EUROPEAN COMMISSION

Community Research

ESDRED

(Contract Number: FI6W-CT-2004-508851)

DELIVERABLE D 4.3 OF MODULE 4, WP3.2

REVISION 1

TEST PLAN FOR THE FULL SCALE DEMONSTRATION OF A SHOTCRETE PLUG

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Date of issue of this report: **20 May 2008**

Start date of project: **01 February 2004** Duration: **60** Months

Project co-funded by the European Commission under the Euratom Research and Training Programme on Nuclear Energy within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
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CO	Confidential, only for partners of the [ESDRED] project	No

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CONTENTS

1 INTRODUCTION

The previous research activities carried out within Module #4 of the IP ESDRED have provided low-pH concrete formulations suitable of being shotcreted. Thereafter, a short low-pH shotcrete plug was constructed and tested (load test to determine its bearing capacity) at the Äspö URL to investigate and validate, according to established requirements, the feasibility of its construction and performance. The results from the test provided valuable information about the mechanical behaviour of confined granite-shotcrete interfaces, which have been used for improving the plug design calculations. As a final step within Module#4, it was decided to construct and test a full-scale low-pH shotcrete plug in the Grimsel URL.

This document presents the test components, the design and the construction details. The organisation of works (roles and responsibilities) and the time schedule are also described at the end.

This is the first revision of the former document, done because the obtained density in the installed buffer was lower than initially expected and due to the difficulties found for performing the planned bentonite saturation. The introduced changes affect only to chapters 5 (Test operation), 6 (Roles and responsibilities) and 7 (Schedule).

2 EXPERIMENT DESCRIPTION

2.1 TEST LAYOUT AND OBJECTIVES

The aim of the test is to demonstrate the support capacity of such plug under realistic conditions, that is with the swelling pressure of a bentonite buffer applied at one side of the plug.

The basic layout of the foreseen full-scale demonstration test consists of a 4 m long parallel low-pH shotcrete plug constructed at the back end of a 3.5 meter diameter horizontal gallery, excavated in granite with a TBM and sealed with 1 m of highly compacted bentonite (Figure 1). The bentonite will be provided with an artificial hydration system to accelerate the saturation process and if required, to impose a pore water pressure in the buffer. Besides, several sensors and a data acquisition and control system will be installed to follow the evolution of the test.

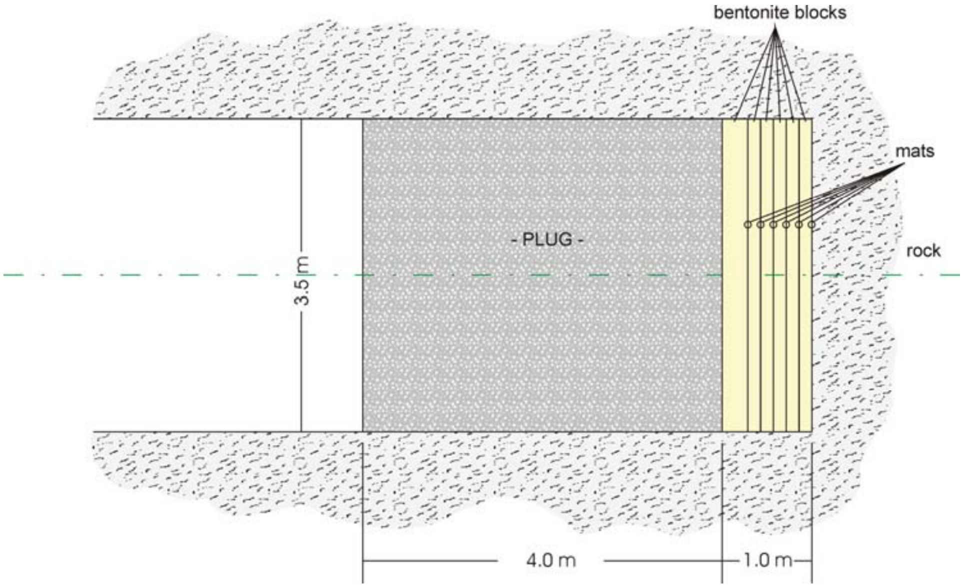


Figure 1: General layout of the full-scale test

2.2 LOCATION

2.2.1 Grimsel URL

The Grimsel Test Site or GTS is at an elevation of 1 730 metres above sea level (asl), around 450 metres below the rock surface of the Juchlistock in central Switzerland. It is linked with the northern Grimsel Pass by a short approach road and a horizontal access tunnel around 1.2 kilometres long leading to the Test Site itself. Despite the sometimes harsh alpine winter, all-year-round operation is guaranteed by the infrastructure of the power station company (KWO) which operates a tunnel railway and an aerial cable car when the pass road is closed.

The layout of the GTS consists of a branching laboratory tunnel with a total length of almost 1000 metres and a central building which houses the whole infrastructure such as offices, the ventilation plant, workshops and so on (Figure 2). The laboratory tunnel has a diameter of 3.50 metres and was bored in six months using a full-face tunnelling machine (TBM).

Figure 2 shows the locations of the most important experiments which have been performed in the GTS.

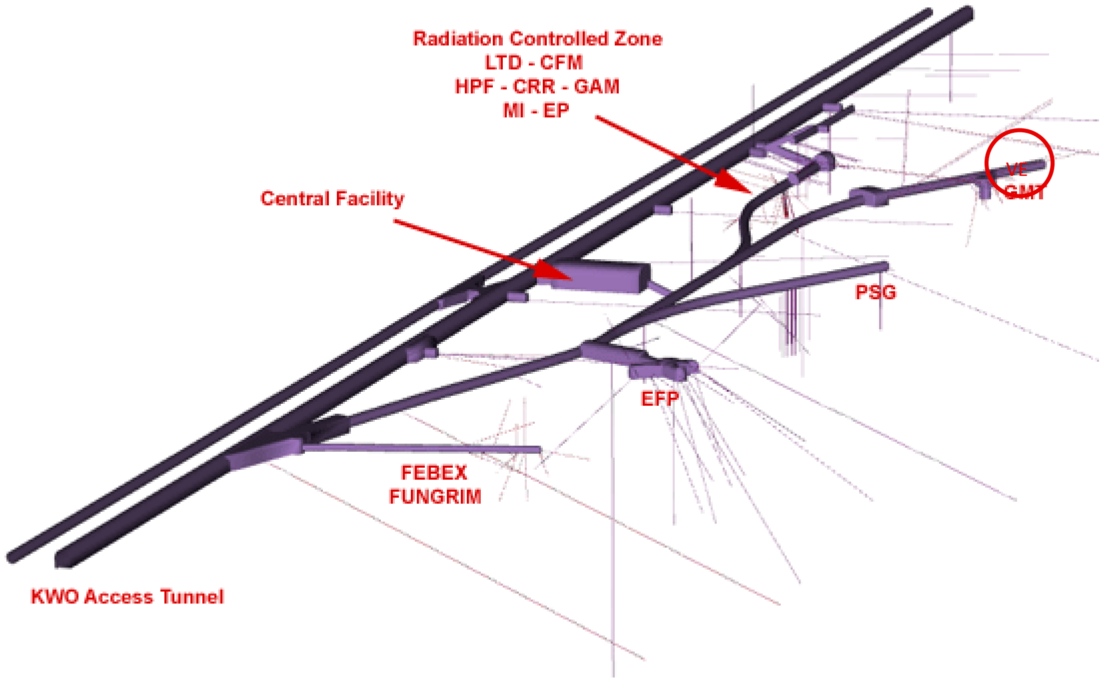


Figure 2: Layout of Grimsel Test Site (Source: www.grimsel.com)

2.2.2 Testing site

The main demonstration test will be carried out at the end of the VE-tunnel (Figure 2 and Test area at Figure 3). All the necessary equipment for the Hydration System (HS) and the Data Acquisition, Display and Control System (DADCS) will be located in the access gallery to the GMT cavern (Equipment area).

The cables and/or tubes from the bentonite chamber to the Equipment area will be conducted through a borehole, drilled from a side gallery to avoid crossing the plug-rock contact. No instruments and cables will 'hinder' the construction of the plug.

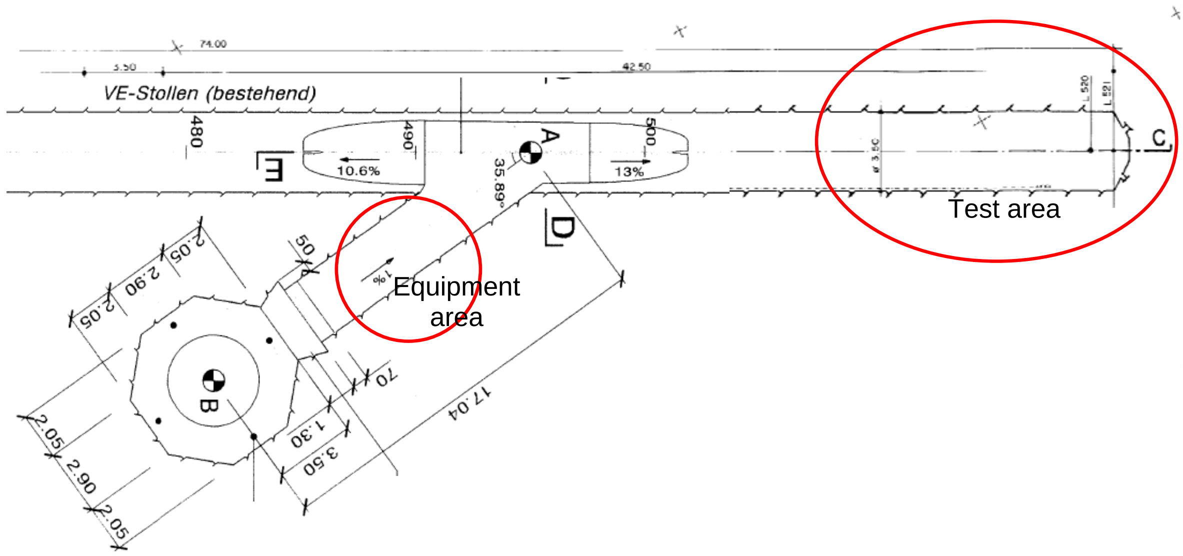


Figure 3: General layout of the full-scale test at VE tunnel

3 TEST COMPONENTS

The required test components comprise the demonstration shotcrete plug, the bentonite buffer, the artificial hydration system, the instrumentation or sensors and the data acquisition and control system. They are fully described in the next sections.

3.1 SHOTCRETE PLUG

3.1.1 Design

Mechanical calculations have been made with FLAC code for a low-pH shotcrete plug measuring 4 m in length and 3.5 m in diameter. An elasto-plastic Mohr-Coulumb model without hydraulic coupling has been assumed, taking into account the experience gained from the Äspö test. According to the calculations, the maximum pressure that the plug can support is estimated in 5 MPa.

Granite parameters:

- Density (γ) = 2600 kg/m^3
- Porosity (n) = 0.01
- Young's modulus (E) = 50 000 MPa
- Poisson's ratio (ν) = 0.30
- Friction angle (ϕ') = 50^o
- Cohesion (c′) = 12 MPa
- Tensile strength (T) = 10 MPa

Shotcrete parameters:

- Density (γ) = 2200 kg/m^3
- Porosity (n) = 0.18
- Young's modulus (E_s) = 18 000 MPa
- Poisson's ratio (ν) = 0.25
- Friction angle (ϕ') = 38^o
- Cohesion (c′) = 3 MPa
- Tensile strength (T) = 1.5 MPa
- Hydraulic conductivity = 10^{-10} m/s

Ubiquitous joint parameters (estimated from Äspö test):

- Friction angle (ϕ'_j) = 38^o
- Cohesion (c'_j) = 0.1 MPa
- Tensile strength (T_j) = 0.1 MPa
- Dilatance angle (ψ_j) = 12^o

The dilation angle was set equal to zero if the interface displacement is greater than 1 mm.

3.1.2 Shotcrete equipment and formulation

The shotcreting equipment will be similar to that used in the Äspö URL test, i.e. a MEYCO Suprema concrete pump with a 30 kW drive and electronic admixture dosage control, providing a maximum output of 3 to 20 m^3/h. Given the bigger size of the gallery a shotcreting robot will be used for the concrete spraying (see more details at 4.1).

The main components of the shotcrete will be similar to those used for the short plug construction but the aggregate will be local and therefore different from those used for Äspö URL. Therefore some adjustments in the shotcrete formulation have been performed by ICCET to adapt it to the new aggregate. The proposed formulation can be found in Table 1.

Table 1. Proposed formulation for long plug

Component	Quantity (kg/m^3)
Portland Cement CEM I 42.5 R/SR	165
Silica fume	110
Water	205
Limestone filler	70
Fine size aggregates (0-4 mm)	1 045
Medium size aggregates (4-8 mm)	590
Superplastizer SIKAMENT TN 100	2.8
Accelerant SIGUNITA L53 AF S	16.5

3.2 BENTONITE BUFFER

A one meter thick bentonite buffer will be built at the rear end of the VE gallery with layers of highly compacted bentonite blocks.

3.2.1 Bentonite blocks

The bentonite blocks dimensions are shown in Figure 4. They will be manufactured from powder bentonite from the Cortijo de Archidona deposit in the Cabo de Gata region (Almería, Spain). The bentonite, with a water content estimated on 12 % in weight, will be compacted to a dry density of 1.70 g/cm^3.

The dry density of the blocks was calculated to obtain a mean swelling pressure of the buffer of 4.5 MPa when fully hydrated, assuming an expected global dry density of 1,562[1] g/cm^3. The initial voids volume in the buffer (construction voids and mats) was estimated in 9 % of the total bentonite volume. According to FEBEX laboratory works, the maximum natural variability of the bentonite for such final dry density should be of 25 % approximately.

[1] According to the formula $\ln P = 6.77 \cdot \rho_s - 9.07$ from ENRESA's Technical Publication 05-0/2006: "Full-Scale Engineered Barriers Experiment. Updated final Report 1994-2004". 2006.

The blocks dimensions will be controlled statistically and then they will be packed over standard euro-pallets with mechanical and moisture protection to be transported to the GTS.

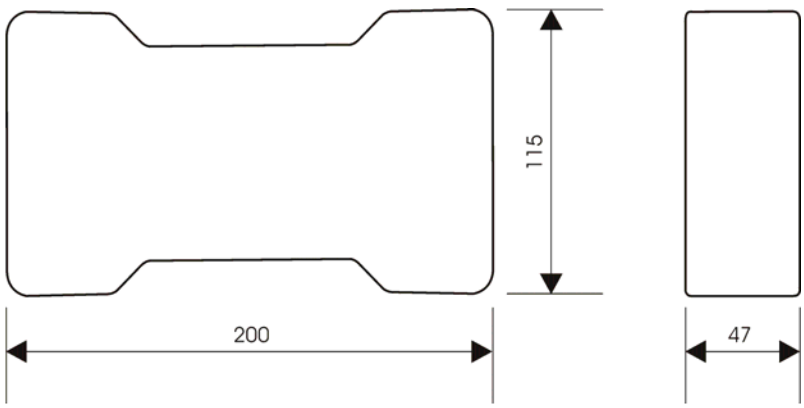


Figure 4. Blocks dimensions (mm)

The final buffer chamber volume is estimated in 9,81 m^3 (3,5 m in diameter by 1,02 m long) due to the expected construction adjustments. The bentonite amount is estimated in 15,46 Tons for the 20 layers of blocks (47 mm each longitudinally) taking into account the construction voids. At least a 20% in excess of blocks will be manufactured to compensate the expected construction losses and to have a reserve margin.

3.3 ARTIFICIAL HYDRATION SYSTEM

The artificial hydration system will be composed of 6 hydration mats (S) installed in the bentonite chamber between the bentonite blocks layers and connected by tubes with a water injection system located in the service area outside the test section.

3.3.1 Hydration mats

Hydration mats will be installed perpendicular to the gallery axis between every three layers of bentonite blocks, thus leaving 141 mm of bentonite in between to guarantee a fast enough hydration of the blocks, with the first mat located at the back end of the buffer chamber (in contact with the concrete that will be used to flatten the rock) and leaving the last five bentonite blocks layers without hydration mat (those closer to the concrete plug).

Each mat (S1 to S6) will be composed of four layers of geotextile Geotesan NT30 with ¼" OD AISI 316L perforated hydration tubes in between to distribute the water (see tubes layout in Figure 5). Four perforated tubes in a cross array are foreseen per mat, joined in the middle with a double T fitting. The tube at right hand side from each mat will be extended up to connect with a distribution panel located at the service area by using tubes led through the pass-through borehole. Another perforated tube, for de-aireation first and for water injection afterwards, will be placed on top of each mat, all of them connected in the same way to another distribution panel.

The initial thickness of each mat is estimated in 10 mm with a minimum of 2 mm for the maximum swelling pressure of the bentonite.

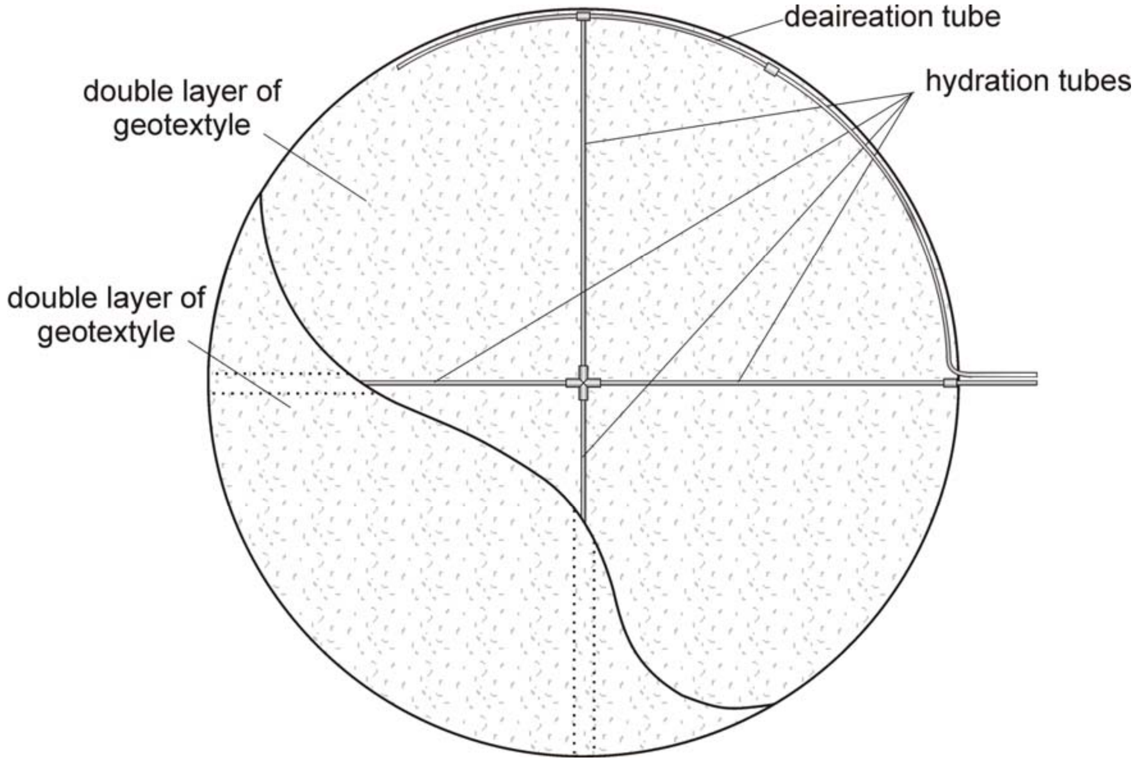


Figure 5. Hydration mat

3.3.2 Water injection system

The water injection system to be installed is intended to fill with water the mats inside the bentonite chamber at a low pressure (maximum 0.1 or 0.2 MPa) to hydrate the bentonite blocks. Afterwards, and if needed, it could serve to impose a pore water pressure in the buffer. The water to be used is normal tunnel water (formation water).

The water injection system will be composed basically of two pumps fed from a water tank and connected to the distribution panels of the mats (Figure 6). The distribution panels for the mats will be used to connect each mat individually to the injection system if required.

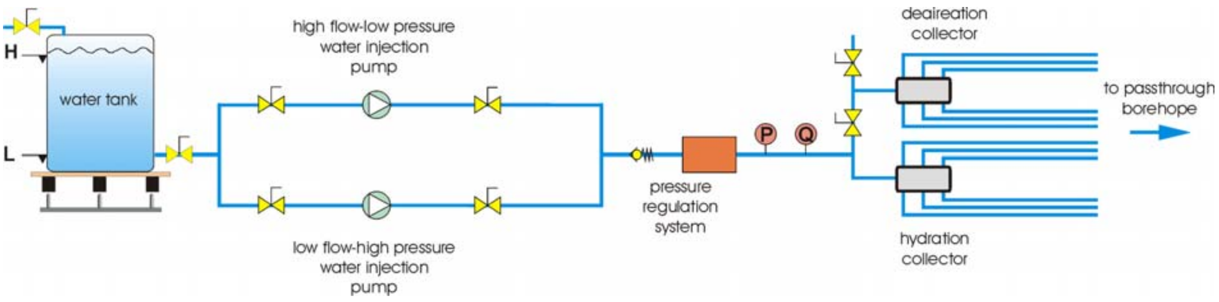


Figure 6. Water injection system (basis)

The pumps, the water tank and associated instrumentation (valves, sensors, indicators...) will be located at the equipment area and close enough to the passthrough borehole.

Water tank

The water tank will have at least 1 m^3 of capacity. It will be made of polyethylene or a similar plastic material and it will be provided with level switches to control the high and low levels for safety reasons. The filling of the tank will be done manually, when required, by the staff on site.

Pumps

Two pumps are foreseen, an HPLC type pump capable of providing a water flow of 1 l/min with a maximum pressure of 50 bar and a flow controllable piston pump with a flow of 0 to 155 ml/min and up to 140 bar of pressure. The HPLC pump will be used at low pressure (maximum 0.7 MPa) to hydrate the blocks.

The water in-flow and pressure will be controlled by manual pressure regulators and manual type two-way ball valves. Besides, electrically operated two-way ball valves will be required to remotely control the injection system and for safety reasons (automatic safe actions). Pressure transducers will be installed for the water pressures recording. All metallic parts will be SS316L or similar quality.

3.4 SENSORS

3.4.1 General description

A number of sensors measuring different parameters will be embedded at different locations in the rock, in the bentonite and in the shotcrete mass during the construction, allowing the continuous monitoring during the test operation phase by means of the associated DADCS. The used sensors are conventional (wired) but there are a number of them connected to a wireless transmission system (see 3.4.2).

The sensors in the rock will consist on piezometers installed in four short radial boreholes, total pressure cells installed in the rock surface for measuring the radial pressure in the interface shotcrete/rock and total pressure cells installed in the rear part of the bentonite chamber to follow the swelling pressure of the buffer.

Humidity sensors will be installed in the middle of some bentonite buffer layers to follow the hydration process. Besides, some piezometres will be installed within the buffer and at the plug-buffer interface too.

The foreseen sensors in the shotcrete mass will consist of piezometers and total pressure cells: two piezometers will be inserted in two horizontal boreholes measuring at least 17 mm in diameter, drilled from the plug face up to 0.5 m from the rear end; five total pressure cells will be installed on the plug surface at the contact with the buffer for measuring the pressure exerted by the bentonite buffer.

After finishing the plug construction, four extensometers will be placed at the plug face for tracking potential displacements.

3.4.2 Wireless system

Monitoring is one of the issues receiving increasingly more attention within the repository program. Especially wireless techniques enable interesting options for repository monitoring concepts. The objective of the task "wireless monitoring" is to assess the performance of the magneto inductive signal transmission through a geological and engineered barrier, in combination with a specially adapted Solexperts data acquisition system monitoring key parameters within the engineered barrier.

The main components of the wireless sensors setup are as follows (Figure 7):

(i) The sensors emplaced within the bentonite section: 2 pore pressure transducers. 2 total pressure cells and two water content probes will be installed in the 1 m long bentonite section.

(ii) The data logger, measuring the sensors and acting as power supply for the sensors. The data logger is placed in an 800 mm long 101 mm diameter borehole (see Figure 7). Battery capacity of the logger is designed for a monitoring period of 3 years.

(iii) MISL transmitter connected to the data logger sending wirelessly the collected data to the MISL receiver. The MISL transmitter is placed in a 600 mm long, minimal 225 mm diameter borehole (see Figure 7). Battery capacity of the transmitter is designed for a monitoring period of at least 3 years.

(iv) MISL receiver; the receiver is normally placed in a nearby drift and connected to a PC equipped with remote control features. In order to check the range for successful data transmission the location of the receiver will be changed regularly.

The sensors will be installed in section B4 except for the total pressure cells which will be installed at the interface of the bentonite section with the tunnel face. In order to place the data acquisition system and the transmitter for the wireless data transmission, two boreholes will be drilled at the tunnel face. For the MISL transmitter a 650 mm long about 20° downwards inclined borehole of a minimal diameter of 225 mm is required. The data acquisition system will be installed in a 800 mm long 101mm diameter borehole also downwards inclined by about 20°. After emplacement of the transmitter and the data acquisition system the annulus of the boreholes will be grouted.

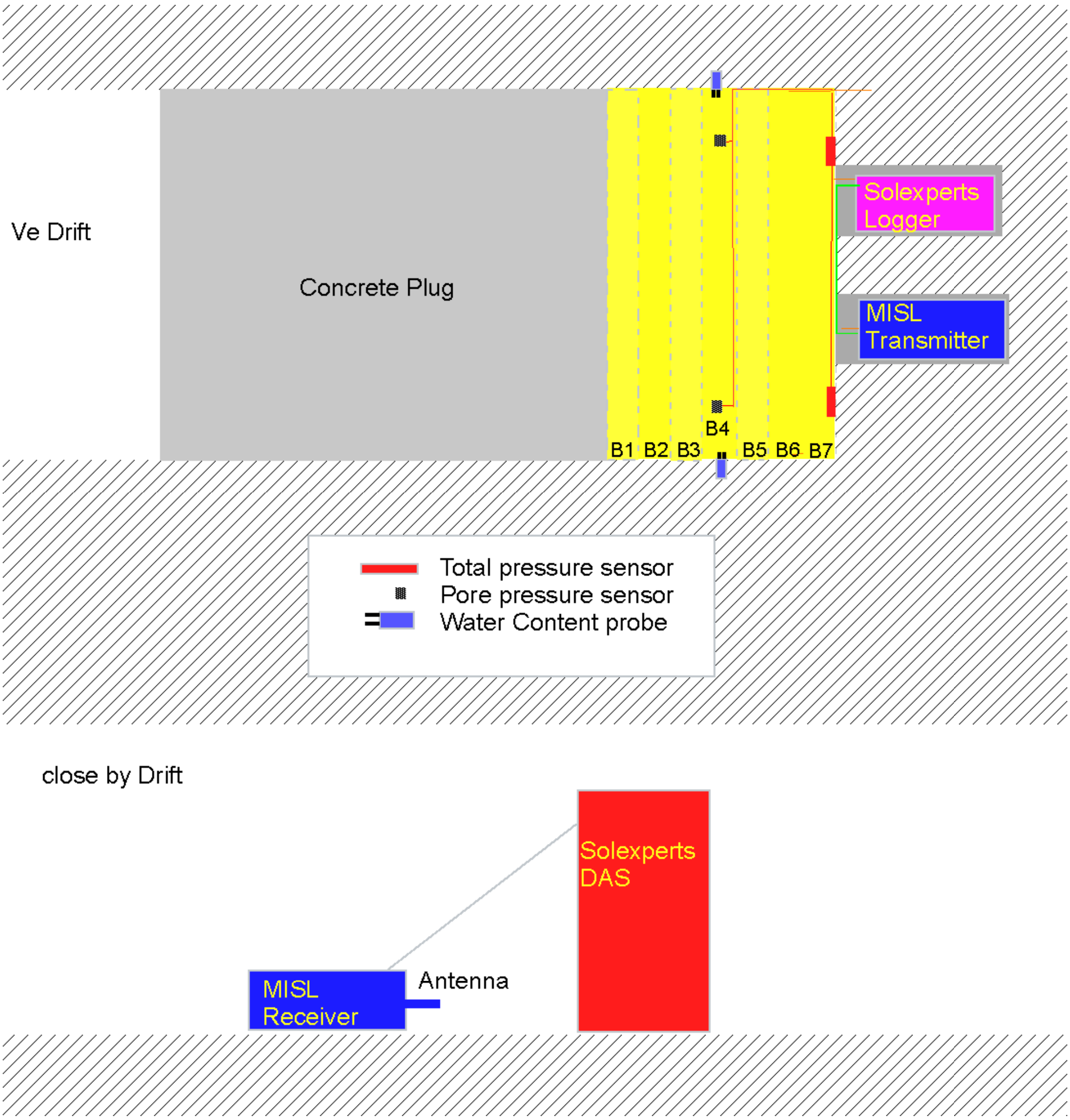


Figure 7: Schematic layout of the wireless monitoring test setup.

3.4.3 Environmental requirements

At the bentonite buffer, the possible effects of the salinity of the pore water and the high pressures to be applied should be taken into account when selecting the sensors and the corresponding cables and cables entry solutions.

3.4.4 Sensors coding system

The sensors will be identified according to a code of the type:

TSS-N

where

T is the sensor type (see Table 2)

SS represents the positioning area:

Test area: instrumented section code (A, B1 to B7, C1 to C5)
Water injection system: *WI*
Spare units: *SP*

N is an order number, only necessary in case that more than one sensor of the same type is installed in the same positioning area. It starts by 1 and increases with the radius r and for the same radius, increases with the value of the angle α.

Table 2: Codes for types of sensors

Tp	Total pressure (absolute)
Pz & Pp	Pore Pressure (absolute)
Dz	Displacement
Hs & Hv	Relative humidity (Water content)
W	Water content (Theta probe)
G	Fluid pressure (relative)
Q	Water flow
L	Level

3.4.5 General Layout

A general layout including the position of sensors and instrumented sections, except those of the wireless system that are shown at Figure 7 and Figure 17, can be seen in Figure 8.

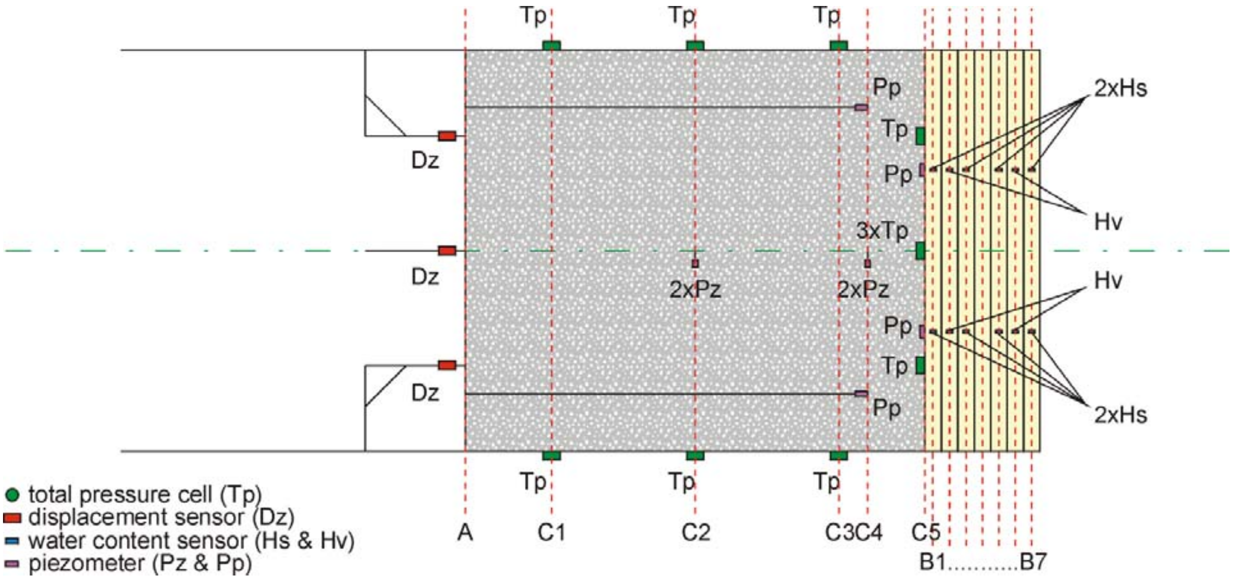


Figure 8. General layout of instrumentation(except wireless sensors)

All the instrumented sections can be seen from Figure 9 to Figure 17.

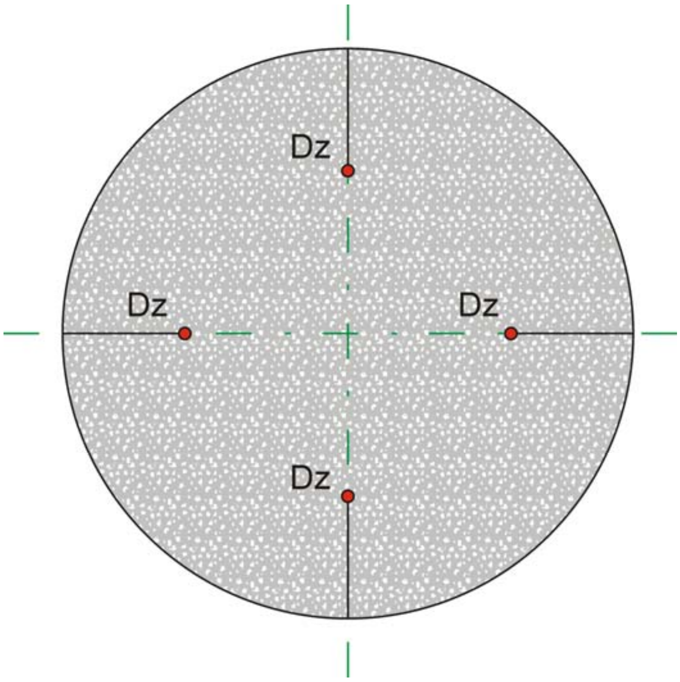


Figure 9. Instrumented section A

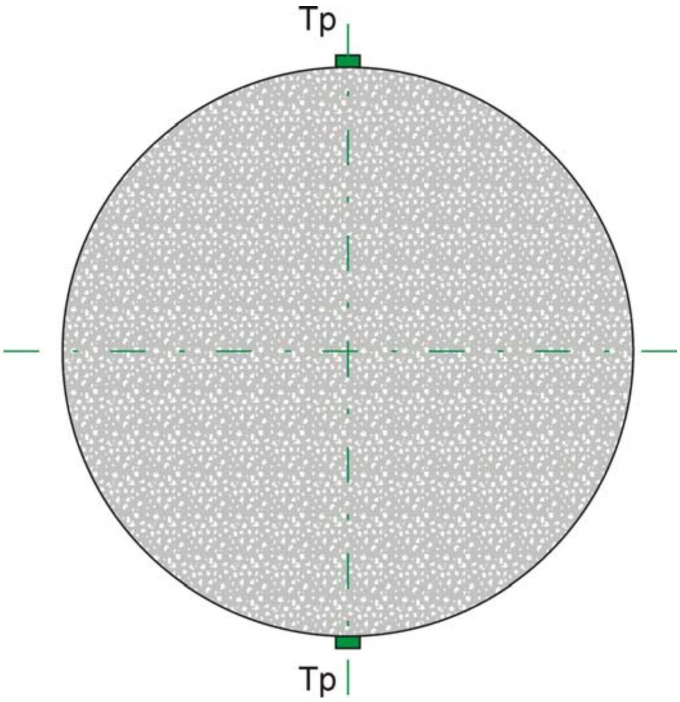


Figure 10. Instrumented sections C1 and C3

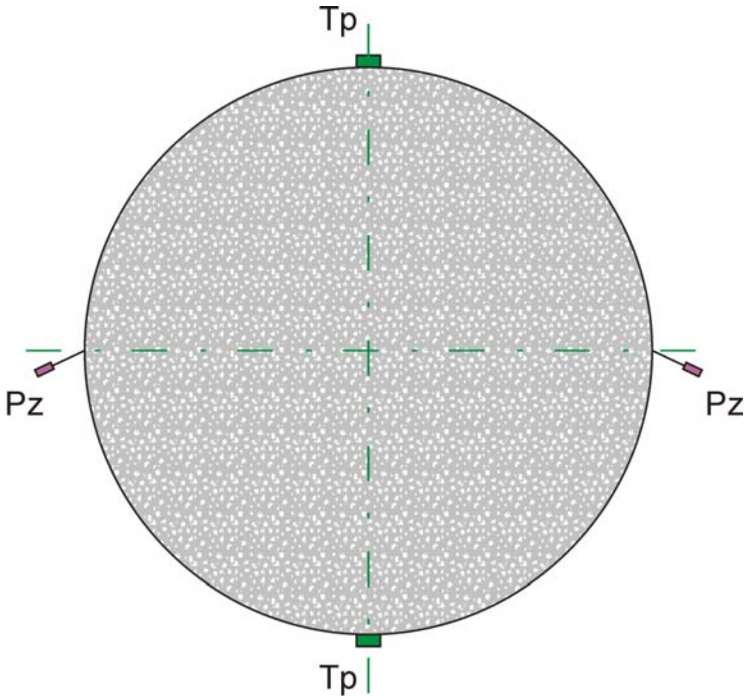


Figure 11. Instrumented section C2

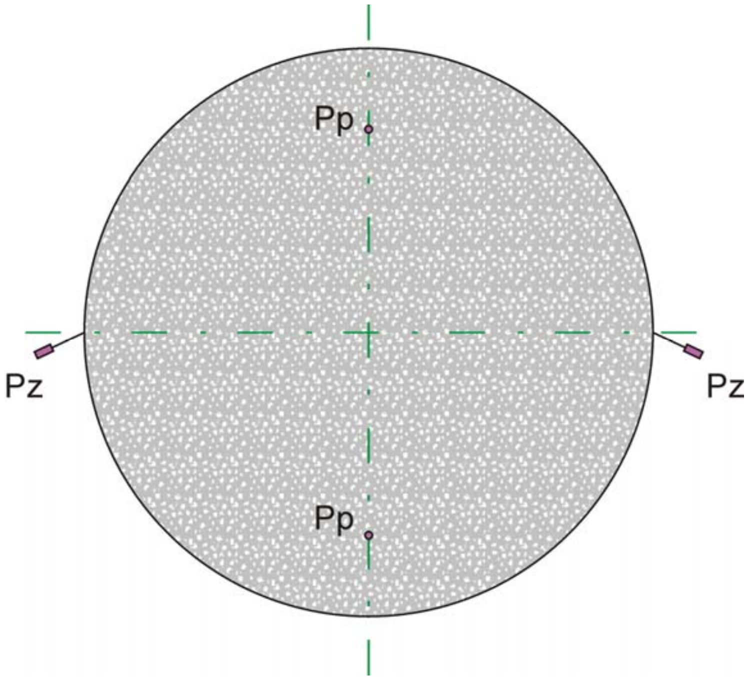


Figure 12. Instrumented section C4

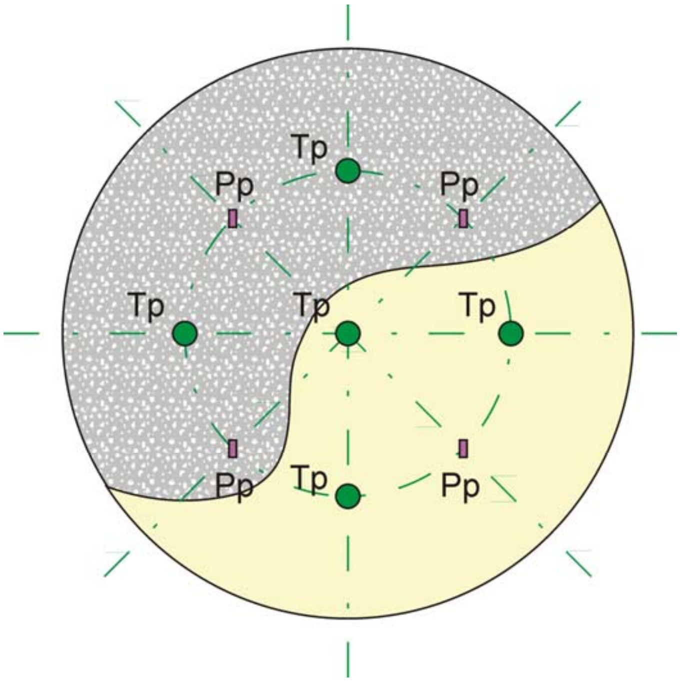


Figure 13. Instrumented section C5

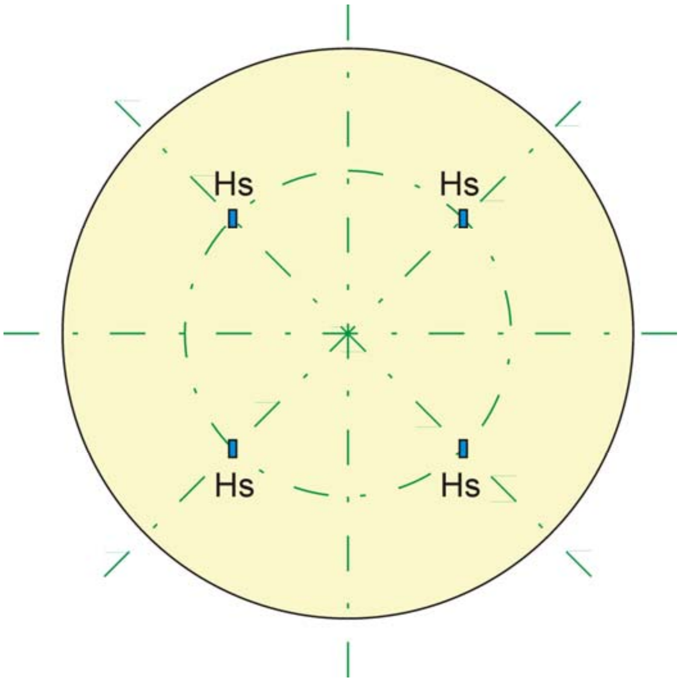


Figure 14. Instrumented sections B1 and B7

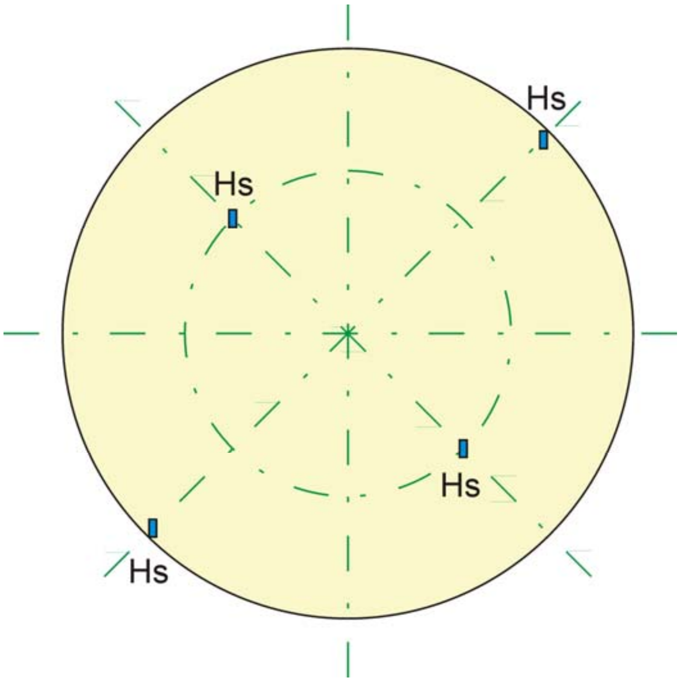


Figure 15. Instrumented sections B3 and B5

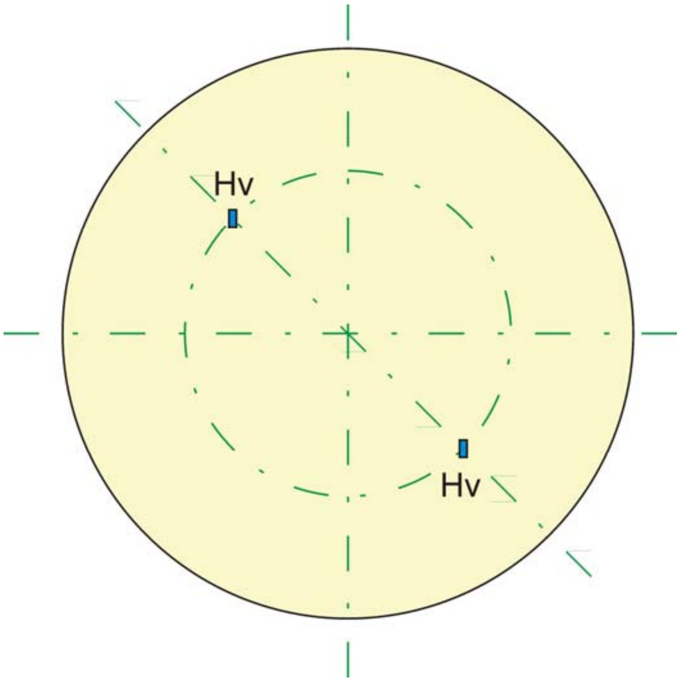


Figure 16. Instrumented sections B2 and B6

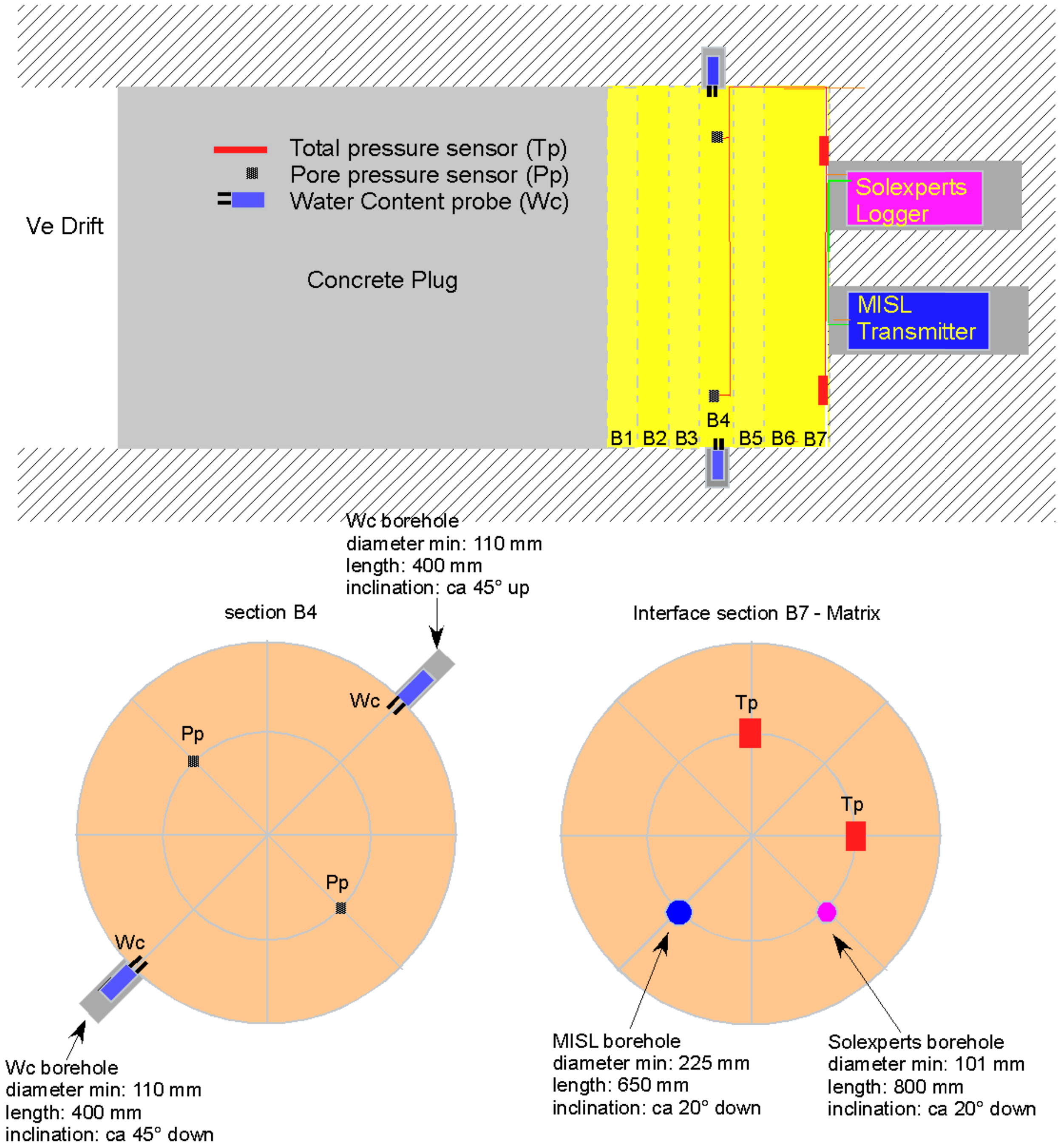


Figure 17. Instrumented section B4 and buffer back-end

3.4.6 Rock instrumentation

Total pressure (Tp)

Six total pressure cells will be installed in the rock surface (sections C1, C2 and C3) to measure the pressure transmitted by the plug to the rock but avoiding any interference with the plug construction or its functioning.

These cells will be of the "jackout" type sensor with a reinforced back plate (i.e. registers load on only one side of the cell) (see Figure 18). The transducer is placed perpendicularly in the back plate. All the assembly is introduced into a short borehole of the adequate diameter, and embedded into mortar, leaving a thin mortar layer between the sensing plate and the surface of the gallery, in contact with the concrete plug.

Characteristics of the suggested model follows.

Make/Model:	Geokon 4820 “Jackout Cell”
Measuring Principle:	Vibrating Wire
Measurement Range:	0 – 2 MPa
Over range capacity:	150 % FS
Output Signal:	2000 – 3000 Hz
Accuracy:	0.1 % FS
Resolution:	0.025 % FS
Cell Diameter:	150 mm
Cell Thickness:	12 mm
Material:	stainless steel SS316L
Cable:	5 mm dia., PVC
Temp. compensation:	By internal thermistor.
Cable connection:	Gas tight, epoxy potted
Nº of wires:	4, Teflon insulation

Figure 18. Pressure cell in rock

<u>Pore pressure (Pz)</u>

Pore pressure will be measured in the four short boreholes drilled in the rock with piezometers constructed as follows: a ¼” SS316L tubing with a sintered filter in its end will be introduced into each borehole. Another tubing of lower diameter (1/16”) will run into the tubing, thus providing a second line for flushing. The borehole mouth will be sealed with resin, leaving enclosed the filter zone. Both tubings will be extended to one of the two dedicated valve panels: one in the service area for the piezometer’s tubings led through the pass-through borehole (section C2), and another in the gallery for the piezometer’s tubings coming through the plug (section C4). In the panels, each external tubing will be connected to a pressure transducer and to a manometer for the remote monitoring and the in situ checking of water pressure, respectively. Each internal tubing will be connected to the necessary valve and port for flushing.

The transducers will be conventional absolute pressure transducers (see Figure 19). The main characteristics of the suggested model are the following:

Model:	KELLER PAA23
Pressure range:	0-60 bar
Accuracy:	0.2% FS
Output:	4 – 20 mA
Cable connection:	4 pin plug
Material:	Stainless steel 316L
Connection:	G ¼"

Figure 19. Example of pressure transducer

3.4.7 Plug instrumentation

Pore pressure (Pp)

Two piezometres as those installed in the rock will be placed into the plug, in the boreholes drilled along its length up to 0.5 m from its rear end (section C4). The tubings from these piezometers will be extended up to the valve panel in the gallery. Another four piezometers will be placed in the contact concrete-bentonite (section C5). These will be extended through the pass-through borehole up to the valve panel in the service area.

Total pressure (Tp)

Five total pressure cells will be installed in the contact concrete-bentonite (section C5) to measure the pressure produced by the bentonite swelling. The total pressure cells will be of the "pancake" type sensor with a reinforced back plate (see Figure 20). The thin sensing plate is mounted on the bentonite while the reinforced back plate is facing the plug.

Characteristics of the suggested model follows.

Make/Model:	Geokon 4810 "Fat-Back Cell"
Measuring Principle:	Vibrating Wire
Measurement Range:	0 – 5 MPa
Over range capacity:	150 % FS
Output Signal:	1200 – 2000 Hz
Sensivity:	0.025 % FS
Accuracy:	0.25 % FS
Resolution:	0.1 % FS
Cell Diameter:	150 mm
Cell Thickness:	12 mm
Material:	stainless steel SS316L
Cable:	5 mm dia., PVC
Temp. compensation:	By internal thermistor.

Cable connection:	Gas tight, epoxy potted
Nº of wires:	4, Teflon insulation

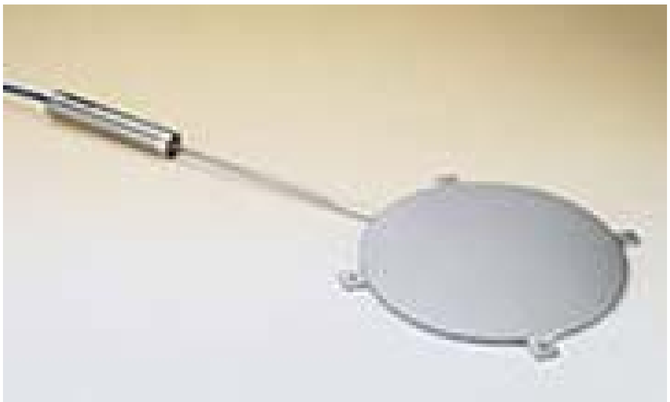


Figure 20. Fat-back total pressure cell.

Displacement sensors (Dz)

Three linear displacement transducers will be installed in contact with the plug surface (entry face, section A) in order to measure any potential movements of the plug. These are LVDT sensors whose characteristics are given below.

Model:	DCTH100AG-l10
Measuring Principle:	LVDT
Measurement Range:	±2,5 mm
Output Signal:	0-10 VDC
Accuracy:	0.1 % FS

The extensometers will be installed with the measuring shaft perpendicular to the concrete plug surface, touching a metallic piece fixed to the concrete. The sensor body will be attached to the drift surface by means of a metallic support (see for instance Figure 21).

Figure 21: Displacement sensor attached to the concrete plug surface (Äspö test)

3.4.8 Bentonite instrumentation

Humidity - Vaisala (Hv)

Four capacitive humidity sensors with associated temperature measurement will be installed in the bentonite buffer. They will be placed centered in the lower right and the upper left quadrants of bentonite layers 2 and 6, with the filter in the middle of the layers thickness (sections B2 and B6). The main features of the selected model follow (Figure 22):

Make/Model:	VAISALA/HMT330
Measuring Principle:	Capacitive (RH)/Pt 100 (temp)
Measurement Range:	0…100 % RH/ -40…+60 ºC
Output Signal:	0-10 VDC
Accuracy:	±1 %RH for 0…90 %RH
	±1.7 %RH for 90…100 %RH
	±0.2 ºC at 20 ºC
Housing material:	G-AlSi 10 Mg (DIN 1725)
Housing classification:	IP65 (NEMA 4)

Figure 22: Humidity sensor from Vaisala

Humidity - Sensirion (Hs)

Sixteen capacitive humidity sensors with associated temperature measurement will be installed in the bentonite buffer. They will be placed centered in the four quadrants of bentonite layers 1, 3, 5 and 7, with the filter in the middle of the layers thickness (sections B2 and B6). The main features of the selected model follow (Figure 23):

Make/Model:	SENSIRION/SHT75
Measuring Principle:	Capacitive (RH)/Bandgap (temp)
Measurement Range:	0…100 % RH/-40…+124 ºC
Output Signal:	12 bit digital reading/14 bit digital reading
Resolution:	0.03 %RH/0.01 ºC
Accuracy:	±1.8 %RH/±0.3 ºC at 25 ºC
Housing materials:	body: stainless steel
	filter: sintered metal
	cable: metal sheathed

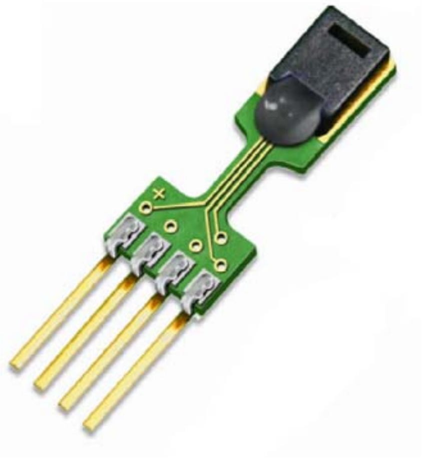


Figure 23: Humidity sensor from Sensirion (internal view)

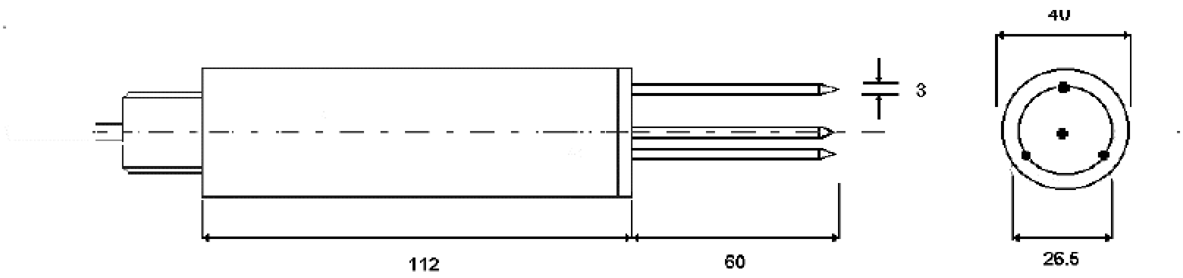
Water content – Theta probe (W)

Water content will be measured within the bentonite section B4 using Theta Probe soil moisture sensors. The probes are equipped with additional protection housings in order to withstand total pressures up to 5 MPa and 15 bar pore water pressure. The Theta Probe measures volumetric soil moisture content by the well established method of responding to changes in the apparent dielectric constant. These changes are converted into a DC voltage, virtually proportional to the soil moisture content over a wide working range.

Volumetric soil moisture content is the ratio between the volume of water present and the volume of the sample. This is a dimensionless parameter, expressed either as a percentage (%vol) or a ratio ($m^3.m^{-3}$).

Battery power consumed by a probe for a single measurement taken with a 1 second warm-up time is typically: 19mA * 1 s = 0.005 mAh.

Figure 24: Picture of a Theta Probe without protection housing



(dimensions in mm)

Technical Specifications		
Type No.	ML2x	
Measurement parameter	Volumetric soil moisture content, θ_V ($m^3.m^{-3}$ or %vol.).	
Range	Accuracy figures apply from 0.05 to 0.6 $m^3.m^{-3}$, Full range is from 0.0 to 1.0 $m^3.m^{-3}$	
Accuracy	±0.01 $m^3.m^{-3}$, 0 to 40°C, ±0.02 $m^3.m^{-3}$, 40 to 70°C,	after calibration to a specific soil type
subject to soil salinity errors, see below	±0.05 $m^3.m^{-3}$, 0 to 70°C	using the supplied soil calibration, in all 'normal' soils,
Soil salinity errors	0.0 to 250 $mS.m^{-1}$, < -0.0001 $m^3.m^{-3}$ change per $mS.m^{-1}$, 250 to 2000 $mS.m^{-1}$, no significant change.	
Soil sampling volume	>95% influence within cylinder of 4.0cm diam., 6cm long, (approx 75 cm^3), surrounding central rod.	
Environment	Will withstand burial in wide ranging soil types or water for long periods without malfunction or corrosion (IP68 to 5m)	
Stabilization time	1 to 5 sec. from power-up, depending on accuracy required.	
Response time	Less than 0.5 sec. to 99% of change.	
Duty cycle	100 % (Continuous operation possible).	
Interface	Input requirements: 5-15V DC unregulated. Current consumption: 19mA typical, 23mA max. Output signal: approx. 0-1V DC for 0-0.5m^3m^{-3}	
Case material	PVC	
Rod material	Stainless steel	
Cable length	Standard: 5m. Maximum length: 100m	
Weight	350 gm approx. with 5m cable.	

Figure 25: Dimensions and specifications of the soil moisture sensors

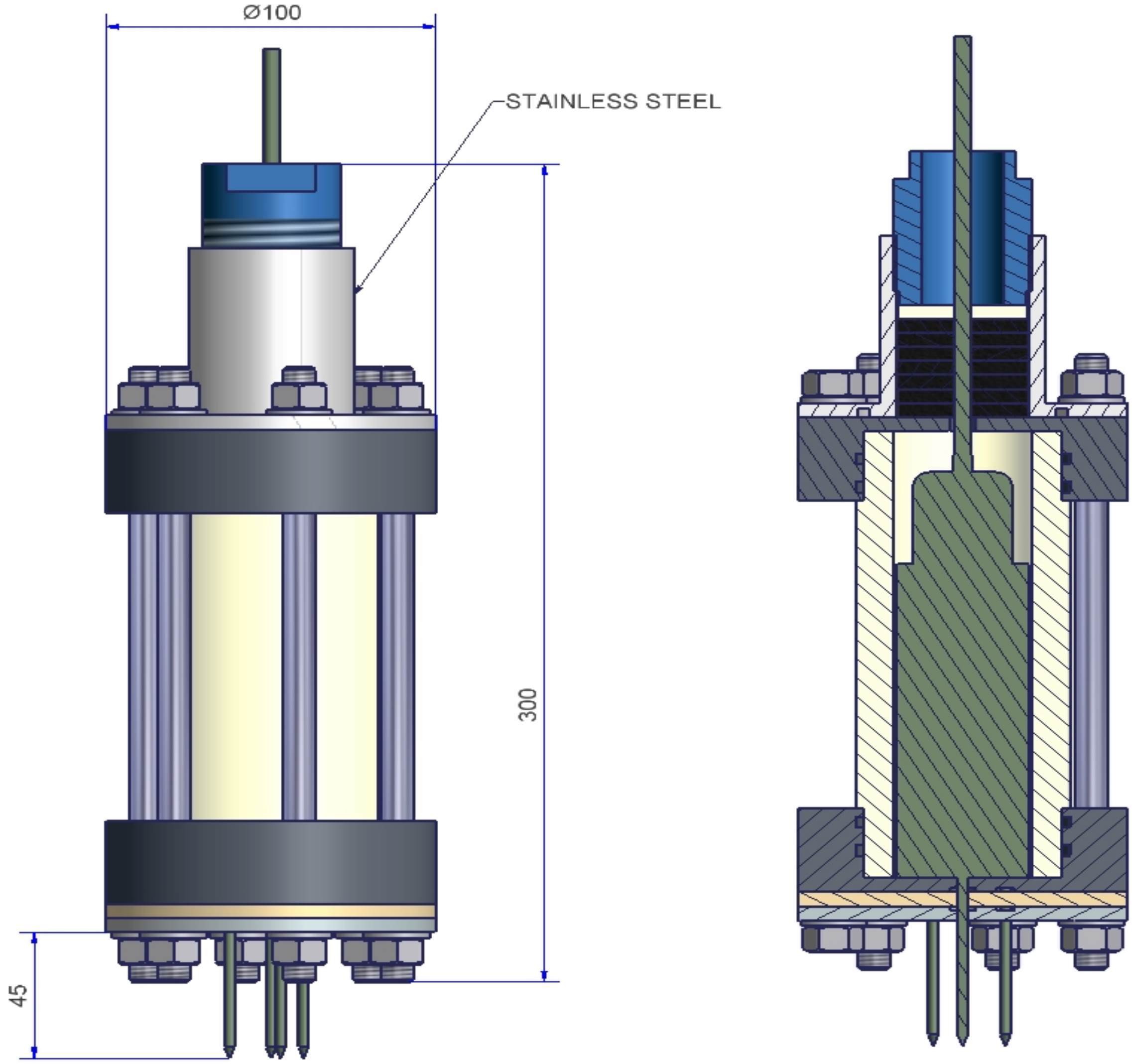
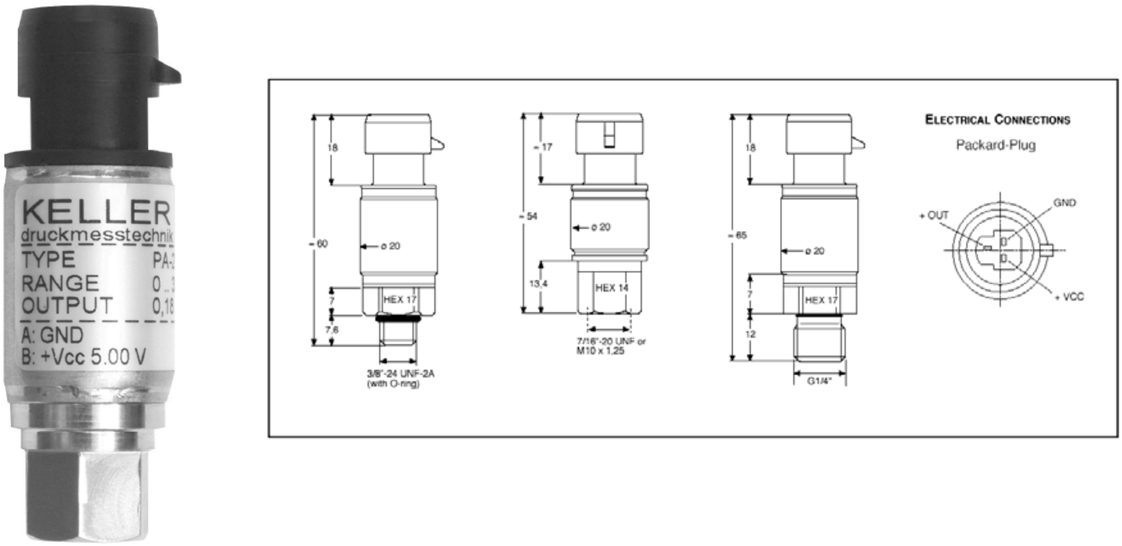


Figure 26: Dimensions of the soil moisture sensors with protection housing

Pore Pressure (Pp)

Pore pressures will be measured at two locations within the bentonite section B4. The sensor specifications and dimensions are listed below. The sensors themselves will be placed within the Solexperts data logger housing. A stainless steel tube filled with a liquid (solution which is not evaporating when under pressure is present) links the sensor and the measuring point within section B4. In order to avoid clogging of the tube, the measuring point is equipped with a sintered stainless steel screen.



Measuring principle:	piezo resistive
Supply:	5 V
Output:	0.5 V - 4.5 V
Accuracy:	1% FS
Range :	0 – 50 bar abs.

Figure 27: Dimensions and characteristics of the pore pressure sensors

Total Pressure (Tp)

Two total pressure cells will be installed in contact with the interface between the bentonite section B7 and the face of the VE-Drift to measure the swelling pressure of the bentonite. Glötzl EEKE 17 K50 A Z4 probes will be used with the following characteristics:

Sensor Type	Glötzl EEKE 17 K50 A Z4
Range:	0 – 50 bar (over range150%)
Pillow size	100mm x 200mm
Supply (10 V DC)	4 mA
Output	0 – 10 V
Accuracy	0.5 %FS
Long time drift	< 10 mV

Figure 28: Picture of a total pressure cell

3.4.9 Water injection system instrumentation

Fluid pressure (G)

This type of sensor will be used to measure the water pressure in different points of the injection.

These will be conventional relative pressure (gauge) type transducers. The suggested model is the following:

Model:	WIKA type 89
Pressure range:	0/20 MPa abs. (range is a function of location and fluid)
Accuracy:	0.5% of span
Thermal Zero shift:	0.2% of span
Thermal sensibility shift:	0.2% of span
Temp. compensation range:	0/100 °C
Output:	4 – 20 mA
Cable connection:	4 pin plug
Nº of wires:	2, Silicone insulation
Material:	Stainless steel, Hastelloy diaphragm
Dimensions:	O.D. 27 mm, 110 mm length (connector included)
Weight:	20

Water flow (Q)

The amount of water injected into the chamber will be measured with a water flow meter in the injection line. The suggested model is the following:

Make/Model:	BRONKHORST/M54R 03S-AAD
Range:	20 kg/h

3.4.10 Sensors list

Table 3 summarises all the planned sensors, except those from the seismic tomography system (see 3.5.4) :

Table 3: Breakdown of sensors

Sensor type	Code	Injection system	Test area													TOTAL
			A	**C1**	**C2**	**C3**	**C4**	**C5**	**B1**	**B2**	**B3**	**B4**	**B5**	**B6**	**B7**	
Displacement	Dz		4													4
Total pressure	Tp			2	2	2		5							2	13
Rock Pore Pressure	Pz				2		2									4
Plug Pore Pressure	Pp						2	4								6
Buffer Pore Pressure	Pp											2				2
Rel. Humidity (Sensirion)	Hs								4		4		4		4	16
Rel. Humidity (Vaisala)	Hv									2				2		4
Water content (Theta probe)	W											2				2
Fluid pressure	G	8														8
Water flow	Q	1														1
Level	L	1														1
TOTAL		**10**	**4**	**2**	**4**	**2**	**4**	**9**	**4**	**2**	**4**	**4**	**4**	**2**	**6**	**61**

3.4.11 Sensors calibration

All sensors will be supplied with the corresponding traceable certificate of calibration, unless constraints on cost and delivery terms made necessary to consider other alternatives, such as a statistic sampling. A checking of all sensors will be carried out upon sensor reception.

3.4.12 Cabling

Except for the wireless system, the cables and/or tubes from the bentonite chamber will be conducted to the Equipment area through an existing borehole, parallel to the gallery, to avoid crossing the plug-rock contact. The parallel borehole will be connected with the bentonite chamber by means of a 600 mm diameter borehole drilled in perpendicular to the gallery (Figure 29).

The cables from the sensors in the bentonite buffer and in the closest part of the plug will be led to a cable connection box. This box will be placed at right hand side when looking from outside, almost in the middle of the buffer thickness and a little above mid level of the gallery. It will be housed in the 600 mm inner diameter borehole excavated to connect with the pass-through borehole. The gap between the rock and the cable box will be sealed with a resin based grout.

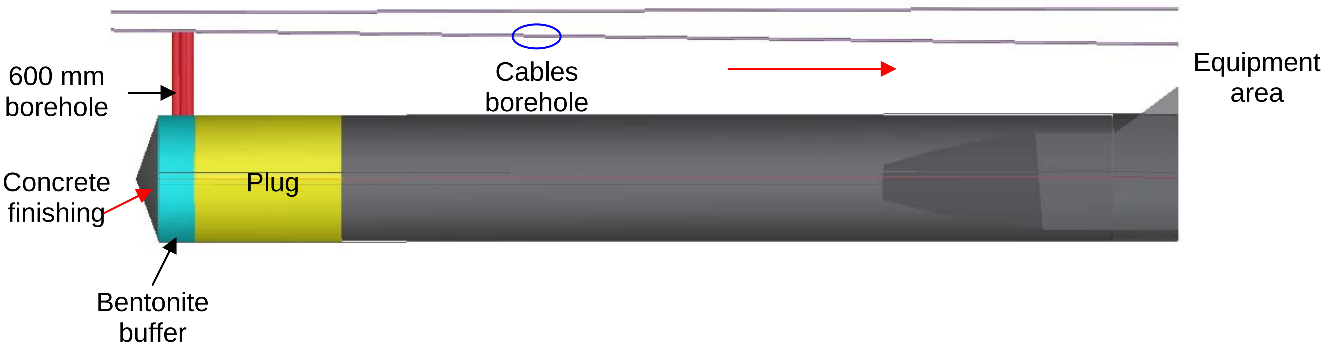


Figure 29: Detail of the gallery with the cable boreholes

The cables from the total pressure cells and from Sensirion humidity sensors will be pealed to the bare conductors and connected to open terminals of the cable box. The electronic boxes of the Vaisala capacitive sensors will be installed inside the cable box and the supply and signals will be wired from there up to the equipment area.

The tubings from the pore pressure sensors and for the mats, will be connected to extension tubes at the cable box and led to the equipment area too.

Finally, the cable box will be filled up with an isolating resin, which will cut out any undesired water flow through sensor cables or between the tubings and will protect the electronics embedded inside.

3.5 DATA ACQUISITION AND CONTROL SYSTEM

3.5.1 General requirements

Besides the data acquistion equipment intended for the wireless, there will be a main data acquisition and control system for the monitoring and management of the test.

The design of such monitoring and control system is determined by the requirements of unattended working and remote control characteristics of the experiment. Such condition calls for two different subsystems, one to be installed at the equipment area named as LMS "Local Monitoring System", and another located at the AITEMIN control office in Madrid called RMS "Remote Monitoring System", being both linked by modem.

The LMS comprises all electrical components and software packages which are necessary for the monitoring and control of the test, and will have enough intelligence and autonomy for self-managing the experiment and for long time data storage. The RMS consists of all equipment and software packages required for the adequate remote supervision and analysis of the test.

Both systems will work in an unattended mode most part of the time and only will connect between themselves, via standard telephone network using an adequate modem, for periodic data recovery from RMS and for introducing changes in the monitoring and control strategy (if required).

3.5.2 Local Monitoring and Control System

The main functions of the Local Monitoring and Control System (LMS) are:

- Acquisition, conversion, visualisation and storage in real time of all data provided by the installed instrumentation (excep wireless).
- Water injection system regulation according to strategy fixed for each phase of the test.
- Automatic, unattended control of the test during the operational phase
- Enable remote supervision and control from the RMS.
- Generation and secure storage of the test master database.

The following main components are required for the LMS:

a/ Signal conditioning and data logging system (excep. wireless).
b/ Host Computer (PC)
c/ Uninterrupted Power Supply system

3.5.3 Remote Monitoring System

The Remote Monitoring System is located at the main office of AITEMIN in Madrid. To perform the experiment remote supervision and data analysis functions, the following subsystems are available:

a/ Data recovery, supervision and analysis system
b/ Data base access system
c/ Uninterrupted Power Supply

Both data treatment systems are integrated in one high performance PC type computer, connected to the UPS network existing at the control office.

3.5.4 Non-intrusive seismic tomography monitoring system

NIREX has initiated a separate non-intrusive monitoring programme, funded outside of ESDRED, with NAGRA at Grimsel Test Site. This programme integrates with the ESDRED Module 4 that provides the opportunity for non-intrusive seismic tomography monitoring to be carried out alongside "wireless" monitoring and conventional hard-wired monitoring techniques, providing a robust opportunity to test and evaluate the three monitoring methods and to gain experience in applying the technique in a granitic geology.

ETH has been contracted to undertake the measurement campaigns and data analysis, providing continuity between this and the Mont Terri work.

The planned work progress will be as follows:

- Drilling of 6 linear boreholes (each 25m long) required for the seismic tomography, to be completed by NAGRA during December 2006.

- The first series of seismic tomography measurements (before installation of the bentonite and construction of the shotcrete plug) to be undertaken in January 2007.

- with the key aspects of the plug experiment construction and hydration phases.

Experience from the Mont Terri experiment indicated that additional geophones that are firmly mounted to the host rock or concrete plug provide very valuable add-on information. Therefore, 25 single-component geophones with a natural frequency of 100 Hz were installed at the frontal face of the concrete plug.

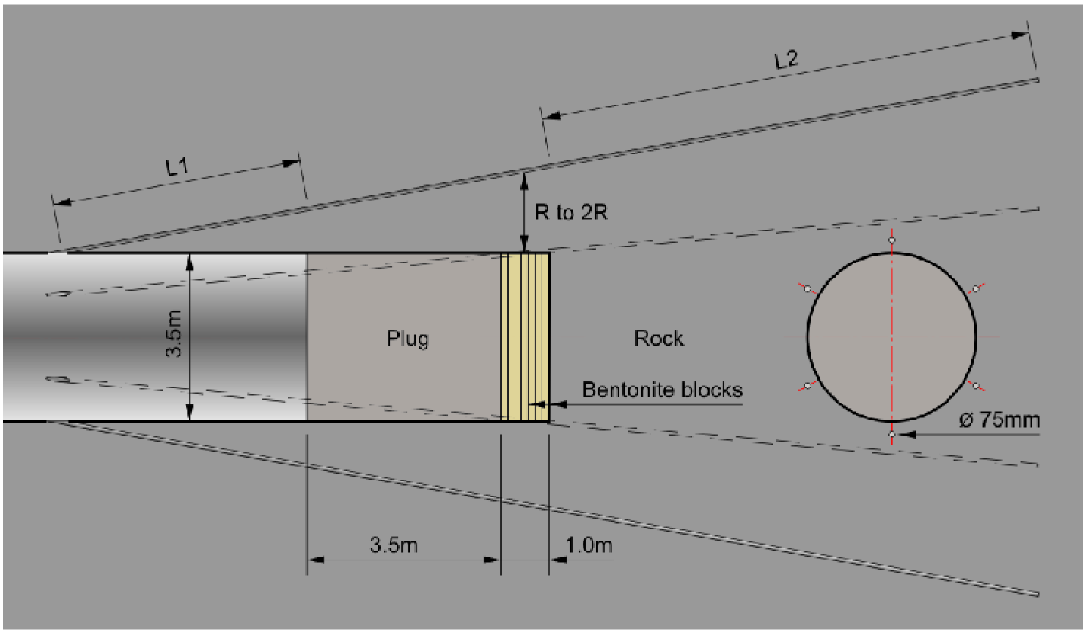


Figure 30: Detail of the boreholes for Non –Intrusive Monitoring

4 TEST INSTALLATION

4.1 ADJUSTMENT OF THE SHOTCRETE EQUIPMENT AND FORMULATION

Before the construction of the plug, shotcreting tests (pre-tests) on panel will be carried out in Switzerland. The pre-tests, scheduled for the 12th December 2006, will be carried out at the Hagerbach facility (www.hagerbach.ch). The objectives of this pre-tests are:

- to optimise the application procedures;
- to adjust the concrete formulation and spraying equipment and technique to the specific site conditions;
- and to determine the reasonable operational times for the construction of the plug.

The environmental conditions at the Hagerbach underground facilities, namely humidity (around 85% relative humidity) and temperature (14 – 16%) are almost the same as at the GTS, so that the pre-tests will provide meaningful input for the final adjustment of the operational procedures at the GTS.

The pre-tests will carried out in two steps as follows:

- 1st step is carried out by mixing 1 – 2 m^3 of wet mix based on the given recipe in order to control the pumpability and workability of the shotcrete;
- 2nd step consist of a large scale sprayed concrete test in order to check the whole procedure of plug work. The work is performed in a simulated tunnel section of 3.5 meter diameter and 1 meter in length. The tunnel section will be made of a circular formwork either formed by a plastic or concrete tube or a wooden formwork.

The idea for the pre-testing is to test the whole operation sequence under conditions that are expected for the main construction. In particular the pre-test will allow to check:

- preparation and mixing of the concrete batches (approx. 3 m^3 each) procedures;
- transport distances of mixed material (500 meter);
- pumping the wet mix to the tunnel face – (80 meter);
- spraying of three to four layers of concrete in total 1 meter at a real time sequence (12 m^3 of concrete);
- final check of concrete properties and hydration time (fresh and hardened material).

The equipment, admixture materials and procedures will be the same as for the main construction scheduled for 3rd week of January (15-19 January 2007). The equipment will be most likely transported to the GTS late December, but in any case during the second week of January 2007, at the latest.

The aggregates excluding the limestone filler both for the pre-testing and main construction will be premixed at the plant, packed in big bags adjusted to the capacity of the planned concrete mixing equipment (less than 500 litre per bag) and transported to the Hagerbach facilities and to the GTS before 12th December 2006. The limestone filler will also be provided by the local plant packed to 25 kg bags. The cement and microsilica will be delivered from Spain in pre-weighted bags of 35 kg and 20 kg respectively, and the additives (set accelerator and superplasticizer), will be also delivered from Spain in containers of 250 kg and 30 kg respectively. In order to avoid any alteration all material apart of the aggregates will be wrapped in plastic foil.

The packages must suit to the constraint conditions for concrete mixing at GTS and shall be delivered in accordance with the needs of the contractor (Hagerbach). Therefore, details for packaging will be agreed with AITEMIN before transport.

The equipment for the wet-mix spraying aims to realize a pulsation-free conveyance of the wet-mix from the pump to the nozzle.

For the tests the following equipment is foreseen (though the equipment may be reduced in accordance to the experience gained during the pre-tests at Hagerbach):

- Wet-mix concrete pump (Meyco Suprema®);
- Spraying manipulator;
- Ready-mixed concrete lorry (3 m^3);
- Electric air compressor;
- Closed concrete mixer (500 litre);
- Small bucket wheel (Diesel);
- Fork lift truck;
- Small dumper (Diesel);
- Electric power cables;
- Ventilation equipment an air tubes;
- Water treatment equipment (water pumps, tanks and neutralisation equipment).

4.2 SITE PREPARATION WORKS

4.2.1 Drilling and excavation

At the test area some drilling and excavations of the rock are foreseen to house some sensors and cables, namely (boreholes for non-intrusive seismic tomography monitoring were already mentioned at 3.5.4) :

- For the pore pressure sensors, two holes measuring a minimum of 17 mm in diameter and 0.3 m in length will be drilled perpendicularly to the gallery, at both sides, and at a distance of 0.5 m from the rear end of the plug (Figure 31). The boreholes will be inclined 20º to facilitate the resin filling. Another two holes with the same characteristics will be drilled in the middle of the plug zone.
- Six total pressure cells are foreseen in the rock surface (Figure 31).. Each pressure cell comprises a circular sensing plate with a diameter of 150 mm, and a transducer placed

on the centre of its non-sensing surface and perpendicularly to it. The cable outlet is located at the end of the transducer. Each cell will be installed in a borehole drilled in the rock with a diameter of 170 mm, and a depth around 30-50 mm. This will house the sensing plate. The transducer will be housed into a deeper drill with a diameter of 50 mm drilled in the centre of the borehole bottom, and the cable will come out from it by a side slot. All tubings and cables from these boreholes will be led through narrow slots along the rock walls up to the rear end or to the face of the plug depending on the cell position.

- The cables and tubings from sensors in the bentonite buffer and the tubings for bentonite hydration will be taken outside through a borehole up to the equipment area (Figure 29). The passthrough borehole parallel to the gallery has 86 mm in diameter with a maximum of 30 m in length. The borehole to be excavated in the rock to connect the bentonite chamber and the pass-through borehole will have an inner diameter of around 600 mm to house a sealing cable connection box inside and to facilitate the passing of the cables.

- To house some components of the wireless system, two boreholes will be drilled at the tunnel face. One borehole of a minimal diameter of 225 mm, 650 mm long and about 20° downwards. Another borehole of 101mm diameter, also downwards inclined by about 20°, and 800 mm long. For housing the Theta probes two boreholes will be drilled radial at the rock face. They will be located at around 0.5 m away from the VE tunnel face, with a diameter of 110 mm and 400 mm in legth (see Figure 17).

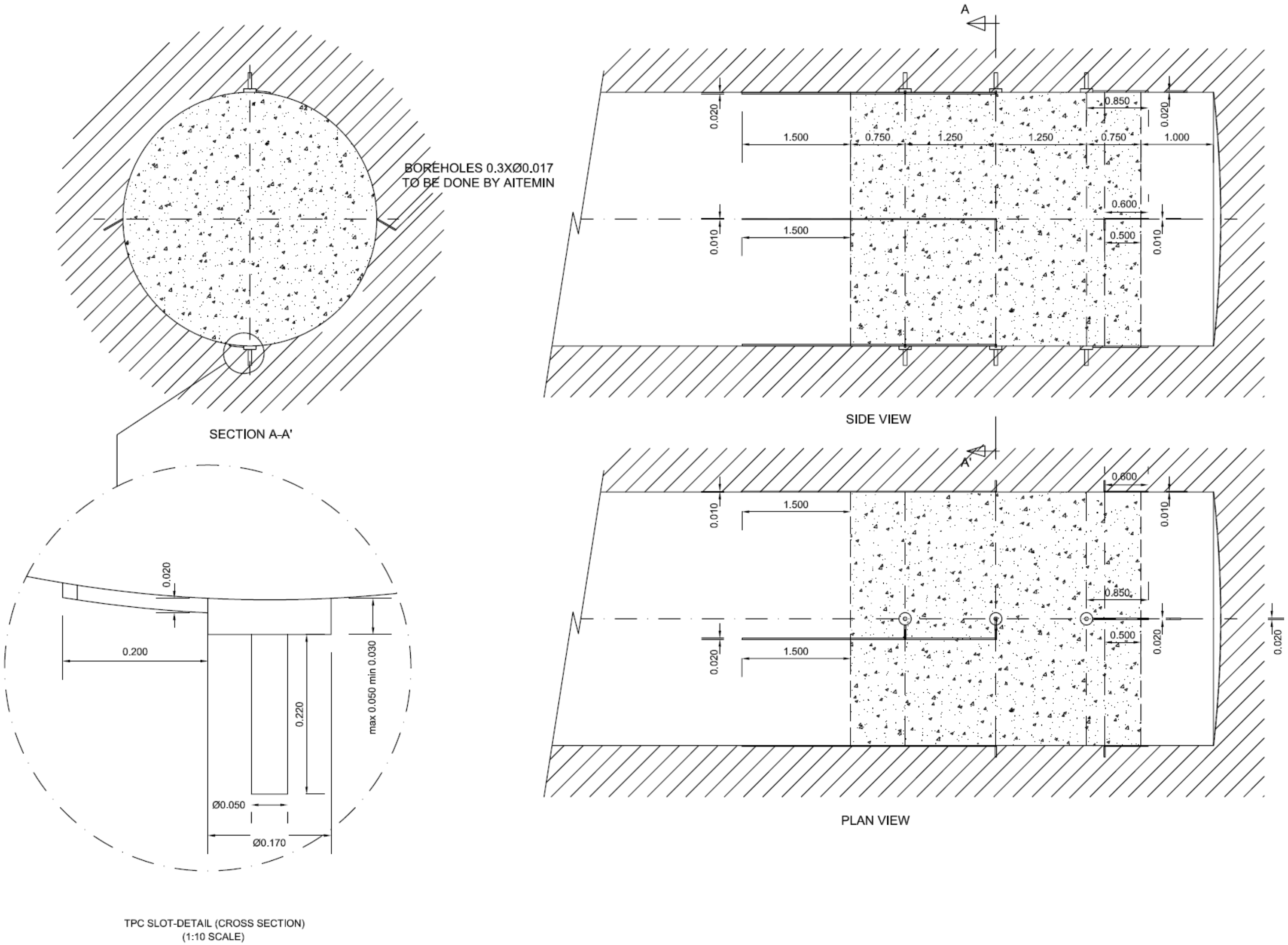


Figure 31: Detail of the slots for the total pressure cells and pore pressure sensors

4.2.2 Flatten of the gallery back-end

The back-end of the gallery has the curvature provided by the TBM machine excavation. In order to avoid problems for the installation of the bentonite blocks this surface will be flatten with concrete.

4.2.3 Infrastructure and services

The test will require the following services to be available at the test niche:

4.2.3.1 Electrical power

The maximum (peak) electrical power consumption required is estimated in 40 kW, with 400 V supply.

4.2.3.2 Telephone lines

The experiment has been planned to work basically in an unattended mode, with remote supervision via modem. Therefore, a permanent telephone connection is required for data communications.

4.2.3.3 Water supply

During the installation phase and for the operational phase, normal tunnel water (formation water) will be required for different activities, such as preparation of mortars, cleaning, water tank filling...etc. This may be done using a provisional hose connection from any nearby water supply point.

4.3 OVERALL INSTALLATION SEQUENCE

1. Preparation works

1.1 The borehole to connect with the pass-through borehole to the service area will be drilled.

1.2 The boreholes for housing the total pressure cells and the rock pore pressure sensors will be drilled.

1.3 The boreholes for housing the wireless system components will be drilled too.

2. Installation of rock sensors

2.1 The cable box will be placed in the 600 mm diameter borehole connecting with the pass-through borehole.

2.2 All the cables and tubings to be passed through the pass-through borehole (sensors in the bentonite, in the closer part of the plug and tubings for hydration and deaireation) will be bundled together in the gallery. The cable bundle will be passed through the cable box and through the borehole excavated in the rock to the service area.

2.3 The DADCS and one valve panel for the pore pressure sensors will be installed in the equipment area. Another valve panel for the pore pressure sensors will be installed in the VE gallery (close to the plug location). The signals from both valve panels will be connected to the DADCS to begin with the registration of rock pore pressure values as soon as they are ready to measure.

2.4 The pore pressure sensors in the rock will be installed. The pipes from those at 0.5 m from the bentonite (section C4) will be led out by the cables borehole up to the valves panel at the equipment area. The pipes from those in the center of the plug (section C2) will be led out through the gallery up to the valves panel. The boreholes will be sealed with an epoxy resin. The flushing and pressurisation of measuring intervals will be carried out.

2.5 The total pressure cells in the rock will be installed and cemented/resined. The cables from the pressure cells at 0.75 m from the bentonite (section C3) will be led out to the cable box, where they will be connected to open terminals, and then to a multiplexed cable led up to the DACDS at the equipment area by the pass-trough borehole (cables borehole). The cables from the other pressure cells in the rock (sections C1 and C2) will be led out through the gallery up to the DACDS.

2.6 The components in the rock of the wireless system will be installed. The necessary cable length will be measured for each sensor to allow reach its final position into the bentonite from there. Then the corresponding sensors will be connected and the boreholes will be grouted.

2.7 The back-end of the gallery will be flattened and the total pressure cells to be installed there will be placed.

3 <u>Construction of bentonite buffer</u>

3.1 Two electric heaters will be installed in the gallery to reduce the air moisture during the construction of the bentonite buffer.

3.2 The necessary cable or tubing length will be measured for each sensor to allow reach its final position into the bentonite from the cable box. The Vaisala electronics will be placed inside the box. The cable box will be filled up with the isolating resin, covering everything inside. The gap around the cable box will be sealed with grout.

3.3 The hydration mat S6 will be installed over the flatten end of the gallery and covering the total pressure cells of the wireless system. The tubings for hydration and deaireation will be connected. The lower half of bentonite layer 7 (B7) will be constructed. During the construction, two Sensirion sensors will be placed in the center of the two quadrants, with the filter in the middle of the layer thickness.

3.4 Hydration mat S5 will be installed. In this case only the lower and sides perforated tubings will be installed. The upper half of the geotextile will be left rolled up over the previous half of bentonite layer. The lower half of bentonite layer 6 (B6) will be constructed. During the construction, one Vaisala humidity sensor will be placed in the center of the lower left quadrant, with the filter in the middle of the layer thickness.

3.5 Hydration mat S4 will be installed as in point 3.4. The lower half of bentonite layer 5 (B5) will be constructed in the same way as bentonite layer 7 (with Sensirion sensors), in point 3.3.

3.6 Hydration mat S3 will be installed as in point 3.4. The lower half of bentonite layer 4 (B4) will be constructed in the same way as the previous ones, with the pore pressure sensor and with the Theta probe (pre-installed in the rock) corresponding to the wireless system.

3.7 Hydration mat S2 will be installed as in point 3.4. The lower half of bentonite layer 3 (B3) will be constructed in the same way as bentonite layer 7 (with Sensirion sensors), in point 3.3.

3.8 Hydration mat S1 will be installed as in point 3.4. The lower half of bentonite layer 2 (B2) will be constructed in the same way as bentonite layer 5 (with a Vaisala sensor), in point 3.4.

3.9 The lower half of bentonite layer 1 (B1) will be constructed in the same way as bentonite layer 7 (with Sensirion sensors), in point 3.3.

3.10 The upper half of bentonite layer 7 will be constructed. During the construction, two Sensirion sensors will be placed in the center of the two quadrants, with the filter in the middle of the layer thickness.

3.11 The upper half of hydration mat S5 will be unrolled. The upper perforated tube for hydration will be threaded into the geotextile from its top, placed vertical and connected to the double T fitting in the middle, so that the cross of hydration tubes of the mat is completed. The perforated tube for deaireation will be fitted on top of the mat, mechanically attached to the top of the vertical tubing. The tubings for hydration and deaireation will be connected The upper half of bentonite layer 6 will be constructed. During the construction, one Vaisala humidity sensor will be placed in the center of the upper right quadrant, with the filter in the middle of the layer thickness.

3.12 Hydration mat S4 will be finished as in point 3.11. The upper half of bentonite layer 5 will be constructed in the same way as bentonite layer 7 (with Sensirion sensors), in point 3.10.

3.13 Hydration mat S3 will be finished as in point 3.11. The upper half of bentonite layer 4 will be constructed in the same way as the previous ones, but with the pore pressure sensor and the Theta probe (pre-installed in the rock) corresponding to the wireless system.

3.14 Hydration mat S2 will be finished as in point 3.11. The upper half of bentonite layer 3 will be constructed in the same way as bentonite layer 7 (with Sensirion sensors), in point 3.10.

3.15 Hydration mat S1 will be finished as in point 3.11. The upper half of bentonite layer 2 will be constructed in the same way as bentonite layer 5 (with a Vaisala sensor), in point 3.11.

3.16 The upper half of bentonite layer 1 will be constructed in the same way as bentonite layer 7 (with Sensirion sensors), in point 3.10.

3.17 The five total pressure cells and the four pore pressure sensors will be installed and fixed in their positions in the bentonite face.

4 Plug construction

4.1 The plug (4 m) will be constructed immediately after finishing the installation of sensors on the interface to avoid problems caused by the swelling of bentonite. The construction will be done by applying successive layers of sprayed concrete. During the construction of the plug, a construction control procedure will be applied for each layer, consisting in testing fresh concrete properties of each batch equals approx. 3 m^3 (slump, air content, water content and temperature) and control of early concrete hardening with a penetrometer. For each batch, cubic samples of the fresh concrete will be taken in addition for testing hydration development (e.g. compressive strength after 7 and 28 days).

5 Installation of the injection system and rest of instrumentation

5.1 After finishing the construction of the plug, the extensometers will be placed at the plug front face, and connected to the DACDS.

5.2 The 25 geophones will be installed into short boreholes drilled in the plug face, and connected to the corresponding acquisition unit.

5.3 The two horizontal boreholes measuring 3.5 m in length and 35 mm in diameter will be drilled, the two corresponding piezometers of section C4 will be installed within and connected to the DACDS, and the boreholes will be backfilled.

5.4 The water injection system will be installed at the service area and connected to the hydration panels located close to the passthrough borehole.

4.4 PLUGS CONSTRUCTIVE LOGISTICS

The plug will be constructed with the same formulation, admixture materials, equipment, procedures and control measures applied during the pre-tests (see 4.1). The binder material (cement and microsilica) and additives (set accelerator superplasticizer) will be transported from Spain. The aggregates (natural sand and gravel, limestone filler) will be provided by a local supplier (Aare Kies AG, Brienz). The sand and gravel will be premixed and packed in big bags. The water will be formation water from the GTS.

The following main operation and handling steps are planned:

- As it can be assumed that winter access for trucks is not possible in January the final concrete will be mixed in the VE cavern located approx. 80 m from the plug construction area;

- The admixture components will be stored either in the FEBEX or in the BK area located approx. 400 m from the VE cavern;

- Each batch will be mixed on-site in a 500 litre closed concrete mixer, based on the predefined mixing protocol. Beside the bags delivered with known weight, the control of the admixture will be done by weighting the materials independently;

- For the transport of the components within GTS a fork lift truck is used. In case concrete is mixed in the FEBEX area, a ready-mix concrete lorry with a rotating drum and a filling capacity of 3 m^3 will be utilised to transport the wet mix to the area of the plug construction;

- The wet-mix pump is located in the VE cavern either. The electronically controlled push-over system provides a minimised pulsation of the material flow to the nozzle;

- The spraying manipulator with the nozzle of course is located at the construction site which means a conveyance distance of approximately 80 m (end of the VE-tunnel);

- Based on the experience gained during the tests performed at Leon (October, 2006) and furthermore the experience gained during the tests performed at Sargans (December, 2006) it is intended to build the plug by spraying 0,1 to 0,5 m thick layers. Each layer will be built beginning from the gallery walls, with the nozzle in perpendicular to the rock walls all around to guarantee the good shotcrete adherence, and then from the floor to the ceiling of the face front and moving the spraying nozzle in horizontal to cover the gallery section with 5 to 10 cm of concrete and then to start again at the floor up to reach the desired thickness of 10 to 50 cm. The objective is to built the plug by means of "onnion" type layers. Although the rebound in Leon and Sanagans was negligible, it is intended to remove the rebound carefully if needed after every layer in order to avoid any rebound being sprayed over;

- Although a maximum pump-rate of 12 to 14 m^3/h is achievable an average pump-rate of 4 to 6 m^3/h is assumed due to the constraints caused by the small cross-section of the tunnel. Hence, the time required for spraying each layer of 50 cm is of around 50 minutes. After the finishing of each layer, there will be a stop due to preparing batch. This will last between 30 to 40 minutes. However, the stop leaves the concrete to harden for a time of maximal 40 minutes. In order to achieve a good bonding between layers, the previous layer should not to be too stiff. Pre-tests at Leon and Sargans indicated that the concrete has to harden for a time of 15 to 30 minutes to reach a minimum proctor of 25 to 50 before it will be possible to start spraying again.

- Even though it should be possible to finalise 1 meter in a normal shift at the GTS, working times can be extended to guarantee 1 meter/day;

- Of course the construction procedure will follow the guidelines set by the environmental and workers protection regulations (water treatment, neutralisation of discharged water or additional ventilation).

4.4.1 Plug Construction Controls

A register will be produced for each batch. The controls are detailed in the following sections.

4.2.1.1 Control of the fresh gunite

a) Control on gunite components

For the aggregates supplied from the plant, a certificate will be asked for consist of sieving curves and petrographical tests. On site, every concrete batch production is being recorded in terms of component weight.

b) control on fresh shotcrete (on every batch mixed).

If necessary, the fresh shotcrete tests will comprise slump, water content and air content measurements. Results are recorded on special forms. After interruptions of more than 15 minutes, the slump should be checked before starting the spraying operation again. The recommended slump should be between 100 and 200 mm.

4.2.1.2 Setting/hardening control

The hardening of each shotcreted layer will be controlled with a penetrometer (needle penetration test) before starting the next one. Tests will be made by AITEMIN according to Spanish Standard UNE 83-603-94. Needle penetration measurements will be made with a standard apparatus at some of the following intervals: 15, 30, and 60 minutes (at least two of them)

4.2.1.3 Controls on hardened shotcrete

Samples will be taken in standard cubic sampling boxes from every batch. A shotcrete panel will be taken too at the same time that the first shotcrete layer is erected. The boxes and the panel will be stored at the entrance of the drift (FEBEX). The following tests will be performed after hardening (28 days) in the panel, for what cores will be extracted:

- Compressive strength
- Tensile strength
- Permeability tests (alternative method prEN 12364 based on ISO 7031 is Applicable.

These tests will be carried out by an external laboratory having a quality certification, and will be made according to ISO or SIA standards. Sample boxes corresponding to batches and not analysed will be retained for future tests.

5 TEST OPERATION

5.1 INITIALLY PLANNED OPERATION

The test operation comprised four phases:

1 After the curing of the plug (around four weeks) the buffer hydration is started using mat S6 only (that one at the rear part of the buffer). The objective is to study the development of the buffer pressure at the initial stage when the effects of the voids could be more relevant. The water is injected at a maximum pressure of 3 bar. This phase lasts until reaching one of the following conditions:

   a) A peak of the swelling pressure is registered (a progressive pressure increase followed by a pressure descent) or

   b) the swelling pressure is lower than 1 MPa after two months or

   c) after a maximum of three months.

2 The buffer hydration continues but using mats S2, S4 and S6. The objective is to study the development of the buffer pressure at a low saturation ratio to better register the buffer evolution. The water is injected at a maximum pressure of 3 bar. This phase lasts a maximum of three months.

3 The buffer hydration continues but using all available mats S1 to S6. The water is injected at a maximum pressure of 3 bar. This phase lasts until reaching one of the following conditions:

   a) The swelling pressure reaches a value of 4.5 MPa (target pressure) or

   b) the plug is “moved” or if it clearly breaks (plug failure).

4 Only if the target swelling pressure is reached and in agreement with the partners, hydraulic pulses are applied to the buffer. It consists of applying increasing pressure steps of 0.5 MPa. The test is concluded after reaching the plug failure, that is, when the plug starts to move or if it clearly breaks.

5.2 REASONS TO MODIFY THE OPERATION

Due to the difficulties found for installing the bentonite blocks (the instability of the compacted bentonite bricks provoked a higher voids volume) the global dry density obtained for the bentonite buffer was 1,55 g/cm^3 and therefore the expected mean swelling pressure of the buffer when fully hydrated, is 4.15 MPa, instead of 4.5 MPa. Nevertheless, the natural variability of the bentonite should be taken into account for such value (±25 %, that is, ± 1 MPa approximately).

Besides, one day after the start of phase 1 on March 27, 2007 a water leakage was detected through the contact of the rock with the bottom of the plug, and the injection was stopped.

Successive injections lasting between 24 and 48 hours were carried out in April and June, and the water leakage appeared every time.

On September 19, 2007 a retaining dam was constructed close to the plug front up to mid height of the gallery, so to allow the retention of water and favour the swelling of bentonite. The water injection was resumed on November 8, 2007, and afterwards total pressure and humidity started rising.

5.3 MODIFIED OPERATION

Hence, the modified test operation comprises three phases:

1 The buffer hydration is continued injecting water at the same low pressure through mat S6 only until end of March 2008 (totalling approximately five months of continuous water injection).

2 Continuation of the hydration from April 1, 2008 through the six mats, S1 to S6, at the same low pressure. The injection pressure will be increased If necessary to maintain the injection (a decision on this issue will be taken upon the water inflow evolution). The objective is to hydrate the buffer as fast as possible to reach the target buffer pressure (4,5 MPa) before the maximum planned duration of the project (December 2008).

3 If before December 2008 the obtained buffer pressure is below the target value (4,5 MPa) an attempt to produce an effective testing pressure of such value on the plug will be made by means of the water injection system. It consists in applying increasing pressure steps of 0.5 MPa trying to increase the effective pressure on the plug (measured on the total pressure cells installed in the interface plug-buffer). The test is concluded if significant water leakage is produced through the rock or the rock-plug interface, or if no effective pressure increase on the plug is registered or if the target pressure is reached.

6 ROLES AND RESPONSIBILITIES

José Luis García-Siñeriz will be the responsible for planned activities and Ignacio Bárcena will be the coordinator for on-site activities.

The overall responsibility for the Nagra activities and the coordination with Enresa / Aitemin lies with Ingo Blechschmidt - with administrative support of Andrea Baumann.

7 TIME SCHEDULE

A time schedule of the basic site activities for the test construction and operation can be found in Table 4. If required, a more detailed schedule will be produced in agreement with the involved participants. The coloured tasks have been already accomplished by the time of issuing of this document.

Table 4: Time schedule

ID	Task	Start	End
1	Test preparation	02/10/06	24/11/06
2	Shotcreting tests	12/12/06	12/12/06
3	Rock instrumentation installation	27/11/06	15/12/06
4	Wireless system installation	06/01/07	13/01/07
5	Buffer construction	15/01/07	14/02/07
6	Plug construction	15/02/07[1]	21/02/07
7	Installation of DADCS and HS	15/01/07	02/02/07
8	Plug hardening	22/02/07[1]	23/03/07
9	Operational phase (Initial Phase 1)	29/03/07	18/09/07[2]
10	Installation of retaining wall	19/09/07	19/09/07
11	Operational phase (Modified Phase 1)	08/11/07	31/03/08[3]
12	Operational phase (Modified Phase 2)	01/04/08	30/11/08[3]
13	Operational phase (Modified Phase 3)	01/12/08	31/12/08[4]

[1] The start-up of the plug construction is linked with the finalisation of the buffer construction. The installation of the DADCS and HS can be done in parallel with the plug construction.

[2] Discontinuous injection with water leakage.

[3] Continuous injection.

[4] Increasing pressure steps of 0.5 MPa.