

Dam Safety for new and aging dams – seepage control using advanced construction techniques – tailor-made to meet the individual project and owner's needs

P.E. Banzhaf

BAUER Spezialtiefbau GmbH

PO Box 12 60

86529 Schrobenhausen

Bavaria, Germany

Introduction

Engineering for safe dams is a vital contribution to the safety of the riparian public, to the infrastructure and the environment in the vicinity of dams particularly downstream in their lower lying areas. Additionally, it is a significant contribution to the sustainability of the structure; reducing maintenance cost and preserving the owner's investment to a high degree.

The safety of dams, particularly of embankment dams, is greatly dependent on seepage control – to control seepage through the dam body and not less important through the foundation of the dam. For new dams economic solutions are provided tailor-made for the particular project; in accordance with the specifications given by the owner's engineer and in consistency with the local geology and material availability – economic and environmentally suitable solutions are found, agreed and installed within the given time schedule.

With a range of foundation engineering techniques the experienced contractor is prepared to support the best solution found preventing undue seepage in and/or under the dam. Drilling and grouting, whether standard penetration-grouting or high pressure jet grouting, could be the technique chosen considering factors like geology, design and economy. More defined cut-off barriers are produced by positive cut-off walls, like secant pile walls or diaphragm walls. Such concrete walls having a defined shape, are installed in all types of geology and are quality controlled throughout the entire process from testing to successful completion. Likewise very economic mixed-in-place walls are being installed in suitable geology to the system-depth.

1. Overview

The available and proven geotechnical/foundation engineering techniques to successfully and durably mitigating seepages are allowing a wide range of design options to adequately serve the developer and investors interest. Providing project specific design solutions incorporating correspondingly environmental and socio-economic approaches, it is important to have knowledge of all opportunities and the wide range of techniques available to specify the best foundation and or seepage mitigation solution for a durable and safe project.

1.1. Techniques available

A wide range of foundation engineering techniques with long and successful history is available by experienced contractors to install barrier walls in almost any soil and rock conditions. For the project-specific planning during feasibility stage or design stage, consultation of such contractors is advisable should in depth and state-of-the-art technical knowledge be required.

1.1.1. Drilling and Grouting

Drilling and grouting is no "positive cut-off" (see ICOLD Bulletin 129 Dam Foundations) but is typically used to construct barriers installing grout curtains – typically in rock as the approach is not normally applied to overburden foundations (see ICOLD Bulletin 129 Dam Foundations).

Drilling and grouting in sandy and river-borne material for a grout curtain barrier is typically executed using the tube-à-manchette (TAM) or sleeve pipe technique to inject low viscosity grout into the pores of the soil. Dependent on geology, the designer may consider the temporary aspect of grout curtains in soil or in specific types of rock (i.e. Karst).

1.1.2. Slurry Walls

Slurry walls executed using the diaphragm wall technique or continuous trenching with backhoe, draglines or trencher have been installed successfully since the middle of the 20th century. Excavated rectangular trenches of different lengths as permitted by the present geology are backfilled with soil-bentonite or soil-cement-bentonite or with concrete depending on the specified wall purpose and requirements. See as well 1.1.4. Positive Cut-off Walls. Slurry walls using continuous trenching typically are designed as downflow baffle with no explicit rock embedment but merely elongating the seepage path preventing the downstream part of the levee or dam to get under undue uplift.

1.1.3. Mixed-in-Place Walls

Mixed-in-place walls installed as permanent barrier walls in a dam or a dike/levee have been used for more than 30 years as a durable and cost-effective method to install a defined cut-off. As is typical for defined (positive) cut-off walls, likewise mixed-in-place walls are properly quality controlled and well documented. Specific project oriented designs allow for temporary overtopping of the structure, for example at extreme flood events. Restoration of the structure (i.e. a levee) after the flood event is simpler and more economical.



Fig. 1. Mixed-in-Place 3-auger technique. A permanent MIP-wall prevents levee to collapse during flood event. © BAUER Spezialtiefbau GmbH

1.1.4. Positive Cut-off Walls

Concrete walls as a secant pile wall or as a diaphragm wall using ductile plastic concrete have been installed for dams since the 70ties of the 20th century. Solutions for the interface cut-off wall to the core are available and established over decades. The significance of the positive cut-offs are the defined layout and form of the wall as well as the defined material installed contrary to grouting techniques. Quality management, particularly quality control is comprehensible and reproducible, therefore easy to document. Wall continuity, as an example, is provided by experienced specialist companies online to allow for instant checking of the element depth, the embedment into the desired strata and the overlapping of the elements assuring the wall continuity.

1.2. Governing factors and basis for the decision making

The aim to support the investor, owner and their engineers in their decision making for the best technical solution for the necessary, **safe and economic seepage mitigation measure**, to install the optimal solution for a barrier in the dam and/or its foundation, or in the cofferdam required to build the new dam, the knowledge about available techniques is important. Similarly these techniques could be used for uprating and refurbishment of existing embankment dams.

The latest state of suitable foundation engineering techniques provide relevant factors to assist in making the best choice for the individual project and offers a selected range of techniques resulting from the lessons learned on projects recently completed.

Governing factors for the decisions are dependent on the purpose of the individual project but classically include:

- Dam safety aspects
- Durability aspects including reduced maintenance cost
- Environmental aspects

- Economic aspects
- Available material resources in the area of the project (both environmentally and economically relevant)

Not considered here are ground treatment techniques (including biological treatments) and driven cut-off walls.

2. Project Example – Case Studies

The significant topic of selected project examples are meant to illustrate the advantages of the techniques used at the specific project. Apart from providing the specialist equipment, most important is the confirmed experience of the selected contractor and its personnel dedicated to the project to assure the desired product, quality and therefore success of the project.

2.1. Grout Curtain at Punatsangchhu-II, Bhutan

The Punatsangchhu-II hydroelectric power project (PHEP-2) is a run-of-the-river hydropower project on the Punatsangchhu River in Wangdue Phodrang Dzongkhag of Western Bhutan. For the temporary function of the upstream cofferdam a grout curtain was specified to reduce the permeability in the alluvial and colluvial river-borne material to 5×10^{-5} cm/sec during the excavation for the foundation of the main dam and its construction to a safe level above the water table. The permeation grouting under the upstream (U/S) cofferdam was applied throughout the entire alignment with three rows of drilling and grouting across the riverbed at a length of about 183 m. One row upstream and one row downstream were executed as cement permeation grouting and the centre row as gel grouting. The drilling was executed to a depth range of 7 meters to 43 meters, ~30 meters in average and had to key in 1.25 m into bedrock. A total of 30,604.48 linear meters had been treated.

Drilling and grouting was chosen as the cut-off served a temporary function only, still being very important for the safety and unhindered working in the excavation pit. The grid of the three row grout curtain contained a spacing of 0.5 m with spacing of 1.5 m row distance. The task was the reduction of seepage to a level resulting in the Lugeon value of less than Lu 100.

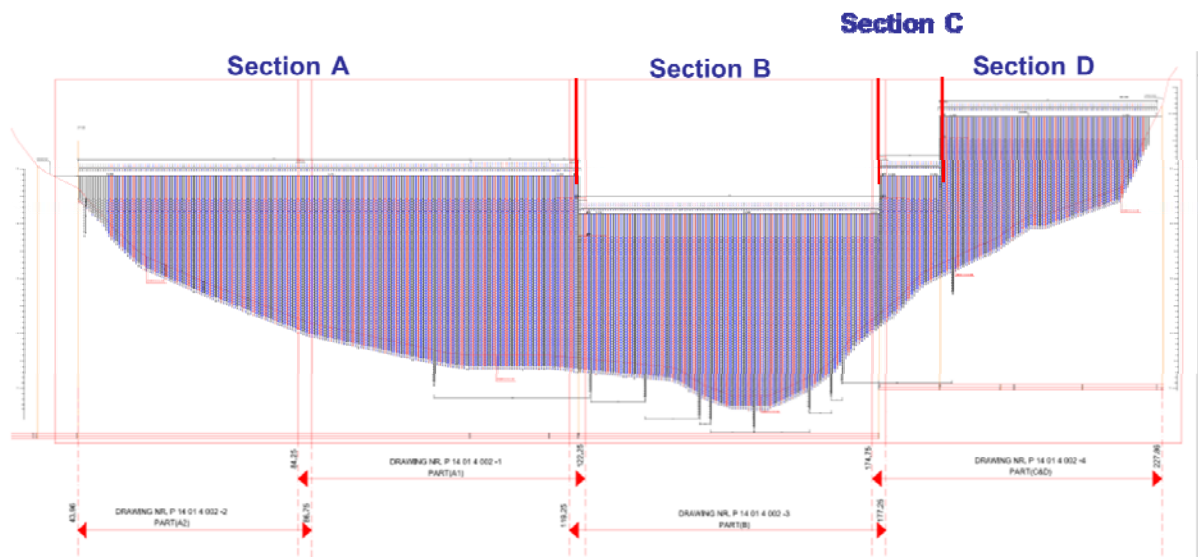


Fig. 2. Layout of the temporary grout curtain at PHEP-2 across the river bed at the upstream cofferdam.

Quality control particularly while drilling in river-borne material with cobbles and boulders of unknown size at unknown depth is critical for the success of the seepage barrier.

2.2. Slurry wall at Albion Sands Fort McMurray, Alberta, Canada

In 2008 Shell awarded works to execute a 70,000 m² soil-bentonite cut-off wall at Albion Sands Expansion I. The purpose of the barrier wall was to establish environmental protection for the adjacent Jackpine River next to the new mine facility. The scope was the installation of a 2.6 km long and up to 50 m deep cut-off wall. After the installation of a 40 m wide working platform, up to 8 m high, the excavation of the trench was performed by a long-boom-long-stick excavator (Longstick) down to an average depth of 18 m. The further excavation of the trench to the final depth of maximum 50 m, including the key into the naturally impermeable oil sand layer, was executed by crane mounted clamshells.

The partially very hard soils required additional measures during excavation. Chisels were used to break up local obstructions like boulders in the trench. Part of the area to be trenched was crossed by very dense sands and sandstone layers. These layers had to be pre-drilled by hydraulic drilling rigs to a maximum depth of 48 m to loosen the soil. The trench being 0.90 m wide was filled with a soil-bentonite mix, thus giving the wall a permeability of 1×10^{-9} m/sec. Permanent on site laboratory facilities and personnel guaranteed the quality of the soil-bentonite mixture and placement.

2.3. Cutter-Soil-Mixing Wall at Fort McMurray, Alberta, Canada

The project was governed by two main factors: schedule and temperature. The specialist foundation-engineering contractor had been approached to execute a cut-off wall that was approximately 900 m long and up to 13 m deep at the South West Sand Storage (SWSS) at the Syncrude site. The main criteria were the execution during severe winter conditions, as the Fort McMurray region is known for its cold conditions from November to March. The construction of the wall in these winter conditions created many unique problems with handling equipment and materials that BAUER Foundations Canada had to solve.

A common soil-bentonite wall was not possible due to the freezing of the slurry in the open trench. Frost would also prevent the mixing of the excavated material with the slurry and bentonite powder to create the homogenous soil-bentonite mixture as usually used. The solution for this project was a Cutter-Soil-Mixing (CSM) wall. The Bauer CSM-method allows the bentonite-cement-slurry to be injected directly into the soil at the location of the treated wall. Only the first 0.5 m to 1 m of frozen soil had to be removed to create a small trench to contain any overflowing suspension. The specialist foundation-engineering contractor's solution for handling the slurry preparation equipment was to set up the mix plant inside a large heated tent. To guarantee that the slurry would not freeze while being pumped from the tent through a heated booster station on to the machine up to 500 m away, the slurry line had heated connections and insulation wrapping the line. The mixing was performed by a BAUER RTG 19 with a BCM 10 cutter attachment. To speed up the production process of the cutter pre-drilling was performed by a BG 18 and a continuous auger. This enabled the contractor to treat the sandy soils and to finish the project on time allowing the client to continue operations without any impact on the production.

2.4. Mixed-in-Place (MIP) Wall at Sonthofen, Germany

After floods in 1999 caused extensive damage along the River Iller in southern Germany, the embankments were post sealed by vertical cut-off walls constructed by the triple-auger Mixed-in-Place method, a technique developed in specialist foundation construction. During the floods of August 2005, the embankments were subjected to a severe test earlier than anticipated. The result: the embankments withstood the lateral pressures caused by the extremely high water table of the river.

The flood protection management concept developed after the 1999 flood event combines all the different components of modern flood protection:

- Semi-natural river alignment
- Creation of flood water retention basins
- Dam strengthening.

The improvement of the existing embankments along the Upper Iller River was a major part of the programme of proposed construction measures.



Photo 1. Levee-embankment being overtopped by flood water – MIP-cut-off wall still being in place.

Construction Measures

To avoid complete reconstruction of the embankments, which would bring them into full compliance with current standards, but at an extremely high cost, vertical barriers against erosion were installed in plastic concrete. These reduced seepage and thus increased the stability of the embankments. By incorporating additional measures, the cut-off walls can be executed as "structurally effective" walls. This enables bending moments to be accommodated that could result, for instance, from a partial destruction of an embankment. From 2001 until 2005, a total of around 71,000 m² of cut-off wall was installed in the various sections of the embankment improvement scheme between Kempten and Oberstdorf using the MIP process patented by Bauer Spezialtiefbau GmbH, Germany.

MIP - the Mixed-in-Place Technique

During the MIP process soil is mixed in-situ with binder slurry into a soil-cement body. Three parallel continuous flight augers each with a diameter of 370 mm are mounted at the front of the leader of a heavy-duty drilling rig. To construct the cut-off wall, the triple counter-rotating augers are drilled into the ground whilst binder slurry is simultaneously injected. On reaching the terminal elevation, the soil-binder mixture is homogenized by alternating rotation of the individual augers and concurrent upward and downward movement of the entire auger assembly. The result is a solidified continuous body of soil the geometry of which is defined by the geometry of the auger unit. To ensure the construction of a continuous wall free of joints, individual panels are constructed in an alternating sequence of overlapping primary and secondary panels, followed by a remixed panel. The width of the primary panels is 1.20 m, the ones of the secondary panels 0.80 m. The construction sequence is characterised by additional re-working of the overlaps between primary and secondary panels. This ensures that each section is penetrated and reworked twice by the triple counter-rotating auger unit. Due to the continuous "wet-into-wet" construction sequence of primary, secondary and remixed panels, the resultant wall is virtually without joints. The use of the triple auger unit in conjunction with the double-alternating construction sequence ensures that every section of the wall is thoroughly mixed through.

Plant and Equipment

Construction of the walls was carried out with the smallest rig generally used in MIP technology, a drilling rig of type BAUER RG 15 T. Both drilling rig and slurry mixing plant type MAT SCW 10/26 CP were designed and built by specialist foundation equipment manufacturing companies of the BAUER Group.

2.5. Cement-Bentonite Single-Phase Cut-off Wall at Assiut Barrage, Egypt

The Assiut Barrage is a barrier structure across the river Nile in the vicinity of the city of Assiut in Upper Egypt (400 km south of Cairo). Between 2000 and 2005, the Egyptian government commissioned an extended feasibility. Based on the results of the feasibility study the decision was made to proceed with the project of constructing a new barrage structure approximately 300 m downstream of the existing barrage. The main works for the project were awarded to the Egyptian – French New Assiut Barrage Joint Venture. Due to the vast experience in both, cut-off wall construction and previous dam projects on the Nile, Bauer was awarded the sub-contract for specialist foundation engineering works.

The engineering works were designed by the Assiut Barrage Development Consultants with robust input from Bauer in the design properties of the temporary single-phase cut-off wall and the cut-off wall material. In a first step Bauer constructed 60,000 m² of temporary single-phase cut-off wall for the ring dam with 38.2 m in depth and 0.8 m thickness. Within the dry excavation pit of the temporary ring dam Bauer then constructed about 12,000 m² of permanent double-phase cut-off wall with varying depths between 20 and 30 m to successfully create a cut-off under the future barrage.

2.6. Concrete Cut-off Wall at Bagatelle Dam, Mauritius

The Bagatelle Dam project is located on the Terre Rouge River, circa 20 km southeast of Port Louise and is a new dam reservoir used as a water retention system for the regional potable water supply.

The installed plastic concrete cut-off wall provides the necessary vertical underground sealing below the actual earth fill dam section for a new water reservoir and extends over a length of 2.4 km.

The permanent cast in-situ plastic concrete cut-off wall has a nominal wall thickness of 800 mm throughout the entire length, but was divided into three main sections (Left Bank, Central Part and Right Bank) as defined in the technical specifications mainly due to the strong variation of the local geology.

Approximately 57,000 m² cut-off wall was completed in May 2015 which included a large percentage (20,000 m²) of excavation through moderately weathered and slightly weathered basalt in order to reach the designed toe-levels. The average excavation depth was 24 m with the maximum depth reaching up to 44 m. Within the Central Area up to 28 m heavy basalt layers had to be excavated to reach the specified toe level of the cut-off wall. The works were

executed by utilizing up to three BAUER cutter units type BC 40 and two grab units over a construction period of 14 months.



Photo 2. Permanent concrete cut-off wall excavation by Bauer Trench Cutters at Bagatelle Dam Project.

References

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2. Web page BAUER Dam Contractors <http://www.bauerdamcontractors.com/en/>
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The Author

Peter Banzhaf, a University Diploma Civil Engineer, who studied in Munich, Germany, joined BAUER in 1983. Starting as site engineer he has been in positions of Managing Director of subsidiaries and Project Director with BAUER Spezialtiefbau GmbH, Germany for more than 25 years. He is primarily focused on barrier wall construction and management. As a director Peter Banzhaf has managed BAUER Spezialtiefbau GmbH's Specialists Department overseeing the execution of all foundation engineering techniques and completing more than 2,000,000 m² of diaphragm and cut-off walls until 2007.

In the past 25 years his job responsibilities have required him to work for BAUER on projects in many parts of the world; at present he heads a team of engineers for Dam Services in BAUER Spezialtiefbau GmbH providing consultancy for the planning and implementation of foundation engineering techniques for hydro projects. Peter Banzhaf is a Member of DTK, the German member of ICOLD, a Member of USSD, a member of CDA and a member of SANCOLD.