# Case Study: Installation of a Soil-Cement-Bentonite Groundwater Cutoff Wall in Argentia, NL

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ABSTRACT
In 2014, Canada Geo-Solutions Inc. (CGSI) completed a deep groundwater cutoff wall on the Avalon Peninsula of Newfoundland & Labrador using the slurry trenching installation method with a soil-cement-bentonite backfill. The objective of the project was to cutoff groundwater flow from the adjacent bay so that a deep, large excavation, approximately 250 m long x 250 m wide x 19 m below sea level, could be effectively dewatered for use as a graving dock for the construction of an offshore oil rig structure. The cumulative length of cutoff walls installed was 773 linear meters with depths up to 40 m below ground surface and a total area, length x depth, of 29,712 $m^2$. The performance requirements for the installed cutoff wall included a maximum hydraulic conductivity of $5x10^{-7}$ cm/s and a minimum shear strength of 100 kPa.

RESUME
En 2014, Canada Geo-Solutions Inc. (CGSI) a réalisé un mur d'isolement profond pour eaux souterraines sur la péninsule d'Avalon, à Terre-Neuve-et-Labrador, à l'aide de la méthode d'installation de tranchée en suspension avec un remblai sol-ciment-bentonite. L'objectif du projet était d'écouler les eaux souterraines de la baie adjacente afin de pouvoir assécher efficacement une grande excavation d'environ 250 m de long sur 250 m de large x 19 m au-dessous du niveau de la mer pour l'utiliser comme dock de gravure pour la construction. d'une structure de plate-forme pétrolière en mer. La longueur cumulée des murs de séparation installés était de 773 mètres linéaires avec des profondeurs allant jusqu'à 40 m sous la surface du sol et une superficie totale (longueur x profondeur) de 29 712 m2. Les exigences de performance de la paroi de séparation installée incluaient une conductivité hydraulique maximale de 5x10-7 cm / s et une résistance minimale au cisaillement de 100 kPa.

## 1 INTRODUCTION

This case study paper provides details about a deep cutoff wall installation completed in Argentia, Newfoundland & Labrador in 2014. The project site is located on the Avalon Peninsula in Eastern Newfoundland & Labrador, Canada (Figure 1).

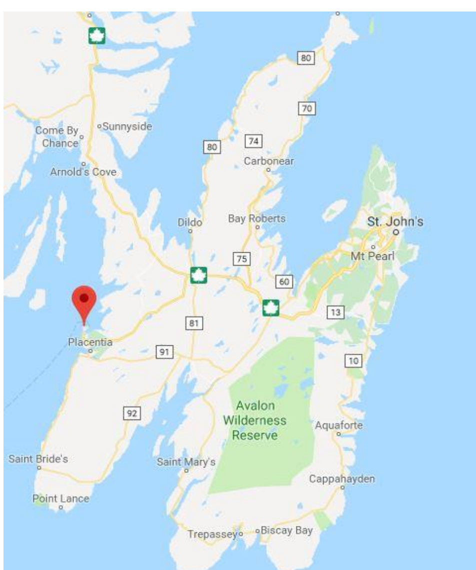


Figure 1. Site Location - Argentia, NL (from Google 2019)

## 2 PROJECT BACKGROUND

In 2013, construction of a purpose-built graving dock began in Argentia, NL. The graving dock was designed for the purpose of creating a dry (dewatered) construction area to form a concrete gravity structure (CGS) foundation for a new offshore drilling platform. Upon completion of the CGS (ongoing), the graving dock will be flooded and the CGS will be floated out to where it will be tied into existing infrastructure.

As part of the graving dock construction, a soil-cement-bentonite cutoff wall was installed to reduce the ingress of water into the excavated graving dock making dewatering feasible next to the Atlantic Ocean. The cumulative length of the cutoff walls installed was 773 linear meters with depths up to 40 m bgs (19 m below sea level) and the total area (length x depth) of the walls installed was 29,712 $m^2$. Figure 2 below shows the cutoff wall alignments. Originally the cutoff walls were split into two distinct features, the Seabund Wall and the Gate Wall. The Seabund Wall was designed for perimeter water control to support the dewatering effort. The Gate Wall was designed to serve as perimeter control beneath a potential future gate structure. The cutoff wall was completed in 2014 through challenging construction conditions.

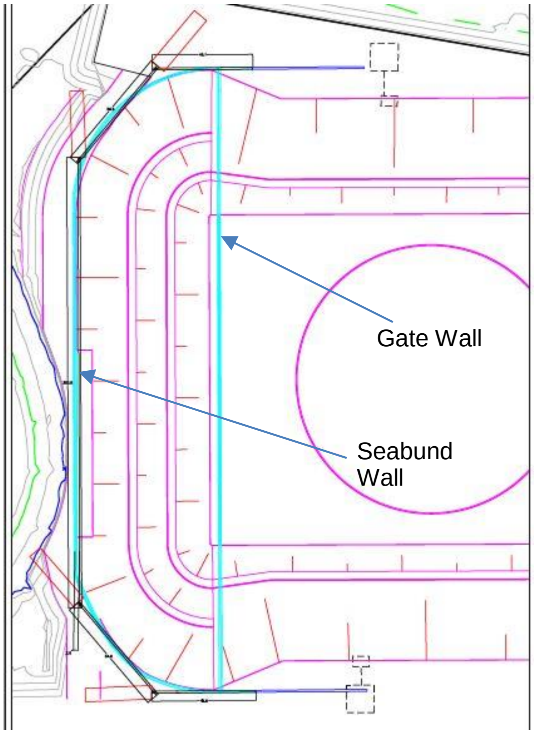


Figure 2. The final cutoff wall alignments shown in blue and teal

## 2.1 Site History

The area surrounding and including the project site in Argentia has a unique history. Once a small fishing village with a population of 750, the peninsula where the project site is located became a United States military base in 1940, selected for its ice-free and landlocked harbour and flat land. It is estimated that the base employed 10,000 to 15,000 Newfoundlanders during WWII bringing a much-needed economic boom to the area. Once completed, the 1,372 hectare base served as an important foreign military base for the Allied forces during WWII and stationed over 12,000 American military personnel throughout the war. After the war, American military activity gradually decreased in Argentia until 1994 when the area and facilities were decommissioned and handed over to the town of Placentia (Heritage NL, 2019). Since then, a deep-water port was developed on the peninsula that serves as a commercial port as well as a seasonal ferry terminal for Marine Atlantic (Canadian Encyclopedia, 2019).

# 3 CUTOFF WALL INSTALLATION METHOD

Early in the design phase of the project, sheet piles were eliminated as an option to construct the cutoff walls due to the known presence of cobbles, hard clay layers, occasional boulders, and possibly bedrock intrusions. Ultimately a bentonite cutoff wall was selected to be installed along the perimeter of the graving dock.

There are several construction methods that can be used to install a bentonite cutoff wall, including slurry trenching, soil mixing, and grouting. Given the ground conditions and project objectives, the slurry trenching method was focused on during proposal development. The cutoff wall design required a minimum shear strength of 100 kPa and a maximum permeability of $10^{-8}$ m/s. The shear strength requirement ruled out the use of a soil-bentonite (SB) backfill as SB does not develop any significant shear strength after placement. That left cement-bentonite (CB) and soil-cement-bentonite (SCB) as the remaining slurry trenching options. Ultimately a SCB cutoff wall was proposed for the project for several reasons, mainly related to the depth and soil conditions.

## 3.1 Soil-Cement-Bentonite Slurry Trenching

The SCB slurry trench installation method utilizes a two-stage process in which bentonite slurry is used for excavation sidewall support and the SCB backfill is later placed into the trench, displacing the slurry. The SCB backfill typically consists of a mixture of site soils, cement, bentonite, and water, with this mixture making up the final cutoff wall. First, the trench is excavated under bentonite slurry. As the trench is being excavated, the excavated material is often loaded into dump trucks and hauled to an onsite location designated for backfill mixing. When the excavation cut or panel is complete, i.e. final depth has been achieved, the excavation proceeds on to the next cut or panel. At the backfill mixing area, the excavated soil is mixed with bentonite slurry and cement until all desired properties have been achieved (e.g. slump, cement content, and bentonite content). At this point, the mixed material is commonly referred to as backfill. When the backfill is ready, it is transported to the trench for final placement. The backfill is placed at the top of the trench and allowed to slump or slide into the trench in a manner that limits the entrapment of slurry and soil within the wall. As backfilling continues, the slope of the backfill (generally on the order of 4 or 5:1 H:V) pushes forward toward the excavation heading. As the backfill slope moves forward, it replaces the bentonite slurry. The SCB backfill then cures in place resulting in a final cutoff wall with low permeability ($1x10^{-8}$ m/s to $1x10^{-10}$ m/s) and moderately high strength (150 kPa to 350 kPa).

The two-stage process of the SCB method allows the trench to stay open longer which is important for deep trenches and difficult soil conditions. SCB is also typically more cost effective than other methods due to the reuse of the excavated soils limiting the amount of materials, e.g. cement and bentonite, needed as well as eliminating or reducing costs associated with trench spoil disposal.

# 4 SCB INSTALLATION PROCEDURE

## 4.1 Proposed Installation Procedure

The proposed procedure for this project included two excavation headings. The cutoff wall was intended to be installed using a large excavator with a specialty stick/boom combination for excavation down to 26 m below grade and a clamshell excavator from 26 m to final depth of 32 m to 40 m (see Figure 3). Understanding that the excavation conditions would be difficult and in order to reduce the chances of downtime, pre-drilling of the entire alignment down to 24 m below grade using a large caisson drill fitted with a 0.75 m auger/bit was planned. Although this drill would be expected to refuse on competent boulders and/or bedrock, it was still included to loosen cobble and gravel layers. In areas with rock layers or boulders, the plan was to move the alignment to avoid the troublesome area. In the event that the area could not be avoided, a drop chisel was planned for crushing boulders and for breaking other rock. In this case, the broken rock, boulders, etc. could then be removed using the excavator or clamshell. The drill used to pre-drill the alignment was also planned to be available to pre-drill locations deeper than 24 m, if necessary. Similar SCB slurry trench installation approaches to those proposed for use at this site had been used successfully used in difficult soil conditions and the pre-drilling/drop chisel contingencies were included to further increase the chances of success.

Figure 3. Initial procedure included a single excavator and a single clamshell

## 4.2 Implemented Procedure

In general, the procedures that were used for construction were similar to those proposed. However, due to unexpectedly difficult excavation conditions, a few key changes were made during construction.

First, the pre-drilling was abandoned early in the project because of a high degree of communication through high permeability layers. When pre-drilling was attempted, the air used for pre-drilling exited through wells and boreholes located 20 m to 30 m away. Due to this, the pre-drilling was abandoned as inefficient and potentially unsafe.

Second, the frequency, depth, and size of boulders encountered in the excavation exceeded expectations. Additional contingency measures, including an additional clamshell excavator and two crane mounted drills were mobilized to deal with these conditions (see Figure 4). The additional clamshell assisted with excavation as the clamshell work was the critical path activity. The crane mounted drills were used to drill through obstructions and pre-drill the clamshell excavation areas through the excavated slurry filled slot (created from the excavation with the excavator).

The other components of the work, including slurry preparation and maintenance, and backfilling, were performed as planned.

Figure 4. Modified procedure included three clamshells and two drill rigs

# 5 PROJECT CHALLENGES

The geological and weather conditions of this site combined to present some challenges to the execution of this project.

## 5.1 Boulders

The biggest challenge on this project was the frequency and depth of boulders. The Contractor anticipated and was prepared for hard excavation conditions, identified in the geotechnical report mostly as: very dense sands and gravels, frequent cobbles, and hard clays.

Throughout the course of the project, boulders were encountered frequently which resulted in difficult excavating conditions, and equipment damage.

### 5.1.1 Boulder Impacts – Production

The frequency in which boulders were encountered during the installation of the SCB cutoff wall was not typical for a cutoff wall installation. Boulders were encountered over 91% of the excavation length and over an average of 22% of the depth in each excavation cut. Figures 5 and 6 display two of the boulders removed from the trench during the cutoff wall installation. Despite the frequency of boulders encountered, the cutoff wall was still able to be installed to full design depth along the entire alignment.

Figure 5. A boulder being removed from the trench with the long stick excavator


Figure 6. Boulder removed from trench measuring 2.3m x 1.1 m x 0.7m

### 5.1.2 Boulder Impacts – Equipment Damage

The unusually high boulder frequency also caused damage to excavation equipment during bolder removal attempts. The excavators, clamshells, and drills used for the SCB wall installation incurred unusual damage both in terms of magnitude and frequency. Figure 7 shows a clamshell damaged during excavation operations while Figure 8 displays a broken bucket cylinder on the long–stick excavator. Through effective resource management and problem solving of the project team, the effects of these damages were able to be minimized as much as possible and allow for trench excavations to continue to full design depth.

Figure 7. Damage to a clamshell bucket during excavation of boulders

Figure 8. An attempt to remove a boulder from the trench resulted in a broken bucket cylinder on the PC-1250

## 5.2 Weather

The weather conditions were also challenging on this project. The winter of 2013/2014 in this area was more severe than normal. Figure 9 shows the cutoff wall being installed during the winter of 2013/2014. The cold winter temperatures slowed production and necessitated the construction of temperature-controlled tent structures for grout/slurry batching and repair facilities. The wind and fog also produced challenges to the project. Wind speeds averaged 20km/h to 30 km/h with gusts regularly surpassing 50 km/h. These high and frequent wind speeds provided challenges to the cutoff wall installation, especially for the crane-mounted clamshells, resulting in safety shutdowns.

Dense fog also became a challenging obstacle to deal with on a regular basis. On an almost daily basis, dense fog would settle on the peninsula where the project was located. The fog would reduce visibility to tens of meters slowing operations and occasionally causing safety shutdowns.

Figure 9. Snowy site conditions during winter work

## 6 QUALITY CONTROL

### 6.1 Performance Requirements

The performance requirements for the SCB cutoff wall were a minimum shear strength of 100 kPa and a permeability less than $10^{-8}$ m/s at 28 days of curing. Rather than testing for shear strength, the SCB backfill was tested for Unconfined Compressive Strength (UCS). UCS testing is a common industry practice for low strength, SCB backfill and the UCS can be correlated to shear strength. Based on Mohr's circle, the shear strength is typically assumed to be half the UCS. Therefore the 100 kPa shear strength was equivalent to a 200 kPa UCS.

### 6.2 Quality Control Testing

The primary Quality Control (QC) testing during the SCB cutoff wall installation was testing of the backfill grab samples for comparison to the performance requirements. During installation of the cutoff wall, grab samples of the SCB backfill were collected prior to placement in the trench and were cast in cylinders for testing. Grab samples were collected at a minimum frequency of 1 per 25 lm along the wall or 1 per 875 $m^3$ of backfill placed, whichever was more frequent. Over the course of the entire project, the SCB backfill samples averaged a UCS between 750 kPa and 800 kPa and a permeability of approximately 5 $x10^{-10}$ m/s.

In addition to the backfill performance testing, extensive QC testing was also performed multiple times per shift on the bentonite slurry and SCB backfill. Frequent testing of the slurry ensured that the fresh slurry being batched and placed in the trench was mixed at the correct proportions and exhibited the necessary properties to provide suitable trench stability. Slurry already in the trench was also tested to evaluate its ability to achieve trench stability would and to identify potential issues relating to the backfilling operations. The backfill was tested for adequate mixing, proper proportioning, and the ability to be properly placed in the trench. The excavation activities themselves were also closely monitored to ensure the trench was excavated continuously to full depth and within verticality requirements.

## 7 PROJECT SUCCESSES

Despite the challenges identified in the previous section, the SCB cutoff wall was successfully installed in accordance with the design plans and specifications. The following sections provide an overview of the successful aspects of the SCB cutoff wall installation.

### 7.1 Installed Product

The SCB cutoff wall was ultimately installed in accordance with the project objectives. Upon completion of the cutoff wall, the excavation and dewatering contractor for the graving dock noticed a substantial decrease in dewatering volume relative to the estimated volume indicating that the cutoff wall was working as well as or better than designed. Based on the geotechnical and groundwater flow studies conducted for the dewatering system design prior to construction, it was anticipated that 80 deep well pumps with a 10 L/sec capacity would be required to maintain water levels below the graving dock floor after installation of the cutoff wall. After installation of the cutoff wall only 24 of the 80 pumps were necessary to maintain water levels below the graving dock floor indicating that the cutoff wall not only met but far exceeded the design intent.

Figure 10. Aerial photo of the completed graving dock. (Dexter Construction Co, 2015).

### 7.2 Team Effort

All of the challenging conditions that were encountered on this project required a very high level of teamwork to ensure successful completion of the cutoff wall. Throughout the project, the project team, consisting of Owner, Engineer, and Contractor representatives, held daily onsite meetings to discuss the project challenges and develop plans to overcome those challenges. This transparency helped the project progress to a successful completion.

# 8 REFERENCES

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