Groundwater control using slurry cut off walls in acidic soils

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ABSTRACT

To facilitate the development of residential area a major upgrade of the storm water management system was required using open channels and flow attenuation ponds. The area is underlain by soft alluvial soils comprising organic silts, clays and peat. The high groundwater level and compressible soils makes the area susceptible to long-term settlement if the general groundwater level is reduced. With storm water channels extending to 3m below groundwater level some form of cut off wall was required to prevent significant groundwater drawdown and associated settlements.

Following an optioneering phase the use of a slurry cut off wall was considered the most appropriate given the site conditions and identified risks. Whilst uncommon in NZ there is significant worldwide use of the method for groundwater or leachate migration control. A slurry wall is excavated under self-hardening cement bentonite slurry; the soil is fully replaced by the slurry. A specific mix design is developed based upon the material sources to ensure that it has the fluid properties required for installation and the hardened properties to provide an effective long-term low permeability barrier.

The paper covers the following aspects of the slurry cut off wall methodology:

- Project requirements
- Material selection
- Laboratory trials and mix development in France
- Site establishment
- Site controls and verification
- Project challenges and solutions
- Project learnings

1 PROJECT REQUIREMENTS & BACKGROUND

A new 2.3 km long stormwater conveyance corridor was required to facilitate the development of a 164 hectare rural catchment. Zoning of the land allowed for significant residential development, however the lack of stormwater infrastructure restricted growth prior to the implementation of this project.

The stormwater conveyance corridor varies in width from 20 to 50 m and includes:

- A series of open water bodies / wetlands maintained by weirs
- Riparian planting alongside the channel, with specimen trees throughout the corridor
- Shared paths, boardwalks and play areas along the corridor
- High level pedestrian bridges / crossings
- Trafficable culvert crossings

The area is underlain by soft alluvial soils comprising organic silts, clays and peat. The high groundwater level and compressible soils makes the area susceptible to long-term settlement if the general groundwater level is reduced. The depth of the stormwater channel varies with a maximum depth of approximately 3m below groundwater level. To reduce the extent and magnitude of groundwater drawdown, and potential settlement, some form of mitigation was required. A number of options were considered including lining the channel, piping a length of the channel or installing an in-ground cut-off barrier. An in-ground cut-off barrier was the preferred option for managing groundwater drawdown related effects of the channel

1.1 Ground Conditions

The geology in the area based on the 1:250,000 geological maps include Recent Alluvium and Puketoka Formation Alluvium comprising soft peats, organic silts and sands. In the eastern area of the catchment, residually weathered East Coast Bays Formation are mapped, comprising stiff clays and silts and clays of the Waitemata Group. Soils and rock of the Auckland Volcanic Group are also present near the site. The detailed geotechnical investigation undertaken by GHD in 2014/15 confirmed this sequence.

For the stormwater conveyance channel design and mitigation measures the alluvial deposits are most influential. These comprise amorphous, fibrous and spongy peat material with interbedded organic cohesive soils and locally non-organic silts and clays, thin beds of rhyolitic ash and locally extensive pockets of wood, kauri stumps and large tree trunks.

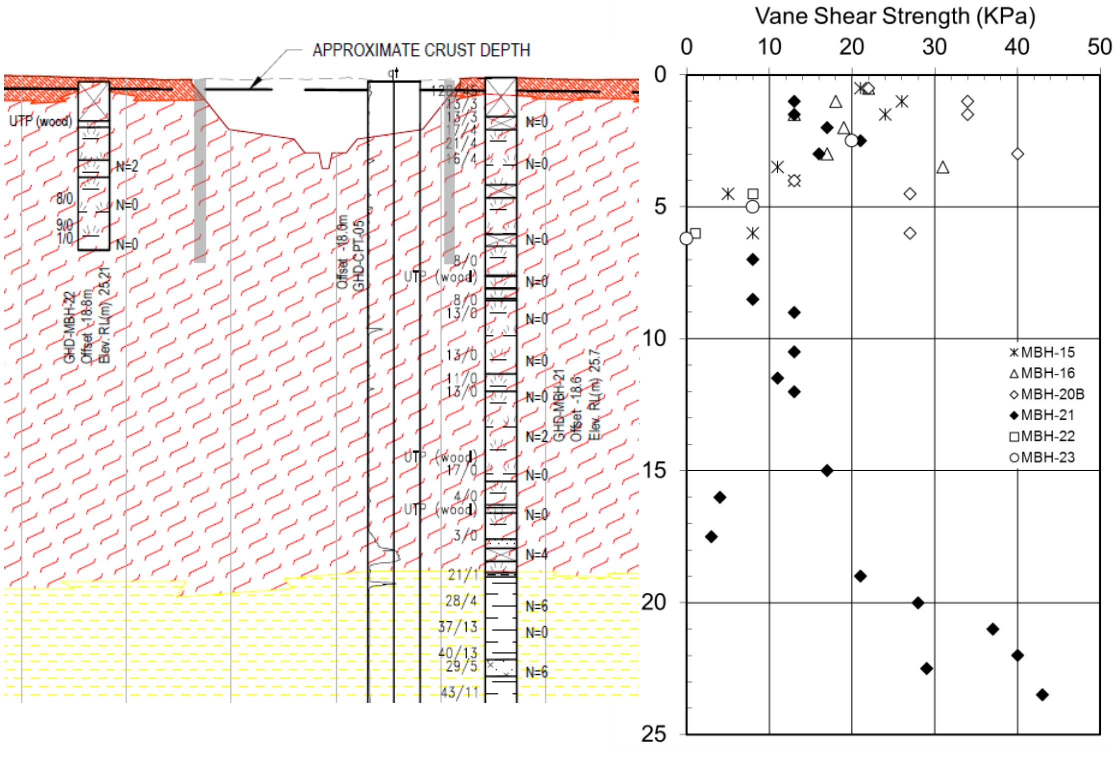

Figure 1: Typical Geotechnical Section and Vane Shear Strength Profile

There are rhyolitic ash layers, with a consistent 100 mm to 500 mm thick layer encountered in many investigation locations at around 1.0 – 1.5 m depth. Thinner lenses were found incorporated into peat deposits which were associated with carbonaceous bands above and below suggesting combustion. This and some of the large logs and stumps found in the sequence may be due to past eruption events.

Peat deposits were encountered in all investigation locations extending from near surface to between 2.2 m and 21 m depth. Peat deposits generally thinned out to the southeast with thickest deposits identified at the northern end of the northern channel alignment. Associated soil and ground water chemistry tests indicated acidic conditions with a pH as low as 4.2

1.2 Hydrogeological Conditions

The deep groundwater movement in the wider Takanini-Drury area is strongly influenced by the presence of large scale structural faulting within the basement Greywacke (and Waitemata Group) rock which effectively compartmentalise the regional groundwater flow system. The site location lies to the east of the inferred Drury Fault line which influences deep groundwater flows. That said, it is the shallow groundwater system resides within the recent Tauranga Group alluvial sediments that will potentially be affected by the stormwater channel. The groundwater flow direction is from east to west with groundwater draining into the Manukau Harbour inlet via the McLennan wetland. Hydraulic gradients are generally fairly flat.

Depths to groundwater in the shallow unconfined aquifer system range from 0.6 m in the eastern part of the subject site to 1.0 m to 1.5 m near Cosgrave Road and are >1.5 m depth in the south western part of the site near Grove Road. A strong relationship between site topography and groundwater levels is noted to exist with groundwater encountered at shallower depths in the eastern part of the site where the ground surface is flatter. In the west, the depth to groundwater increases with proximity to McLennan Park and drains towards the ponds.

The vertical permeability of the peat was estimated as between 1x10-4 m/s to 1x10-6 m/s, while the horizontal permeability was estimated between 1x10-5 m/s to 1x10-7 m/s. These values were confirmed via a long-term pumping test of the groundwater and analysis of the resulting dewatering curve.

1.3 Cut off Wall Requirements

Groundwater flow modelling of the stormwater channel section was performed using the derived soil parameters to understand the drawdown profile resulting when the stormwater channel was in steady state low flow conditions. The potential impact extended to over 100m away from the channel that would result in unacceptable long term settlement. Sensitivity analysis considering the location and depth of the cut off wall lead to the selection of a 7m deep wall located within the batter of the channel with a permeability, k = 1x10-8 m/s.

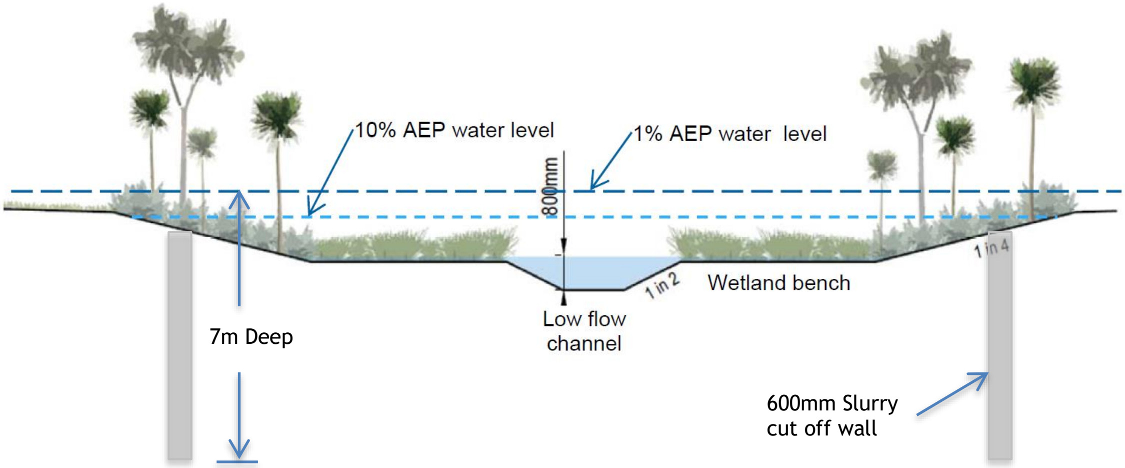

Figure 2: Typical channel section with slurry cut off wall

2 OPTIONEERING

A ground water cut off can be formed by a number of different construction methodologies including concrete panels, secant piles, sheet piles, soil mix walls and slurry walls. Whilst cost is the primary driver it is the final cost to complete the works to the desired performance criterion that must be evaluated taking into account the associated risks.

The most efficient installation solution needs to consider how the ground conditions will affect the installation and the impact on the long term properties of the cut off wall. At this site the primary physical factors are:

- soft organic soils
- high ground water level
- acidic soils
- potential buried timber obstruction

Table 1 provides a list of potential options with comparative evaluation against cost and other risk factors.

Table 1: Option evaluation - primary risk and cost

Construction Methodology	Permeability	Durability	Soil Acidity	Obstructions	Cost
Diaphragm or Secant pile walls (Cased / CFA)	Multiple cold joints ✓✓	Concrete mix design to standards ✓✓✓	Replacement methodology ✓✓✓	Coring ✓ Impact on sequencing ✗	$$$$$
Soil Mixing (DSM / CSM, Trenchmix©)	Homogeneity of soil mix & cold joints ✗✗	Binder selection & dispersion ✓✗	Effect on binder reactivity ✗✗	Impact on mixing and homogeneity ✗✗	$$$$
Sheet Piling - lightweight steel	Sheet pile joint / clutch treatment ✓	Sacrificial thickness ✓	Corrosion ✗✗	Installation and material / clutch damage ✗✗✗	$$
- Mandrel - driven GRP		✓✓	✓✓		$$$
Slurry Wall	Mix design & Verifiable ✓✓✓	Mix design and material selection ✓✓✓	Replacement methodology ✓✓	Coring but effect on soft organic soils ✓	$$$

In terms of providing a reliable cut off wall solution the diaphragm wall or secant pile wall using appropriate materials would be the most robust solution as it represent a soil replacement method but has the highest cost. The use of deep soil mixing provides a potentially cheaper methodology because it uses the soil to form the structure but relies on the effective dispersion and reaction of a binder and the soil. An earlier trial on the site highlighted that the acidity, organic matter and timber adversely affect the reactivity and dispersion of the binder which compromised the quality of the cut off formed. This leads to a strong preference to adopt a replacement methodology.

If the basic cost was the selection criterion for a replacement method, the use of a thin wall steel sheet piles would be the obvious choice. The acidic conditions make the long-term performance questionable leading to consideration of alternative mandrel-driven GRP sheet pile options. However, large timber obstructions are known to be present in the area; these represent a significant installation risk. Apart from the programme and material wastage issues the primary risk is associated with potential damage / de-clutching which ultimately affects the integrity of the cut off wall.

A slurry wall using appropriate materials and self-hardening mix design can meet the long-term cut off wall requirements as it is a replacement methodology. The obstructions can be removed by the excavator with the fluid slurry to maintaining a stable trench. The obstruction risk associated with this methodology is primarily the additional time and slurry consumption.

3 SLURRY WALL METHODOLOGY

Soletanche Bachy have used of slurry walls to provide low permeability cut off walls around the world typically to contain plumes of contamination or contain leachate from landfill sites. The method involves the excavation, removal and replacement of the soil with self-hardening slurry to form the trench. The nature of the landfill, soil or other material that the trench is constructed through generally has no impact on the strength and permeability of the slurry. The excavation under the full pressure of the fluid slurry serves to support the trench and prevent the ingress of groundwater resulting in no contamination and delivery of a full replacement methodology. When hardened and below the water table the slurry is of low density with a permeability in the order of 1 x 10-8 m/s. Above the water table the slurry can desiccate without appropriate cover / capping.

3.1 Quality control of slurry wall

Apart from the basic slurry trench geometry, the slurry wall quality control is focussed on the slurry material so generally the following is implemented:

a) The design of the slurry mix is undertaken in the laboratory to test the interaction of the mix-water, cement, bentonite and other cement replacement materials.
b) Quality control of the slurry is via batching records and tests carried out to evaluate fluid properties (primarily density, pH and viscosity) for mix consistency.
c) Wet sampling from different depths in the trench is used to form specimens and facilitate strength and permeability testing as required.

3.2 Slurry wall materials

The soil chemistry and in this particular case the pH = 4.2 – 4.5 needs to be considered for long-term durability; General Purpose (GP) OPC is not sufficient based upon the Soletanche Bachy experience of forming slurry cut off walls in acidic soils with a pH in the range of 3.0 – 5.0. Blended cement with 60% GGBS was recommended based upon the following:

a) Where soil / water pH < 4 durability is an issue and a membrane advocated.
b) Where soil / water pH is in the range 4.0 – 4.5 the use of OPC / GGBS blended cements are required, adding a further element, PFA, blend can increase overall durability.
c) The GGBS replacement reduces the strength development of the slurry.

Around the world GGBS and PFA by-products are widely used to reduce cost at cementitious replacement levels of between 30 – 90%. The use of these blended materials has many affects including reduced heat of hydration and improved durability in concrete. However, these materials are not readily available in New Zealand resulting in the use of Duracem, an imported Holcim blended cement.

4 SLURRY TRIALS IN FRANCE

A slurry wall has not been used in such conditions in New Zealand to form a long-term groundwater cut off. The use of the imported cement and bentonite makes a robust mix design trial essential to provide confidence in the site batched product. It is also worth noting that test results are not available for 28 days which impacts the programme and means a significant volume of slurry is produced at an industrial level prior to QC results being obtained.

Soletanche Bachy has a research and development laboratory in Paris, France that has testing facilities and experts in the geotechnical and associated geo-materials field. The ability to draw on this international experience is invaluable to minimise learning curves when applying new technology. The laboratory testing programme was based upon the approach used on similar successfully delivered grout, slurry and soil mixing projects; comparison of the fluid and hardened properties with similar mixes is also possible as can be seen in Figure 2.

All materials were sampled and sent to the laboratory in Paris. The testing regime implemented based upon the following objectives:

- Fluid properties - Viscosity: 32 < MVF < 50 s
  - Stability: Bleeding @3h < 5%
- Long-term - Permeability: k = 1 E-08 m/s
  - Strength: UCS @ 28 days > 1.5 MPa

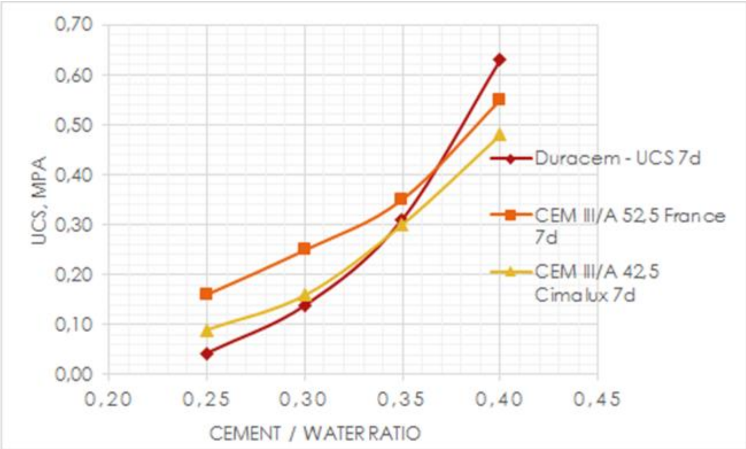

Figure 3: Cement reactivity comparison from other Soletanche Bachy projects

A series of mixes were prepared to understand the sensitivity of the fluid and hardened properties of the slurry constituents. It is worth noting that the samples prepared for permeability testing use disposable crystal plastic moulds to ensure representative results. The long-term permeability was the critical parameter but it is important to recognise that this test is time consuming to perform and hence the use of strength represents a good early quality control guide.

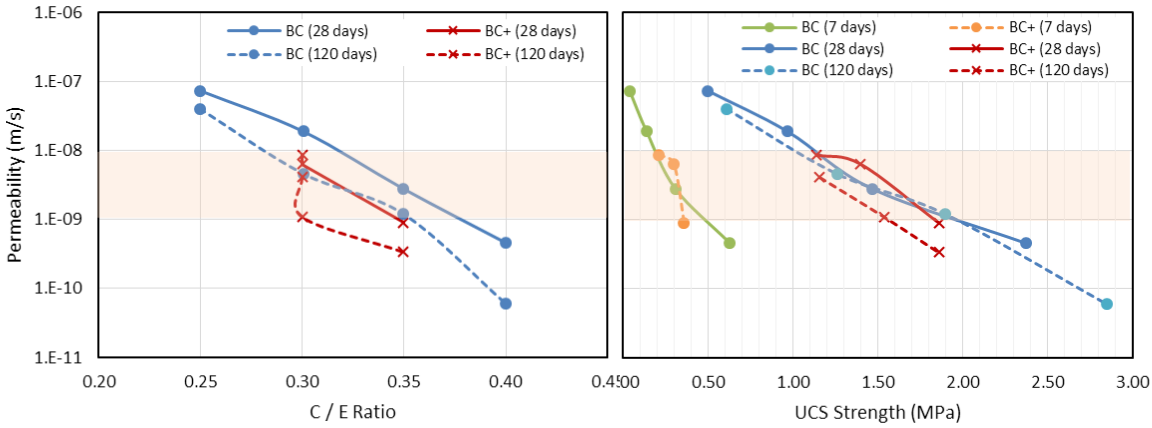

Figure 4: Laboratory trial summary permeability and strength results

The selected mix design needs to consider that the laboratory trials represent very accurate batching and efficient mixing. Industrial batching and mixing will result in more variability. Furthermore, the impact of the excavation process and potential contamination by soil or groundwater whilst excavation through the slurry needs to be considered. To provide some margin an order of magnitude in the target permeability it is normally considered appropriate.

5 SLURRY WALL INSTALLATION

The slurry batching plant was set up with automated mixer, bentonite mixer, bentonite hydration tanks, cement silos and slurry reticulation. The mixing process is shown schematically in Figure 5. Excavation was performed with a long-reach excavator.

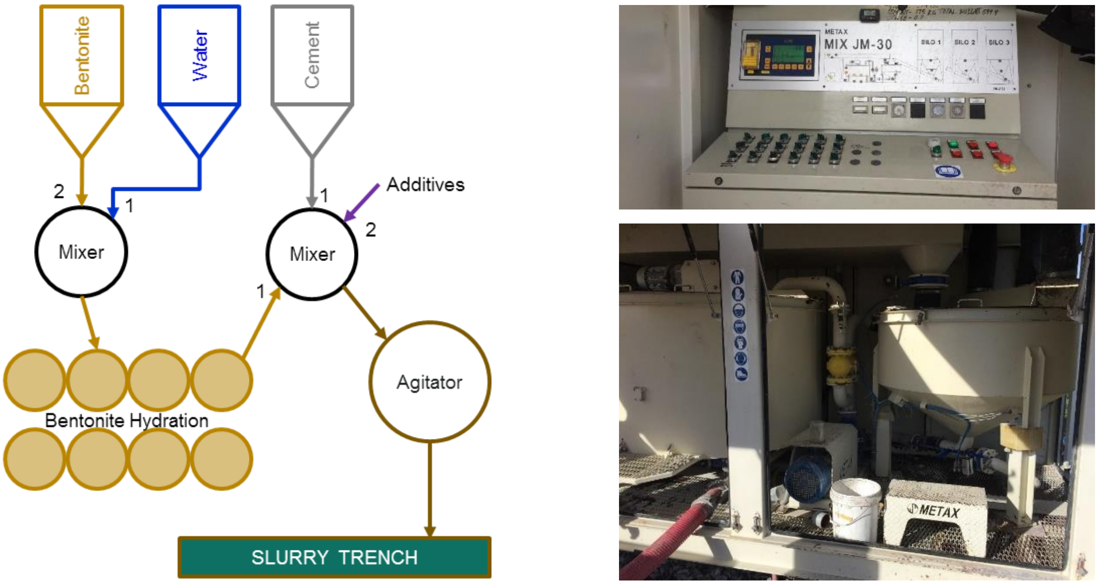

Figure 5: Mixing methodology

5.1 Monitoring of the slurry production

During the initial stages of slurry production intensive sampling and testing was adopted to facilitate training, allow benchmarks to be established with the site team and to ensure site batched material was in line with the laboratory trials. The fluid properties of the bentonite slurry pre & post hydration were tested to optimise production mixing and hydration time. The fluid properties of self-hardening cement bentonite mix were visually monitored as "instantaneous" quality control to ensure consistency of the mix; density, pH, viscosity and bleed tests were recorded. For strength and permeability testing four samples were made for each, sufficient for 7, 28 and 56 day testing.

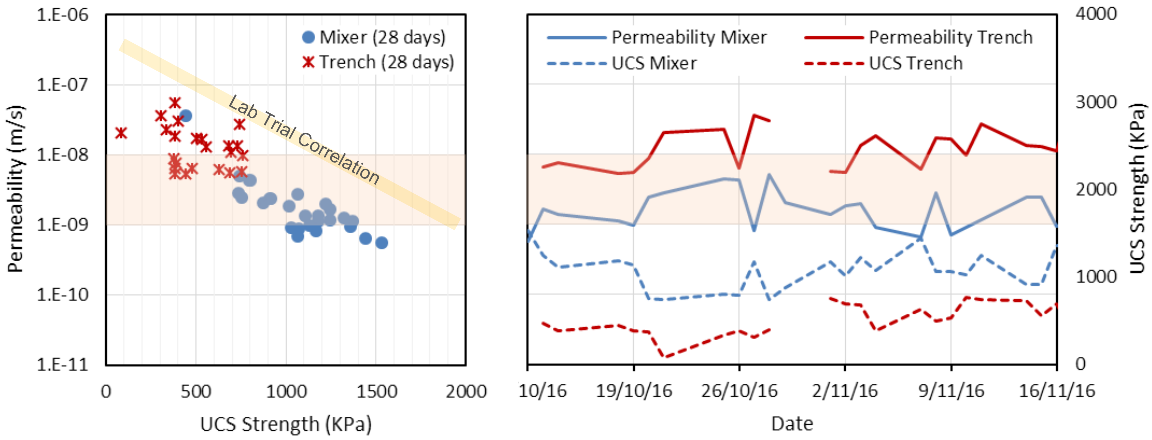

Figure 6: Industrial permeability and strength results

As can be seen from Figure 6 there is a reasonably good correlation between strength and permeability albeit offset from the laboratory trial data. It is also evident that the results from the mixer are better than those from the trench in terms of strength and permeability at a test age of 28 days.

5.2 Obstructions in soft organic deposits

The primary issue on the site was the extensive buried timber obstructions typically encountered between 2m and 4m depth. These tree trunks were in some cases up to 2m in diameter and several metres in length. From a design perspective it was not acceptable to leave these obstructions encapsulated in the slurry wall as future excavation or degradation would compromise the integrity of the slurry cut off wall. Following a probing exercise, it was possible to re-align the wall around some of the obstructions where the site delineation and development extents permitted. Where this was not possible coring was carried out to cut and remove the obstruction; using light weight plant given the low bearing capacity crust / working platform.

Figure 7: Slurry wall installation and obstruction removal

6 LESSON LEARNT

The acidic ground conditions and obstructions at the site make the installation of a permanent cut off wall challenging which provides a number of key points of learning, namely:

1. As part of a global company with appropriate connections it is possible to find potential solutions to address similar challenges; in this case slurry cut off walls in acidic soils.
2. Well planned laboratory mix trials using the actual materials are essential to develop a robust mix design; noting the difference between laboratory and industrial processes.
3. Variability of the fluid properties of bentonite, above API minimum standards, can impact slurry mixing; monitoring fluid properties is a good quality control mechanism.
4. The slurry sampling from the trench needs to be representative.
5. The removal of obstructions in a low strength high water content soil matrix will cause loss of structure and strength reduction; this disturbance can result in slurry wall contamination requiring pre-treatment.

7 CONCLUSIONS

A cut off wall has been successfully implemented in the prevailing acidic ground conditions using a cement bentonite slurry wall. This outcome is due to the collaboration between Auckland Council (Client), GHD (Designer) and March Construction (Contractor) with the technical support of the Soletanche Bachy laboratory. It is fair to say that the obstructions were a particularly challenging but solutions were developed to locate and overcome these and as a result a further phase of work is underway