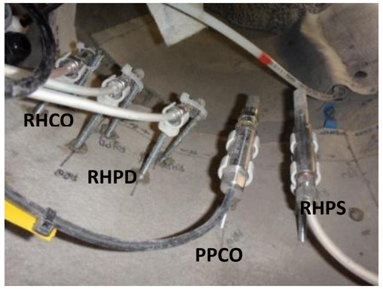
B2	TTCO, ARQUIMEA TRANSMITTER, RHCO, RHFR, RHTN, 2 RHPD, RHPS, PPFO AND PPCO		8	TTCO, ARQUIMEA TRANSMITTER, RHCO, RHFR, RHTN, 2 RHPD, RHPS AND PPCO			The TTCO is not shown in the photo.
B3	3 TPFO		3	3 TPCO			The TPCO installed outside the blocks, 3 sensors around the blocks.

B4	3 TPCO		3	3 TPFO			The TPFO were installed outside the blocks, 3 sensors around the blocks.
B5	NONE		0	NONE			No sensors were installed, just part of RHTN and RHFR.

B6	RHTN, RHCO, RHFR, TTCO AND PPCO		3	RHTN, RHFR AND TTCO			In the photo is observed block 5 where the block 6 was fit to house RHTN and RHFR sensors
B1 to B6					 		

B7	THMC TPCO		2	THMC TPCO			Block7 with the upper quarter removed. Mat 5 can be seen. When the GBM filling was finished the upper quarter of the block was placed. The THMC sensor was located below TPCO and was covered by the half of the retaining wall (white colour panel).
MAT1	¼ tube TPFO TPCO		-	¼ tube			Mat1 was installed with Block 0 on top, it can be seen at the back of block 0 and the tubings at the bottom

MAT2	¼ tube		-	¼ tube			
MAT3	¼ tube TTCO RHCO PPWL PPCO		3	¼ tube TTCO PPWL PPCO			

<table>
<tr>
<td>MAT4</td>
<td>¼ tube
TTCO
RHCO
RHFR
RHTN
2 RHPD
RHPS
PPCO</td>
<td></td>
<td>8</td>
<td>¼ tube
TTCO
RHCO
RHFR
RHTN
2 RHPD
RHPS
PPCO</td>
<td></td>
<td></td>
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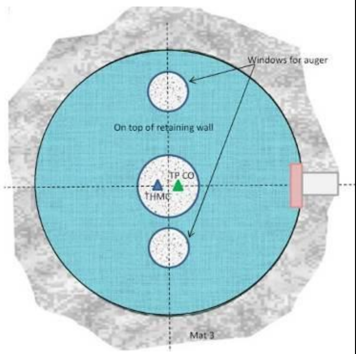
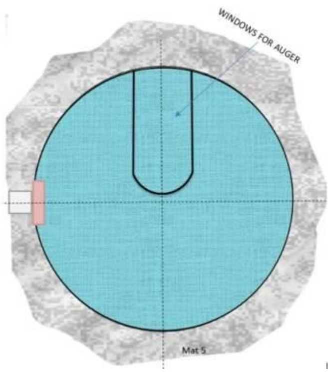
<td>MAT5</td>
<td>¼ tube</td>
<td></td>
<td>-</td>
<td>¼ tube</td>
<td></td>
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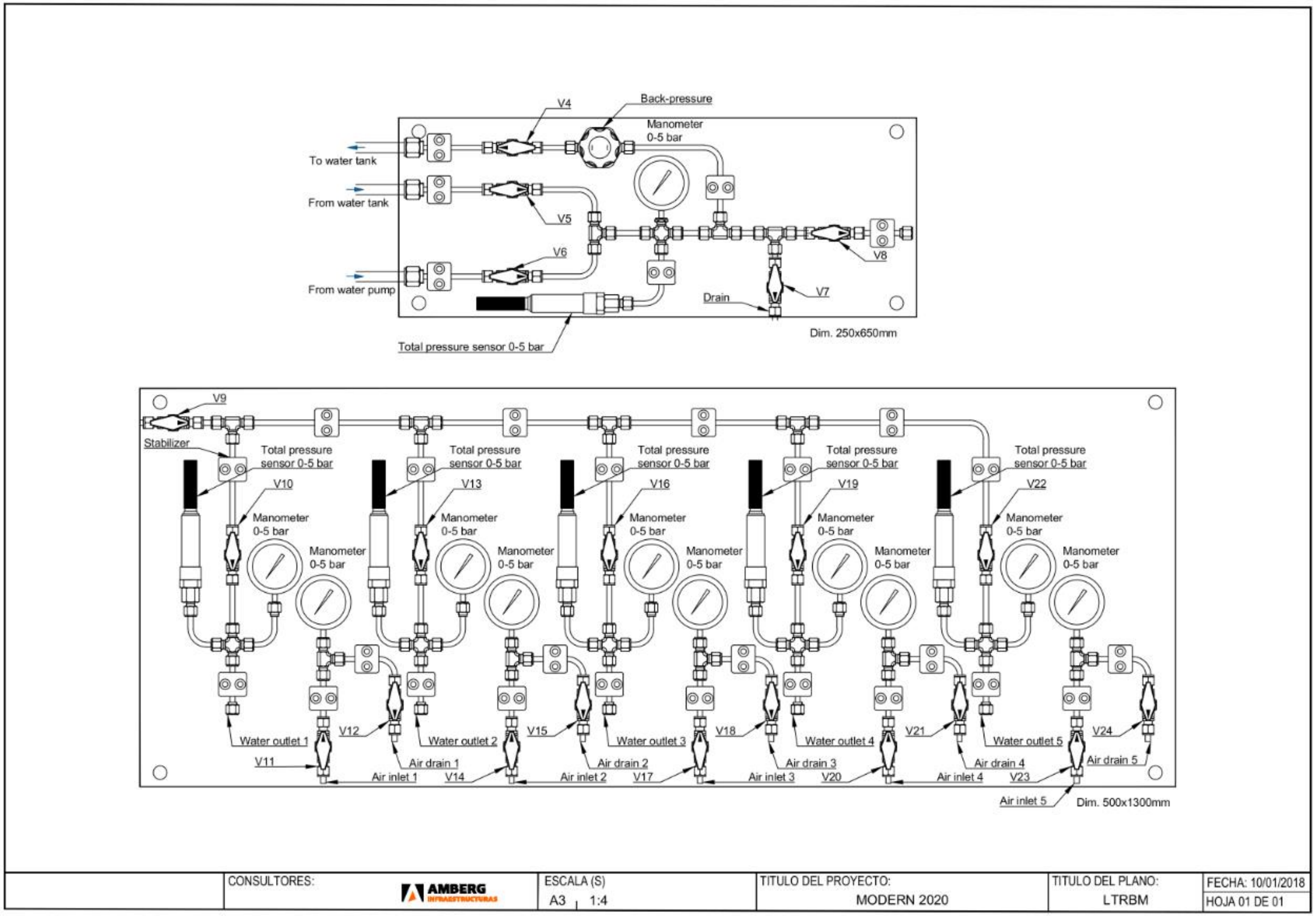
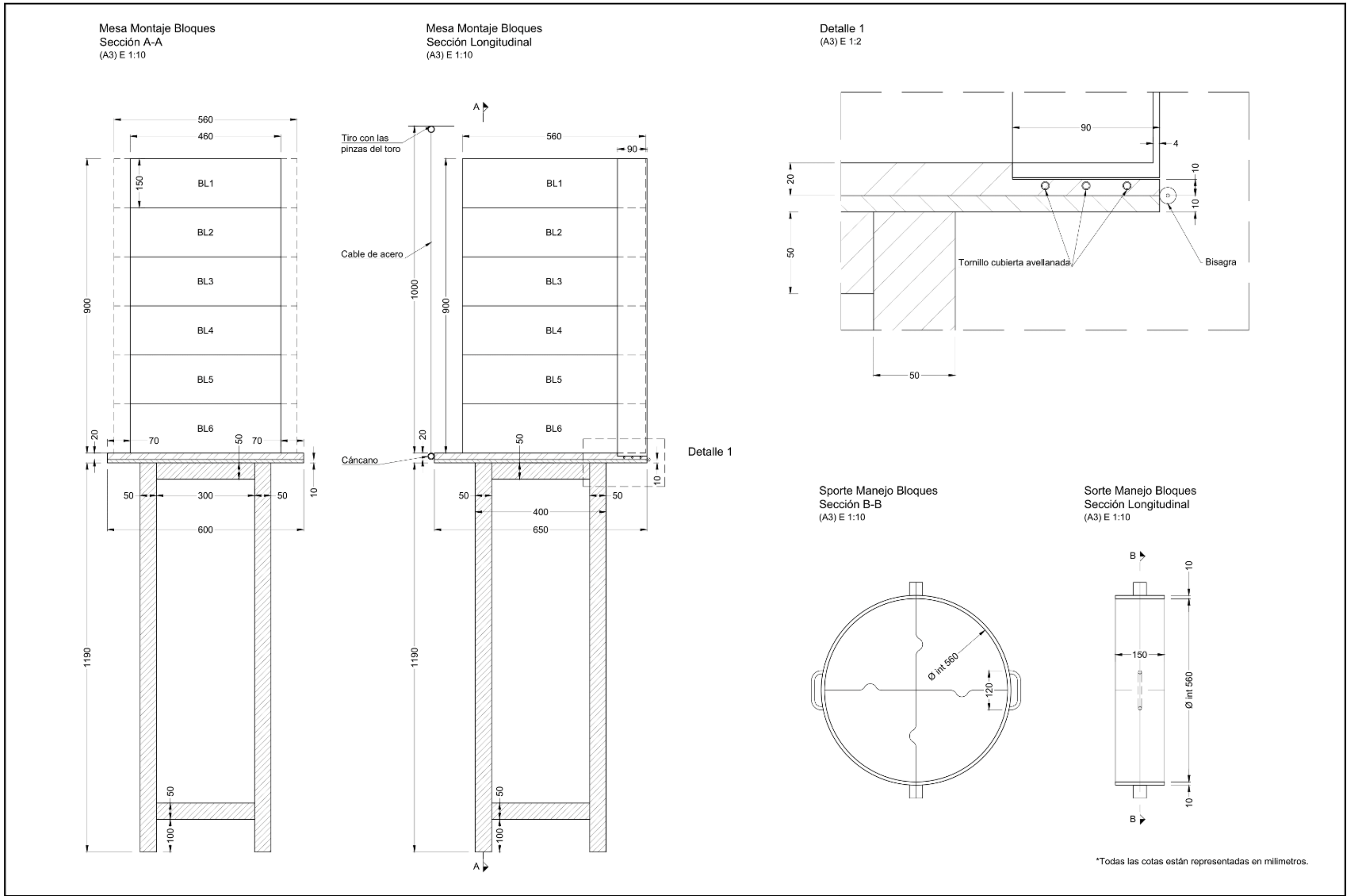
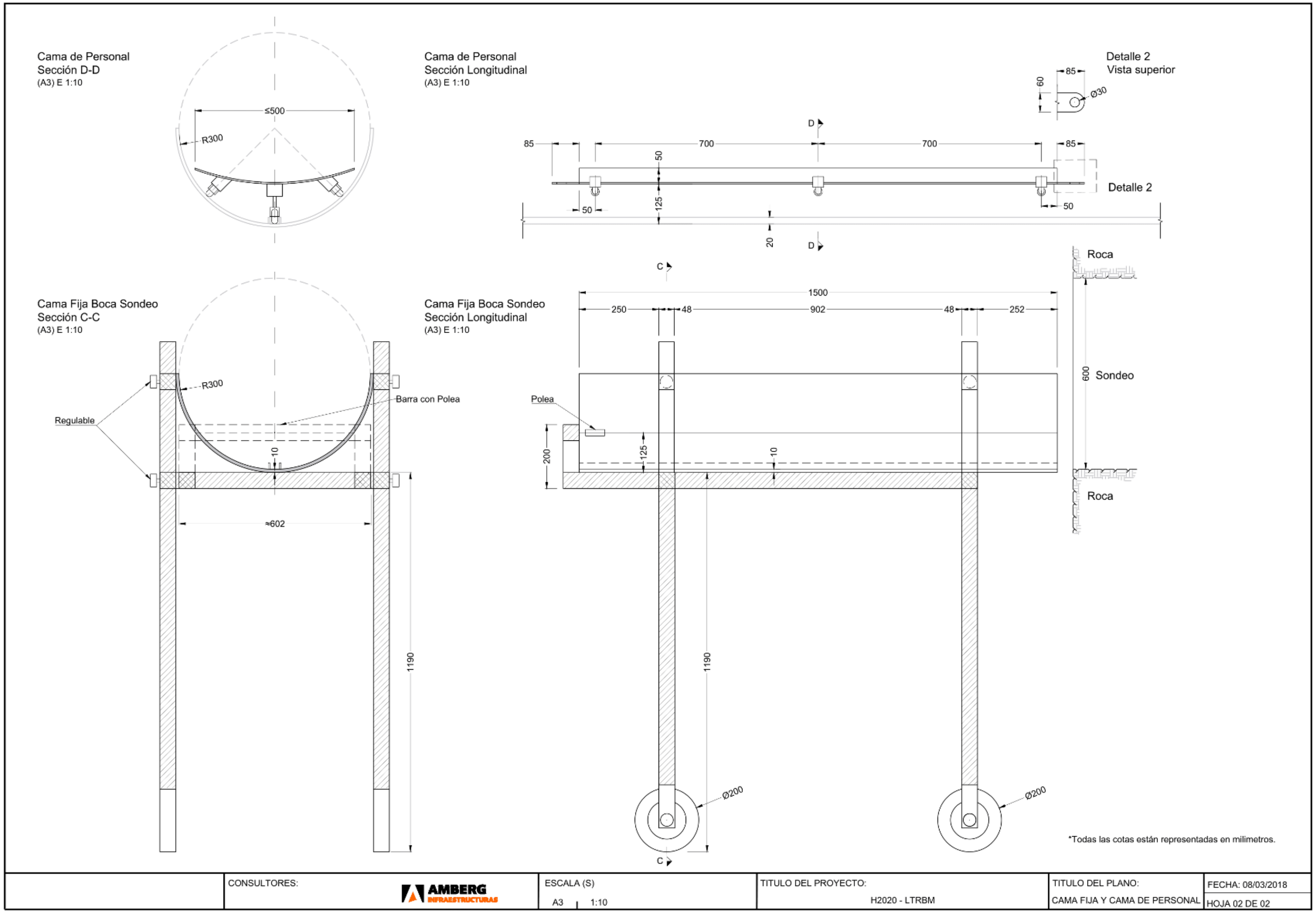
ANNEX II

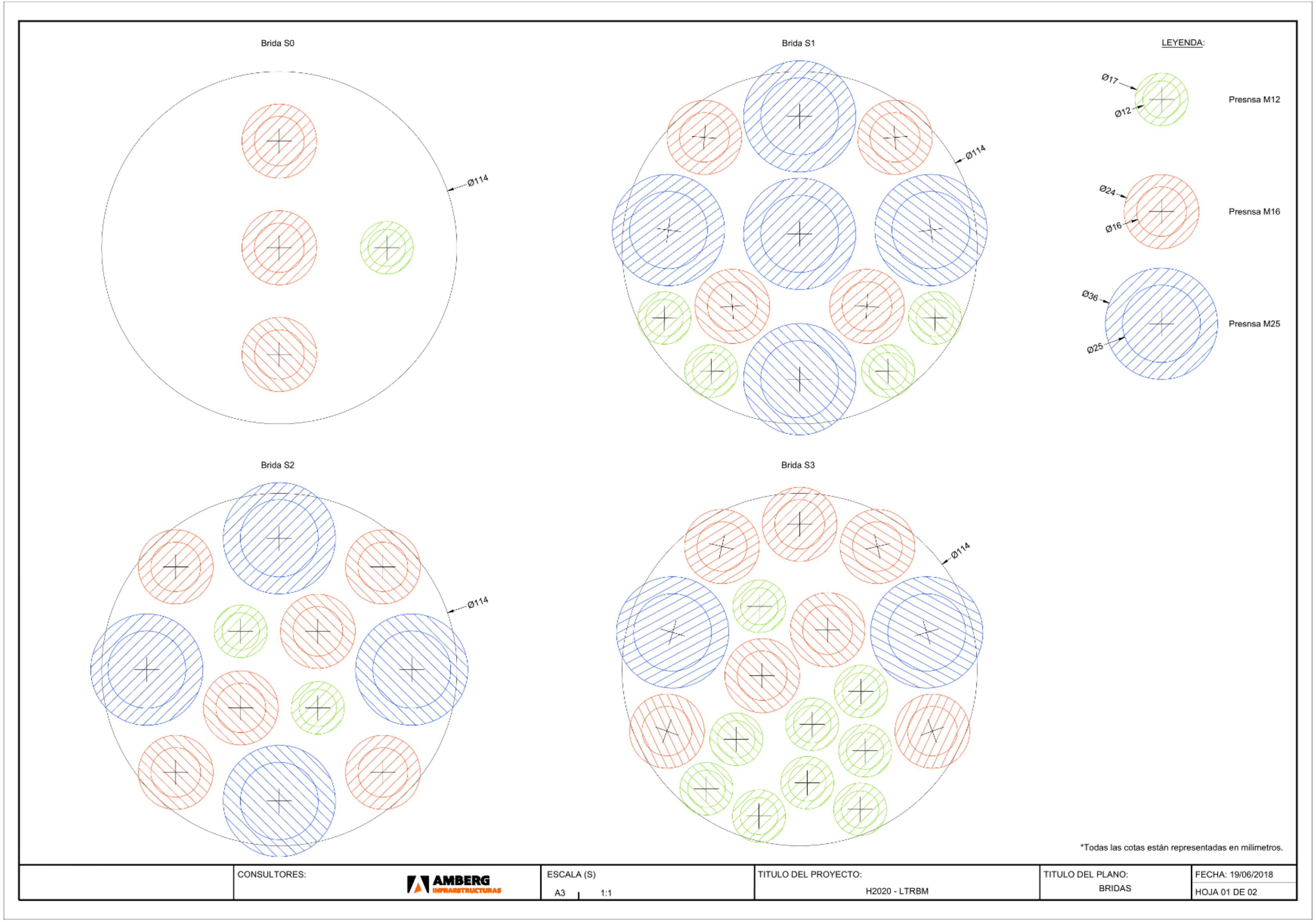
DRAWINGS

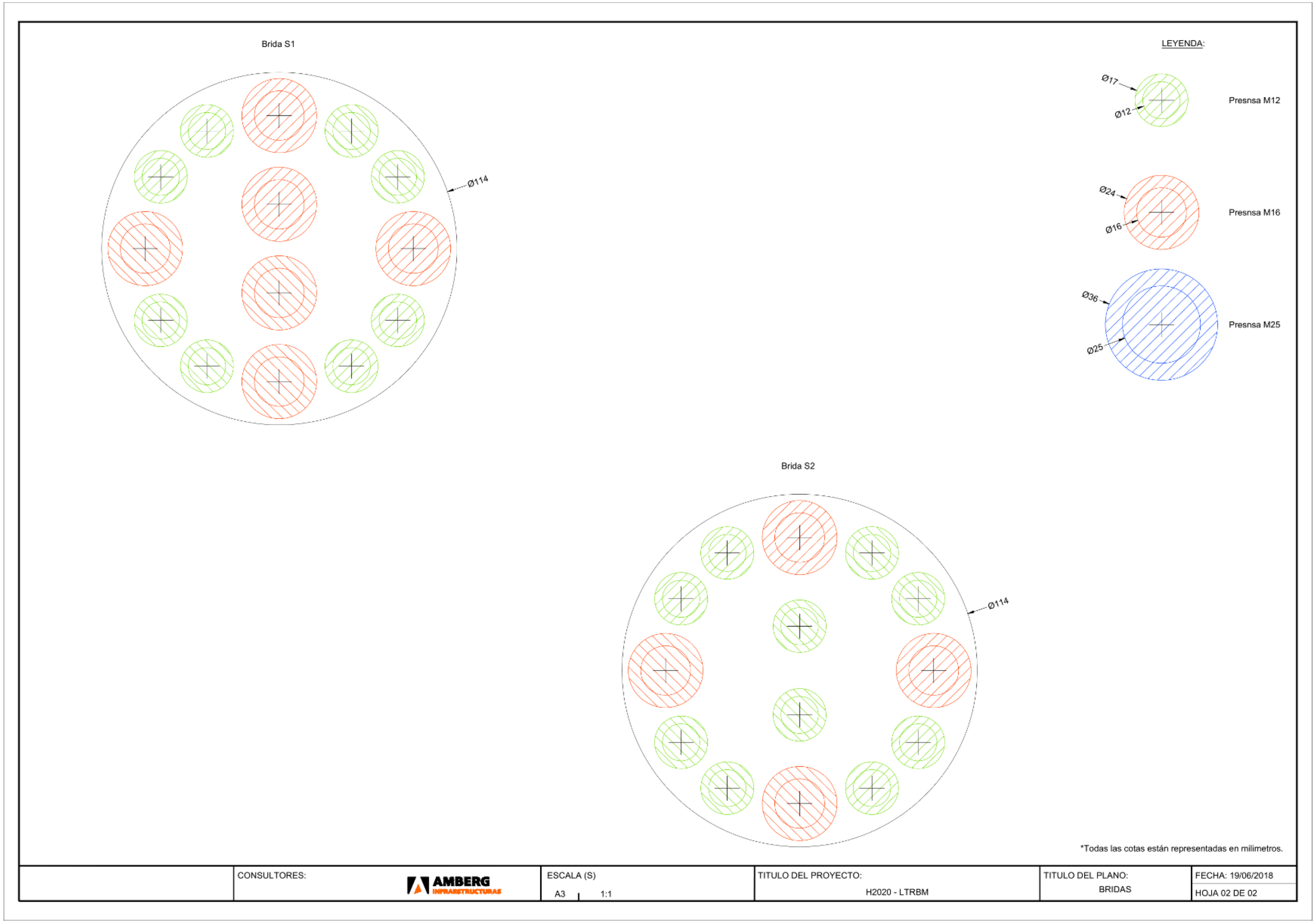

V4
Back-pressure
Manometer
0-5 bar
To water tank
From water tank
V5
V6
V8
From water pump
Drain
V7
Total pressure sensor 0-5 bar
Dim. 250x650mm
V9
Stabilizer
Total pressure
sensor 0-5 bar
V10
V13
V16
V19
V22
Manometer
0-5 bar
Water outlet 1
Water outlet 2
Water outlet 3
Water outlet 4
Water outlet 5
V11
V12
V14
V15
V17
V18
V20
V21
V23
V24
Air drain 1
Air drain 2
Air drain 3
Air drain 4
Air drain 5
Air inlet 1
Air inlet 2
Air inlet 3
Air inlet 4
Air inlet 5
Dim. 500x1300mm
CONSULTORES:
AMBERG
ESCALA (S)
A3 1:4
TITULO DEL PROYECTO:
MODERN 2020
TITULO DEL PLANO:
LTRBM
FECHA: 10/01/2018
HOJA 01 DE 01



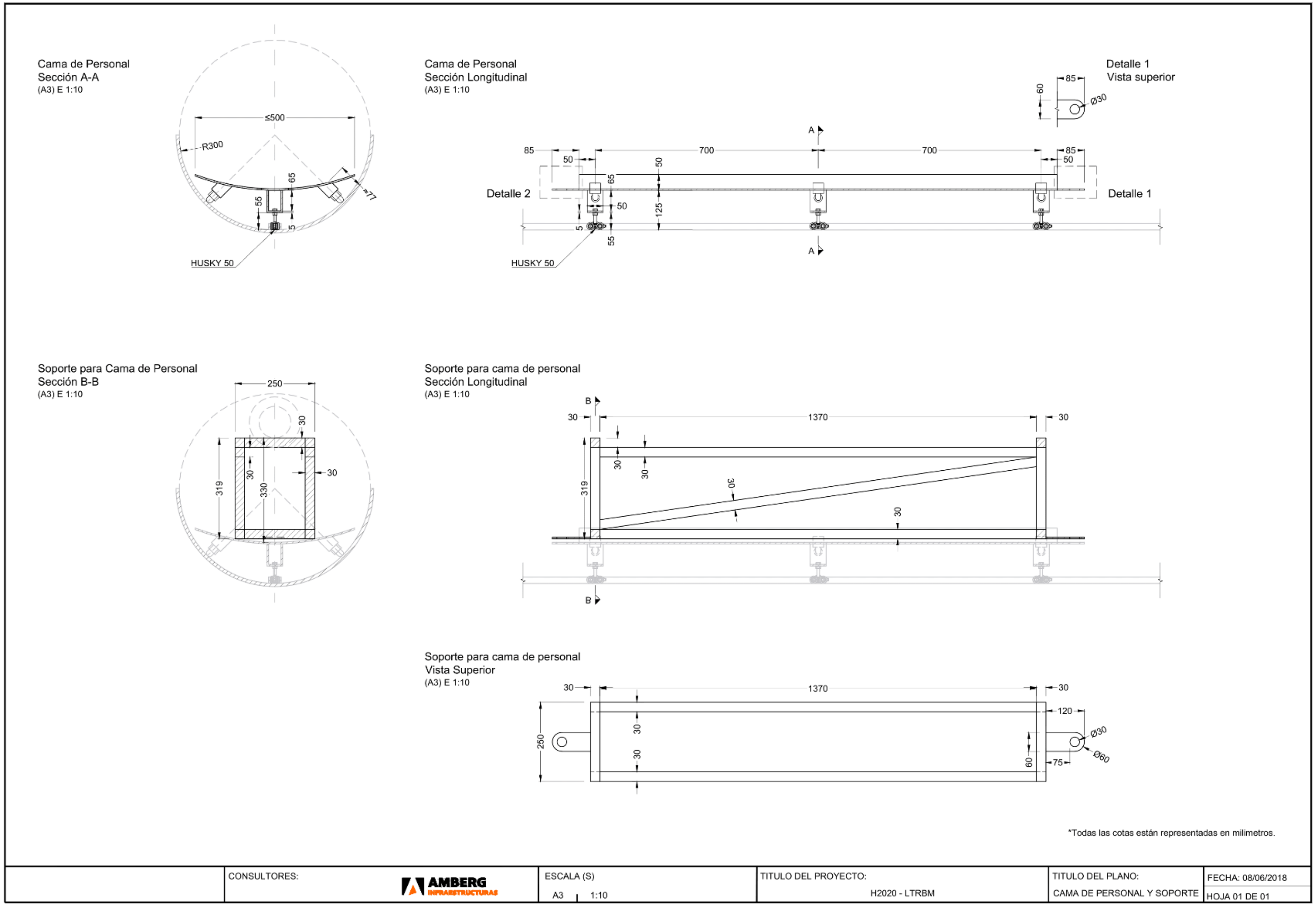
	CONSULTORES: AMBERG INFRAESTRUCTURAS	ESCALA (S) A3 1:10 / 1:2	TITULO DEL PROYECTO: H2020 - LTRBM	TITULO DEL PLANO: MESA DE MONTAJE DE BLOQUES	FECHA: 08/03/2018 HOJA 01 DE 02

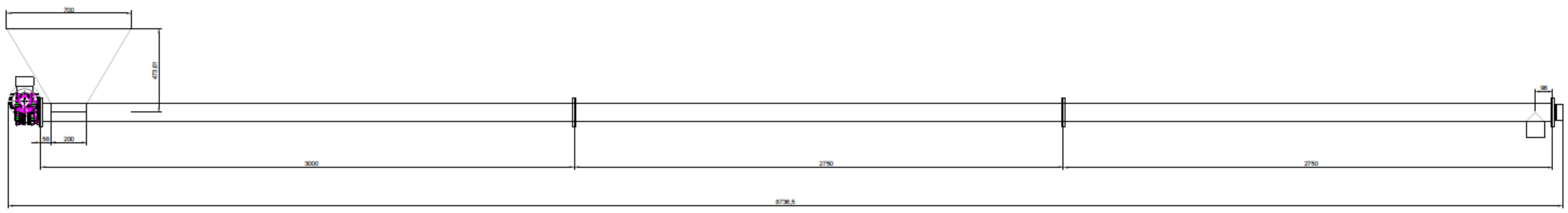

Cama de Personal
Sección D-D
(A3) E 1:10
≤500
R300
Cama de Personal
Sección Longitudinal
(A3) E 1:10
Detalle 2
Vista superior
85
60
Ø30
700
700
85
50
125
50
50
20
Detalle 2
Cama Fija Boca Sondeo
Sección C-C
(A3) E 1:10
R300
Barra con Polea
Regulable
10
≈602
1190
Cama Fija Boca Sondeo
Sección Longitudinal
(A3) E 1:10
1500
250
48
902
48
252
Roca
Sondeo
600
Roca
Polea
200
125
10
1190
Ø200
Ø200
*Todas las cotas están representadas en milímetros.
CONSULTORES:
AMBERG INFRAESTRUCTURAS
ESCALA (S)
A3 1:10
TITULO DEL PROYECTO:
H2020 - LTRBM
TITULO DEL PLANO:
CAMA FIJA Y CAMA DE PERSONAL
FECHA: 08/03/2018
HOJA 02 DE 02

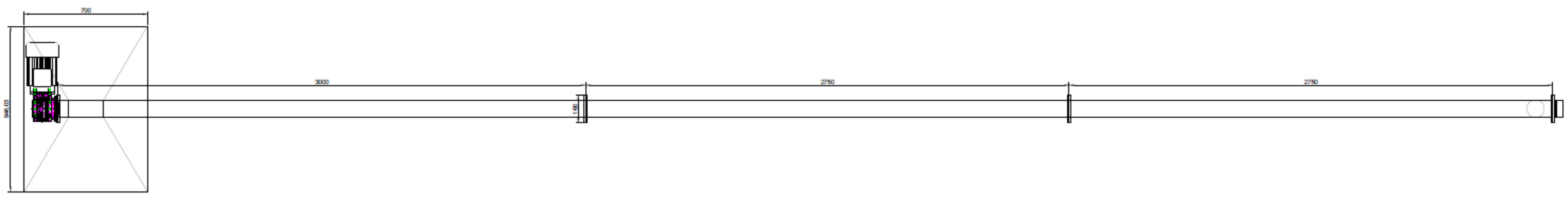

Brida S0
Ø114
Brida S1
Ø114
LEYENDA:
Ø17
Ø12
Presnsa M12
Ø24
Ø16
Presnsa M16
Ø36
Ø25
Presnsa M25
Brida S2
Ø114
Brida S3
Ø114
*Todas las cotas están representadas en milímetros.
CONSULTORES:
AMBERG INFRAESTRUCTURAS
ESCALA (S)
A3
1:1
TITULO DEL PROYECTO:
H2020 - LTRBM
TITULO DEL PLANO:
BRIDAS
FECHA: 19/06/2018
HOJA 01 DE 02

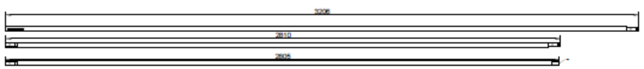


Brida S1
Ø114
LEYENDA:
Ø17
Ø12
Presnsa M12
Ø24
Ø16
Presnsa M16
Ø36
Ø25
Presnsa M25
Brida S2
Ø114
*Todas las cotas están representadas en milimetros.
CONSULTORES:
AMBERG
INFRAESTRUCTURAS
ESCALA (S)
A3
1:1
TITULO DEL PROYECTO:
H2020 - LTRBM
TITULO DEL PLANO:
BRIDAS
FECHA: 19/06/2018
HOJA 02 DE 02


Cama de Personal
Sección A-A
(A3) E 1:10
≤500
R300
65
55
5
≈77
HUSKY 50
Cama de Personal
Sección Longitudinal
(A3) E 1:10
Detalle 1
Vista superior
85
60
Ø30
A
85
50
700
700
85
50
Detalle 2
Detalle 1
65
50
125
50
5
55
HUSKY 50
A
Soporte para Cama de Personal
Sección B-B
(A3) E 1:10
250
30
30
319
30
330
Soporte para cama de personal
Sección Longitudinal
(A3) E 1:10
B
30
1370
30
30
30
319
30
30
B
Soporte para cama de personal
Vista Superior
(A3) E 1:10
30
1370
30
120
250
30
30
Ø30
60
75
Ø60
*Todas las cotas están representadas en milímetros.
CONSULTORES:
AMBERG
INFRAESTRUCTURAS
ESCALA (S)
A3
1:10
TITULO DEL PROYECTO:
H2020 - LTRBM
TITULO DEL PLANO:
CAMA DE PERSONAL Y SOPORTE
FECHA: 08/06/2018
HOJA 01 DE 01







ANNEX III

BLOCKS DETAILS

BLOCK	PART NUMBER	PRESSING POWER (MPa)	DRY DENSITY (g/cm3)	WEIGHT BEFORE MACHINING (Kg)	WEIGHT AFTER MACHINING (Kg)
0	A22	30.6	1.889	9.64	9.35
				9.32	8.75
	A28	31.7	1.866	9.45	8.97
				9.41	9.41
1	A24	31.7	1.885	19.33	19.33
	A26	28.1	1.873	19.14	18.09
	A29	31.7	1.871	19.31	18.81
	A30	31.8	1.878	19.31	19.31
2	A5	26.6	1.882	19.28	19.28
	A19	30.7	1.886	19.29	18.5
	A20	28	1.863	19.3	18.63
	A21	28.5	1.865	19.36	19.36
3	A4	25.1	1.867	19.32	19.32
	A6	26.1	1.879	19.17	19.17
	A7	26.6	1.877	19.3	19.3
	A14	24.5	1.883	19.19	18.61
4	A10	26.5	1.879	19.31	19.31
	A8	26.6	1.877	19.2	19.2
	A9	26.6	1.866	19.27	19.27
	A11	26.5	1.871	19.26	19.26
5	A2	26.6	1.883	19.21	19.16
	A12	26.6	1.882	19.2	19.2
	A15	26.5	1.86	19.26	18.59
	A25	31.7	1.881	19.26	19.26
6	A1	29.3	1.885	19.29	19.29
	A3	22	1.873	19.21	19.21

	A16	28.2	1.871	19.21	19.1
	A17	27.1	1.862	19.25	18.25
7	B1	13.2	1.516	16.38	16.38
	B2	12.3	1.513	16.3	16.3
	B3	13.2	1.519	16.26	16.26
	B4	13.3	1.52	16.36	16.36