Jet grouting for the Highbury Interceptor Siphon access chamber

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ABSTRACT
The Highbury Interceptor Siphon consists of three concrete pipes conveying sewage under the North Arm of the Fraser River from Vancouver to the Iona Island Wastewater Treatment Plant in Richmond, BC. The eastern pipe of the siphon was successfully lined with the Cured-In-Place-Pipe (CIPP) method in the summer of 2009. Jet grouting was used to create an access chamber to the pipe, located about 9 m below ground level on the Iona site. The nature of the soil, Fraser River sand overlying deep silt, and the presence of a high water table ruled out conventional dewatering and construction methods for the access chamber. Jet grouting was chosen as the most viable method to construct the access chamber in these sub-surface conditions.

RÉSUMÉ
Le Siphon Highbury Interceptor se compose de trois tuyaux en béton qui transportent les eaux d'égout sous le bras nord du fleuve Fraser de Vancouver à l'usine de traitement Iona Island à Richmond, Colombie-Britannique. Le tuyau oriental du siphon a été correctement aligné avec la technologie de chemisage (CIPP) au cours de l'été 2009. Jet Grouting a été utilisé pour créer une chambre d'accès pour le tuyau, situé à environ 9 m au-dessous du niveau du sol. La nature du sol, sable du Fraser River et limon profond, et la présence d'une nappe phréatique très proche du sol, exclut les méthodes classiques de construction et d'hydro-extraction pour la chambre d'accès. Jet-Grouting a été choisi comme la méthode la plus viable pour construire la chambre d'accès dans ces conditions souterraines.

1 INTRODUCTION

The Highbury Interceptor Siphon, constructed in 1959, consists of a reinforced concrete structure with three conduits conveying sewage under the North Arm of the Fraser River to the south bank where it transitions into three reinforced concrete pipes leading into the Iona Waste Water Treatment Plant. Figure 1 shows the location of the project at the edge of the Fraser River delta. Figure 2 shows the site arrangement.

Figure 1. Iona WWTP location, Richmond

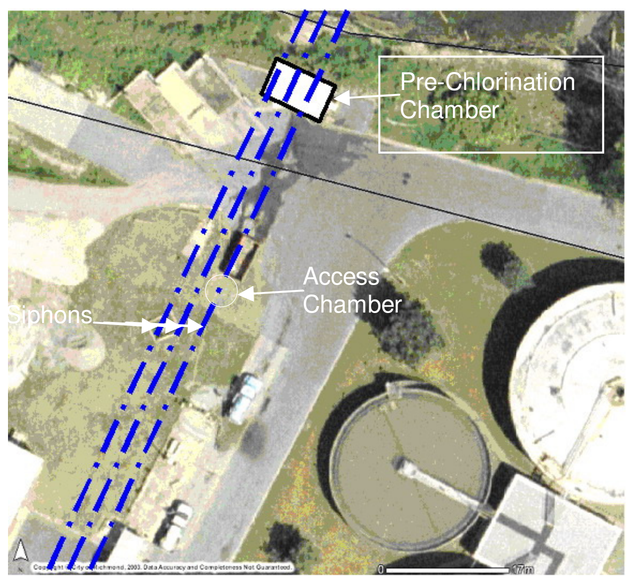

Figure 2. Site arrangement

After nearly 50 years of service, the siphon had aged and river water infiltrated through multiple cracks in the structure. A continuous liner was designed to seal these cracks and restore the structural integrity of the siphon. Metro Vancouver required an access chamber of about 4 m inner diameter, at the Iona site, to install the liner.

2 HISTORICAL SITE DEVELOPMENT CONDITIONS

The site originally consisted of tidal flats and deltaic deposits, slightly above mean sea level at about El. 1.0 m. During the original plant site development in the late 1950s, dredged, hydraulically placed Fraser River sand fill was used to raise the site to a nominal grade of El. 3.5 m. Preload fills were placed above this elevation at structure locations. At the siphon location, the underlying native sands and silts were excavated to at least El -6.0 m, but perhaps deeper, to allow installation of the three siphon pipes. Dewatering at this time appears to have been conducted using a series of well points and dewatering wells, as can be seen in Figure 3. After installation of the siphon, the area was backfilled to the current site grade of El. 3.0 to 3.5 m with compacted Fraser River sand.

Figure 3. Aerial view of siphons during original construction

The bell-and-spigot siphon pipes have an internal diameter of 1677 mm, a wall thickness of 184 mm, and an external diameter of 2045 mm. The spacing between the pipes is approximately 500 mm, based on construction drawings and on probe holes water-jetted to locate the crowns of the pipes. At the location of the proposed access chamber, the invert of the siphon is at about El. -6 m, or 9.5 m below ground surface.

3 FOUNDATION CONDITIONS

Prior to the chamber design, a site investigation comprising two Cone Penetration Tests was conducted to confirm ground conditions. The soil consisted of approximately 14 m of loose to compact, uniform, fine grained, silty sand or sand, overlying silt to the end of the holes at 25 m depth. Of the 14 m of sand, about 9.5 m is estimated to be fill from the 1950s construction. The bottom 5 m of sand is likely native material. Groundwater was at about 2.5 m below the existing ground level and fluctuated with the river, tide and precipitation levels.

4 ACCESS CHAMBER ALTERNATIVES

There were several possibilities to create construction access to the siphon. The following alternatives were considered:

- Dewatering and open excavation;
- Sinking a precast caisson and permeation grouting (chemical or cementitious) or jet grouting to create a bottom plug to withstand uplift;
- Sheet piles to the siphon level and permeation grouting or jet grouting to create a bottom plug;
- Permeation grouting for both the chamber walls and bottom plug; and
- Jet grouting both for both the chamber walls and bottom plug.

An open excavation was quickly dismissed. The site is crowded (see Figure 2) and daily access was required by operations personnel, adjacent to the shaft location. The risk of settlement of nearby facilities due to dewatering was very high, due to the presence of compressible silt beneath the site.

Installation of a caisson to the top of the siphon pipes was feasible. However, it was anticipated that permeation grouting of the silty Fraser River sand would be difficult due to the relatively fine grain size. In addition, the complex geometry, requiring grouting around and beneath the closely-spaced siphon pipes to create a large watertight seal to withstand uplift, was considered too challenging.

The sheet pile alternative was also abandoned due to the difficulty of sealing the sheet piles around the siphon pipes and the difficulty of grouting for the bottom slab as previously mentioned. Permeation grouting for both wall and bottom plug was also abandoned for the reasons previously described.

The jet grouting solution was considered the most flexible and likely to succeed. With jet grouting it was considered possible to:

- Create a structure with a rigid circular wall and impervious bottom plug; and
- Control the jet grouting parameters to create smaller diameter columns for the shaft wall and much larger, overlapping diameters around and beneath siphon pipes to create an impervious bottom plug, resistant to uplift pressures.

5 CONTRACT APPROACH AND JET GROUTING DESIGN

In recognition that the chamber was a temporary construction facility and in order to permit contractors to take full benefit of their experience, Metro Vancouver prepared a performance-type specification identifying the final requirements of the works: circular chamber with inner diameter sufficient to open a 3 m length of the siphon pipe at its springline; minimum diameter of soil-cement columns for the chamber wall (1.0 m) and base plug (2.2 m); minimum thickness of chamber wall at column overlaps (0.8 m); minimum soil-cement compressive strength (5 MPa); maximum leakage rate of clear water (not carrying soil particles) of 10 l/min into the completed chamber. The chamber wall was to be capable of withstanding AASHTO HS-20 loading adjacent to it, to allow for construction and operations vehicles. A concept design was issued with the tender to illustrate one means by which the required performance could be achieved. The concept included a detailed layout of the locations, diameters, and construction sequence for the base plug jet grout columns. Tenderers were required to retain a registered professional engineer to design shoring to withstand the geotechnical and specified traffic loadings; the intent was to let the contractor use a shoring method it was familiar with, rather than a method imposed by the Owner. The specifications included a requirement for a trial demonstration to provide confidence that the 2.2 m diameter columns required beneath the pipes could be achieved. Finally, jet grouting equipment was to be continuously monitored to provide quality control for items such as rotation speed, jet nozzle depth, pressure of cement grout, water, and air, and consumption rate and total volume of injected grout.

A possible major risk was the condition of the siphon concrete and its ability to withstand the high velocity of the grout jet (typically between 160 and 220 m/s at the nozzle). To avoid the potential for damage to the concrete pipes, the specification required the jet pressure to be limited to a maximum of 200 bars within 1 m of the pipes; this would reduce the grout jet speed at the nozzles to around 110 to 160 m/s.

Metro Vancouver awarded the contract to Matcon Excavation and Shoring, which retained Geopacific Consultants Ltd. for the preparation of the detailed design. Figures 4, 5, and 6 show the final design of the jet grout columns. Matcon had completed an extensive trial installation to document its capabilities in terms of achievable column diameters in silt and sand at a site near Iona, as they were tendering for the chamber project, and this was accepted as the trial demonstration.

6 INSTALLATION OF COLUMNS

The jet grouted columns were installed in June and July 2009. The contractor initially chose to install the wall columns with the split-space method sequence (primary, secondary, tertiary columns), followed by the bottom slab using a sequential (“fresh on fresh”) sequence. One additional column, compared to the design layout, was installed. Figure 7 shows drilling for a chamber column, while Figure 8 shows the mud pit and grout plant arrangement.

Quality control was performed on site by the contractor, with monitoring by Metro Vancouver. The grout plant and drill rigs were equipped with electronic monitors to automatically weigh the components of the grout mix (plant) and continuously record all parameters of the jet grouting at the pump and drill rig.

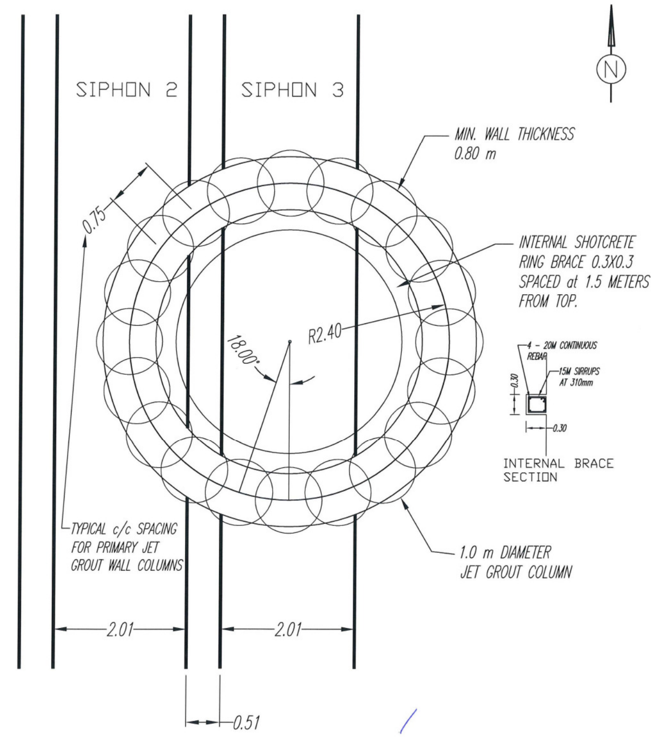

Figure 4. Plan of chamber wall columns

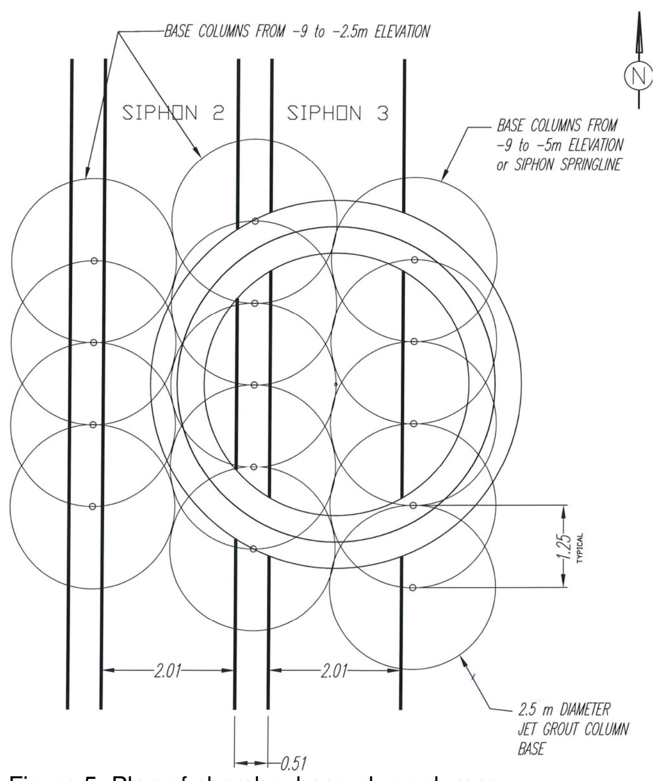

Figure 5. Plan of chamber base plug columns

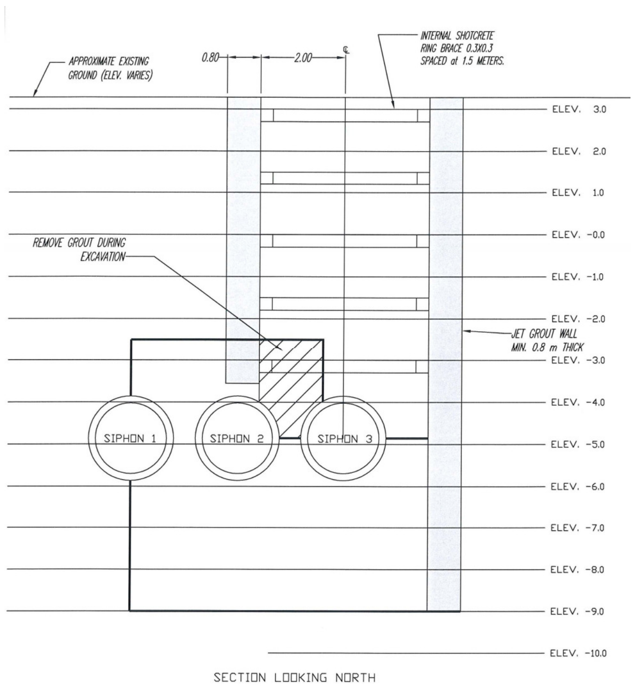

Figure 6. Section through chamber and base plug


Figure 7. Drill rig excuting chamber wall column

The main quality control was the grout mix and spoil (grout mix returned to the ground surface) density control, done with mud balance, at the grout plant and during the jetting phase. Site preparation began on June 9, 2009. Jet grouting of the 21, 1 m diameter wall columns began June 24 and was completed about 5 days later on June 29. Jet grouting of the 2.5 m diameter base slab columns began on June 29 and was completed about 6 days later on July 4, 2009.


Figure 8. Mud pit and grout plant

No detailed quality assurance was required on the layout of columns, considering that the shaft was to be excavated and the entire wall was to be visible. The watertightness of the bottom slab would also evident at the end of the chamber excavation.

During column installation, several unconfined compressive strength tests were performed on soil-cement samples collected from the spoil. The average strengths were 4.1 MPa and 9.7 MPa at seven and 11 days, respectively.

7 EXCAVATION, LEAKAGE, AND REMEDIATION

After completion of the columns for the wall and bottom plug, the contractor started excavation inside the shaft with a conventional backhoe on about July 5, 2009. Figure 9 shows the upper shaft being prepared for the first ring of reinforced shotcrete. The first observation, during the excavation of the first few metres, was that the thickness of the wall was larger than specified; 1.1 to 1.2 m vs. 0.80 m specified minimum. The large column diameter had an impact on construction as some soil-cement had to be excavated by hand to achieve the minimum specified clearance at the siphon pipe. However, this was not an onerous undertaking due to the low compressive strength. The contractor's design called for internal bracing (reinforced shotcrete rings) every 1.5 m from the top, but considering the increased thickness of the wall and the much higher compressive strength obtained, omission of the bracing was accepted after assessment by the contractor's engineer, with the exception of the first ring immediately below the ground surface.


Figure 9. Shoring ring installation in upper shaft

Excavation at depth was performed with a long-arm backhoe excavator and, at the bottom, with a vacuum truck. Figures 10 and 11 show early excavation and the nearly-completed chamber. The chamber columns were watertight. However, as excavation was nearing completion on about July 14, 2009 a small leakage of water occurred at the crown of the siphon, where the connection between the bottom of the jet grout wall columns and the top of the siphon pipes was not adequate to prevent the inflow of water. This was due to the fact that the jet nozzles are approximately 200 mm above the bottom of the bit; since the jet shoots horizontally and not downward, it was not able to seal adequately around the crown of the siphon pipes.


Figure 10. Excavation with long-arm backhoe


Figure 11. Completion of shaft using vacuum line

The excavation was dewatered and flooded several times during the initial attempts to seal the leak. Labourers first tried by hand to seal the leak from the inside without success. In order to seal the leak at the crown of the siphon, additional columns were installed around the outside of the west chamber wall. For these columns, the drill pipe was modified to allow grout to be jetted out the bottom of the rods, rather than just through the horizontal nozzles.

A second, more serious problem was discovered as the excavation was extended below the crown of the siphon pipe. At this time it became evident that a column was missing, as can be seen in Figure 12. Water and sand under pressure started to run in from the area of the missing column and in a few minutes the shaft was filling rapidly. The excavation was backfilled to prevent excessive piping of sand into the chamber. The Contractor initially tried to seal the area by grouting through a grout pipe drilled to the vicinity of the leak. However, it was not possible to achieve a positive seal that would withstand the water pressure.


Figure 12. Missing column, left side of base

After discussions and assurances regarding the status and position of the siphon, the obstruction was drilled, the hole was advanced to design depth, and the missing base slab column was jetted. On July 27, 2009, about 35 days after the first column was installed, and about 22 days after excavation began, the excavation was completed. The top of the siphon was subsequently cut on August 1, 2009 with success and the lining installed on schedule. See Figures 13 and 14. Once the access chamber was sealed around the siphon, the top half of the siphon (from the crown to the springline) inside the chamber was removed over a 3 m length to provide access for the lining process. Following liner installation, a permanent manhole, constructed within the construction chamber, completed the work.

8 CONCLUSIONS

Despite the unfortunate episode of the missing column, the project can be considered an interesting achievement and a success. Jet grouting proved to be an efficient and flexible method for dealing with the high groundwater table and the difficulty of sealing around the siphon pipes. The initial concern regarding the high-pressure grout jet against the concrete siphon pipes was adequately addressed by reducing the jet pressure in proximity to the pipes. By carefully controlling the locations and diameters of the jet grout columns, it was possible to improve the soil below and around the existing pipes without damage to the concrete siphons and to create a soil-cement mass with the required physical and geometrical characteristics to permit the excavation.


Figure 13. Completed chamber with siphon exposed


Figure 14. Final opening of the siphon

Sealing at the top of the siphon pipes was difficult as the jet nozzles are 200 mm above the tip of the drill pipe; this was overcome with a minor modification. The omission of a large-diameter soil-cement column beneath the pipe created a delay to the program; however, this was ultimately overcome. Despite these difficulties, the shaft excavation and the siphon cut were completed on time for the arrival of the contractor for the installation of the siphon pipe liner. The jet grouting method provided a flexible means of dealing with the ground conditions and the unique geometry of the required construction for chamber and uplift block.

All parties involved (Owner, Owner’s Engineer, Contractor and Contractor’s Engineer) played key roles in the execution of the work, demonstrating that the performance-based contractual approach was appropriate.

ACKNOWLEDGEMENTS

The authors thank Metro Vancouver for permission to publish this paper. The authors also thank Matcon Excavation and Shoring and its Engineer, Geopacific Consultants, for permission to present part of their technical documentation in this paper.