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Initial data report for the Multi Purpose Test

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P-15-03 KBS-3H. Initial data report for the Multi Purpose Test

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Abstract

The MultiPurpose Test (MPT), currently underway at the Äspö HRL, is a full-scale, demonstration of the KBS-3H reference design. The test is conducted without heating and includes the main KBS-3H components in a partial deposition drift configuration. The test installation was carried out according to the Drainage, Artificial Watering and air Evacuation (DAWE) procedure and the system behaviour is now being monitored through in-situ instrumentation. Dismantling and post-mortem analysis will be carried out at a later stage and the timing for this will be dependent on the measured data. MPT activities were started in 2011 as part of the KBS-3H project development (SKB 2012). The MPT is also affiliated with the LucoeX project and is partly funded by the European Commission.

This report presents measurement data from the in-situ instrumentation in the MPT during the period from December 7, 2013 to June 10, 2014. A total of 227 sensors were installed in the MPT. The pressure development is monitored as total pressure in the rock (27 sensors), bentonite blocks (13 sensors) and plug (3 sensors). Additionally pore pressure is measured in the rock (27 sensors) and bentonite blocks (23 sensors). The saturation process is followed by measuring the relative humidity (34 sensors), suction (32 sensors) and volumetric water content (13 sensors). The movements of the components are determined with extensometers (13 sensors) and inclinometers (6 sensors). The outflow through the plug is measured with a flowmeter outside the drift. The strains on the Supercontainer and the plug are measured with strain gauges (8 on the Supercontainer and 24 on the plug). A set of three gas pressure sensors were also installed.

Some of the sensors (33) were fitted to transmit their signals wirelessly. Seven transmitters and two receivers were installed for this purpose. Wireless signal transmission is a novel technique in nuclear waste management and its development is advanced in the MPT.

Contents

1. INTRODUCTION

1.1 General

The common goal of SKB and Posiva is disposal of spent nuclear fuel from Swedish and Finnish nuclear power plants at depth in crystalline bedrock to ensure the safety of human beings and the environment for long periods of time. The method selected for the final repository is the KBS-3 method (Figure 1-1).

The reference design is KBS-3V employing vertical disposal of the waste canisters. Horizontal disposal of the canisters, KBS-3H, is a possible alternative which is being examined by the two organisations. SKB´s and Posiva´s current programmes for KBS-3 are detailed in SKB´s RD&D Programme (SKB 2013) and in Posiva´s TKS-2009 (Posiva 2010).

The Multi Purpose Test (MPT), currently underway at the Äspö HRL, is a full-scale, demonstration of the KBS-3H reference design carried out at -220 m. The test is conducted without heating and includes the main KBS-3H components in a partial deposition drift configuration (Figure 1-2). The test installation was carried out according to the Drainage, Artificial Watering and air Evacuation (DAWE, see chapter 1.2) procedure and the system behaviour is now being monitored through in-situ instrumentation. Dismantling and post-mortem analysis will be carried out at a later stage and the timing for this will be dependent on the measured data.

MPT activities were started in 2011 as part of the KBS-3H project development (SKB 2012). The MPT is also affiliated with the LucoeX project and is partly funded by the European Commission.

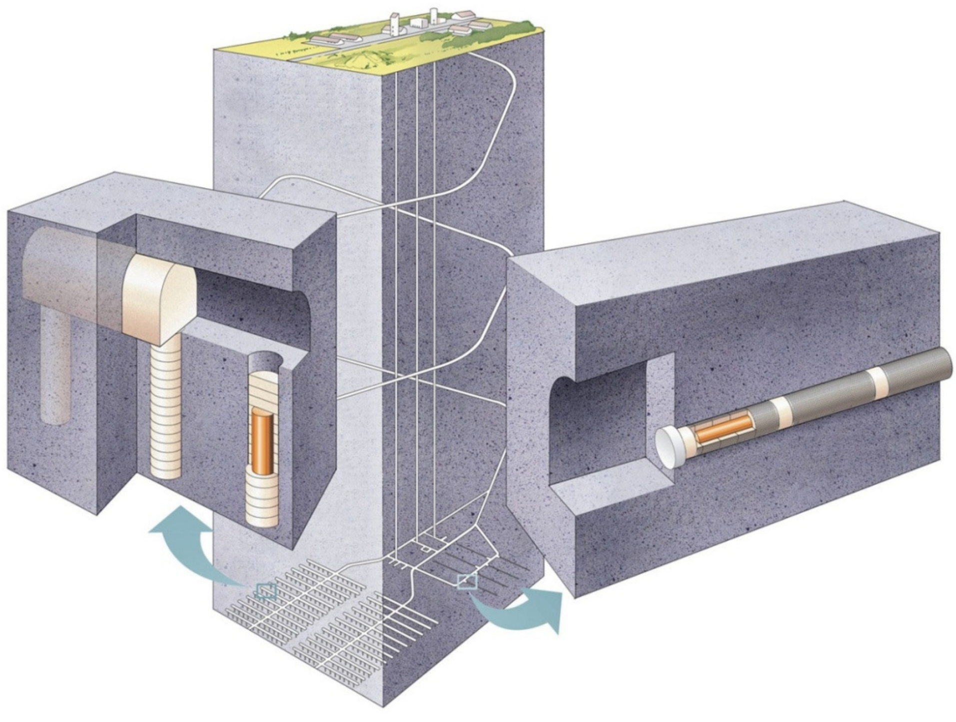


Figure 1-1. *Schematic illustration of the KBS-3 method with its three barriers: the canister, the buffer and the rock. The vertical reference design is illustrated to the left and the horizontal alternative to the right.*

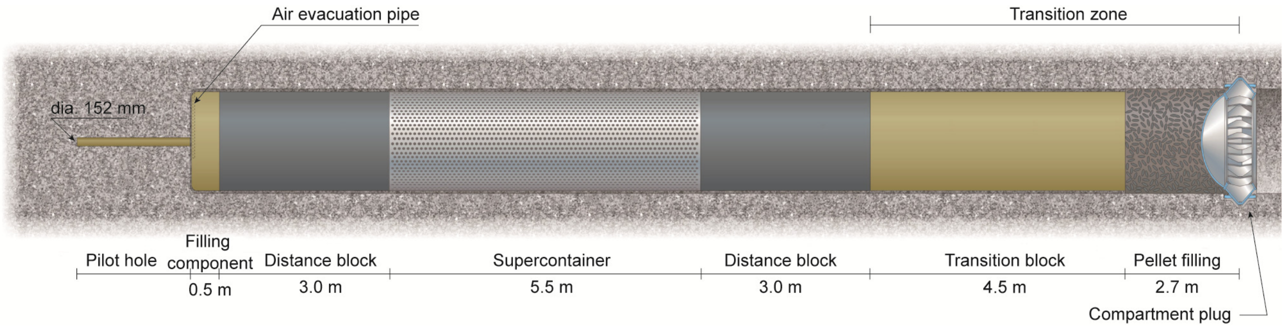


Figure 1-2. *The main KBS-3H components (Supercontainer, distance blocks and a compartment plug with transition zone) as configured in the MultiPurpose Test.*

The initial conditions of the bentonite components used in the MPT are described in Table 1-1 (D4;01 Johanesson, 2014).

Table 1-1. *Initial conditions of the bentonite components.*

Type	Bulk density (kg/m^3)	Water content (%)	Degree of saturation (%)	Dry density (kg/m^3)
Distance/Transition blocks	2 071	20.6	92.4	1 718
SC ring blocks	2 106	11.0	65.6	1 898
SC end blocks	2 069	17.2	83.2	1 766
Pellet filling	1 000	21.0	32.8	826

1.2 Purpose and scope of this report

The objective of the MPT instrumentation is to study the buffer and filling component behavior during the early evolution of the system.Displacements, water content, pore and total pressure and swelling pressures at the rock and plug interfaces are measured.

This report presents the MPT instrumentation scheme and the associated set of initial data. This data set corresponds to the time period from the December 7, 2013 at 08:30 (initiation of DAWE procedures) to June 10, 2014 at 23:50. At 14:50 on December 7, 2013, increasing pressure due to the DAWE filling was observed and a maximum pressure of 235 kPa was reached at 15:15 after which the filling was stopped.

Practical details of the sensor and component installation procedures were reported previously (D4:03, Kronberg, 2015).

2 GEOMETRY AND COORDINATE SYSTEM

Given that the Supercontainer, distance and transition blocks are assembled in a facility above ground and installed as full components (packages), the sensor coordinates cannot be measured when installed in their final location. Instead, the position of the component is measured and the sensor coordinates calculated based on the measurement and the drawings. Adding to the complexity is that the sections are mirrored when comparing the above ground sensor installation with the below ground installed component, i.e., when looking at a sensor being installed to the left side on top of a bentonite block in the assembly facility that sensor will eventually be located to the right inside the drift (when looking from the outside and into the drift).

The MPT instrumentation was set up according to the coding system presented in chapter 2.1 with regard to the onsite Data Acquisition System (DAS.) From this standpoint the center of the plug collar is regarded as the zero position.

Data from the DAS is fed into SKB's SICADA database under a different coding system, which is described in chapter 2.2. For this purpose the drift end is considered to be position zero.

2.1 Data Acquisition System (DAS)

The frame of reference for the positions of the sensors in the MPT is indicated in Figure 2-1.

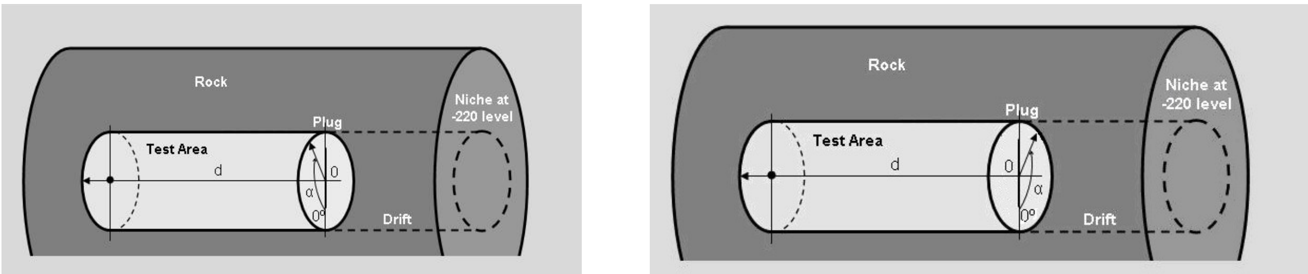


Figure 2-1. *Frame of reference for MPT rock sensors (left) and frame of reference for MPT block sensors (right).*

Three coordinates are used to identify specific positions in the drift:

r = radial distance (mm) from the center of the sensor to the drift axis

α = Clockwise angle (degrees) from the drift axis for the rock sensors and counterclockwise angle from the drift axis for the blocks sensors, relative to the vertical diameter of the drift

d = distance (mm) from the origin of the test area (middle of the plug collar) towards the rear of the drift

This is a relative coordinate system referenced to the drift axis with origin in the plug. The absolute (topographic) coordinate system is given by the position of the drift in the Äspö HRL.

It should be noted that the total pressure sensors in bentonite blocks coded as 0990 do not follow the reference coordinate system described above. This discontinuity results from two of the total pressure sensors being moved to the plug after it was decided that more information about the pressure on the plug would be necessary. It was not possible to purchase new total pressure sensors because the delivery time did not fit with the schedule of the test.

Coding system

The sensors are identified according to the following code:

SS-DDDD-N where:

- SS refers to sensor type (see Table 2-1)
- DDDD refers to the position at which the sensor is installed (depth in cm from the center of the plug collar)
- N refers to sensor ordering and is only necessary in cases where several sensors of the same type are installed in the same zone and at the same depth. Sensor ordering starts by 1 and increases with the radius r. For the same radius, it increases with the value of angle α taking into account that the view is from the drift front towards the drift entrance.

Table 2-1. *Codes for types of sensors.*

Code	Sensor
TP	Total pressure
PP	Pore pressure
WC	Water content capacitive
WP	Water content psychometric
WF	Water content soil moisture
DS	Displacement Supercontainer
DB	Displacement bentonite
DC	Displacement collar
IS	Inclination Supercontainer
IB	Inclination bentonite
SG	Strain Gauge
GP	Gas Pressure
FM	Flow Meter

2.2 SICADA

SICADA is SKB's main database, and the associated codification for the MPT sensors is as follows:

P XK DDD S N where:

- P refers to object point
- XK refers to KBS-3H experiment
- DDD refers to position at which the sensor is installed (depth in dm from the drift front)
- S refers to type of sensor (see Table 2.2)
- N refers to sensor ordering

Table 2-2. *Codes for types of sensors in SICADA codification.*

Code	Sensor
T	Total pressure
U	Pore pressure
W	Water content capacitive/psychrometric
D	Displacement Supercontainer/bentonite
I	Inclination Supercontainer/bentonite
S	Strain Gauge

The as-built design with the position (coordinates) of the sensors is presented in Appendix 1.

3 DESCRIPTION OF THE SENSORS

The different sensors that are placed in the blocks, pellets, Supercontainer, plug and rock are described in this chapter. The chapter also includes background information regarding sensor distribution and placement.

3.1 Sensor types

Total pressure measurement

Total pressure is the sum of the swelling pressure and the pore water pressure. It is measured with the following sensors:

- Geokon total pressure cells with vibrating wire transducers were installed in the rock wall at axial (to the drift, S1) and radial to the drift, S2, S4, S7, S8, S9 and S9$^+$) measurement directions. Additionally, one of these sensors was placed in the axial direction at the S8/S9 block/block interface.

- Geokon total pressure cells with piezo resistive transducers (custom modified by ÅF, Sweden) were installed in bentonite block drift components. Specifically, these cells were placed in ring blocks and end blocks at block/canister interfaces, measuring radially to the drift axis for the former and along the drift axis for the latter, in distance blocks at the Supercontainer endplate/block interface measuring along the drift axis and at the pellet-filling/plug interface measuring along the drift axis.

Pore water pressure measurement

Pore water pressure is measured with the following sensors:

- Keller pore pressure piezo resistive sensors. These sensors are installed outside the test area and the pressure is transmitted through tubing connected to the borehole measurement locations. The tubing is equipped with porous stainless steel filters at the sampling ends. The boreholes are isolated with packer assemblies.

- Measurement Specialities 4 arm Wheatstone bridge. These sensors are installed in the blocks and pellets-filled zones.

Gas pressure measurement

Gas pressure is measured with the following sensors:

- Keller pore pressure sensors piezo resistive sensors. These sensors are installed outside the test area and the pressure is transmitted through tubing connected to the measurement location. The tubing has a porous stainless steel filter at the end.

The main aim for installing these sensors was for measuring the evolution of gas pressure if the DAWE was discarded. Essentially these sensors end up measuring the water pressure in the gap and should be changed by other sensors with higher range.

Water saturation measurement

The water saturation in the bentonite blocks is recorded by measuring the relative humidity in the pore system, which can be converted to total suction (negative water pressure). The following techniques and devices are used:

- Aitemin SHT75 v3 capacitive hygrometer. The measuring range is from 0 to 100% RH.

- Wescor type PST-55 thermocouple psychrometer with modification by Aitemin. The effective measuring range is from 95 to 99.6 % RH corresponding to suction between 54 to 6 916 kPa at 20ºC. The psychrometer response is showed in Figure 3-1. Interpretation of the psychrometer signals requires parameter values in order to represent the different regions of the output trace (a-b-c-d-e) versus time. The signal corresponding to the c-d plateau is explicitly used for suction calculation. Therefore it is important to check the consistency of the input parameters and the times constants over long periods of signal collection.

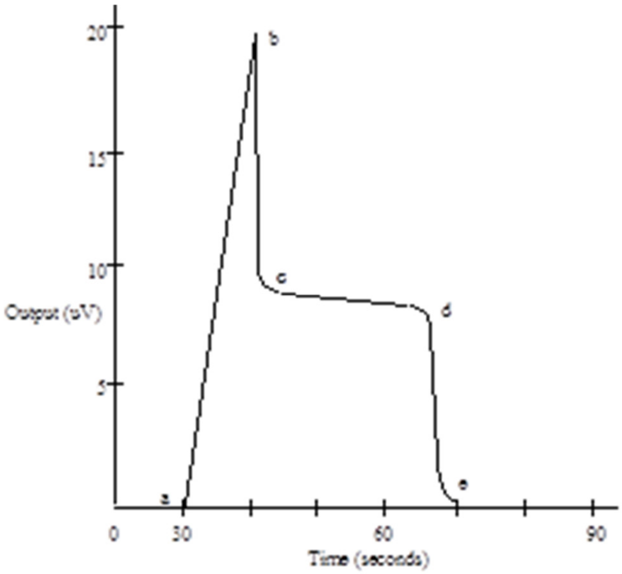


Figure 3-1. General *psychrometer response during the measurement process.*

Volumetric water content measurement

The volumetric water is defined as V_ω/V_T (volume of water/total volume) and is measured in the MPT drift as follows:

- Soil moisture sensors (ThetaProbe type ML2x, Delta-T Devices with custom modification by Aitemin) were installed in the bentonite blocks. The measuring range should cover all possible volumetric water contents. These sensors consist of a waterproof PVC housing, which contains the electronics, and, at the other end, four sharpened stainless steel rods that are inserted into the material to be analyzed. Given the swelling capacity of the bentonite buffer, the standard housing of the units was reinforced with a SS316L casing provided with a fitting for ¼" OD tubing (to protect the cable). Any remaining empty space in the casings was filled with resin. The output signal of these sensors is 0 to 1 V DC (Figure 3-2) for a range of soil dielectric constants, ε, from 1 to 32, which corresponds to a range of 0 to approximately 0.5 m^3/m^3 volumetric moisture content for generalized mineral soils. Soil-specific calibrations should be performed for these sensors.

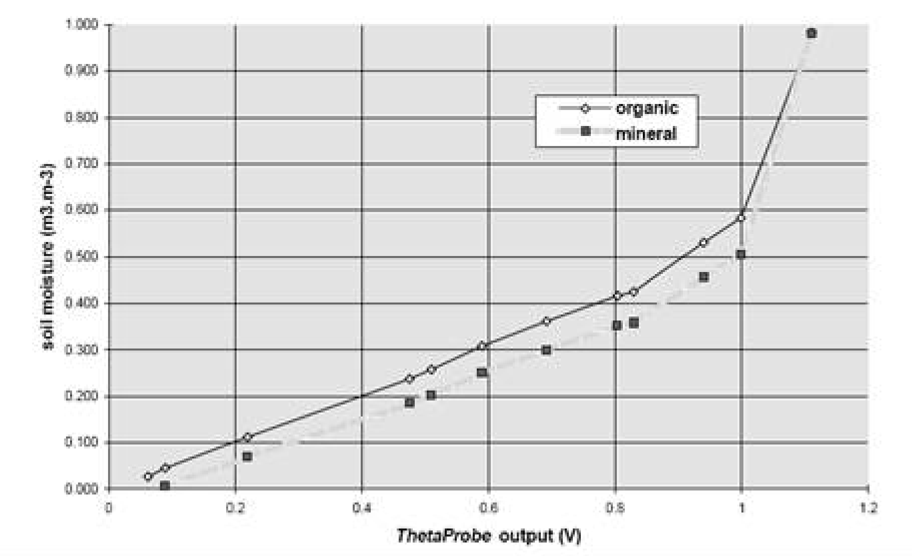


Figure 3-2. *Relationship between ThetaProbe output and soil moisture content for generalized mineral and organic soils.*

The FDR sensors were placed in holes filled with powder with the same water content the block:

- Distance/transition blocks 21 %.
- Rings in Supercontainer, 11%
- Discs in Supercontainer, 17%

Strain measurement

Strains on the Supercontainer and plug face are measured with the following strain gauges:

- HBM 1-LY41-3/350 with a range of 0-50 000 µm/m (plug face).
- HBM 1-XY101-3/350 with a range of 0-50 000 µm/m (Supercontainer).

Displacement measurement

Displacements within the MPT drift are measured as follows:

- RDP LVDT sensors with a range ±25 mm were installed inside the drift to measuredisplacements of the Supercontainer with respect to the rock wall (section 4). In these cases, positive displacements indicate movement of the Supercontainer away from the rock. LVDT sensors were also installed in drift section 5 to measure the displacement of bentonite blocks with respect to the canister where positive displacements indicate movement away from the canister. Finally, in drift section 9, LVDT sensors were installed to measure the displacement between two blocks and where any positive increase indicates that the space between the blocks is increasing.
- RDP LVDT sensors with a range ±12.5 mm were installed outside the drift on the plug face to measure displacement of the plug along the drift axis.. Positive displacements indicate movement of the plug toward the drift.

Ideally these sensors would be installed measuring zero displacement but they were configured in a workshop and it is possible that they experienced some movement during emplacement of the blocks and Supercontainer.

Inclination measurement

Inclinations of the Supercontainer and bentonite blocks are measured as follows:

- Measurement Specialities DPL series inclinometers with a range of ± 5° were installed in bentonite blocks in sections S2 and S7. The x-axis for the inclinometers corresponds to the longitudinal direction along the bottom of the drift and a positive angle response indicates an incline (counter clockwise rotation) away from the plug face. The y-axis for the inclinometers corresponds to the lateral direction of the drift and a positive response indicates an incline (clockwise rotation) away from the rock wall as drawn in Figure 2-1.

  In section S4, the inclinometers were installed completely opposite to those in sections S2 and S7. As such, the y-axis for the inclinometers corresponds to the longitudinal direction along the bottom of the drift and a positive response indicates an incline (clockwise rotation) away from the rear of the drift and the x-axis corresponds to the lateral direction of the drift and a positive response indicates a decline (counter clockwise rotation) toward the rock wall as drawn in Figure 2-1.

3.2 Installed sensors

The locations of the measurement sections along the drift are presented in Figure 3-3 and the type and number of sensors are presented in Table 3-1.

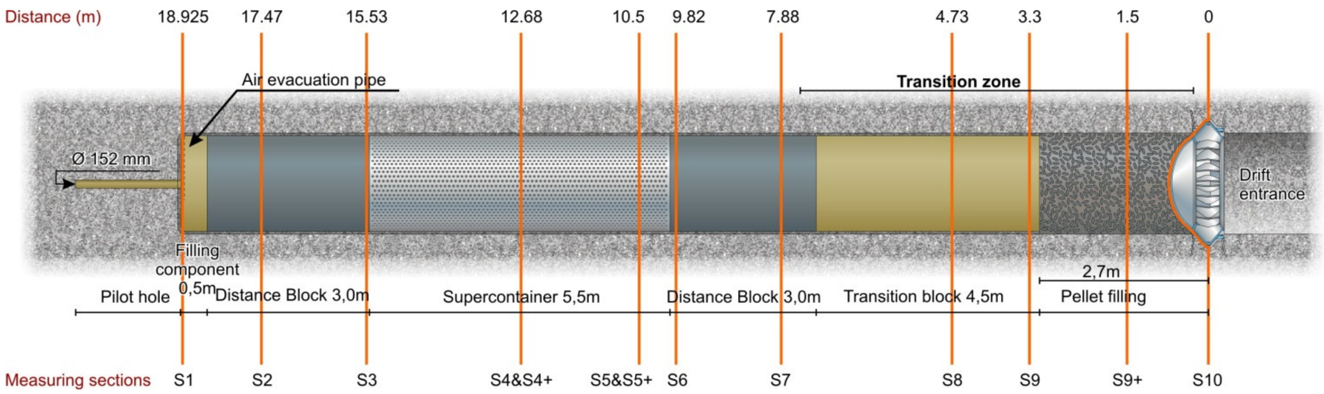


Figure 3-3. *Measurement section locations (DAS coding, with the plug as position 0).*

Table 3.1 *Distribution of sensors by sections showing the distribution between those that are read by means of conventional cables (wired), wireless or tubing that transmits pressure.*

	SECTIONS												
Sensors	**S1**	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	**S9**	**S9+**	**S10**	**OUT**	**TOT**
TP rock	5	4		2			4	4	2	6			**27**
TP plug											2+1		**3**
TP buffer				4	4	4			1				**13**
PP rock short	1	4					4						**9**
PP rock borehole									18				**18**
PP buffer		3+3		4	2+3		1+3				3+3		**23**
WC		3+3		4	2+3		3+3	4+3	3+3				**34**
WP		6		4	4		6	6	6				**32**
WF	1	2		2	2		2	2	2				**13**
DS				4	4								**8**
DB									2				**2**
DC												3	**3**
IS				2									**2**
IB		1					1		1+1				**4**
GP	1					1					1		**3**
SG					8							24	**32**
FM												1	**1**
Total	8	27	0	26	32	5	27	19	39	6	10	28	**227**
Tubings	**2**	**4**	**0**	**0**	**0**	**1**	**4**	**0**	**0**	**0**	**1**	**0**	**12**
Wireless	**0**	**6**	**0**	**0**	**6**	**0**	**6**	**5**	**6**	**0**	**4**		**33**
Wired	**8**	**21**	**0**	**26**	**26**	**5**	**21**	**14**	**33**	**6**	**6**	**28**	**194**

3.3 Reasoning behind the distribution of sensors

This section introduces the reasoning behind the sections and their instrumentation.

Section S1

This section is in contact with the rock at the end of the drift. The instrumentation was installed to give the swelling pressure evolution in five points in contact with the rock. A pore pressure transducer was installed to give the drain effect inside the rock. A soil moisture sensor was installed to provide information about the evolution of the water content of the buffer (inner filling block).

A filter connected with a steel line was installed to be able to measure the remaining gas pressure at the upper part of the drift but also to measure the gas composition taking samples and analyzing in the laboratory. Due to DAWE procedure, this sensor was flooded from the beginning and no gas pressure was measured.

Sections S2 and S7

Both are hydraulically instrumented sections within the distance blocks at both sides of the Supercontainer. Four pore pressure transducers were installed to give the drain effect inside the rock walls and four total pressure cells were installed to track the swelling pressure evolution in contact with the rock. Within the buffer, the distribution of the sensors is radial in order to study the evolution of the saturation process from the rock to the inner part of the buffer. The distribution is in 4 different orientations for studying the effect of the saturation process in gravity sense and in perpendicular direction. The capacitive hygrometer and the psychrometers were installed to give the saturation process in all range (water potential which is related with the water content with the water retention curve). The soil moisture sensors were installed to give the volumetric water content. The installation of pore pressure transducers at the same radius as in the rock was done to monitor the positive pressure when the buffer is saturated. An inclinometer was installed to inform about blocks tilting.

Section S3

This section only has a radio module to pass the Supercontainer.

Sections S4 & S4+
Located in the middle of the Supercontainer, the instrumentation of this section was installed to give the swelling pressure developed against the Supercontainer shell and the canister surface from the ring blocks. Capacitive hygrometers and psychrometers were distributed in two diameters to follow the evolution of the saturation process in the blocks from the rock to the inner part of the buffer. Two additional soil moisture sensors were installed to give the volumetric water content and four pore pressure transducers were installed to give the positive pressure when the buffer saturates. Two inclinometers were installed to inform about the package tilting (one close to the shell and another one close to the canister) and four extensometers were installed to monitor movements (S4+, in the next block because the lack of room in the previous one).

Sections S5 & S5-
This section, located close to the canister end, was instrumented for different purposes: first to follow the saturation process inside the Supercontainer thanks to the pore pressure transducers, the capacitive hygrometers, the psychrometers and the soil moisture sensors; second to track the swelling pressure developed against the canister by the end block bottom; third to measure the saturation process in the center of the end block bottom; and fourth to monitor canister movements regarding the Supercontainer shell (again located in the annex block due to the lack of room, S5-).

This section is also devoted to monitor the mechanical behavior of the Supercontainer. 8 strain gauges were glued on to the Supercontainer shell to detect failures when the strains change suddenly.

Section S6
The instrumentation of S6 was installed to give the swelling pressure developed against the Supercontainer from the distance blocks. A filter connected with a steel line was installed to be able to measure the gas pressure due the possible corrosion of the Supercontainer but also to measure the gas composition taking samples and analyzing in the laboratory. Due to the DAWE procedure, this sensor was flooded from the beginning.

Section S7
See S2, these have the same configuration and objectives.

Section S8
This section was installed to follow the saturation process within the transition blocks by means of suction and water content instrumentation and total pressure cells installed at the rock walls. Two additional soil moisture sensors were installed to give the volumetric water content.

Section S9
This section is the closest to the pellets filling, so it will be possible to see if there are any differences with respect to the other sections and to assess the effect of the pellets on block saturation. In the pellet zone, a total pressure sensor is installed for assessing the swelling pressure developed by the pellets onto the blocks.

Soil moisture sensors and suction instruments were installed in four perpendicular radii to study the saturation process on the opposite side respect to the pellets in order to avoid quick saturation of the sensors during the DAWE. The swelling pressure development against the rock is measured too. Two sensors were installed in the buffer to monitor possible movements; two inclinometers were also installed.

Pore pressure sensors were installed in the three boreholes in this drift section to provide information about groundwater flow.

Section S9+
Section S9+ is located 0.9 m from the plug and was added in order to install six total pressure cells that could not fit in sections S9 & S10 for practical reasons.

Section S10
This section is mainly for studying the swelling pressure development against the plug. The instrumentation has a double purpose. On the one hand it provides information about the stresses against the plug (total pressure in some locations) and on the other it provides information to compare with the swelling pressure developed in the Supercontainer side (section 4 and the other sections from 4 till plug) for studying the development of friction between the bentonite and the rock. In order to be able to measure the effective pressure, pore pressure sensors were installed. There was a gas pressure sensor in this section but it was flooded from the beginning due to the DAWE procedure.

Section OUT
This is not strictly a section. It comprises all the transducers installed outside the sealed test section.

As with the Supercontainer shell, 16 strain gauges were installed on the cap to monitor the stress state. A temperature sensor was installed to measure for temperature compensation in the strain gauges measures. Three displacement transducers were installed to inform about plug movements and for comparing the behavior of this system with the plug tested before (SKB 2012).

A flowmeter system was installed to be used for measuring the water leakage from the plug.

In the following chapters (4 - 6), outer sensor positions refer to those sensors located at the interface between the MPT drift boundaries (i.e., rock wall or plug) and drift components whereas inner sensor positions refer to those sensors located within MPT drift components.

4 DISTANCE BLOCKS

The sensors in the distance blocks are located in drift sections S-1, S-2, S-6 and S-7 (Figure 3-1).

4.1 Inner sensor positions

The location of the inner sensors and other information is presented in Tables 4-1 (section 1), 4-2 (section 2), 4-3 (section 6) and 4-4 (section 7).

Table 4-1. *Numbering and position of inner distance block sensors in drift section 1.*

	Coordinate system ÄSPÖ 96							
Point No.	**Easting [m]**	**Northing [m]**	**Point Elevation [m]**	Drawing label	Sensor code in SICADA	Sensor code in SCADA	Assembly tag label	Manufacturer
1	**1904.721**	**7253.178**	**-217.881**	WF	**PXK003WF1**	WF-1867	ML2x377/048	Delta-T
2	**1904.870**	**7253.179**	**-216.447**	GP	**PXK004GP1**	GP-1856	GP 1892-1	Keller

Table 4-2. *Numbering and position of inner distance block sensors in drift section 2.*

	Coordinate system ÄSPÖ 96							
Point No.	**Easting [m]**	**Northing [m]**	**Point Elevation [m]**	Drawing label	Sensor code in SICADA	Sensor code in SCADA	Assembly tag label	Manufacturer
1	**1906.208**	**7253.179**	**-216.564**	WF2	**PXK017WF2**	WF-1722-2	WF 1722-2	Delta-T
2	**1906.208**	**7252.972**	**-216.592**	WP4	**PXK017WP4**	WP-1722-4	WP 1722-4	Wescor
3	**1906.207**	**7253.386**	**-216.591**	WC5	**PXK017WC5**	WC-1722-5	WC 1722-5	Aitemin
4	**1906.082**	**7253.179**	**-216.809**	IB1	**PXK016IB1**	IB-1722	IB 1722-1	Measurement Specialities
5	**1906.203**	**7252.613**	**-216.798**	PP3	**PXK017PP3**	PP-1722-3	wireless	Measurement Specialities
6	**1906.202**	**7253.745**	**-216.798**	PP2	**PXK017PP2**	PP-1722-2	wireless	Measurement Specialities
7	**1906.195**	**7253.114**	**-217.123**	WP1	**PXK017WP1**	WP-1722-1	WP 1722-1	Wescor
8	**1906.195**	**7253.244**	**-217.123**	WC2	**PXK017WC2**	WC-1722-2	wireless	Aitemin
9	**1906.191**	**7252.380**	**-217.314**	WP5	**PXK017WP5**	WP-1722-5	WP 11722-5	Wescor
10	**1906.189**	**7252.381**	**-217.414**	WC6	**PXK017WC6**	WC-1722-6	WC 1722-6	Aitemin
11	**1905.940**	**7253.842**	**-217.303**	WSU	**transmitter**	WSU-S2	wireless	Aitemin
12	**1906.189**	**7253.978**	**-217.314**	WP3	**PXK017WP3**	WP-1722-3	WP 1722-3	Wescor
13	**1906.187**	**7253.978**	**-217.414**	WC4	**PXK017WC4**	WC-1722-4	wireless	Aitemin
14	**1906.184**	**7253.054**	**-217.581**	WP2	**PXK017WP2**	WP-1722-2	WP 1722-2	Aitemin
15	**1906.184**	**7253.304**	**-217.581**	WC1	**PXK017WC1**	WC-1722-1	wireless	Wescor
16	**1906.173**	**7252.779**	**-218.057**	PP4	**PXK017PP4**	PP-1722-4	PP 1722-4	Measurement Specialities
17	**1906.171**	**7252.972**	**-218.137**	WP6	**PXK017WP6**	WP-1722-6	WP 1722-6	Wescor
18	**1906.170**	**7253.179**	**-218.163**	WF1	**PXK017WF1**	WF-1722-1	WF 1722-1	Delta-T
19	**1906.170**	**7253.386**	**-218.137**	WC3	**PXK017WC3**	WC-1722-3	WC 1722-3	Aitemin
20	**1906.172**	**7253.580**	**-218.057**	PP1	**PXK017PP1**	PP-1722-1	wireless	Measurement Specialities

Table 4-3. *Numbering and position of inner distance block sensors in drift section 6.*

	Coordinate system ÄSPÖ 96							
Point No.	**Easting [m]**	**Northing [m]**	**Point Elevation [m]**	Drawing label	Sensor code in SICADA	Sensor code in SCADA	Assembly tag label	Manufacturer
1	**1913.463**	**7252.635**	**-217.644**	TP3	**PXK090TP3**	TP-0990-2	TP 0990-3	Geokon /ÅF
2	**1913.461**	**7253.745**	**-217.644**	TP5	**PXK090TP5**	TP-0990-4	TP 0990-5	Geokon / ÅF
3	**1913.449**	**7253.190**	**-218.199**	TP2	**PXK090TP2**	TP-0990-1	TP 0990-2	Geokon / ÅF
4	**1913.704**	**7253.190**	**-216.787**	GP1	**PXK092GP1**	GP-0967	GP 0967-1	Keller
5	**1913.462**	**7253.190**	**-217.088**	TP4	**PXK092TP4**	TP-0990-3	TP 0990-4	Geokon / ÅF

Table 4-4. *Numbering and position of inner distance block sensors in drift section 7.*

	Coordinate system ÄSPÖ 96							
Point No.	**Easting [m]**	**Northing [m]**	**Point Elevation [m]**	Drawing label	Sensor code in SICADA	Sensor code in SCADA	Assembly tag label	Manufacturer
1	**1915.653**	**7252.628**	**-217.158**	PP3	**PXK112PP3**	PP-0820-3	wireless	Measurement Specialities
2	**1915.657**	**7252.986**	**-216.952**	WP4	**PXK112WP4**	WP-0820-4	WP 0820-4	Wescor
3	**1915.658**	**7253.193**	**-216.924**	WF2	**PXK112WF2**	WF-0820-2	WF 0820-2	Delta-T
4	**1915.657**	**7253.401**	**-216.951**	WC5	**PXK112WC5**	WC-0820-5	WC 0820-5	Aitemin
5	**1915.651**	**7253.759**	**-217.158**	PP2	**PXK112PP2**	PP-0820-2	wireless	Measurement Specialities
6	**1915.645**	**7253.128**	**-217.483**	WP1	**PXK112WP1**	WP-0820-1	WP 0820-1	Wescor
7	**1915.644**	**7253.258**	**-217.483**	WC2	**PXK112WC2**	WC-0820-2	wireless	Aitemin
8	**1915.641**	**7252.395**	**-217.673**	WP5	**PXK112WP5**	WP-0820-5	WP 0820-5	Wescor
9	**1915.639**	**7252.395**	**-217.773**	WC6	**PXK112WC6**	WC-0820-6	WC 0820-6	Aitemin
10	**1915.634**	**7253.068**	**-217.940**	WP2	**PXK112WP2**	WP-0820-2	WP 0820-2	Wescor
11	**1915.633**	**7253.319**	**-217.940**	WC1	**PXK112WC1**	WC-0820-1	wireless	Aitemin
12	**1915.639**	**7253.992**	**-217.673**	WP3	**PXK112WP3**	WP-0820-3	WP 0820-3	Wescor
13	**1915.636**	**7253.992**	**-217.773**	WC4	**PXK112WC4**	WC-0820-4	wireless	Aitemin
14	**1915.623**	**7252.793**	**-218.416**	PP4	**PXK112PP4**	PP-0820-4	PP 0820-4	Measurement Specialities
15	**1915.621**	**7252.986**	**-218.496**	WP6	**PXK112WP6**	WP-0820-6	WP 0820-6	Wescor
16	**1915.620**	**7253.193**	**-218.522**	WF1	**PXK112WF1**	WF-0820-1	WF 0820-1	Delta-T
17	**1915.620**	**7253.401**	**-218.496**	WC3	**PXK112WC3**	WC-0820-3	WC 0820-3	Aitemin
18	**1915.622**	**7253.594**	**-218.416**	PP1	**PXK112PP1**	PP-0820-1	wireless	Measurement Specialities
19	**1915.532**	**7253.193**	**-217.175**	IB1	**PXK109IB1**	IB-0820	IB 0820-1	Measurement Specialities
20	**1915.449**	**7253.856**	**-217.664**	WSUS7	**transmmiter**	WSU-S7	wireless	Aitemin

4.2 Inner sensor results and comments

4.2.1 Relative humidity

The relative humidity sensors in the peripheral positions of the blocks have measured increases in the relative humidity as expected. No changes have been measured with the sensors in more inward locations of the blocks. The results are presented in Figures 4-1 and 4-2.

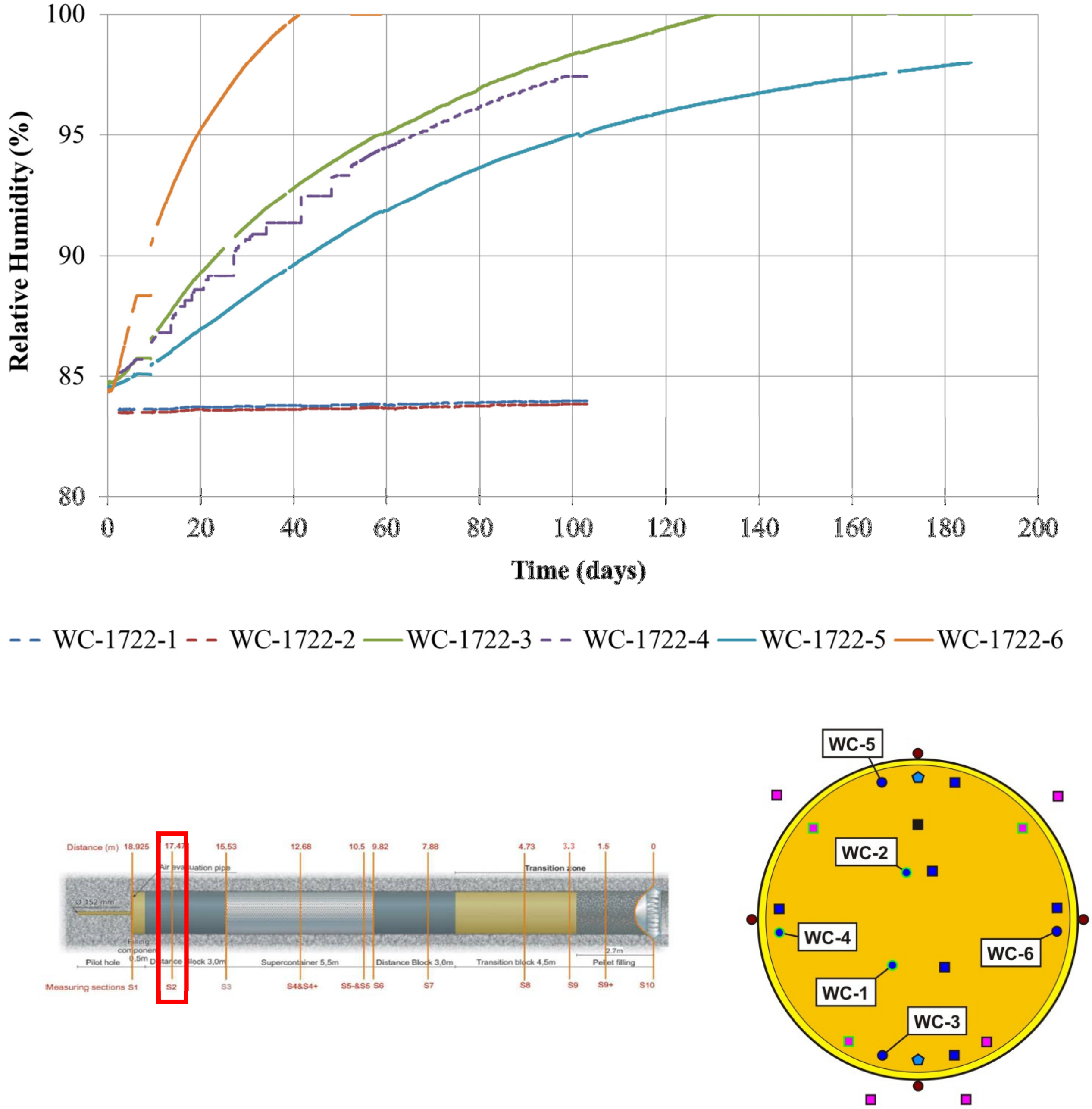


Figure 4-1. *Response of capacitive hygrometer sensors at inner distance block positions (in the bentonite block) in drift section S-2. A total of six such sensors were installed in this section (bottom-right inset; WC-1 corresponds to WC-1772-1, etc.). The sensors in more peripheral positions recorded increases in relative humidity from the beginning of the test whereas the sensors closer to the center showed little to no increase in relative humidity. Dashed lines correspond to wireless sensors (WC-1, WC-2 and WC-4). Signal was being received from these sensors until just over 100 days into the test after which they have not transmitted as intended.*

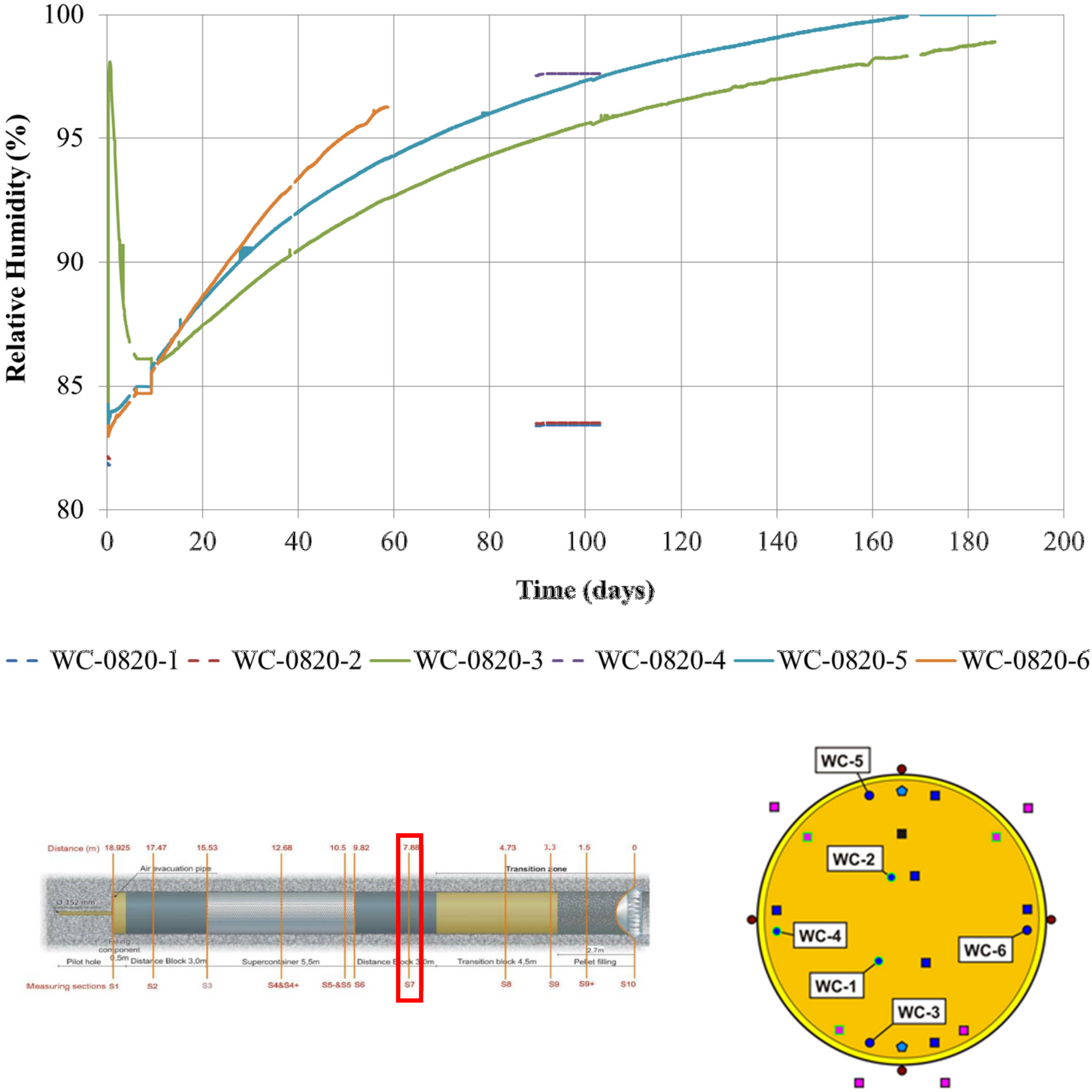


Figure 4-2. *Response of capacitive hygrometer sensors at inner distance block positions (in the bentonite block) in drift section S-7. A total of six such sensors were installed in this section (bottom-right inset; WC-1 corresponds to WC-0820-1, etc.). The sensors in more peripheral positions recorded increases in relative humidity from the beginning of the test whereas the sensors closer to the center showed little to no increase in relative humidity. Sensor WC-3 showed an early spike in relative humidity perhaps due to the initial water filling of the gap. Dashed lines correspond to wireless sensors (WC-1, WC-2 and WC-4). Signal was received from these sensors only from around 90 until just over 100 days into the test, before and after that they have not transmitted as intended.*

It seems that the response pattern is similar in both sections, showing that the sensor at the right side (WC-6 in both sections) measured an increase in relative humidity before the other sensors. The reason could be related with a higher gap (more water available) on the right side during the emplacement of the blocks or due to a sudden movement/rotation just after the water filling. Such an asymmetric wetting process is evident in the psychrometer results as well.

4.2.2 Suction

In-range signals from the psychrometer sensors correspond only to suction established at 95% relative humidity. For temperatures between 5 ºC and 15 ºC, the suction at 95% relative humidity should be between 6.6 and 6.8 MPa based on the psychometric law. The results are presented in Figures 4-3 to 4-6.

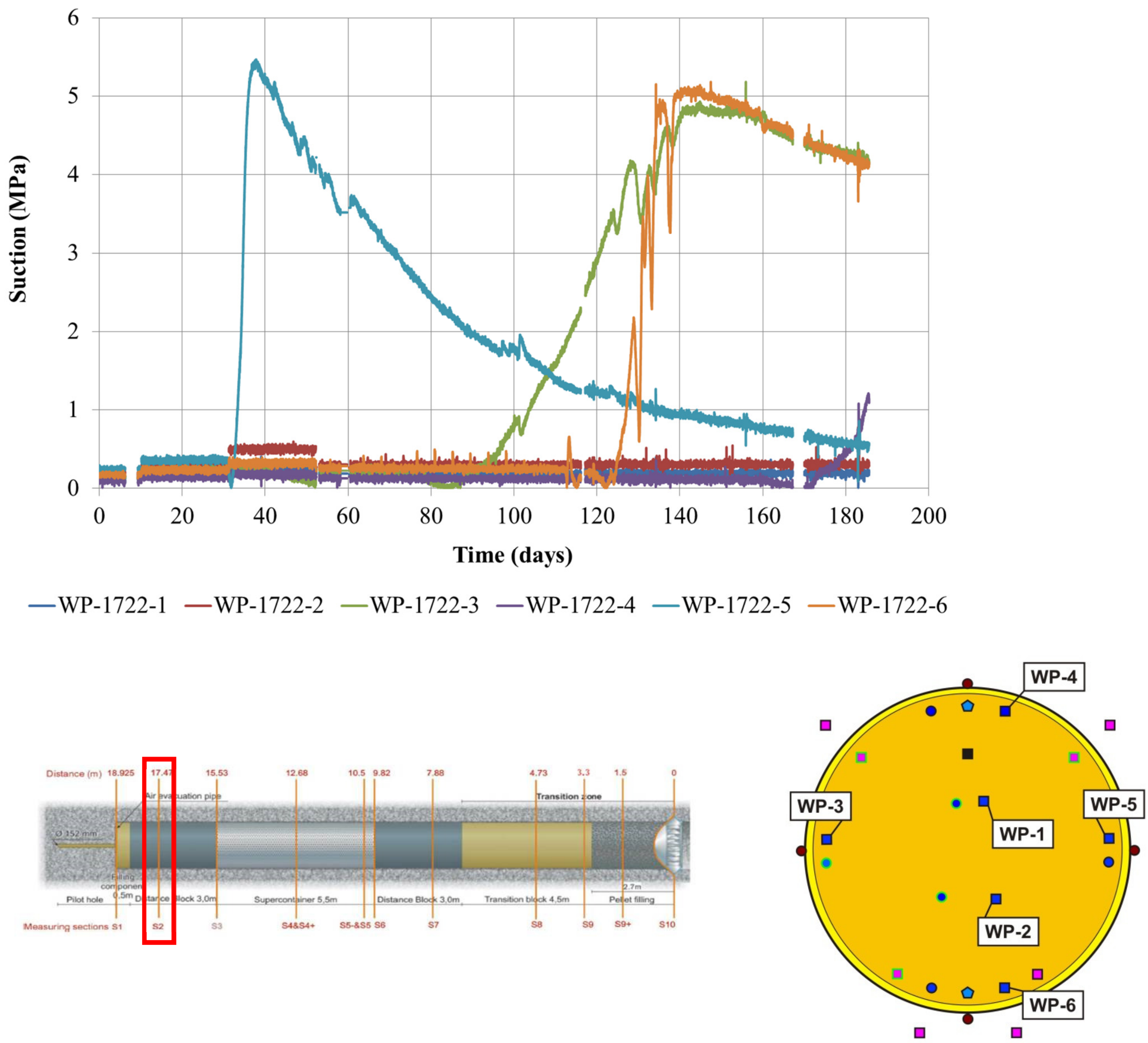


Figure 4-3. *Response of psychrometers at inner distance block positions (in the bentonite block) in drift section S-2. A total of six such sensors were installed in this section (bottom-right inset; WP-1 corresponds to WP-1722-1, etc.). Sensors WP-3, WP-5 and WP-6 in more peripheral locations have reached in-range suction limits (see also Figure 4-4). The signals for sensors closer to the center have not yet started to approach in-range limits.*

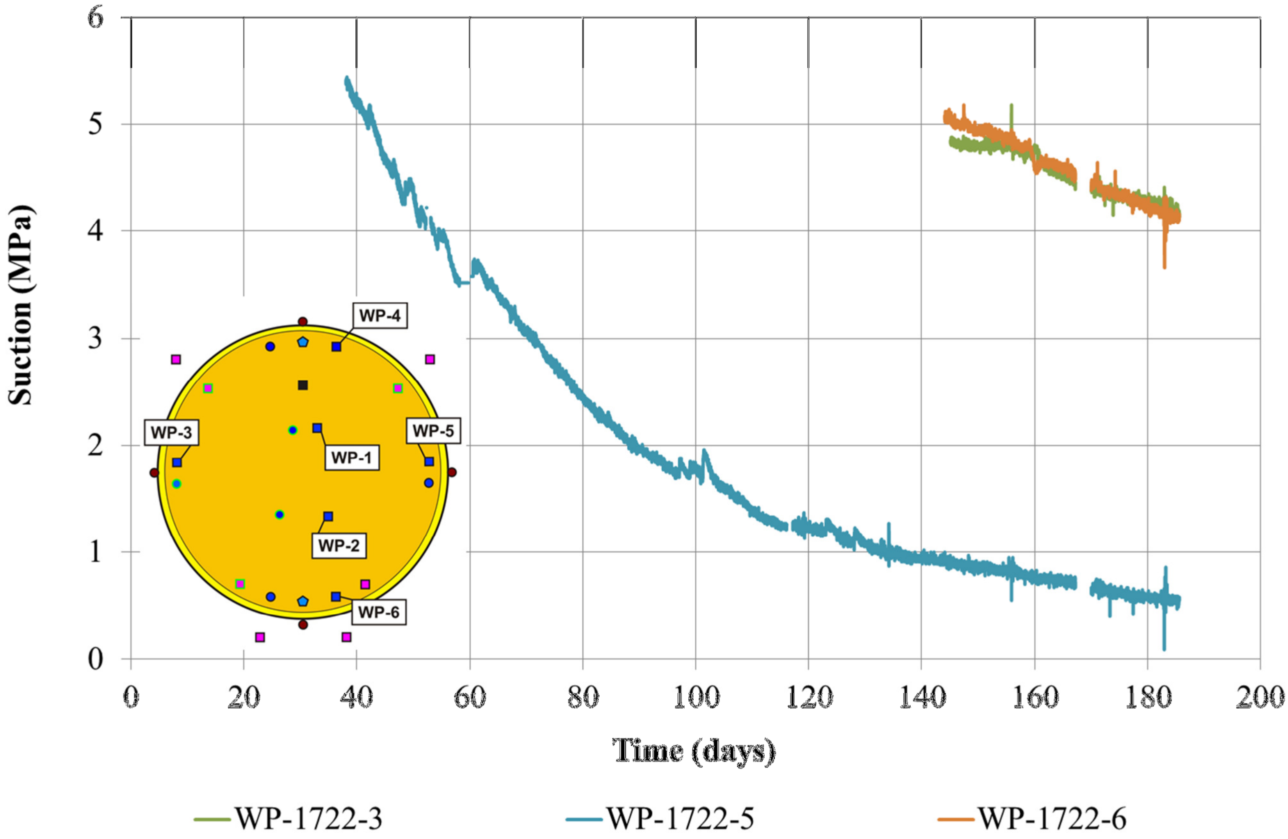


Figure 4-4. *Decay in psychrometer signal for sensors WP-3, WP-5 and WP-6 in inner distance block positions in drift section 2 after reaching in-range suction limits.*

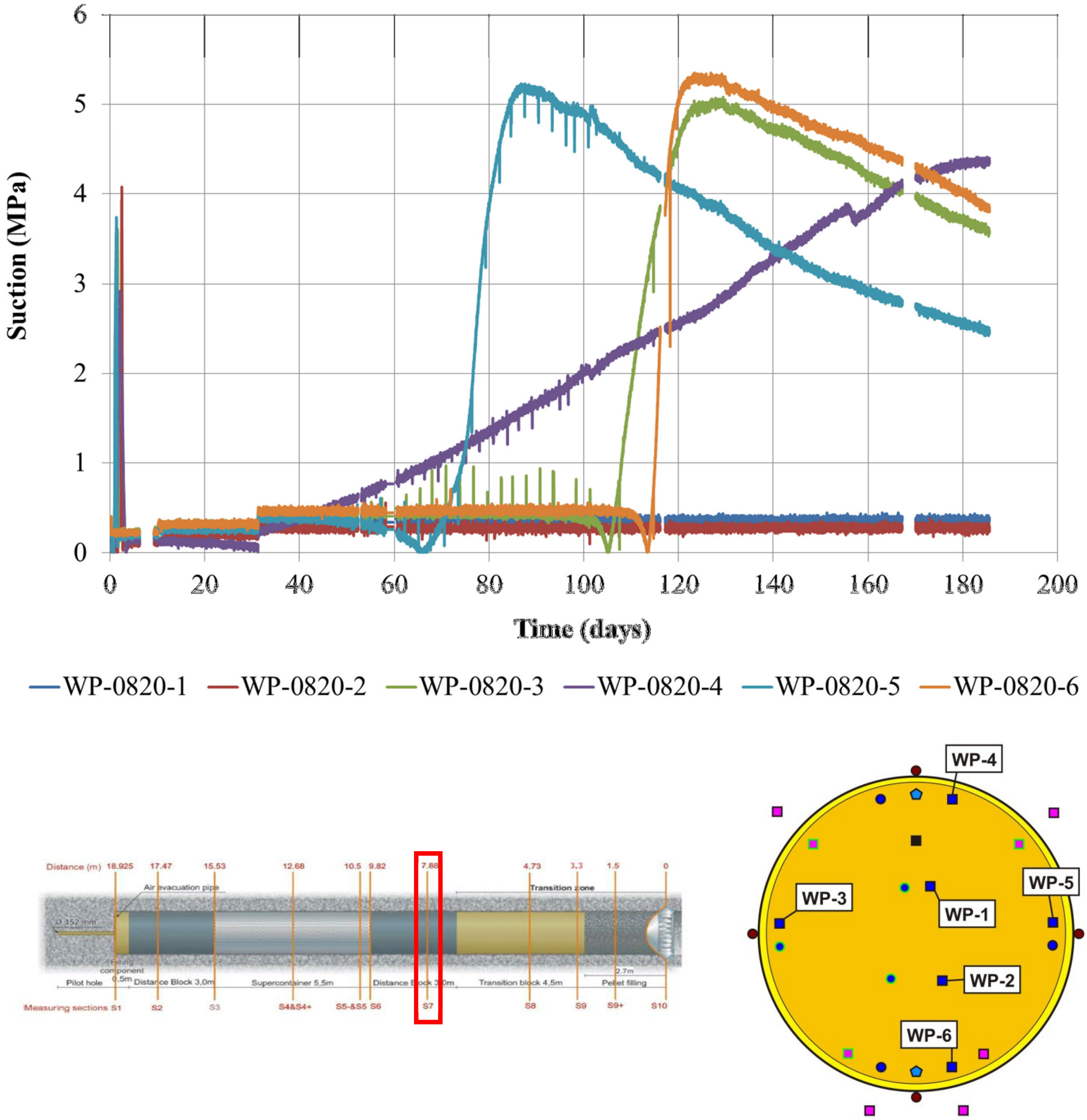


Figure 4-5. *Response of psychrometers at inner distance block positions (in the bentonite block) in drift section S-7. A total of six such sensors were installed in this section (bottom-right inset; WP-1 corresponds to WP-0820-1, etc.). Sensors WP-3, WP-5 and WP-6 in more peripheral locations reached in-range suction limits after 85 to 125 days (see also Figure 4-6). The signals for sensors closer to the center have not yet started to approach in-range limits.*

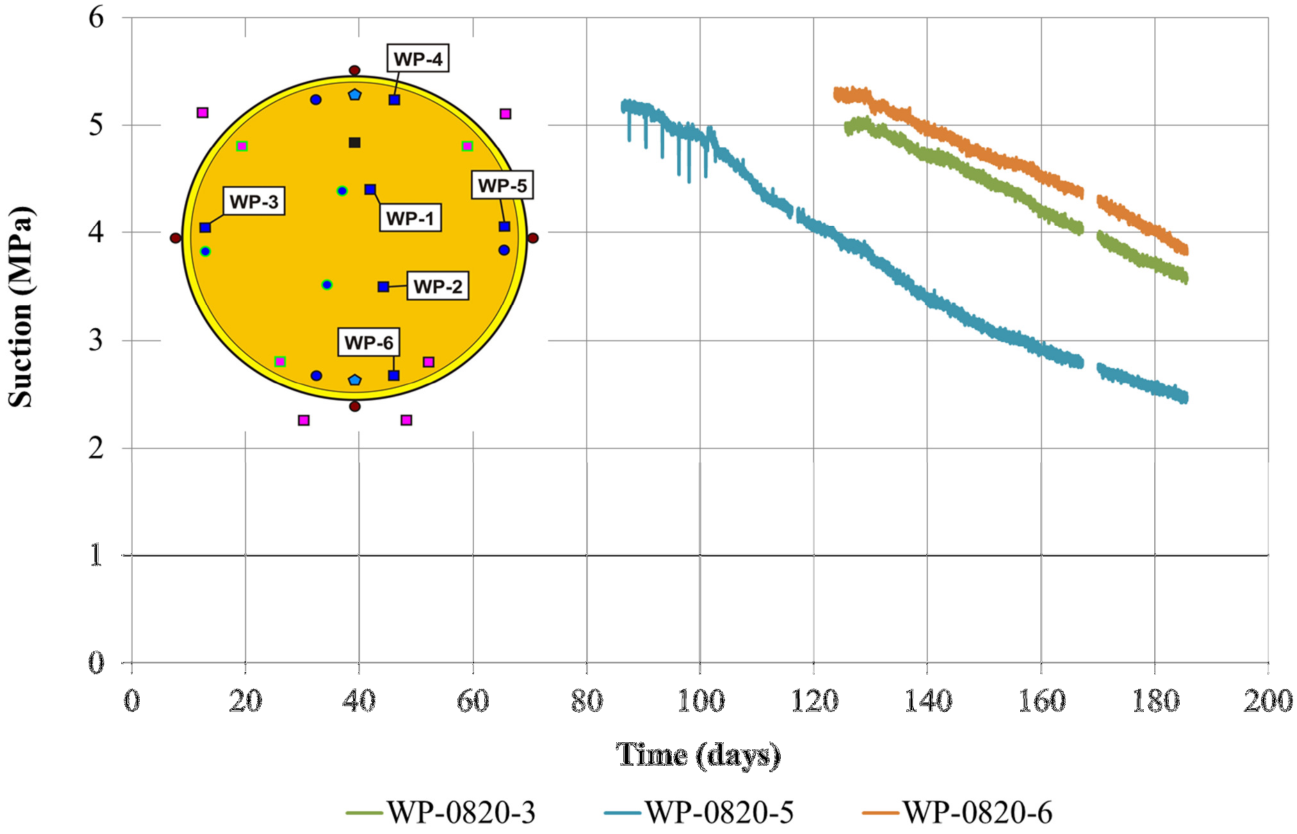


Figure 4-6. *Decay in psychrometer signal for sensors WP-3, WP-5 and WP-6 in inner distance block positions in drift section 7 after reaching in-range suction limits.*

4.2.3 Pore pressure

Pore pressures in the blocks were measured with pore pressure sensors (Figures 4-7 and 4-8). The pressure in the gap was measured (Figure 4-9) with a gas pressure sensor. In most cases, the pore pressure sensors in the blocks did not measure any increase in pore pressure. This observation may be due to the low hydraulic conductivity of the bentonite. The measurement results are presented in Figures 4-7 to 4-9.

Similarly, the BRIE test, also conducted in the Äspö HRL, was instrumented with pore pressure sensors and pressure increases were not observed (Fransson et al., 2014). Other examples indicating delays in the development of measurable pore pressures in bentonite blocks include the FEBEX test (Enresa, 2000) and the ESDRED test both performed at the Grimsel Test Site (Switzerland).

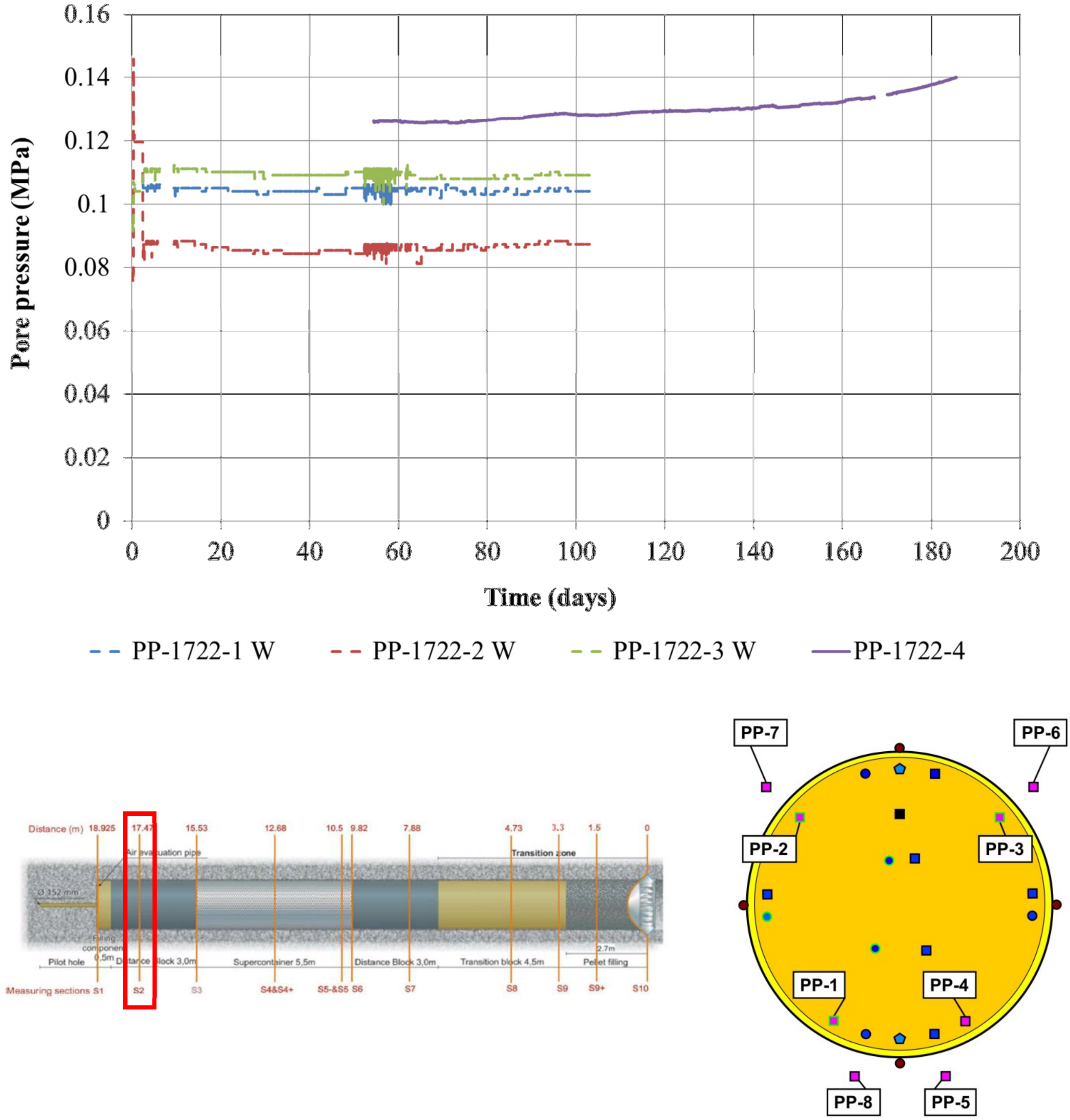


Figure 4-7. *Response of pore pressure sensors at inner distance block positions (in the bentonite block) in drift section S-2. A total of four such sensors were installed in this section (bottom-right inset; PP-1 corresponds to PP-1722-1, etc.). Dashed lines correspond to wireless sensors (PP-1, PP-2 and PP-3). Signal was being received from these sensors until just over 100 days into the test. Sensor PP-4 was starting to show increasing signal after 140 days.*

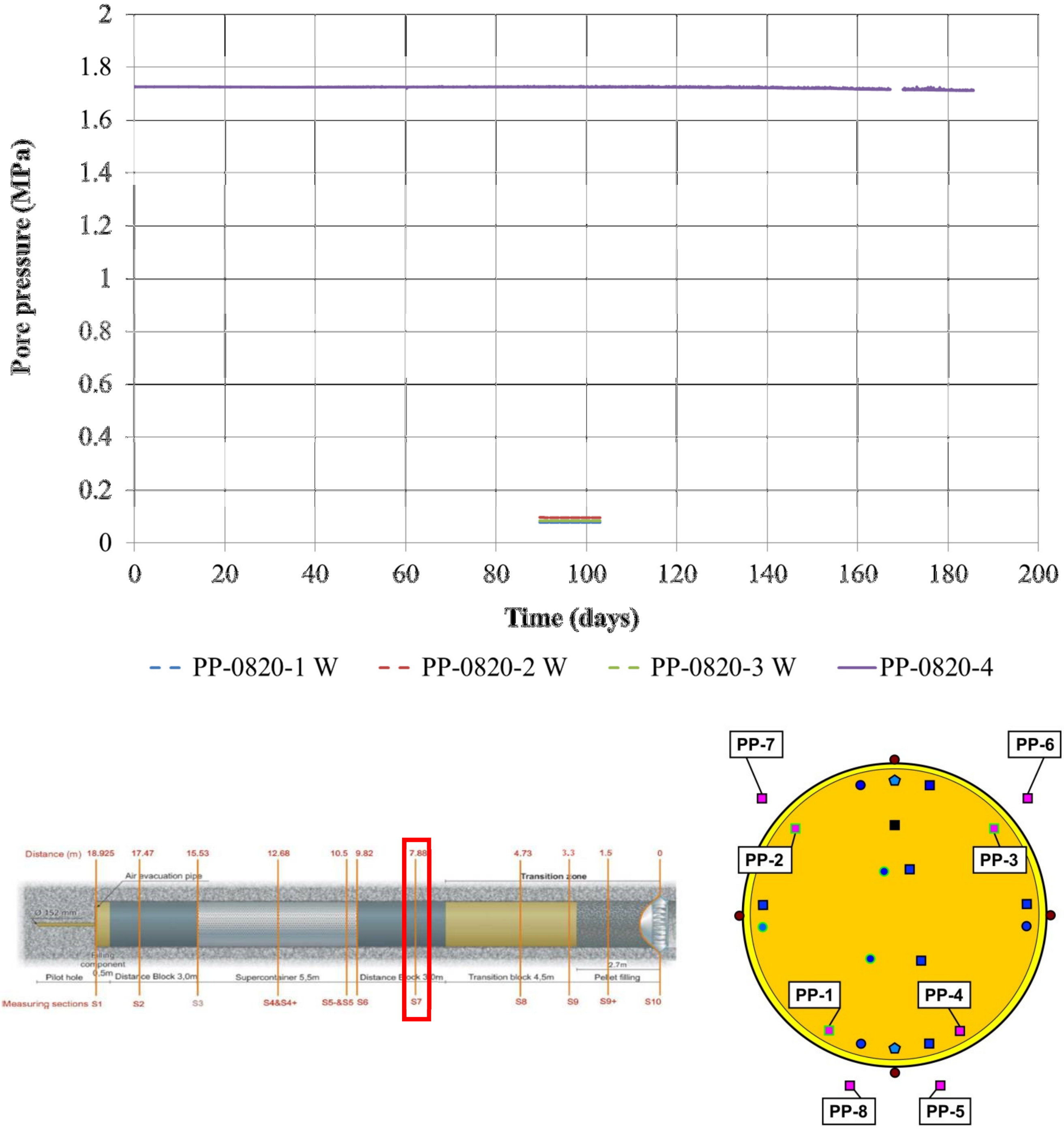
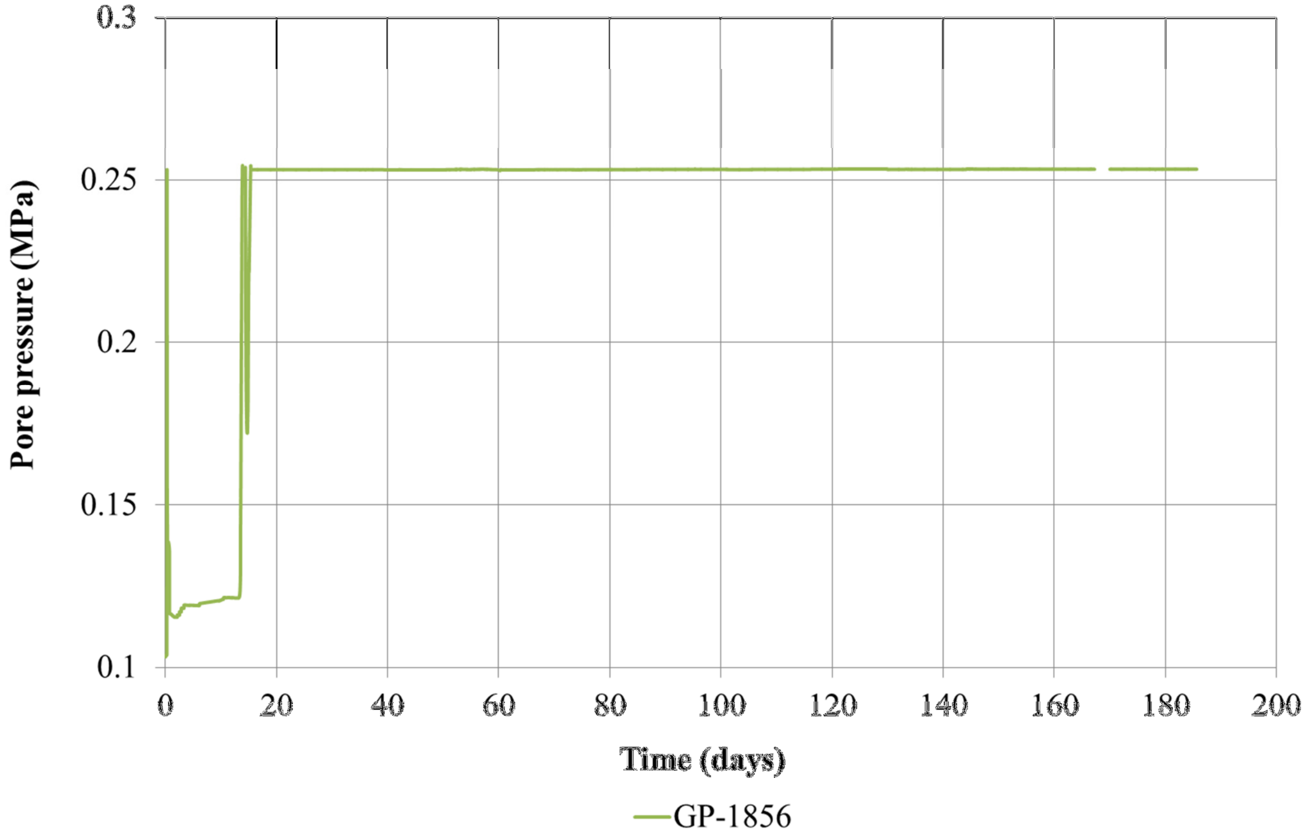
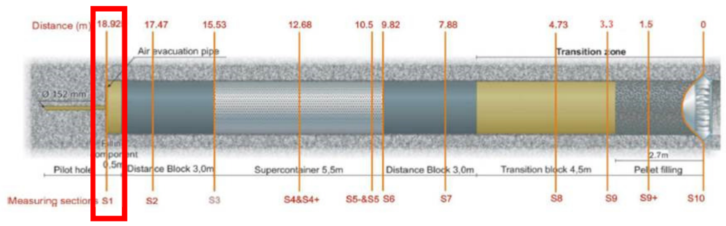


Figure 4-8. *Response of pore pressure sensors at inner distance block positions (in the bentonite block) in drift section S-7. A total of four such sensors were installed in this section (bottom-right inset; PP-1 corresponds to PP-0820-1, etc.). Dashed lines correspond to wireless sensors (PP-1, PP-2 and PP-3). Signal was received from these sensors only from around 90 until just over 100 days into the test. Sensor PP-4 has displayed an unreasonably large signal since the beginning of the test and may be malfunctioning.*





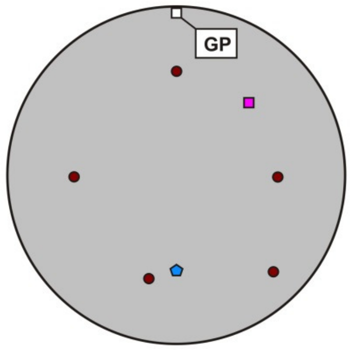


Figure 4-9. *Response of gas pressure sensor in drift section S-1 (bottom-right inset). The full sensor range is 250 kPa and it was installed for the purposes of measuring the gas pressure during the water filling if the DAWE procedure was not followed. The sensor was flooded and essentially measured water pressure. After less than 10 days it reached the maximum capacity. This sensor should be changed to a higher range pore pressure sensor which is possible because the gas pressure sensors are located outside of the drift.*

4.2.4 **Water content**

Volumetric water content was measured with soil moisture sensors (Figures 4-10 to 4-12).

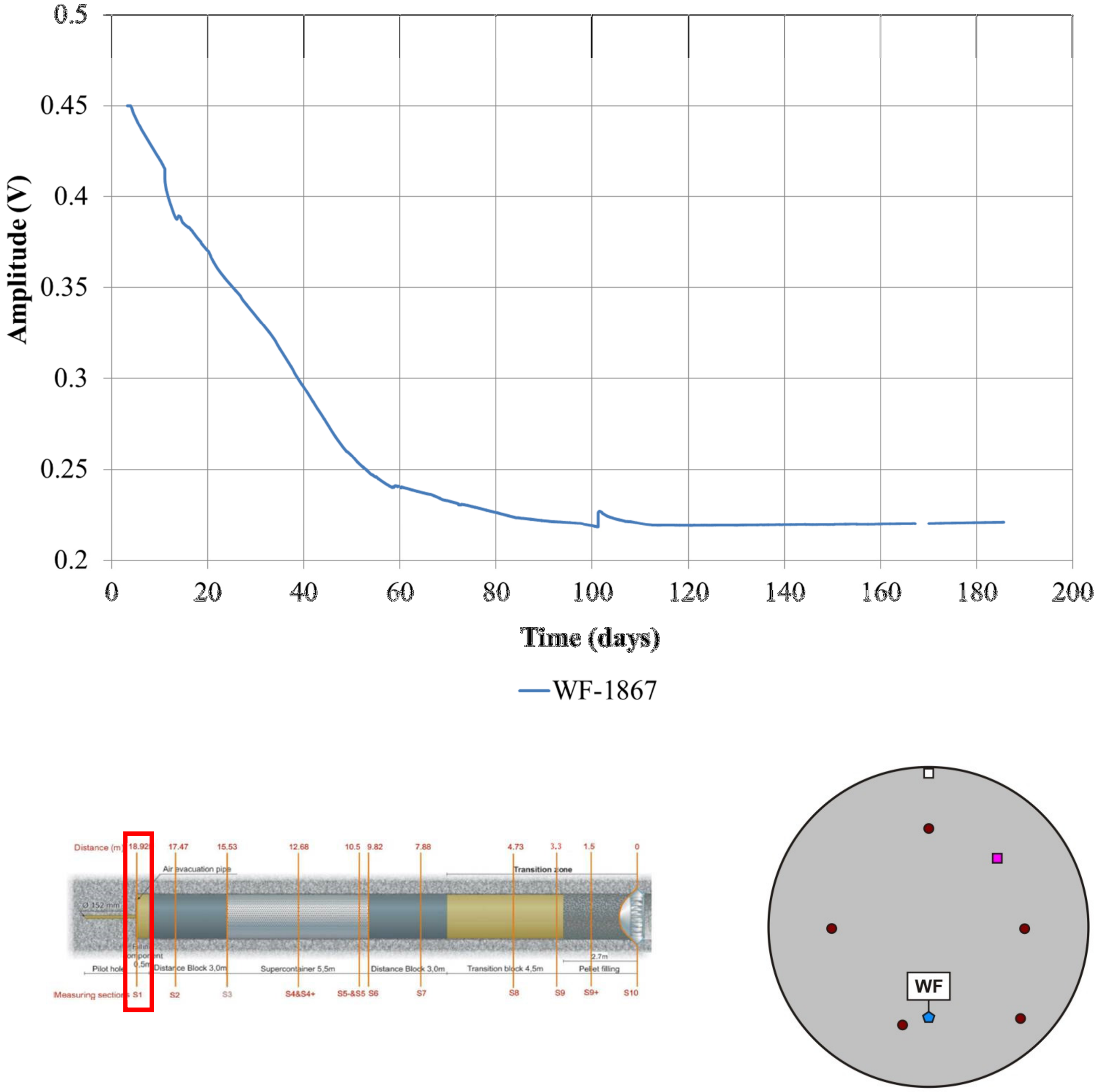


Figure 4-10. *Response of soil moisture sensor at inner distance block position (in the bentonite block) in drift section S-1. The sensor measured a decrease in signal until a constant value was reached after 100 days. This behavior could be related with expansion/fracturing of the bentonite which could lead to new voids in the vicinity of the measuring rods and lower signal. This block is in the rear of the drift and may be more prone to suffer expansion/breaking.*

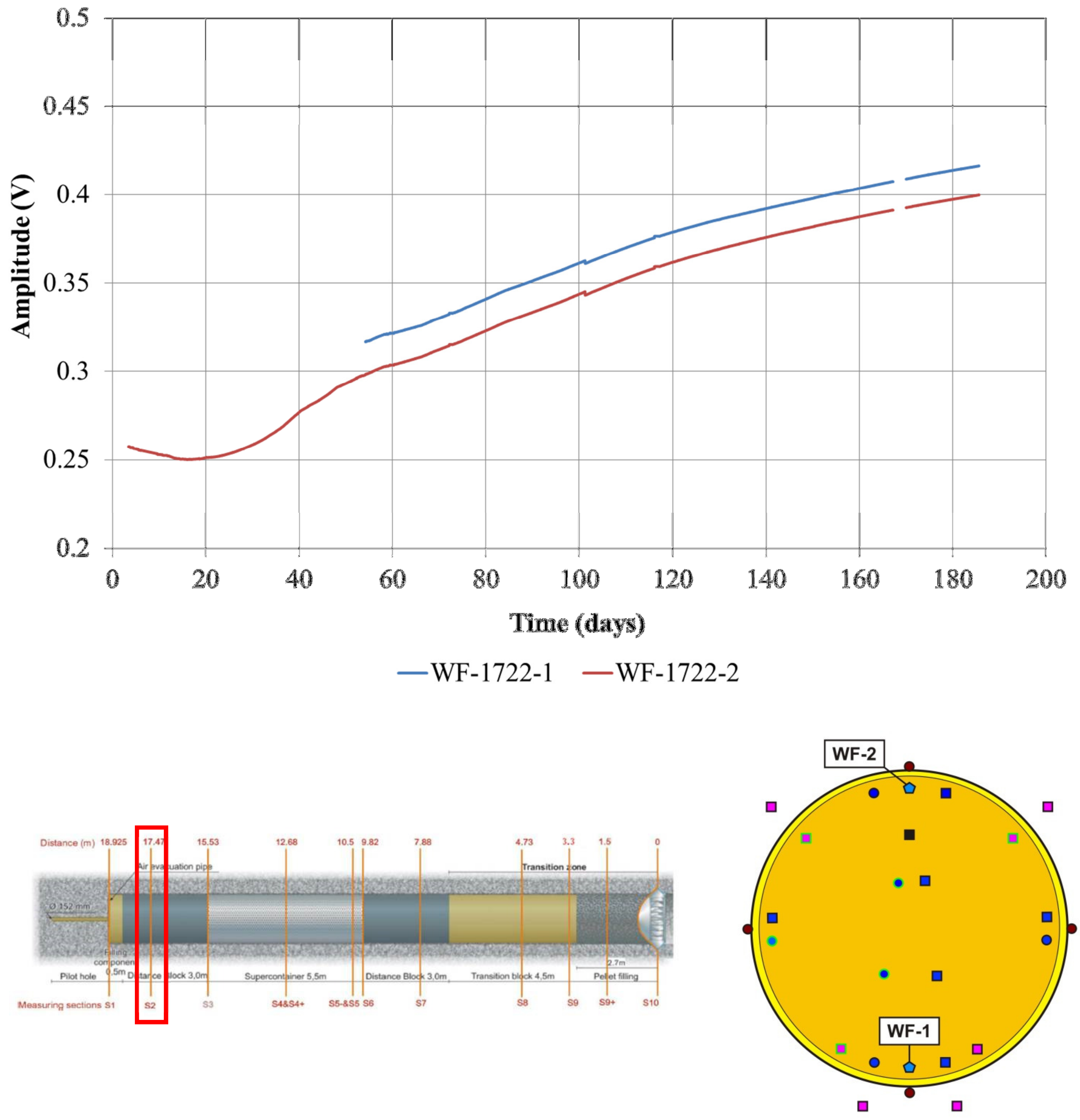


Figure 4-11. *Response of soil moisture sensors at inner distance block positions (in the bentonite block) in drift section S-2. A total of two such sensors were installed in this section (bottom-right inset; WF-1 corresponds to WF-1772-1 and WF-2 corresponds to WF-1772-2). Increasing signals were measured by both sensors over the course of the test.*

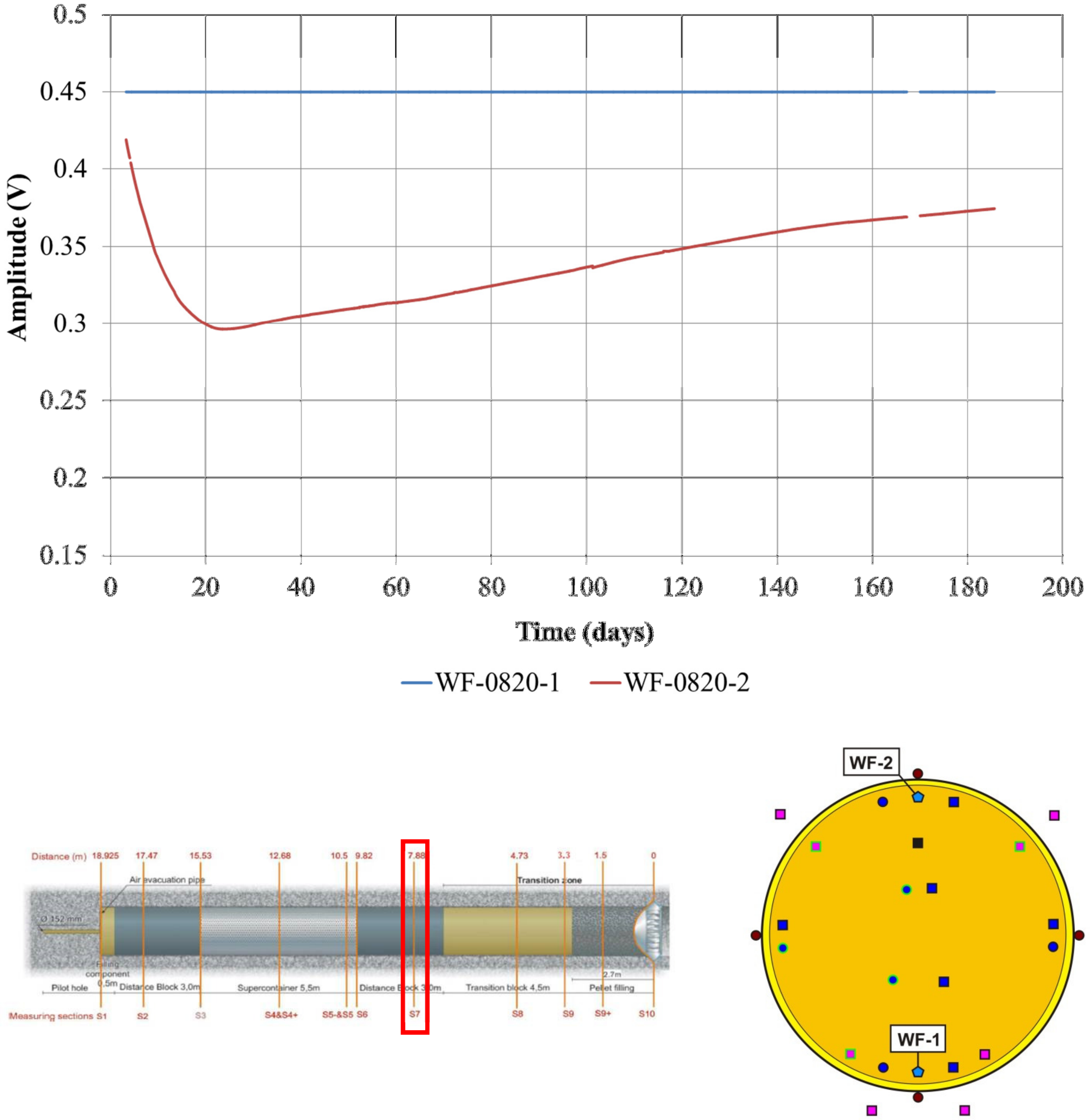
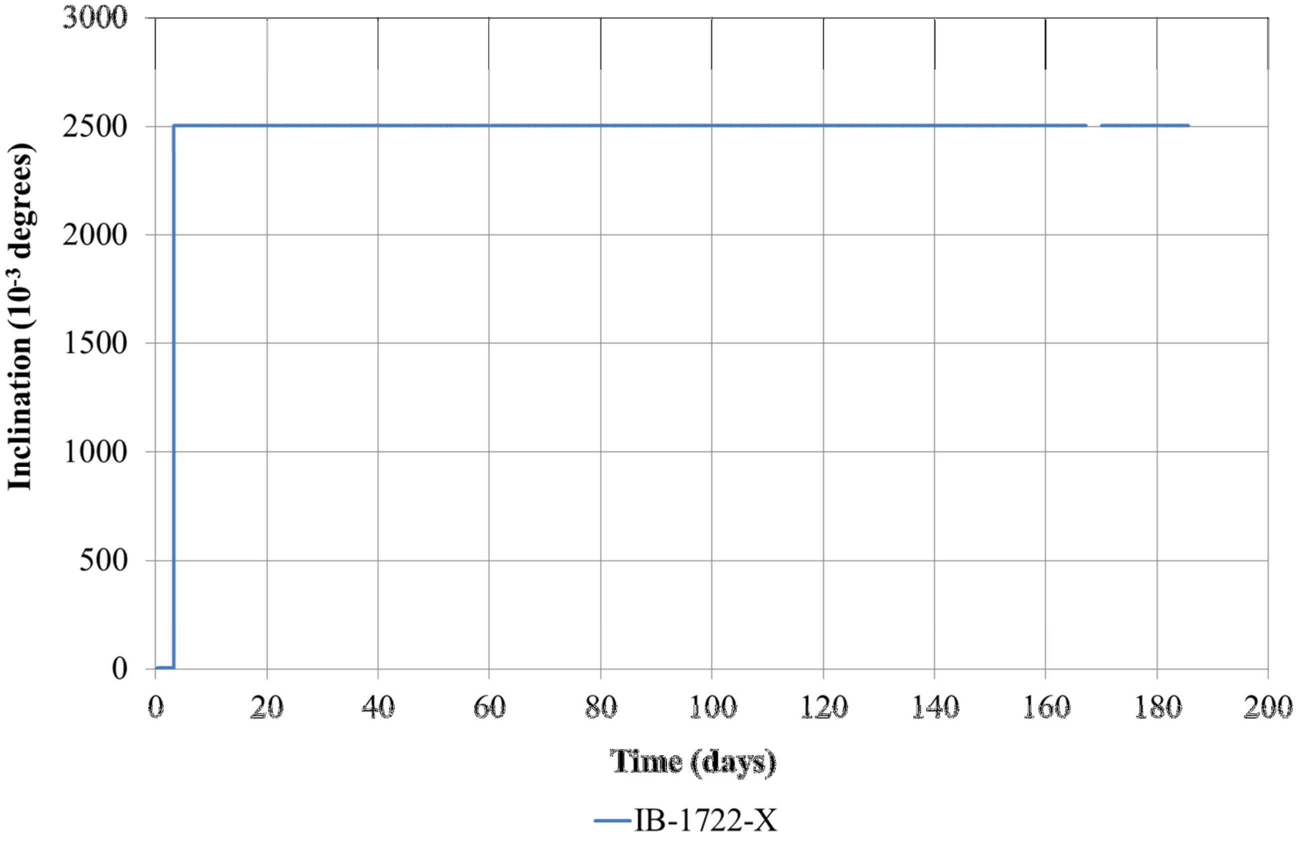


Figure 4-12. *Response of soil moisture sensors at inner distance block positions (in the bentonite block) in drift section S-7. A total of two such sensors were installed in this section (bottom-right inset; WF-1 corresponds to WF-0820-1 and WF-2 corresponds to WF-0820-2). Sensor WF-2 measured an increasing signal over most of the test but sensor WF-1 displayed a constant signal throughout which indicates it may be malfunctioning. The behavior of WF-2 at the beginning of the test is similar to WF-1867 (Figure 4-10) but the signal decreases less and an increase of the signal is also observed. The explanation for this behavior could be the same: expansion/fracturing of the bentonite but to a lesser extent due to higher confinement of the blocks.*

4.2.5 Inclination

Results from the inclinometer sensors are presented in Figures 4-13 and 4-14. The reference inclination is the one after the emplacement.



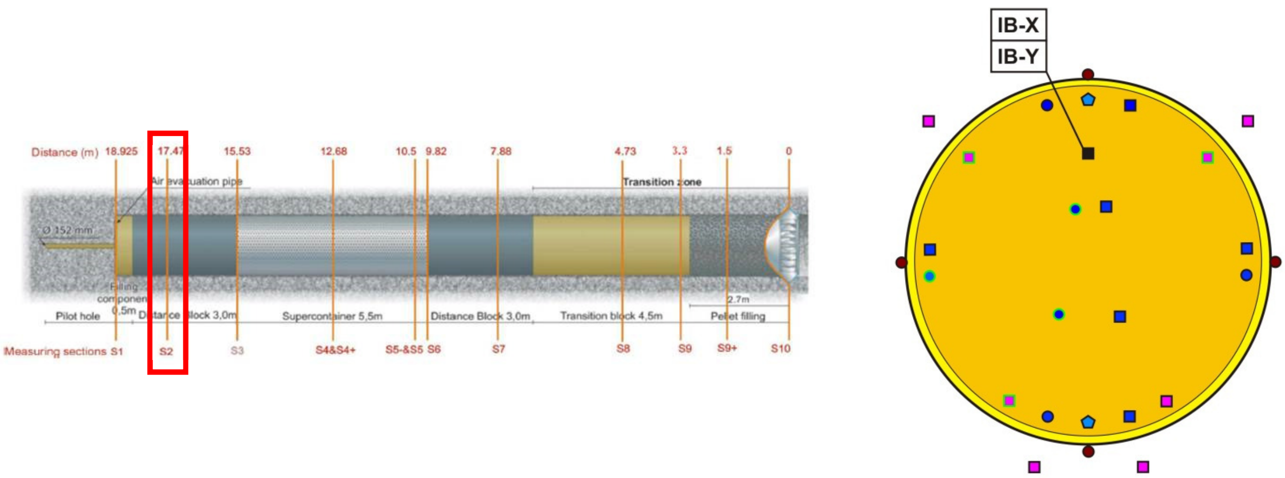


Figure 4-13. *Response of the inclinometer sensor at inner distance block position (in the bentonite block) in drift section S-2. A sudden change in inclination at 3 days to a constant value was measured suggesting a sudden rotation of the block towards the pilot borehole possibly due to block swelling.*

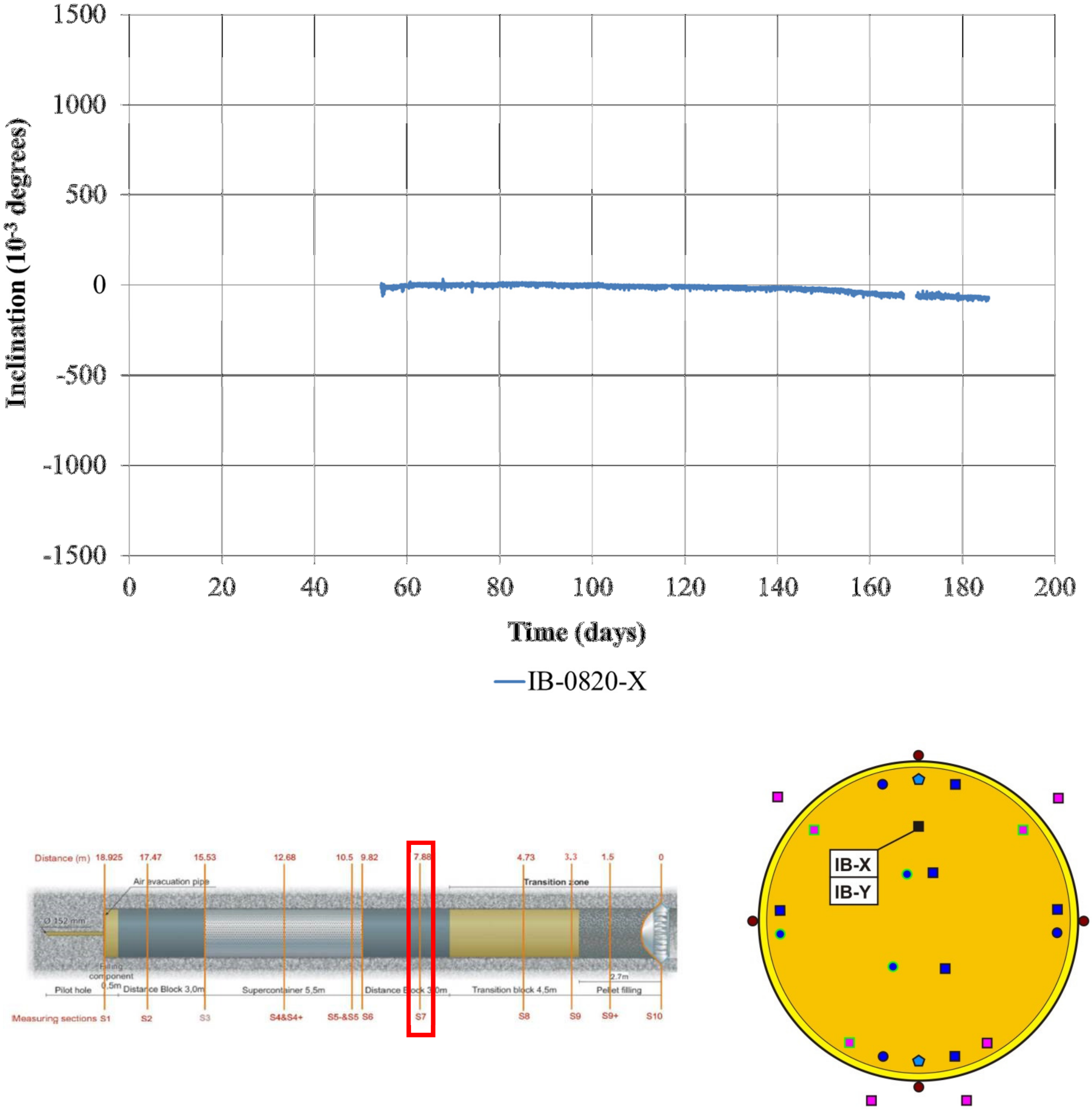


Figure 4-14. *Response of inclinometer sensor at inner distance block position (in the bentonite block) in drift section S-7. One sensor was installed in this block (bottom-right inset) and only inclination along the x-axis was measured. Signal was recorded from this sensor after 54 days. The signal trend appears to indicate a slow inclination towards the plug.*

4.3 Outer sensor positions

The location of the outer sensors and other information is presented in Tables 4-4 (section 1), 4-5 (section 2) and 4-6 (section 7).

Table 4-4. *Numbering and position of outer distance block sensors in drift section 1.*

	Coordinate system ÄSPÖ 96							
Point No.	**Easting [m]**	**Northing [m]**	**Point Elevation [m]**	Drawing label	Sensor code in SICADA	Sensor code in SCADA	Assembly tag label	Manufacturer
4	**1904.504**	**7252.779**	**-216.885**	PP-1	**PXK000PP1**	PP-1877-1	PP-1877-1	Keller
6	**1904.509**	**7253.186**	**-216.724**	TP-2	**PXK000TP2**	TP-1877-2	TP-1877-2	Geokon
5	**1904.483**	**7253.754**	**-217.303**	TP-3	**PXK000TP3**	TP-1877-3	TP-1877-3	Geokon
3	**1904.460**	**7253.329**	**-217.857**	TP-4	**PXK000TP4**	TP-1877-4	TP-1877-4	Geokon
1	**1904.465**	**7252.656**	**-217.820**	TP-5	**PXK000TP5**	TP-1877-5	TP-1877-5	Geokon
2	**1904.483**	**7252.601**	**-217.302**	TP-1	**PXK000TP1**	TP-1877-1	TP-1877-1	Geokon

Table 4-5. *Numbering and position of outer distance block sensors in drift section 2.*

	Coordinate system ÄSPÖ 96							
Point No.	**Easting [m]**	**Northing [m]**	**Point Elevation [m]**	Drawing label	Sensor code in SICADA	Sensor code in SCADA	Assembly tag label	Manufacturer
10	**1905.955**	**7252.519**	**-216.707**	PP-6	**PXK015PP6**	PP-1732-6	PP-1732-6	Keller
12	**1905.954**	**7252.950**	**-218.239**	PP-5	**PXK015PP5**	PP-1732-5	PP-1732-5	Keller
14	**1905.951**	**7253.424**	**-218.236**	PP-8	**PXK015PP8**	PP-1732-8	PP-1732-8	Keller
8	**1905.950**	**7253.849**	**-216.708**	PP-7	**PXK015PP7**	PP-1732-7	PP-1732-7	Keller
11	**1905.954**	**7252.261**	**-217.359**	TP-2	**PXK015TP2**	TP-1732-2	TP-1732-2	Geokon
13	**1905.957**	**7253.180**	**-218.268**	TP-1	**PXK015TP1**	TP-1732-1	TP-1732-1	Geokon
9	**1905.946**	**7254.106**	**-217.365**	TP-4	**PXK015TP4**	TP-1732-4	TP-1732-4	Geokon
7	**1905.950**	**7253.186**	**-216.425**	TP-3	**PXK015TP3**	TP-1732-3	TP-1732-3	Geokon

Table 4-6. *Numbering and position of outer distance block sensors in drift section 7.*

Point No.	**Easting [m]**	**Northing [m]**	**Point Elevation [m]**	Drawing label	Sensor code in SICADA	Sensor code in SCADA	Assembly tag label	Manufacturer
17	**1915.376**	**7252.533**	**-217.076**	PP-6	**PXK109PP6**	PP-0788-6	PP-0788-6	Keller
19	**1915.372**	**7252.956**	**-218.613**	PP-5	**PXK109PP5**	PP-0788-5	PP-0788-5	Keller
21	**1915.381**	**7253.433**	**-218.610**	PP-8	**PXK109PP8**	PP-0788-8	PP-0788-8	Keller
23	**1915.373**	**7253.853**	**-217.075**	PP-7	**PXK109PP7**	PP-0788-7	PP-0788-7	Keller
18	**1915.376**	**7252.270**	**-217.712**	TP-2	**PXK109TP2**	TP-0788-2	TP-0788-2	Geokon
20	**1915.387**	**7253.201**	**-218.642**	TP-1	**PXK109TP1**	TP-0788-1	TP-0788-1	Geokon
24	**1915.387**	**7254.114**	**-217.715**	TP-4	**PXK109TP4**	TP-0788-4	TP-0788-4	Geokon
22	**1915.376**	**7253.198**	**-216.796**	TP-3	**PXK109TP3**	TP-0788-3	TP-0788-3	Geokon

4.4 Outer sensor results and comments

4.4.1 Total pressure

Total pressure is measured in sections 1, 2 and 7 (see Figures 4-15 to 4-17).

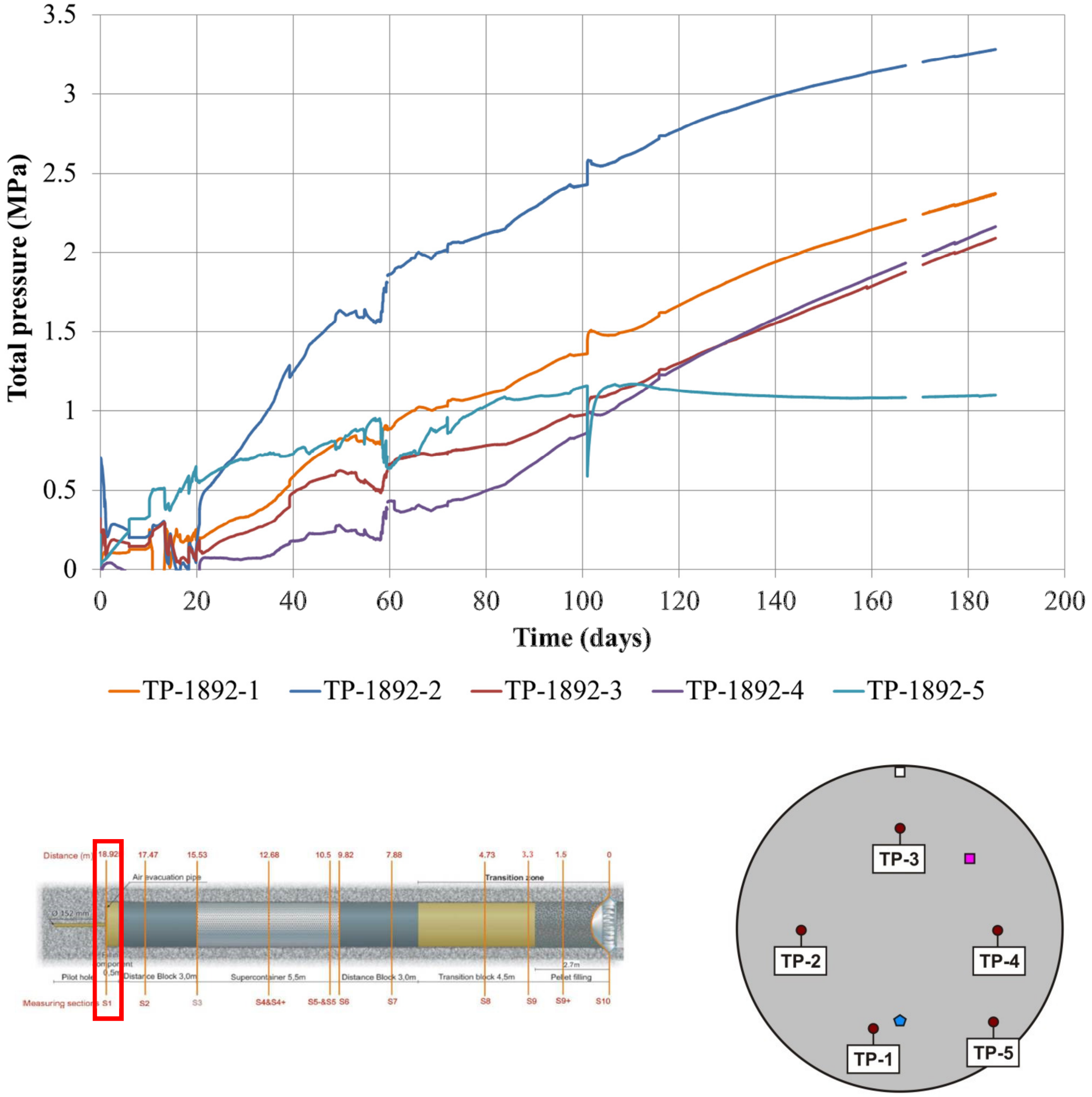


Figure 4-15. *Response of total pressure sensors at outer distance block positions (measuring axial pressures at the rock wall surface) in drift section S-1 (bottom-right inset). A total of five such sensors were installed in this section (bottom-right inset; TP-1 corresponds to TP-1892-1, etc.). The sensors generally show increasing pressure. The signal from sensor TP-1892-5 appears to level off after 100 days. The negative values are due to changes in the baseline signals. This effect is very common because of the installation and rearrangement of the oil inside the cell. It is negligible for these sensors.*

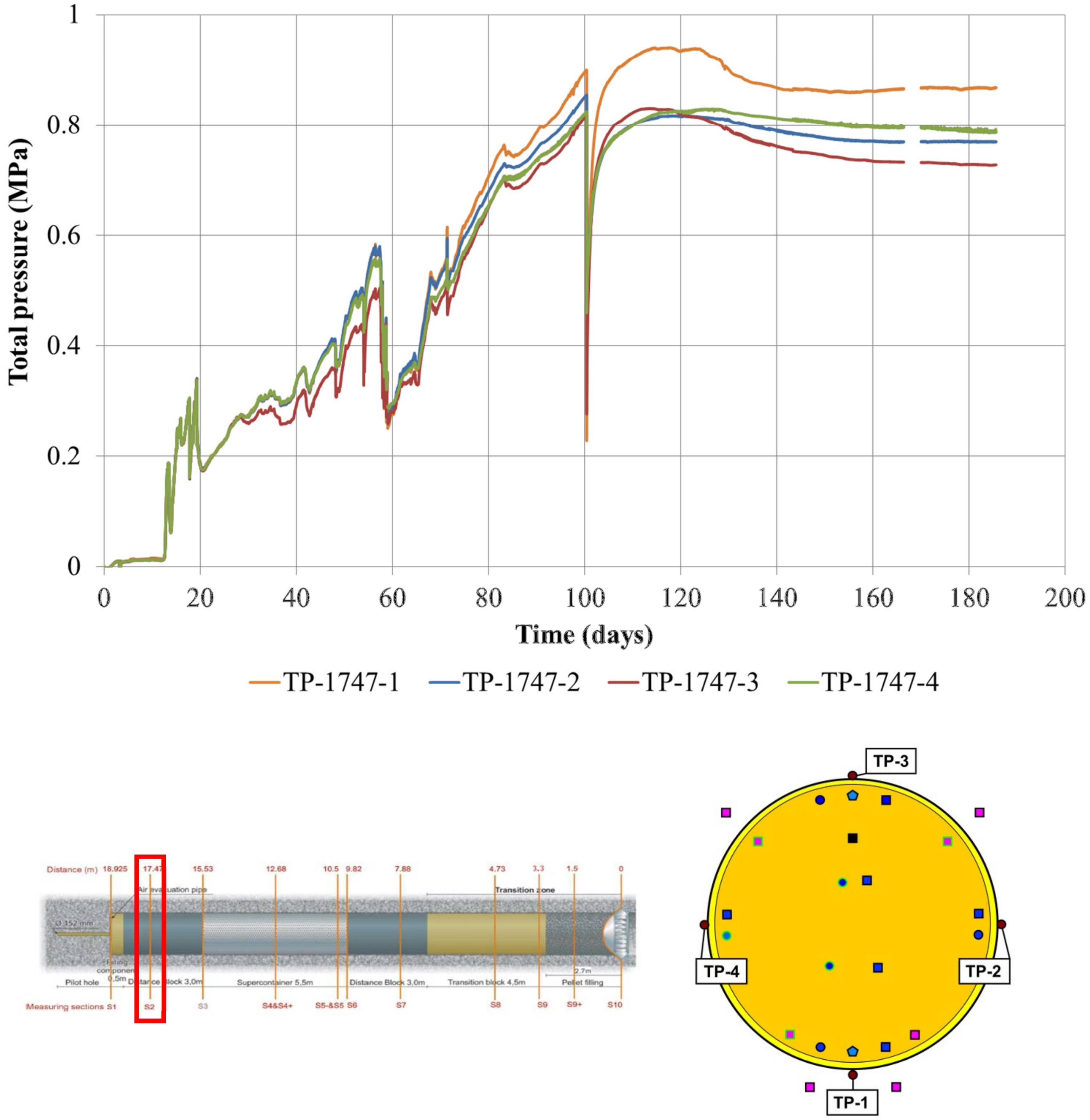


Figure 4-16. *Response of total pressure sensors at outer distance block positions (measuring radial pressures at the rock wall surface) in drift section S-2 (bottom-right inset). A total of four such sensors were installed in this section (bottom-right inset; TP-1 corresponds to TP-1747-1, etc.). The sensors generally show increasing pressure with a leveling off after 100 days. The sensors also respond similarly to TP-1895-2 (see Figure 4-15), indicating that the bentonite is still not in contact with the rock or the swelling pressure is still low and the pressure measured is mainly water pressure.*

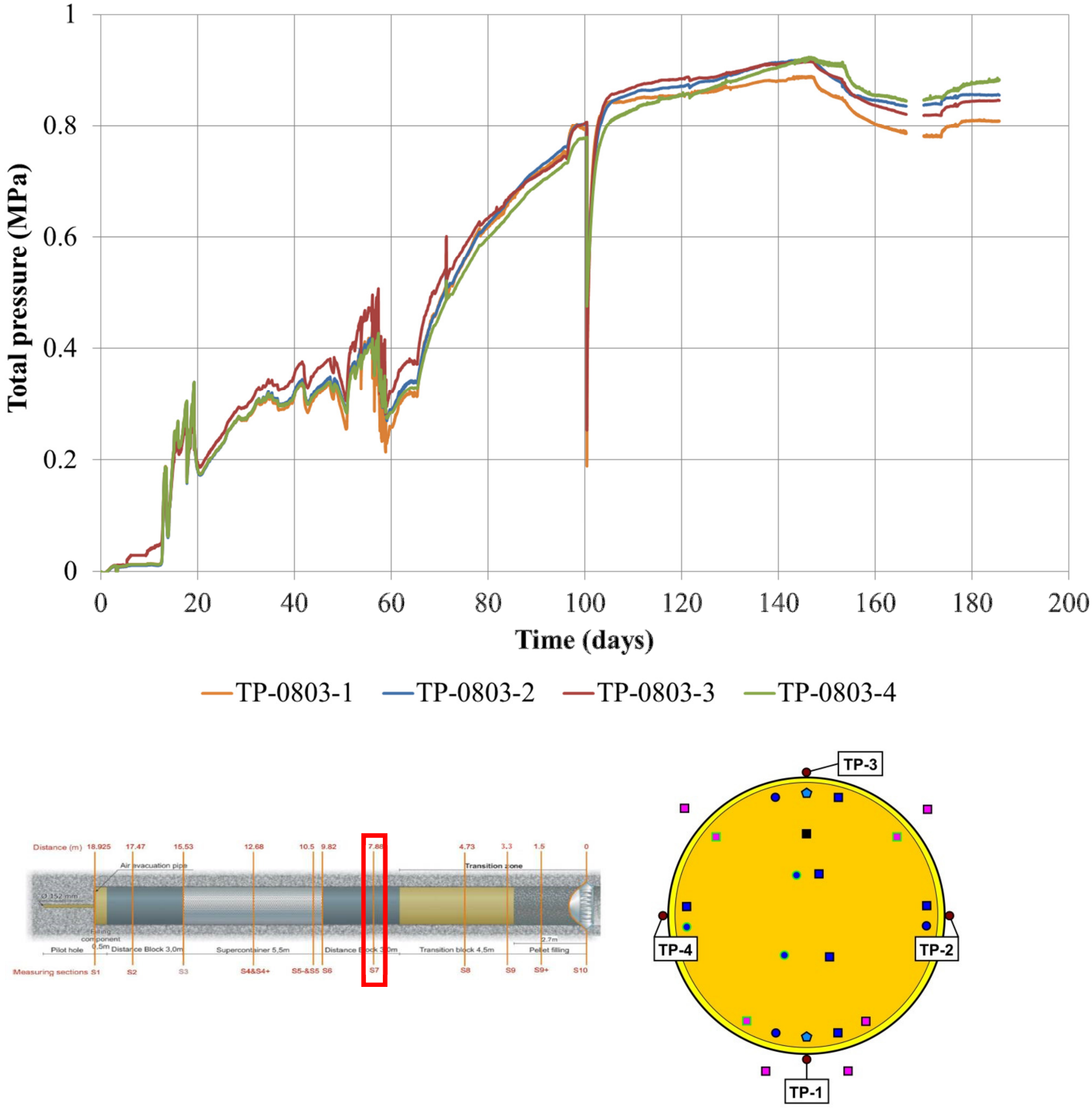


Figure 4-17. *Response of total pressure sensors at outer distance block positions (measuring radial pressures at the rock wall surface) in drift section 7 (bottom-right inset). A total of four such sensors were installed in this section (bottom-right inset; TP-1 corresponds to TP-0803-1, etc.). The sensors generally show increasing pressure with a leveling off after 100 days. The sensors also respond similarly to TP-1895-2 (see Figure 4-15), indicating that the bentonite is still not in contact with the rock or the swelling pressure is still low and the pressure measured is mainly water pressure.*

4.4.2 Pore pressure

Pore pressure is measured in drift sections 1, 2 and 7 (see Figures 4-18 to 4-20).

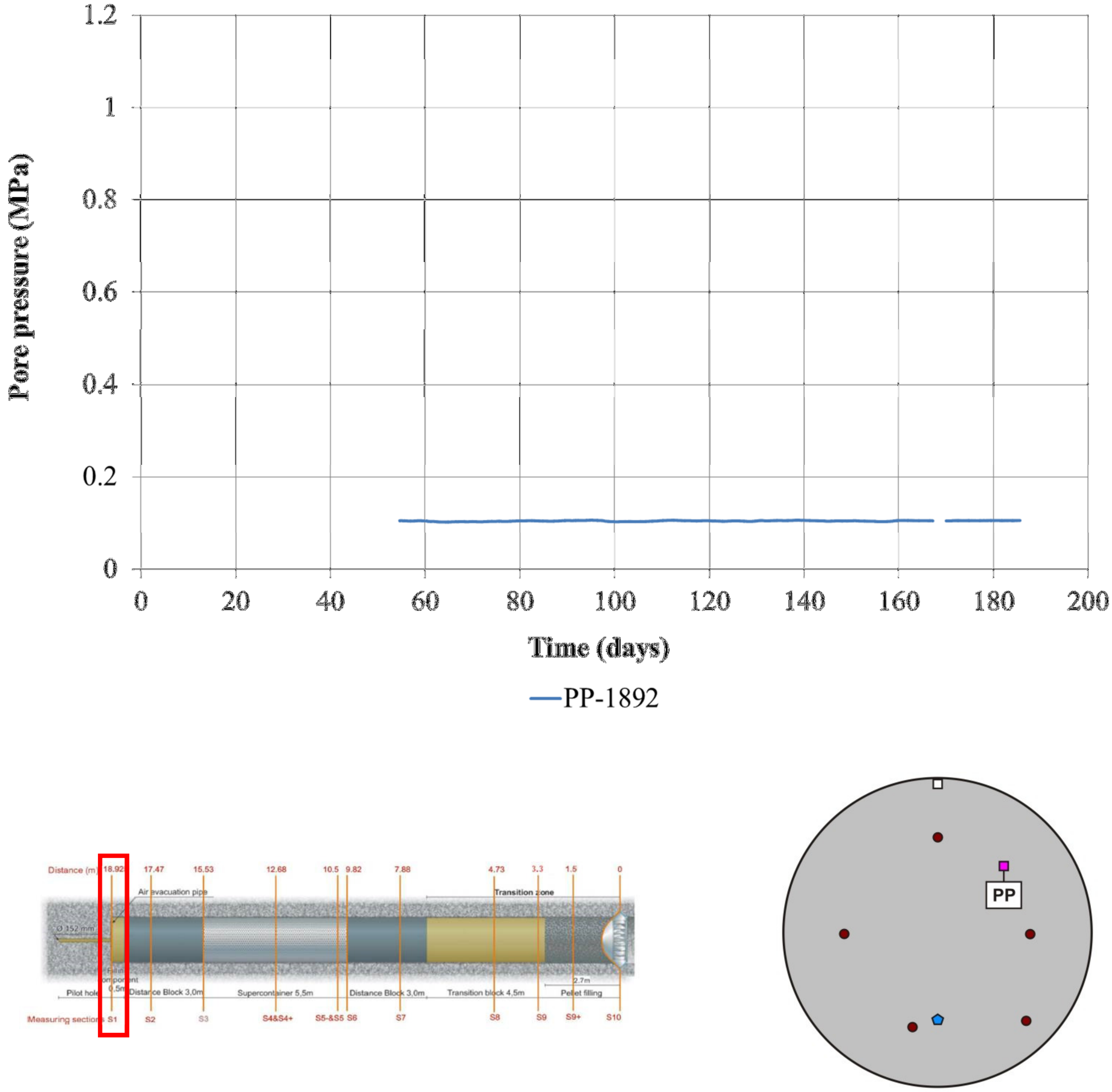


Figure 4-18. *Response of pore pressure sensor in drift section 1 (bottom-right inset). The sensor appears to be malfunctioning or the tubing is not fully air purged.*

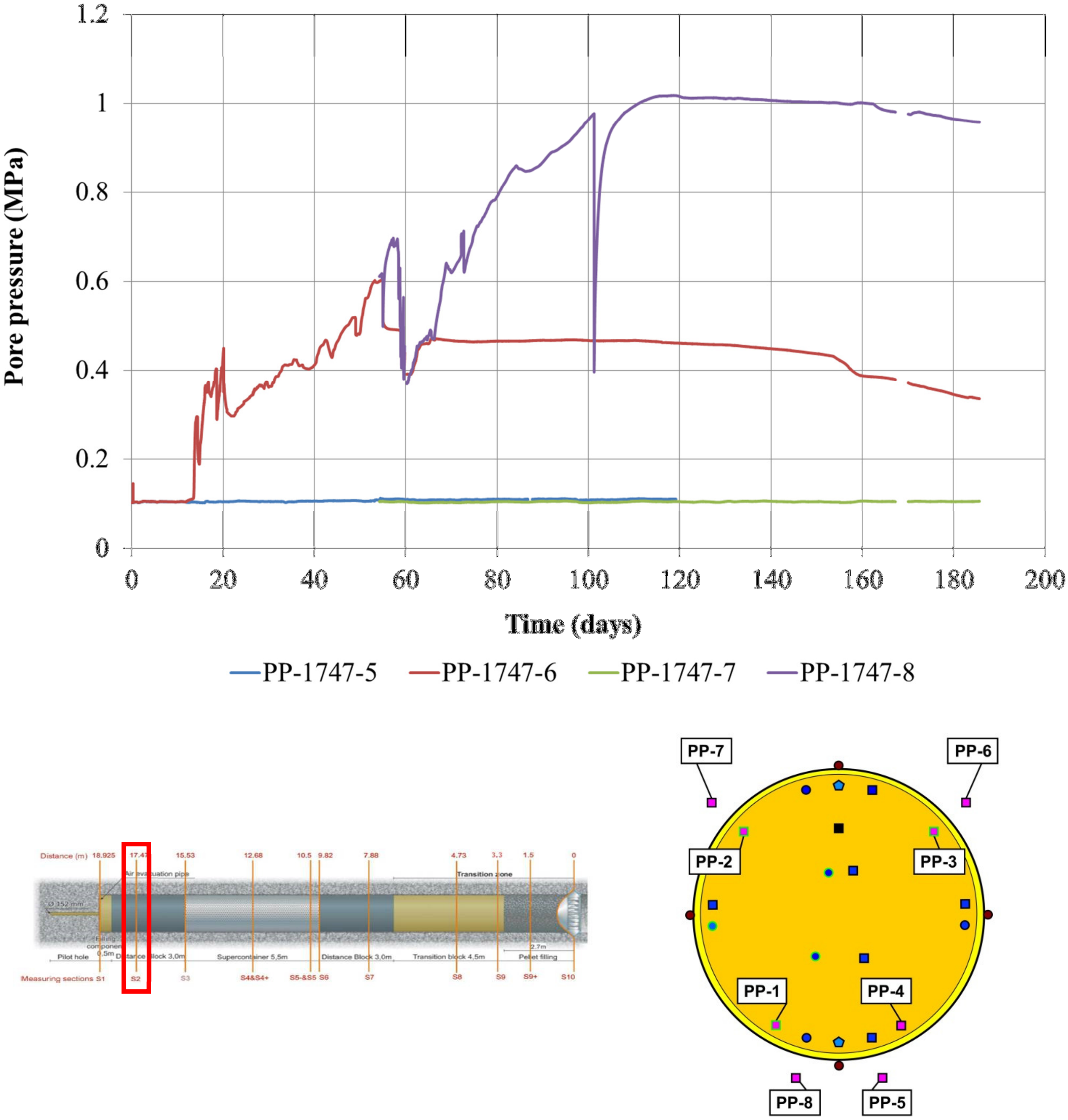


Figure 4-19. *Response of pore pressure sensors in drift section S-2 (bottom-right inset, PP-5 corresponds to TP-1747-5, etc.). Sensor PP-6 showed an increase in pressure through 55 days and decreasing pressure thereafter. This behavior could be due to gas compression, especially taking into account that the PP-6 is in upper position, so it has more risk of having air inside. Sensor PP-8 displayed similar behavior to that observed for the total pressure sensors (see Figure 4-16), i.e., increases in pressure until approximately 100 days flowed by a levelling off. Sensors PP-5 and PP-7 may be malfunctioning or the tubing is plugged.*

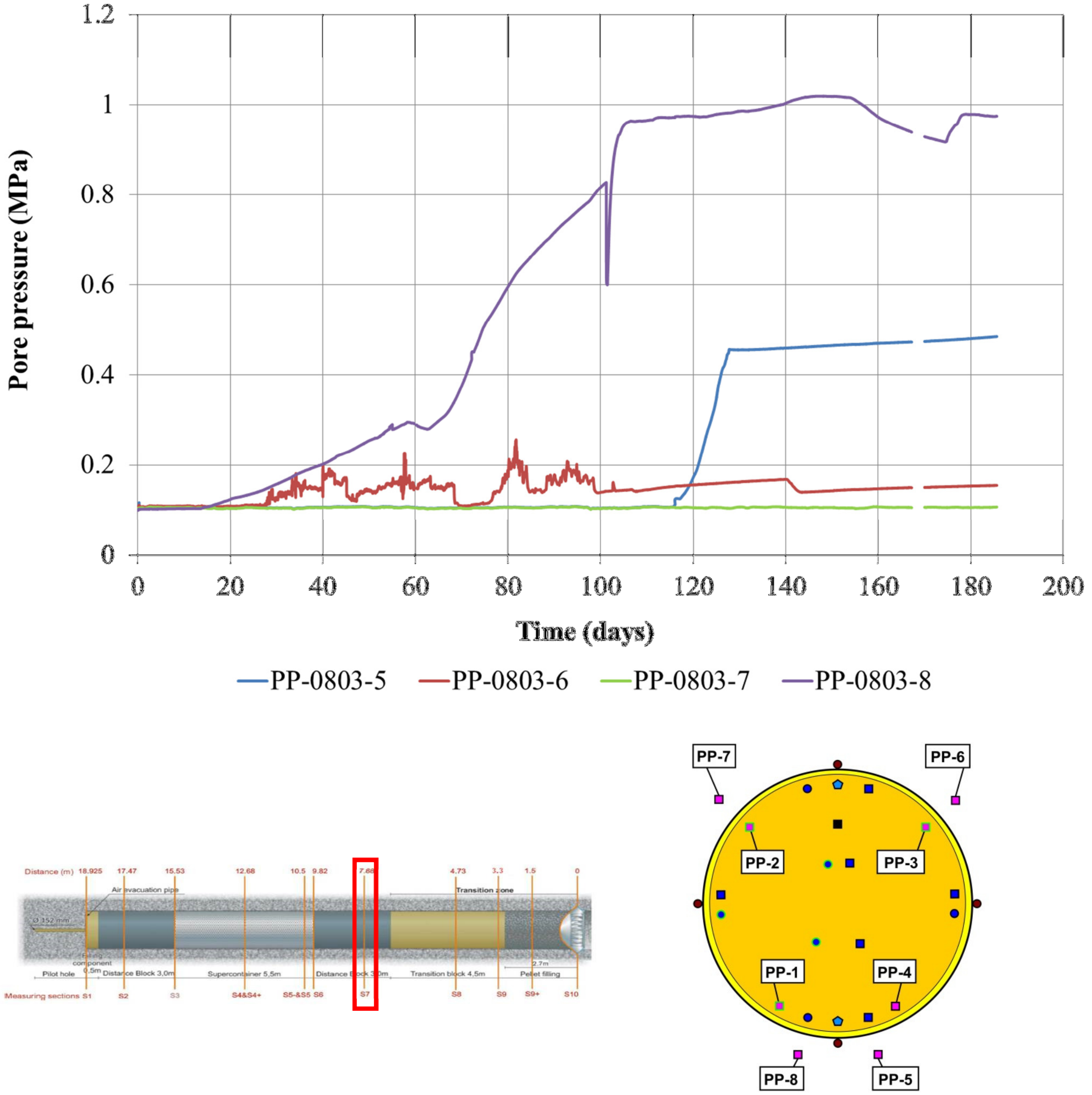


Figure 4-20. *Response of pore pressure sensors in drift section S-7 (bottom-right inset, TP-5 corresponds to TP-0803-5, etc.). Sensor PP-5 showed a sudden increase in pressure starting at 105 days. Sensor PP-8 displayed similar behavior to that observed for the total pressure sensors (see Figure 4-17), i.e., increases in pressure until approximately 100 days flowed by a levelling off. Sensor PP-6 shows unexpectedly low pressures. This behavior could be due to gas compression, so the pipes should be purged. Sensor PP-7 appears to be malfunctioning or the tubing is plugged.*

5 TRANSITION ZONE

5.1 Inner sensor positions

The location of the inner sensors and other information is presented in tables 5-1 (drift section 8, transition blocks), 5-2 (drift section) and 5-3 (drift section 10). All sections are presented in Figure 3-1.

Table 5-1. *Numbering and position of inner transition zone sensors in drift section 8 (transition blocks).*

	Coordinate system ÄSPÖ 96							
Point No.	**Easting [m]**	**Northing [m]**	**Point Elevation [m]**	Drawing label	Sensor code in SICADA	Sensor code in SCADA	Assembly tag label	Manufacturer
1	**1919.068**	**7252.991**	**-217.082**	WP4	**PXK146WP4**	WP-0480-4	WP0480-4	Wescor
2	**1919.069**	**7253.198**	**-217.054**	WF2	**PXK146WF2**	WF-0480-2	WF0480-2	Delta-T
3	**1919.068**	**7253.406**	**-217.081**	WC6	**PXK146WC6**	WC-0480-6	WC0480-6	Aitemin
4	**1919.062**	**7253.062**	**-217.346**	WP1	**PXK146WP1**	WP-0480-1	WP0480-1	Wescor
5	**1919.062**	**7253.336**	**-217.346**	WC3	**PXK146WC3**	WC-0480-3	WC0480-3	Aitemin
6	**1919.052**	**7252.400**	**-217.803**	WP5	**PXK146WP5**	WP-0480-5	WP0480-5	Wescor
7	**1919.050**	**7252.400**	**-217.903**	WC7	**PXK146WC7**	WC-0480-7	WC 0480-7	Aitemin
8	**1919.050**	**7253.198**	**-217.853**	WC1	**PXK146WC1**	WC-0480-1	WC0480-1	Aitemin
9	**1919.040**	**7253.082**	**-218.287**	WP2	**PXK146WP2**	WP-0480-2	WP0480-2	Wescor
10	**1919.039**	**7253.315**	**-218.287**	WC2	**PXK146WC2**	WC-0480-2	WC0480-2	Aitemin
11	**1919.032**	**7252.991**	**-218.626**	WP6	**PXK146WP6**	WP-0480-6	WP0480-6	Wescor
12	**1919.031**	**7253.198**	**-218.652**	WF1	**PXK146WF1**	WF-0480-1	WF0480-1	Delta-T
13	**1919.031**	**7253.406**	**-218.626**	WC4	**PXK146WC4**	WC-0480-4	WC0480-4	Aitemin
14	**1919.050**	**7253.997**	**-217.803**	WP3	**PXK146WP3**	WP-0480-3	WP0480-3	Wescor
15	**1919.047**	**7253.997**	**-217.903**	WC5	**PXK146WC5**	WC-0480-5	WC0480-5	Aitemin
16	**1918.860**	**7253.861**	**-217.794**	WSUS8	**transmmiter**	WSU-S8	wireless	Aitemin

Table 5-2. *Numbering and position of inner transition zone sensors in drift section 9 (transition blocks).*

	Coordinate system ÄSPÖ 96							
Point No.	**Easting [m]**	**Northing [m]**	**Point Elevation [m]**	Drawing label	Sensor code in SICADA	Sensor code in SCADA	Assembly tag label	Manufacturer
1	**1920.398**	**7253.200**	**-217.360**	IB2	**PXK159IB2**	IB-0286-2	IB0311-2	Measurement Specialities
2	**1920.499**	**7253.264**	**-218.148**	WC1	**PXK160WC1**	WC-0286-1	wireless	Aitemin
3	**1920.372**	**7253.200**	**-218.450**	IB1	**PXK159IB1**	IB-0286-1	wireless	Measurement Specialities
4	**1920.739**	**7253.201**	**-217.921**	TP1	**PXK163TP1**	TP-0292-3	DRIFT	Geokon
5	**1920.524**	**7253.200**	**-217.112**	WF2	**PXK160WF2**	WF-0286-2	WF0286-2	Delta-T
6	**1920.486**	**7253.408**	**-218.681**	WC3	**PXK160WC3**	WC-0286-3	WC0286-3	Aitemin
7	**1920.523**	**7252.993**	**-217.137**	WP4	**PXK160WP4**	WP-0286-4	WP0286-4	Wescor
8	**1920.523**	**7253.408**	**-217.136**	WC5	**PXK160WC5**	WC-0286-5	WC0286-5	Aitemin
9	**1920.507**	**7252.402**	**-217.858**	WP5	**PXK160WP5**	WP-0286-5	WP0286-5	Wescor
10	**1920.505**	**7252.402**	**-217.958**	WC6	**PXK160WC6**	WC-0286-6	WC0286-6	Aitemin
11	**1920.511**	**7253.136**	**-217.668**	WP1	**PXK160WP1**	WP-0286-1	WP0286-1	Wescor
12	**1920.510**	**7253.265**	**-217.669**	WC2	**PXK160WC2**	WC-0286-2	wireless	Aitemin
13	**1920.505**	**7253.999**	**-217.858**	WP3	**PXK160WP3**	WP-0286-3	WP0286-3	Wescor
14	**1920.502**	**7253.999**	**-217.958**	WC4	**PXK160WC4**	WC-0286-4	wireless	Aitemin
15	**1920.315**	**7253.863**	**-217.849**	WSUS9	**transmmiter**	WSU-S9	wireless	Aitemin
16	**1920.742**	**7252.746**	**-217.651**	DB2	**PXK163DB2**	DB-0286-2	wireless	RDP
17	**1920.723**	**7253.655**	**-218.176**	DB1	**PXK163DB1**	DB-0286-1	wireless	RDP
18	**1920.499**	**7253.136**	**-218.146**	WP2	**PXK160WP2**	WP-0286-2	WP0286-2	Wescor
19	**1920.487**	**7252.993**	**-218.681**	WP6	**PXK160WP6**	WP-0286-6	WP0286-6	Wescor
20	**1920.486**	**7253.200**	**-218.707**	WF1	**PXK160WF1**	WF-0286-1	WF0286-1	Delta-T

Table 5-3. *Numbering and position of inner transition zone sensors in drift section 10 (pellets).*

	Coordinate system ÄSPÖ 96							
Point No.	**Easting [m]**	**Northing [m]**	**Point Elevation [m]**	Drawing label	Sensor code in SICADA	Sensor code in SCADA	Assembly tag label	Manufacturer
1	**1922.700**	**7252.311**	**-217.995**	PP5	**PXK182PP5**	PP-0029- 5	PP-0000-5	Measurement Specialities
2	**1922.697**	**7254.097**	**-217.995**	PP4	**PXK182PP4**	PP-0029-4	PP-0000-4	Measurement Specialities
3	**1922.698**	**7253.204**	**-217.995**	TP1	**PXK182TP1**	TP-0029-1	wireless	Geokon / ÅF
4	**1922.698**	**7253.205**	**-217.925**	PP1	**PXK182PP1**	PP-0029-1	wireless	Measurement Specialities
5	**1922.935**	**7253.205**	**-217.347**	PP3	**PXK185PP3**	PP-0029-3	wireless	Measurement Specialities
6	**1922.903**	**7253.205**	**-218.667**	PP2	**PXK185PP2**	PP-0029-2	wireless	Measurement Specialities
7	**1922.719**	**7253.250**	**-217.099**	GP1	**PXK182GP1**	GP-0029	GP-0000-1	Keller
8	**1922.719**	**7253.158**	**-217.099**	PP6	**PXK182PP6**	PP-0029-6	PP-0000-6	Measurement Specialities
9	**1922.642**	**7253.467**	**-217.934**	WSUS10	**transmmiter**	WSU-S10	wireless	Aitemin
10	**1923.892**	**7253.207**	**-217.531**	DC1	**PXK200DC1**	DC-100-1	Aitemin	RDP
11	**1923.875**	**7253.207**	**-218.031**	DC2	**PXK200DC2**	DC-100-2	Aitemin	RDP
12	**1923.867**	**7253.207**	**-218.531**	DC3	**PXK200DC3**	DC-100-3	Aitemin	RDP
13	**1922.849**	**7253.205**	**-218.569**	TP-2	**PXK182TP2**	TP-0029-2	close to PP2	Geokon / ÅF
14	**1922.902**	**7253.205**	**-217.404**	TP-3	**PXK182TP3**	TP-0029-3	close to PP3	Geokon / ÅF

5.2 Inner sensor results and comments

5.2.1 Relative humidity

The relative humidity sensors in the peripheral positions of the blocks have measured increases in the relative humidity as expected. No changes have been measured with the sensors in more inward locations of the blocks. The results are presented in Figures 5-1 and 5-2.

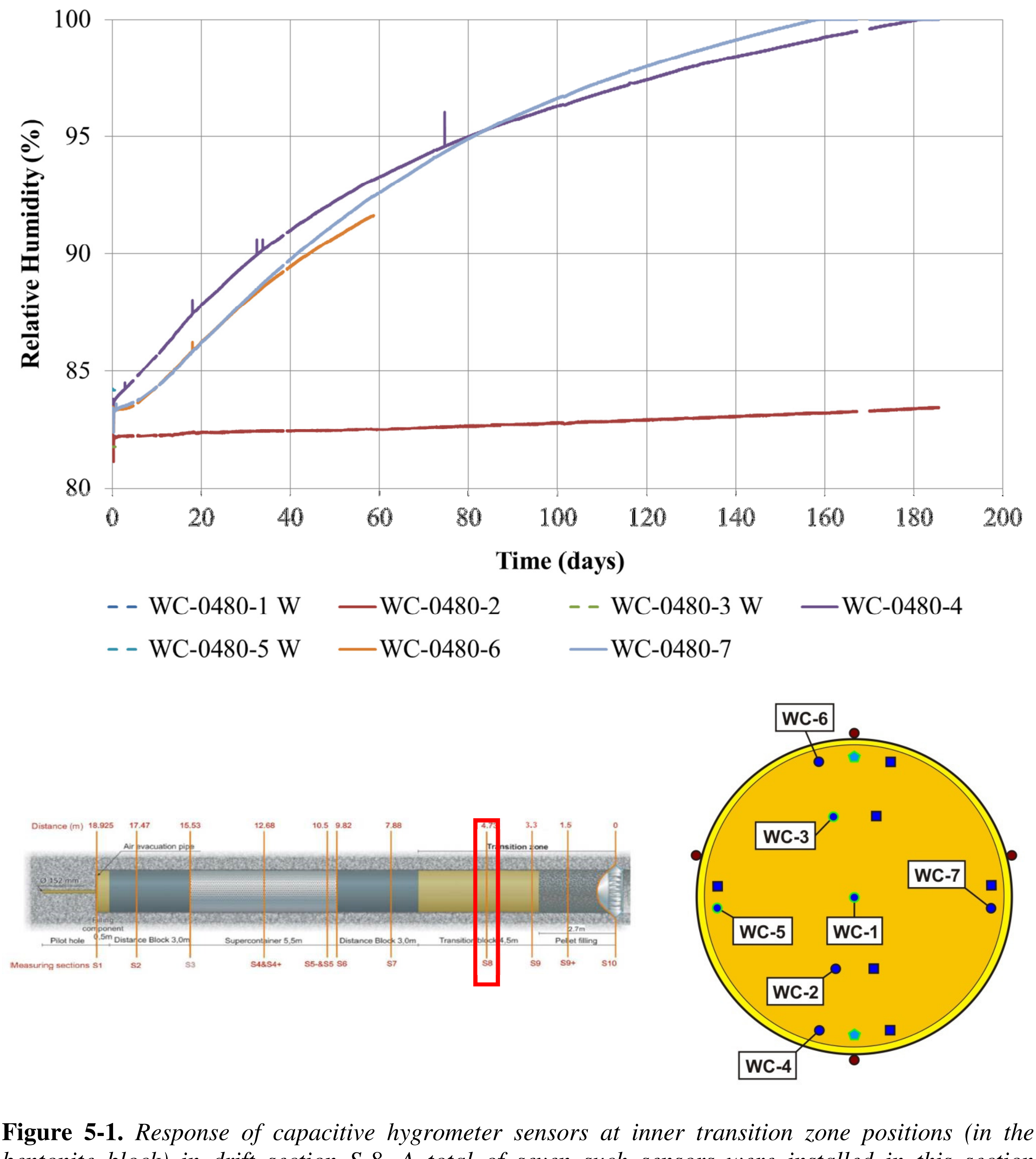


Figure 5-1. *Response of capacitive hygrometer sensors at inner transition zone positions (in the bentonite block) in drift section S-8. A total of seven such sensors were installed in this section (bottom-right inset; WC-1 corresponds to WC-0480-1, etc.) and signal is being recorded from four of them. Dashed lines correspond to wireless sensors (WC-1, WC-3 and WC-5). Signal was lost from these sensors a few hours into the test. The signal from sensor WC-6 was lost at close to 60 days.*

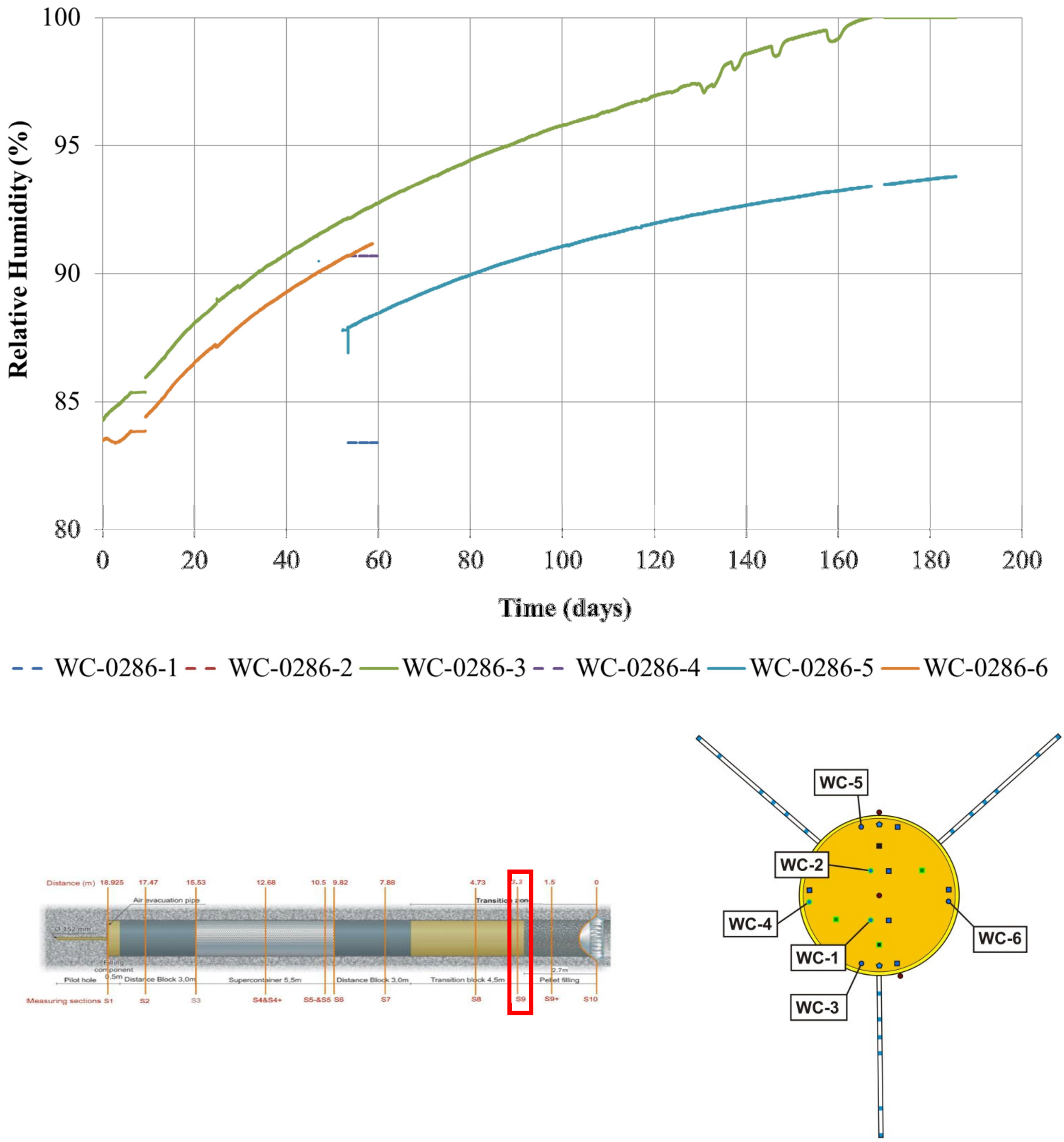


Figure 5-2. *Response of capacitive hygrometer sensors at inner transition zone positions (in the bentonite block) in drift section S-9. A total of six such sensors were installed in this section (bottom-right inset; WC-1 corresponds to WC-0286-1, etc.). Dashed lines correspond to wireless sensors (WC-1, WC-2 and WC-4). Signal was received from sensors WC-1 and WC-4 only from 50 to 60 days. No signal was received from sensor WC-2. The signal from sensor WC-6 was lost at close to 60 days.*

5.2.2 Suction

In-range signals from the psychrometer sensors correspond only to suction established at 95% relative humidity. For temperatures between 5 ºC and 15 ºC, the suction at 95% relative humidity should be between 6.6 and 6.8 MPa. The results are presented in Figures 5-3 to 5-5.

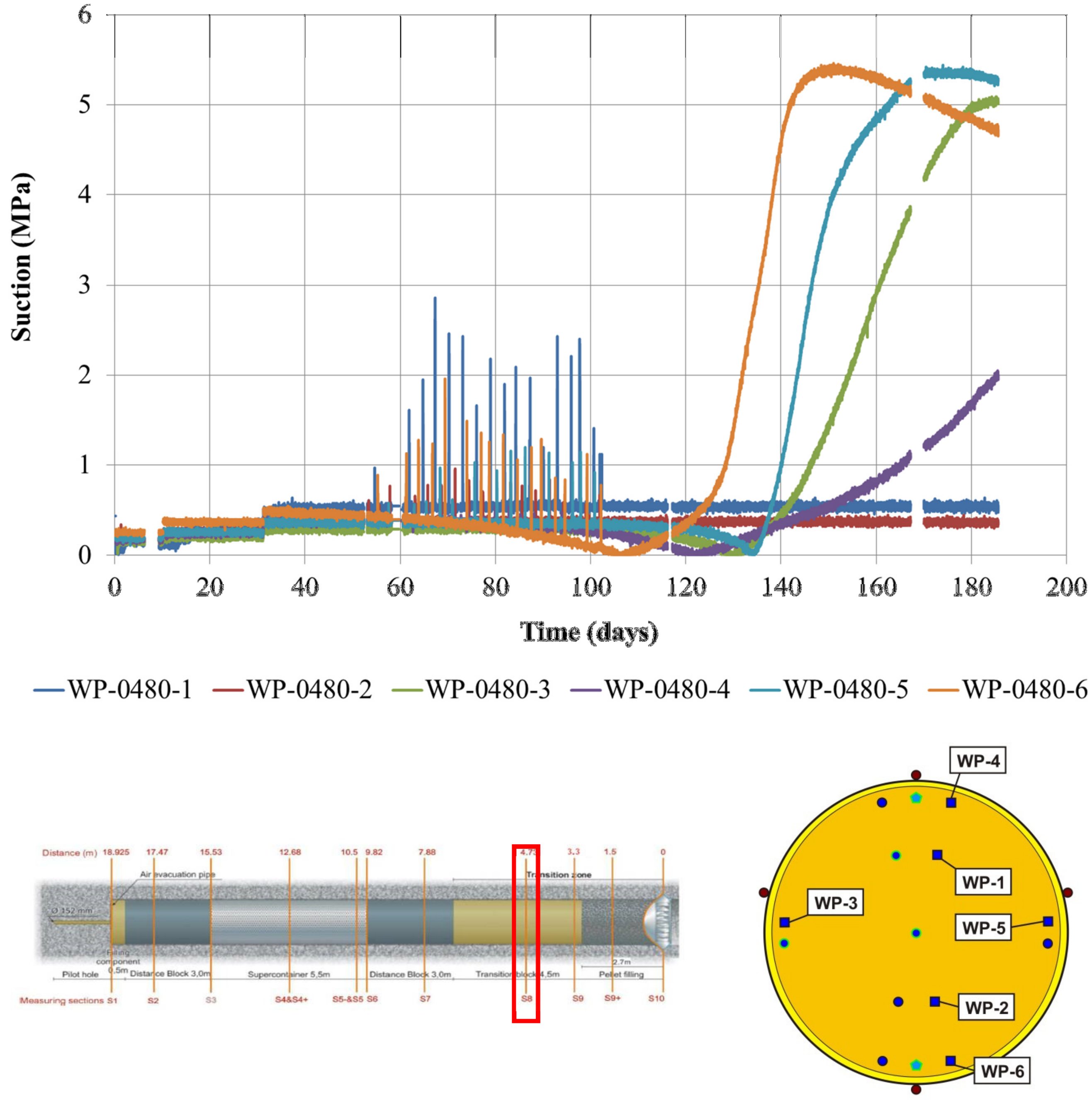


Figure 5-3. *Response of psychrometers at inner transition zone positions (in the bentonite block) in drift section S-8. A total of six such sensors were installed in this section (bottom-right inset; WP-1 corresponds to WP-0480-1, etc.). Sensors WP-5 and WP-6 in more peripheral locations have reached in-range suction limits (see also Figure 5-4). The signals for sensors closer to the center have not yet started to approach in-range limits.*

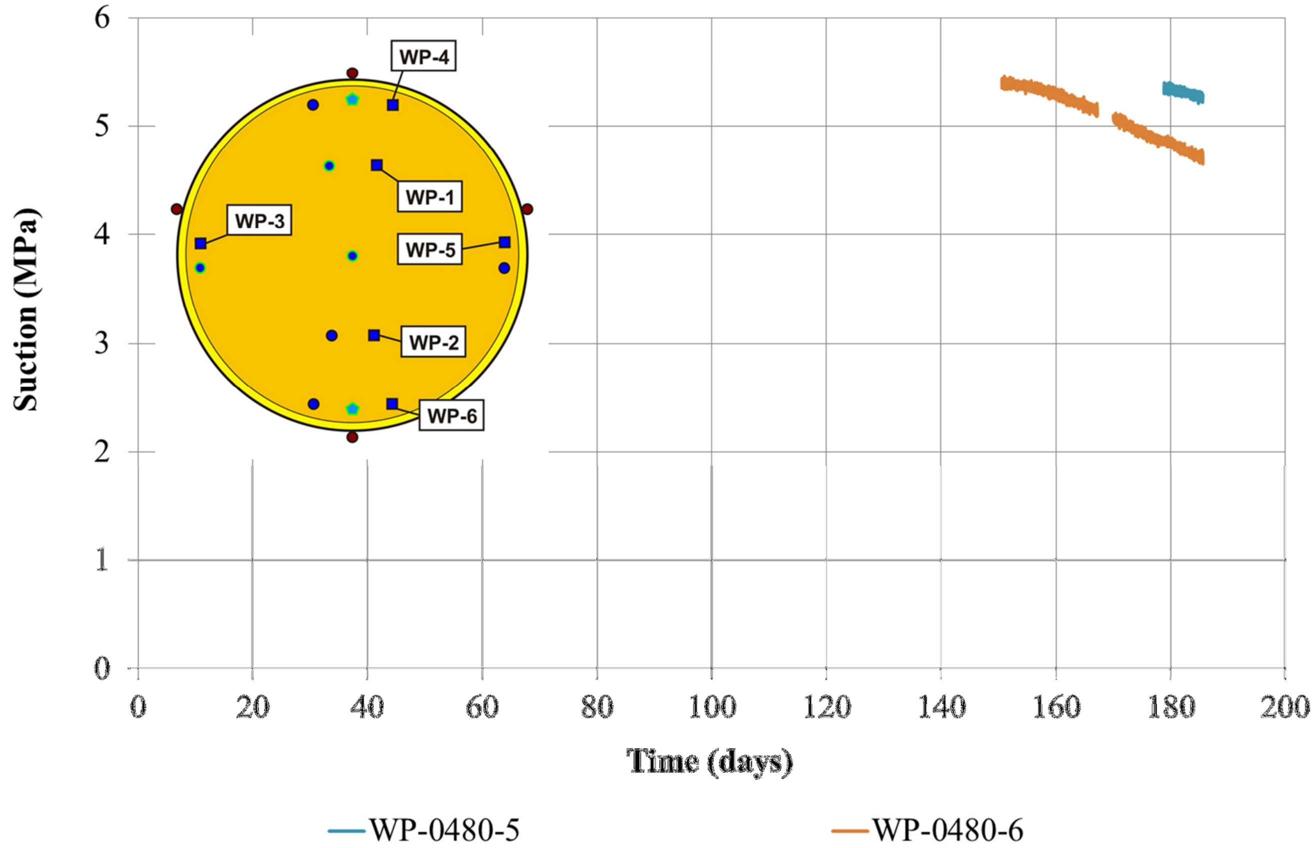


Figure 5-4. *Decay in psychrometer signal for sensors WP-5 and WP-6 in inner transition zone positions in drift section 8 after reaching in-range suction limits.*

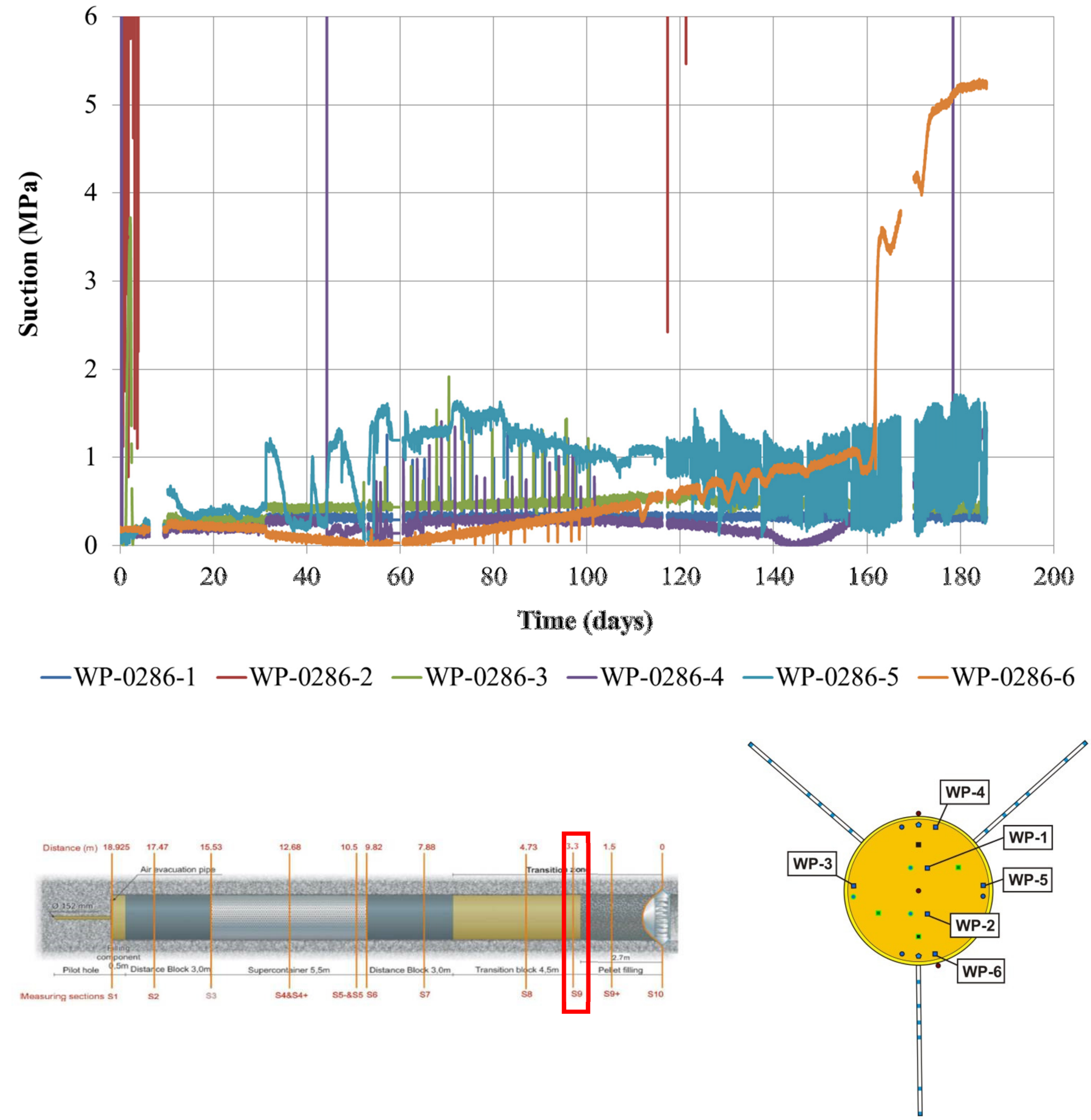


Figure 5-5. *Response of psychrometers at inner transition zone positions (in the bentonite block) in drift section S-9. A total of six such sensors were installed in this section (bottom-right inset; WP-1 corresponds to WP-0286-1, etc.). Sensors WP-4 and WP-6 are approaching in-range suction limits while the other sensors have not yet started to approach in-range limits. Sensor WP-2 appears to be malfunctioning. It should also be taken into account that these sensors are close to the pellet filling (on the opposite side of the block in contact with the pellets, i.e., 485 mm) and the resulting signals may be influenced by any block/pellet interactions.*

5.2.3 Pore pressure

The pore pressure sensors are located at the pellet-filling/plug interface in drift section 10 (Figures 5-6 and 5-7).

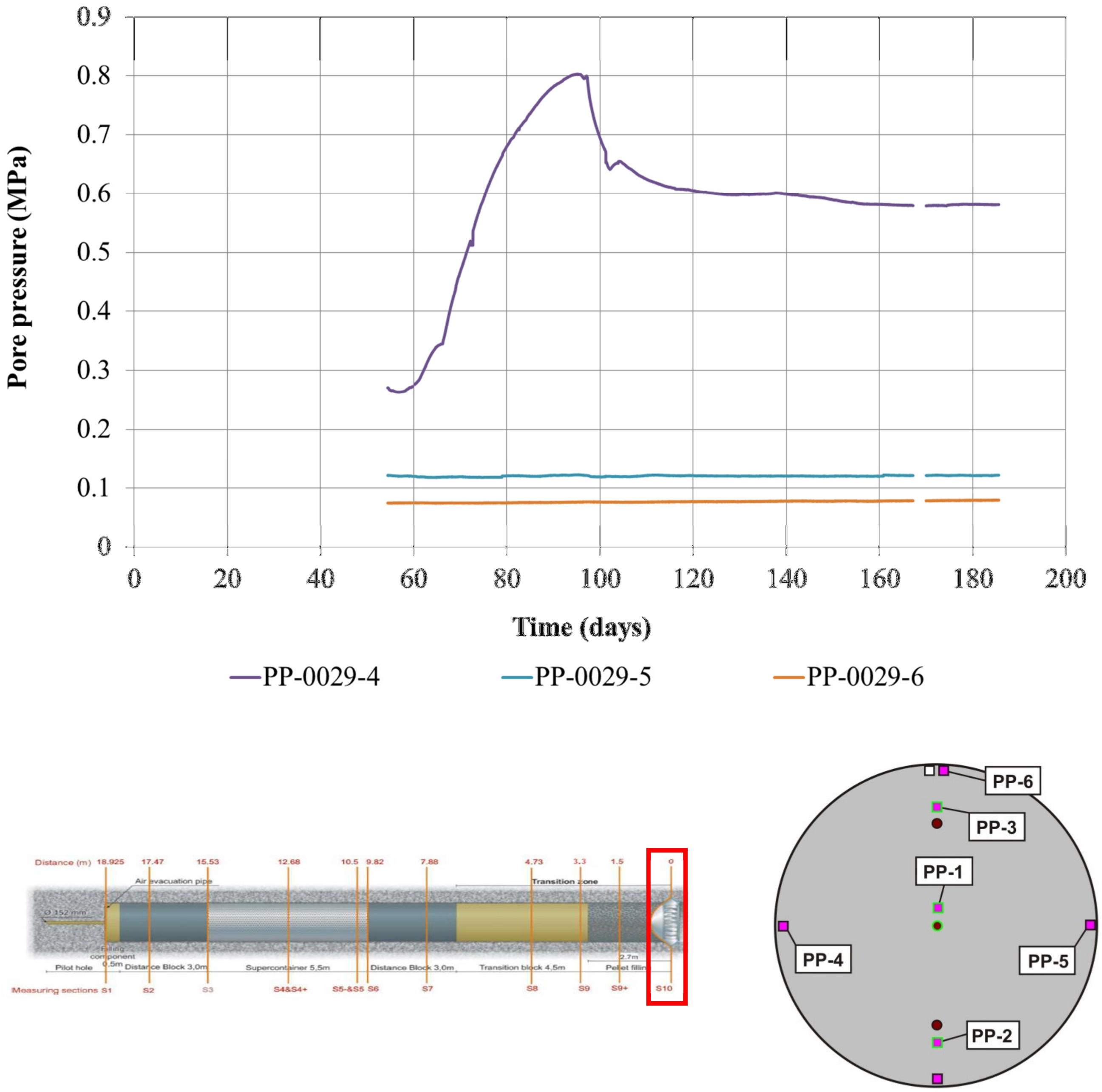
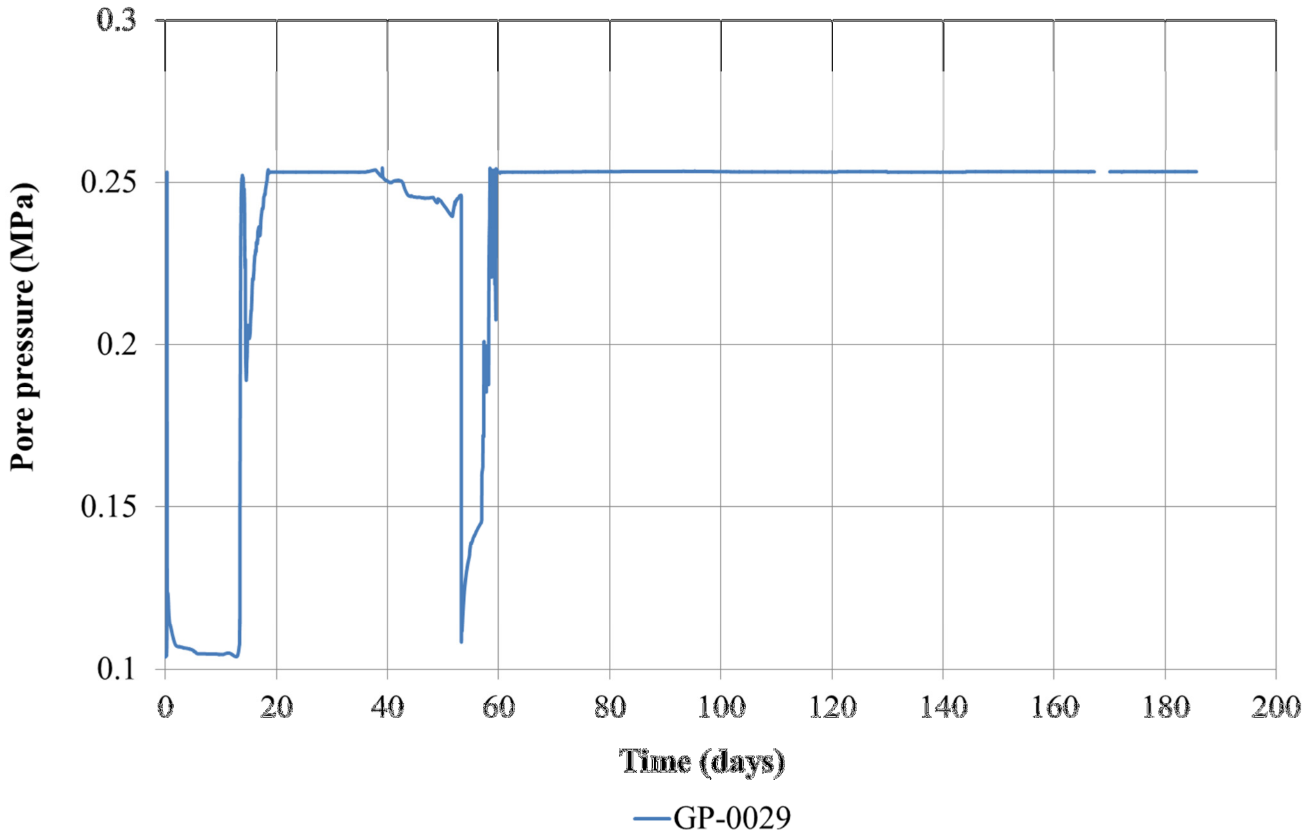
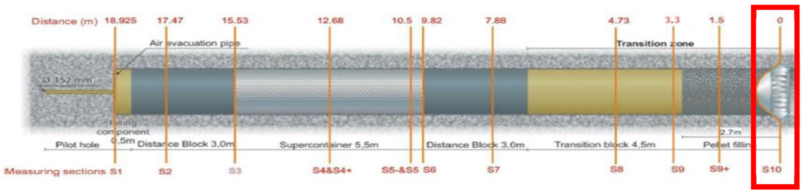


Figure 5-6. *Response of pore pressure sensors at inner transition zone positions in the pellet-filled zone in drift section 10. A total of six such sensors were installed in this section (bottom-right inset; PP-1 corresponds to PP-0029-1, etc.). Signal was not recorded from sensors PP-4, PP-5 and PP-6 until approximately 50 days. No signal has been received from wireless sensors PP-1, PP-2 or PP-3 since 11.12.2013. Although it is expected that the pellet zone is filled with water, only sensor PP-4 shows a clear increase in pressure and levelling off but sensors PP-5 and PP-6 do not. If the water filled the pellet zone at a spatially localized inflow point, inhomogeneous wetting, swelling and sealing may result (see e.g., Hoffman, 2005).*





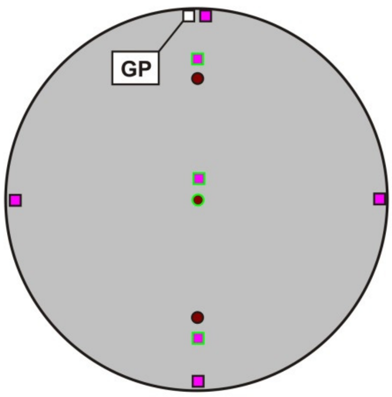


Figure 5-7. *Response of gas pressure sensor at inner transition zone position in the pellet-filled zone in drift section 10 (bottom-right inset). The full sensor range is 250 kPa and it was installed for the purposes of measuring the gas pressure during the water filling if the DAWE procedure was not followed. The sensor was flooded and essentially measured water pressure. This sensor should be changed to a higher range pore pressure sensor which is possible because the gas pressure sensors are located outside of the drift. This sensor is close to sensor PP-6 (see Figure 5-6).*

5.2.4 Water content

Volumetric water content was measured with soil moisture sensors (Figure 5-8).

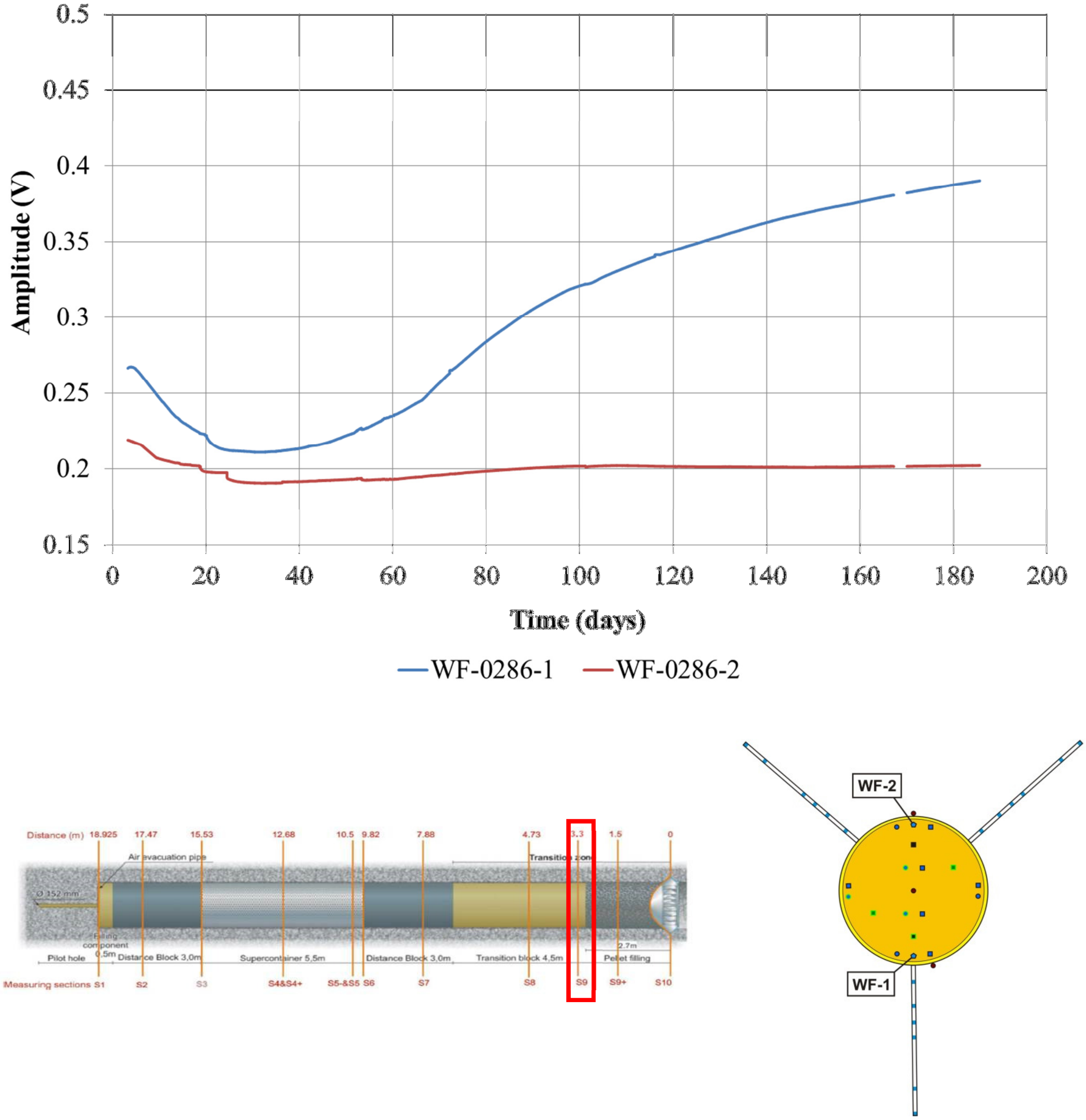


Figure 5-8. *Response of soil moisture sensors at inner transition zone positions (in the bentonite block) in drift section S-9. A total of two such sensors were installed in this section (bottom-right inset; WF-1 corresponds to WF-0286-1 and WF-2 corresponds to WF-0286-2). An increasing signal was measured by sensor WF-1 whereas sensor WF-2 displayed a lower, relatively constant signal.*

5.2.5 Inclination

Results from the inclinometer sensors are presented in Figure 5-9.

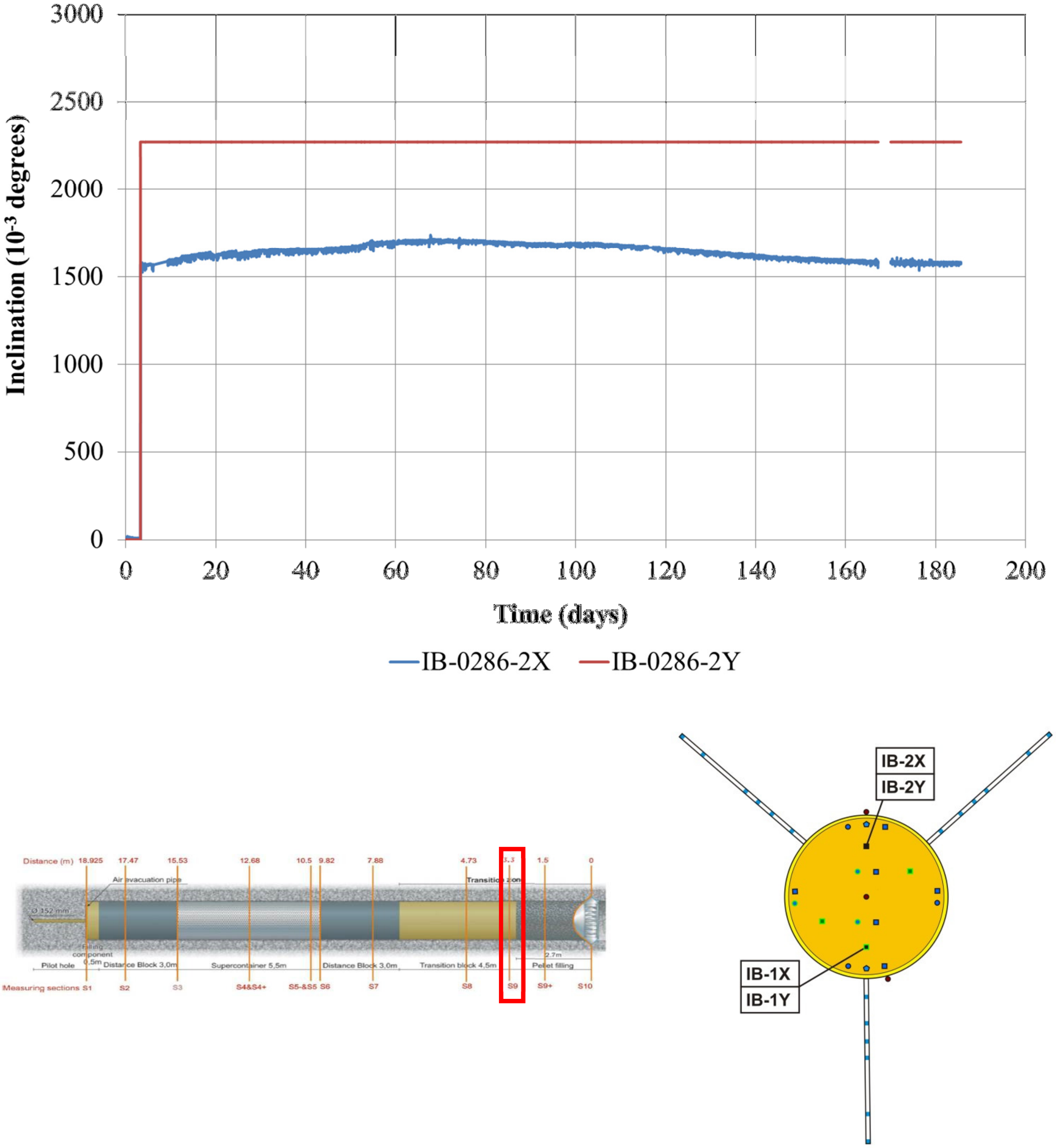


Figure 5-9. *Response of the inclinometer sensors at inner transition zone positions (in the bentonite block) in drift section S-9. A total of two such sensors were installed in this section (IB-0286-1 and IB-0286-2). Sensor IB-1 is a wireless sensor and no signal has been received from this sensor. Sensor IB-2 showed a sudden change in both the positive x- and y-directions after 3 days to constant values. This behavior is similar to IB 1722-X (Figure 4-13).*

5.2.6 Displacement

Two wireless, displacement sensors (DB-0286-1 and DB-0286-2) were installed in drift section 9. Signal was received from these sensors only from 29 January to 5 February 2013.

5.2.7 Total pressure

Total pressure sensors were installed at the pellet-plug interface to the inner face of the plug (Figure 5-10).

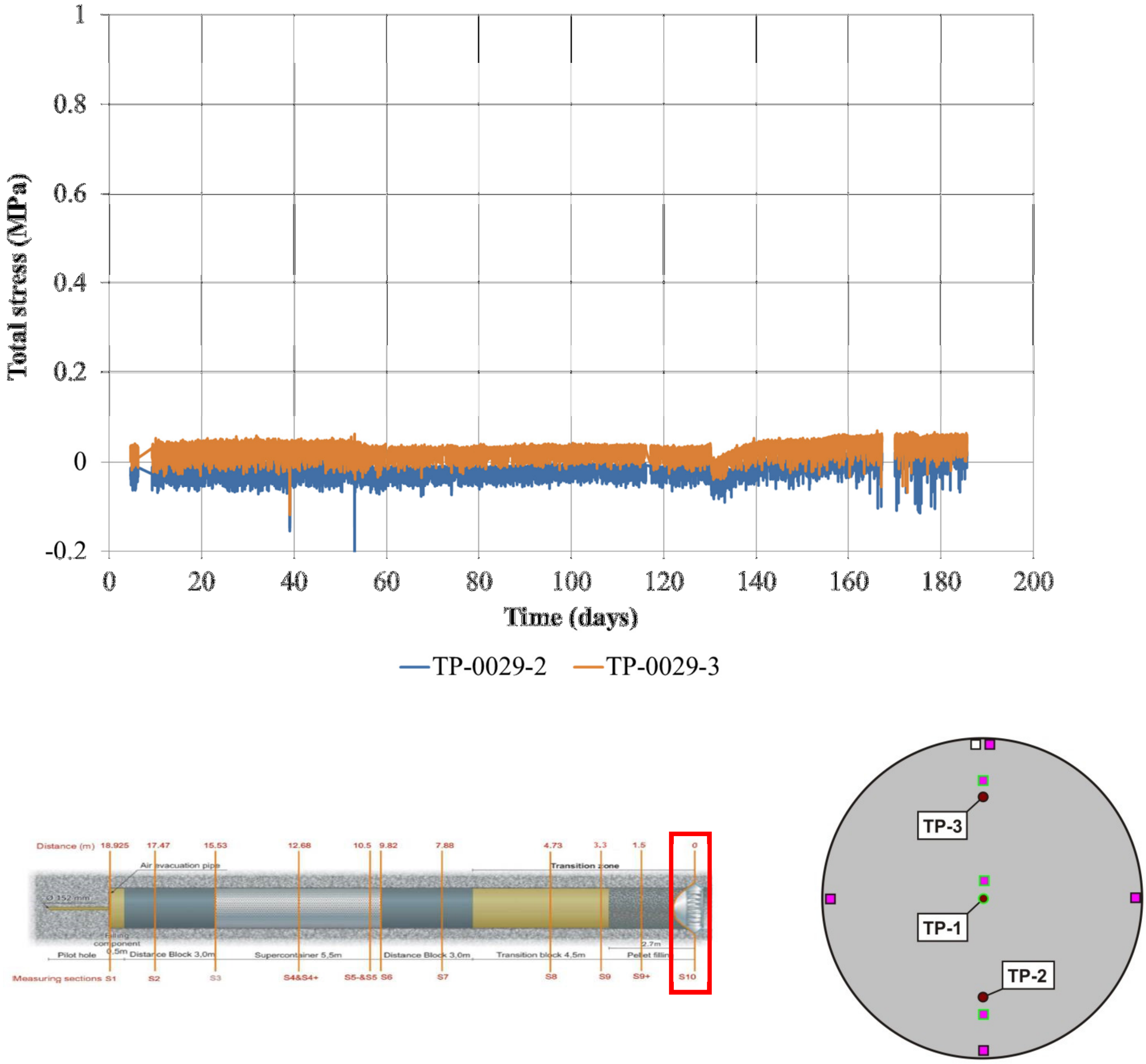


Figure 5-10. *Response of total pressure sensors at the pellet-plug interface in drift section S-10. The pressure is measured orthogonal to plug. A total of three such sensors were installed in this section (TP-0029-1, TP-0029-2 and TP-0286-3). Sensor TP-1 is a wireless sensor and no signal has been received from this sensor. Little to no pressure has been detected by sensors TP-2 and TP-3.*

5.3 Outer sensor positions

The location of the outer sensors and other information is presented in tables 5-4 and 5-5 (drift sections 8 and 9, transition blocks) and 5-6 (drift section 9+, pellets). This section also contains information regarding the strain gauges on the plug face (Table 5-7).

Table 5-4. *Numbering and position of outer transition zone sensors in drift section 8 (transition blocks).*

Point No.	**Easting [m]**	**Northing [m]**	**Point Elevation [m]**	Drawing label	Sensor code in SICADA	Sensor code in SCADA	Assembly tag label	Manufacturer
25	**1918.782**	**7253.204**	**-216.928**	TP-3	**PXK143TP3**	TP-0449-3	TP-0449-3	Geokon
26	**1918.778**	**7252.300**	**-217.620**	TP-2	**PXK143TP2**	TP-0449-2	TP-0449-2	Geokon
27	**1918.774**	**7253.203**	**-218.771**	TP-1	**PXK143TP1**	TP-0449-1	TP-0449-1	Geokon
28	**1918.774**	**7254.085**	**-217.615**	TP-4	**PXK143TP4**	TP-0449-4	TP-0449-4	Geokon

Table 5-5. *Numbering and position of outer transition zone sensors in drift section 9 (transition blocks).*

Point No.	**Easting [m]**	**Northing [m]**	**Point Elevation [m]**	Drawing label	Sensor code in SICADA	Sensor code in SCADA	Assembly tag label	Manufacturer
29	**1920.494**	**7252.961**	**-218.804**	TP-2	**PXK161TP2**	TP-0277-2	TP-0277-2	Geokon
30	**1920.498**	**7253.212**	**-216.991**	TP-1	**PXK161TP1**	TP-0277-1	TP-0277-1	Geokon

Table 5-6. *Numbering and position of outer transition zone sensors in drift section 9+ (pellets).*

Point No.	**Easting [m]**	**Northing [m]**	**Point Elevation [m]**	Drawing label	Sensor code in SICADA	Sensor code in SCADA	Assembly tag label	Manufacturer
31	**1922.365**	**7253.203**	**-217.058**	TP-4	**PXK178TP4**	TP-0000-4	TP-0000-4	Geokon
32	**1922.316**	**7252.301**	**-217.739**	TP-1	**PXK178TP1**	TP-0150-1	TP-0150-1	Geokon
33	**1922.314**	**7252.303**	**-218.227**	TP-3	**PXK178TP3**	TP-0000-3	TP-0000-3	Geokon
34	**1922.302**	**7253.192**	**-218.901**	TP-2	**PXK178TP2**	TP-0000-2	TP-0000-2	Geokon
35	**1922.324**	**7254.082**	**-218.233**	TP-5	**PXK178TP5**	TP-0000-5	TP-0000-5	Geokon
36	**1922.363**	**7254.081**	**-217.739**	TP-2	**PXK179TP2**	TP-0150-2	TP-0150-2	Geokon

Table 5-7. *Numbering and position of sensors inside rock in drift section 9.*

	Coordinate system ÄSPÖ 96							
Point No.	**Easting [m]**	**Northing [m]**	**Point Elevation [m]**	Drawing label	Sensor code in SICADA	Sensor code in SCADA	Assembly tag label	Manufacturer
1	**1920.505**	**7251.669**	**-217.045**	PP-2	**PXK16PP2**	PP-0292-2	PP-0292-2	Keller
2	**1920.547**	**7250.325**	**-216.256**	PP-5	**PXK16PP5**	PP-0292-5	PP-0292-5	Keller
3	**1920.572**	**7249.549**	**-215.800**	PP-8	**PXK16PP8**	PP-0292-8	PP-0292-8	Keller
4	**1920.600**	**7248.635**	**-215.264**	PP-11	**PXK16PP11**	PP-0292-11	PP-0292-11	Keller
5	**1920.625**	**7247.851**	**-214.803**	PP-14	**PXK16PP14**	PP-0292-14	PP-0292-14	Keller
6	**1920.742**	**7244.135**	**-212.622**	PP-17	**PXK16PP17**	PP-0292-17	PP-0292-17	Keller
7	**1920.448**	**7253.208**	**-219.700**	PP-1	**PXK16PP1**	PP-0292-1	PP-0292-1	Keller
8	**1920.384**	**7253.206**	**-221.259**	PP-4	**PXK16PP4**	PP-0292-4	PP-0292-4	Keller
9	**1920.347**	**7253.205**	**-222.158**	PP-7	**PXK16PP7**	PP-0292-7	PP-0292-7	Keller
10	**1920.262**	**7253.202**	**-224.226**	PP-10	**PXK16PP10**	PP-0292-10	PP-0292-10	Keller
11	**1920.226**	**7253.201**	**-225.125**	PP-13	**PXK16PP13**	PP-0292-13	PP-0292-13	Keller
12	**1920.090**	**7253.196**	**-228.433**	PP-16	**PXK16PP16**	PP-0292-16	PP-0292-16	Keller
13	**1920.523**	**7254.695**	**-217.053**	PP-3	**PXK16PP3**	PP-0292-3	PP-0292-3	Keller
14	**1920.557**	**7255.607**	**-216.515**	PP-6	**PXK16PP6**	PP-0292-6	PP-0292-6	Keller
15	**1920.586**	**7256.382**	**-216.058**	PP-9	**PXK16PP9**	PP-0292-9	PP-0292-9	Keller
16	**1920.643**	**7257.906**	**-215.159**	PP-12	**PXK16PP12**	PP-0292-12	PP-0292-12	Keller
17	**1920.672**	**7258.680**	**-214.701**	PP-15	**PXK16PP15**	PP-0292-15	PP-0292-15	Keller
18	**1920.815**	**7262.476**	**-212.461**	PP-18	**PXK16PP18**	PP-0292-18	PP-0292-18	Keller

5.4 Outer sensor results and comments

5.4.1 Total pressure

Total pressure measurements are presented in Figures 5-11 to 5-13.

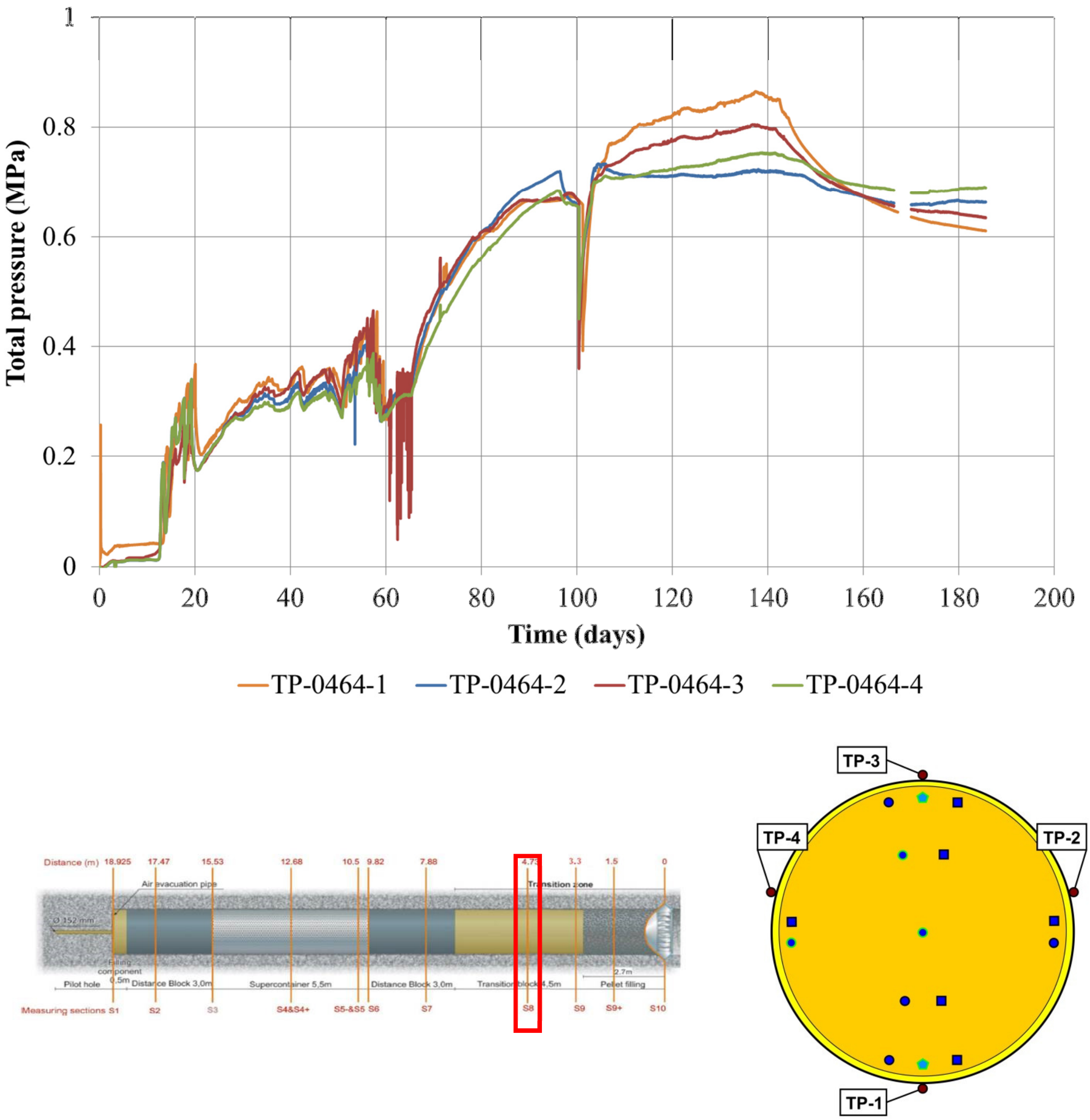


Figure 5-11. *Response of total pressure sensors at outer transition zone positions, at the rock wall surface, in drift section 8. A total of four such sensors were installed in this section (bottom-right inset; TP-1 corresponds to TP-0464-1, etc.). The sensors all show similar behavior of increasing pressure leveling off after 100 days.*

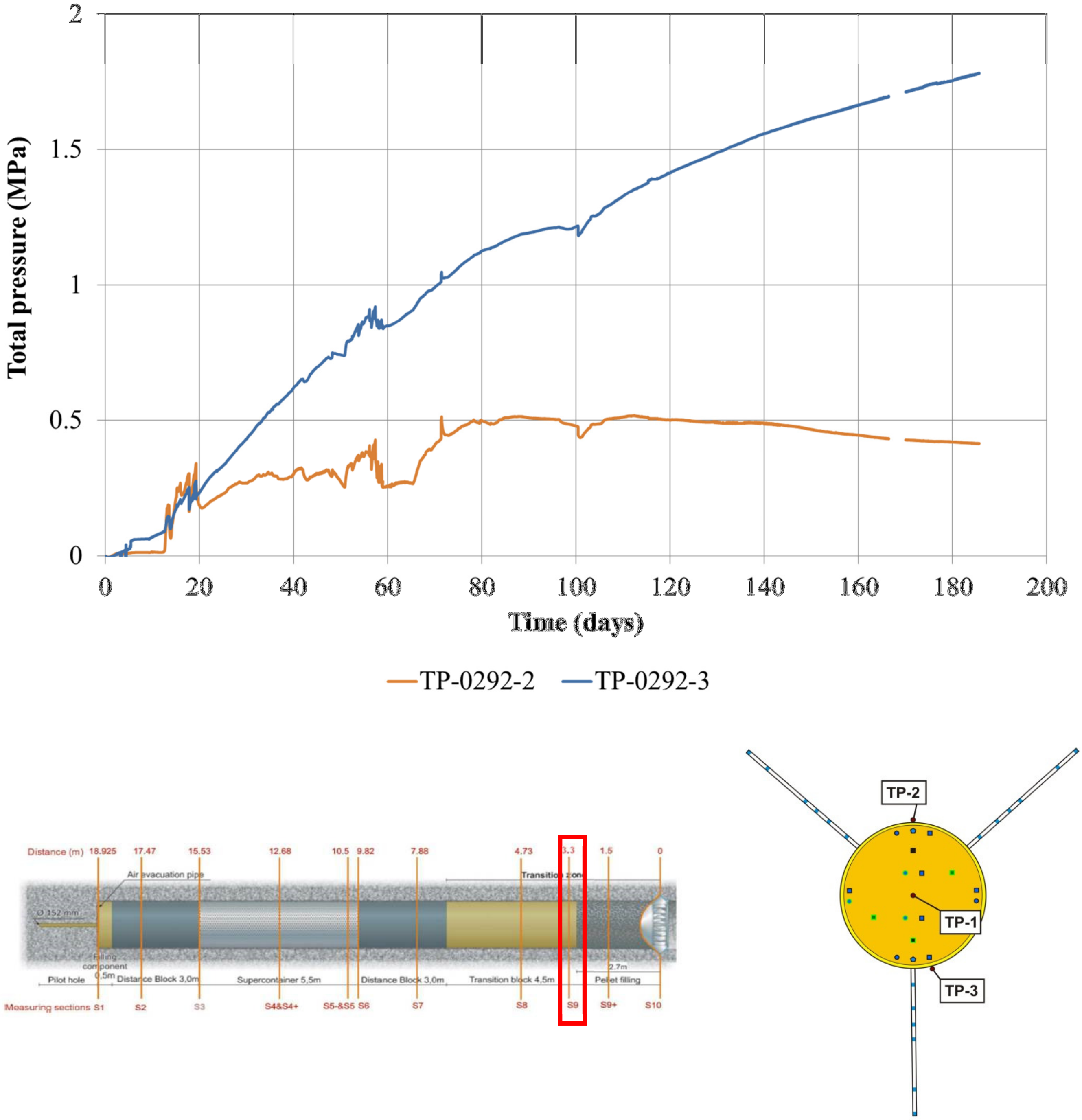


Figure 5-12. *Response of total pressure sensors at outer transition zone positions (at the rock wall surface) in drift section 9. A total of two such sensors were installed in this section (bottom-right inset; TP-2 corresponds to TP-0292-2 and TP-3 to TP-0292-3). TP-1 corresponds to a sensor installed in the buffer block. Similar to the total pressure sensors in drift section 8 (see Figure 5-11), sensor TP-2 shows increasing pressure with a leveling off after 100 days. It is likely this sensor is measuring pore pressure. Sensor TP-3 displays continuously increasing pressure; it is possible that more significant swelling pressure has developed at this position and/or the block has shifted to a resting position on the bottom of the drift.*

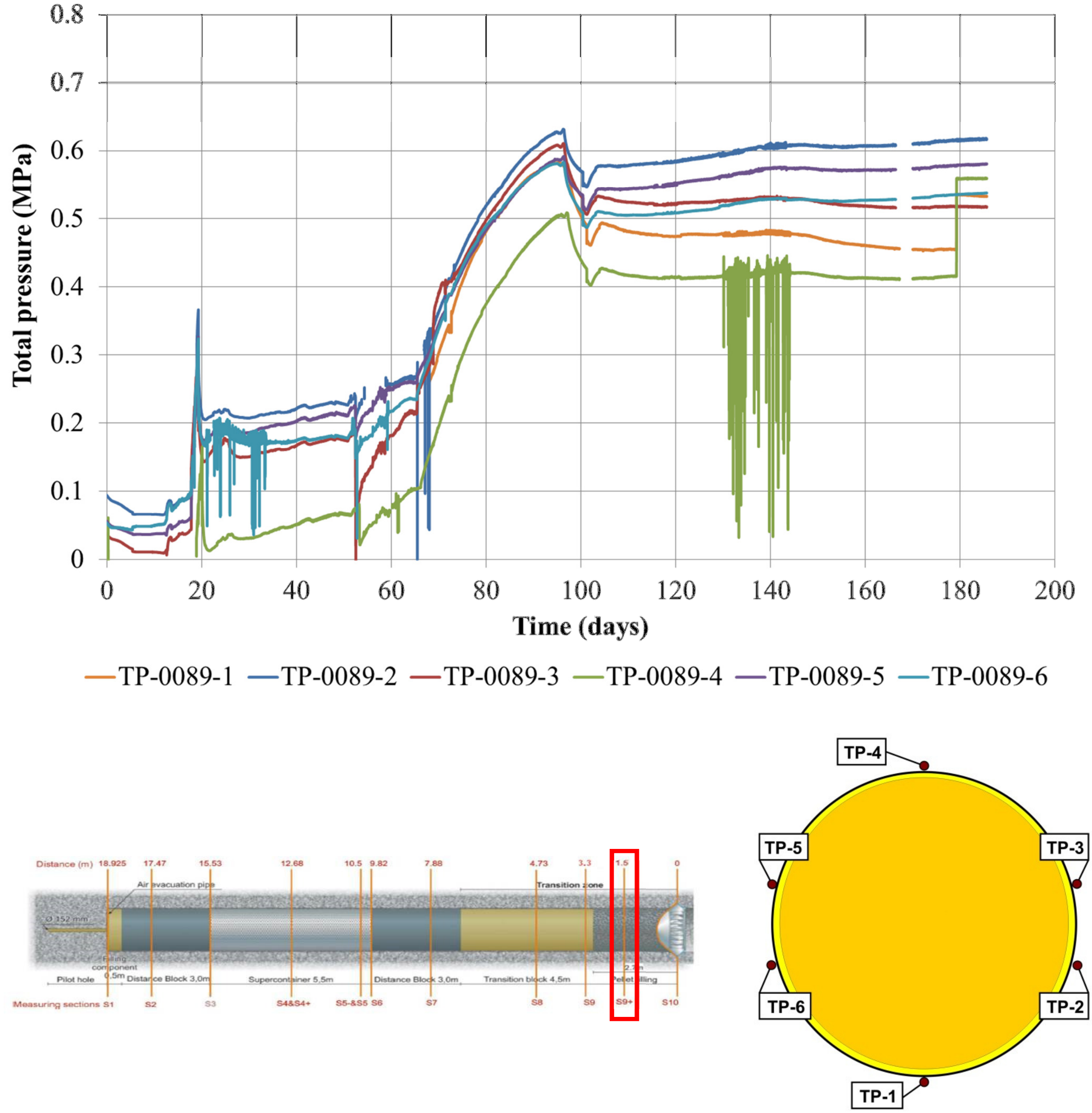


Figure 5-13. *Response of total pressure sensors at outer transition zone positions (at the rock wall surface) in drift section 9+. A total of six such sensors were installed in this section (bottom-right inset; TP-1 corresponds to TP-0089-1, etc.). The sensors all show similar behavior of increasing pressure leveling off after 100 days and resemble that observed for sensor PP-0029-4 (see Figure 5-6) in the pellet-filled zone in drift section 10. The initially lower values from sensor TP-4 may be due to a shallow collapse of the pellets during the DAWE phase. This sensor also displayed signal instability between 130-145 days and a jump in pressure at 180 days probably due to material rearrangement, very common in pellets (Mayor et al., 2005a, 2005b).*

5.4.2 Pore pressure

Pore pressure measurements in the three boreholes drilled into the rock wall in drift section 9 are presented in Figures 5-14 to 5-16. The packer system generated peak pressures on December 10 and 27, 2013. These peaks were registered by the total pressure sensors.

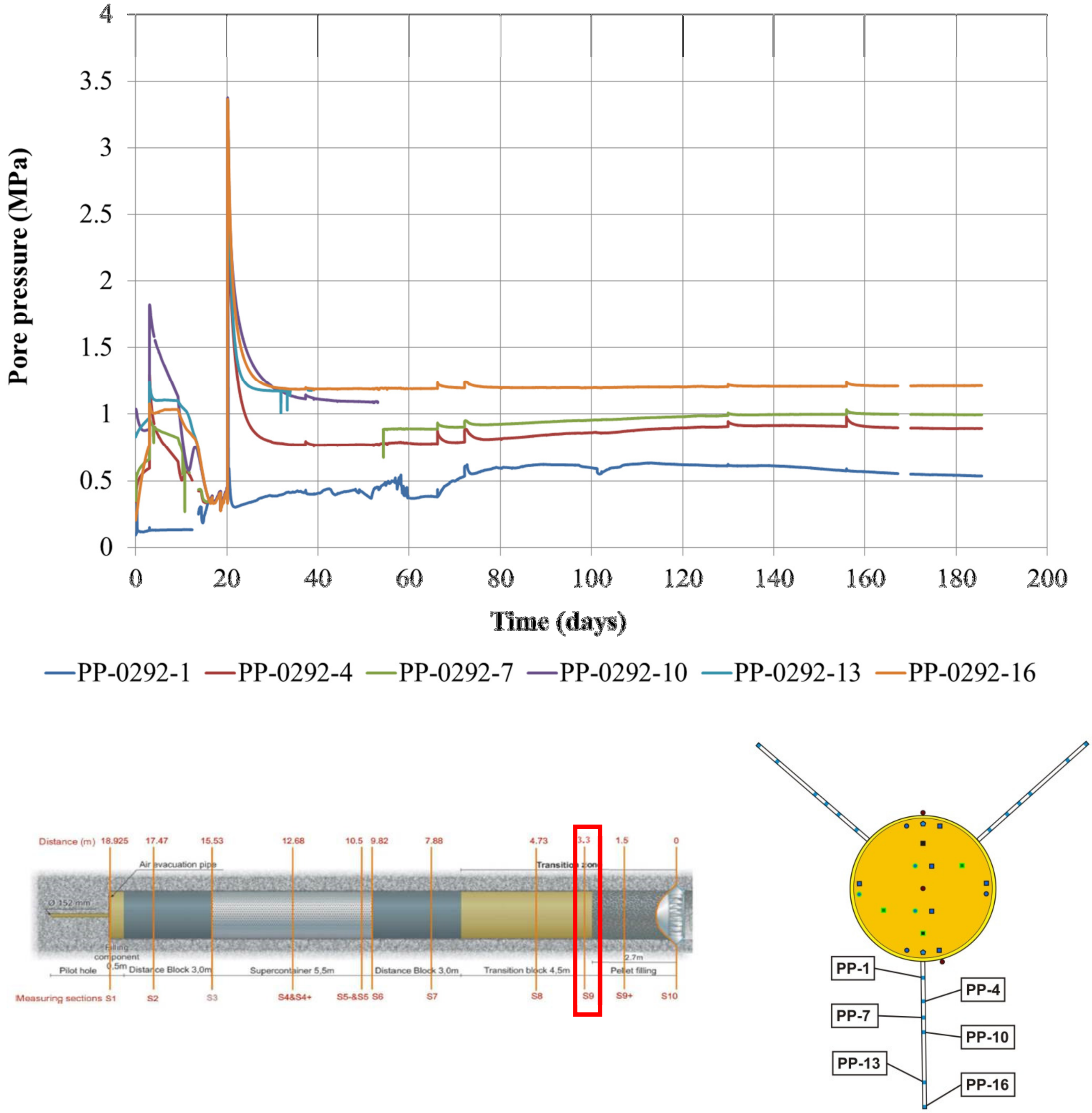


Figure 5-14. *Response of pore pressure sensors at outer transition zone positions in borehole 1 (KA1619A05 in Äspö reference) in drift section 9. A total of six such sensors were installed in this borehole (bottom-right inset; PP-1 corresponds to PP-0292-1, etc.).*

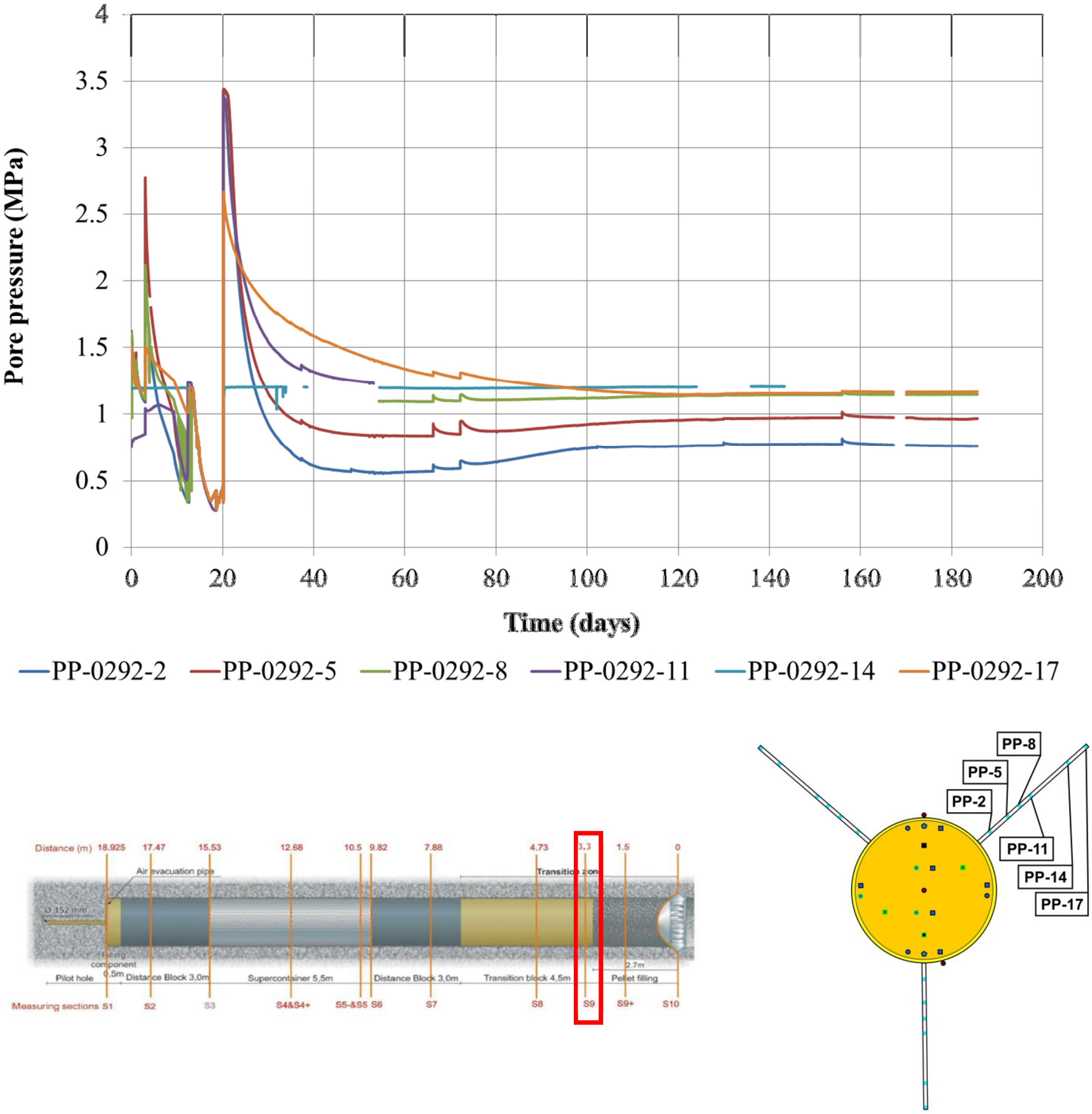


Figure 5-15. *Response of pore pressure sensors at outer transition zone positions in borehole 2 (KA1619A06 in Äspö reference) in drift section 9. A total of six such sensors were installed in this borehole (bottom-right inset; PP-2 corresponds to PP-0292-2, etc.).*

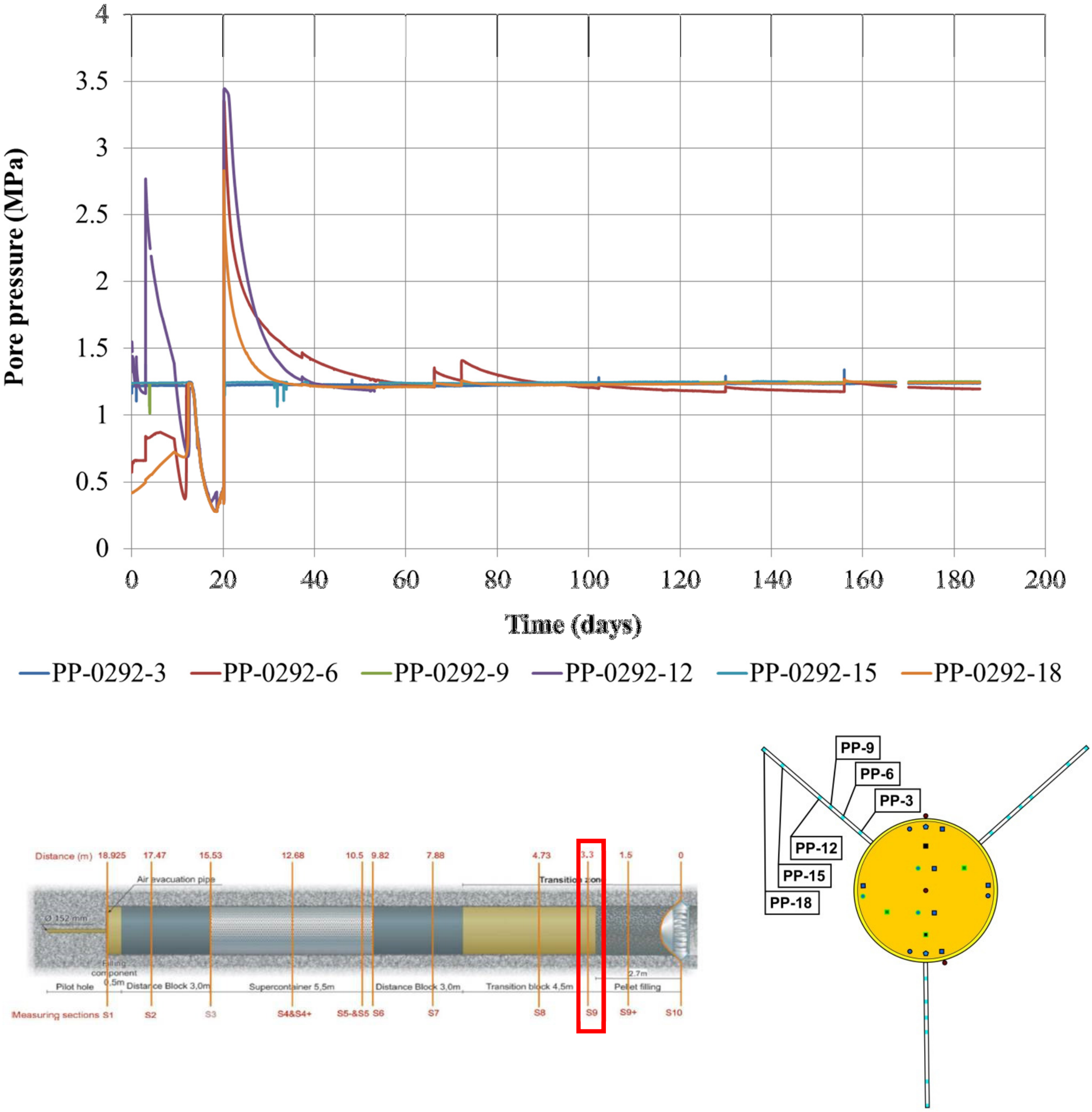
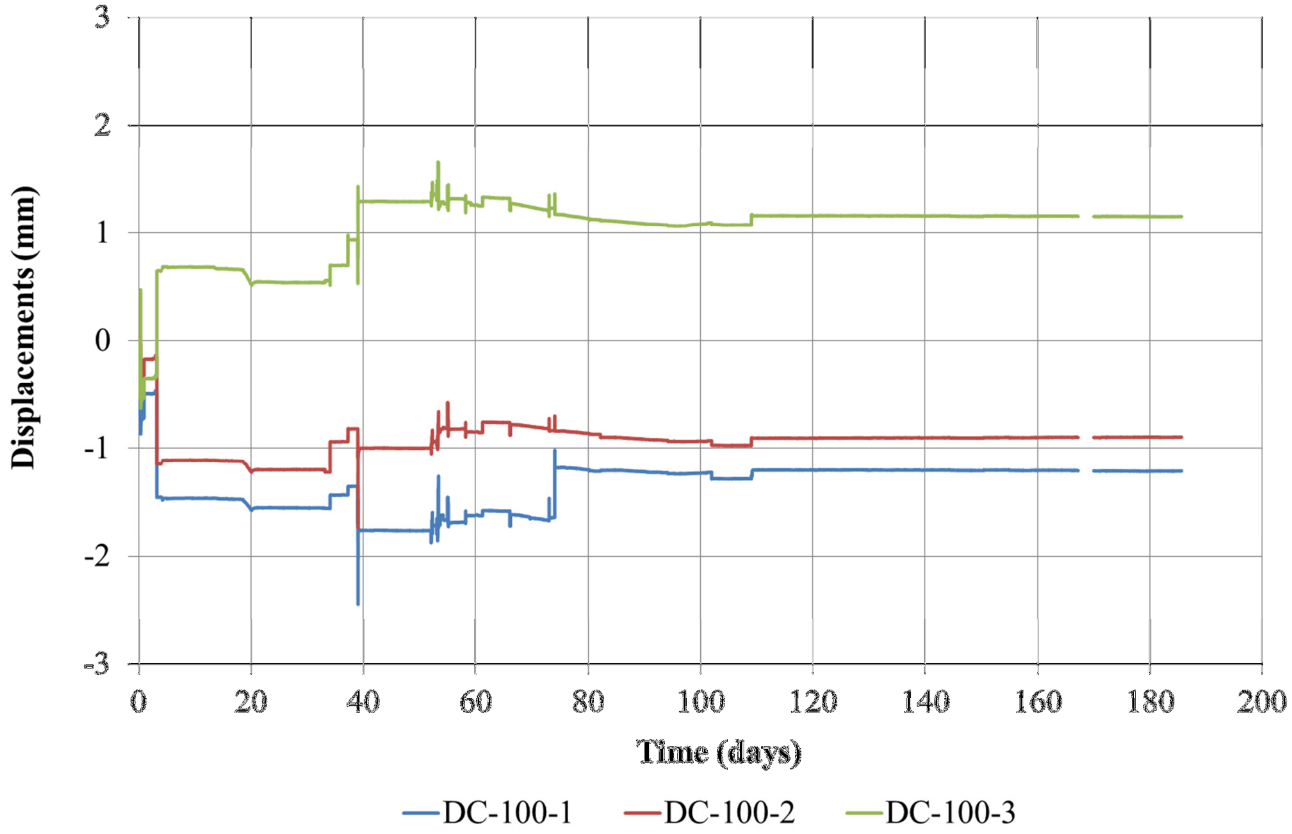
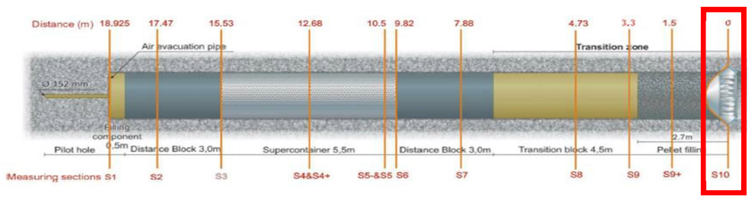


Figure 5-16. *Response of pore pressure sensors at outer transition zone positions in borehole 3 (KA1620A02 in Äspö reference) in drift section 9. A total of six such sensors were installed in this borehole (bottom-right inset; PP-3 corresponds to PP-0292-3, etc.).*

5.4.3 Displacements in plug

Signals from displacement sensors on the plug face are presented in Figure 5-17.





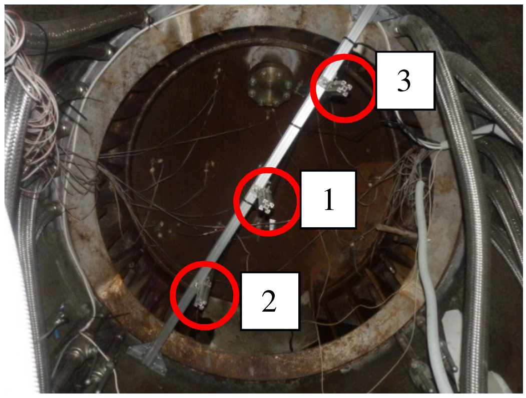


Figure 5-17. *Response of displacement sensors on the plug face in drift section 10 (bottom-right inset). Overall the measured displacements are quite small and near the limit of detection of the sensors. The observed jumps in displacements are likely due to work being performed at or near the plug face.*

5.4.4 Strains in plug

Signals from strain gauge measurements on the plug face are presented in Figures 5-18 and 5-19.

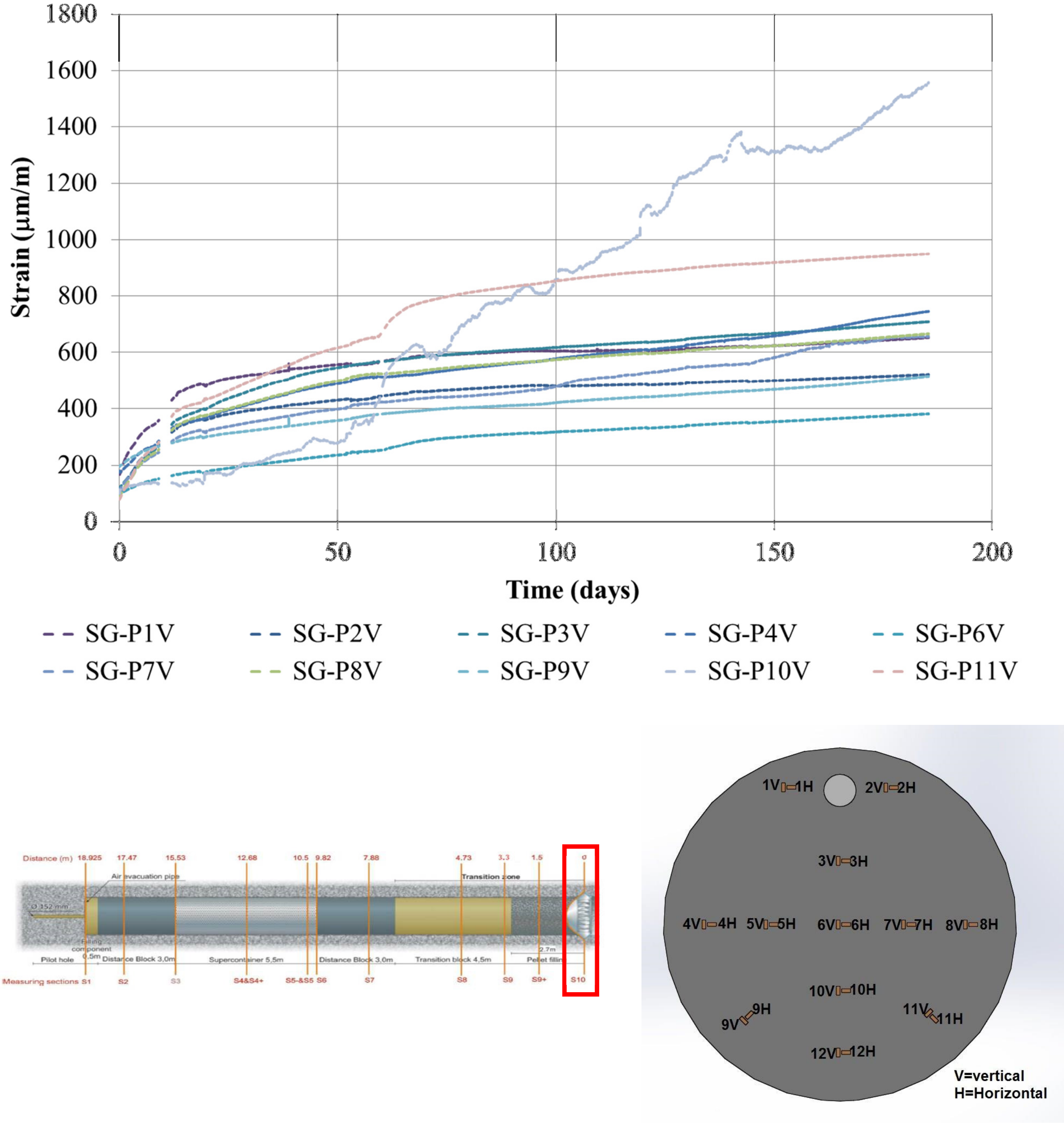


Figure 5-18. *Response of vertical strain gauges on the plug face in drift section 10 (bottom-right inset). Increasing strains are observed over the course of the test at every position indicating the development of pressure behind the plug. Strain gauge SG-P10V displays anomalous behavior relative to the others. Strain gauges SG-P5V and SG-P12V have failed.*

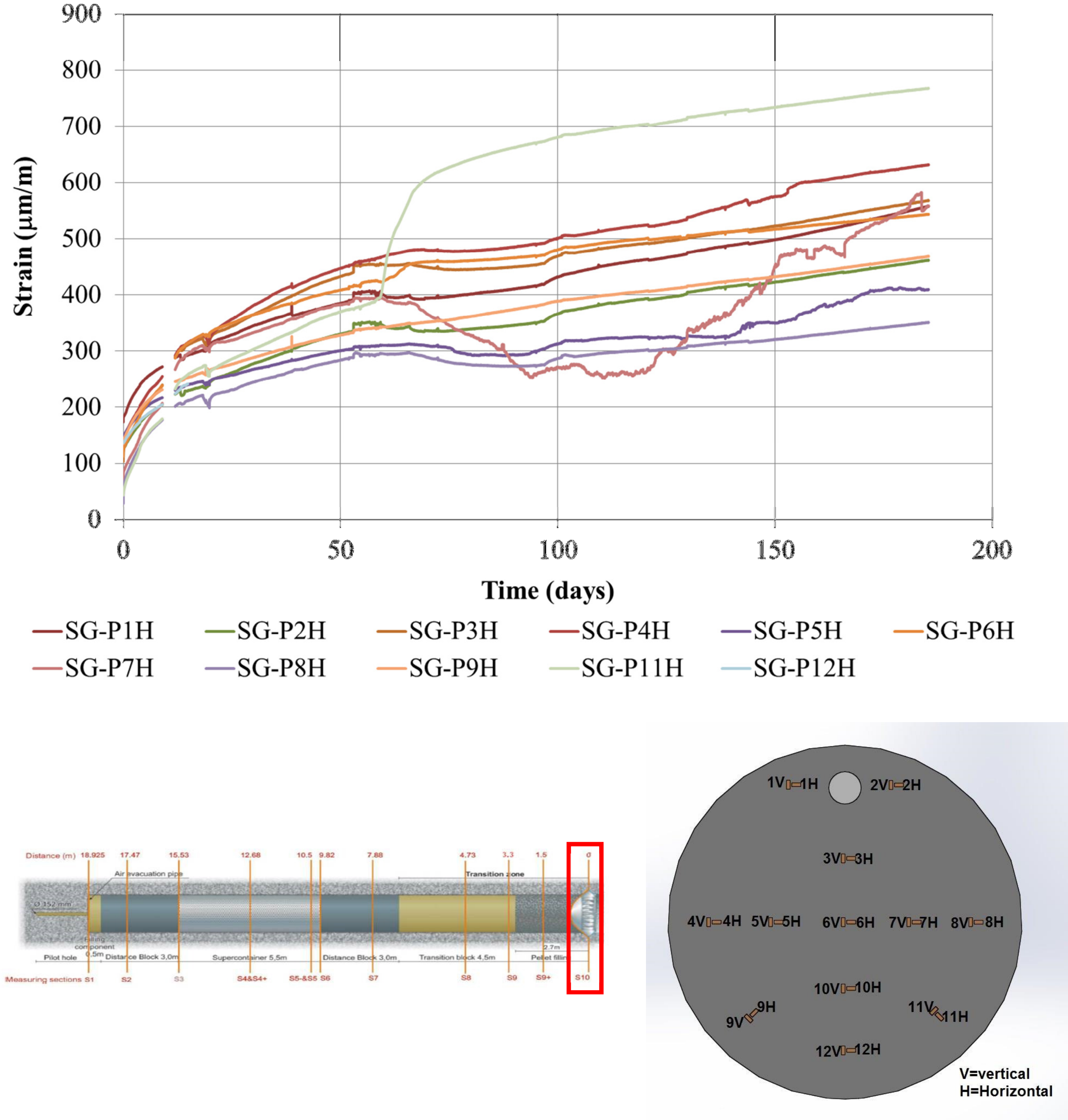


Figure 5-19. *Response of horizontal strain gauges on the plug face in drift section 10 (bottom-right inset). Increasing strains are observed over the course of the test at every position indicating the development of pressure behind the plug. Strain gauge SG-P11H displays a jump in measured strain at approximately 60 days.*

6 SUPERCONTAINER

6.1 Inner sensor positions

The location of the inner sensors and other information is presented in Tables 6-1 (drift section 4), 6-1 (drift section 2) and 6-3 (drift section 7). This section also contains information regarding the strain gauges on the Supercontainer in drift section 3 (Table 6-4). All sections are presented in Figure 3-1.

Table 6-1. *Numbering and position of inner Supercontainer sensors in drift section 4.*

	Coordinate system ÄSPÖ 96							
Point No.	**Easting [m]**	**Northing [m]**	**Point Elevation [m]**	Drawing label	Sensor code in SICADA	Sensor code in SCADA	Assembly tag label	Manufacturer
1	**1910.864**	**7252.987**	**-216.798**	WP2	**PXK061WP2**	WP-1299-2	WP-1293-2	Wescor
2	**1910.861**	**7252.599**	**-216.954**	PP3	**PXK061PP3**	PP-1299-3	PP-1293-3	Measurement Specialities
3	**1910.848**	**7252.418**	**-217.491**	WP3	**PXK061WP3**	WP-1299-3	WP-1293-3	Wescor
4	**1910.846**	**7252.419**	**-217.591**	WC4	**PXK061WC4**	WC-1299-4	WC-1293-4	Aitemin
5	**1910.833**	**7252.599**	**-218.128**	PP4	**PXK061PP4**	PP-1299-4	PP-1293-4	Measurement Specialities
6	**1910.828**	**7252.987**	**-218.284**	WP4	**PXK061WP4**	WP-1299-4	WP-1293-4	Wescor
7	**1910.827**	**7253.386**	**-218.284**	WC1	**PXK061WC1**	WC-1299-1	WC-1293-1	Aitemin
8	**1910.831**	**7253.773**	**-218.128**	PP1	**PXK061PP1**	PP-1299-1	PP-1293-1	Measurement Specialities
9	**1910.843**	**7253.955**	**-217.591**	WC2	**PXK061WC2**	WC-1299-2	WC-1293-2	Aitemin
10	**1910.846**	**7253.955**	**-217.491**	WP1	**PXK061WP1**	WP-1299-1	WP-1293-1	Wescor
11	**1910.859**	**7253.186**	**-217.006**	TP2	**PXK061TP2**	TP-1299-2	TP-1299-2	Geokon /ÅF
12	**1910.864**	**7253.186**	**-216.771**	WF2	**PXK061WF2**	WF-1299-2	WF-1293-2	Delta-T
13	**1910.867**	**7253.187**	**-216.678**	TP4	**PXK061TP4**	TP-1244-4	TP-1299-4	Geokon /ÅF
14	**1910.845**	**7253.722**	**-217.541**	TP1	**PXK061TP1**	TP-1299-1	TP-1299-1	Geokon /ÅF
15	**1910.827**	**7253.186**	**-218.311**	WF1	**PXK061WF1**	WF-1299-1	WF-1293-1	Delta-T
16	**1910.847**	**7252.651**	**-217.541**	TP3	**PXK061TP3**	TP-1299-3	TP-1299-3	Geokon /ÅF
17	**1910.863**	**7253.386**	**-216.798**	WC3	**PXK061WC3**	WC-1299-3	WC-1293-3	Aitemin
18	**1910.859**	**7253.774**	**-216.954**	PP2	**PXK061PP2**	PP-1299-2	PP-1293-2	Measurement Specialities

Table 6-2. *Numbering and position of inner Supercontainer displacement and inclinometer sensors in drift section 4.*

	Coordinate system ÄSPÖ 96							
Point No.	**Easting [m]**	**Northing [m]**	**Point Elevation [m]**	Drawing label	Sensor code in SICADA	Sensor code in SCADA	Assembly tag label	Manufacturer
1	**1911.329**	**7253.187**	**-217.007**	IS2	**PXK072IS2**	IS-1252-2	no data	Measurement Specialities
2	**1911.060**	**7253.187**	**-218.433**	DS1	**PXK069DS1**	DS-1275-1	DS-1492-1	RDP
3	**1911.079**	**7254.069**	**-217.554**	DS2	**PXK069DS2**	DS-1275-2	DS-1492-2	RDP
4	**1911.082**	**7252.305**	**-217.553**	DS4	**PXK069DS4**	DS-1275-4	DS-1492-4	RDP
5	**1911.295**	**7253.187**	**-218.407**	IS1	**PXK072IS1**	IS-1252-1	no data	Measurement Specialities
6	**1911.102**	**7253.187**	**-216.671**	DS3	**PXK069DS3**	DS-1275-3	DS-1492-3	RDP

Table 6-3. *Numbering and position of inner Supercontainer sensors in drift section 5.*

	Coordinate system ÄSPÖ 96							
Point No.	**Easting [m]**	**Northing [m]**	**Point Elevation [m]**	Drawing label	Sensor code in SICADA	Sensor code in SCADA	Assembly tag label	Manufacturer
1	**1913.289**	**7252.991**	**-216.889**	WP2	**PXK0087WP2**	WP-1008-2	WP 1008-2	Wescor
2	**1913.289**	**7253.190**	**-216.863**	WF2	**PXK0087WF2**	WF-1008-2	WF 1008-2	Delta-T
3	**1913.288**	**7253.390**	**-216.890**	WC4	**PXK0087WC4**	WC-1008-4	wireless	Aitemin
4	**1913.291**	**7253.190**	**-216.804**	PP4	**PXK0087PP4**	PP-1008-4	wireless	Measurement Specialities
5	**1913.272**	**7252.361**	**-217.633**	PP5	**PXK0087PP5**	PP-1008-5	PP 1008-5	Measurement Specialities
6	**1913.273**	**7252.422**	**-217.583**	WP3	**PXK0087WP3**	WP-1008-3	WP 1008-3	Wescor
7	**1913.271**	**7252.422**	**-217.683**	WC5	**PXK0087WC5**	WC-1008-5	WC 1008-5	Aitemin
8	**1913.253**	**7252.991**	**-218.376**	WP4	**PXK0087WP4**	WP-1008-4	WP1008-4	Wescor
9	**1913.251**	**7253.190**	**-218.462**	PP2	**PXK0087PP2**	PP-1008-2	PP 1008-2	Measurement Specialities
10	**1913.252**	**7253.190**	**-218.403**	WF1	**PXK0087WF1**	WF-1008-1	WF 1008-1	Delta-T
11	**1913.252**	**7253.389**	**-218.376**	WC2	**PXK0087WC2**	WC-1008-2	WC 1008-2	Aitemin
12	**1913.271**	**7253.959**	**-217.583**	WP1	**PXK0087WP1**	WP-1008-1	WP 1008-1	Wescor
13	**1913.269**	**7254.020**	**-217.633**	PP3	**PXK0087PP3**	PP-1008-3	wireless	Measurement Specialities
14	**1913.268**	**7253.959**	**-217.683**	WC3	**PXK0087WC3**	WC-1008-3	wireless	Aitemin
15	**1913.272**	**7253.190**	**-217.583**	PP1	**PXK0087PP1**	PP-1008-1	wireless	Measurement Specialities
16	**1913.270**	**7253.190**	**-217.683**	WC1	**PXK0087WC1**	WC-1008-1	wireless	Aitemin
17	**1913.040**	**7253.190**	**-217.377**	TP3	**PXK085TP3**	TP-1033-3	TP 1033-3	Geokon / ÅF
18	**1913.034**	**7252.940**	**-217.627**	TP2	**PXK085TP2**	TP-1033-2	TP 1033-2	Geokon / ÅF
19	**1913.028**	**7253.190**	**-217.877**	TP1	**PXK085TP1**	TP-1033-1	TP 1033-1	Geokon / ÅF
20	**1913.033**	**7253.440**	**-217.627**	TP4	**PXK085TP4**	TP-1033-4	TP 1033-4	Geokon / ÅF
21	**1913.081**	**7253.853**	**-217.573**	WSU	**transmmiter**	WSU-S4	wireless	Aitemin

Table 6-4. *Numbering and position of inner Supercontainer displacement sensors in drift section 5.*

	Coordinate system ÄSPÖ 96							
Point No.	**Easting [m]**	**Northing [m]**	**Point Elevation [m]**	Drawing label	Sensor code in SICADA	Sensor code in SCADA	Assembly tag label	Manufacturer
1	**1912.546**	**7252.813**	**-217.233**	DS3	**PXK081DS3**	DS-1082-3	DS-0977-3	RDP
2	**1912.544**	**7253.565**	**-217.233**	DS2	**PXK081DS2**	DS-1082-2	DS-0977-2	RDP
3	**1912.526**	**7253.565**	**-217.985**	DS4	**PXK081DS4**	DS-1082-4	DS-0977-4	RDP
4	**1912.527**	**7252.806**	**-217.992**	DS1	**PXK081DS1**	DS-1082-1	DS-0977-1	RDP

6.2 Inner sensor results and comments

6.2.1 Relative humidity

Signals from sensors measuring relative humidity evolution are presented in Figures 6-1 and 6-2.

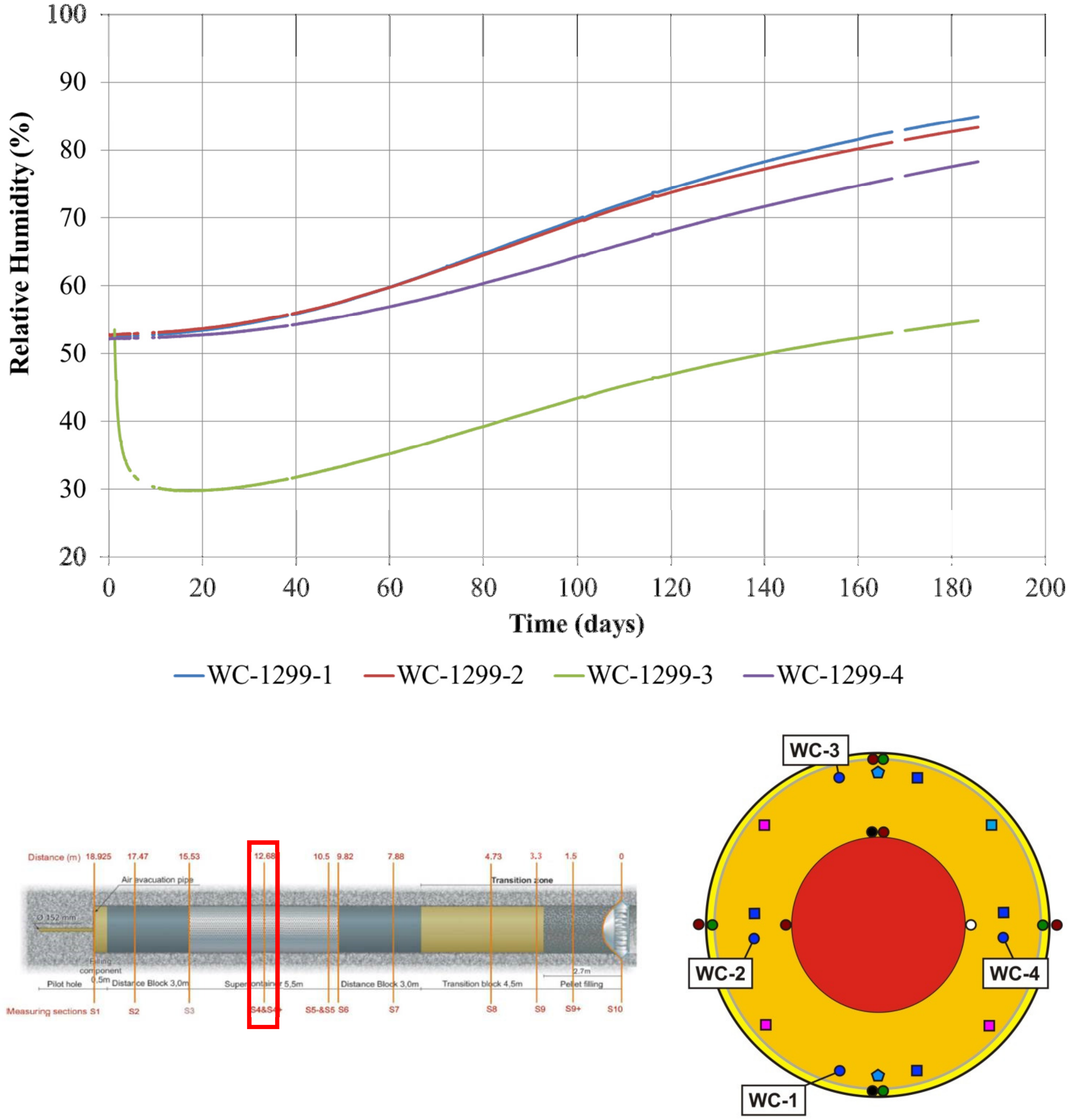


Figure 6-1. *Response of capacitive hygrometer sensors at inner Supercontainer positions (in the bentonite block) in drift section 4. A total of four such sensors were installed in this section (bottom-right inset; WC-1 corresponds to WC-1299-1, etc.). Generally, the sensors indicate increasing relative humidity levels over the course of the test. The reason for the initial drop in signal for sensor WC-1299-3 is unknown but it could be related with block cracking/expansion. Initial signals correspond to 52% RH rather than 84% RH (see Figures 4-1, 4-2, 5-1 and 5-2) because the buffer blocks (inside the Supercontainer) are dryer than the transition zone blocks or distance blocks.*

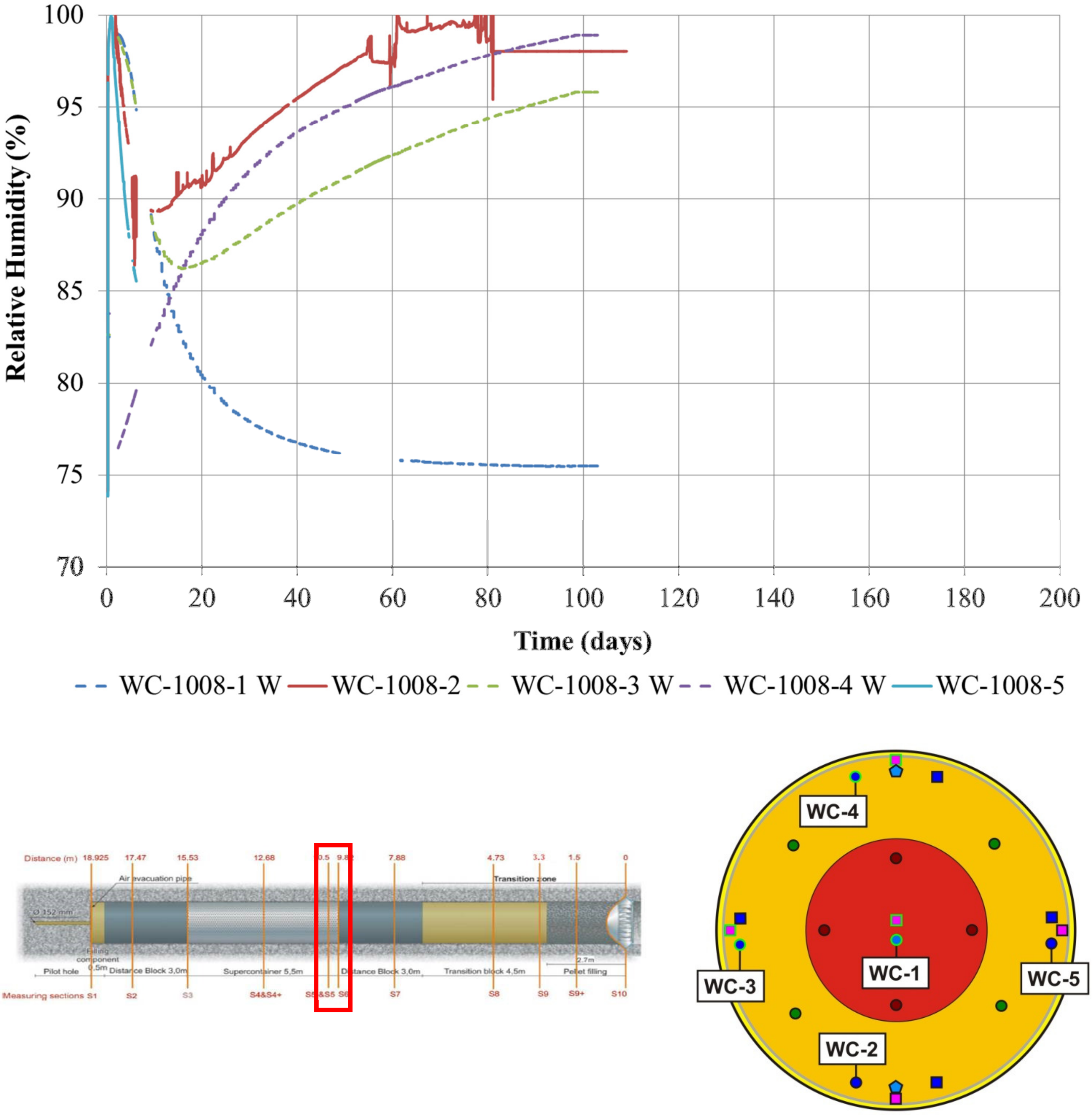


Figure 6-2. *Response of capacitive hygrometer sensors at inner Supercontainer positions (in the bentonite block) in drift section 5. A total of five such sensors were installed in this section (bottom-right inset; WC-1 corresponds to WC-1008-1, etc.). Sensors WC-1, WC-2, WC-3 and WC-5 showed a spike in relative humidity during the DAWE phase of the test probably due to a gap between the final disc block and the ring and canister. This gap was sealed quickly due to the bentonite swelling. Sensor WC-1 is between the the block and the canister inside the block. Signal was no longer available form sensor WC-5 after 5 days. Sensor WC-2 reached full saturation after approximately 60 days. Signal was no longer received from the wireless sensors (WC-1, WC-3 and WC-4) after just over 100 days.*

6.2.2 Suction

In-range signals from the psychrometer sensors correspond only to suction established at 95% relative humidity. For temperatures between 5 ºC and 15 ºC, the suction at 95% relative humidity should be between 6.6 and 6.8 MPa. The results are presented in Figures 6-3 to 6-5.

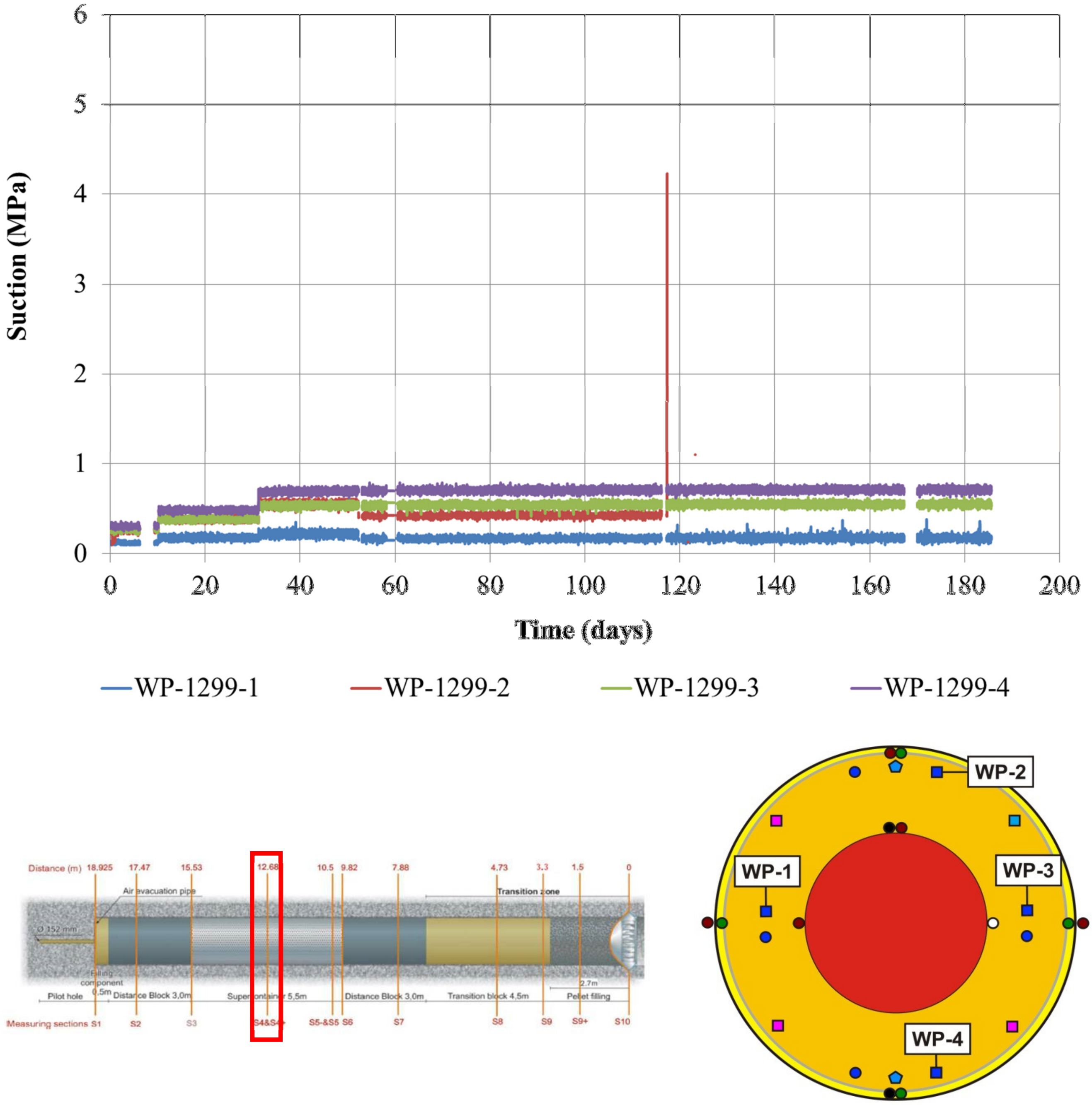


Figure 6-3. *Response of psychrometer sensors at inner Supercontainer positions (in the bentonite block) in drift section 4. A total of four such sensors were installed in this section (bottom-right inset; WP-1 corresponds to WP-1299-1, etc.). The signals for these sensors have not yet started to approach in-range limits, i.e., the block is not sufficiently saturated.*

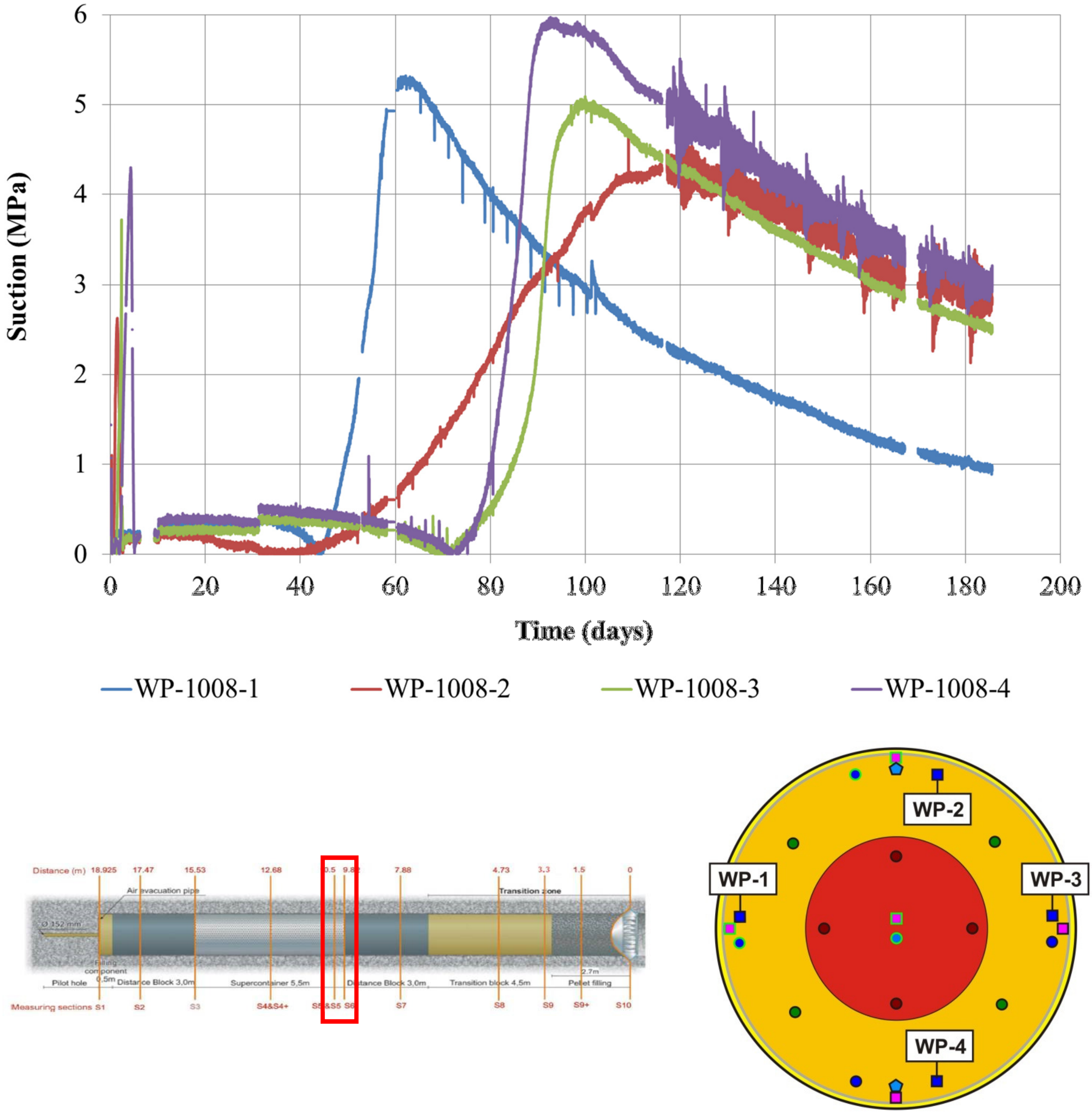


Figure 6-4. *Response of psychrometers at inner Supercontainer positions (in the bentonite block) in drift section S-5. A total of four such sensors were installed in this section (bottom-right inset; WP-1 corresponds to WP-1008-1, etc.). The sensors were in range at the early stage of the test probably due to a gap between the final disc block and the ring and canister. This gap was sealed quickly due to the bentonite swelling. It is possible to see the same behavior in capacitive hygrometers in Figure 6-2. All of the sensors have reached in-range suction limits (see also Figure 6-5).*

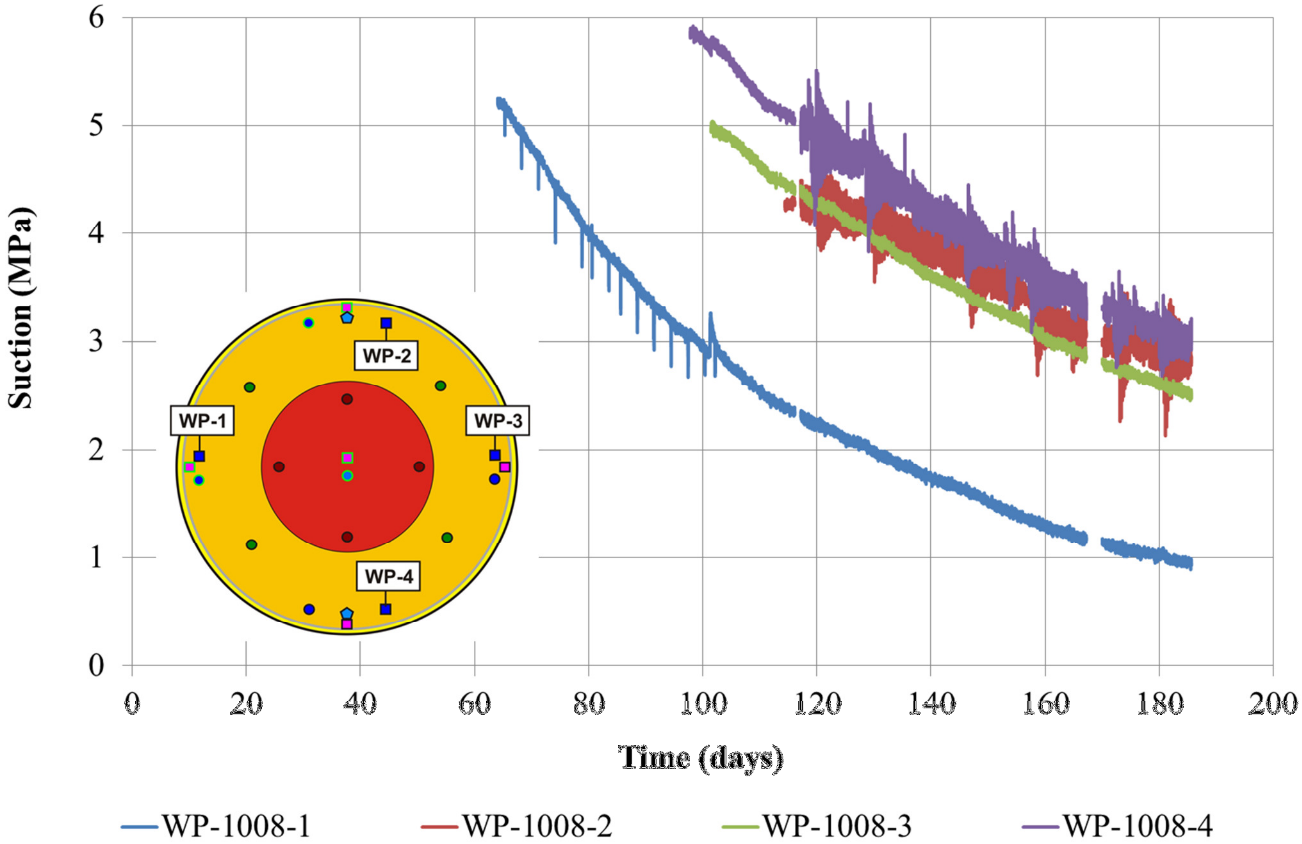


Figure 6-5. *Decay in psychrometer signal for sensors WP-1, WP-2, WP-3 and WP-4 in inner Supercontainer positions in drift section 5 after reaching in-range suction limits. The sensors WP-2 and WP-5 were somewhat noisy which could be related to chamber contamination. The bentonite salts moved with the water towards the sensor and the signal is affected due to the operating principle of the sensor (drying/wetting cycles).*

6.2.3 Pore pressure

Pore pressures in the Supercontainer blocks was measured with pore pressure sensors (Figures 6-6 and 6-7). The pressure in the gap was measured (Figure 6-8) with a gas pressure sensor.

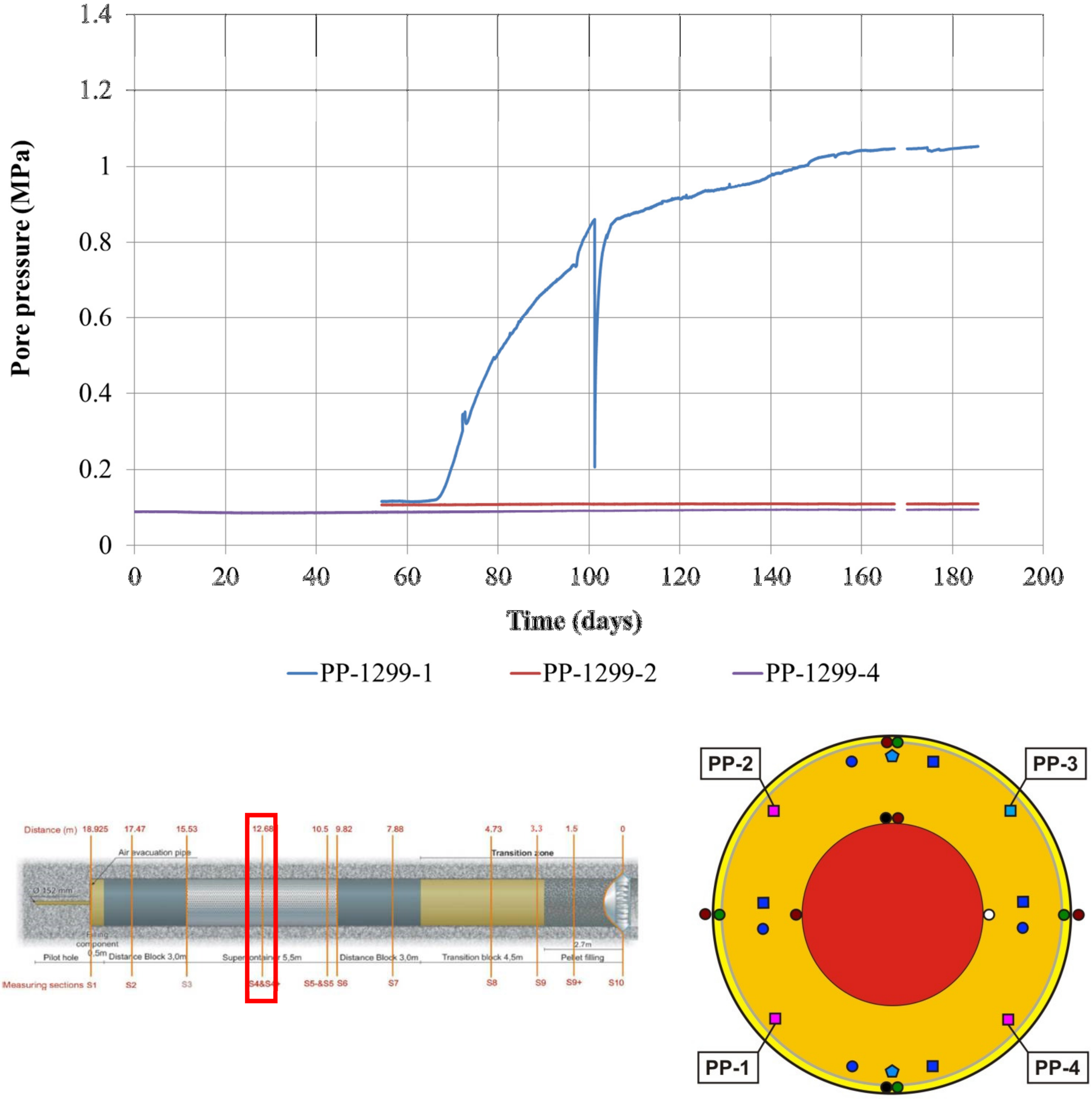


Figure 6-6. *Response of pore pressure sensors at inner Supercontainer positions (in the bentonite block) in drift section 4. A total of four such sensors were installed in this section (bottom-right inset; PP-1 corresponds to PP-1299-1, etc.). Signal was not available from sensor PP-3.*

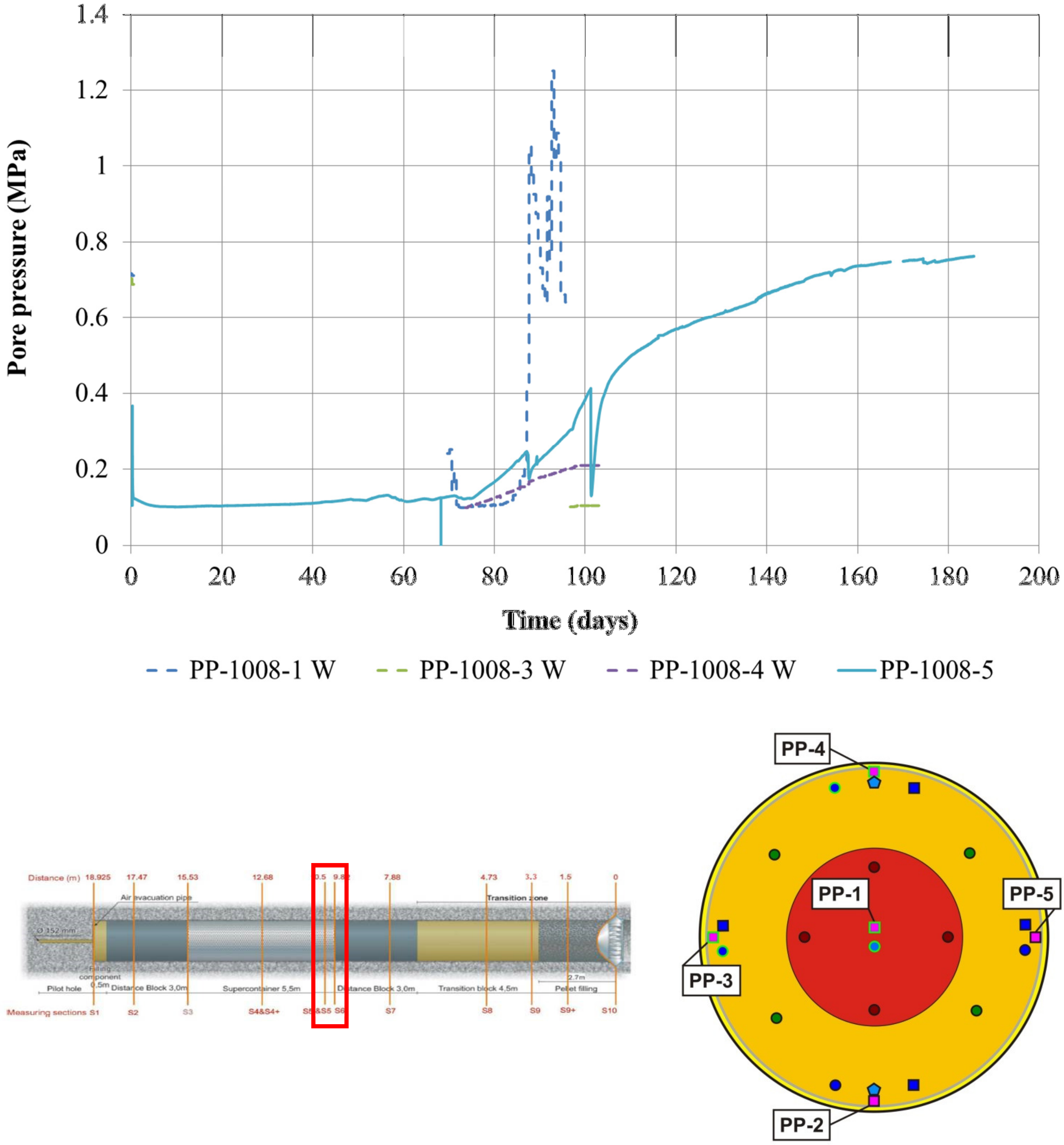


Figure 6-7. *Response of pore pressure sensors at inner Supercontainer positions (in the bentonite block) in drift section 5. A total of five such sensors were installed in this section (bottom-right inset; PP-1 corresponds to PP-1008-1, etc.). Dashed lines correspond to wireless sensors (PP-1, PP-3 and PP-4). Signal was received from these sensors only between 70 to just over 100 days into the test. Signal was not available form sensor PP-2. Sensor PP-5 probably is in contact with the gap filled with water due to block cracks.*

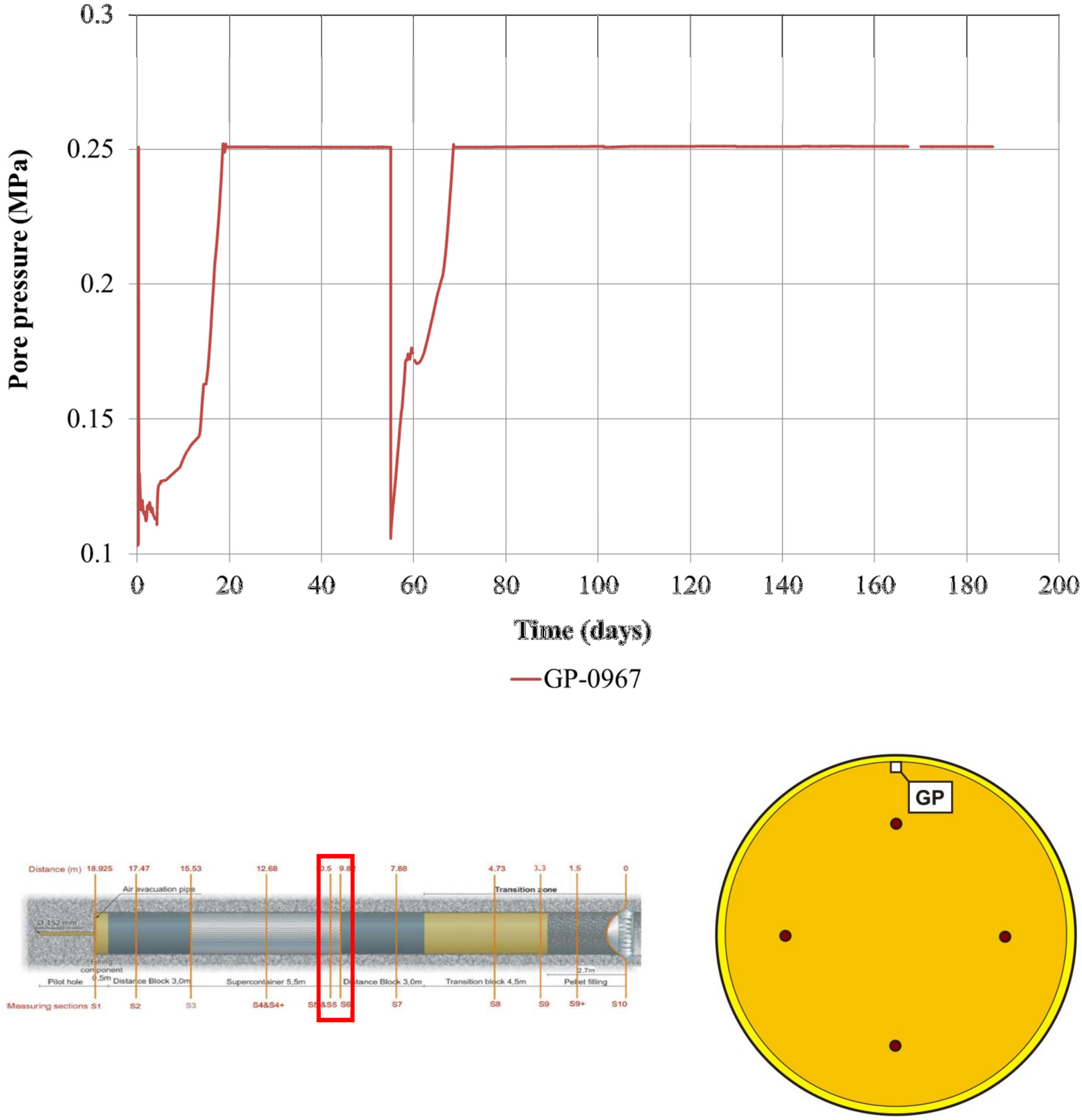


Figure 6-8. *Response of gas pressure sensor in drift section 6 (bottom-right inset). The full sensor range is 250 kPa and it was installed for the purposes of measuring the gas pressure during the water filling if the DAWE procedure was not followed. The sensor was flooded during the water filling and essentially measured water pressure. After approximately 20 days it reached the maximum capacity. This sensor should be changed to a higher range pore pressure sensor which is possible because the gas pressure sensors are located outside of the drift.*

6.2.4 Water content

Volumetric water content was measured with soil moisture sensors (Figures 6-9 and 6-10).

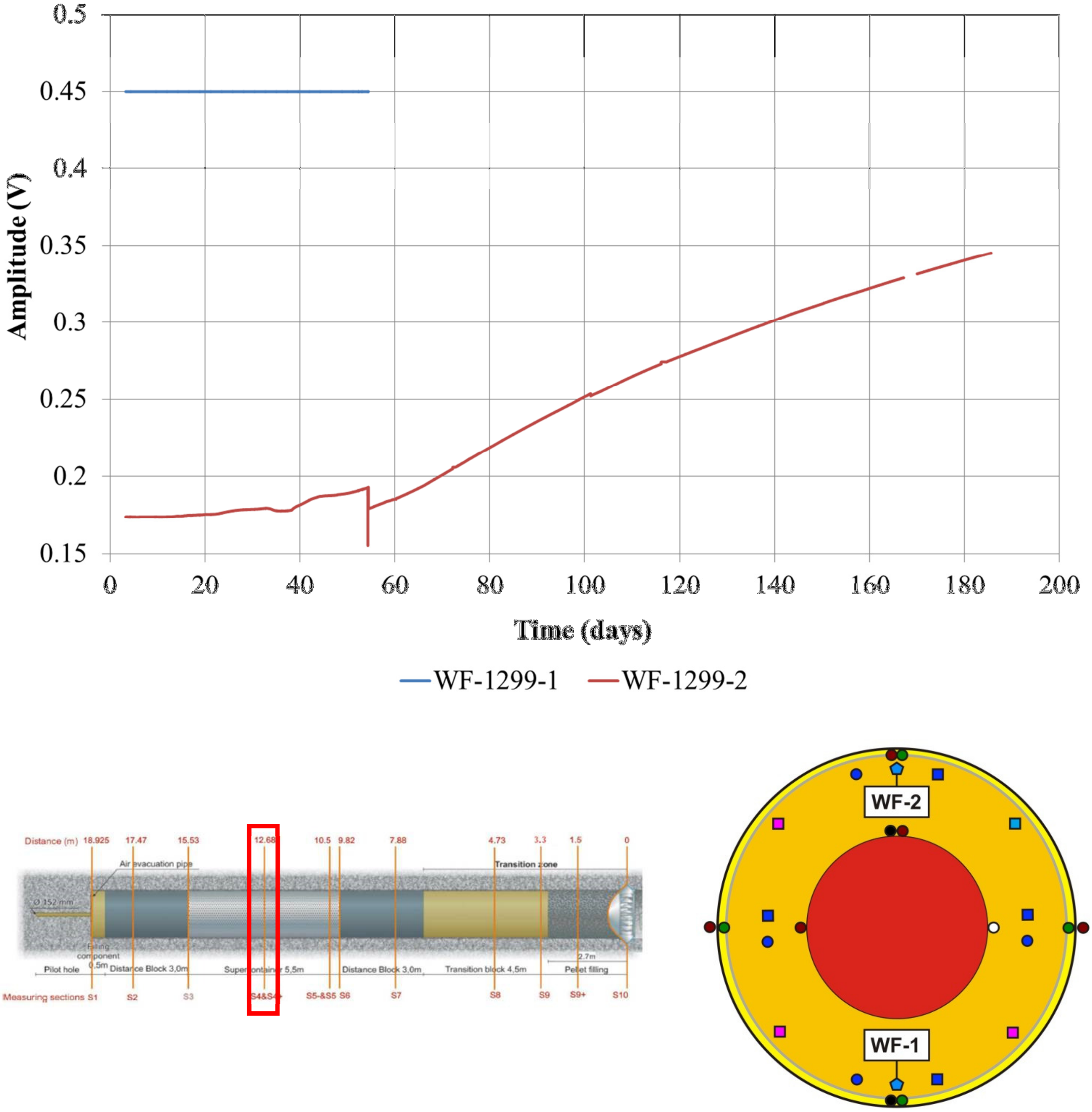


Figure 6-9. *Response of soil moisture sensors at inner Supercontainer positions (in the bentonite block) in drift section 7. A total of two such sensors were installed in this section (bottom-right inset; WF-1 corresponds to WF-1299-1 and WF-2 corresponds to WF-1299-2). Sensor WF-2 measured an increasing signal over the course of the test but sensor WF-1 may have malfunctioned as it displayed a constant signal until almost 60 days after which signal was no longer available.*

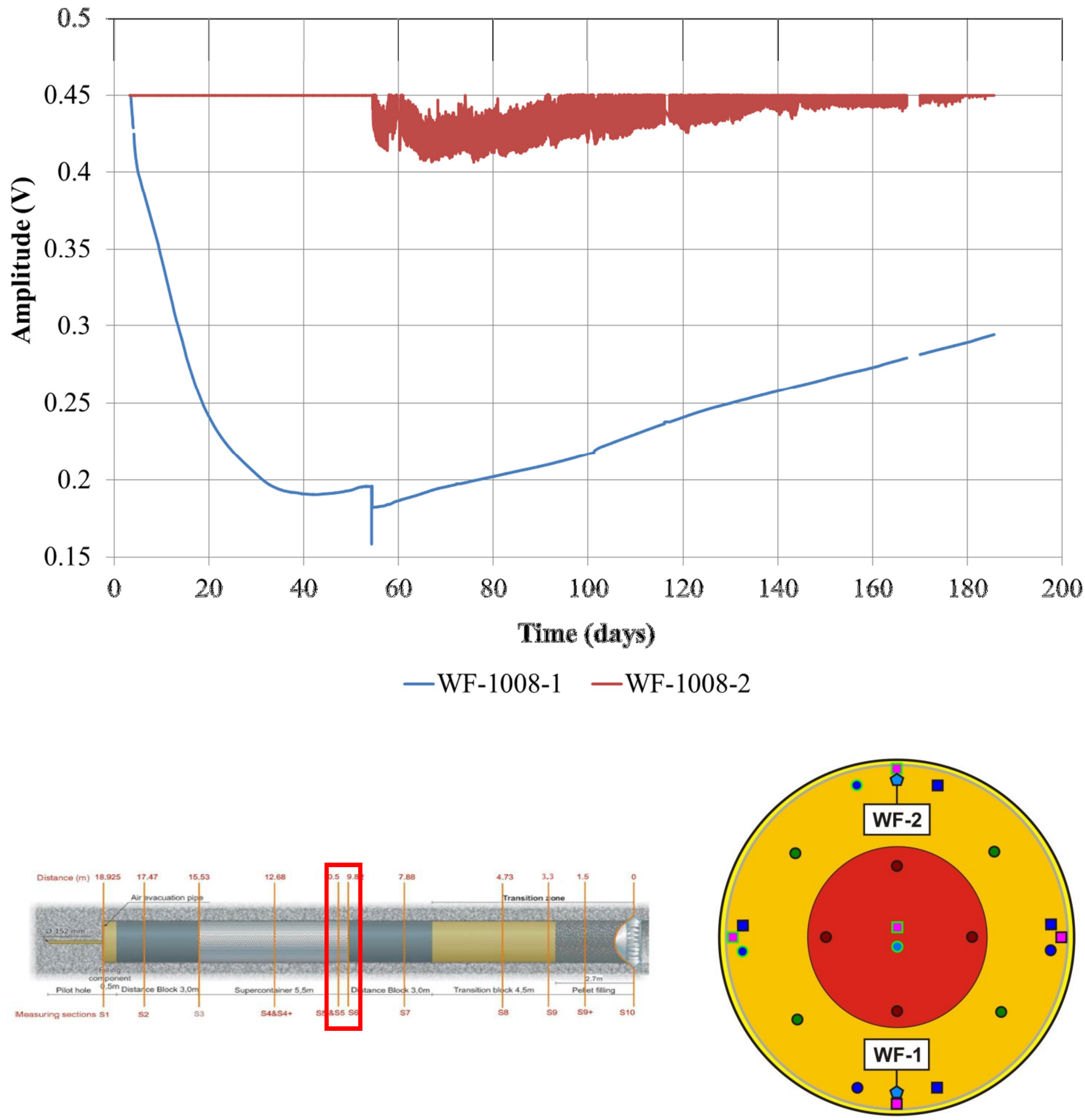


Figure 6-10. *Response of soil moisture sensors at inner Supercontainer positions (in the bentonite block) in drift section 5. A total of two such sensors were installed in this section (bottom-right inset; WF-1 corresponds to WF-1008-1 and WF-2 corresponds to WF-1008-2). After an initial drop, sensor WF-1 measured an increasing signal over most of the test but sensor WF-2 displayed a relatively constant signal throughout which indicates it may be malfunctioning.*

6.2.5 Inclination

Results from the inclinometer sensors are presented in Figure 6-11.

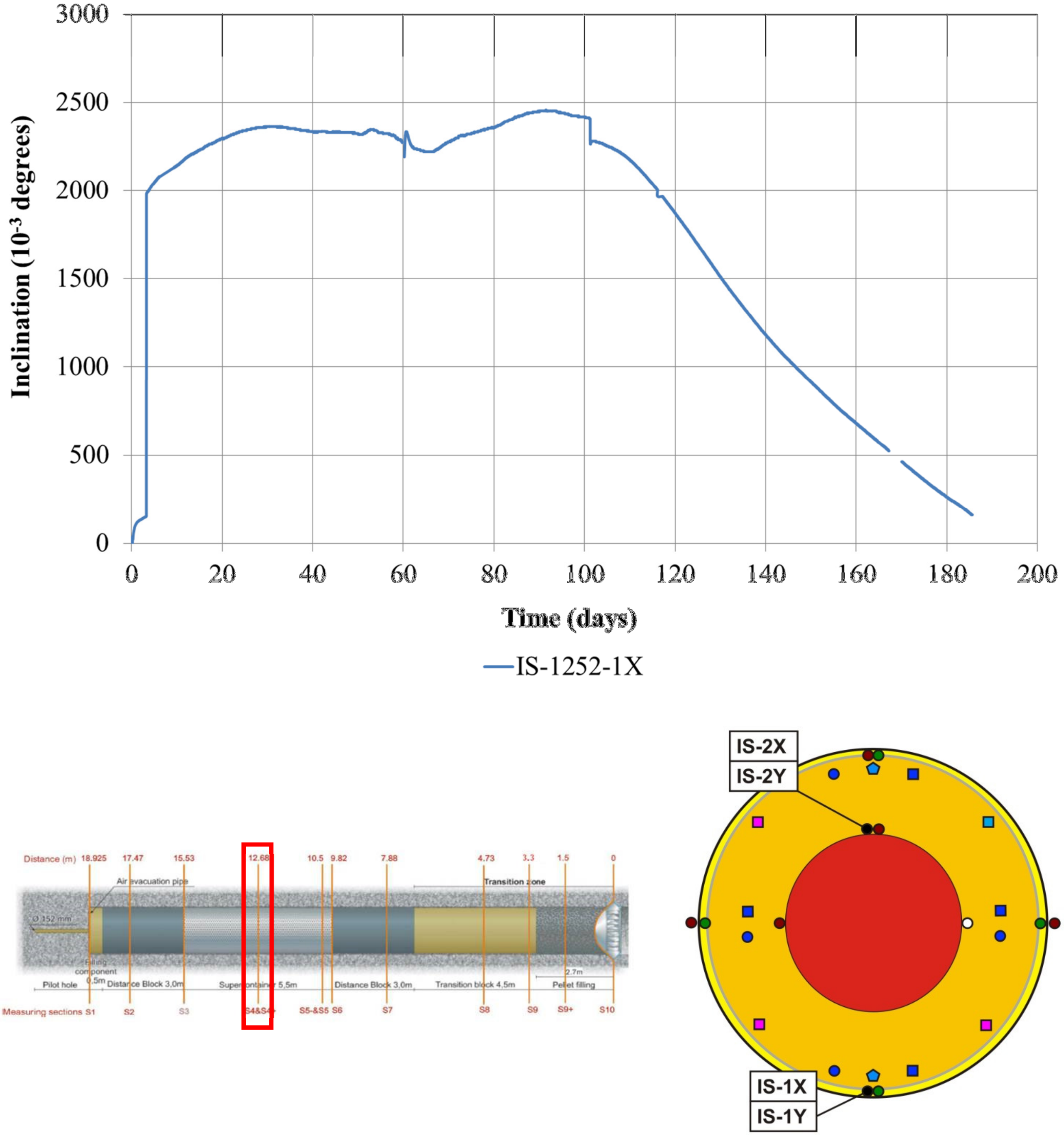


Figure 6-11. *Response of inclinometers at inner Supercontainer positions (in the bentonite block) in drift section 4. A total of two such sensors were installed in this section (bottom-right inset; IS-1 corresponds to IS-1252-1 and IS-2 corresponds to IS-1252-2). Signal is being recorded only from sensor IS-1 along the x-axis. This sensor suggests that the block showed first a sudden rotation to the left (counterclockwise) after 3 days which gradually reversed over 100 to 180 days.*

6.2.6 Displacement

Results from the displacement sensors are presented in Figures 6-12 and 6-13.

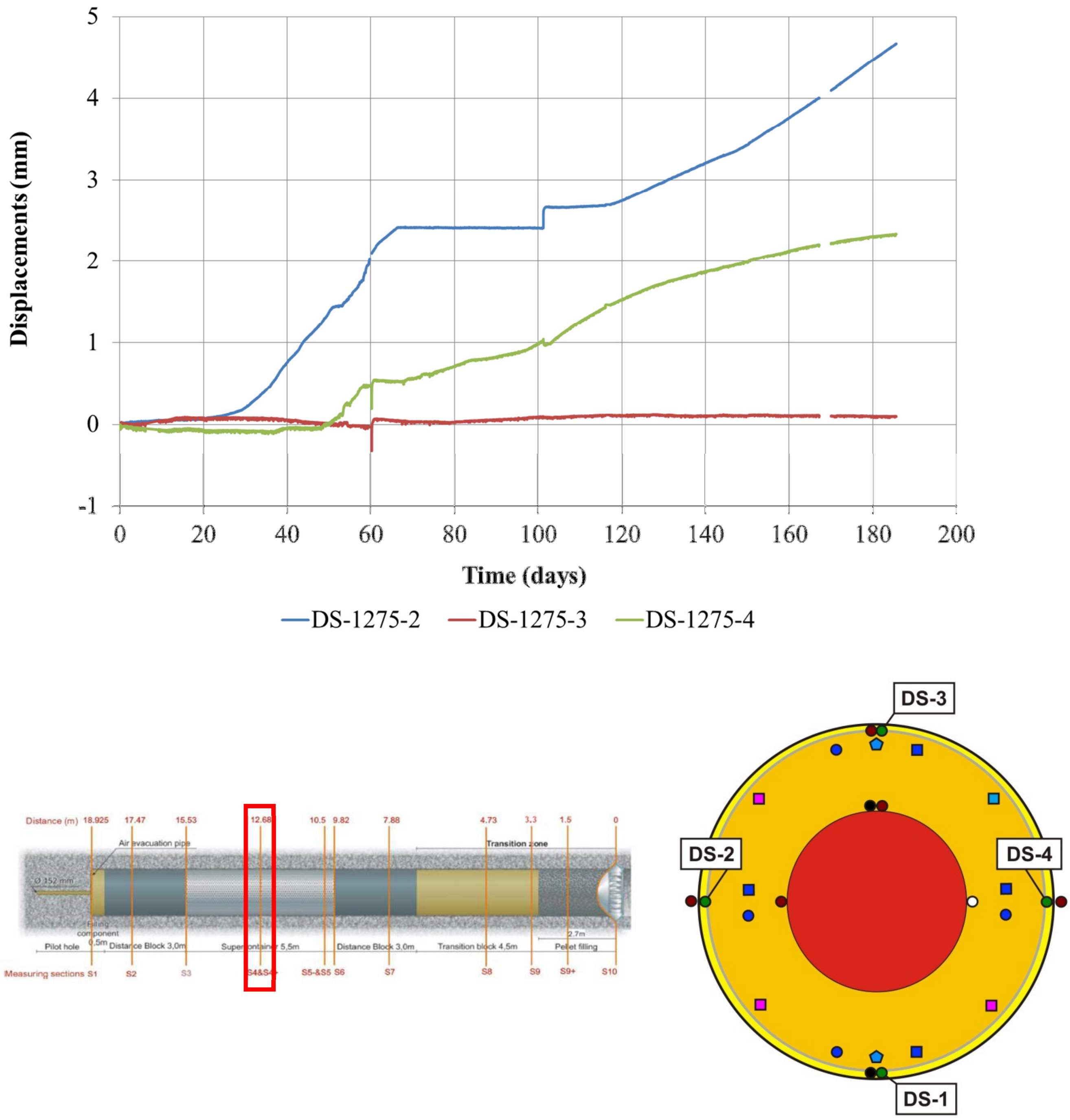


Figure 6-12. *Response of displacement sensors at inner Supercontainer positions in drift section 4. These sensors measure the displacements between the Supercontainer shell and the drift wall. A total of four such sensors were installed in this section (bottom-right inset; DS-1 corresponds to DS-1275-1, etc.). Sensors DS-2 and DS-4 both measured positive displacements from 30 to 50 days onward. Sensor DS-3 did not register any change in displacement. No signal was recorded from sensor DS-1. These sensors are fixed to the Supercontainer and measure displacement with respect to the rock wall. Sensors DS-2 and DS-4 both show positive displacement which may indicate that the Supercontainer moved up or down. The interpretation of these signals is complex because they can be influenced by a variety of different movements.*

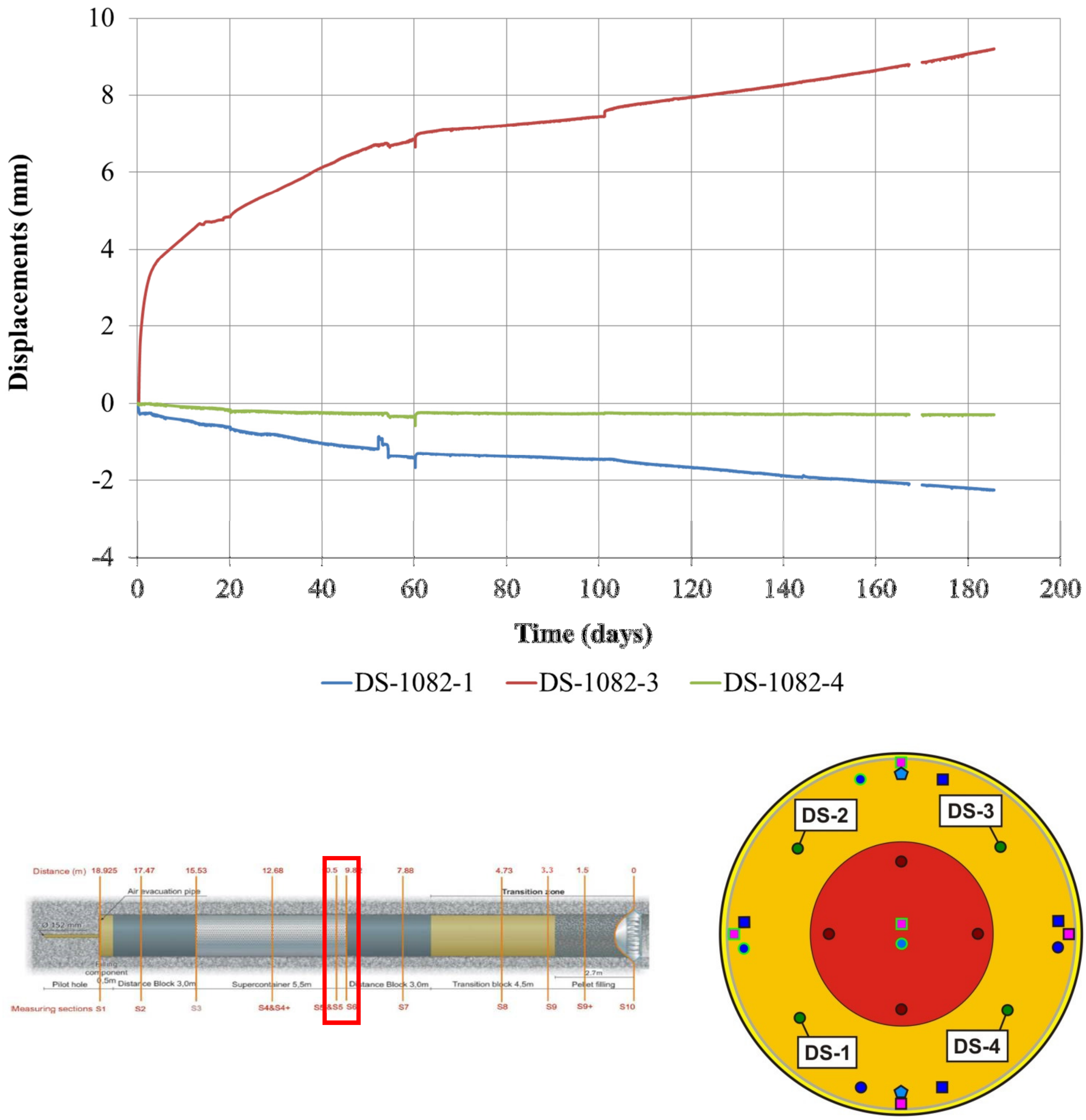


Figure 6-13. *Response of displacement sensors at inner Supercontainer positions in drift section 5. These sensors measure the displacement between the bentonite block and the canister. A total of four such sensors were installed in this section (bottom-right inset; DS-1 corresponds to DS-1082-1, etc.). Sensor DS-3 measured a positive displacement (movement away from the canister) over the course of the test. Sensor DS-1 showed a smaller, negative displacement (movement toward the canister). Essentially no change in displacement was observed with Sensor DS-4. No signal was recorded from sensor DS-2. These signals are difficult to interpret. The block may be expanding more in the upper right area.*

6.2.7 Total pressure

Results from the total pressure sensors are presented in Figures 6-14 to 6-16.

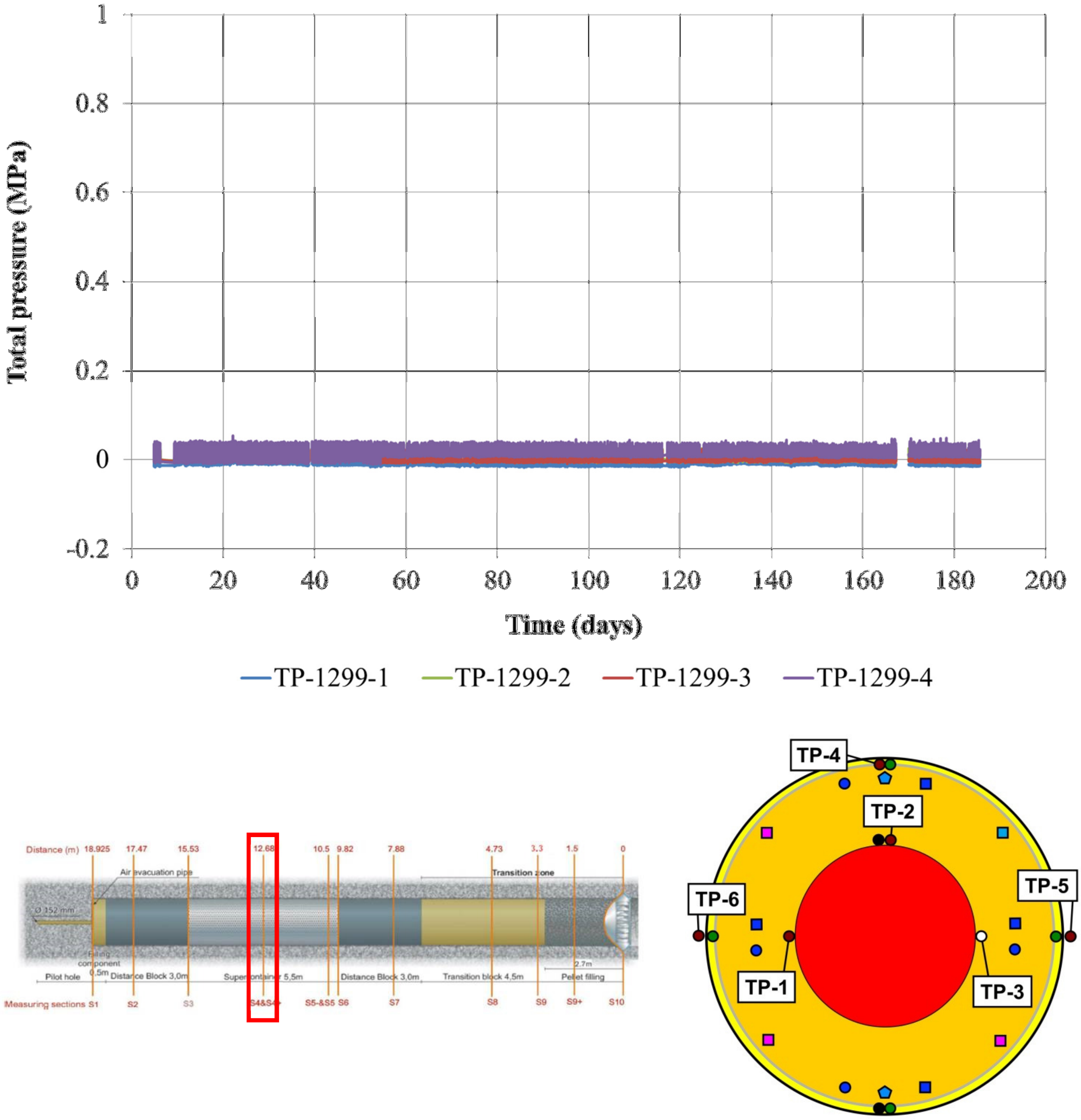


Figure 6-14. *Response of total pressure sensors at inner Supercontainer positions (in the bentonite block at the ring block/canister interface measuring radially to the drift axis) in drift section 4. A total of four such sensors were installed in this section (bottom-right inset; TP-1 corresponds to TP-1299-1, etc.). Only background noise was thus far recorded by these sensors over the course of the test.*

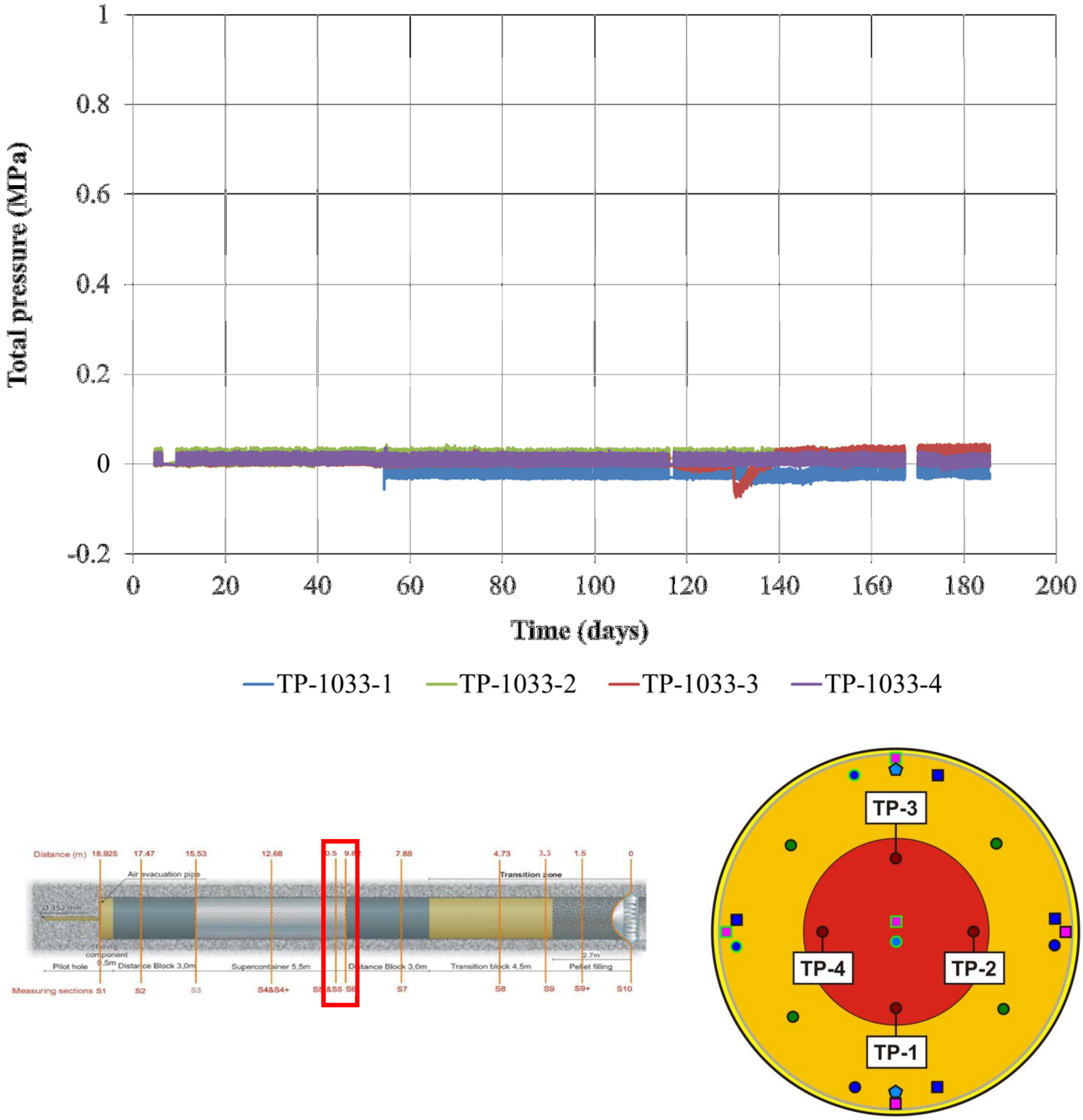


Figure 6-14. *Response of total pressure sensors at inner Supercontainer positions (in the bentonite block at the end block/canister interface measuring along the drift axis) in drift section 5.A total of four such sensors were installed in this section (bottom-right inset; TP-1 corresponds to TP-1033-1, etc.). Only background noise was thus far recorded by these sensors over the course of the test.*

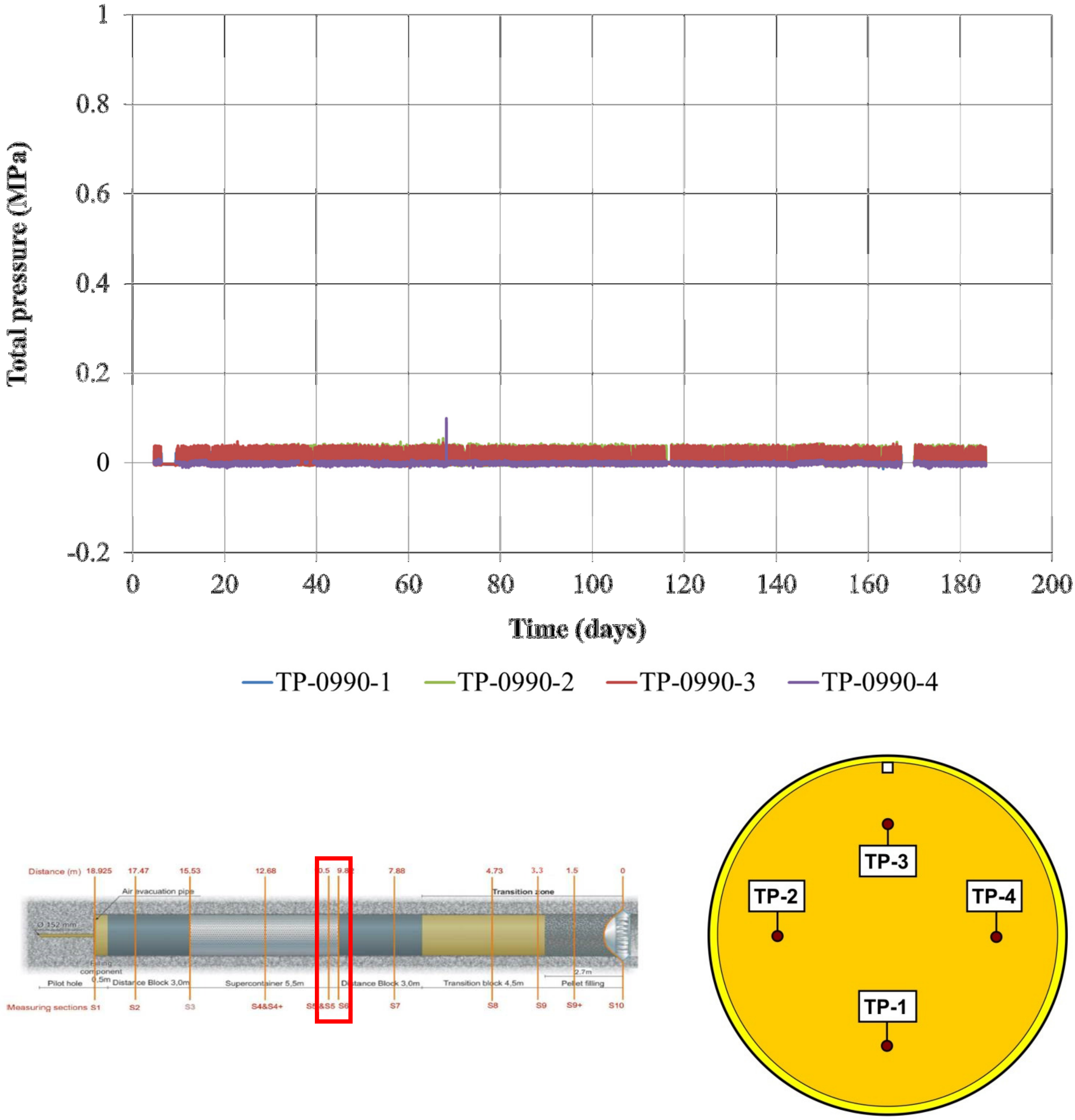


Figure 6-15. *Response of total pressure sensors at inner Supercontainer positions (in the bentonite block at the Supercontainer endplate/distance block interface measuring along the drift axis) in drift section 6.A total of four such sensors were installed in this section (bottom-right inset; TP-1 corresponds to TP-0990-1, etc.). Only background noise was thus far recorded by these sensors over the course of the test.*

6.2.8 Strains

The results from the strain gauge measurements on the Supercontainer surface are presented in Figure 6-16.

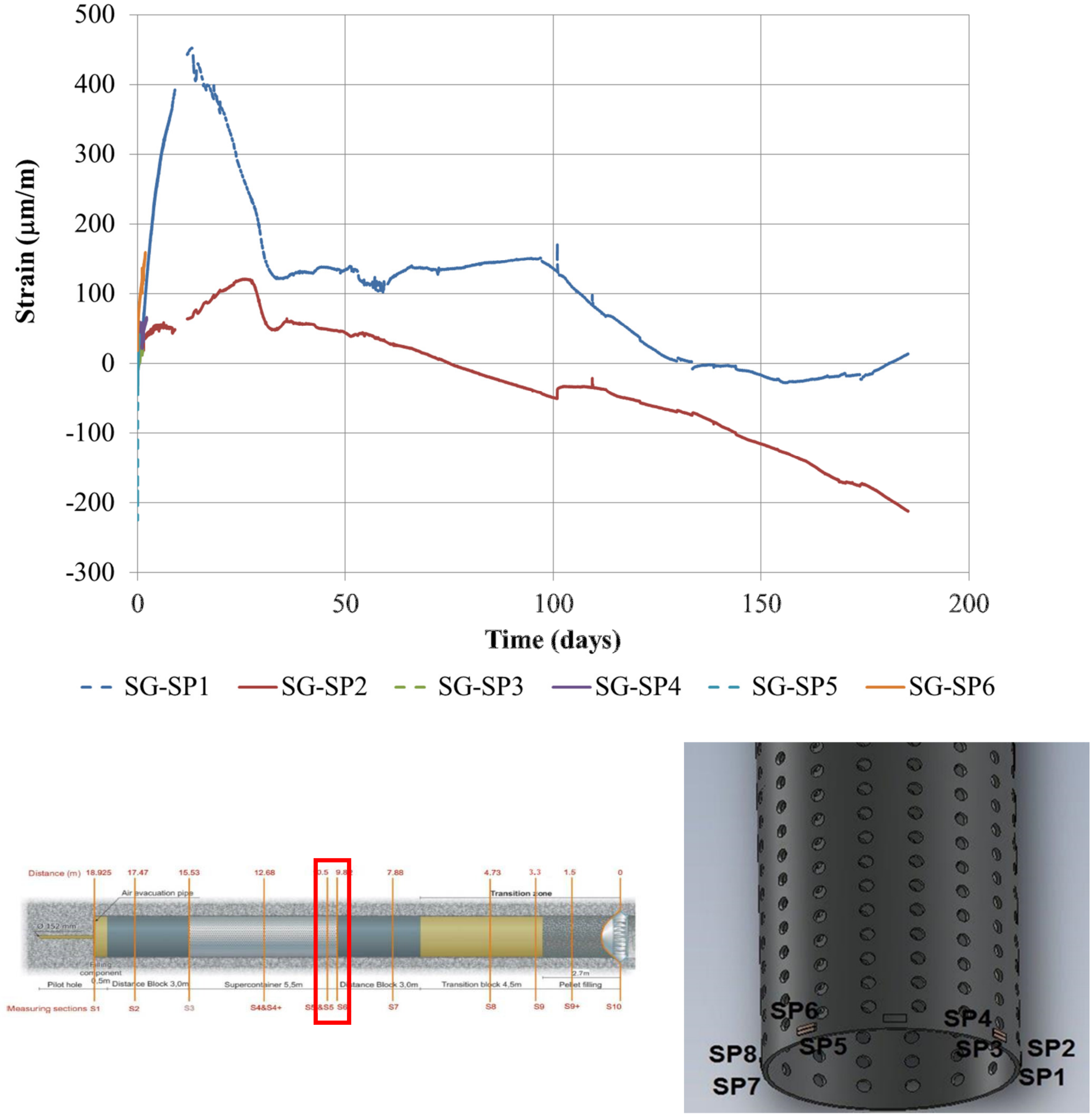


Figure 6-16. *Response of strain gauges to circumferential strains on the Supercontainer surface in drift section 6 (bottom-right inset). Signal was recorded from only two of the strain gauges (SG-SP1 and SG-SP2) beyond a few days into the test. These gauges have not measured any significant strains and show similar behavior from approximately 50 days onward.*

6.3 Outer sensor positions

The location of the sensors and other information is presented in Table 6-6.

Table 6-6. *Numbering and position of outer Supercontainer sensors in drift section 4.*

	Coordinate system ÄSPÖ 96							
Point No.	Easting [m]	Northing [m]	Point Elevation [m]	Drawing label	Sensor code in SICADA	Sensor code in SCADA	Assembly tag label	Manufacturer
15	1910.661	7254.110	-217.551	TP-8	PXK062TP8	TP-1259-8	TP-1259-8	Geokon
16	1910.670	7252.268	-217.547	TP-7	PXK062TP7	TP-1259-7	TP-1259-7	Geokon

6.4 Outer sensor results and comments

Only total pressure measurements are made in outer Supercontainer positions (Figure 6-17).

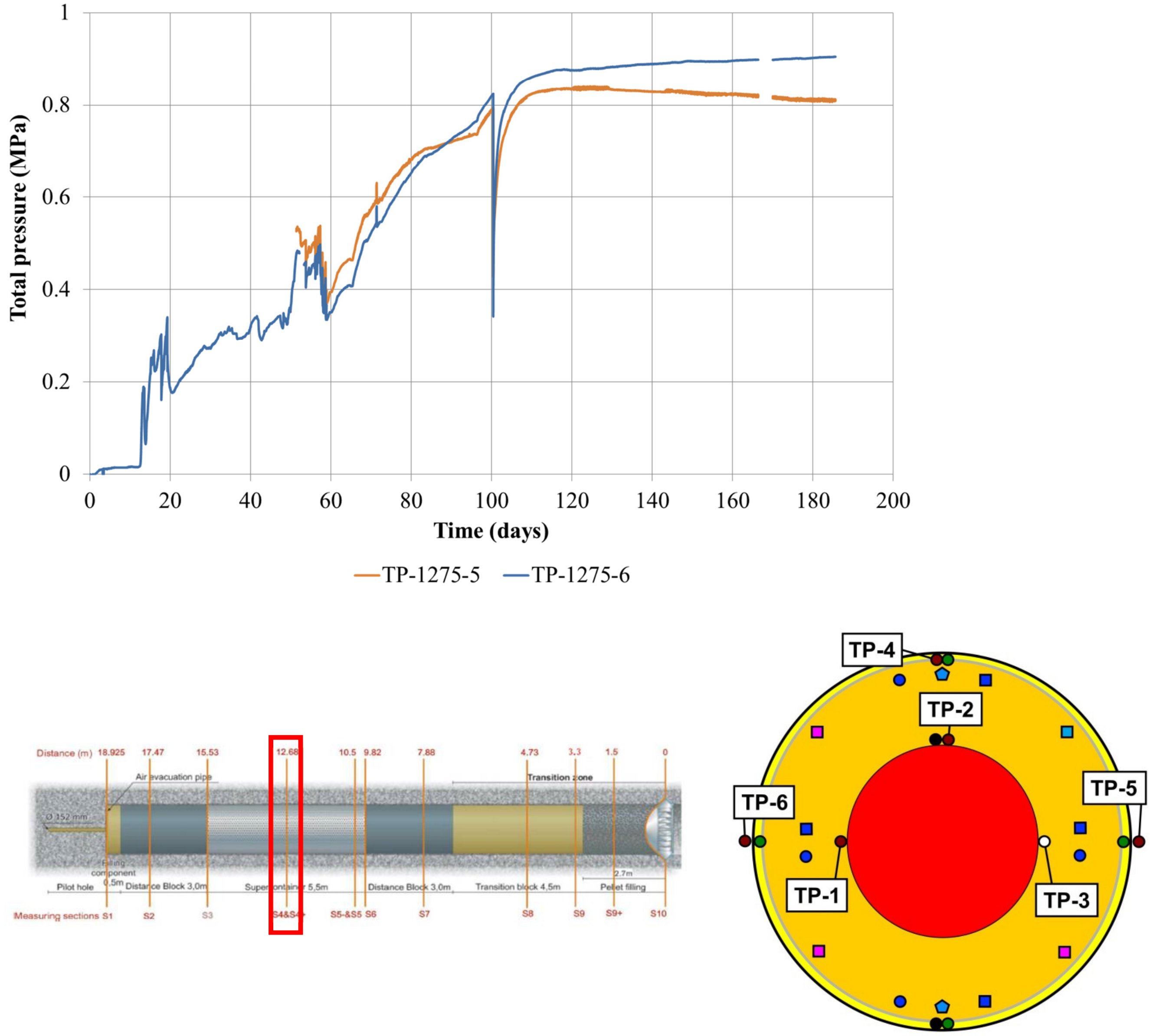


Figure 6-17. *Response of total pressure sensors at outer Supercontainer positions (at the rock wall surface) in drift section 4. A total of two such sensors were installed in this section (bottom-right inset; TP-5 corresponds to TP-1275-5 and TP-6 corresponds to TP-1275-6). The sensors generally show increasing pressure which appears to level off after 100 days.*

7 ASSESSMENT OF THE INITIAL STATE OF THE TEST

7.1 Total pressure

The total pressure measured at the drift walls is similar to the pore pressure measured by some of the pore pressure sensors in the rock and by sensors located in blocks at the gap interface (see Figures 7-1 and 7-2). It is only in drift section 1 that higher pressures (possibly including some component of swelling pressure against the rock wall) are measured. The existence of limited swelling pressure against the plug could be inferred from the strain gauges measurements.

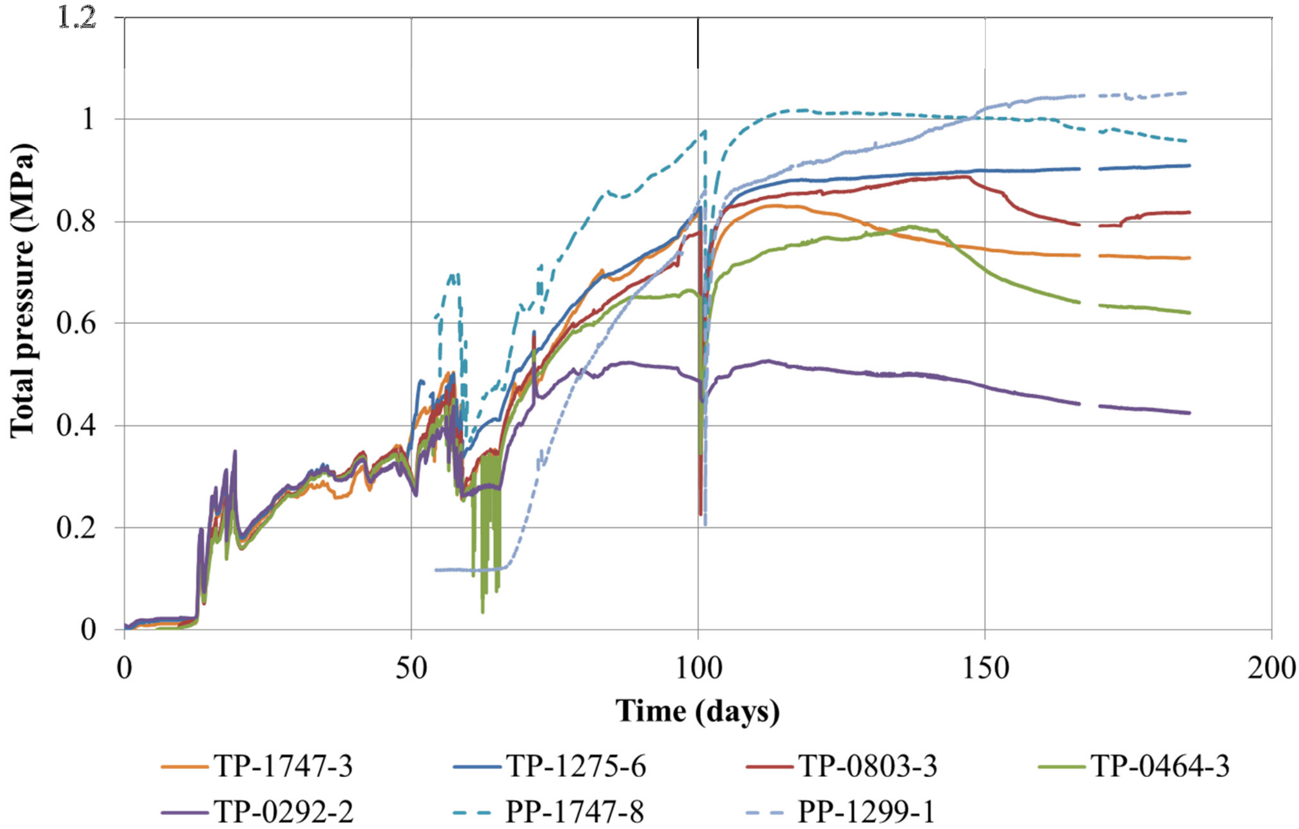


Figure 7-1. *Response of total pressure sensors at outer Supercontainer positions at the rock wall surface in the MPT drift (TP-1747-3 in S-2, TP-1275-6 in S-4, TP-0803-2 in S-7, TP-0464-3 in S-8 and TP-0292-2 in S-9). All of the total pressure sensors are in the highest parts of the tunnel except TP-1275-6, which is located in the gable end of the tunnel. PP-1747-8 is a pore pressure sensor in the rock located in S-2 and PP-1008-5 is a pore pressure sensor in the block located in S-5. All of the sensors display similar evolution measuring pressures between approximately 400 to 1000 kPa at the end of the measurement period.*

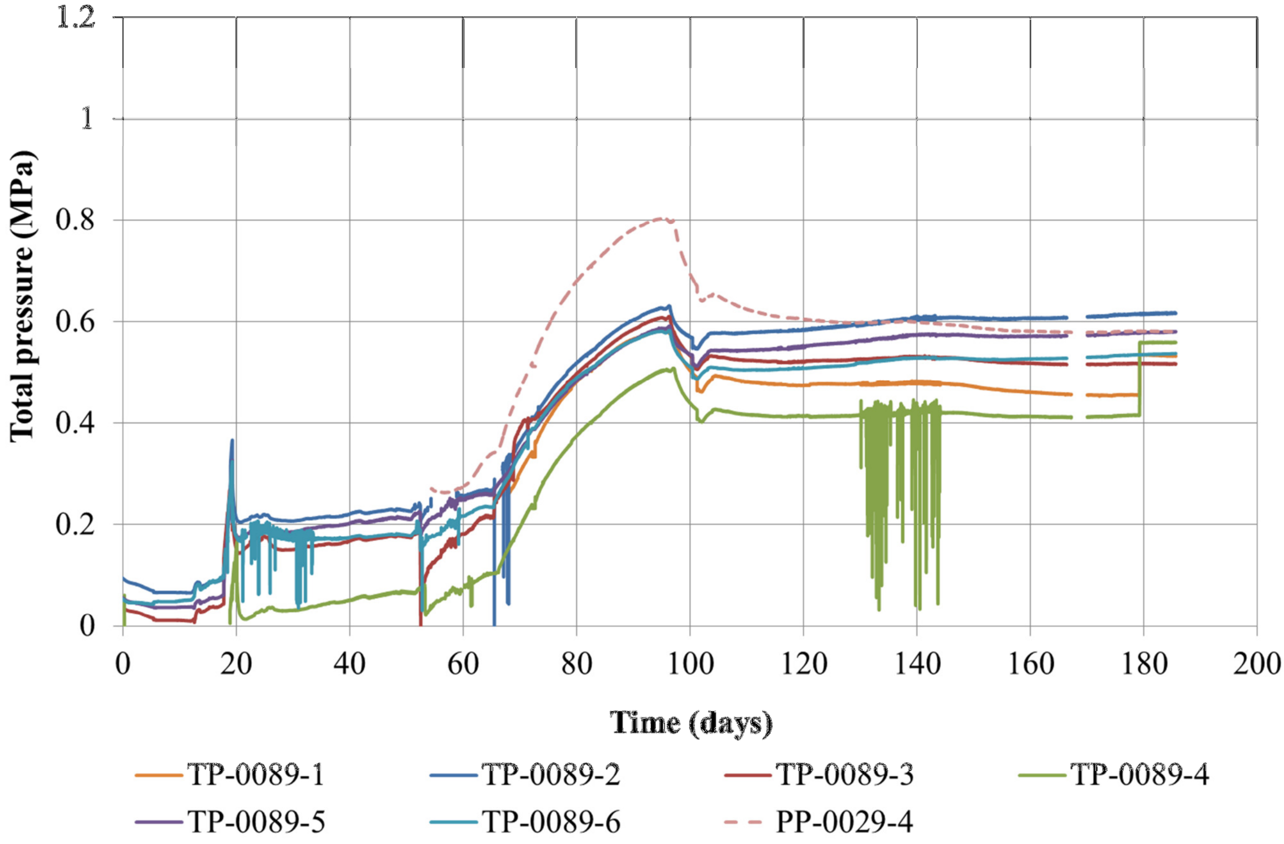


Figure 7-2. *Response of total pressure sensors in transition zone positions in the pellet-filling (S-9+) and the pore pressure measured in S-10 with sensor PP-0029-4. The tendency was the same for all sensors although the values were different. All of the sensors display similar evolution measuring pressures between approximately 400 to 600 kPa at the end of the measurement period.*

The total pressure measured in the drift walls is strongly correlated with pore pressure.

Inflow into the 95 meter drift has been monitored since it was excavated in 2005. Initially, the inflow was approximately 12 l/min but by 2007 it had naturally come down to around 5 l/min. In 2007-2008 the five positions of highest inflows into the drift were grouted. As a result the inflow was reduced to approximately 0.4 l/min (Eriksson and Lindström, 2008). By 2011 the inflow had naturally decreased to roughly 0.25 l/min.

In order to monitor the inflow into the MPT drift, a set of wooden weirs were installed along its length (Figure 7-3). The weirs were placed where the rock conditions allowed it, but they match up quite well with the component lengths. Inflow data is presented in Table 7-1.

Figure 7-3. *Wooden weir used to enable monitoring of groundwater inflow into the MPT drift.*

A summary of the inflow data is provided below:

Full MPT section two months prior to installation	~32 l/day (22.2 ml/min)
Supercontainer section in 2012	~19 l/day (13.2 ml/min)
Inner distance block section in 2012	~8 l/day (5.6 ml/min)
Outer distance block, transition block and pellets section in 2012	~3 l/day (2.1 ml/min)

It can be noted that the inflow into the MPT drift is well below 0.1 l/min which is the KBS-3H limit for emplacement of a Supercontainer.

Table 7-1. *Inflow into the MPT drift during 2011-2013; possible outliers are marked in red. Measurements were limited in 2013 due to development work on the deposition machine.*

Date	drift end-4,07 m (l/min)	drift end-9,07 m (l/min)	drift end-11,17 m (l/min)	drift end-17,87 m (l/min)	drift end-19,27 m (l/min)	drift end-34,47 m (l/min)	drift end-94,47 m (l/min)*
2011-09-20	0,0060	0,0140		0,0240		0,1480	0,2200
2011-09-21	0,0060	0,0230	0,0290	0,0220		0,1460	0,2200
2011-09-22	0,0065	0,0215	0,0215	0,0225		0,1470	0,2100
2011-10-06	0,0062	0,0182	0,0212	0,0217		0,1560	0,2100
2011-10-20	0,0058	0,0200	0,0202	0,0215		0,1500	0,2130
2011-11-08	0,0060	0,0200	0,0205	0,0205		0,1540	0,1980
2011-11-21	0,0055	0,0195	0,0205	0,0210		0,1360	0,1930
2011-12-06	0,0060	0,0194	0,0197	0,0205		0,1330	0,1930
2012-01-10	0,0060	0,0195	0,0195	0,0205		0,1350	0,1930
2012-05-22	0,0056	0,0190	0,0190	0,0205		0,1700	
2012-06-07	0,0053	0,0186	0,0190	0,0193		0,1330	0,1830
2012-06-28	0,0056	0,0190	0,0190	0,0198	0,0202	0,1330	0,1900
2012-07-10	0,0055	0,0190	0,0190	0,0200	0,0260	0,1300	0,1830
2012-09-27	0,0050	0,0162			0,0162	0,1280	
2012-10-17	0,0050	0,0180	0,0180	0,0180	0,0200	0,1260	0,1800

*There is a natrual tendency for lower inflows over time

Date	drift end - 13,47 m (l/min)
2013-08-23	0,0220
2013-08-26	0,0220
2013-09-09	0,0216
2013-09-10	0,0236
2013-09-12	0,0230
2013-09-16	0,0232
2013-09-18	0,0224
2013-09-19	0,0224
2013-09-23	0,0224
2013-09-25	0,0200
2013-09-30	0,0280
2013-10-04	0,0228

Additional inflow measurements along the test section of the drift have been ongoing since 2011 (see Figure 7-4).

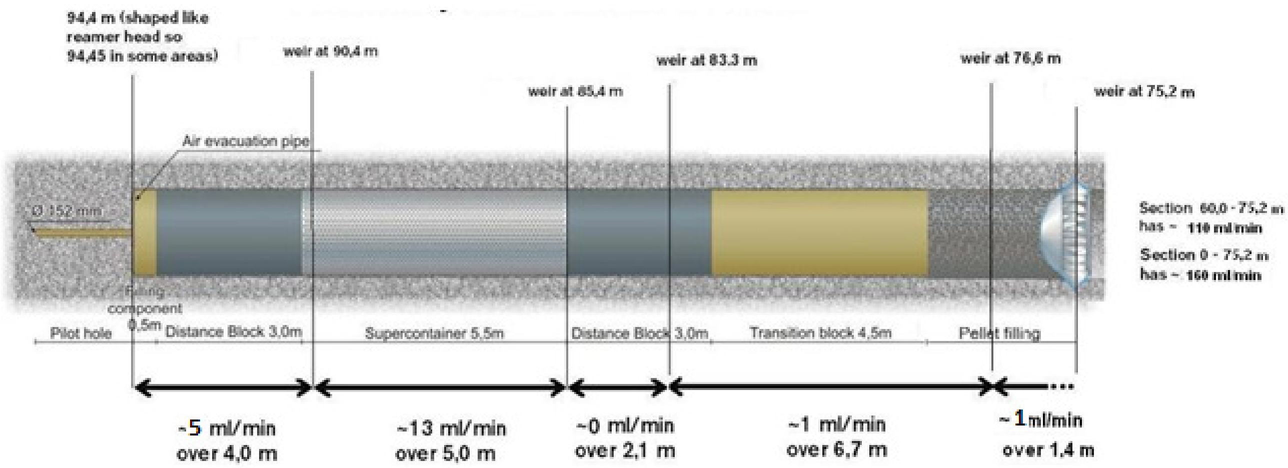


Figure 7-4. *Inflows in different sections of the drift since 2011.*

7.2 Borehole pore pressures

Pore pressure measurements were made in three boreholes drilled into the rock wall in drift section 9. Stable measurements were observed in boreholes 1 and 3 after 40 days but not until 100 days in borehole 2. Pore pressure after 185 days is presented in Figure 7-5.

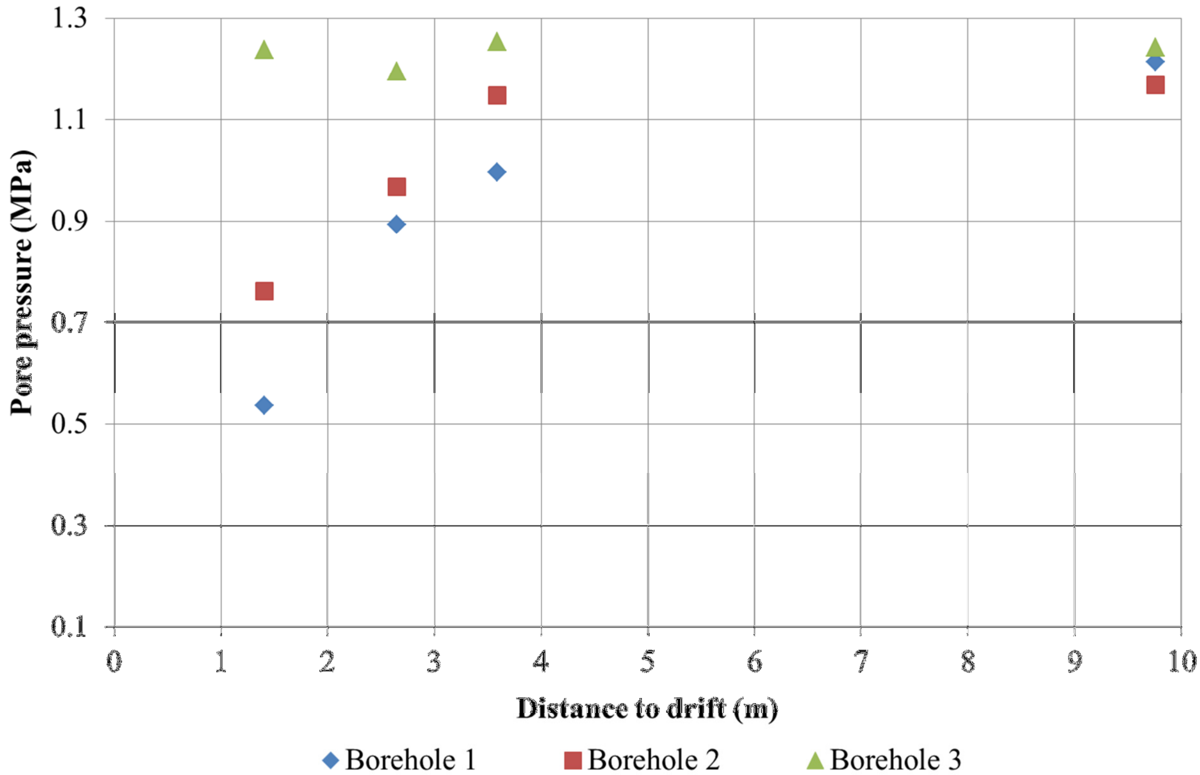


Figure 7-5. *Borehole pore pressures as a function of distance to drift after 185 days. The sensors in boreholes 1 and 2 displayed expected responses; decreasing pressures closer to the drift. The sensors installed near to the drift showed lower pore pressure than sensors inside the drift (PP-1747-8 and 1299-1) possibly due to the initial water filling. The behavior of the sensors in borehole 3 is unexpected and it is possible that the packers have not properly sealed the sensor cavities. Another possibility is that borehole 3 intersects other fractures and the cavities are connected to each other.*

7.3 Saturation

The saturation process can be followed with the capacitive hygrometers (Figures 7-6 and 7-7). These sensors are able to measure the full range of humidity from 0-100% but above 95% the errors are too large and another sensor is needed for measuring at the highest relative humidities. Psychrometers were installed in order to cover the full range.

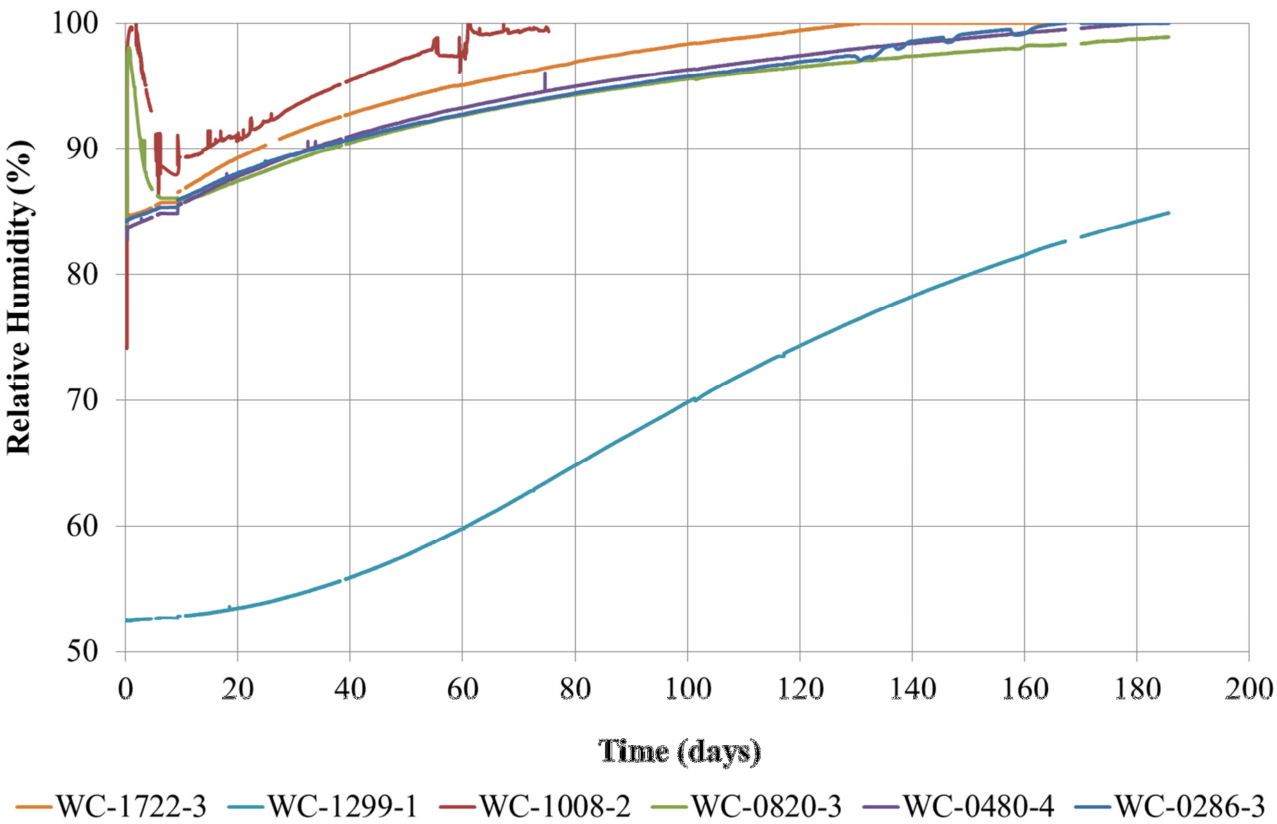


Figure 7-6. *Evolution of the relative humidity in different sections along the bottom of the drift. 1722 corresponds to section 2, 1008 to section 4, 1299 to section 5, 0820 to section 7, 0480 to section 8 and 0286 to section 9.*

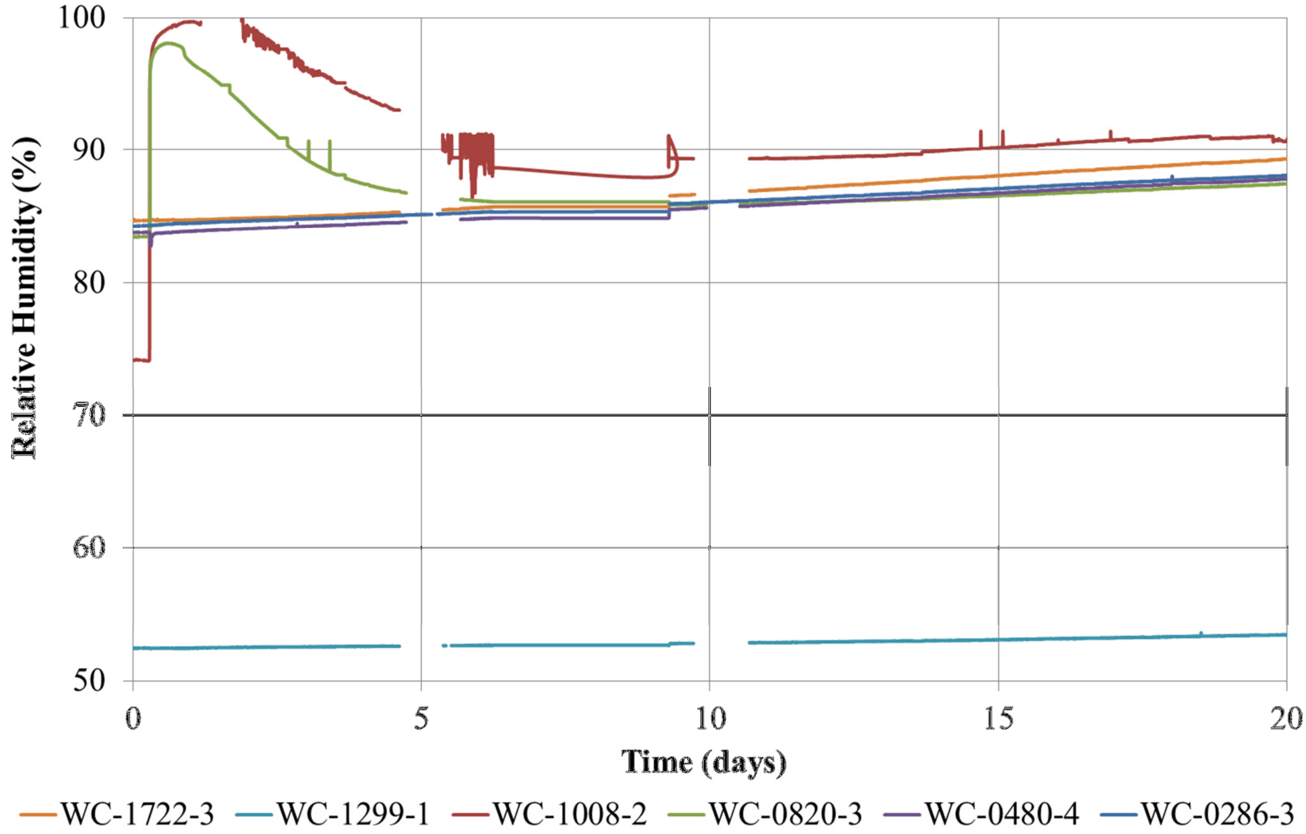


Figure 7-7. *Early evolution of the relative humidity in different sections along the bottom of the drift. 1722 corresponds to section 2, 1008 to section 4, 1299 to section 5, 0820 to section 7, 0480 to section 8 and 0286 to section 9. Sensors WC-1008-2 and WC-0820-3 showed increases in relative humidity due to DAWE which abated, presumably, due to the filling water being drawn away from the sensor positions.*

The initial relative humidity measurements depend on the initial water content of the blocks. Different blocks have different initial water contents as follows:

- Distance blocks and transition blocks: 21 ± 1 %
- Supercontainer end blocks: 17 ± 1 %
- Supercontainer ring-shaped blocks: 11 ± 1 %

As such, the initial relative humidity values measured with the capacitive hygrometers differ as a function of their position.

- Distance blocks and transition blocks: In drift section 2, the wireless hygrometers measured 83.5% and the wired hygrometers measured 84.5%. The wireless hygrometers are located in the inner part of the block. In drift section 7, the hygrometers measured between 81.9 and 83.5% independent of whether they were wired or wireless. In drift section 9, only the wired sensors provided signals at the beginning of the test which were between 84.3 and 83.5%.
- Supercontainer end blocks: In drift section 5 the wired sensors measured 73.9% but the wireless sensors measured 83% (see Figure 7-8).
- Supercontainer ring-shaped blocks (section 4): In drift section 4 all of the sensors are wired and measured relative humidities between 52.2 and 52.8%.

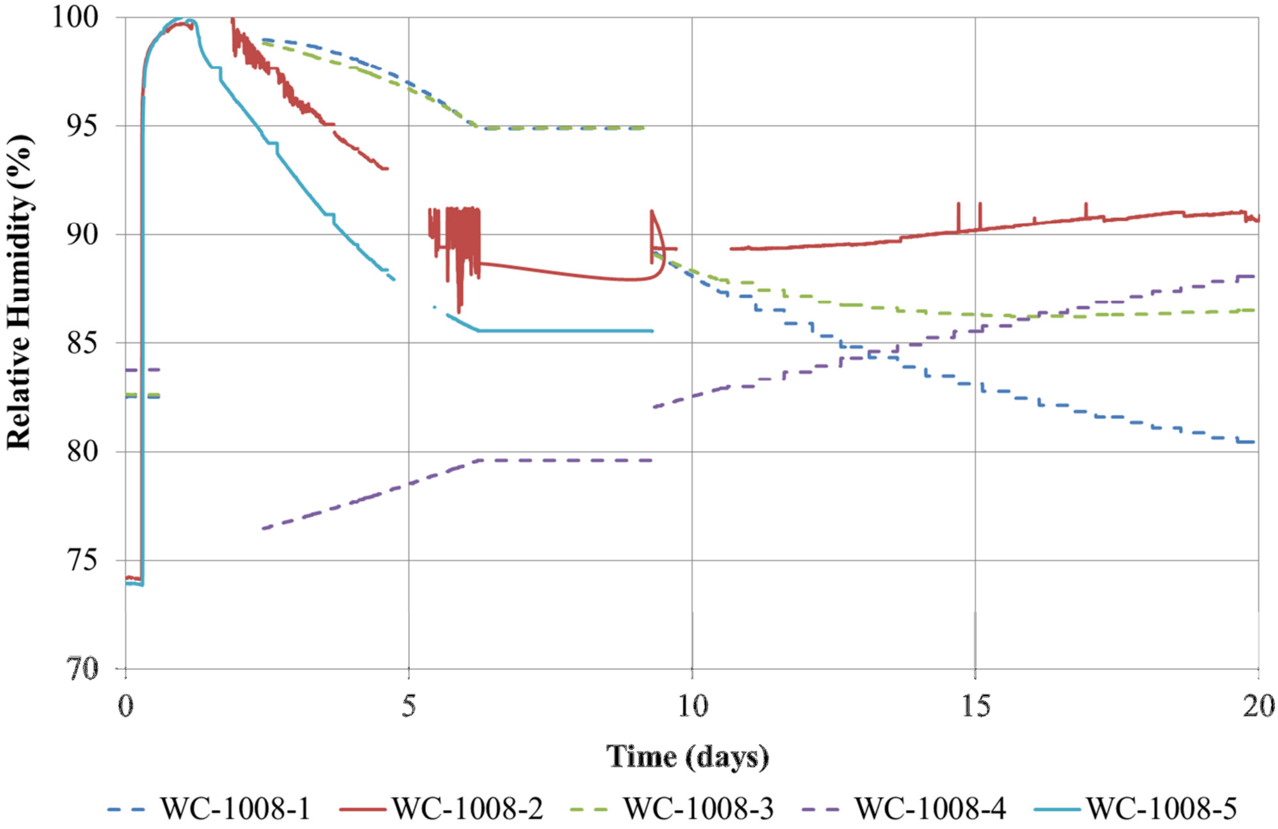


Figure 7-8. *Early evolution of the relative humidity in drift section 5. Sensor WC-4 showed an initial value under 83%. There was a general increase in relative humidity due to DAWE. Drift section 5 has a complex tubing system and it is possible that the water flowed directly to the sensors and was later drawn away.*

The psychrometers started to be in range at different times. It depends more of the position in the block than the section.

The pore pressure sensors need to have access to free water in order to make measurements, therefore (long) delays between the moment the block reaches 100% relative humidity and the moment the pore pressure sensors start reading are not unusual.

The signals from the soil moisture sensors are presented in Figure 7-9. In some cases, signal decreases are observed probably due to initial cracking/expansion of the blocks. After some time, the signals begin to increase due to block saturation. In other cases, the signals are continuously increasing.

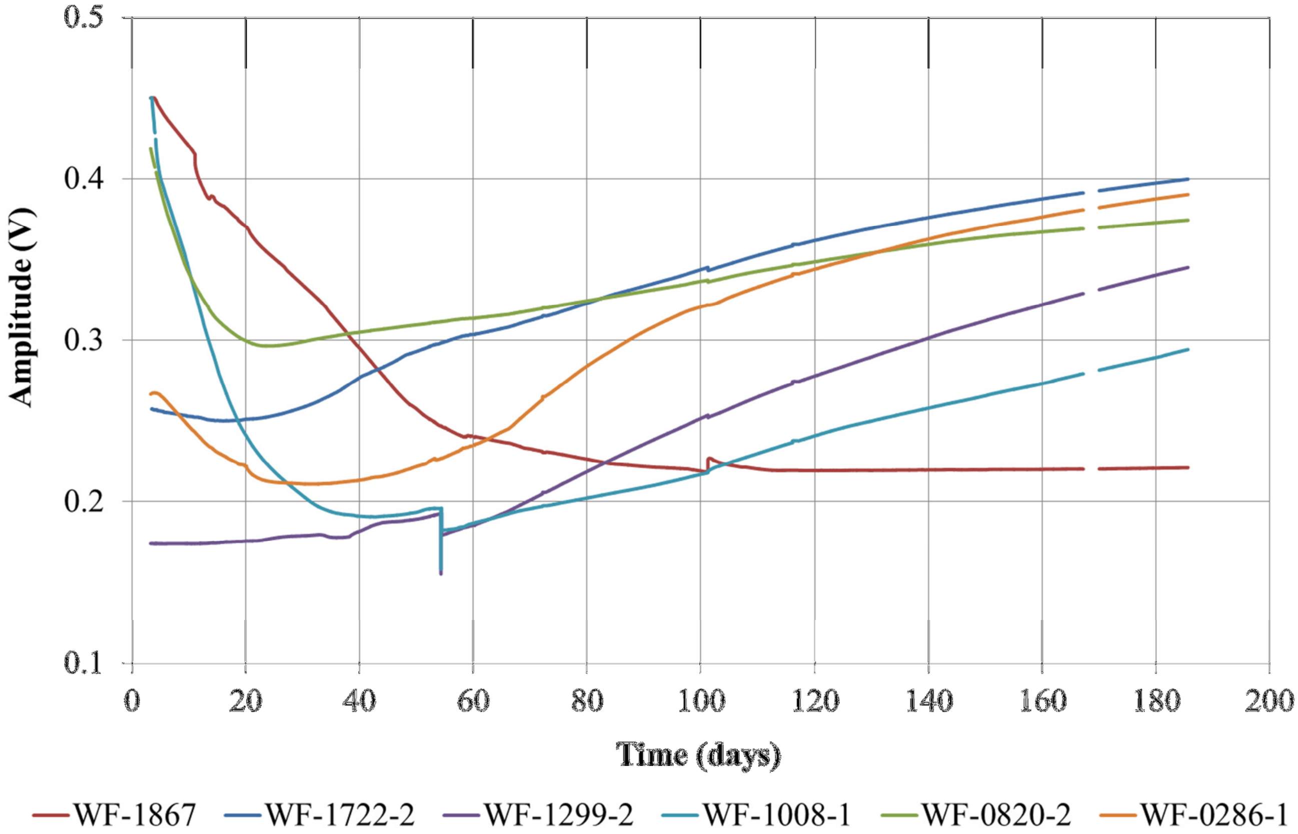


Figure 7-9. *Evolution of the soil moisture sensor signals in different sections. The sensor could be at top or at bottom of the block. The best signal in each section has been chosen. 1722 corresponds to section 2, 1008 to section 4, 1299 to section 5, 0820 to section 7, 0480 to section 8 and 0286 to section 9. Some sensors started measuring at 0.45 V and the signal dropped and increased later. This behavior could be due to water uptake during the DAWE and further drying when the water flowed from the sensors to drier bentonite. The sensor in Section 1 remained dry. In any case, it is clear the sensors indicated that the buffer blocks were wetting. The results must be analyzed carefully as the sensors were installed in powder-filled cavities in the blocks.*

7.4 Movements

An assessment of the movements of the different components may help to better understand the system behavior as well, especially if there is any asymmetry in the saturation process.

The displacements measured on the plug face were too small to be accurately measured with the installed sensors. The strain gauges on the plug face did measure increasing levels of strain.

The sensors for measuring displacements in Supercontainer have a range of ±25 mm. This range may be too small when taking into account the installation process. The initial measures in DS-1082-1, DS-1082-4 and DS-1275-4 were more than 20 mm and DS-1275-3 more than 25 mm. If the sensors are out of the range, it is possible the signals are no longer linear with the displacements. This issue can be checked after dismantling and the sensors can be recalibrated if necessary. The displacements measured by sensors DS-1275-2 and DS-1275-4 were contradictory. The measured displacements could be due to movements of the sensors within their original block positions rather than any displacement of the Supercontainer itself.

The sudden rotations indicated by the inclinometers in very early stages could be due to adjustments of the blocks due to swelling once the gap was water filled.

7.5 Strains

No significant or abrupt strains on the Supercontainer were measured. However, such strains were measured only near one end of the structure and signal was recorded from only two of the strain gauges beyond a few days into the test.

The strains measured on the plug complement the measures from the total pressure sensors and from the displacements sensors. Unfortunately, measurable signal was detected only with the strain gauges. The strains are an indirect measure of the pressures against the plug. It is possible to estimate pressure values from the measured strains (Bendito and Pintado, 2014).

8 WIRELESS SYSTEM STATUS

The wireless transmitters were encapsulated in Äspö on October 2013. After installation (Figure 8-1), nodes 3 to 7 were functioning and nodes 1 and 2 were not. Node 1 has a RS-485 cable for sending data to the MP-40 unit, so this node does not have wireless transmission problem. Receivers 2 and 3 were also functioning.

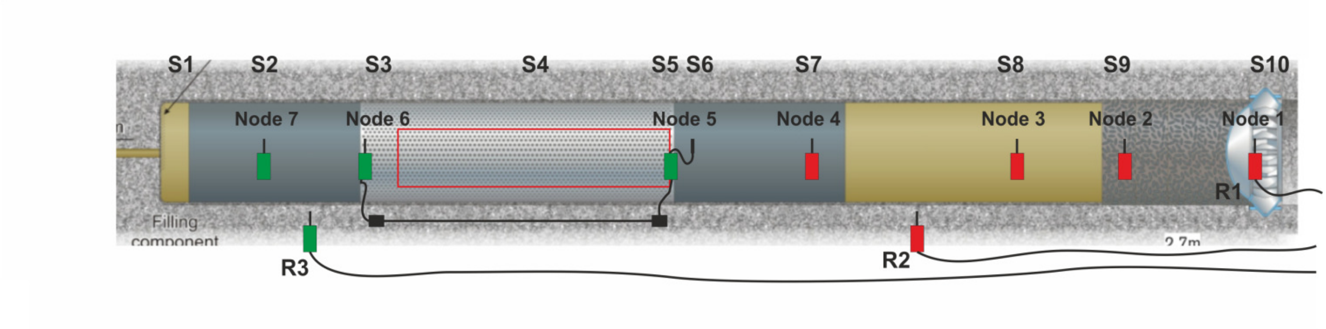


Figure 8-1. *Location of wireless transmitters (or nodes) and receivers in MPT experiment (red-colored instruments correspond to those from which signal was lost after DAWE).*

Nodes 3 and 4 failed on December 7, 2013 at 22:25, a few hours after filling the gap and the pellets with water. The reason could be due to the difficulty in transmitting wireless signal through water but only the gap was filled with water and the nodes were sending signal for some hours after filling the gap.

Receivers 1 (R-1) and 2 (R-2) were inspected in January 2014 and the conclusions were that relay 1 did not suffer any electrical short, so the problem lies in the receiver/transmitter itself. Receiver 3 (R-3) was working well.

An attempt was made to recover the signal from the nodes by inserting an antenna through the pellet-filling hole (Figure 8-2) on the plug face and connecting it to a new external receiver. Two antenna lengths were checked using two different rods (0.85 and 1.2 m length). No signals were detected. The 1.2 m length antenna was left in place and the hole was resealed. Additionally, two boreholes (200 mm deep and 20 mm diameter were drilled into the rock near the plug face (see Figure 8-2 for locations) and antennas were inserted. These antennas were also connected to the external receiver. Signals were detected with limited success.

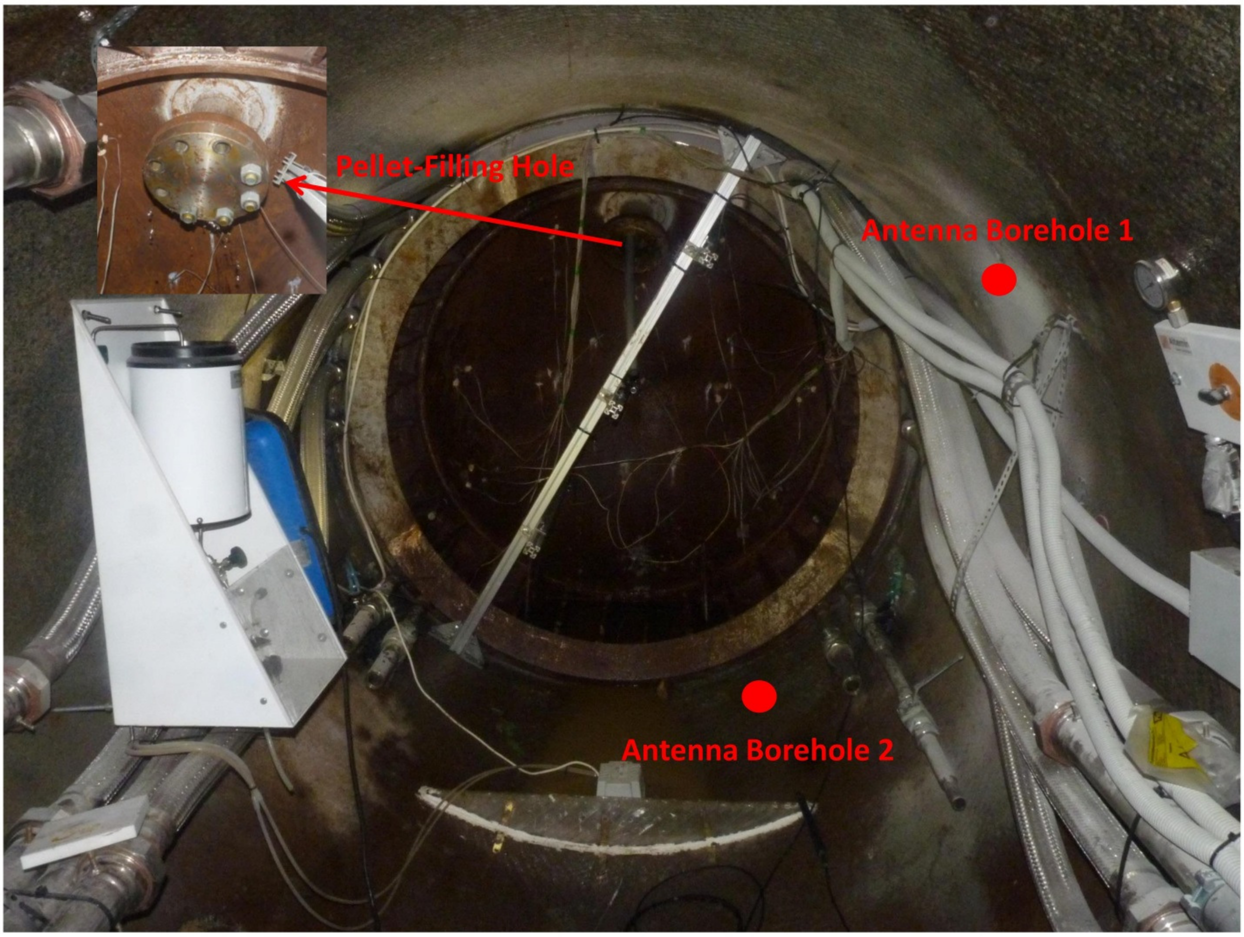


Figure 8-2. *Photographic image of plug face showing locations of pellet-filling hole (through which an antenna was inserted) and additional antenna boreholes.*

Nodes 5, 6 and 7 were working and sending signal for 103 days (until 20.03.2014). Node 4 started to send signal on 07.03.2014 but also stopped on 20.03.2014. The signals from the capacitive hygrometers and pore pressure sensors became constant from 7.03.2014 in sections 2, 5 and 7.

Node 2 started providing signal on 29.01.2014 and stopped on 05.02.2014. The displacement sensors DB-0286-1 and DB-0286-2 gave constant signals. Sensor WC-0286-1 provided constant signal. Sensor WC-0286-2 may be malfunctioning.

The fuse of the MP-40 failed on 20.03.2014. The fuse was changed but the unit was not functioning correctly. It was sent to Aitemin and returned to Äspö after repairs. However, no signal is currently being recorded. The reasons for this malfunctioning are not evident. The battery capacity should be sufficient because the transmission frequency was 12 hours and the battery duration should be four years at this frequency. R-3 was working but is now disconnected due to short-circuiting.

9 CONCLUSIONS

The total pressure sensors in the rock, the pore pressure sensors in the rock, the capacitive hygrometers, the psychrometers and the soil moisture sensors appear to be functioning adequately.

The total pressure sensors in the rock are measuring some hundreds of kPa and their signal evolution is similar to that of the pore pressure sensors in rock suggesting that these sensors are not measuring bentonite swelling pressure except in section one, where the sensors are closer to the blocks and are in contact with the bentonite, measuring swelling pressure as well.

There are no significant differences between distance blocks, blocks inside the Supercontainer and blocks in transition zone both in terms of the total pressure development in the rock and in the saturation process measured by the capacitive hygrometers, psychrometers and soil moisture sensors. The only differences are due to the position of the saturation sensors inside the blocks: the closer sensor is to the gap the faster is the saturation process (as expected). Some unexpected rapid saturation recorded by a few of the sensors at the beginning of the test could be explained by to the presence of cracks or damage in the blocks leading to direct contact between the sensors inside the blocks with the gap. This contact was then lost when the bentonite swelled, thus sealing the different flow paths.

There are clear differences in the evolution of the total pressure measurements when comparing the pellet filling and the bentonite blocks. This is attributed to the different behavior of the pellet filling when swelling.

The pore pressure sensors in the buffer are not measuring positive pressures yet. This is due to the long time necessary for filling all the experiment gaps with water, including the bentonite pores and the sensor cavities. The bentonite has an extremely low hydraulic conductivity and the saturation of the pores and sensor cavities will likely require some years.

The sensors for measuring movements in the blocks and in the Supercontainer have provided some information but due to complexity of the potential movements of KBS-3H components, it is difficult to analyze the data. The installation of the KBS-3H components is quite complex and the sensors could remain over-ranged after the installation. The installation of higher range sensors could avoid this problem in future tests.

The strain gauges are a novel sensor for “in situ” tests in nuclear waste management. They can provide useful information from the early stages of the test but it is clear that the corrosion of the plug and the saturation process in the Supercontainer will be problematic for using these sensors in long term tests if they cannot be properly protected.

The extensometers in the plug have not measured any displacement yet because the inner total pressure is still very low. Extensometers with lower ranges in parallel with higher range sensors could be useful. In this case, a deep study about the displacements expected in the plug should have been done before the dimensioning of the test. The tool proposed in the next chapter for plug pressure calculation could be useful in the future.

The wireless system was working as intended at the very beginning of the test. Although the transmitters were properly encapsulated and their batteries calculated to run for 4 years at a measuring interval of 12 hours, most signals were lost during the early stages of the test. The potential advantages offered by this kind of system justify the attempt made.

The main conclusion gathered is that higher redundancy is needed. For instance, by including additional receivers or even just antennas connected to redundant receivers. In this sense, the existing memory card inside the transmitters for saving the data could provide part of the data lost when dismantling the test.

For future experiments, transmitter operation could be improved if they collect signals over certain periods of time and send them once per week or per month, thus decreasing the battery consumption and therefore extending their life. As the measuring frequency of the transmitters can be remotely changed, the best approach could be to set a relatively high frequency (every 10 minutes for example) for adjusting and measuring at the early stages and then change to a lower frequency in order to preserve the duration of the battery. If the transmitter does not receive any order from the receivers during a certain period of time (one day for example), the measuring period could be increased to 12-24 hours automatically.

10 FUTURE ACTIONS

The gas pressure sensors in the gap have a range of 250 kPa. In order to be able to measure the pore pressure in gap and to discriminate the swelling pressure from the water pressure, the sensors will be changed to others with higher range.

The datalogging system will be reviewed. There are some sensors which are not reading and others with strange behavior that should be checked, for instance, it could be possible to recover the total pressure sensors in blocks (the ones manufactured by ÅF/Geokon).

The sensors measuring displacements on the plug face could be changed to those with lower range.

The pressures measured in the boreholes of section 9 should be compared with pressures measured separately in other boreholes close to the drift if such data exists. It should be taken into account that the boreholes in section 9 are close to a drain (i.e., the drift) and it is possible that these pressures may not follow the water pressure evolution of other boreholes which lie farther away.

The strain gauge data could be used to estimate the inner pressure on the plug face (Figures 10-1 and 10-2). It is necessary to develop a computational tool for performing such estimates but this tool can be used for future analysis.

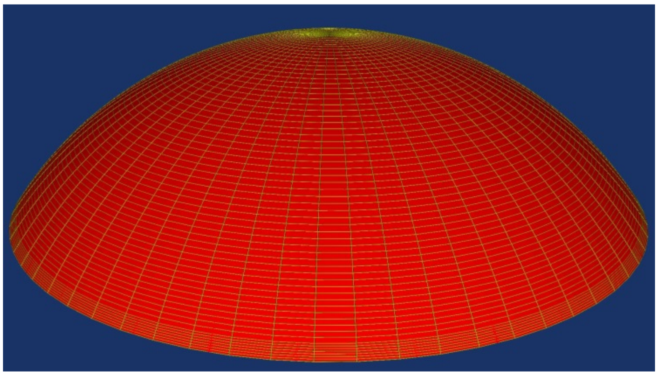


Figure 10-1. *Plug discretization.*

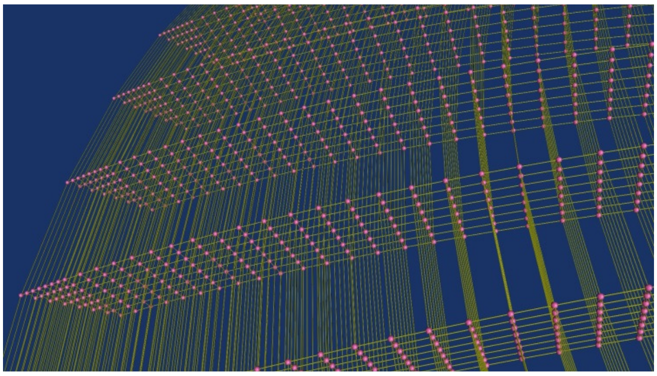


Figure 10-2. *Detailed mesh.*

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