Proceedings of the 10th Australia New Zealand
Conference on Geo-Mechanics, "Common Ground"
Brisbane Australia, October 2007

Vertical groundwater barriers for contaminated site reclamation

Christopher Ryan
Geo-Solutions Inc, New Kensington, Pennsylvania, USA
Charles Spaulding
Austress Menard, Sydney, NSW, Australia

Keywords: groundwater barrier, slurry cut-off wall, soil bentonite slurry wall, biopolymer drain, soil mixing, passive reactive barrier, permeable reactive barrier, MGP waste

ABSTRACT

Groundwater barriers are used to maintain separation between contaminated and non-contaminated groundwater regimes. They are often used as part of site reclamation works. In this paper, case studies of actual constructed barriers will be used to illustrate some innovative technologies that include slurry cut-off walls, biopolymer drainage trenches, soil-mixed barriers, and passive reactive barriers. In each case, a specific site will be used to illustrate the application of the technology to a project where the contaminated site will be returned to productive use. Examples of design mix considerations and results will be provided and significant details of construction will be described. Quality control data from the actual projects will be used to show how the final products conformed to the standards set for the works and to the design mixes established for the projects. The principal technical and economic advantages for each method are described.

Example applications include a large size slurry wall project recently performed in Australia as well as other examples from the US where there is fully mature market for these technologies.

1 INTRODUCTION

Vertical barriers constructed underground to stop, collect and/or treat the flow of contaminated groundwater are a feature of many site reclamation projects. The technologies to accomplish these goals have been becoming more varied and more sophisticated in recent years. There is a lot of actual construction experience around the world, and in the US in particular. In fact, some of these technologies have more than 30 years experience and one of the authors has personally dealt with close to one thousand sites that have been reclaimed using a groundwater barrier as a feature in the design.

Soil bentonite slurry cut-off walls are built by excavating long trenches supported by bentonite slurry and subsequently backfilling the trenches with blended impervious backfill. This technology will be illustrated by an example of a 1500 lineal meter, 50 meter deep wall constructed in Mayfield, NSW. This project, the deepest of its kind, is being used as part of a cleanup strategy to remove wastewater left by a former steel-making facility and associated Manufactured Gas Plant (MGP). The site will be returned to productive service as a container port. Data presented will include pre-job testing to develop a design mix for the project and summaries of QC testing taken during construction.

Biopolymer Drainage trenches are also constructed under slurry. When completed to full depth, they are backfilled with pervious materials and the special slurry is then degraded back to water and the trench functions as a collector drain. An example of this system being used as a barrier will be presented using a case study constructed in Binghamton NY, USA. This site was formerly used as an MGP, and the underground wastes include light and dense non-aqueous phase liquids (NAPL). The drain will be used as a passive collector to prevent off-site migration of the wastes.

Soil mixing is the physical mixing of some reagent at depth to create columns of treated soil. The mixing can be accomplished by purpose-built equipment that adds liquid reagent while spinning a configuration of augers and/or paddles to break up and blend the soil, or it can also be done with jet-grouting equipment. The example presented is of another MGP site located in Nyack NY, USA. At this site, soil mixing was used to encapsulate and contain the wastes so that the river-front site could be returned to productive commercial use.

The Passive Reactive Barrier (PRB) is a technology that allows contaminated water to flow through a porous medium that is placed in a slot perpendicular to the direction of flow. As the contaminated water passes through, it undergoes a chemical or catalytic reaction that removes the contaminant of concern. Typically, the deeper PRB's are placed using biopolymer slurry trenching techniques. The project example is a site in Seattle WA, USA, where a former industrial operation had left Trichloroethylene (TCE) in the groundwater flowing to an adjacent waterway. The PRB used a combination of sand and iron filings to clean the plume as it flowed through.

2 CASE STUDY — SOIL-BENTONITE CUT-OFF WALL

The recently completed slurry cut-off wall located in Mayfield NSW (2006) was designed as an upgradient barrier to prevent the leaching of contaminants from the former steelworks into the Hunter river.

In essence, the soil-bentonite (SB) technique is a continuous trench that is dug under a bentonite slurry that maintains the stability of the trench walls, even under the water table. Once the trench is dug to full depth where it is usually keyed into a low permeability layer, it is backfilled with a blend of excavated soils, bentonite and bentonite slurry. The blended mixture is placed using either a tremie or by sliding it down the slope to form a continuous low-permeability barrier to the lateral flow of ground water.

The advantages of SB cut-off walls are the following:

- Enabling the use of high-productivity extended reach excavators to dig most of the walls
- Re-use of most of the materials excavated from the walls, including contaminated spoils
- The best permeability range of competing options (10^{-8} to 10^{-10}m/s)
- High degree of resistance to a wide variety of contaminated water.
- Rapid construction sequences
- Lowest cost barrier methodology

In the case of Mayfield, the depths required the combined use of extended excavator (to 24 m) followed by clamshell excavation which could go to the required depths as shown on Fig. 1 below.

Fig. 1 – Trench excavation for SB wall

A pre-job design mix study had determined the correct backfill mix to use for this project. It consisted primarily of the clean sandy soils which had been excavated from the trench, supplemented with approximately 20% of imported fine borrow. In addition, bentonite formed part of the final blend. It was added in the form of bentonite slurry used to adjust the backfill consistency. The final amount of bentonite was approximately 1-2% of the dry weight of backfill. This blend was tested for the project design requirements for permeability, both in the short term and in the long term against contaminated water from the project. Wastes from a previous steel-making operation and associated MGP were to be contained

Backfill was mixed alongside the trench and for most of the project was placed at the top of a long slope of previously placed backfill and allowed to slide down that face, displacing the lighter bentonite slurry forward. The initial slope was established using a tremie to place backfill.

One segment of the trench had to be constructed under a sensitive overhead pipeline structure with the trench passing within a couple of meters of the structure's foundations. This was done as two short segments and was backfilled with soil-cement-bentonite (CB) backfill. This material took a weak set (e.g. in the range of 400kPa of Unconfined Compressive Strength), allowing the adjacent SB panels to be excavated and backfilled to form the connection.

The result was a very low permeability barrier that was constructed within the allotted project schedule to previously unattained depths.

Data on Fig. 2 below show that all the permeability results from field QC samples met the project criteria with most results a full order of magnitude better than the design criterion of 1 x 10-8 m/sec.

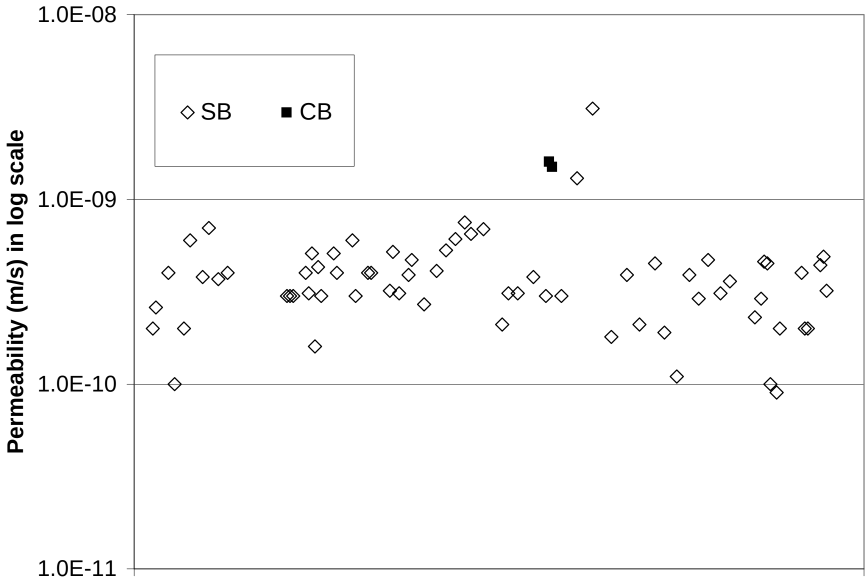

Figure 2 – Production hydraulic conductivity tests results - Mayfield

There are now several examples in Australia of the use of the SB slurry wall technology to construct cost-effective groundwater barriers. The US market, where several thousand of these have been installed over the last thirty years, shows the potential of this technology.

3 CASE STUDY—BIOPOLYMER DRAIN

A related but very different technology is the biopolymer drain, a method to construct deep drains with none of the normal support and dewatering problems. With this technology, slurry is again used to hold open the trench with vertical sidewalls as it is excavated. Once the trench is at full depth, materials like wells, underdrain pipes, filter media and drainage media are all placed into the trench, through the slurry. Because the eventual product is a drain, bentonite slurry cannot be used in this application—it would plug the trench sidewalls and the drainage media. Instead, a natural polymer (guar gum) or synthetic polymers are used to create viscous slurries with much the same capability of trench support. Once the trench is backfilled completely, these polymer slurries can be biologically or chemically “broken” and returned to a watery consistency that can be pumped when the drain is ready to operate.

Normal drain construction often involves either very wide excavations (with lots of expensive backfill) or complex support systems. They almost are always complicated by difficult dewatering situations. On contaminated sites, treating the water can be a big problem, particularly if the on-site processing plant is not yet complete. The advantages of the biopolymer drain are as follows:

- The slurry allows for a vertical walled excavation, reducing the cost of drain material
- No excavation support system is needed
- No dewatering is needed during construction
- Any system of components can be installed in the drain
- Nothing needs to be pumped from the drain until the treatment systems are ready
- Fast construction time
- Low construction cost.

The case study for this technology is a project in Binghamton NY, USA. This site also involved MGP wastes. The design called for the installation of a collector drain that was a total of about 200 m long and 15-18 m deep. The upper portion of the drain had an exterior impervious liner and a shallow well system for collecting LNAPL's (light non-aqueous phase liquids) and the bottom of the trench was fitted with a horizontal collector pipe and vertical collector wells to catch and collect the DNAPL's (dense non-aqueous phase liquids). The whole trench was backfilled with a graded stone, approximately 10 mm diameter.

Figure 3: Excavating the Bio Polymer Drain using an extended-reach excavator

Figure 4: Outer Geo-membrane being placed in slurry-supported trench

Fig. 3 and 4 above show the work in progress. The proximity of adjacent roadways and some underground utilities would have made any other form of drain construction additionally difficult.

This technology, originally developed in the US, has yet to be used in Australia. There are hundreds of installations in the US, for collection of contaminated water, for toe relief drains at dam sites and for landslide stabilization projects.

4 CASE STUDY—SOIL MIX BARRIER

Another technology that has not been used yet in Australia is soil mixing to clean up contaminated sites. With this technique, a large (1.5 to 3.0 m diameter) mixing auger is drilled into the ground in an overlapping pattern to form a barrier or even to treat entire sites.

This technique presents numerous advantages over competing technologies, such as:

- Treating the wastes in situ avoids costs and risks of excavation and disposal
- No control of groundwater is necessary
- Any combination of reagents can be added to either treat or stabilize a site.

The project example is a site in Nyack New York, USA. Again, a former MGP site threatened the nearby river with serious contamination. A barrier was formed along the river bank using soil mixing and then the interior of the site was completely treated using a cementitious grout.

Figure 5: Aerial view of the project site

Figure 6: Soil mixing machine with mixer

In this case, completion criteria included both strength and permeability. The resulting blend was essentially a concrete block, effectively blocking access for any groundwater to enter or leave the contaminated area.

In the US, this technique has been used extensively, including contaminated projects, liquefaction control, foundation improvement and buttresses for sliding land masses.

5 CASE STUDY—PERMEABLE REACTIVE BARRIER

In Seattle, Washington, USA, a former manufacturing site was contaminated with chlorinated solvents. Previous attempts to cleanup the site using pump and treat systems failed because the soils were heterogeneous, making it difficult to control the contamination. The owner came to the conclusion that the technology with the highest probability of success for the site was a permeable reactive barrier using zero-valent iron to treat the groundwater. The engineer developed and implemented an innovative plan to install a funnel and gate system up to 11 m deep, using cement-bentonite (CB) slurry walls for the funnels and biopolymer degradable slurry to install the iron-filled gates (Fig. 7)

Figure 7: Placing Iron blend In PRB panel in tight site

One year after installation, measured chlorinated solvent destruction efficiencies are greater than 95%. Down-gradient from the gates, natural attenuation processes, including intrinsic biodegradation, are further reducing solvent concentrations to below surface water cleanup standards before reaching a public waterway less than 70 m from the site.

The results of the monitoring are summarized in the following table.

Compound	Up-gradient	Within PRB	Down-gradient
TCE (μg/L)	11,000	8.9	3.4
cis-DCE (μg/L)	8,000	60	470
VC (μg/L)	610	16	110

Contamination downstream of the funnel and gate continues to improve as the plume that formerly existed in this area dissipates. Groundwater elevation data indicate that the funnel and gate system is effectively controlling the plume and that contamination is not migrating above, below or around the wall. The contamination values are higher downgradient than they are inside the PRB because there is residual contamination from the former plume which is expected to clean up over time.

6 CONCLUSION

The techniques described in this paper have been shown to be cost-effective solutions to remediation of contaminated sites as well as numerous other soil and groundwater problems. To date, there has been limited use of these methods in Australia, but there is clearly potential for more widespread use.