# Sealing of a Ring-Dam using Mixed-in-Place method

*Dogern, Germany – 40 years ago, the Aubecken Reservoir in the river Rhine was put into operation next to the village of Dogern. Due to leaks in the ring dam of the pumped storage equalizing reservoir, the owner Schluchseewerk AG decided to overhaul it. BAUER Spezialtiefbau GmbH produced around 13,500 m² of cut-off wall using the Mixed-in-Place (MIP) technology in geotechnical demanding soil conditions over a length of 980 m. The method offered significant time and cost savings over alternative construction methods.*

*Aerial view of the Aubecken Reservoir (© Schluchseewerk AG)*

The Schluchseewerk AG operates five pumped-storage power plants in the southern Black Forest with a total output of around 1,800 MW, which corresponds to around a quarter of the pumped storage capacity installed in Germany. The Aubecken was built from 1975 to 1978 on the Upper Rhine on the so-called 'Au-Island', downstream of the Dogern weir. With a net capacity of 2.2 million m³, it serves as a water equalizing reservoir for the pumped storage power plants of the Schluchsee AG. For the installation of the basin, the original area was lowered by an average of approx. 7 m. On the Rhine side, an earth dam was built along the original shoreline. On the works canal side, the existing canal dam was supplemented by an Aubecken-side embankment (= separation dam). The resulting ring dam has a composite sealing system: the upper part of the slope is sealed by means of asphalt concrete surface sealing; a vertical diaphragm wall, which penetrates into the rock, forms the lower part of the seal. These two elements are connected by a reinforced capping beam.

**Reason for the remediation**

Since commissioning, the seepage water measurements in the ring drainage showed clear deficiencies in the sealing system. Partial rehabilitations in the 1980s and 90s in the area of diaphragm wall joints and in the form of underground injections brought no durable success. Especially in the winter months, exceptionally high seepage water outflows occurred at high basin water levels, which in some cases even led to pressure head-loss in the drainage pipes. In addition, regular checks of the seepage water shafts of the ring drainage system revealed sand deposits. The regular fine measurements of the ring dam also showed a progressive settlement behavior, especially in the area of the separation dam. It was concluded that the pronounced flow conditions in the subsoil or in the dam body led to material relocations.

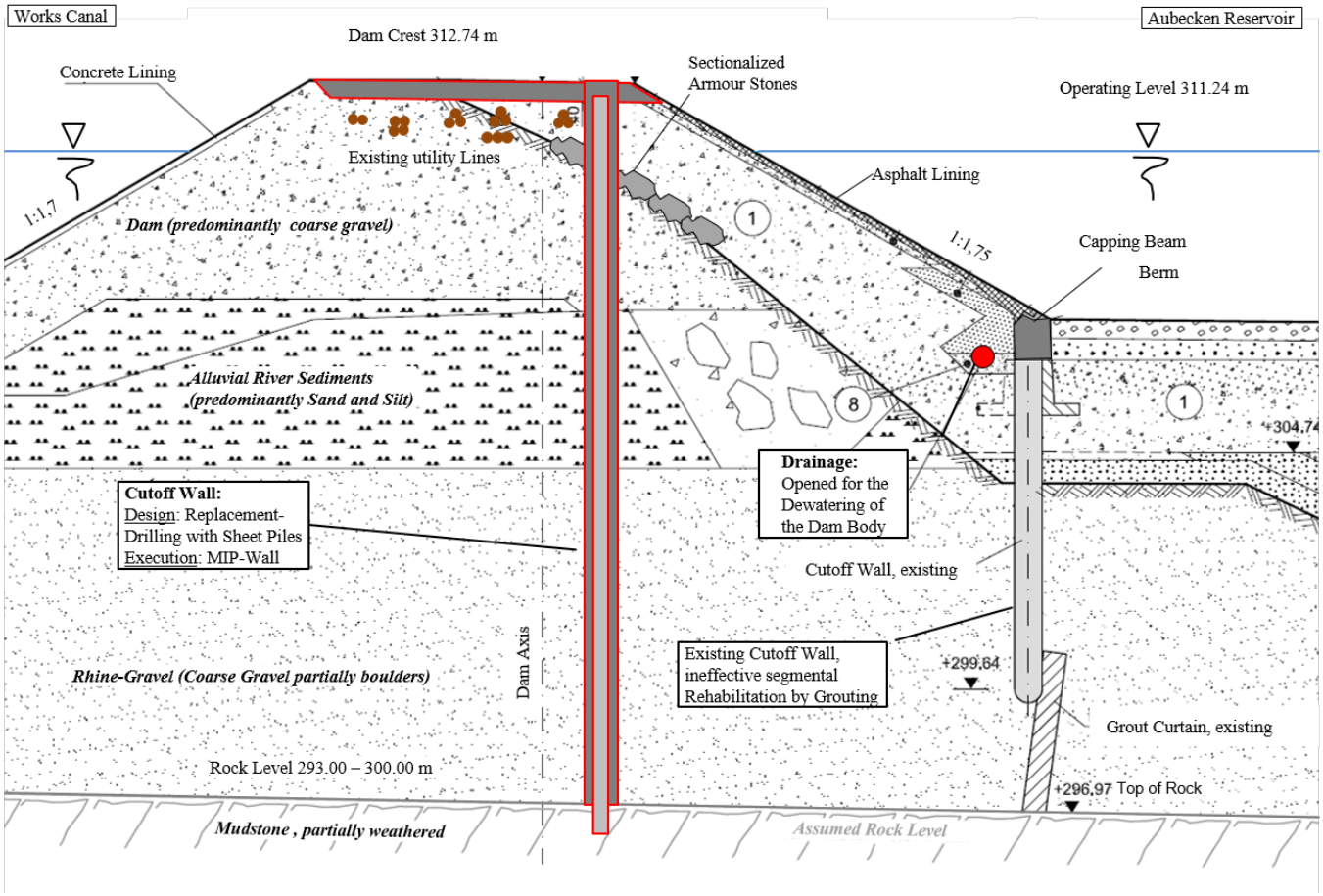
Extensive measuring campaigns and expert opinions showed that the infiltration took place in particular in the area of the diaphragm wall joints and in the underground connection of the diaphragm wall into the rock. It was therefore no longer possible to guarantee the long-term stability of the separation dam without operational restrictions and a comprehensive remediation of the basin sealing in the area of the separating dam was decided upon. As part

of a feasibility study, the target variation was defined as a new inner seal extending from the dam crest into the rock. Compared to the alternatives, this comparatively complex solution was characterized by the best quality sealing function, a minimization of the required tank restriction during remediation and lower future maintenance costs.

**Overall concept and boundary conditions**

By and enlarge following the feasibility study, the tender planning envisaged the remediation of the entire separation dam between the transition to the circular dam in the west and the inlet and outlet structure in the east of the basin by means of an approx. 980 m long and between approx. 12 to 20 m deep inner seal. For reasons of cost, it should be possible to dispense with dismantling the upstream asphalt concrete seal and the new construction of an embankment protection with armour stones. Furthermore, the cut-off wall in the upper area should have a load-bearing effect, so that possible slope failures do not influence the stability of the dam.

A geotechnical report revealed the following subsoils:




*Standard cross-section remediation Aubecken (© RMD-Consult GmbH)*

The embankment consists of coarse gravel with cobble formations:

- Young river deposits: sandy to silty
- Rhine gravel: coarse gravel with partial boulders
- Rock: mudstone with a weathering horizon of a few decimeters

In the transition area from the old works canal dam and the subsequently installed embankment of the separation dam, a cover of armor stones was found, which had not been recognized as part of the geotechnical examinations.

Basically, the rehabilitation measures from west to east could be divided into three main sections:

- West: connection of inner seal to the existing cut-off wall with a capping beam
- Cut-off wall with connection to the hard-to-drive, dense rock
- East: Cutting through the anchors instalkled during the earlier construction of the basin and connection to the inlet and outlet structure of the reservoir

**Inner seal**

Due to the soil conditions with cobbles and boulders, a seepage cut-off by driving of sheet piles was not possible here. Therefore, it was decided to tender for replacement-drilling with a diameter of 880 mm, which should be filled with sand gravel material of the grain size 0.06 / 8 mm. The aim of the replacement drill holes was to clear out the gravels interspersed with cobbles to enable sheet pile installation and to gain insights into the elevation of the existent rock or weathering horizon. In addition, information about the required sheet pile lengths was to be collected and the straightforward installation of the sheet piles was to be ensured. The quantities of soil material to be exchanged were thus approx. 13,500 $m^3$.

**West connection:** The tight connection between the designed sheet piles in the area of the dam crest and the existing diaphragm cut-off wall with a capping beam on a length along the fall line of the embankment of approx. 10 m should be ensured at the western connection using a jet-grouting wall, which is made through the asphalt concrete lining of the Aubecken basin. A minimum wall thickness of 1 m was required. Other forms of injection were excluded in advance by the expert panel.

**East connection:** Similar to the separation dam, the cuttings from the replacement drilling should also be replaced here. The connection to the inlet and outlet structure itself should be made by two jet grouting columns - one on the downstream side and one the upstream side.

Several special proposals and variants of the advertised measures were presented in the tender evaluation. After extensive discussions and assessments by the expert panel, the decision was made to award BAUER Spezialtiefbau GmbH to install the cut-off by the Mixed-in-Place (MIP) method. The following rehabilitation measures were offered and executed accordingly:

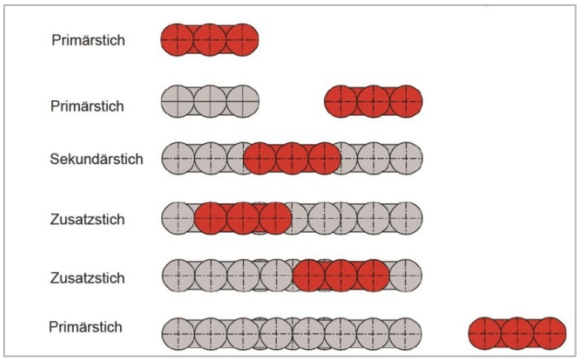
- Cut-off wall: MIP wall without pre-drilling with connection to the rock by passing through the weathered mudstone layer.
- West connection: temporary embankment supported by a steel structure and a 3-row grout curtain from the embankment by jet grouting
- East connection: pre-drilling with bored pile rig. Remove steel parts and coarse stones and backfill the hole. Production of the cut-off wall by means of MIP device. Connection to the inlet and outlet structure by means of two jet grouting columns.

**Mixed-in-Place method**

The patented Mixed-in-Place method has been successfully implemented by Bauer for over 25 years in flood protection, but also for retaining walls and foundation measures. The main feature is the in-situ mixing of the existing soil with a suspension of cement and bentonite. The soil is broken up by means of a triple auger and the binder slurry is incorporated. The triple auger is drilled with the addition of slurry to the final depth. During the subsequent homogenization process, the direction of rotation of the individual augers is varied so that a vertical material cycle in the MIP panel is created.

*Production of the Mixed-in-Place wall by means of an RG 25 with triple auger (© BAUER Group)*

To ensure a continuous, jointless wall, the MIP walls were constructed in a double back-step method, which ensures that each wall element is passed through and mixed at least twice by the triple auger.




*Manufacturing sequence "double pilgrim step" in the Mixed-in-Place method (© BAUER Group)*

Advantages of the mixed -in-place method include:

- By using the triple auger with continuous flight, heterogeneous, layered soil structures are homogenized and processed into a uniform soil mortar with constant material properties.
- Thanks to the use of the existing soil as a construction material or as aggregate, resources are saved; costly transport of cuttings or concrete for pile production is avoided. Compared to the tendered sheet piles, significantly lower $CO_2$ emissions already resulted from the less energy-intensive production of the starting materials.
- MIP technology has a clear advantage in terms of a holistic life cycle assessment compared to conventional specialist foundation engineering methods.
- Low-vibration wall production through rotary drilling protects previously damaged dams. In addition, noise emissions are reduced to a minimum.

- High productivity results in a short construction period - in this project, the execution time was approximately halved compared to the originally planned procedure, which included replacement drilling and the insertion of sheet piles.

Bauer produced a total of 13,500 m² of cut-off wall with a design width of 550 mm over a length of 980 m. The drilling depths ranged from 12.5 m at the intake structure in the east to 20.4 m at the western terminus of the separation dam to be remediated. The MIP works were carried out from early October to early December 2016 in day and night shifts. An RG 25 of the RTG pile driving technology with triple auger was used as well as a BAUER BG 24 H rotary drilling rig executing the replacement drillings in some areas. Furthermore, the gap was closed to the existing sealing by means of jet grouting (HDI).

**Challenges in the construction procedure**

With a crest width of only 8.15 m, the working area on the separation dam was severely restricted, with no alternative areas. Another complicating factor was that the construction site area - virtually a dead end - was only accessible from one side. Even the difficult, extremely heterogeneous surface conditions presented a challenge. Especially the anthropogenic embankments with armour stones, which partly had to be removed with replacement drilling, as well as the integration into the upcoming rock, which was partially overlaid by Nagelfluh banks, put special demands on the equipment and tools used and extended the previous application limits of the Mixed-in-Place method clearly. By means of the patented on-line verticality measurement in the augers, deviations in the area of very large boulders could be detected immediately and additional re-mixing arranged. Due to the 110 KV lines near the drilling axis, it was not possible to bypass the critical area with further MIP panels. Therefore, the gap closure was created by the creation of HDI columns.

Likewise, special measures had to be taken in terms of occupational safety. Since the works canal has a significant flow, the wearing of a life jacket was mandatory for the construction site staff. In addition, a fall protection was placed in the work area. Furthermore, the RG 25 was also retrofitted with a traversable walkway. Since work was also carried out at night, anti-glare lighting of the entire construction site area was a matter of course.

After the scheduled completion of the overall measure in February 2017, there was an unpredictable leak in an area immediately adjacent to the intake structure, which was outside the dam area remediated by Bauer. Obviously, water from the Aubecken basin reached the 1.5 m wide gap filled with coarse material between the northern side wall of the inlet and outlet structure and the former retaining wall. From there, it could then reach beyond the executed MIP wall via the existent anchor holes that were not permanently sealed at that time. This gap was subsequently successfully closed by means of jet grouting.

**Test filling**

After completion of the remediation work, a trial was carried out in order to be able to evaluate the quality of the new sealing level in the area of the separating dam and to observe the buoyancy conditions on the asphalt concrete lining in the area of the separating dam. Measurements showed that the dewatering system of the dam body via the existing drainage in the area of the dam foot worked very well and there was no need for additional relief holes in the area of the embankment. The evaluation of the data also showed that the measure reduced the fluctuations in the groundwater level by an average of 84%. In particular, the maximum groundwater levels in the separation dam could be reduced by an average of approx. 2 m. Thus, no high flow gradients occur in the separation dam, which in the past could lead to internal erosion processes in the dam body.

**Summary**

Even when deciding on the special proposal to bring in an MIP wall, it was clear that this procedure would test the limits in several areas. The quality assurance measures such as the actual water gauges and the permanent and later graphically evaluated display of the individual MIP wall panels together with the systematic of the MIP wall method that can be produced without disturbance through the weathered into the dense rock, nevertheless gave preference to this method. Last but not least, of course, the reduced costs, the shorter construction period and the lower demand for material transports were significant in the decision-making process. The remediation works, which were completed in February 2017, will now ensure the continued operation of the Aubecken for many decades to come.

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