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A Case Study on the Design and Construction of a Groundwater Cut-off Structure Using Secant Piling Techniques and Geosynthetics

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Abstract

The construction of a groundwater cut-off structure often entails a wide battered excavation that requires movement of a large volume of material or the use of specialised equipment such as a diaphragm wall grab and slurry plant. This paper details a case study in the use of secant pile foundation auguring techniques coupled with geosynthetic technology to install a contiguous groundwater cut-off structure. Restricted by available space due to existing infrastructure and client safety protocols, a method of installing a groundwater cut-off structure to a depth of up to 12m in residual and soft sandstone and siltstone rock had to be devised that could be implemented from surface. A method using pre-fabricated geotextile socks, sequentially installed into 1050mm diameter secant pile holes was developed. This method allowed the construction of the continuous groundwater cut-off to be completed safely from above surface, within limited site space and while adhering to time and budget requirements.

Keywords: *Groundwater Cut-off; Prefabricated Geotextiles; Secant Pile Wall*.

1 Introduction

The installation of a 240m long and 12m deep groundwater cut-off curtain structure to monitor the groundwater down gradient of a processing plant was required. The cut-off curtain had to be constructed directly adjacent to the plant to make groundwater monitoring effective. Additionally, the cut-off curtain was to be separated into panels so that monitoring of the groundwater from discreet areas of the plant could be implemented.

The site is founded on compacted fill material to depths of 1.7m to 3.2m below ground level (BGL). The fill material was placed over reworked residual sandstone to construct the terrace on which the industrial plant is situated. Below the reworked residual sandstone is residual sandstone and soft rock sandstone to depths of up to 9m BGL. Layers and lenses of soft rock siltstone and water bearing fractured siltstone were present to depths of up to 13m BGL with an average depth of roughly 12m BGL. A distinct carbonaceous siltstone horizon was present below the soft rock siltstone and water bearing fractured siltstone layers. The carbonaceous siltstone layer was expected to have a low permeability due to the rock's fine constituent grain size. Geohydrological modeling by the client determined the carbonaceous siltstone layer to be an aquiclude to the groundwater in the area and was specified as the target depth of the cut-off. The carbonaceous siltstone horizon was surveyed by a series of boreholes drilled along the expected alignment of the drain and was found to lie at between 10m to 13m BGL as per Figure 1-1 below.

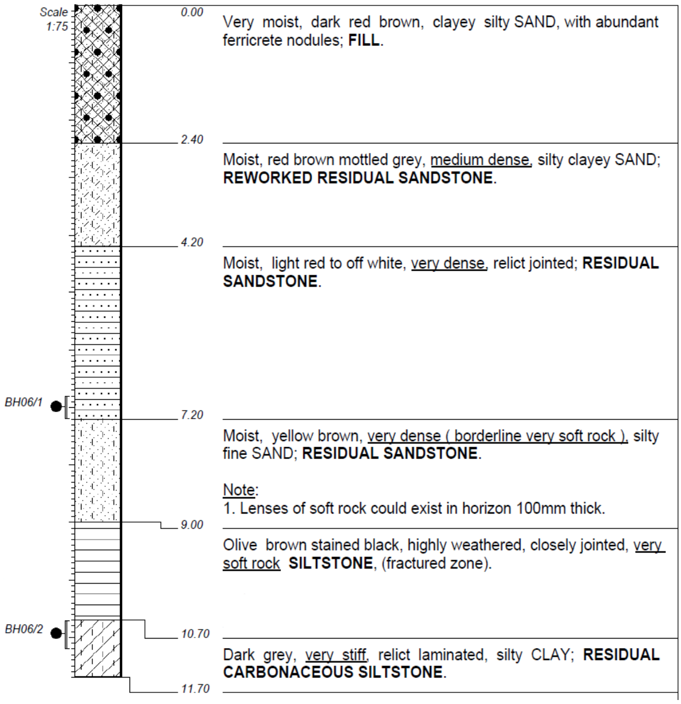

Figure 1-1. A borehole log of the in-situ geology as typically experienced (Antrobus et al 2016).

Space was restricted on the site due to the layout of the industrial plant where the cut-off was to be constructed as shown in Figure 1-2. The area demarcated for construction was a single lane access road with infrastructure on both sides, on average roughly 8m wide but with a minimum width of around 5m in certain areas as shown in Figure 1-2. The space available for construction was further restricted by a railway line and pipe rack on the north side of the road and a pipe rack on the south side of the road as well as a pipe bridge crossing over the road. In addition to the site space restriction, strict safety protocols were enforced by the client – the most prominent being that no person would be allowed into any excavation. This meant that the construction of the cut-off had to be done mechanically from above ground level as there was no space to excavate a safely battered trench to the required depth of 13m.

Figure 1-2. Site access below the pipe bridge

2 Method Study

There are numerous groundwater cut-off construction techniques that are practiced in the South African market. Due to the restricted space on the site technical options that require large site areas for excavations or for plant establishment had to be ruled out. Therefore, design options using construction techniques such as; open box-cut excavations; diaphragm grab and slurry plant trenching (diaphragm wall); and, braced sheet pile trenching could not be considered as possibilities. Open box-cut excavations incur a wide width at the surface of the exaction; given the site's narrow access width and the client's safety protocols this was the first possibility to be ruled out. In addition, a large battered excavation would have created large volumes of spoil that would have been practically difficult to manage on site. Diaphragm wall construction appeared to be a potential candidate technology with successful projects having been completed in the past typically to construct water tight lateral support walls for basement excavations. However, due to the narrow site width it was deemed impractical to establish the slurry plant alongside the access road. In addition, the crane carrying the diaphragm grab would require more space than available on the single lane access road. Braced sheet pile trenching appeared to also be a possible candidate. Given the in-situ residual sandstone, soft sandstone and siltstone rock as well as the depths to which the sheet pile would have to penetrate it was likely that predrilling of the in-situ material, heavy section sheet piles and heavy duty driving equipment would be required. This meant that a large crawler crane would be established on site to mobilise the heavy vibrating/driving equipment and sheet piles. Thus, the space available on site again became the limiting factor. Vibrations during installation of the sheet piles may have also not been permissible due to sensitive equipment in the industrial plant alongside the site.

A promising candidate technology was the use of secant piling techniques to construct a fully contiguous ground water cut-off curtain drain to specified depths along the drain's alignment. Secant pile wall construction technology was recently used in New Zealand to successfully install a deep ground water cut-off to control piping erosion of the foundation of the Arapuni Dam wall. The cut-off wall was installed to 90m deep maintaining a minimum width of 400mm of concrete (Amos et al 2017). While secant piling techniques are commonly used in South Africa to construct lateral support structures for the excavation of deep basements on restricted sites and to construct mine shaft compression rings there have been few projects to use this technique to construct groundwater monitoring, cut-off structures. There is, however, nothing stopping the local market from using the available equipment and expertise to build groundwater monitoring structures. A similar approach to using secant piles to install an impermeable barrier was envisioned for this project but with the novel alteration of the method to allow installation of drainage medium within the cut-off wall structure.

3 Design

3.1 Concept

The secant piling construction technique was chosen as the most practicable option to install the cut-off drain. It was decided to install the cut-off drain using a series of 1050mm diameter secant auger piles. Each pile would be constructed at 950mm centres along the drain centre line creating an overlap of 100mm and a minimum nominal drain width of 447mm. A system of mass concrete primary piles and filter sand filled secondary piles was devised to construct the cut-off curtain structure as shown in Figure 3-1 below. The mass concrete primary piles, installed first, inhibit the collapse of the side walls of the secondary piles into which the permeable filter sand drainage medium of the groundwater cut-off is installed. In order to drain the water from the structure, in-line extraction points had to be constructed where submersible pumps could be used. Extraction wells were thus located at low points of each panel of the cut-off curtain. These low points were determined from survey of the carbonaceous siltstone horizon. To compartmentalise the cut-off curtain into isolated panels solid mass concrete primary piles were installed at the start and end of each panel.

In order to cast the drainage medium into the bottom of the piles, a method using prefabricated geotextile socks was devised. Each sock would be sewn into a cylindrical tube, roughly the diameter of the receiving pile hole – generally the socks had a larger diameter to create room for the geotextile to fill cavities caused by minor collapsing of the pile’s wall. The geotextile socks were to be lowered into the bottom of the primary and secondary piles and filled from surface with drainage medium using a specially designed jig on the end of a tremie pipe. The first layer of drainage medium was decided to be clean 19mm stone that was to be placed inside the geotextile socks at the bottom of the primary and secondary piles. The primary piles were filled with low strength concrete to the surface using a second geotextile sock with a layer of sand at the bottom to separate the concrete from the 19mm stone. The secondary piles were also first filled with a layer of 19mm stone inside a geotextile sock. A second geotextile sock was then placed above the first containing the 19mm stone and filled to surface with a specifically graded filter sand. In order to drain the water out of the cut-off curtain effectively extraction well points were positioned at low points in the carbonaceous siltstone layer, as determined by the geotechnical survey. The levels of the drain were then designed to slope towards the extraction well points. The extraction wells were constructed 1m deeper than the adjacent cut-off curtain and were filled from the bottom to surface with 19mm stone inside a geotextile sock. Well screens were to be installed in each of the extraction wells for the installation of submersible pumps. To separate the cut-off curtain into discrete panels, solid mass concrete piles were cast at high points in the carbonaceous siltstone layer in between panels.

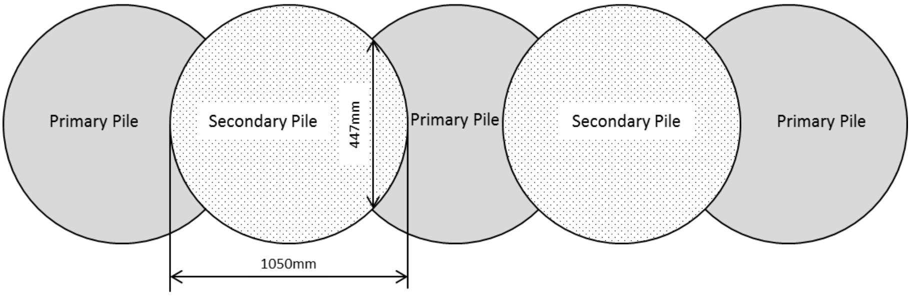

Figure 3-1. General secant piling arrangement for construction of the cut-off drain.

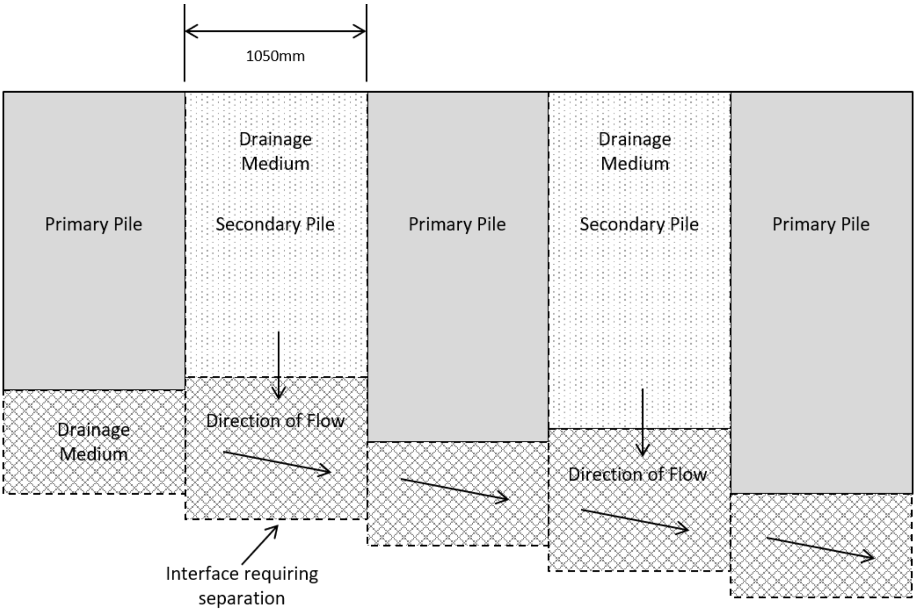

Figure 3-2. Long section of secant pile arrangement

More detailed descriptions of the design and construction process of each of the components used to install the cut-off curtain drain are given below. The construction sequence is indicated by the numbers 1 to 13 in the figures to follow.

3.2 Primary Piles

The primary piles were augered before the secondary piles. The bottom of each primary pile hole was separated from the in-situ material using a 1.7m long geotextile sock lowered in from surface using a jig suspended from an auxiliary crane. This sock was then filled with a 1.2m thick column of drainage stone placed using a tremie pipe. Another 1.7m long geotextile sock for separation was installed above the drainage stone and filled with a concrete plug placed by tremie pipe. The remainder of the open hole was then filled with a 10MPa concrete column to 0.6m below BGL. See Figure 3-3 for a schematic representation of the installation of a primary pile. The method shown was that devised for the worst case scenario if the piles were unstable and collapsing and thus includes the use of a casing.

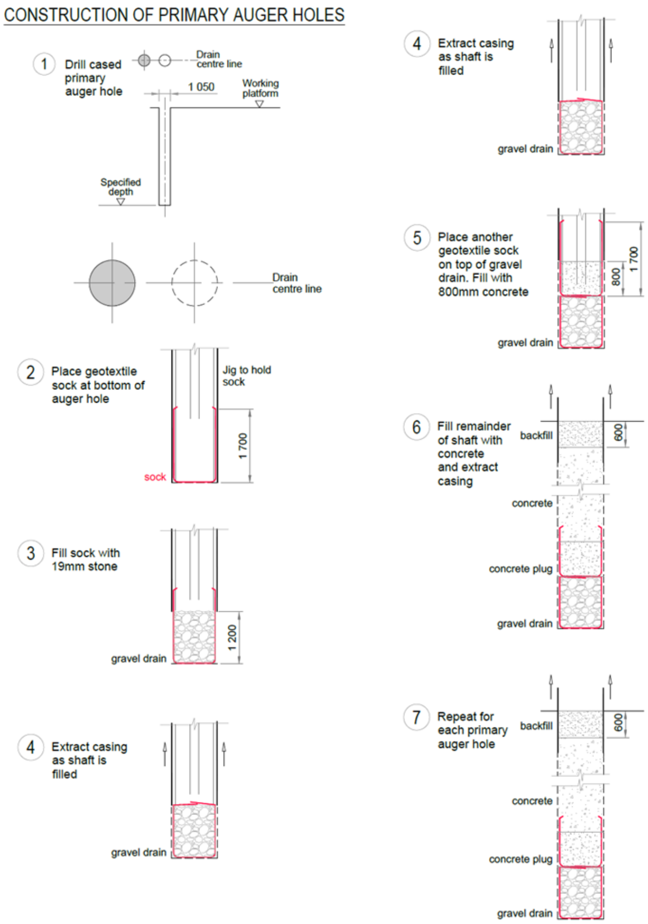

Figure 3-3. Construction technique used to install the primary piles

3.3 Secondary Piles

Secondary piles were augered 100mm into the adjacent primary piles. This was done before full curing of the 10MPa concrete, to prevent kicking out of the auger and misalignment of the drain. At the bottom of each secondary pile a 1.7m long geotextile sock was placed from surface and then filled with a 1.5m thick column of drainage stone. Above the drainage stone a second 13m long geotextile sock was placed and filled with a column of selected filter sand to 0.6m BGL. The second geotextile sock separates the filter sand in the secondary piles from the in-situ material and the drainage stone below. See Figure 3-4 showing a schematic representation of secondary pile installation between already installed primary piles.

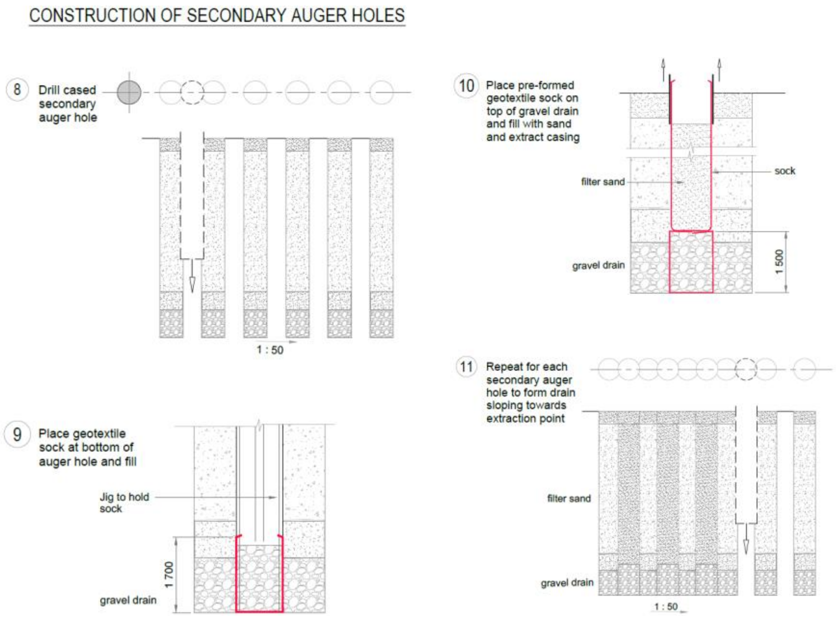

Figure 3-4. Construction technique used to install the secondary piles

3.4 Extraction Wells

The depth of the piles was specified beforehand based on the required slope of the drain and the depth of the underlying carbonaceous siltstone. This allowed the fall in the drain to be controlled and its implementation strictly monitored. Each of the cut-off drain panels were constructed to slope inwards and towards an extraction well. The extraction wells were augered to a specified depth 1m deeper than the surrounding drain. A 13m long geotextile sock was placed to separate the extraction well hole from the in-situ material. A 160mm diameter uPVC well screen, slotted along the bottom 3m, was placed in the extraction well hole by auxiliary crane. Drainage stone was placed, via tremie pipe, around the well screen to 0.6m BGL. The extraction wells provide the location from which the panels are drained. See Figure 3-5 below showing installation of an extraction well and well screen in between the already installed primary piles.

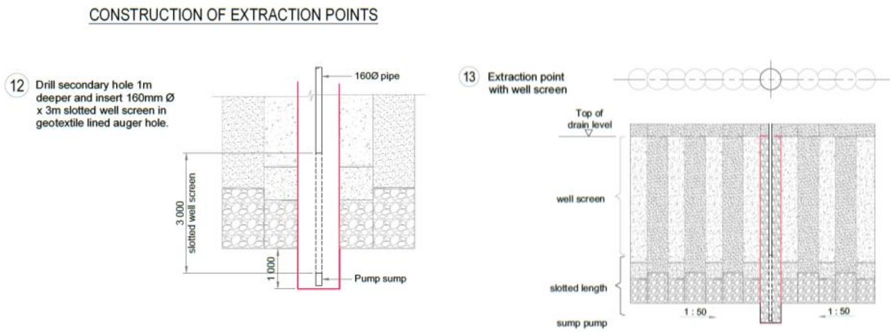

Figure 3-5. Construction technique used to install the extraction well piles

3.5 Solid Piles

In between each panel a solid mass concrete pile – essentially an un-reinforced secant pile – was cast to the depth of the carbonaceous siltstone to create a barrier between the adjoining cut-off panels. The piles were located at local highpoints along the drain profile.

3.6 Filter Criteria

One of the main challenges facing the design was to ensure that the drain does not block over time. A GRI GT13 Class 2 geotextile for separation was specified as the primary geotextile to be used for the fabrication of the geotextile socks. Due to concerns over the durability of the geotextile socks during construction the contractor opted to use the geotextile with higher survivability specification. The geotextile used to fabricate the geotextile socks was a GRI GT13 Class 1 polypropylene non-woven geotextile. The apparent opening size of 60µm of the specified non-woven needle punched geotextile satisfied the appropriate filter criteria and long-term stability for the surrounding in-situ soil and the drainage medium according to the Designing with Geosynthetics handbook (Koerner 2005). This required compatibility between a wide range of particle size distributions from silt to gravel. The grading of the filter sand specified was determined according to Terzargi's and Peck's filter criteria (Terzargi and Peck 1948). This was done to ensure that if the geotextile socks were to tear, the filter sand component of the drain should not be blocked by ingress of the fine silt particles present in the in-situ material.

3.7 Design Concerns

One of the concerns raised during tender of the project was the integrity of the stone drainage medium below the piles. The first and foremost concern raised was that upon augering of a secondary pile the geotextile socks of the adjacent primary piles, i.e. that geotextile separating the stone drainage medium from the in-situ material, would be torn by the auger exposing the stone drainage medium to the silty in-situ material. In addition a separate concern was raised that the stone below the primary piles would not remain in place and would collapse into the secondary pile auger holes upon removing the confining effect of the soil mass adjacent to the primary pile. The concern relating to tearing of the geotextile socks was deemed to be minor as the torn area should be an area that comes into contact with the geotextile sock of the subsequently installed secondary pile. The concern relating to the collapse of the stone was also believed to be minor. From the design phase it was assumed that the normal stress on the washed 19mm aggregate stone used as the stone drainage medium would lock the stone's matrix in place. This assumed locking action caused by an imposed normal load should thus prevent collapsing of the stone into the secondary auger holes. This was, none the less, highlighted as a risk and if collapse of the stone drainage medium from the primary piles into the secondary piles then the piles would need to be installed using a casing.

4 Construction

4.1 Specialised Construction Equipment Used

The contractor used recently purchased construction equipment for the project. Part of the success of the construction operation can be attributed to the contractor's skill and disposition to achieve the objective of the design. Plant established on site was specifically suited to the site restraints and client enforced safety protocols. A Casagrande® B175XP auger rig allowed accurate and efficient auguring of the pile holes through the residual and soft rock on the site to a maximum depth in excess of the required 13m. In additional the rig was suitable to install 1000mm diameter casings if the pile holes were collapsing. A 4.8m^3 volumetric capacity Carmix® 3.5TT was obtained for batching, transport and deployment of the drainage stone and filter sand. The Carmix® was fitted with a mass scale so that the amounts of stone and sand deployed into each pile could be carefully monitored.

4.2 Geotextile Sock Construction

The supplier of the non-woven geotextile also fabricated and packaged the geotextile socks for quick deployment on site. The socks were constructed in South Africa by local labour. During the project, refinement of the sock design was required and the manufacturer responded to new requirements in the orders in a timely manner without causing delays to project. One such refinement was the addition of geotextile straps as handles to the long geotextile socks. These handles provided hand holds and anchor points at the top of the socks.

4.3 Placement Jig

The contractor designed and custom fitted a special geotextile sock placement jig to the end of a standard tremie pipe. This jig allowed the geotextile socks to be deployed fully open in the auger holes and filled with drainage material or concrete from surface. The jig ensured that the correct orientation of the geotextile socks could be maintained from surface and socks could be placed in the correct position while filling to allow the geotextile to function as a separator and filter.

4.4 Quality Control and Assurance

At the start of the project the co-ordinates and depth of each pile were calculated. The depths were calculated based on the required slopes of the panels of the cut-off drain to the extraction points. During construction each pile was set-out by a surveyor and during augering the depth of the piles were carefully monitored by the depth gauge within the mast and confirmed by dip meter. Once the target depth was reached, or in some cases past, the depth of the pile was recorded to the nearest decimeter and verified by an independent resident engineer. The required depth of stone was then calculated based on the augered depth. For every pile installed this data was recorded in a pile inspection record. Data captured during construction was used by the engineer to monitor the accuracy of the depth of the drain that the contractor was achieving. By checking the continuity of the levels of the stone drainage medium of each and every pile the slope and continuity of the drain could be verified.

5 Construction Challenges

5.1 Blocking and Reinstating Services.

Several stormwater services were present along the alignment of the drain at depths of on average about 3m BGL. These services were generally constructed of 600mm nominal diameter concrete stormwater pipes and were augered through and reinstated after construction of the cut-off curtain drain. The method of reinstatement devised by the contractor was to install a shop-fabricated 1.5m diameter cylindrical steel casing to the depth of the top invert of each service. Labor was then lowered into the casing by Boson chair. The soil around the intercepted pipe was excavated by hand inside the casing and once exposed the damaged section of concrete pipe was cut out with an angle grinder. A new section of concrete pipe was installed to replace the damaged section and the joints were sealed and strapped. Concrete collars were then cast around the joints and the excavation was backfilled. This method allowed reinstatement of the services without requiring a battered excavation. It also revealed the versatility and flexibility of the secant piling system used to install the ground water cut-off curtain as the services could be augered through and reinstated using the same construction plant.

5.2 Geotextile Sock Draw-down

One issue that was experienced with the geotextile socks was a draw down phenomenon that occurred when filling the extraction wells with drainage stone and in some cases the secondary piles with filter sand. The geotextile sock of the first extraction well was gripped by the stone placed in the pile hole. The geotextile sock was then drawn into the hole as the stone was poured. This caused the geotextile sock to tear where it was pegged down at surface. To cater for this effect non-woven geotextile strips – reinforced by heavy duty stitching – were added to the long geotextile socks and the drainage stone in the extraction wells was placed via tremie pipe over the full depth backfilled.

5.3 Stone Movement During Pile Cleaning

One of the issues encountered during construction was movement of the 19mm stone at the toe of the cut-off drain. On one occasion, during cleaning of the bottom of a secondary pile near the end of completion of a panel of the drain the geotextile bag of the already installed extraction well one primary pile over from the secondary pile being cleaned ruptured. The 19mm stone from the extraction well proceeded to be washed into the secondary well underneath the intermediary primary pile. This was noticed by the site personnel as the cleaning bucket began to deposit large amounts of 19mm stone on surface with each cleaning cycle. It is believed that the withdrawal of the cleaning bucket from the bottom of the pile being cleaned created a low pressure in the groundwater. The 19mm stone in the drainage course was then pulled towards the low pressure with such force that it tore the geotextile bag of the extraction well. Then, with each removal of the cleaning bucket from the bottom of the secondary pile more 19mm stone was washed into the bottom of the pile. Eventually roughly 3.5m^3 of 19mm stone was drawn from the extraction well. The cleaning was ceased, and a remediation solution sought. The affected extraction well was drilled out and re-installed using a 1000mm dimeter casing that prevented any lateral movement of material between the piles. This issue was addressed by specifying that the extraction wells be installed last. However, the same stone movement complication occurred on one other occasion during installation of an extraction well, where the stone and sand from an adjacent secondary pile was washed into the extraction well during cleaning. The issue was again dealt with by using a casing to install the extraction well and reinstall the affected secondary pile. As this issue only occurred twice out of the hundreds of piles that were installed it was apparently minor on this project but is non-the less an issue that could manifest itself more severely in different circumstances.

6 Conclusion

This project showcased a successful and innovative use of specialised foundation construction equipment coupled with geotextile fabric to construct a secant pile wall as a continuous groundwater cut-off curtain drain. Very confined site access was overcome and the drain was constructed to an average depth of 12m and a maximum depth of more than 13m. The depth achievable by the method is not limited to 13m and could be extended to much greater depths if required. The client’s strict safety protocols were adhered to and the project was completed within budget and programme. The coupled use of secant piling and geosynthetic technologies was novel in the South African region and has proven successful as well as flexible as site specific difficulties were overcome. It is believed that this project has extended the body of technological experience in the construction of ground water cut-off drains and has added a new technique to the available methodologies.

References

Amos, P.D. Bruce, D.A. Lucchi, M. Watkins, N. Wharmby, N. 2017. Design and Construction of Deep Secant Pile Seepage Cut-Off Walls Under The Arapuni Dam In New Zealand. Wellingon: DamWatch Services Limited.

Antrobus, B. van Rensburg, M. Wardle, G. 2016. Confidential Report: Geology Along Line C for Extraction Drain. Johannesburg: Jones & Wagener Engineering and Environmental Consultants.

Koerner, R. 2005. Designing with Geosynthetics 5th Edition. New Jersey: Pearson Prentice Hall

Terzargi, K. Peck, R.B. 1948. Soil Mechanics in Engineering Practice. New York: Wiley.