The Application of Interlocking Rock-Socketed Pipe Piles for a Cut-Off Wall in Ontario

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GeoCalgary 2022 October 2-5
Reflection on Resources

ABSTRACT
During construction of a downstream cofferdam to accommodate tailings dam expansion in Dubreuilvile, Ontario, unexpected ground conditions were encountered requiring a novel geotechnical solution. Upon excavation along the proposed cofferdam, an infilled valley was discovered comprising of 2.0 – 9.0m thick sand and gravel till with cobbles, boulders and flowing water underlaid by bedrock. Various ground engineering solutions were considered and ultimately a 45-meter-long interlocking pipe piles (IPP) cut-off wall was installed to address the technical, constructability, and the time-sensitive requirements for this critical project.

A rotary percussion reverse circulation drilling process with a down the hole hammer was used to advance the IPP to the target depth in a single pass. Interlocking pipe piles are prefabricated pipe piles completed with a ring bit, robust steel connectors including watertight sealant and grout pipes. In total, 68 no. x 610 mm diameter interlocking pipe piles with lengths varying from 5 m to 11 m were installed, with each IPP embedded a minimum of 1m into the sound rock. A stringent quality control program was implemented throughout the installation of the interlocking pipe pile cut-off wall.

This paper outlines various benefits of IPP, a detailed description of this project, subsurface conditions, design considerations, construction approach, quality control, and quality assurance requirements.

RÉSUMÉ
Lors de la construction d'un batardeau en aval pour permettre l'expansion de la digue à résidus à Dubreuilville, en Ontario, des conditions de sol inattendues ont été rencontrées nécessitant une nouvelle solution géotechnique. Lors de l'excavation le long du batardeau proposé, une vallée comblée a été découverte comprenant un till de sable et de gravier de 2,0 à 9,0 m d'épaisseur avec des cailloux, des rochers et des conditions d'eau courante reposant sur le substratum rocheux. Diverses solutions d'ingénierie au sol ont été envisagées et, finalement, un mur de coupure de pieux tubulaires imbriqués (IPP) de 45 mètres de long a été installé pour répondre aux exigences techniques, de constructibilité et aux défis urgents de ce projet critique.

Un processus de forage à circulation inverse à percussion rotative avec un marteau fond de trou a été utilisé pour faire avancer l'IPP jusqu'à la profondeur cible en un seul passage. Les pieux tubulaires à emboîtement sont des pieux tubulaires préfabriqués complets avec un foret annulaire, des connecteurs en acier robustes, y compris des tuyaux d'étanchéité et de coulis. Au total, 68 non. x Des pieux tubulaires imbriqués de 610 mm de diamètre et de longueurs variant de 5 m à 11 m ont été installés, chaque IPP étant encastré à au moins 1 m dans la roche saine. Un programme rigoureux de contrôle de la qualité a été mis en œuvre tout au long de l'installation du mur parafouille en pieux tubulaires à emboîtement.

Cet article décrit les divers avantages de l'IPP, une description détaillée de ce projet, les conditions du sous-sol, les considérations de conception, l'approche de construction, le contrôle de la qualité et les exigences d'assurance de la qualité.

1 INTRODUCTION

Unanticipated ground conditions were encountered during the construction of a tailings dam expansion project in Dubreuilville, Ontario for an active gold mine. A 45m long rock-socketed cut-off wall was required in the challenging sub-surface profile. Several ground engineering techniques were considered for the cut-off wall and ultimately, an interlocking pipe pile (IPP) system was chosen as the preferred solution. IPP was selected based on the performance requirements and the project schedule.

A suitable cut-off wall was also required for compliance with the Ministry of the Environment, Conservation and Parks (MECP) since the existing water discharge was approximately 600,000 L per day. There were also concerns regarding the dam stability and seepage. Excavation and replacement of the soils beneath the proposed dam extension was not feasible due to the required depth of excavation and proximity to the current dam.

The cut-off wall was designed to provide a water barrier and limit its permeability to 1 x 10-7 m/s through the overburden soils and the fractured bedrock.

The project location is shown in Figure 1.

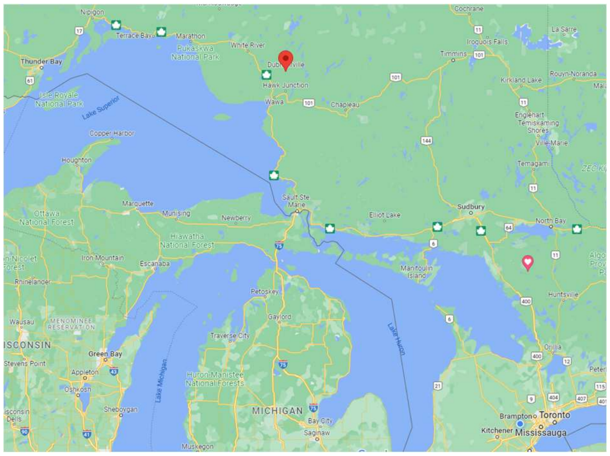

Figure 1: Project location

2 INTERLOCKING PIPE PILES (IPP) OVERVIEW

Interlocking pipe piles (IPP) consists of tightly interlocked pipe piles formed by an innovative mechanical “ball-and-socket” type connector welded to the full length of the pipe to create a continuous watertight wall that can be either temporary or permanent.

Common uses of interlocking pipe piles are support of excavations, groundwater flow barriers, flood control barriers in low-lying areas, cofferdams, dry docks, etc. Interlocking pipe piles (IPP) can be rapidly installed in a single-pass construction. It is also a robust technique in challenging ground conditions which may otherwise require a combination of several conventional techniques to meet the specified requirements and to address constructability challenges. This system can be installed in boulder soils, concrete and rock. The mechanical watertight interlocks ensure complete water cut-off.

Figure 2 shows the typical arrangement of interlocking pipe piles.

3 GEOTECHNICAL SETTINGS

Limited borehole information was available at the initial stage of the project. Top of sound rock elevation and the permeability of the weathered rock along the proposed cut-off wall alignment was unknown. Supplemental geotechnical investigations were performed by the Owner prior to the commencement of production work on site. The top of sound rock elevation along the alignment of the proposed cut-off wall was established.

The typical subsurface profile is shown in Figure 3. It consists of sand and gravel till with cobbles and boulders. The water table was approximately 1 m below working grade. The thickness of the cobble/boulder zone is 4 to 8 m. The thickness of the weather rock zone is approximately 1 m. The design required a 1m key into competent rock to limit the water seepage through this section of the dam (see Figure 4). The dam geometry and profile are illustrated in Figure 5.

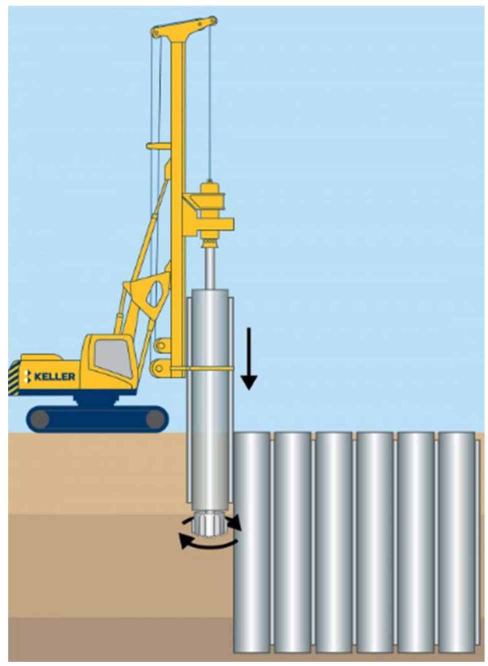

Figure 2: Typical arrangement of interlocking pipe piles

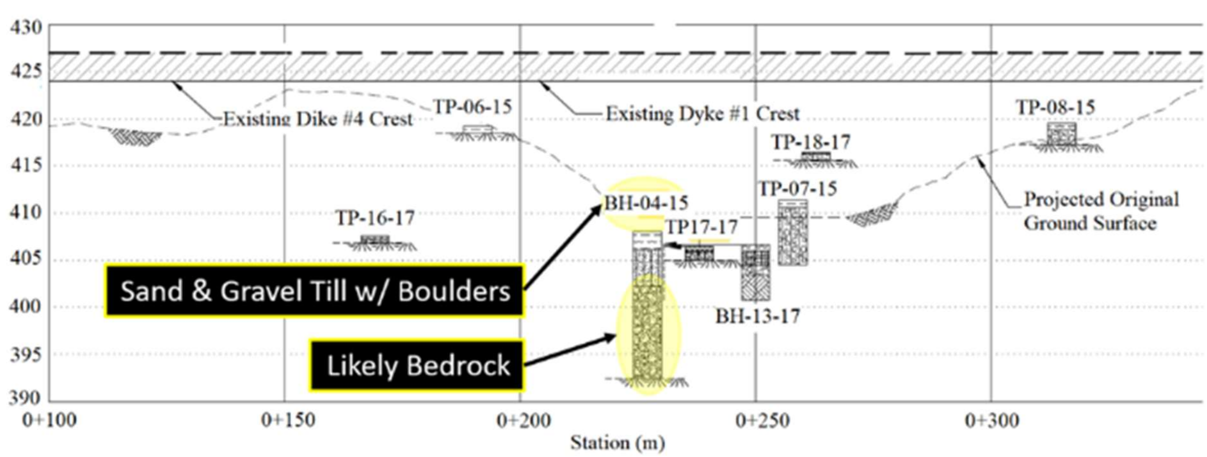

Figure 3: Subsurface conditions

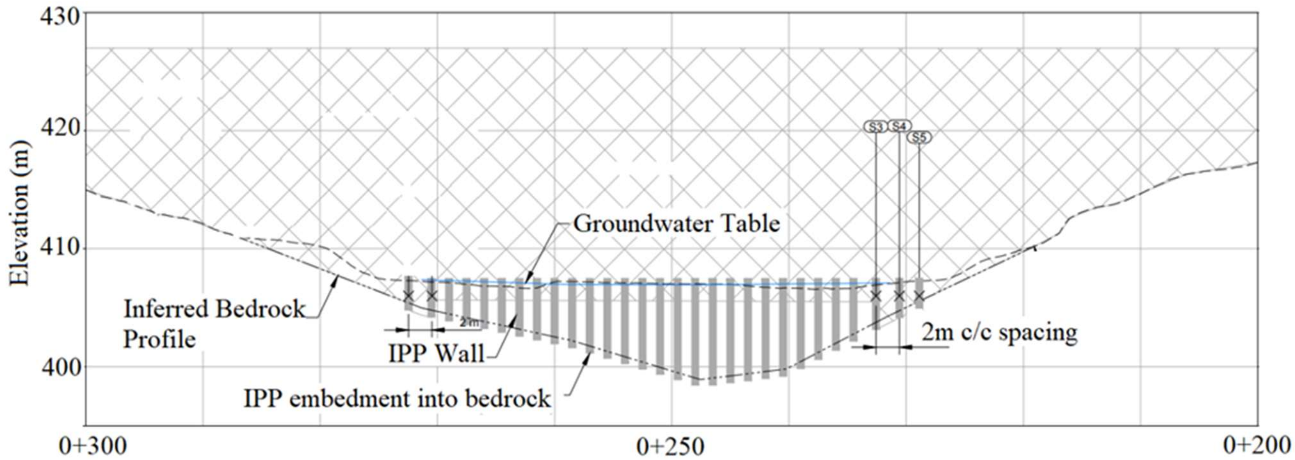

Figure 4: As-built profile of cut-off wall

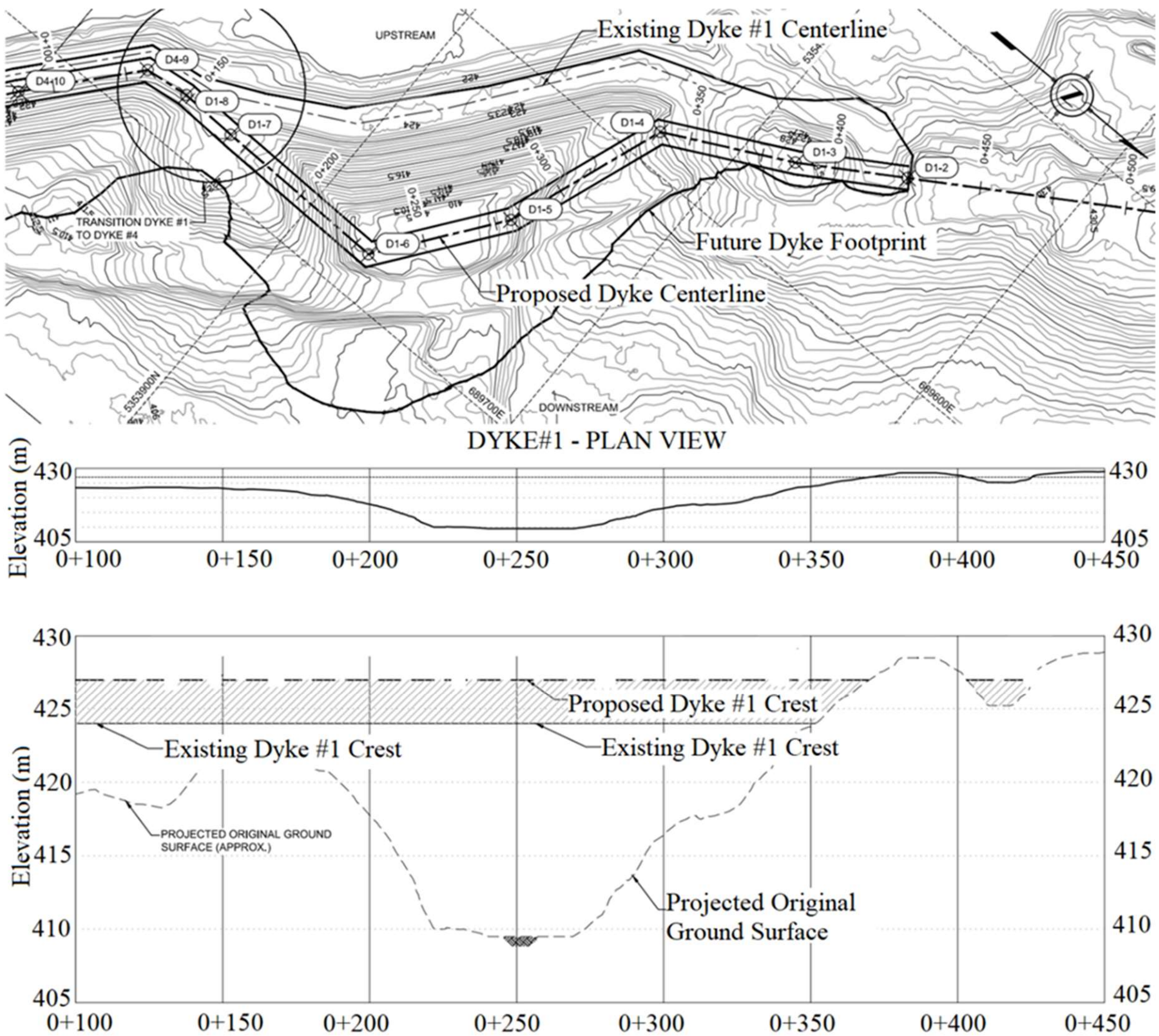

Figure 5: Cut-off wall profile

4 INSTALLATION PROCESS

Interlocking pipe piles (IPP) can be installed through boulder laden ground conditions and socketed into rock. The pipe was lowered into a mounting device, followed by the drill string assembly, and secured to the pipe shoe (see Figure 6). A pile guide/template was laid out on the surface to ensure the verticality is maintained during installation (see Figure 7). Interlocking pipe piles were typically installed using a rotary percussive reverse circulation drilling process with air/water flush and a down-the-hole hammer to advance through boulders, obstructions and rock.

Figure 6: Pipe and Drill String Mounting Device

Figure 7: Pile Guide for IPP installation

The accurate determination of top-of-rock elevations allows the pile assembly to be prefabricated off-site. This saved time in the overall installation schedule. The pipe pile assembly, complete with an interlock, was advanced to the design depth in a single pass and embedded into sound rock. Grouting was performed inside the pipe and the annulus to complete the cut-off. A typical layout of the IPP at the site is shown in Figure 8. The sealant was pre-installed inside the female connector. During drilling, the connection between male and female connector extruded the excess sealant inside the female connector, creating a watertight joint.

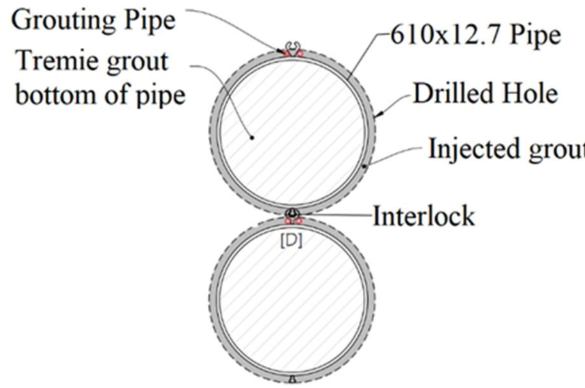

Figure 8: Typical layout of IPP

Reverse circulation (RC) drilling uses a double wall drill pipe with the circulating medium (usually air). The drilling fluid is conveyed through an annulus in the outer section of the drill string to the bit or hollow down-the-hole hammer. This process is illustrated in Figure 9. The cuttings were conveyed up the centre section of the drill string (i.e. inner tube) and out through the top opening of the swivel into a collection hopper or cyclone (shown in Figure 10).

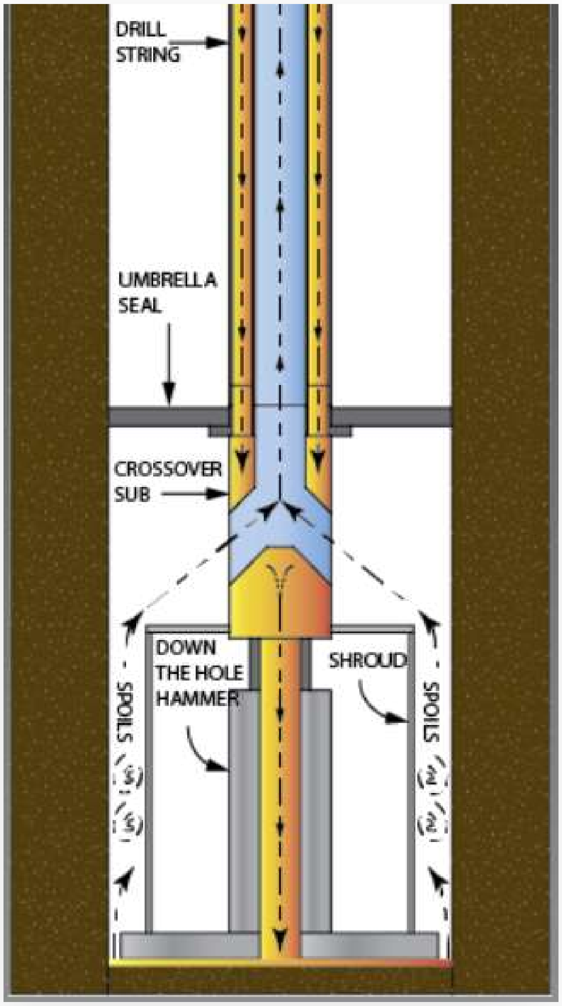

Figure 9: Reverse circulation drilling

Figure 10: Drilling cuttings – diversion and containment

5 QUALITY CONTROL & ASSURANCE PLAN

A dedicated full-time Engineer was assigned to perform quality control during the installation of the interlocking pipe pile wall. The information captured and monitored included pre-and post-wall installation pump tests, pile verticality checks during installation, production pile drill logs, and grout logs to confirm the adequacy of the cut-off wall. Daily installation reports, drill logs, grout logs (i.e. tremie and pressure grouting) and inspection and testing plan reports (ITP) were prepared and submitted for each pile. This information was also summarized on a record of piling spreadsheet.

Quality assurance was performed by the Owner's representative. A pumping test was conducted by the Owner's representative to assess the performance of the cut-off wall once it was completed. The pumping test was performed to determine whether grouting outside of the interlocks was required.

A two-phase pumping test was conducted to assess the performance of the cut-off wall. The first phase was done prior to the installation of the cut-off wall to assess the in situ hydrogeologic conditions and establish the baseline conditions. The second phase was conducted after the cut-off wall construction to assess the effectiveness in reducing groundwater flow through the sand and gravel unit.

6 RESULTS

Pump testing was conducted by the Owner's representative. Drawdown data from the pump well both during the pre IPP installation test and the post IPP installation test showed that the bulk hydraulic conductivity of the till in the immediate vicinity around the IPP is on the order of 2 x 10^{-5} m/s. This is consistent with initial assumptions for the hydraulic conductivity of the till formation in the seepage analyses (for all dykes), though does not necessarily reflect potential local hydraulic conductivity values in areas of higher boulder presence, which is believed to be higher.

Total drawdown of the upstream wells over time between the pre-test and the post-test were similar, however the response time (i.e. lag in time between when the pump well flow rate reached steady state and when the upstream wells began to first show a decrease in water table elevation) was slower for the post-test by a factor of 4 across all wells that were instrumented with level loggers. These results generally showed that the IPP wall is having an effect in the transmissivity rate between upstream and downstream ends, however trying to quantify how that translates to a change in hydraulic conductivity is complex and would involve several days of 3-D modelling to pinpoint what is driving the reduction. There is likely increased seepage pathway around and below the wall, but this cannot be shown through the pump test data.

Post IPP installation, indicated minor artesian conditions in the wells upstream of the IPP wall, specifically along the middle 30 m or so. Piezometric head difference between the upstream side and the downstream side of the wall ranges from about 0.3 m across the middle portion where the artesian conditions were around 0.15 m towards the end points of the wall. Using Darcy's Law (Q/A = Ki), based on the difference in gradient on either side of the wall, it was inferred that the IPP wall is reducing the seepage flow rate by about one order of magnitude, from 10^{-5} m/s to 10^{-6} m/s.

Seepage analyses of pre and post IPP installation scenarios confirm the decrease in the seepage flow rate from 10^{-5} m/s to 10^{-6} m/s. Seepage analyses were also able to mimic the upstream water level observations (and therefore gradient difference) that were observed in the field.

A photo of the final IPP wall extent is shown in Figure 11.

Figure 11: Final cut-off wall photo

7 CONCLUSIONS

The key objective to reduce groundwater flow through the natural sand gravel till unit (with boulders) overlying bedrock was successfully achieved by the installation of a rock-socketed interlocking pipe pile cut-off wall. A stringent QA/QC program was implemented throughout the execution of the work. Detailed records were captured and reported for each installed element. The pre and post installation testing indicated that the wall performed well in terms of meeting the project requirements.

ACKNOWLEDGEMENTS

The authors would like to acknowledge the work performed by the Field and Operations personnel from Keller and the project team.

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