UTILISATION OF DEEP GROUNDWATER BARRIER WALLS USING SOIL BENTONITE AND BIOPOLYMER SLURRIES IN GEOTECHNICAL AND ENVIRONMENTAL APPLICATIONS

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1. INTRODUCTION

Menard Bachy has carried out over the last 15 years a large number of groundwater containment structures utilising a wide range of techniques. One particular technique is the Soil Bentonite (SB) wall which is one of the most efficient, cost effective and environmentally friendly solution to implement in-situ cut off (low permeability) walls. SB walls have been utilised historically for a wide range of applications including confinement of contaminated ground water around landfills, toxic tailing ponds but also for the improvement of performance of dams and other types of water retention structures. In the delivery of complex projects SB walls have also been utilised in combination with other mechanical and hydraulic structures such as PVC membranes, hydraulic gates, leachate collection trenches, and sumps but also sheet piles and other retention systems.

For the particular case of sites presenting environmental challenges, involving soil and groundwater pollution, a strategy requiring both removal and treatment of the source of the contamination as well as control of the contaminated groundwater plume acting as the pollution carrier is required. In the case of urban excavations where treatment is complicated by access and impact on community contamination confinement is often preferred. In any case, the adopted strategy needs to take into account the future use of the site, combined solutions involving both the reduction of the source of pollution and control of the pollution carrier generally offer the most sustainable outcome.

This paper presents a range of projects performed in Australia and overseas utilising different forms of SB walls. A particular focus is given on project methodology, site validation and trial testing but also production and quality control. The paper also provide a comparison of the environmental impact that different cut off wall techniques have and how they compare with SB type walls.

2. TECHNICAL OPTIONS FOR CONSTRUCTIONS OF A GROUNDWATER BARRIER

2.1. SLURRY CUT- OFF WALL

Slurry Walls are a trenching technique that utilises the thixotropic properties of a fluid to provide excavation support. The slurry prevents the trench from collapsing by providing outward pressure, hence balancing the inward hydraulic forces and preventing water flow into the trench. Slurry design vary based on the in-situ soil and groundwater composition, however typical properties are highly viscus (flow cone <40seconds), a density slightly higher than water (>1025kg/m^3) and filtrate loss <25ml.

The method is a continuous process where excavation and backfilling operations are undertaken through the slurry.

(Stage 1) The leading face of the excavation is progressed using a long reach excavator, typically capable of 18m - 20m deep reach. Deeper excavation (up to +50m depth) is then progressed in panel sections using a crane rig equipped with a clam shell excavation tool. Excavation is then verified by physical observation of key material (aquitard) and depth measurements.

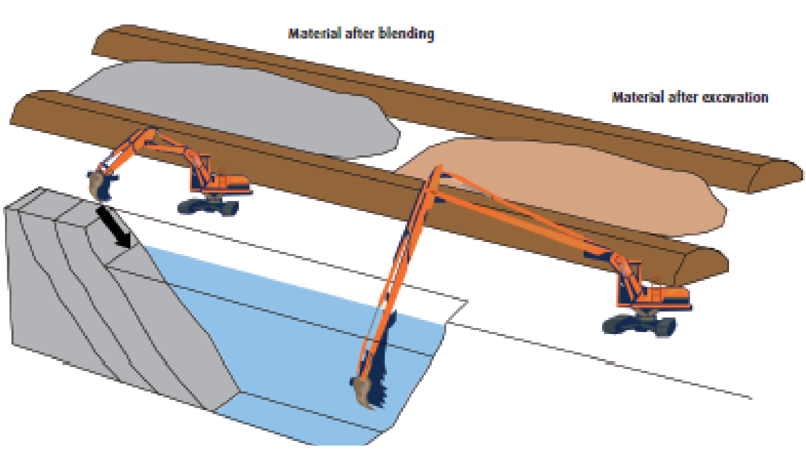


Figure 1: Schematic of slurry wall excavation under

(Stage 2) The leading face is then followed with a backfilling operation that progressively displaces the slurry to balance out the excavated volume, in this way a balance in slurry height is targeted. Slurry height is maintained at a minimum of 1m-2m higher than the in-situ groundwater to ensure the outward pressure is maintained. Typically the backfilling process firstly utilises a tremie pipe that allows initial backfilling of the trench from the base of the excavation to the top. The secondary phase utilises a batter to maintain the progressive filling operation of the trench.

Picture 1: Slump Testing

(Stage 3) The back fill material is specific to each application of the slurry cut-off wall and is designed prior to installation. Example backfill material comprise Soil Bentonite, Cement Bentonite, Soil Cement Bentonite or a combination of permeable and reactive material (implemented in Drainage and Permeable Reactive Barriers). Mixing operations utilising in-situ material is carried out concurrently to the excavation process. Backfill material primarily engineered from imported material may be mixed offsite or in a centralised mixing area. Verification of mixing is undertaken by regular testing for backfill slump and slurry viscosity as well as periodic permeability testing as appropriate.

Picture 2: Viscosity Testing

This continuous process is one key defining aspect of the method resulting in one element without multiple joints often required with most forms of alternative cut-off wall techniques.

Picture 3: Clam Shell – Mascot (Left), Mayfield (Centre) and Long Reach Excavator – Mt Arthur Coal (Right)
technique.

Table 1: Advantages of different type of Slurry cut off wall

Groundwater Barrier	*Advantages*
Soil Bentonite	• Lowest Cost of all underground barriers, • High Productivity • Verifiable continuity and depth • Low Permeability (10^{-9} m/sec), • Positive connection with aquitard (key inspection possible), • Excellent resistance to contaminated groundwater • Accommodates large strains and is ideal where large ground movements are to be expected, • The slurry remains fluid, allowing time for penetrating difficult layers or obstacles. • Can be combined with HDPE membrane to provide air tightness, • Re-use of most of the excavated materials
Soil Cement	• Most of the advantages of SB slurry walls apply to SCB walls • Higher strength than SB or CB walls • Greater trench stability is possible because the SCB backfill creates a shorter backfill slope. • More resistant to erosion and burrowing animals – essential in levee applications
Cement Bentonite	• Useful on smaller project with limited access or narrow work zones because of the smaller equipment footprint. • Low Permeability (10^{-8} m/sec), • No excavated soils are used in the final barrier wall, which is beneficial in areas with contaminated backfill soils. • Since CB slurry is heavier than bentonite slurry and self-hardens, this method can provide improved trench stability and more easily overcome weaker ground conditions. • Since the slurry sets after ~1 day, overlapping segments can be constructed in any direction or order to form a continuous barrier. • Segments can be used to traverse up or down moderate slopes (5-15%) with minimal earthwork construction. • Construction of walls through porous ground conditions is possible. • Can be used to remove unsuitable materials below the groundwater without shoring or dewatering. • CB backfill, once set, has a higher strength than SB backfill.
Composite Slurry Walls	• Use of the slurry method allows for the economical insertion of vertical panels or elements into the ground in a narrow self-supporting trench, even below the groundwater table. • Use of plastic panels may be necessary in extremely aggressive groundwater environments or in cases where methane or other gas migration needs to be prevented. • The use of the slurry trench technique provides a way to install steel sheeting in difficult driving conditions
Combination Slurry Wall Systems	• Minimum cost for maximum benefit using two or more slurry wall technologies. • Capability to solve isolated constructability issues with minimum cost and risk. • Capability to modify groundwater patterns by diverting, extracting or containing groundwater with one continuous system.

2.2. BIO-POLYMER DRAINS

Bio-Polymer trenches are constructed for draining, diverting or collecting groundwater or leachate or underground gas. They offer a cost effective way to construct deep collection drain trenches by eliminating the difficulties and costs associated with temporary shoring and dewatering associated with conventional construction.

Bio-Polymer trenches utilise the continuous trenching method as described in Section 2.1, however the slurry composition consist of polymer chains within the fluid that is highly viscous, entrain suspended soil particles and engage the trench surface to promote trench stability. Similar to the bentonite slurry technique the excavation and backfilling operations are undertaken through the Bio-Polymer slurry for trench stability. However following trench installation the polymer chains are readily broken down through a chemical reaction leaving the permeable backfill material in place.

The ability to support continuous trenches within complex groundwater and contaminated environments for the backfill of a wide range of media provides an opportunity that is both cost effective and low risk. The applications are somewhat limited to the imagination of the engineers tasked with solving the groundwater and contaminated land issues. Some examples of applications consist of:

- Drainage lines combined with HDPE liners allow the capture of leachate and gas and avoid draw down of neighbouring groundwater environments
- Rapid installations of air sparging systems for treatment of contaminated plumes
- Subsurface drain to lower groundwater level or encapsulate sites

(a) (b) (c)

Picture 4: Conventional Trenching Methods (right & Center) compared to Slurry Trench (Right), (a) propping, (b) Sheet piling, (c) Bio-Polymer

2.3. PERMEABLE REACTIVE BARRIERS

Permeable reactive barriers (PRB) are an in-situ method of remediating contaminated ground water plumes. The bio-polymer trenching method is utilised for the installation of an engineered back fill material to target and treat ground water as it flows through the barrier wall.

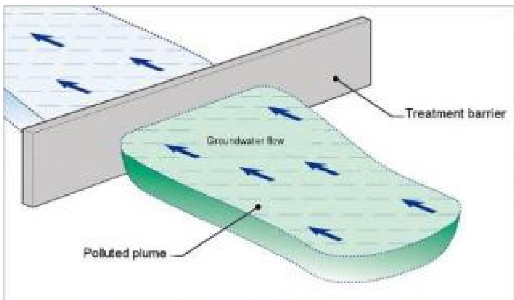


Figure 3: Active Barrier Polluted plumed treated when passing

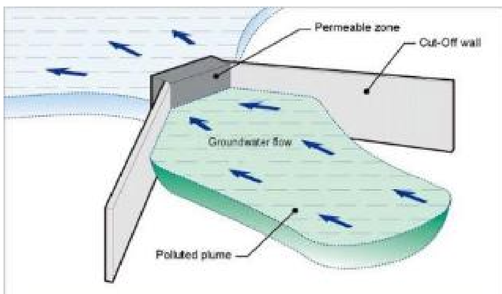


Figure 4: Funnel Gate Polluted plumed forced to a high capacity

The bio-polymer trenching method allows rapid installation without over excavation of contaminated soils and unnecessary exposure to construction personnel.

PRB walls address a wide range of contaminants such as chlorinated solvents, organics, metals, inorganics and radionucleides. Several processes are used within PRBs to treat contaminants and include:

- Adsorption (eg using activated coal and zeolite for organics)
- Precipitating for non-organics (eg lead precipitation using lime)
- Degradation (eg PCE, TCE can be degraded by iron filings)

Often the primary cost for PRB installations is the reactive material installed within the barriers. Hence there is pressure to optimise the barrier dimensions to achieve the ideal residence time and concentration for the intended design life. Reactive material is often blended with a clean sand to reduce the density of a reactive material across the barrier. Funnel and gate systems offer opportunities to utilise low cost soil bentonite cut-off walls to funnel ground water into a treatment zone. This zone can further be designed with a cell arrangement that allows maintenance of the reagent material. This concept allows a controlled response to the investment in reactive material as well as facilitate long term monitoring of the treatment process.

3. CASE STUDIES

3.1. SLURRY CUT- OFF WALL

3.1.1. SOIL BENTONITE SLURRY: MAYFIELD, NSW

The Mayfield site is approximately 155 ha within the former Newcastle Steelworks site on the south bank of the Hunter River at Mayfield. Over a period of 130 years this site has housed copper smelters, steelworks and ancillary operations. Steelworks wastes (slag) have been used to fill much of the site. The site was previously occupied by coke ovens, gas holders and other processes associated with steel making. Contaminants of concern identified on site include petroleum hydrocarbons (including benzene, toluene, ethyl benzene and xylenes), metals, ammonia, cyanide, phenols and polycyclic aromatic hydrocarbons.

Following the in-depth review of 32 options and alternatives, Menard Bachy was engaged to design and construct the barrier wall to reduce the migration of contaminated groundwater to the adjacent Hunter River, as part of a remediation strategy for the site.

The strategy finally adopted for the steelworks site initially relied on containment and comprised the following key elements as shown on Fig. 1:

- Construction of an upgradient groundwater barrier wall diverting flows away from the most contaminated area of the site (Area 1)
- Sealing the site surface area with an inert capping layer, which both prevents the infiltration of surface water, and provides a physical barrier between contaminated soils and humans on the site.
- Improved drainage infrastructure and contouring of the site, which will contribute to both the reduction of surface water infiltration and the management of possible contaminated surface water run-off from the site.

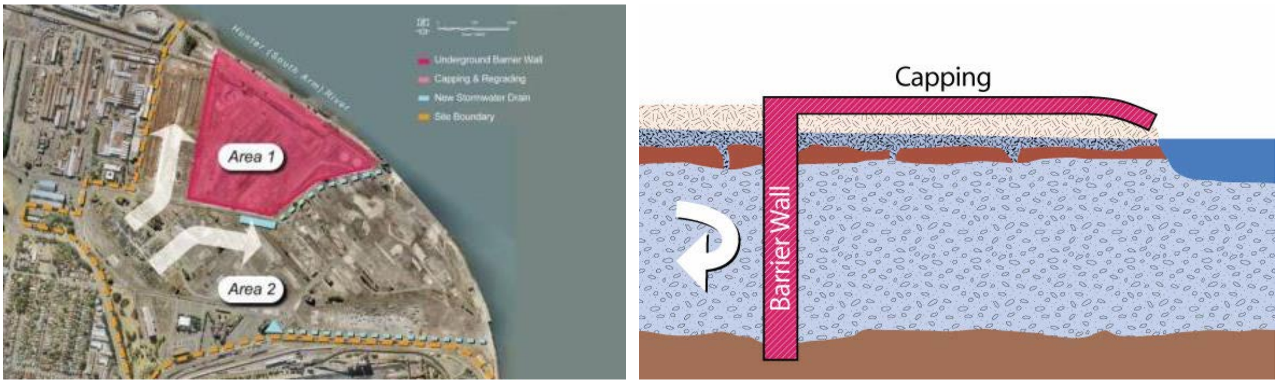


Figure 2: Schematic of Mayfield Site Remediation concept

The soil bentonite wall is 1,510m long, 0.8m wide and has depths ranging from 25m to 49m, keyed into the basal confining layer of clay or weathered rock. Given the range of depths of excavation, two pieces of equipment working in sequence were used: a backhoe modified to dig to 25 metres to complete the first phase of the trench, and a mechanical clamshell to excavate the deeper material.

The success of the ground barrier was demonstrated through a thorough quality control program implemented during each phase of the project and which satisfied the design criteria:

- maximum required permeability of 10^{-8}m/s
- surface completion to be trafficable: long term settlement of the wall less than 50 mm total settlement, and 1:50 differential distortion

The long term performance of the wall is being closely monitored, including via a system of groundwater monitoring wells fitted with automatic water level loggers located both inside and outside of the barrier wall.

3.1.2. SOIL BENTONITE SLURRY: MT ARTHUR MINE, NSW

The Mt Arthur alluvial cut-off wall project comprised the construction of a dam wall style bund along the western boundary of BHP Billiton’s Mt Arthur Coal site, near Denman Road, Muswellbrook. The structure

was required to protect the mine from a 1000yr flood event. Due to the presents of alluvial gravel deposits above the bedrock, the cut-off wall was required beneath the flood levee to block off subsurface flow given the increase in water pressure in association to the proposed flood.

The cut-off wall was 1340m in length and was socketed into the underlying bedrock at depths ranging between 4m and 13m below existing ground level. The Slurry Bentonite cut-off wall was constructed prior to the bund wall with a target permeability of 1×10^{-9}m/s, with a thickness of 0.8m.

One of the main challenges on the project was to allow for utilisation of water from the mine into the slurry design. Water quality testing of the source water showed results up to 5 times the recommended limit for slurry design, recording Total Dissolved Solids at 2500mg/L and Hardness at 1000mg/L. Resulting mix design found an additional 30% additional bentonite was required to achieve the target slurry properties.

Assessment of the actual depth to rock compared with the assumed rock depth from geotechnical investigations, found a close relationship. Variation is likely explained by varying soil/rock strength and possible variation due to the constructed working platform. This assessment for the client and contractor is crucial to provide accurate budget estimates, however variation is always likely based on the actual encountered aquitard interface.

Picture 6: Slurry sedimentation assessment mine water compared with

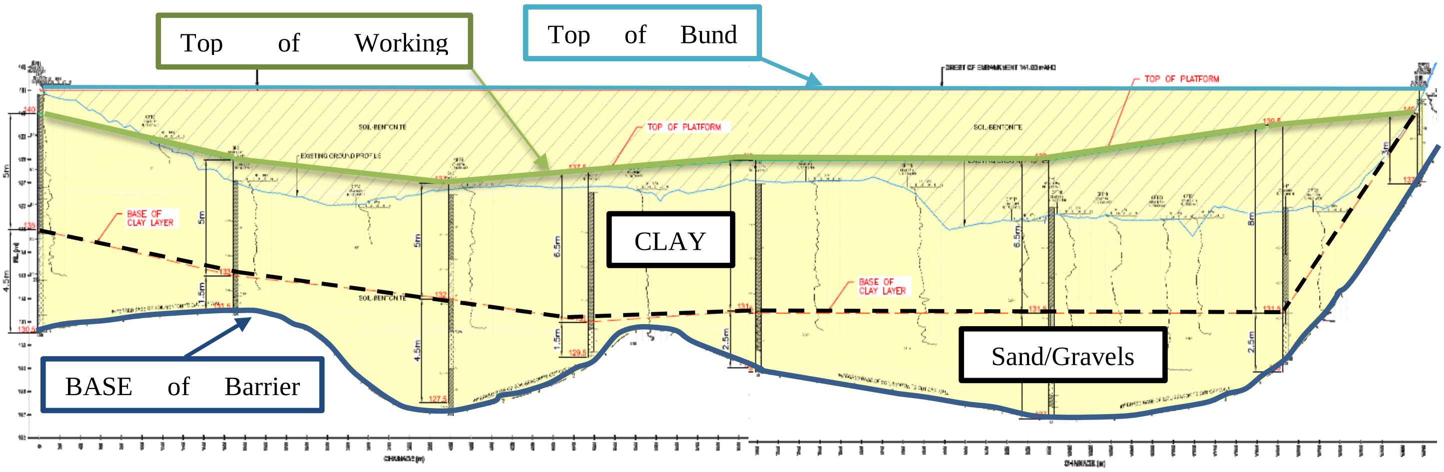


Figure 3: Geological Section Compared with Barrier Wall Toe

3.1.3. SOIL BENTONITE SLURRY: LIDDELL COAL MINE, NSW

Operational requirements at Liddell Coal Operations (Glencore) required an increase in water storage within one of the water storage dams. In order to achieve the design capacity of 2GL Menard Bachy was engaged by Glencore to install a bentonite slurry cut off wall in the mining spoil around the perimeter of the new water storage dam. This cut off wall was designed to prevent the flow of water through the mining spoil anticipated when the water level was increased in the water storage dam above 1GL. The design permeability was set at 1×10^{-8}m/s.

Over this 5 week period in 2014, 5,200m2 of bentonite slurry cut off wall was installed over 600 linear metres. The ground conditions consisted of up to 7m of replaced overburden overlying shale bands and clay over bedrock. The max depth excavated using the longreach excavator was 14m.

Picture 7: Barrier Wall being excavated through dragline spoil

The existing dam had been constructed within the area of an old dragline spoil area. As a result the subsurface material consisted a wide range of material including boulders up to 1m in diameter. This provided a unique constructability challenge to implement a barrier with large obstructions. To handle the obstructions the risk was assessed as a possible increase in trench width at localised obstruction locations and a reduced productivity. Considering the project was a remote site the risk of an enlarged trench was observed as acceptable. A Komatsu PC850 was paired with a long arm boom to meet the challenge of clearing the obstructions, however during the project a typical 0.8m trench width was maintained for the full length of the wall.

Picture 8: Subsurface material – up to 1m diameter

3.1.4. CEMENT BENTONITE SLURRY: PORT BONYTHON, NSW

The Santos Port Bonython Hydrocarbon Fractionation Plant is located on Weeroona Bay, approximately 35km from Whyalla in the Northern Spencer Golf. Soil and groundwater beneath the site appeared to be primarily impacted by crude oil leaking from adjacent storage tanks. The groundwater impacts were in the form of light non-aqueous phase liquids (LNAPL) typically floating on the groundwater or locked up in the formation and dissolved phase hydrocarbons in the groundwater. The presence of both off-site impacts and the potential for discharge to the marine environment necessitated a rapid evaluation of long-term mitigation and remediation options. In a collaborative evaluation of options a cement bentonite barrier wall was selected by Santos as the preferred remedial alternative, as it provides the highest level of confidence that off-site migration would be controlled and the long-term impacts mitigated.

Picture 9: Depth sounding

The barrier wall is aligned adjacent to and sub-parallel to the ocean shoreline over a length of about 450m and is required to extend to a typical depth of 6-7m below initial surface level. The scope of works included the pre-excavation along the wall alignment through extremely high strength, abrasive sandstone, progressive backfilling and re-excavation under cement bentonite slurry, installation of a capping beam spanning the trench, the tracking and burial of contaminated spoil and finally reinstating the site to natural contour levels.

After the initial rock breaking excavation, the wall was re-excavated under the cement bentonite slurry in panels which replaced the excavated material with the final cement bentonite mix to form the low permeability barrier. The mix design adopted produced a final wall with a permeability in the order of 5 x 10^{-9}m/sec and unconfined compressive strength of approximately 80kPa.

3.2. PERMEABLE REACTIVE BARRIERS

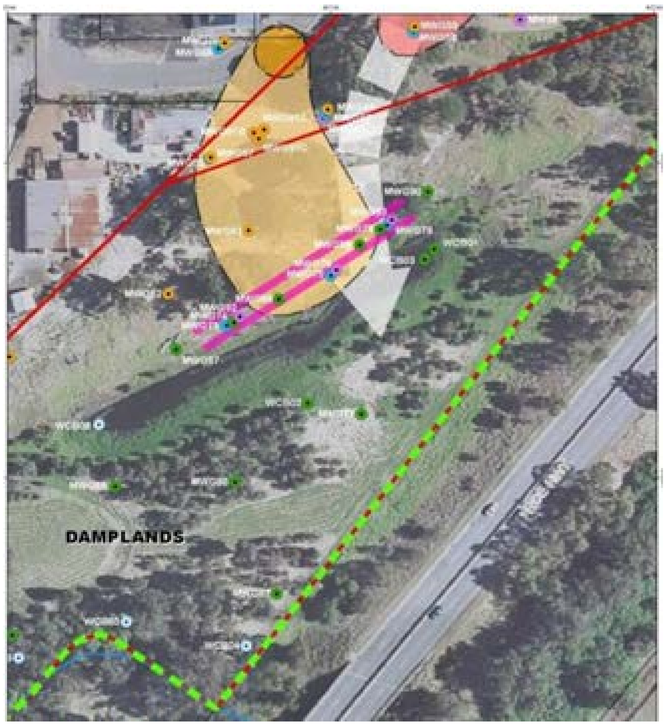
3.2.1. CONTINUOUS PRB WALLS: BELLEVUE, WA, AUSTRALIA

A waste storage site operated a chemical/oil recycling and treatment facility in Bellevue, WA until a fire destroyed the facility in February 2001. Following the fire a series of investigations and risk assessments were undertaken at and in the vicinity of the property. Groundwater investigations confirmed the presence of a plume of hydrocarbons and halogenated organics originating from the former waste storage site. Subsequent groundwater monitoring indicated the presence of a separate off-site plume from a local source containing trichloroethene (TCE). Monitoring of data indicated that the two plumes converged beneath the escarpment prior to entering the Damplands.

A zero valent iron (ZVI) permeable reactive barrier (PRB) was proposed. As elevated concentrations of nitrate in the groundwater were confirmed during the delineation investigation, calculations showed that most of the ZVI material thickness would be consumed through nitrate passivity. Thus, a second PRB for denitrification was also designed upstream and in front of the ZVI wall.

Each PRB was designed to be 76m long and extending down to the Leederville Formation clay layer at depth of approximately 11 m. The ZVI PRB was a mixture of ZVI and sand. The denitrification PRB was a mixture of saw dust, chips and sand.

Menard Bachy was awarded the contract for the construction of the pair of PRBs based on an alternative proposal using deep trenching technology with a biopolymer slurry in lieu of execution of caissons and secant piles using a large diameter steel casing pushed into the ground and excavating the soil from within the casing. This alternative had a number of advantages including lesser cost and reduction of total and on site construction time, controlled width and continuity, control of key in depth, simplification of the environmental management plan, and lesser consumption of PRB material.



Picture 10: Operation Diagram

Picture 11: One of two parallel trenches dug to install permeable reactive barriers in Bellevue

This project is the first application of a ZVI wall of industrial scale in Australia utilising the technique of PRB trenching.

3.2.2. FUNNEL & GATE PRB: SOLVA CHEMIE PLANT, BERNE, SWITZERLAND

The solvent reprocessing plant belonging to Solva Chemie is located at Bätterkinden, between Soleure and Berne. Until 1992, without a protective concrete slab, plant subsoil was polluted by chlorinated solvent infiltrations. The source of contamination having run dry, ground water was still polluted by a mixture of chlorinated solvents that canton authorities requested to be eliminated in accordance with the Swiss Federal order on contaminated sites.

The Engineering Consultant (Geotechnisches Institute) studied several solutions and proposed treatment of the natural ground water to the authorities, via an active wall through which solvents would be eliminated. The characteristic feature of this site is a ground water table with a low flow rate (about 10 l/mn for the whole site) flowing towards Mühlibach, a subsoil with average perviousness and watertight substratum. After agreement from the authorities, the Geotechnisches Institute chose the solution proposed by Sif Groutbor (Soletanche Bachy subsidiary), associated with ATE, of installing a filtering gate.

This system includes the following:

- a water-collecting drainage system: horizontal drilling and draining wall,
- a soil bentonite slurry wall,
- a filtering gate built according to the patented panel-drain technology, containing a filter with a volume of 1 m3 and weighing about 5 tons, through which water can filter. The also patented treating product is Iron with an added set of catalysts, enabling to lower pollutant levels to canton administration-permitted thresholds. The whole unit is gravity operated, is always accessible via the top and requires minimal maintenance.
- a discharge system including an observation well and gravity flow towards Mühlibach.

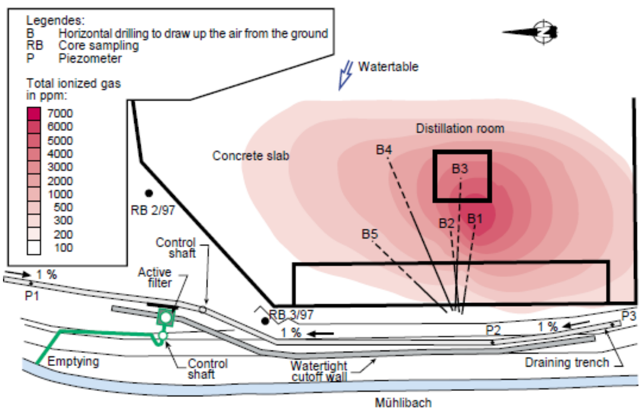


Figure 4: Operation Diagram

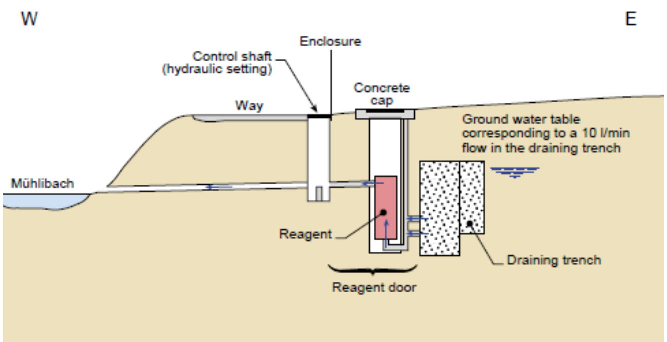


Figure 5: Schematic section

Ground Water samples were analysed both upstream and downstream. The following table presents the results obtained and demonstrate the effectiveness in reducing concentration of key contaminants immediately following the installation of the Funnel and gate system.

Table 1: Analysis results after 15 days of operations

Dissolved elements (µg/l percentage)	Upsteam	Downstream
Vinyl chloride	3	0.23
Trichlorethylene	94	0.46
Cis 1-2 dichlorethylene	199	2
Perchlorethylne	25	0.16
1.1.1. trichlorethane	9	0.22
1.1 dichlorethane	0.67	0.5

4. SUSTAINABILITY CONSIDERATIONS

The key contribution of slurry Wall technologies to the sustainable development aspect is the ability to install underground structure whilst both involving limited quantities of excavation and minimal amount of imported materials such as cement or steel both high contributors in CO2 emissions for instance.

Another key benefit of the Slurry wall techniques over other traditional methods is associated with the very high production rates. This translates into overhead cost savings and benefit projects with tight construction schedules. In particular, the performance of civil works in urban contaminated environment can often lead to negative impact on the local community. Production of excessive noise, increased traffic and potential for air contamination represent a few of such adverse impacts. As a result, a reduction in overall program of works results in decreased impact over the local communities.

Further, excavation works are carried out under slurry limiting both risk of generating dust but also providing increased certainty in construction schedule through improved ability to control geotechnical risks such as subterranean voids and presence of localised weaker strata. Experience indeed shows that many conventional shoring techniques suffer extended delays due to unforeseen ground conditions of either geotechnical or hydrogeological nature.

The ability to install cut off walls in a controlled fashion, with minimal exposure of contaminated material and in an unmatched of time provides unrivalled construction benefits for modern urban civil works.

When scoring sustainability for geotechnical works, the estimated carbon footprint can often be an important indicator. Carbon footprint is the sum of all emissions of CO_2 in a year, induced by site activities and by the production of materials used in construction.

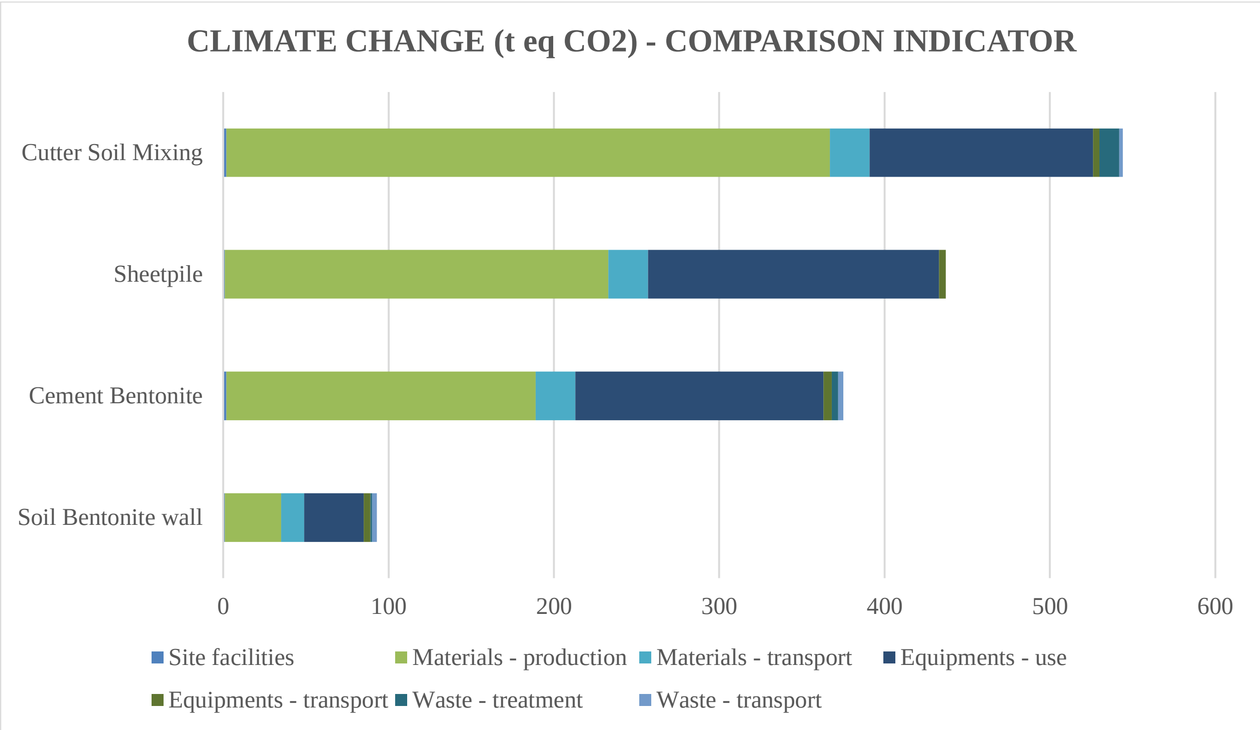


Figure 6: Climate Change (t eq CO2) – Comparison of various Cut off wall schemes (Prism solution – Menard Bachy)

Today’s access to new tools for assessing and benchmarking several environmental indicators for various competing solutions allows for acurate comparison of ground improvement techniques and assist both contractors and clients in retaining the “best for project” schemes. The figure below illustrate such a comparison beeing performed on a range of solutions in accordance with the European Norm En 15804.

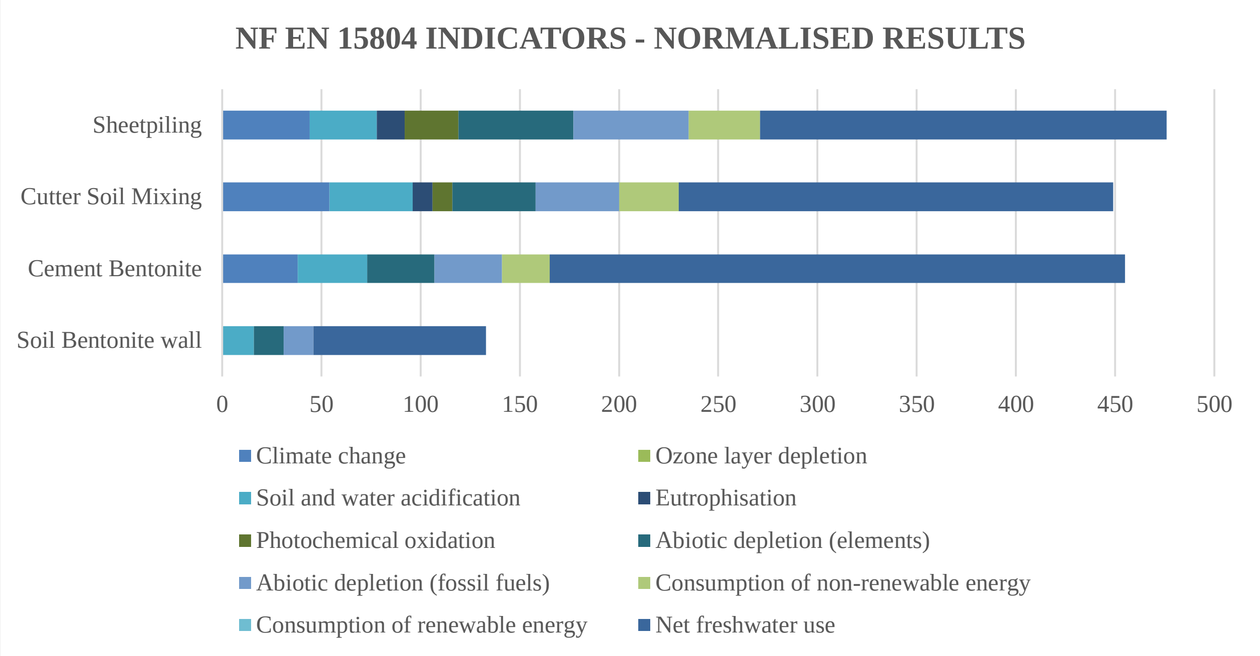


Figure 7: NF EN 15804 Indicators – Comparison of various Cut off wall schemes (Prism solution – Menard Bachy)

Going forward, it is anticipated that regulation to limit carbon emmissions with the view to limit the impact on climate change will become tougher. Further, increasing constraints on urban development to meet stringent environmental regulation as well as stakeholders requirements to limit impact on local community are strong incentives to develop more environmentally friendly techniques.

5. CONCLUSIONS AND RECOMMENDATIONS

Low permeability barriers can be succesfully implemented to control groundwater in a diverse range of applications such as open cut excavation in urban environement, control of horizontal seepage and channeling of contaminated water to prevent discharge in watercourses but also control of groundwater inflow in open cut mines, upgrades of dam and landfills capacity.

The methods utilised to install such walls are readily adaptable through use of a range of alternative stabilising agents to also install permeable barriers. These can then be utilised to install deep collection drains, or even reactive agents to breakdown or capture groundwater contamination.

Whilst enabling to perform tasks that could not be achieved before, the methods of slurry bentonite and bio-polymer installation of underground barriers also grant significant benefits in advancing the construction performance on criteria such as cost, program and environmental impact.

The slurry wall concept is a highly flexible construction technique that is proven to be the most effective method for developing in ground installations. Therefore the future of slurry type wall is somewhat limited to the imagination of the engineer/environmentalist assessing individual projects over a wide range of industries.

8 REFERENCES

Jones. S, Spaulding,C & Smyth.P. *Design and construction of a deep soil-bentonite groundwater barrier wall at Newcastle, Australia.* Proceedings of the 10th Australia New Zealand Conference on Geomechanics 2007, Brisbane

Spaulding,C. *Soil Bentonite Cut-off Walls for Confinement of Existing Landfills: Tempe Tip - A Case Study*. XVIth SEAsian Geotech Conference 2007

Ryan,C & Spaulding,C. *Vertical groundwater barriers for contaminated site reclamation.* Proceedings of the 10th Australia New Zealand Conference on Geomechanics 2007, Brisbane

Liausu,P & Spaulding,C. C*onstruction d'une paroi etanche en sol-bentonite sur le site de l'ancienne acierie de Newcastle.* Revue Travaux 2007, no. 836, pp. 75-79

NEPM (2003). *Impact Statement for the National Environment Protection (Air Toxics) Measure* 2003, National Environment Protection Council, NSW Australia

US EPA (1998), '*Evaluation of Subsurface Engineered Barriers at Waste Sites'* EPA-542-R-98-005, July 1998

Bouzalakos S, Crane R, Liu H, Timms W, *Geotechnical and modelling studies of low permeability barriers to limit mine water seepage*. Water in Mining congress, Chile, 28-30 May 2014

BRGM/RP – 25609 – FR, *Quelles techniques pour quels traitements – Analyse couts – bénéfices,* May 2010