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Cut-off wall and drilling and grouting for the strengthening of the Rosshaupten dam, Germany

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Introduction

Corresponding measurements and several geotechnical investigations at the dam induced the owner to the decision to conduct a remediation [3]. This article explains the rehabilitation of the Rosshaupten dam using various methods and techniques of specialist civil engineering. Both the work executed in advance, which included drilling and grouting, the construction of two Mixed-in-Place walls and the coring works, as well as the installation of a diaphragm wall as cut-off wall (CoW) made of plastic concrete itself, are described briefly.

1. Rosshaupten Dam

The Rosshaupten Dam is located in the south of Germany, close to the famous Neuschwanstein Castle. The dam forms the Forggensee, the largest reservoir in Germany.
The construction of the dam was completed in 1954 and subsequently created the lake Forggensee, with a total area of 16 km². The dam structure and reservoir were built to generate electric power as well as for low water elevation and flood protection of the downstream areas. The area has also naturally developed into a popular place for recreational activities since its construction.
The dam structure is an approximately 230 m long and 40 m high earth-filled dam with a supporting body of gravel and boulders and with a central sealing core consisting of clay and loam.

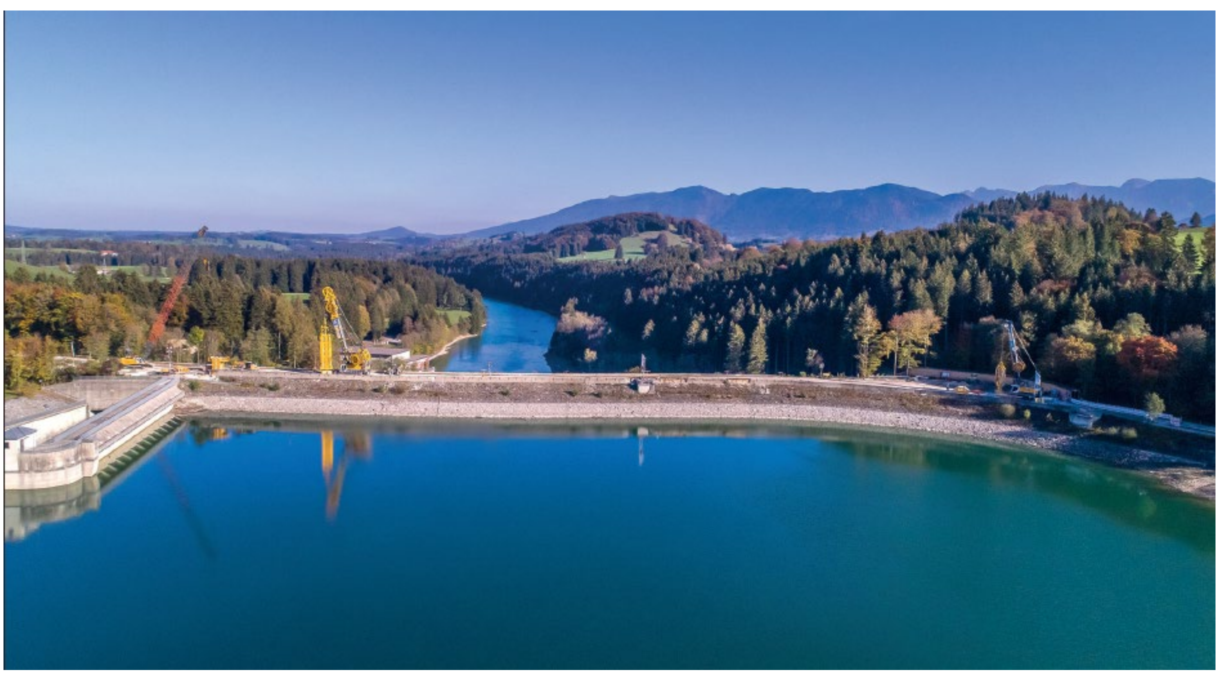


Fig. 1. Cut-off wall construction on the dam crest

The bedrock on which the dam was erected consists of alternate mudstone and marlstone layers, permeated by bands of sandstone as well as coal in some places. The molasse layers often alternate at intervals of a few centimeters; rarely is there a layer several decimeters thick. Tectonic deformation has folded the sedimentary rocks almost vertically, often leading to the formation of joints and fissures. The un-weathered, fresh bedrock at the dam has compressive strengths of up to 85 MPa [1].
As part of the rehabilitation concept, it was decided to install a 1m-thick cut-off wall, up to 70 m depth, using plastic concrete as construction material [2].
BAUER Spezialtiefbau was awarded to construct this cut-off wall, including additional exploratory drilling and soil stabilization package which was executed prior to the cut-off wall construction. The soil stabilization package consisted of sleeve pipe (Tube-á-Manchettes) and rock grouting as well as Mixed-in-Place walls (see Fig. 2).

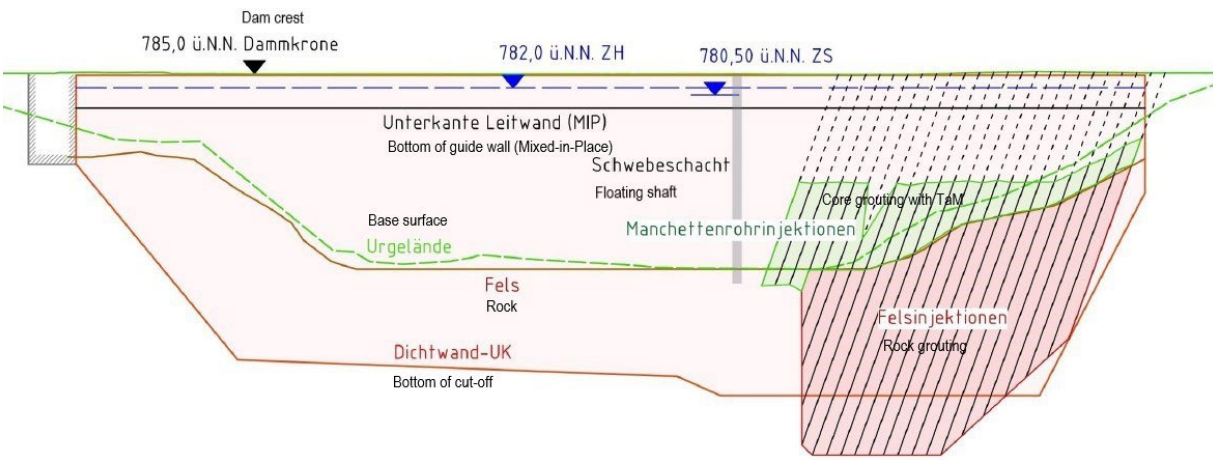


Fig. 2. Rehabilitation concept

Seven exploratory boreholes with a maximum length of 91 m were drilled. These boreholes were recorded and documented by scans and surveys. The data obtained and the results (including lugeon values) of water pressure tests (see Fig. 5) were summarized and visually processed [5].

2. Soil Stabilisation Package

2.1 Drilling and grouting campaign

A drilling and grouting campaign was executed to seal specific areas of the existing dam body (see Fig. 2) to a depth of 85 m.
The drilling and grouting campaign involved a single-row grout curtain of cement slurry, which served both to stabilize the bottom of the right abutment for a short time to allow for impoundment, and to reduce the permeability before the cut-off wall construction began [6].
The impervious grout curtain consisted of 24 boreholes, each inclined at 20° to the vertical (see Fig. 3). The core of the dam was drilled through and injected in 0.5 m sections using the tube-à-manchette technique (see Fig. 4). The transition to the underlying competent rock was grouted using the descending (downstage) technique due to the risk of borehole collapse in this distinctive fracture zone. Subsequently, the boreholes were drilled to the required depth and the rock was grouted in sections of 3 m each using the ascending (upstage) technique. In order to protect the core of the dam structure, i.e. to avoid risk as far as possible, drilling in the dam body was carried out using the so-called sonic drilling method, a technology that uses high-frequency vibrations without the need of drilling fluid. For the bedrock, the Wassara drilling method was applied. The grouting of the slurry, with a W/C-ratio between 0.8 and 1.0, was carried out in the dam body with pressure-controlled grouting. In the rock, it was planned and applied according to the GIN method (GIN = Grouting Intensity Number) (see Fig. 6) to ensure that the cavities were filled as completely as possible. This method reduced the risk of fracturing the dam core or even the rock due to excessive grouting pressures.

Fig. 3. Drilling inclined holes using KLEMM drill rig
Fig. 4: Hose drum systems; here with double-packer for tube-à-manchette grouting in the existing dam body

In total, a grout curtain with an area of 3,300 m² was constructed in the right dam area using this method. A total volume of approx. 275 m³ of cement slurry was injected above and below the interface between the dam body and the competent rock.

Fig. 5. Water-Pressure Test
Fig. 6. Controlling and monitoring the grouting work

The data recorded during the drilling and grouting work were digitalized and a 3D model was created step by step using real time documentation and visualization (see. Fig. 7) This was done in real time with Bauer's b-project.

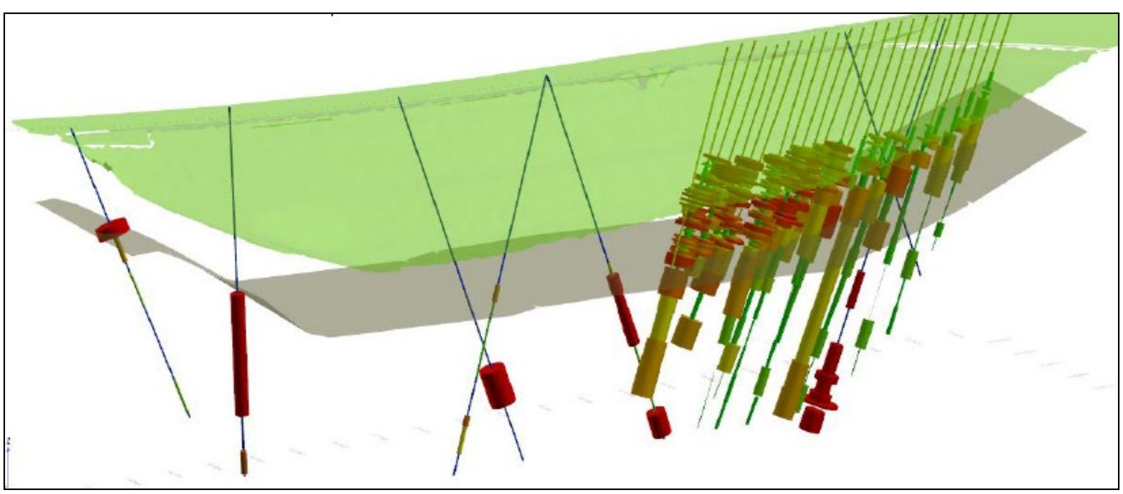


Fig. 7. Visualization of drilling and grouting work

2.2 Mixed-in-Place walls

A unique feature at Rosshaupten dam was the construction of a BAUER Mixed-in-Place (MIP) retaining wall (see Fig. 8) with a maximum depth of 11 m on either side of the alignment of the later cut-off wall as additional stabilization of the guide wall (see Fig. 10).

Fig. 8. Execution of the Mixed-in-Place-encasement walls, prior to the diaphragm wall

Mixed-in-Place (MIP) is an in-situ soil mixing technique[6]. Triple continuous augers drill down to the final depth, under low pressure injection of cement slurry (see Fig. 9). Upon reaching the final depth, the homogenization process takes place. During the homogenization process, the soil along the whole depth is mixed with the cement slurry. The use of triple continuous flight augers enables a vertical material flow, along the whole depth of the MIP-element, which assures homogenized mixed soil along the whole depth of the element. To achieve a continuous water barrier and to ensure the homogeneity of MIP walls, in the horizontal direction as well, MIP walls are constructed using the patented double pilgrim step method. This construction method is characterized by additionally mixing of the overlapping areas between primary and secondary bites. This aims to ensure that along the MIP wall, each wall element was mixed at least twice. MIP uses the existing natural soils as aggregates. Cement and bentonite are used as construction materials and the soil is not replaced. Therefore, it represents a sustainable solution for cut-off walls.

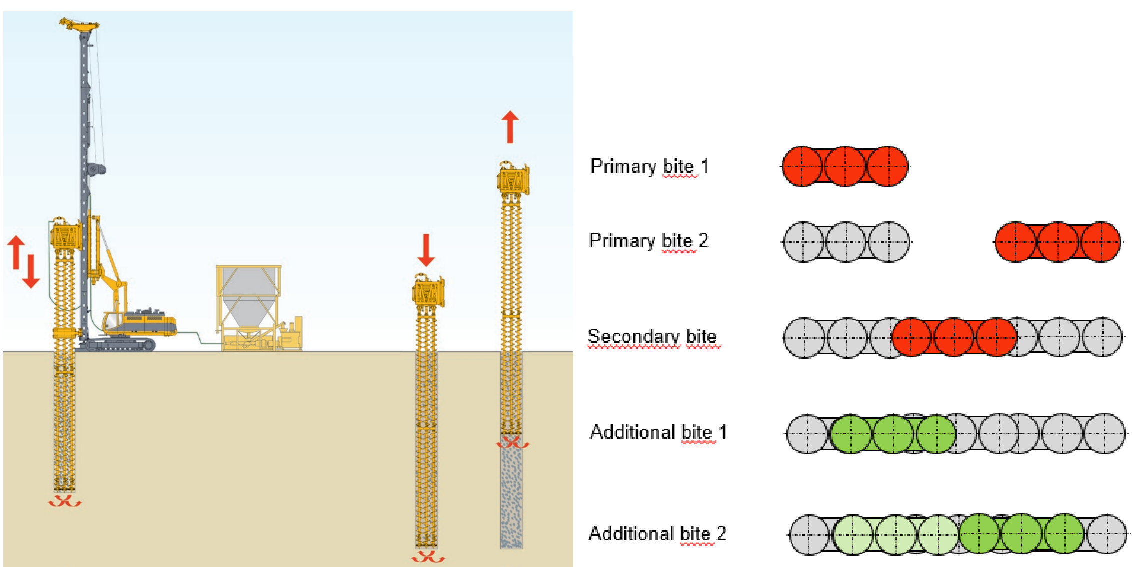
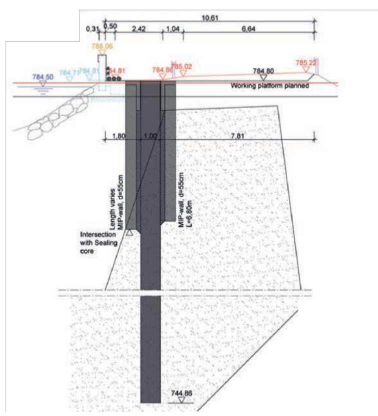


Fig. 9. Mixed-in-Place construction sequences

The MIP walls were reinforced with steel beams (see Fig. 11). This was necessary to accommodate any bending moments that might occur in the event of a sudden drop in the supporting slurry level in the open trench. The MIP-slurry was designed for a characteristic UCS of 3 MPa and the steel beams were placed in the fresh soil-slurry mix at a predetermined spacing. The lateral pressure (from the dam body) on the cured MIP material is transmitted towards the steel beams by an arching effect.



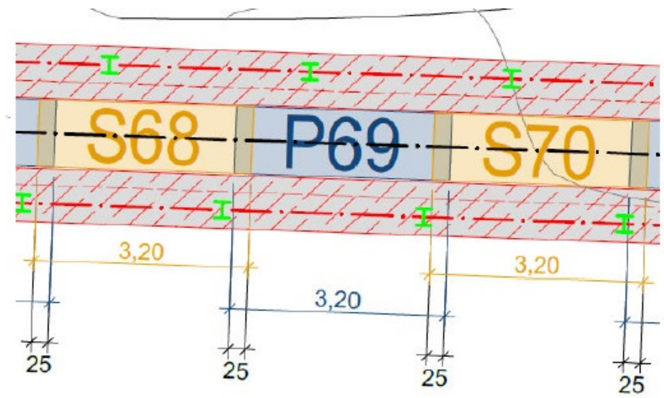


Fig. 10. Standard cross section regarding the Mixed-in-Place walls and diaphragm wall
Fig. 11 Mixed-in-Place walls on both sides (dashed) with inserted steel beams (green), in between them are primary (P) and secondary (S) panels of the cut-off wall, by means of diaphragm wall

3. Plastic concrete cut-off wall

3.1 Coring work / preliminary measure

Another additional part of the preparatory work was the removal of an existing reinforced concrete structure (floating shaft) to a depth of 48 m (see Fig. 2). All obstacles within the cut-off wall alignment were removed using a BAUER BG 48 drilling rig and 1,000 mm coring equipment and backfilling with lean concrete.

3.2 Cut-off wall construction

The CoW was installed without widening the dam crest. To ensure this, the base carrier was equipped with the turnable BAUER HDS-T hose drum system (see Fig. 12) enabling the BC 40 trench cutter to rotate on its own axis and to ensure the execution of all panels, despite the location.

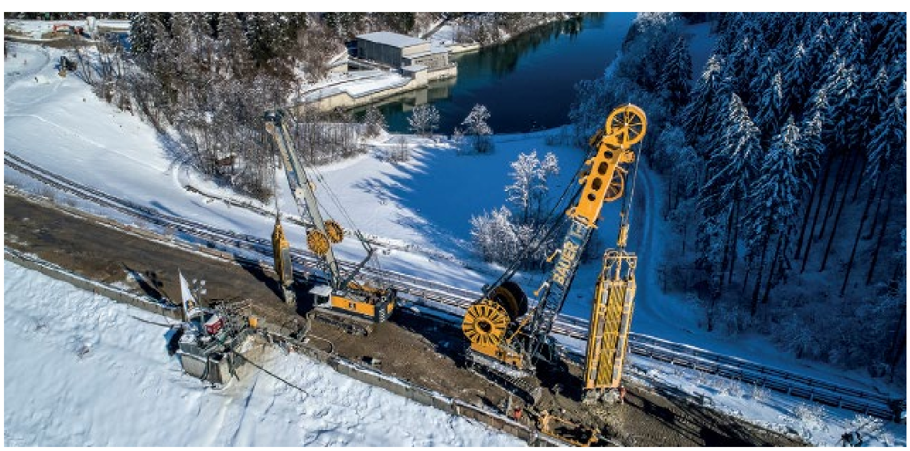
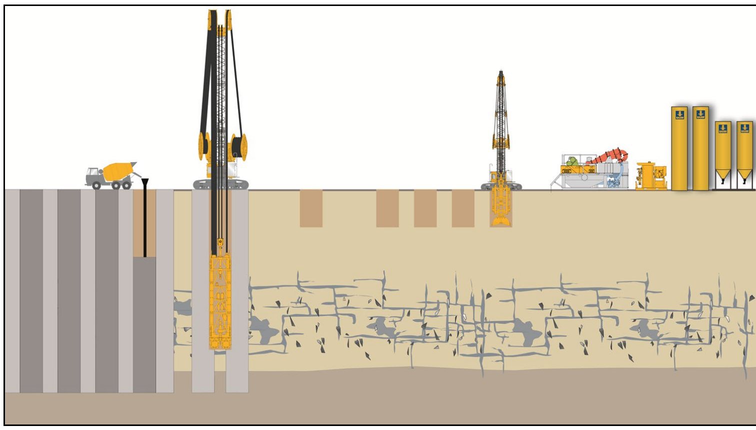


Fig. 12. BAUER MC 96 with turnable BAUER HDS-T hose reel system and BC 40 trench cutter (right) BAUER MC 64 equipped with BAUER DHG hydraulic grab

The cut-off wall, by means of diaphragm wall was executed by single bites and the so-called double-phase method. In the first step, a defined partial area (panel) was excavated with appropriate excavation equipment (see Fig. 12, 13 and 17) using a supporting bentonite slurry. This was followed by the treatment of the supporting slurry. The last step was the pouring of the plastic concrete using the contractor method via tremie pipes (Fig. 14).
During cutting, the mixture of soil and slurry was continuously pumped to the treatment plant using a pump installed in the trench cutter frame and via fixed pipes (see Fig. 14). At the treatment plant, the soil and rock chips were separated from the slurry by means of shaker screens and cyclones, and the cleaned slurry was subsequently pumped back into the open trench. During concreting, the supporting slurry displaced from the panel by the plastic concrete was pumped out, treated in the above-mentioned plant and stored in appropriate silos for using at the next panel [6].



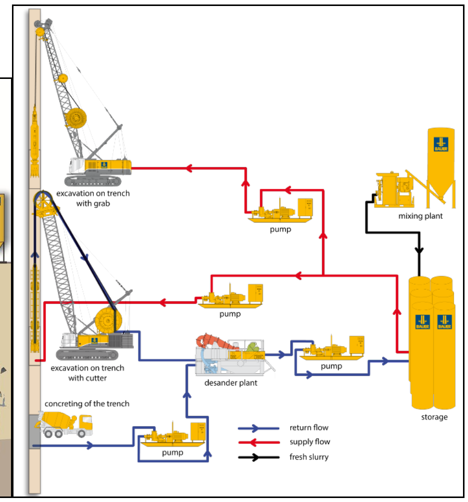
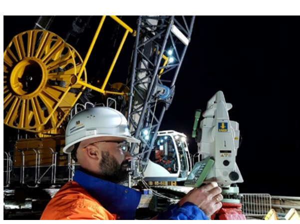


Fig. 13. Schematic illustration of the double-phase method using grab and trench cutter
Fig. 14. Schematic illustration of the bentonite slurry circuit, using grab and trench cutter

Two independent methods for surveying the open trench during excavation were used, to monitor and to check on each other. Inclinometers were installed both in the hydraulic grab and the trench cutter, which indicated initial reference points for the verticality deviation of the excavation tools. In addition, the Cutter Inclination System (CIS) and the Grab Inclination System (GIS) developed and patented by Bauer were applied (see Fig. 15 & 16). In both systems, the inclination of the wire ropes on which the grab or the cutter are suspended provided information about the exact position in the trench. A tachymeter recorded the position of the wire ropes Three dimensionally in space with every measurement making precise statement on the actual location of the trench center at all depths measured.



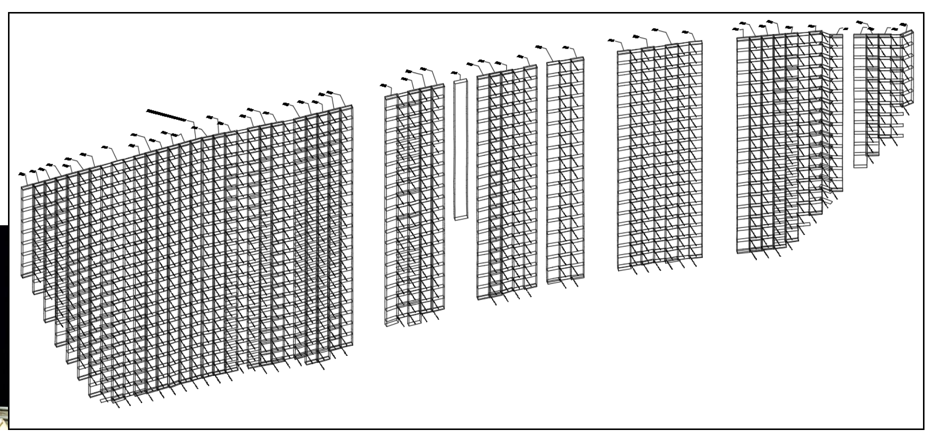


Fig. 15. Controlling of inclination using tachymeter
Fig. 16. Results of CIS and GIS measurement for each panel during the cut-off wall works

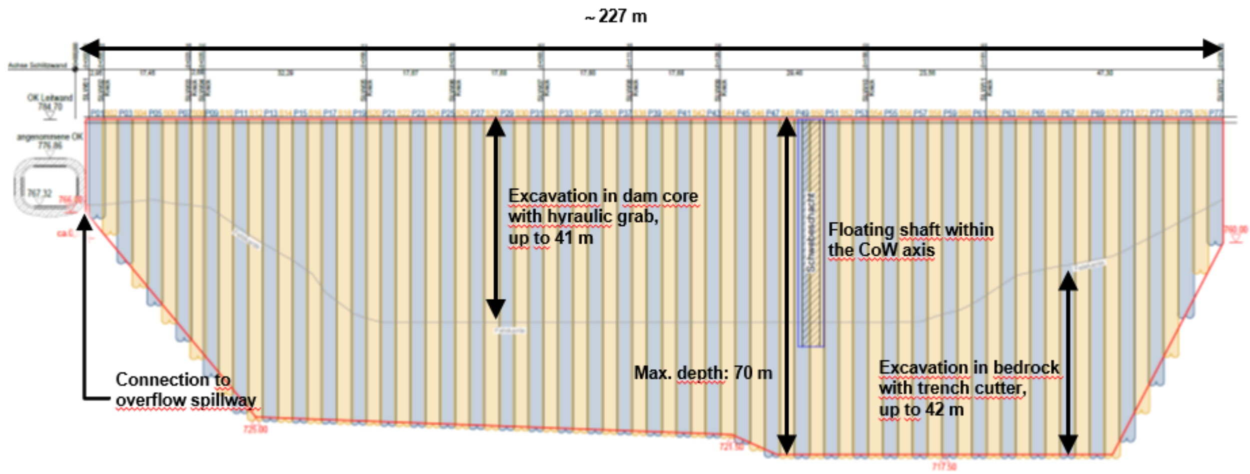


Fig. 17. Application of hydraulic grab and trench cutter depending on the soil/rock

In order to meet the specified construction schedule, the cut-off wall work also had to be executed in the winter months (see Fig. 18). Temperatures were as low as -10° Celsius (-20° Celsius taking into account the wind chill factor) and required special winter equipment for the mixing plants and slurry pipes.

Fig. 18. Photo showing both the execution of cut-off wall in winter, and the results of the Quality Control

A total of 13,780 m² of cut-off wall consisting of 77 panels was installed in the existing dam core and in sound rock. The length of the single panels was 3.20 m. The overcut on both sides was 25 cm and the minimum compressive strength of the plastic concrete q(28days) > 0.5 MN/m².

Conclusion

Six years after the successful completion of the rehabilitation works on the Sylvenstein dam, Bauer was awarded another contract to install a cut-off wall in an existing dam body in the south of Germany. Widening the dam crest could be avoided, due to Bauer´s turnable hose drum system, which additionally saves on time and costs.
To install a concrete cut-off wall for a positive, clearly defined seepage barrier in challenging ground conditions experience is essential. Mobilization, setting up on a small area site, testing materials and method was the basis for the successful execution of the required cut-off wall.
Proper planning was essential to keep safe working conditions, protection of the precious environment and good performance to finish this challenging project with timely critical parts successfully in time.
We would like to thank all those involved in the project, especially our client, Uniper Kraftwerke GmbH; SKI GmbH & Co.KG, Munich and Prof. (EoE) Dr.-Ing. Strobl.

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