Cut-off Wall Technologies in Mining

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Abstract

Cut-off wall technologies are widely used in civil engineering, in dam and dike construction, for temporary and permanent groundwater barriers. Innovative construction methods and cut-off wall equipment have been developed over the last 40 years and grow the application of cut-off walls to a large variety of construction sites with vastly different constraints and subsurface conditions, both in civil and in mining related projects. Also in environmental cases cut-off walls are used to enclose contaminated areas or to direct contaminated ground water to a central water treatment facility.

During the construction of deep foundations in groundwater bearing strata or for the construction of e.g. concrete dams with powerhouses in river beds, temporary cut-off walls in coffer dams are commonly used to minimize dewatering efforts during the construction phase. Permanent cut-off walls form a seepage barrier in or underneath new built dams, but also in existing dams which needs to be remediated against seepage through the dam itself or through the foundation under the dam and the consequences of such seepage. Permanent cut-off walls are also used in dikes where temporary flood events with high seepage and underflow, risk the overall dike stability.

In mining, such systems are more and more applied due to their proven, long term reliability and due to the increase in mine safety regulations. Cut-off systems minimize the influx of ground water or surface water into open-pit mines, allow the development of open-pit mines extending from onshore into nearby lakes or even oceans. Since more and more low grade deposits are mined with higher volumes of tailings and higher grades of toxic materials in the treated tailings, cut-off walls in tailings dams become necessary to mitigate the risk of mine water to contaminate nearby ground water systems and surface waters and minimize the amount of seepage water to be treated before release to the environment. Cut-off walls may also help to achieve better acceptance of tailings ponds from the authorities and the public which are very critical towards mining and its tailings dams after various collapses of tailing dams in recent history.

Key words: cut-off wall, mining, tailings dam, ground water flow, seepage

1. Water Dams versus Mine Tailing Dams

Tailings dams and water dams are designed for fundamental differences from construction til closure.

* Tailings dam must safely contain tailings and process water with various contaminants. Water dams contain water only.
* Active operational life time of a tailings dam is for about 10 to 30 years. Water dams are designed for about 100 years and more
* After Mine closure, tailings ponds still have to safely contain the tailings for perpetuity. After the closure of water dams, the water is released without any further safety concerns.
* Construction of tailings dams happens normally in stages over the life of a mine. Construction of water dams is in one construction phase.

2. Classification of risks for tailings dams

Tailings dams are exposed to risks which can cause severe consequences to the environment, not only in the case of failure, but also in case of uncontrolled seepage or Acid Mine Drainage AMD.

* Internal instability due to design mistakes, improper construction or unsuitable materials used in construction
* Long term erosion of the dam body by seepage with piping effect
* Instability by overloading with tailings and mine water
* Instability caused by flooding and overflow
* Instability caused by leakage through the foundation of the dam with piping effect
* Instability caused by settlements of the foundation
* Instability caused by seismic events
* Instability due to chemical reaction between the cutoff medium and the contaminants

To minimize most of the risks listed above, a positive tailor made cut-off wall in relation to erosion stability, chemical stability, permeability and flexibility is the solution of choice.

3. Cut-off wall systems

Depending on the soil formations encountered, the design depth of the wall as well as the requirements for erosion stability a selection of different cut-off wall systems is available. Key to any successful, economic cut-off system is the optimum installation performance including the successful key-in at the bottom of the wall into a low-permeability soil or rock formation. The COW mix design can be tailor made to achieve the required permeability which normally is in the order of 10-8 m/sec. Cut of walls can also be designed as flexible walls to accommodate expected dike settlements and the like.

Excavation equipment	**Long reach excavator**	**Soil Mixing Systems**	**Hydraulic grab**	**Trench cutter**
Cut-off system	Soil Bentonite Wall	Soil Bentonite Wall	Soil Bentonite Wall	Soil Bentonite Wall
		Soil Cement Bentonite Wall		
			Cement Bentonite Wall	
			2-Phase COW	2-Phase COW
Depth	25 m	60 m	80 m	150 m
Soil strength UCS	0-10 MPa	0-30 MPa	0-25 MPa	0-100 MPa
Boulders / Obstructions	small	small	medium	all
Rock socketing	no	yes	no, only with chisel	yes

Figure 1 *Cut-off wall systems*

3.1. Soil Bentonite Cut-off Wall

In soft formations and for shallow Cut-off walls (COW) with low hydraulic gradients soil bentonite walls are very cost effective and therefor frequently installed. Up to a depth of about 25 m, back-hoe excavators with a long reach boom are used for digging. For greater depth and when obstructions or hard layers are encountered, mechanical or hydraulic grabs are very effective. Under normal conditions the thickness of the wall is between 30 and 100 cm. Excavation takes place by simultaneously back filling of bentonite slurry properly mixed ideally with the excavated material into the trench. The excavated soil is dumped on the ground next to the trench, sprayed with bentonite slurry, homogenized by a dozer walking across and then pushed back into the trench. Other mixing methods may provide an even better result. The low permeability of the cutoff results primarily from the native clay and the bentonite in the backfill mixture. Secondarily, low permeability results from the development of a bentonite "filter cake" on each wall of the trench and from slurry entering the voids of the formation adjacent to the trench.

A key factor in selecting the Soil Bentonite cutoff is economics, especially when the excavated material can be used to backfill the trench. This avoids trucking and only a small amount of bentonite needs to be added. Soil bentonite walls have proven to be effective seepage barriers on various projects.

Soil-Bentonite Cut-off wall for lignite mine, Vattenfall, Welzow, Germany

The mining of the lignite started almost 200 years ago. To enable open pit mining, a suitable dewatering system was required. At first, wells and drainage system were used. With the increasing demand to go deeper to enable full use of the existing resources a decision taken back in the 60[th] of the last century, the amount of water which had to be pumped increased dramatically. In peak times, approx. 1.2 billion m³/year had to be pumped. This led to a lowering of the groundwater level for up to 70 m, impacting the regional lake landscape. In order to reduce the influence on the water balance, and bring the water level back to pre1970[th], a first development took place to implement the use of specific COW system to depth of about 45m. Nowadays the surrounding ground water level can be kept unchanged with the use of such COW.

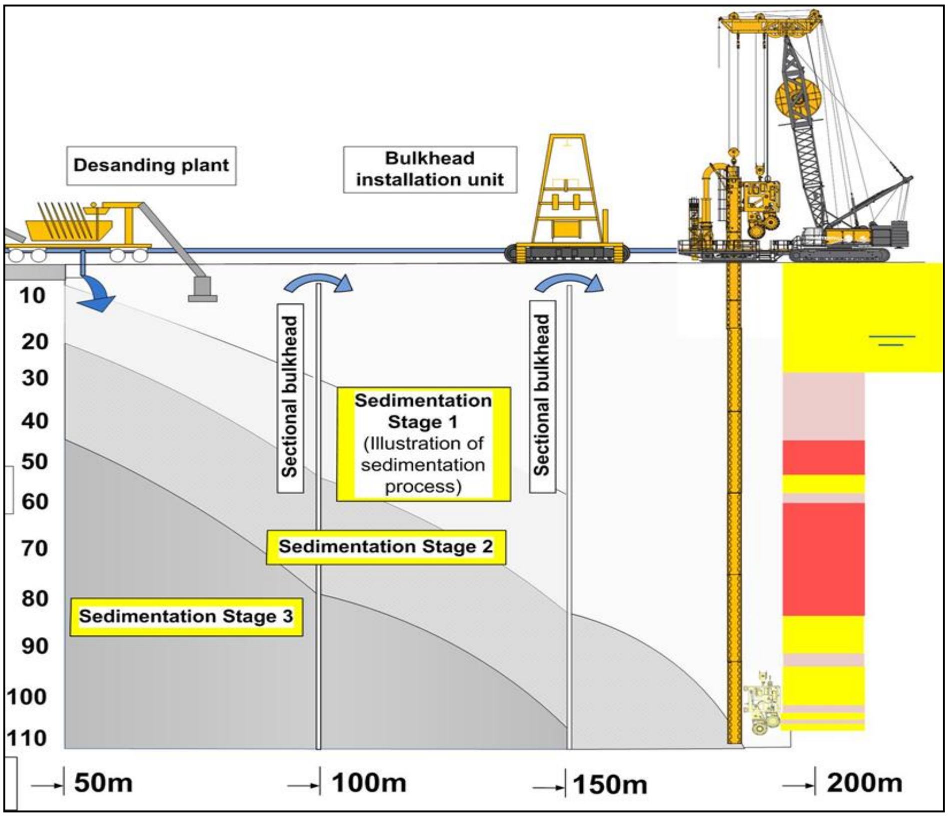

Figure 2: *Pile guided Trench Cutter Cut-off wall systems*

The pile-guided trench cutting system is a worldwide unique technique, originally developed by the engineers of the mining companies themselves. It guarantees a continuous, joint free, COW during a continuous installation process. At this specific site in Welzow, this technique has been pushed to new limits in order to address the local lake region. Depth capability has been designed to about 130m at a constant trench width of 1000 mm. This project has an approximately 11 km long COW, scheduled to be completed in a construction period of 12 years.

The system flushes special clay which forms a filter crust at the inner surface of the trench. Only natural clay resources are used, in order to achieve the cut-off effect. The effectiveness of the continuous COW construction process is based on the formation of a filter cake on both sides of the trench. Continuously, a mixture of natural clay, so called "Friedländer Blauton", and water are pumped into the fresh excavated trench. The slurry initially stabilizes the open trench according to the demands of the trench stability calculation.

Figure 3: *BAUER BCV 40 – 130 on MC 128*

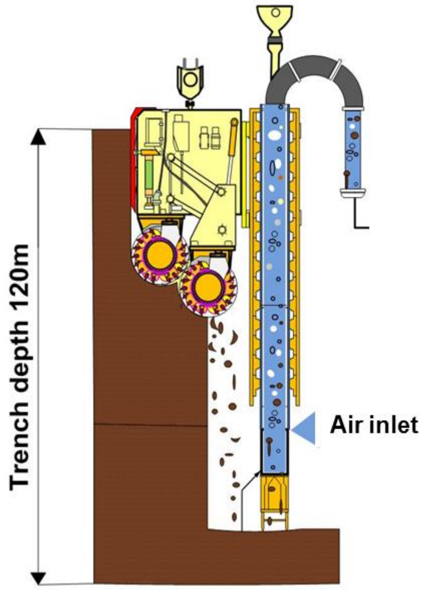

Figure 4: *Guide pile and Cutter BCV 40*

Depending on the geology met, the density varies in a range of 1.1 – 1.2 g/cm³. At the same time the slurry penetrates into the pores and the clay particles adsorbs at the trench wall surface. Already after a few minutes the filter cake then starts to grow, and a 2.5 – 5 cm thick filter cake, which is nearly impermeable, is formed after approximately three hours. The full process takes about 20 hours. Thereafter the trench will be backfilled with the screened excavation material, partially displacing the slurry in the trench over the bulk heads.

3.2. Cement Bentonite Cut-off wall

For projects with higher hydraulic gradients, erosion in soil bentonite walls may occur, leading to piping effects and instability of the dike. In such cases a cement bentonite wall, excavated by an hydraulic grab, is a suitable solution. Premixed bentonite slurry is mixed with cement and then pumped to the excavation, where it stabilizes the trench and then forms an erosion resistant membrane. Excavation by grab is performed in primary and overlapping secondary panels wet-in wet, which guaranties integrity of the of the cut off system. For harder soils, sometimes with boulders, hydraulic grabs are preferred over mechanical grab to securely achieve the required penetration depth and socketing into the specified impermeable layer. After completion of the excavation, the cement causes the slurry to harden to a strength comparable to that of a stiff clay. The cement-bentonite slurry contains no aggregate other than some suspended soil particles from the excavation process, Strength and plasticity of the hardened cement-bentonite slurry will vary, depending mostly on the cement/water ratio and the type of cement, with higher strengths having lower plasticity. The permeability of C-B cutoff walls depends on the proportions of bentonite, cement and sometimes filler used in the mix.

Cement-Attapulgite Cut-off wall, Namdeb, Pocket beaches, Namibia

The on-shore pocket beaches along the shore line of Namibia between Oranjemund and Luederitz, the so-called Sperrgebiet, are mined by DeBeers and later on Namdeb since first discovery of diamonds in 1908. Meanwhile most of the onshore alluvial deposits are mined out.

Figure 5: *Pocket beach mining area*

Figure 6: *Bogenfels*

The beach is pushed out further and further into the Atlantic ocean to allow open pit mining behind so called seawalls in dewatered pits even in areas which had been under water till now. The system however reaches its limits with the increasing water depth behind the seawall.

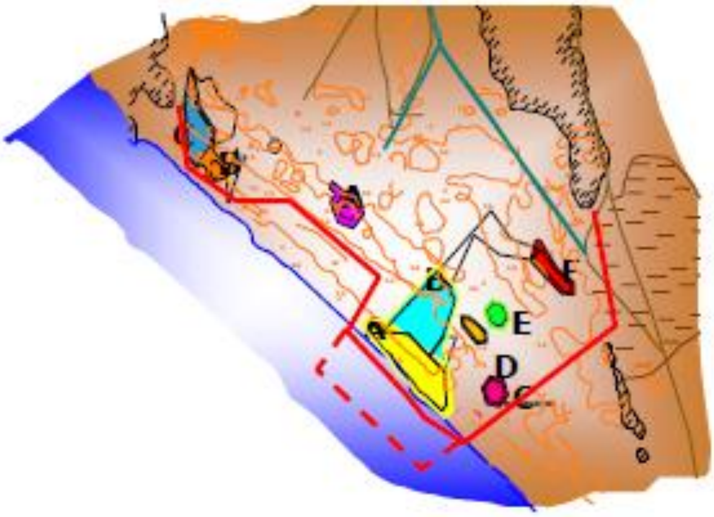

Figure 7: *Mining area with hot spots and cut-off walls*

To allow open pit mining in the dry of the diamond rich pocket beaches in vicinity of the Bogenfels, the mining area and the seawalls had to be sealed with a bentonite-cement cut-off wall to a depth of 25 m.

The design asked for a 400 mm wide cut-off wall and a slurry mix consisting of

2 x 40 kg Attapulgite
50 kg Cement
3 x 50 kg Slagment
900 kg Seawater

Since no fresh water was available in this very remote arid area, seawater directly pumped from the Atlantic had been used for the slurry mix. To achieve the required properties Attapulgite had to be used instead of bentonite, which also forms gel structures when mixed with salt water. The fresh slurry finally had a density of around 1,20 kg/dm³ and reached a compressive strength of 1,2 N/mm² after 35 days. Excavation of sections of the completed wall showed a final wall thickness of around 45 cm.

Figure 8: *Cut-off wall installation BAUER GB 60*

Figure 9: *Excavated cut-off wall*

In total approximately 54.600 m² Attapulgite-bentonite cut-off wall had been installed over a length of approximately 3000 m to allow for the safe mining of the diamond hot-spots in the Bogenfels area over a period of 2 years, including waiting periods when moving the dredger from one mining spot to the next.

3.3. Soil Mixing Wall

To minimize or even prevent disposal of excavated material during cut-off wall construction and to minimize the amount of self-hardening slurry used, active soil mixing systems are nowadays state of the art technology. Best results in quality and performance can be achieved in uniform soil formations. Limitations of the systems are in difficult, mixed soils with boulders and hard soils and rocks.

The BAUER Cutter Soil Mixing (CSM) system is technologically the most advanced system, using a modified trench cutter technique for constructing a cut-off wall. Deep Auger Mixing Systems are also frequently used but face various limitations compared to CSM.

The two counter rotating CSM cutter wheels penetrate into the ground at a continuous rate. The soil matrix is broken up by the cutting wheels and at the same time a fluid is pumped to the nozzles set between the cutting wheels, where it is mixed thoroughly with the loosened soil. Adding a compressed air stream can improve the breaking and mixing process in the down stream phase. The rotating cutter wheels cutter teeth push the soil particles through vertically mounted shear plates with the effect of a compulsory mixer. The penetration speed of the cutter and the volume of fluid pumped in are adjusted by the operator to create a homogeneous, plastic soil mass which permits easy penetration and extraction of the machine.

Having reached the design depth, the soil mixing cutter is slowly extracted while cement slurry is continuously added. Homogenization of the liquefied soil mixture is ensured by the rotation of the cutter wheels. A continuous wall is formed in a series of overlapping primary and secondary panels. Overcutting into fresh adjacent panels is called «fresh-in fresh method», but also the «hard-in-hard method» is possible, whereby the panel is cut into already hardened primary panels

For greater depth a two-phase system is recommended with bentonite only slurry introduced during lowering the cutter and cement slurry is added and mixed with the soil cuttings during retrieval of the cutter.

CSM wall, Herbert Hoover Dike, Lake Okeechobee, Florida, USA

The Herbert Hoover Dike (HHD) is a 143-mile earth dam that surrounds Lake Okeechobee, the heart of the Kissimmee-Okeechobee-Everglades system. The dam was built after several devastating hurricanes with flooding in the period from 1930 to 1937.

Figure 10: *Hurricane 1928*

The project reduces impacts from flooding as a result of high lake levels for a large area of south Florida. Since 2007, the Army Corps of Engineers has made a significant investment of over $500 million, in projects designed to reduce the risk of catastrophic failure of the aging structure. Actions taken include the installing of a partial cutoff wall in several dike sections which helps reduce the risk of failure by eliminating existing piping and preventing additional internal erosion through the dike and foundation. The rehabilitation is still ongoing in several sections and is planned to be completed in 2021.

Prior to the installation of the soil mixing wall bigger lenses with peat in the upper half of the wall had to be predrilled and the peat removed since the organic ingredients of the peat prevent the cement in the slurry from hardening and thus having a cut-off wall with open windows.

Figure 11: *CSM installation with RG 25 S*

Figure 12: *BCM 5 CSM Cutter wheel assembly*

Installation of 5,6 km, 640 mm wide cut-off wall was executed with two BAUER BCM 5 on base carrier BAUER BG 28 and on RTG RG 25 S, a cutter with 5 tom torque on each cutter wheel 2013 and 2014 to a maximum depth of 17 m. The slurry introduced consisted of a mix of slagment and bentonite with a compressive strength between 0,7 and 3,5 MPa and a permeability of 1 x 10-8 m/sec.

3.4. Two-phase Cut-off Wall

For great depth and difficult soil and rock conditions, the two phase cut-off wall is recommended, where excavation takes place under bentonite slurry to final trench depth and replacing the slurry in

tremie method by a lean concrete mixed to special properties for each project in regards to permeability, erosion stability and plasticity.
Depending on depth and also on the soil conditions, which may constitute a risk to verticality, the width of the Cut-off wall can be selected from 800 mm to 2000 mm. Modern cutter systems can be equipped with hose winding systems which can reach down up to 250 m. Trench cutter can be fitted with various type teeth to penetrate different soils as well as boulder and rock and are best suited to achieve a proper seal at the bottom of the wall penetrating sufficiently into pre-determined low permeable layers. The over-cut joint system between primary and secondary panels is an excellent system to minimize leakage through the joints even for extremely deep cut-off walls.

Two-Phase Cut-off wall, Teck Cominco, Red Dog Zinc Mine, Alaska

To extend the life of the Red Dog Mine for another 20 years by mining the so called Aqqaluk Deposit also the capacity of the tailings pond needed to be heightened by about 10 m and forced by tightened mine regulations seepage through the foundation minimized.

Figure 13: *Red Dog Mine, Alaska*

Due to the arctic conditions on site and the limited access by sea and road for only 100 days a year, three arctic summers were needed to execute 53.300 m² cut-off wall in hard rock conditions over a length of 1500 m, with a wall thickness of 800 mm. Due to the ph value of 3,5 of the mine water in the pond, with high concentrations of heavy minerals and other chemicals, seating into the shale rock base was mandatory. Also to avoid any seepage, even in case of melting of the permafrost, the wall had to be socketed in competent rock, which was specified as 1 m core length with maximum one visible crack, to a depth of 48 m and UCS of more than 150 MPa. In consequence quite a number of panels had to be seated 25 m deep into fairly hard rock.
Grouting was no options, since the voids and cracks are filled with frozen water in permafrost which cannot be replaced by grout.

Figure 14: *Cut-off wall installation with cutter BC 40*

3.5. Sheet-pile walls

Due to their easy and fast installation, but limited depth reach to about 30 m, sheet piles are often used as temporary barrier during construction in water like harbor and bridge foundation construction, but can be re-used several times. In areas with limited space, sheet pile walls are quite common for flood water protection in dikes or instead of dikes.

Figure 15: *Construction of a ship lock near Quitzöbel, Germany. Sheet pile installation with RTG RG 19T and Top Vibrator MR 105 V*

Sheet pile wall, Waikaia Alluvial Gold Mine, Northern Southland, New Zealand

In rare cases sheet piles are used also in mining applications to allow for easier dewatering or minimizing water influx into mining cells.
The Waikaia Gold mine in New Zealand sits in a environmentally very sensitive tourist area with very high ground water table along the Waikaia river which is also famous for trout fishing and gold panning. The Waikaia valley was first panned for gold in the early 1860s and up to eight dredges operated by the early-1900s.
Sited in mining cells a few hundred meters from the Waikaia River, a recovery plant floats in a pit up to 16m deep, surrounded by vertical sheet piles up to 19 m deep, installed by RTG RG 19T with top vibrator MR 100 to minimize ground water seepage and protect from flooding. The floating plant is fed with ore by an excavator and the tailings are fed back ashore. The pit water is pumped to settling ponds, to remove solids, before going into the Waikaia river.

Figure 16: *Sheet pile installation with RG 19T*

Figure 17: *Mining area with settling ponds*

5 million cubic meters of gold bearing gravels and 17 million cubic meters of overburden will be mined by Waikaia Gold Ltd over the 7.5 year mine life producing approximately 145,000 oz of gold. After annually removing 2 million to 3 million cubic meters of topsoil and gravel, which is then used as backfill as the pit is dug and sheet piled further up the mining cell, about 700,000 cu m will be

processed through the floating plant every year. Once the mining cell is backfilled, the sheet piles are recovered with the same rig as for installation and used for construction of the next mining cell again.

Figure18: *Floating recovery plant*

Over the seven to eight-year mine-life, the mine site will work its way about 5km upstream, then be shifted across the road to an adjacent stream, and might be shifted back downstream on the other side of the Waikaia River.

Conclusions

To achieve best results to minimize seepage into and out of mines and tailings ponds, cut-off walls are the best systems available to protect the mines and the environment. With various systems shown, the cut-off wall design can be optimized to every single mine in regard to seepage control and cost-efficiency.

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