CONSTRUCTION METHODS FOR THE INSTALLATION OF PERMEABLE REACTIVE BARRIERS USING THE BIO-POLYMER SLURRY METHOD

Steven Day (sday@geo-solutions.com, Geo-Solutions, Denver, CO), and
Robert Schindler (Geo-Solutions, Pittsburgh, PA)

ABSTRACT: Permeable reactive barriers have evolved since their inception in the 1980’s into a technique that is increasing applied to treat contaminated ground waters. Since the reactive media, typically granular iron is quite expensive, installation techniques that ensure the minimum plan width of the barrier, without undue waste, are favored. For installations in most soil types, with depths in the range of 3 to 30 meters, slurry trench techniques usually provide the most cost-effective construction method. In addition, trench installations provide continuity across the contaminate plume that is superior to other installation methods. The most common permeable reactive barrier (PRB) is the continuous wall. Usually a trench 0.6 to 3 meters wide is excavated while supported by bio-polymer slurry and backfilled with reactive media. Bio-polymer (BP) slurry techniques have been combined with methods borrowed from concrete diaphragm slurry wall construction to control backfill placement and minimize contamination of the media. Funnel and gates can also be installed using slurry wall techniques. Impermeable funnel sections can be created by constructing impermeable slurry walls that are connected to the reactive media installed by the bio-polymer-installed gate sections. This paper relates the experience of the authors in constructing over one-half of the nearly two dozen permeable reactive barriers installed by slurry trench methods and the success of certain construction methods. A case study is included.

INTRODUCTION

PRBs are a relatively recent advance in environmental remediation, which offers a simple, less costly solution to groundwater cleanup. A PRB is constructed underground**,** across the flow path of a contaminant plume. As the groundwater passes through the PRB, the contaminants are precipitated, adsorbed or degraded by the reactive media in the PRB with treated groundwater emerging on the down-gradient side. This passive type of remediation results in reduced costs due to the semi-permanent installation, lack of external energy input, reduced monitoring requirements, conservation of clean water, and continued productive use of the site almost immediately after installation.

The construction of PRBs requires installation below the groundwater table, and often to substantial depths on dangerous and difficult sites. For many of these sites, the bio-polymer slurry drainage trench can provide better, faster, cheaper, and safer installations. The BP trench installation offers the following advantages:

1) Maintains the dimensions of the installation to avoid wasting costly reactive materials without expensive shoring or sheeting,
2) Eliminates dewatering and subsequent treatment of contaminated groundwater during construction,
3) Minimizes safety risks by eliminating entry into the trench and suppressing toxic or unpleasant odors,

4) Provides a rapid and simple construction sequence,
5) Adaptable to a variety of soil types and sites,
6) Provides ensured continuity, superior to other installation methods, and
7) Is less costly than most other methods.

After reagent, the most important construction cost factors is soil conditions and safety.

BIO-POLYMER SLURRY

Slurry trenching using bentonite slurry has been in common use for many decades in civil engineering projects for creating controlled, narrow, excavations without shoring or dewatering. The slurry for PRB installations must not affect the long-term conductivity of the soil or diminish the reactivity of the media; therefore different slurry besides bentonite is required. Dozens of successfully completed projects and research (Hubble, et. al, 1999) has shown that reactive barriers can be installed using biologically degradable polymer slurry without significantly decreasing the reactivity or long term treatment characteristics of the reactive media. BP trenches have been common in the United States for more than a decade; most constructed as lineal drains to collect contaminated groundwater or to drain unstable soils.

The most common polymer for slurry trenching is guar gum. It is tolerant of salt solutions, relatively low cost, requires simple maintenance and easy to breakdown. Guar gum is a naturally occurring carbohydrate polymer derived from guar beans. While the slurry formulation is much more complex than bentonite (up to 10 additives may be needed), there are specialty contractors and consultants in North America that are experienced with guar gum chemistry and use. Unlike bentonite, the guar gum slurry does not form a cake on the trench sidewalls that can plug soil pores. Guar gum slurry is broken down by naturally occurring microorganisms and/or by introducing enzyme compounds. Residual by-products (prior to consumption by soil micro-organisms) are simple sugars (mannose and galactose) and water. Guar gum is generally regarded as safe and a FDA-approved food additive. There are also synthetic polymer slurry materials available, however, synthetic polymer materials degrade prematurely in the presence of iron compounds and therefore, cannot be used.

The challenge when using BP slurry in construction is to keep the slurry active long enough to complete the required construction. Without additives, the slurry will only remain active for a few hours. With additives (biocides and/or pH controls) the active life of the slurry can be extended to about two weeks, while continually replenishing with fresh slurry. While BP slurry is resistant to most chemical contaminants, hot weather and concentrated microorganisms (e.g. septic field, buried organic waste, etc) can create a situation in which stability is much more difficult or impossible to control.

Conventional trench stability theory predicts that the weight of the slurry and slurry hydraulic head (freeboard) over the groundwater table combine, to retain the trench walls. However, experience with constructed BP trenches has shown that conventional theory does not apply. BP slurry has a density that is too low (almost equal to water) for conventional theory to apply. BP slurry does provide considerable shear strength (since it is used at a thicker viscosity) and it creates temporary bonds with clay particles that contribute to trench stability. While, conventional theory fails to accurately predict trench stability, experience has shown that BP trenches can be successfully installed in a variety of soil types including; sands & gravels, silts & clays, and even cobbles & boulders.

Slurry trenches are usually excavated with hydraulic excavators. A picture of a 10 m deep trench excavation is shown in figure 1. As the trench is excavated, BP slurry provides liquid support to the trench walls while the excavator removes the soil. Dewatering is not required as long as the ground surface is at least a meter above the local groundwater table. An experienced slurry specialist is usually specified to supervise the use and control the BP slurry.

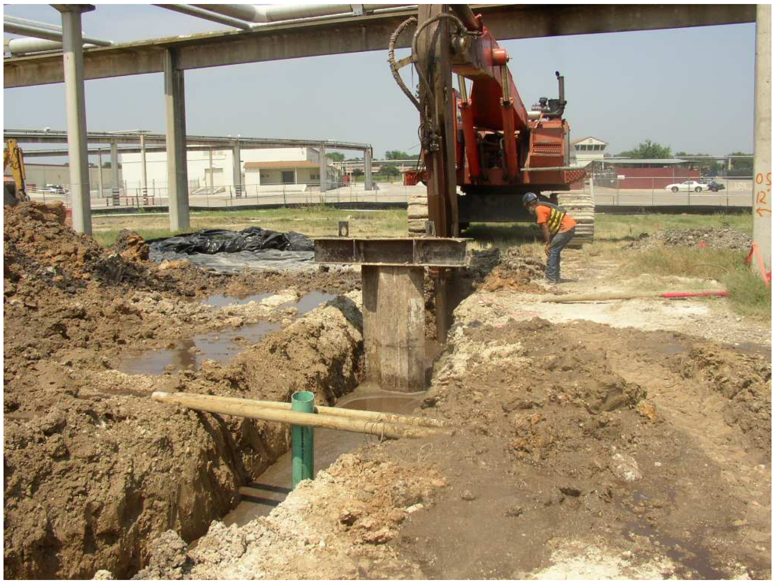

FIGURE 1. Excavating BP trench (note also temporary well and end stop).

BACKFILLING WITH REACTIVE MATERIALS

Once a slurry trench excavation has progressed to some point clear of the starting point, it can be backfilled with reactive materials. Backfill placement is critical to the quality and cost of the installation. The methods relied upon for the placement of reactive materials have evolved and are derived from other slurry trench techniques.

With granular iron/sand backfill mixtures, tremie placement is the preferred placement method. Tremie placement ensures positive placement without the potential for segregating materials of different weights (e.g. iron and sand) and grain sizes. Unlike tremie placement of concrete (e.g. diaphragm slurry walls), larger diameter tremie tubes (diameters >30 cm) must be used to allow the material to pass without plugging. The reactive materials are usually pre-wetted to improve flow through the tremie. Generally, the maximum free drop from the bottom of the tremie pipe to the top of the backfill is less than 1.5 m. Tremies can be filled with conveyors, transit mixers, or excavating equipment. Wetting the iron can initiate the reactive media (especially iron) so the time between wetting and placement must be limited, usually to less than 8 hours.

With coarser grained and less expensive backfill mixtures, for example mixtures containing gravel, lime, sawdust, etc., simpler backfilling methods are more often used. A lead-in trench and the progressive displacement (or advancing slope) method commonly used in soil-bentonite slurry walls is the preferred method. A well-mixed backfill, even if it includes lightweight ingredients (e.g. saw dust, compost, carbon, etc) can be placed using progressive displacement. The slope of the backfill as it flows in the trench is critical in the placement of all reactive materials and often determines the most applicable method. Even with iron/sand backfill mixtures, if the trench is relatively long and/or shallow, and the backfill is designed to extend up near the surface, there eventually comes point when the backfill rises to the surface and continued use of a tremie is impractical and the progressive displacement becomes the most efficient method.

When placing reactive materials in a slurry trench, an end stop is normally used to separate the backfilling and the excavation operations. Most reactive materials easily flow along the bottom of the trench toward the excavator or create a very flat backfill slope that easily creeps into the excavation area. Just like in diaphragm slurry walls, an end stop provides a positive means to retain the backfill away from the excavation. End stops are usually made from steel tubes or steel sheet piles with dimensions the same width and depth as the trench. A perfect seal between the end stop and the trench walls is not required as long as the backfill is retained. End stops are usually moved with a crane to keep pace with the excavation and backfill.

One of the advantages of BP slurries is that they only suspend sand for a limited period of time. However, this results in a continuing and relatively rapid settling out of sand behind the excavation, which must be controlled. Backfilling with iron tends to exacerbate the perception of settling, since some iron particles are very fine and tend to become suspended in the slurry and settle out more slowly. This settling appears to be unique to granular iron backfills. Settling of iron and sand particles makes it more difficult to control horizontal layering with different backfill materials (e.g. different iron/sand recipes). The result is usually overfilling. For example, after a period of inactivity (e.g. overnight) iron settling may result in an apparent increase in the elevation of the backfill. Experience has shown that the settling of iron and sand do not affect the proportion of the iron in the backfill. Regular cleaning of the bottom of the trench, the use of end stops, and timely backfilling tend to minimize settling. An experienced slurry specialist is usually required to supervise proper backfill operations.

BACKFILL MIXING

A unique feature of many reactive materials is that a tightly specified mixture of different ingredients is often required. Methods to mix the materials must result in a homogeneous blend. A variety of proportioning and mixing methods are available, from both slurry wall and concrete technologies, including; pugmills, belt scales, transit mixers, volumetric scales, mixing boxes, and others.

Contaminate loading, reaction rates, and groundwater flow patterns are used by designers to calculate the amount of iron in a PRB, but the practical considerations often dictate the minimum width. Excavating equipment generally cannot be any narrower than about 0.6 m, depending on depth and resistance of soils. In order to install a PRB with a design width less than 0.6 m, sand is mixed with the iron to fill the extra volume. Mixing sand with the iron also has the added value of reducing the potential for fouling or plugging. The minimum amount of iron in any iron/sand mixture is usually no less than 20% by volume.

With iron/sand mixtures one preferred method of mixing is a transit mixer or ready mix truck. Weighing the amount of sand added and counting the number of preweighed bags placed in the truck is a simple method to control proportioning. Complete mixing is usually assured by rotating the truck's drum for about 5 minutes or 100 revolutions. An advantage of transit mixers is that the trucks are simple to move around site and readily unload into tremie hoppers and conveyors. Mixing iron and sand with a transit mixer and placing it into a 15 m deep trench with a tremie is shown in figure 2.

FIGURE 2. Filling tremie from transit mixer.

Another proven method of mixing iron and sand is a mobile volumetric concrete mixer or "Elkin mixer". These mixers use a volumetric screw auger to blend the ingredients. Unlike mixing with transit trucks there is no scale or weight tickets, so other means must be used to verify proportions. Usually, magnetic separation testing is used to verify the amount of iron in a mixture.

For some backfills, batch mixing can be accomplished with standard earthmoving equipment. For these mixtures the basic ingredients can be placed on a prepared pad or in a large box in their desired volumes and then blended together with repeated stirring and agitation using earthmoving equipment such as hydraulic excavators or wheel loaders. With backfill materials that include gravel, saw dust, lime, etc. weight-volume proportioning is usually adequate. Typical concerns for mixing with earthmoving equipment are dust generation and waste.

PRB DEVELOPMENT

Once the backfill material is placed in the trench, the last step is trench development. This process is similar to development of a well. The goal is to "break" the slurry remaining in the void spacing of the reactive media. The breakdown of the BP slurry is accomplished by breaking down the polymer to simple carbohydrates, and then by encouraging native soil microbes to consume the carbohydrates. Proper trench development ensures a free flow of groundwater through the PRB.

In order to ensure adequate distribution of enzyme breakers, temporary wells are installed approximately every 10 to 15 linear meters in the trench during the backfilling process. This well spacing is much tighter than a typical BP collection trench because the iron/sand mix generally used in PRBs is finer-grained and less permeable than gravel that may be used in a typical collection trench. When dealing with iron and sand backfill materials, tighter spacing ensures better trench development.

To develop the PRB, enzyme breakers are added and circulated through the backfill by pumping from the temporary wells. Trench depth and backfill permeability generally determines the type of pump required. Pumps are set up to withdraw slurry from near the bottom of the temporary wells and discharge the slurry over the surface of the backfill. Pumping in this manner sets up a circulation of the slurry from the well over the backfill and back to the well. The opposite circulation direction (into the well) may be equally as effective. Each temporary well should be pumped in turn; multiple pumps may be used. Pumping and development of a PRB is shown in figure 3.

FIGURE 3: Pumping temporary well to break BP slurry and develop PRB.

The BP slurry is considered broken when the liquid in the trench has a Marsh Funnel viscosity less than 30 seconds and the pH is within range of background. The degraded slurry should show greatly reduced turbidity, but may retain some “sticky feel”, which will be later consumed by natural microbes. Cold weather, variable groundwater chemistry, and sterile conditions may reduce the efficiency of the slurry breakdown and may require additional methods.

FUNNEL AND GATE INSTALLATIONS

As mentioned previously, the funnel and gate is a type of PRB having both permeable (gates) and low permeable (funnel) components. These can be more economical as portions of the PRB can be made up of less expensive soil-bentonite, soil-cement bentonite, and/or cement-bentonite slurry walls or other constructed barrier. The most common selection for funnel sections is the soil-cement-bentonite (SCB) slurry wall because the material combines low permeability with adequate strength. A significant cost advantage of slurry walls is that the same general equipment can be used to construct both the funnels and the gates.

During the construction of the funnel and gate connections, the funnel material must remain in place and not mix with, or contaminate the reactive media. The strength of the funnel material is critical during installation, but may be unimportant for operation of the system, where low permeability is the critical parameter. An unconsolidated soil-bentonite funnel for example, may have a low permeability, but would likely flow into a slurry supported excavation of a gate without additional structural support.

The site investigation and groundwater modeling done during the design stage will determine the configuration and length of the funnels and gates. The most simple funnel and gates have a funnel-gate-funnel configuration with a ratio of about 4 to 6 parts funnel to one part gate (Day, et. al. 1999). Increasingly, multiple funnels and gates are being used to combine features of containment and groundwater diversion with reactive media treatment at many sites.

CASE STUDY

A former manufacturing plant in the northeast United States had a history of TCE (trichloroethene) contamination of the groundwater. The plant was located a short distance upgradient of municipal well field. The plant had installed a number of recovery wells and an on site treatment plant, but the heterogeneity of the soils, poor yield from the wells, and costly maintenance demands of the system encouraged the owner to look for a more positive and less costly system to replace pump and treat.

Soils at the site were of glacial origin and the contamination was in evidence as deep as the bedrock. At a depth of approximately 26 m, shale bedrock existed that provided an aquitard. A soils investigation was initiated and a design was developed for two PRBs.

FIGURE 4: Installing end stop in deep trench (note well and tremie in background).

The first PRB was designed to run close by the manufacturing building. This PRB consisted of a funnel and gate system about 220 m long and 21 to 26 m deep and 0.75 ft wide. These dimensions were determined by the size of the plume (for length and depth) and the minimum excavating width (for width). Four funnels and three gates were configured to intersect contaminated groundwater near the plant. The funnel sections were constructed of SCB. The gate sections were backfilled with a mixture of granular iron and sand. The two outside gates and the top of the middle gate were backfilled with a mixture of 20% iron and 80% sand. The bottom 10 m of the middle gate was backfilled with a mixture of 30% iron and 70% sand to optimize treatment in the middle of the plume. The select of the funnel and gate system reduced overall iron costs, because the amount of iron required was determined by the minimum acceptable iron mixture (20% iron) and would have been considerably more for a continuous wall of the same length.

The second PRB was designed to protect the municipal well field. This PRB was a continuous trench backfilled with a 20% iron mixture. The trench was 0.75 m wide, 60 m long and 15 m deep. The trench was positioned within hundred meters of the nearest public water well.

First, buried utilities were identified and removed or rerouted away from the PRB alignment. Next, an earthen working area was leveled and cleared of vegetation. Then a slurry plant was mobilized and erected. The slurry plant was configured so that with minor modifications it could produce slurry for either the SCB and BP portions of the work. Both PRBs were excavated with an extended stick excavator. The funnel sections were constructed first. The SCB was designed to have a minimum unconfined strength of 200 kPa and a maximum permeability of 1 x 10^{-6} cm/sec. An added benefit of the SCB was that it provided a stable foundation for the replacement of utilities and for the main road into the plant.

The gates were excavated using BP slurry as liquid shoring. It was possible to excavate into the previously completed SCB to make the gates the proper dimensions. The iron and sand mixture was blended in transit trucks that were supplied by the local ready mix vendor. Temporary wells, 15 cm in diameter were installed in the gates during backfilling and later used to provide access for breaking the slurry. The iron and sand mixture was tremied into the trench. After the iron and sand mixture was in place the BP slurry was broken and the temporary wells pumped for 2 pore volumes of the backfill to develop the trench and ensure free flow of the groundwater through the barrier wall.

This installation and others have demonstrated that success of the bio-polymer slurry trench method when supervised by knowledgeable practitioners.

REFERENCES:

Hubble, D.W., R.W. Gillham, R.W., and J.A. Cherry, 1999, “Emplacement of Zero-Valent Metal for Remediation of Deep Contaminate Plumes” In S. Chamberlain, CC. Chien, and N. Lailas (Eds), *International Containment Technology*, pp. 872-878, Florida State University, St. Petersburg, FL.

Day, S.R., S.F. O’Hannesin, and L Marsden, 1999, “Geotechnical Techniques for the Construction of Reactive Barriers”, *Journal of Hazardous Materials* B67: 285-297, Elsevier Science, New York, NY.