Cut-off Wall for the Strengthening of the Sylvenstein Reservoir (70 km south of Munich, Germany) Cut-off Wall executed with BAUER cutter & grab and Plastic Concrete

Dipl.-Geol. Michael Baltruschat; Dipl.-Ing. Peter Banzhaf;
Dipl.-Ing. Sebastian Beutler; Dipl.-Ing. Stefan Hechendorfer
BAUER Spezialtiefbau GmbH
BAUER-Str. 1,
86529 Schrobenhausen
Germany

Introduction

The Sylvenstein Reservoir was built between 1954 and 1959. For its reconditioning after 50 years of operation, it has been planned to strengthen the dam core by means of a deep concrete cut-off wall (COW) and to equip the dam with a state-of-the-art water collection and a monitoring system for water seepage.

In this context, the Bavarian Ministry of Environment via its Bavarian State Office for Water Management in Weilheim (WWA-WM) has entrusted Bauer with the construction of the 70 m deep and 1 m thick diaphragm wall.

The reservoir was originally meant to regulate the minimum low water flow of the Isar River but meanwhile it had to deal with detention of water during flood seasons and helped protecting the area of Bad Tölz and Greater Munich from devastating floods in 1999 and 2005. Thereafter, the refitting of the reservoir has to allow for prevention measures in case of climate changes.

The 42 m high and 180 m long earthen embankment dam is underlain by a 100 m deep gully formed into dolomite and filled by alluvial river sediments, which made it necessary during dam construction to perform grouting works to create a multi-layered sealing curtain of clay-cement grout.
The watertight thin core of the dam consists of a mix of gravel, fine sand, silt and bentonite sandwiched between filters of moraine gravel from both downstream and upstream sides.

The refit-design asked for a new sealing element by means of a 2-phase cut-off wall which had to be constructed offset to the core of the dam slightly towards the downstream side and had to key in to the steep rock flanks. The depth of the cut-off wall has been determined based on reconnaissance drillings performed down to 140 m deep in the substratum of the dam.

Due to imbedded layers of gravel and rock sediments and to the fluctuating permeability in the bottom sealing, the cut-off wall had to be extended down to 70m below the dam crest (suffusion stability).

The 10,000 m² cut-off wall was constructed by Bauer Spezialtiefbau from dam crest which is stretching over 180 m; cutting of the trench was executed in its upper parts using a grab and continued to the final depth (70 m) by means of a BC40 cutter mounted on MC128 where the edges of the wall had to be embedded in very hard rock. Particularly challenging was the timely execution from a restricted working platform width.

Due to the topography of the site and the restricted working space at the dam crest, logistic challenges had to be dealt with; concrete batching plants were installed downstream in the valley below the embankment dam and the plastic concrete had to be pumped 50 m upwards. Moreover, the traffic on the adjacent scenic road could be kept up by means of a temporary road over the dam in direction towards the Achenpass.

Function of the Embankment Dam – Reasons for the Strengthening

The Sylvenstein Dam is the oldest water reservoir in the State of Bavaria. It has demonstrated its protective function during several flood water flows at the rivers Isar, Dürrach and Walchen for the downstream communities and of the State Capital Munich.

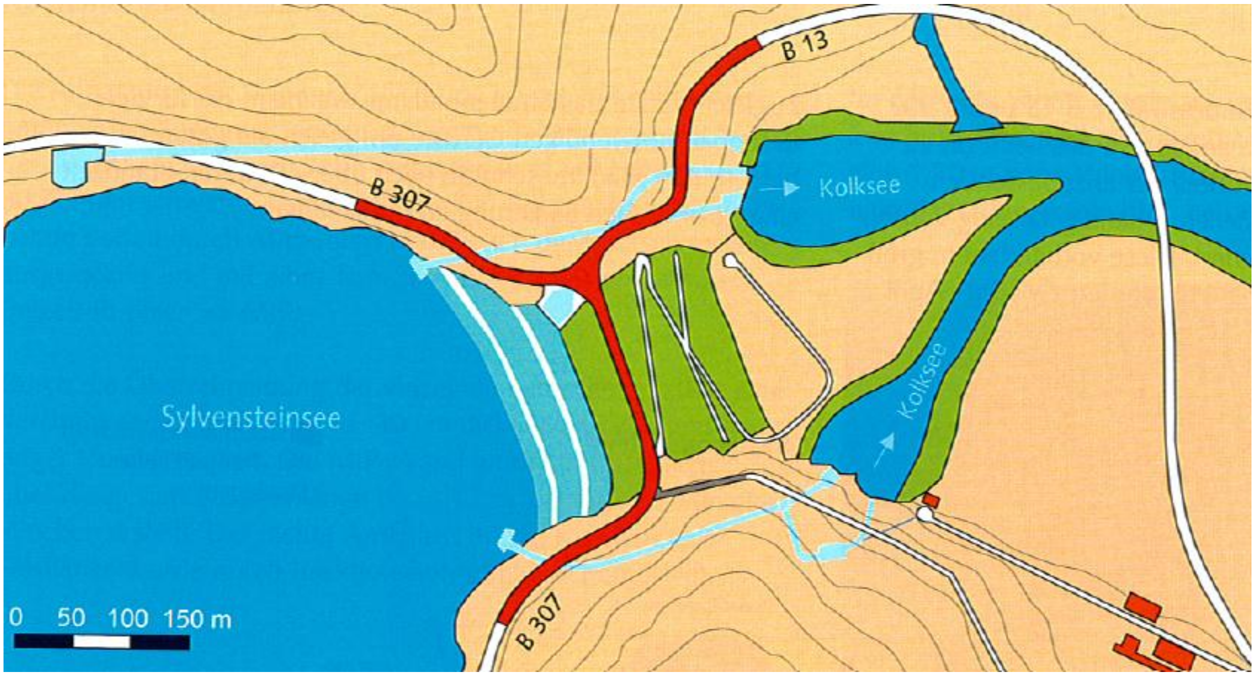

Fig. 1: Overview Sylvenstein Dam and adjacent roads (Source: WWA-WM)

Dam Data

- Crest-length 200 m x Height 45 m,
- Embankment (45 m): mixture of gravel, sand and fine grain, containing approx. 13 – 25% of fine grain
- Overburden (25 m up to 95 m): alluvial gravel with sandy and fine-grained minor components; layers of lake marl with low extension
- Bedrock: Dolomite with an uniaxial compressive strength (UCS) 21MPa to 96 MPa (average 60 MPa)

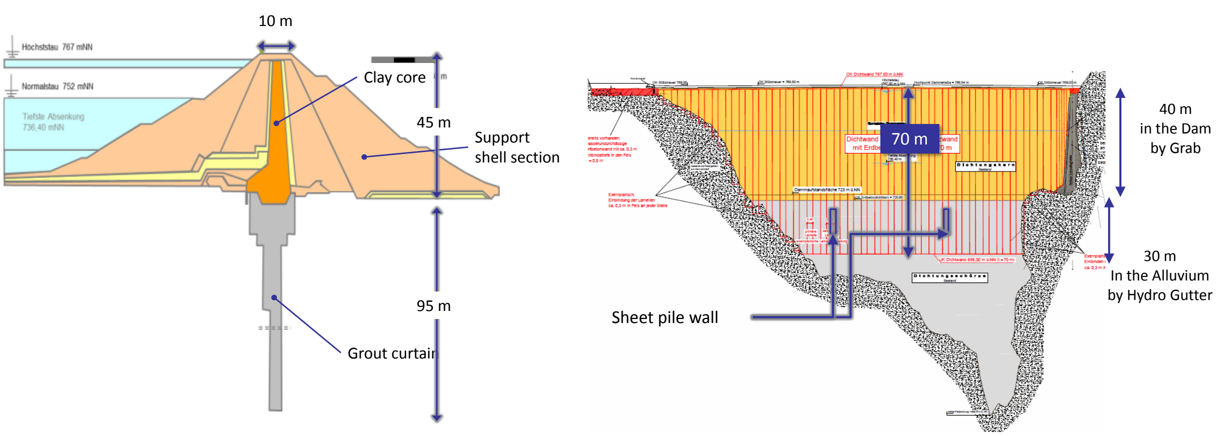

Fig. 2: Sections showing the Sylvenstein Dam prior to COW installation and planned COW (Source: WWA-WM)

Reasons for actual reconditioning

- Improve the structure of dam and foundation;
- Strengthen the slim watertight 50 year old core;
- High settlement rates during the first years after installation with possible changes and movements at core
- High loads during extraordinary floods in the years 1999 and 2005

⇨ Installation of a new watertight sealing

- Measuring system;
- Precise localization of leakage water is not possible at the moment;
- Only indirect monitoring of leakage water by 46 pore-water sensors;
- Old measuring system and enormous effort to change defect sensors

⇨ Installation of a direct, segmental leakage water monitoring system

Fig. 3: Sylvenstein Dam – view from downstream – COW under execution.

Design of the Cut-Off Wall (Provided by the Client)

Refer to Item 2 of the article by Nöll, Langhagen et. al. ("Rehabilitation of the Sylvenstein Earth-Fill Dam – Design and Construction of the Cut-Off Wall", *WasserWirtschaft 5/2013*)

CDM Smith Consult GmbH delivered the design.

The cut-off wall has two functions:

- Sealing the embankment dam
- Sealing the underground structure

The following steps were essential to ensure long range functionality of the Sylvenstein:

- The depth of the COW had to be designed in such a way that there is no damage caused by seepage in the substratum below the COW.

    - NB: There are no construction measures planned / executed below the COW – in the area of the "old" grout curtains.
- Embedment into the existing rock and concrete structure has to be watertight.

Based on large scale test drillings and a subsequent analysis as well as a calculative examination of the suffusion security a necessary minimum depth of 60 m was establish for the COW. Considering the subsoil structure and due to constructive reasons the depth of the cut-off wall was determined with 70 m.

Other Pre-settings:

- Wall-thickness of 1 m; based on the required depth
- Two-phase diaphragm wall
- Material: plastic concrete
- Permeability: not exceed 1 x 10^{-9} m/s in the laboratory
- Tensile strength: 500 kN/m²
- Max. stiffness: 450 MN/m²

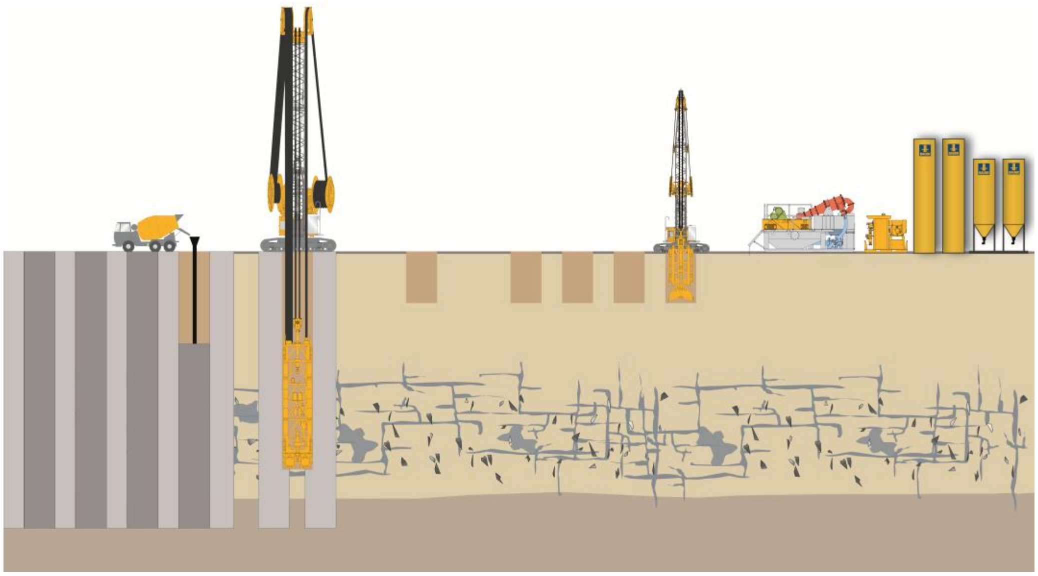

Fig. 4: Typical Method and Equipment Technology

Constructing the Plastic Concrete Cut-off Wall

The individual panel-elements were excavated under slurry, using grab and hydrocutter. According to schedule, individual panels were pre-excavated with a hydraulic grab (Type BAUER DHG) to a depth of approx. 40 m (corresponds approximately to a level shortly above dam foundation level). Then the panels were completed to the specified depth of up to 70 m. At both abutments the full-face embedment into the rock was executed with the hydrocutter. The individual steps of the cut-off wall installation are shown in Fig. 4 and Fig. 6.

 

Fig. 5: The main equipment; left: BAUER MC 64 with hydraulic grab – right: BAUER MC 128 wit BC 40 Cutter

Panel Layout and Alignment

Only individual panels with a dimension of 3.2 x 1.0 m (length x width) were constructed for the Sylvenstein project, typically for an impounded reservoir. The only exceptions are the panels at the final ends both in the west (area Hennenköpfl) and in the east (area Sylvenstein) of the COW. In the east there is an existing conical buttress. The peripheral panels had to be connected to this structure with individual special solutions.

The single panels were constructed in the so called pilgrim-step-method. The subsequently constructed secondary panels overlap with the adjacent primary panels by typically 40 cm each side.

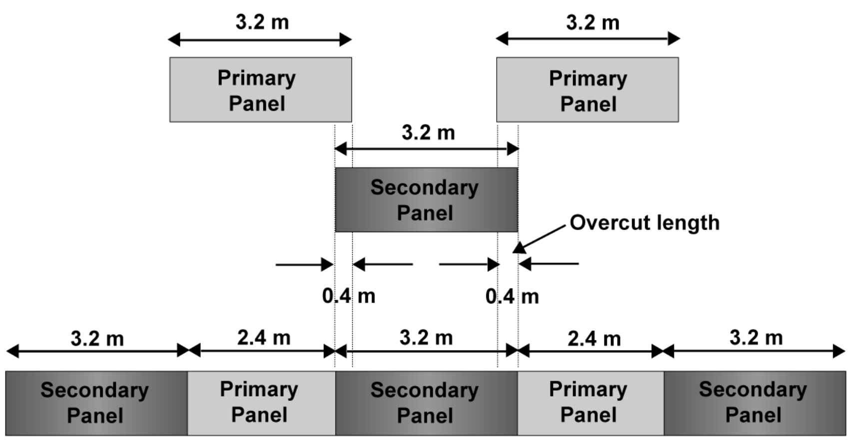

Fig. 6: Primary and Secondary Panel-layout; schematically.

Construction Tasks for COW installation

- Narrow working platform width (16.5 m) => longitudinal working position is necessary
- Extension of the existing main road with permanent concrete abutment and backfill material
- Maximum depth 70 m;
- Rock embedment: 30 cm at each location
- Connection to existing concrete structure (conical buttress);
- Old existing sheet piles in the COW-axis

Fig. 7: Construction Tasks – narrow platform width and permanent traffic upstream along the platform

Construction Task Examples

Listed from east (Sylvenstein) to west (Hennenköpfl):

Area 6: Attached to concrete buttress

The cut-off wall has a depth here of max. 45 m. The cut-off wall was attached to the newly constructed buttress by a special construction. The COW was constructed in H-shaped geometry consisting of two panels which follow the concrete structure and of a connecting panel.

To prevent water conductivity the concrete surface of the buttress was cleaned with a so-called Putzmeißel, after having finished the excavation process.

Area 5: Rock embedment (horizontal upper edge) of Sylvenstein

The cut-off wall has a depth here of max. 45 m. The rock upper edge is almost horizontal. The excavation was done with grab technology until the upper edge of the rock, the rock embedment with cutter technology.

Area 4: Rock embedment (vertical upper edge) of Sylvenstein

The COW has a depth of max. 70 m. The upper rock edge is almost vertical. Based on the investigation bores it was determined to construct at first a (primary) panel which was cut around 30 m through the existing dolomite. Using the subsequent secondary panel facing the valley the rough rock surface was levelled and thus a consistent cut-off wall could be executed.

Area 2: Embedment in the vicinity of Hennenköpfl

The maximum depth is here approx. 70 m. It was excavated with a grab to a depth of 35 m and/or until the upper edge of the rock. The required embedment into the dolomite was determined, using the analysis of the output from the regeneration plant.

Plastic Concrete: mobile mixing plant, properties

To produce the clay concrete, a mobile concrete mixing plant of the type ELBA ESM 105 was installed and operated on the downstream dam footing. Concrete delivery at the trench was done with a stationary concrete pump and pump hoses connected to it (DN 125 mm) directly into traditional tremie pipes. This version goes with the requirements of DIN EN 1538 and offers a few advantages concerning the filling process (better and more continuous raising of the concrete until the upper edge of the guide wall possible) and concerning work safety (no risk of sputtering concrete).

Mixing Recipe

In order to meet the already shortly mentioned requirements, a mixing recipe with a comparatively low cement content was chosen. To ensure a sufficiently low permeability powdered clay was mixed with the concrete. The basic recipe was determined by TU Munich (Technical University), Department of Civil Geo and Environmental Engineering, and was included in the tender documents. Based on these investigations the tenderers had to make up their own cut-off wall mixtures and to prove the suitability with the relevant tests. The time needed for execution was approx. 3 weeks to work out a general recipe and approx. 2 months for the proper suitability test based on the actually used construction material.

The following mixing recipe was determined in the course of the suitability test.

MIX	Water (kg/m³)	Binding Agent (kg/m³)	Powdered Clay (kg/m³)	Gravel (kg/m³)	Sand (kg/m³)	VZ (%)	BV (%)
H 0,57	375	125	220	521	782	4	1,5

Table 1: Mixing recipe of the plastic concrete used

Measurement - QA/QC-System

To supervise the verticality and to prove sufficient overlapping rates the following methods were chosen:

Method	Frequency	Additional time / production delay per measuring process	Remark
Inclinometer probe – grab	permanently, simultaneous excavation	none	
Inclinometer probe – cutter	permanently, simultaneous excavation	none	
Inclinometer measuring unit – cutter	after having reached final depth of each panel	approx. 0.5 – 1.5 h	separate measuring unit by further lowering of cutter
Inclination measuring instrument	for each panel one measuring net consisting of a reference measurement and approx. 4 nos. subsequent measuring	approx. 5 min per measurement (i.e. approx. 15 – 45 min. per panel)	inclination measuring was not required by client; was only for internal control
Koden measuring	when requested by client at the panels chosen	approx. 1 – 3 h	time required varied enormously depending on the excavation depth and the calibration

Table 2: Summary of methods applied for verticality determination

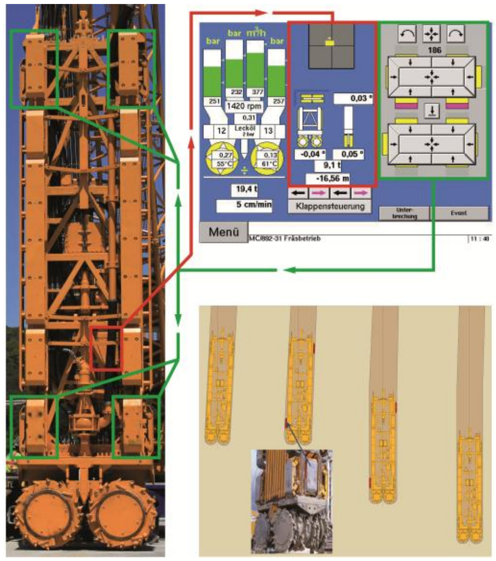

Fig. 8: Cutter Verticality Control

The data resulting from the inclinometer measuring unit (*Fig. 8)* were displayed in as-built drawings to check a sufficient overlapping, sections drawn to scale (two primary panels and the relevant secondary panels adjacent at both sides) were prepared. For the relevant final depth the primary panels were already marked in their relevant as-built position in these section drawings. After completion of the measurement for the secondary panel the site manager was able to mark its position in as-built drawings and assess prior to the concreting works if there was the necessary overlapping or remedial measures need to be taken. According to the Quality Management Plan (QMP) a sufficient overlapping rate had to be verified.
After completion, the as-built dimensions of the secondary panel were added to the in as-built drawings, thus a thorough CAD-plan about the complete wall was created.
The BAUER-inclination-measuring was executed as an additional tool for quality assurance during the on-going works for all panels.
The results gained there were always compared to the inclinometer measuring and verified with the executed Koden measurements.

Requirements for Hardened Cut-Off Wall Material

The requirements posed to the completed COW are displayed in the following chart:

Material: COW	
Material density	> 2.0 t/m³ testing method jar spreading width ± 0.05 t/m³
minimum strength for panel cut from stability prove	➢ testing method: p_{φ} – tests at 3 samples from the 1 concreting section at the point in time ≤ cutting time, execution External-control ➢ minimum value 0.3 MN/m³ (cutting of primary panels) 0.1 MN/M³ (following primary panels)
curing time sampling age 2 days 7 days pls. refer to hardening curve 28 days and 58 days	➢ development of compressive strength at approx. 5 to 10°C surrounding temperature, single axial compressive strength accord. to DIN 18136: ➢ planned value qφ28 >= 1300 kN/m³ ➢ planned value qφ64 >= 1600 kN/m³
tensile strength sampling age 28 days	➢ determining the bending tensile strength planned value 400 to 500 kN/m³
rigidity module (stiffness module)	➢ < 450 MN/m² (in single axial compression test)
material permeability	➢ k≤ f x 10^{-9} m/s

test in laboratory	
wall density (system density) field tests, samples from bores, etc.	➢ k≤f x 10^{-8} m/s
erosion security at i=50	➢ test method: DIN 18136 ➢ at compression strength qφ > 0.5 MN/m³ we assume erosion security (compare with chapter. 4.3.1)
single axial compression strength	➢ test method: DIN 18136

Table 3: Requirements to hardened COW (QMP)

Conclusion

The manageable flood control storage space of the Sylvenstein reservoir reached on August 3rd, 2013 a level of 99.7% impoundment volume. The detention storage reached 61 Mio. m³ and was almost completely used. The maximum inflow into the reservoir was at 675 m³/sec (02.06.2013 at 17:00 h) at the same time the maximum permissible outflow was only 60 m³/sec. With the reservoir management and limited release of water it was achieved to keep the strain on the downstream abstractors in the region towards Munich-Freising-Landshut and the Danube towards Passau to a minimum.
The present retrofitting of the Sylvenstein Dam, supported by the EU, has reached an essential mile stone with the COW installation in 2012 (by BAUER Spezialtiefbau GmbH). Due to the achieved definite permeability of the dam it was possible to increase the amount of water retained to a new record height and to reduce the outflow considerably to spare the downstream abstractors. Thus, even higher strain is put on the dam structure compared to previous floods. The relatively long time during which the water can be retained is striking. The flood can be considered as the first real endurance test for the new cut-off wall.
Source/Quote: Dr. Tobias Lang (Wasser-Wirtschaftsamt Weilheim; Bayern)

References

1. **Nöll, H.; Dr. Langhagen, K.; Popp, M. and Dr. Lang, T.** "Rehabilitation of the Sylvenstein Earth-Fill Dam – Design and Construction of the Cut Off Wall", *WasserWirtschaft 5/2013*.
2. **Dr. Lang, T. – Bavarian State Office for Water Management Weilheim** "Der Sylvensteinspeicher" 9/2009.

The Authors: Dipl.-Geol. Michael Baltruschat; Dipl.-Ing. Peter Banzhaf; Dipl.-Ing. Sebastian Beutler; Dipl.-Ing. Stefan Hechendorfer

Dipl.-Geol. Michael Baltruschat graduated as Diploma Engineer in Geology -(equivalent to BS and MS) from Technische Universität Berlin (Germany) in 1994 and joined BAUER Spezialtiefbau GmbH as site engineer and project manager in 1995. He has been involved in numerous large scale geotechnical projects in Germany and abroad and specialised in diaphragm wall techniques, slurry walls and permeation grouting and headed the respective department within the specialist department of BST. In 2012 he joined the Global Dam Services of BAUER Spezialtiefbau GmbH as senior tender engineer and project manager.

Dipl.-Ing. (FH) Peter Banzhaf, Diploma Civil Engineer from University of Applied Sciences in Munich, Germany. He is a Director in BAUER Spezialtiefbau GmbH (BST), Germany working for the company since 30 years. As a director Peter Banzhaf has managed specialists department in BAUER Spezialtiefbau primarily focusing on barrier wall construction and management executing more than 2,000,000 m² of diaphragm and cut-off walls until 2007. He worked for BAUER on projects in many parts of the world amongst others providing high quality consultancy services to URS for barrier wall construction at Hinze Dam Upgrade, Australia. At present Peter Banzhaf is Head of Global Dam Services in the BST and Director in BAUER Dam Rehabilitation Company FZE.Peter Banzhaf is a Member of ASDSO since 2008, a Member of USSD since 2009 and member of the German ICOLD member DTK since 2010.

Dipl.-Ing. Sebastian Beutler graduated as Diploma Civil Engineer from Technische Universität Munich, Germany in 2007 and joined BAUER Spezialtiefbau GmbH as site engineer in 2008. He worked on Hinze Dam Project as QA/QC manager, cut-off-wall and as project manager on vibro works, bored piles, sheet piles and anchors on GIFP Giurgiulesti Internat'l Free Port, Moldova. In 2011 he joined the Global Dam Services of BAUER Spezialtiefbau GmbH as tender engineer.

Dipl.-Ing. Stefan Hechendorfer graduated as Diploma Civil Engineer from Technische Universität Munich, Germany in 2009 and joined the Geotechnical Centre at the Chair of Foundation Work, Soil Mechanics, Rock Mechanics and Tunnel Construction as scientific assistant in 2010. In 2012, he joined BAUER Spezialtiefbau Gmbh and worked as construction and quality manager on the dam construction project Sylvensteinspeicher at Lenggries, Germany: strengthening the dam by a cut-off wall; excavation with diaphragm wall grab and trench cutter.