Completion of borehole ISC-SB.15.001

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1. Introduction

Swiss Environment SA and Polymetra GmbH were contracted to complete borehole ISC-SB15.001 with a multi-packer system based on grout-packers. Three test sections filled with quartz sand were isolated with three grout-packer, each filled with a different grout mixture.

The borehole ISC-SB15.001 has a length of 18.2 m and is inclined 15° from vertical. It was completed in the period of April 11 – 13, 2016.

A sketch of the completed borehole is presented in Appendix 1. Pictures showing different steps of the installation can be found in Appendix 2, and the installation schedule is given in Appendix 3.

2. Design and installation of multi-packer system

2.1. General design

The packer system is built with a ½"-stainless steel tube in the center. The originally 6-m long tubes had been cut to 1-m and 2-m long pieces with threads on both ends. Fittings of 34 mm length were used to combine the tubes.

Two vibrating wire pressure sensors were placed inside each of the grouted sections, one two meter above the bottom end and the other two meter below the upper end of the 5-m long packers, thus leaving a 1-m section between them.

All three sand filled sections are accessible by pressure measurement lines. The central stainless steel tube acts as a pressure measurement line for the lowermost section at the bottom of the hole. For this is the reason pipe sealant was carefully applied to the connecting threads of the tubes and fittings during installation. The central and the top sand sections are accessible through 6 x 4 mm polyamide tubes.

All three grouted sections were filled from bottom up via separate injection lines made from black 20-mm PE-tubing.

Disks made of Delrin were used as centralizers to hold the stainless steel tube in the center of the borehole but also as packer ends.

Geotextile sleeves were used for the bottom and the central section grouted sections ("geotextile grout packer"), whereas the top section was filled in the open borehole.

2.2. Preparation of lowermost test section

The bottom section of the borehole was filled with quartz sand which was poured into the hole using a funnel (fig. 1.). The volume to reach a thickness for the sand bed of 1 meter was roughly estimated. The level of the sand surface was then checked using a water level meter as a plumb and more sand was filled in until the desired level had been reached.

2.3. Installation of the bottom packer and the central interval section.

For the bottom packer a Delrin disk was attached on a short ½" tube of 10cm which was connected to the lowermost 2-m long stainless steel tube. The connecting fitting prevented the disk from sliding up. Wrapping 2-3 layers of tape around the tube prevented any leakage of grout through the central hole of the disk. A 1-m stainless steel tube was connected on top of the 2-m piece and the lower pressure sensor in the bottom packer was attached with tape to the fitting connecting these two tubes. The black injection line was attached to the stainless steel tube close above the bottom packer end after it was fed through all upper disks and laid out on the tunnel floor.

Then the geotextile sleeve was pulled from the bottom up. Its lower end was attached with cable ties and wire to the bottom disk (fig. 2).

The next 2-m tube was placed on top of the 1-m tube and the upper sensor was attached at the fitting using adhesive tape (fig.3). The geotextile was stretched out and fixed to the upper disk which had been placed above the next fitting. The injection line was sealed again with adhesive tape and cable glands were used to hold and seal the sensor cable in the Delrin disk. With this the bottom packer was completed.

The polyamide tube for pressure measurement of the central interval section was attached to the stainless steel tube shortly above the upper end of the bottom packer, fed through all upper disks and laid out on the tunnel floor.

The geotextile had been cut to an overall length of about 6.5 m. This excess length, allowed making up the central sand section. The geotextile sleeve was stretched over the 1-m tube connected above the bottom packer and fixed to next disk. This section was carefully lowered into the borehole after the next 2-m was connected and the system had been secured with a chain hoist. Following that, the 1-m long section above

the bottom packer was filled with sand, the geotextile preventing the sand to fall out and squeeze into the gap between borehole wall and packer end disk (fig. 4 and 5).

2.4. Installation of the central packer and the top interval section.

The top disk of the central interval section was placed below the fitting and the bottom disk of the central packer just above the fitting connecting the 1-m tube with the next 2- m rod as shown in fig. 6.

The central packer was installed the same way as the lower one, with two pressure sensors two meters above the bottom end and two meters below the upper end, leaving a distance of one meter between them. The injection line was again attached to the central tube near the bottom end of the packer. All four sensor cables and the pressure measurement line of the central interval section were sealed with cable glands in the disk at the upper packer end whereas adhesive tape was used for sealing the two injection lines. The same technique had been used in the lower disk for sealing the cables and lines passing from below. Rubber bands were used to compact the geotextile sleeve in order to reduce the friction during lowering of the system (fig. 7).

The top interval section and the top grouted section were designed without geotextile sleeve. The interval section was prepared between the top disk of the central packer and a disk at the bottom of the top grouted section. The injection line for the top grouted section was passed through a hole in this disk but it was not attached to the central tube. Quartz sand was filled into the top section through the injection line using a funnel at its upper end after the entire system had been installed in the borehole and was seating on the bottom sand filled section. The injection line was vigorously moved up and down while filling in the sand until the interval section was completely filled. Only then the injection line was pulled further out with the bottom end finally placed above the disk in order to fill the top grouted section from bottom up.

2.5. Top grouted section

Three smaller disks with larger holes for the three grout injection lines around the center and peripheral holes for holding the pressure measurement lines and the cables were fixed on the central tube along the top grouted section. They had the function to spread all lines and cables and to prevent formation of not grout-filled channels that would lead to zones of higher permeability. Their diameter of only 60 cm allowed proper grouting along the borehole walls.

3. Grout injection

One of the goals of this completion was to test grout mixtures with three different additives. The grout was based on CEM1 42.5 cement with:

- Sikament 12s and Intraplast EP
- Opalit
- Bentonite

All grout mixtures were prepared in a mixer which was connected directly with a grout pump. Water, cement and additives were thoroughly mixed and then pumped through the injection line which was attached with a hose coupling to the pump outlet valve. A maximum volume of 40 l of grout mixture could be prepared per batch. All mixtures were prepared in two batches as additional grout samples for laboratory tests was required. A scale was used to weigh the components. The second batch was always prepared with half the masses used for the first batch.

3.1. Grouting of bottom packer

The bottom packer was prepared with Sikament 12s, a superplasticizer for concrete that allows preparation of grout mixture with lower W/C-factor (mixture of higher density). The other additive used in this mixture was Intraplast EP which has expansive properties to increase the sealing effect and to avoid formation of crack during hardening.

No difficulties were encountered to prepare the mixture with Sikament 12s and Intraplast EP.

The following grout mixture was used for the bottom packer:

Packer	Mix Nb	Cement (kg)	Water (liter)	Additive	W/C factor
1 (bottom)	1	50	20	Sikament 12s (1%) 0.5kg Intraplast EP (1%) 0.5kg	0.4
	2	25	10	Sikament 12s (1%) 0.25kg Intraplast EP (1%) 0.25kg	0.4

3.2. Grouting of central packer

Opalit was used as an additive for the grout in the central packer. Opalit is ground Opalinus clay. It has sealing properties as it consists of about 70% of clay minerals including illite/smectite mixed-layer minerals which have swelling properties. The grout prepares with Opalit had the highest W/C-factor of all prepared grout mixtures.

No difficulties were encountered to prepare the mixture with Opalit.

The following grout mixture was used for the central packer:

Packer	Mix Nb	Cement (kg)	Water (liter)	Additive	W/C factor
2 (central)	1	40	23	Opalit (10%) 4kg	0.55
	2	20	11.5	Opalit (10%) 2kg	0.55

3.3. Grouting of top sealing section

Bentonite, a ground weathering product of volcanic ash or pyroclastica, is widely known for its swelling properties. AMC Euro Gel Universal was used to increase the sealing effect of this grout mixture.

Preparation of this mixture was more difficult as the bentonite tended to form clumps even it was added carefully to the cement-water slurry. Thorough mixing reduced the size of the clumps but was not able to remove them completely.

The following grout mixture was used for the top sealing section:

Packer	Mix Nb	Cement (kg)	Water (liter)	Additive	W/C factor
3 (top)	1	50	25	Bentonite (1%) 0.5kg	0.5
	2	25	12.5	Bentonite (1%) 0.25kg	0.5

4. Pressure measurement

Pressure sensors were installed in the grouted sections to monitor the sealing effect of the different grout mixtures for their evaluation for future borehole completion with grout packers. Pressurizing an interval section by water injection will lead to a propagation of the pressure through the adjacent packers and will be picked up by the pressure sensors. The injection pressure is monitored with a pressure sensor at the end of each pressure measurement line.

Vibrating-wire pressure sensors of Geokon Ltd. were installed inside the grouted sections but also at the surface at the end of the pressure measurement line.

Two 4500S type pressure sensors with a range of 0 – 2 MPa were installed 2 and 3 m above the lower end of each grouted section. The O-ring sealed filter screen was removed, the chamber properly filled with water and the screen replaced before the sensors were attached to the central rod with adhesive tape. The filter screen is designed that no water flows from the chamber even when the sensor hangs vertically.

A 4500H type pressure sensor with a range of 0 – 2 MPa was installed for each pressure measurement unit which consist of a valve and a mechanical pressure gauge. All three units are combined in a pressure measurement panel which was mounted to the tunnel wall. Each pressure measurement line of the three interval sections was connected to its dedicated unit. The pressure of the lowermost interval section is measured through the central tubing which was extended with a polyamide line to the pressure measurement panel.

All pressure sensors are connected to a 16-channel data logger which was also mounted to the tunnel wall.

Bezeichnung	Tiefe (MD) [m]	Sensor-Typ	Serie-Nr.	Bereich [MPa]
P1	15.1 (bottom)	Geokon 4500 S	1601506	0..2
P2	14.1(bottom)	Geokon 4500 S	1601507	0..2
P3	9.1 (center)	Geokon 4500 S	1601508	0..2
P4	8.1 (center)	Geokon 4500 S	1601509	0..2
P5	6.1 (top)	Geokon 4500 S	1601510	0..2
P6	5.1 (top)	Geokon 4500 S	1601511	0..2
P7	Panel (I bottom)	Geokon 4500 H	1601512	0..2
P8	Panel (I center)	Geokon 4500 H	1601513	0..2
P9	Panel-(I top)	Geokon 4500 H	1601514	0..2

5. References

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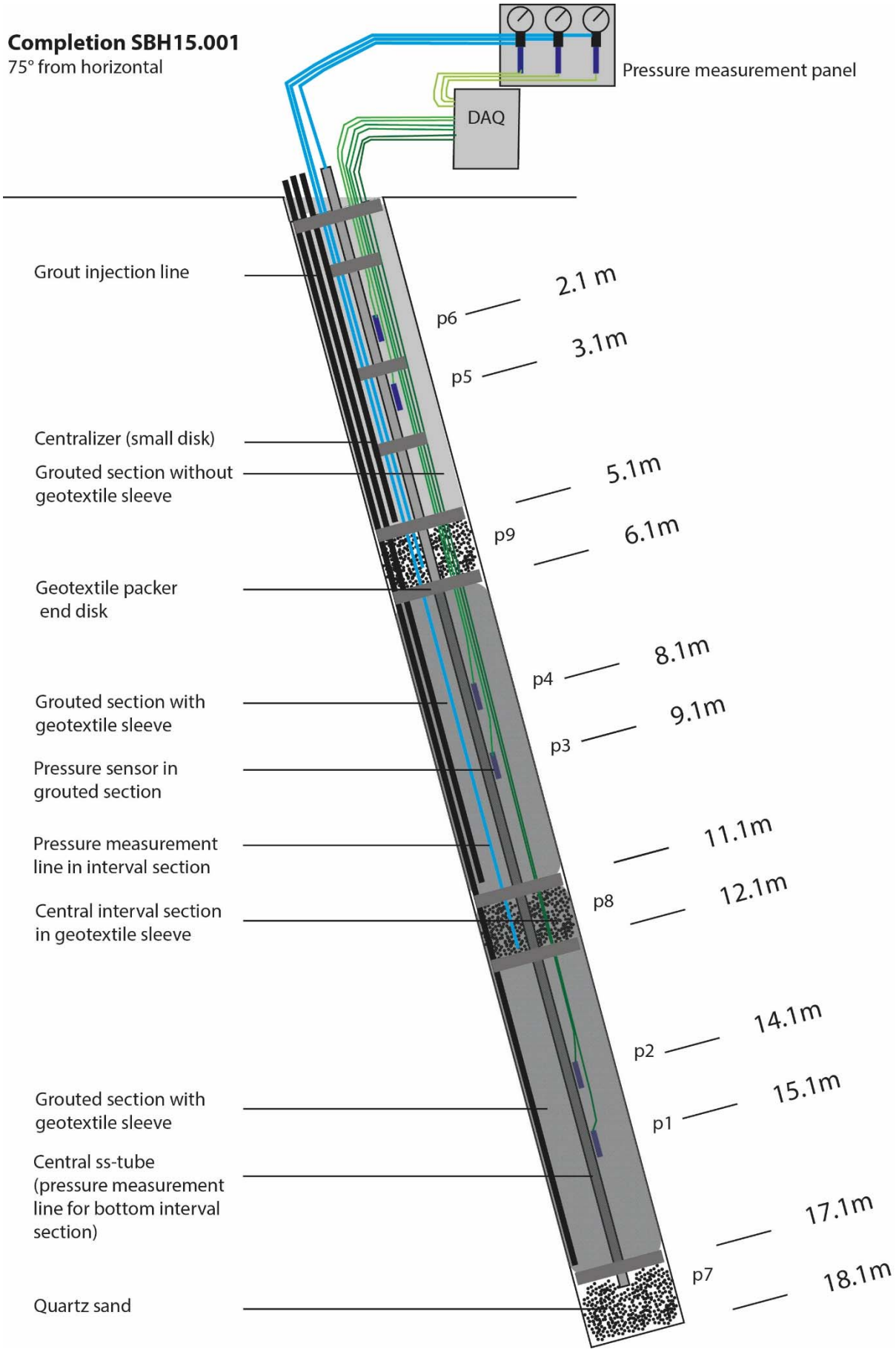
Fällanden/Russikon, 14. 6. 2016

Appendix 1

Completion SBH15.001
75° from horizontal



Appendix 2

Fig. 1. Filling the bottom interval section with quartz sand.

Fig. 2. Preparation of the bottom packer with the geotextile sleeve mounted to the bottom disk.

Fig. 3. Attaching a pressure sensor to a fitting of the central tube with adhesive tape.¨

Fig. 4. Filing the geotextile sleeve of the central interval section with quartz sand.

Fig. 5. Central interval section completely filled with quartz sand.

Fig. 6. Top disk of lower interval section and bottom disk of central grout-packer.

Fig. 7. Compacting the geotextile sleeve with rubber bands to reduce friction.

Appendix 3

Schedule of completion of borehole ISC-SBH15.001 at Grimsel Test Site; Monday 11.4.2016 to Wednesday 13.4.2016

Monday 11.4.2016

Departure at 5:30/6:00 from Russikon / Fällanden
9:00-9:30 arrival at the site
11:00 starting installation
17:00 installation till about 13m (end of second packer)
17:30 leaving site, discussion grouting

Tuesday 12.4.2016

7:00 arrival at the site
10:30 completion of installation, checking all sensors
11:00 start 1st Injection
14:00 start 2nd Injection
16:30 start 3rd Injection
17:30 cleaning site, checking all sensors
18:00 leaving site

Wednesday 13.4.2016

7:00 arrival at site, checking all sensors
8:00 connection to manometers, panel and datalogger
10:00 installation software and checking results, programming, interval setting
11:00 leaving site
15:00/15:30 arrival in Fällanden/Russikon