Sometimes Big Problems Require Small Solutions – Microtunneling in New York City Reduces CSO Events

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1. ABSTRACT

The Bergen Basin Sewer project consists of the construction of a new 48-inch parallel interceptor sewer beneath the busy Belt Parkway near JFK Airport in New York City. The project is intended to reduce combined sewer overflow (CSO) discharges into Bergen Basin and Jamaica Bay by relieving an existing hydraulic bottleneck in the West Interceptor to the Jamaica Wastewater Treatment Plant.

To reduce construction cost, minimize traffic and environmental impacts, and expedite construction schedule, the new interceptor sewer was specified to be constructed using trenchless methods in lieu of open-cut construction. Soil, groundwater, and environmental conditions were favorable for microtunneling, which was the required method of construction.

This paper will describe the risks and challenges associated with microtunneling and shaft construction in an urban environment where there are significant underground utilities, both existing and abandoned. The use of horizontal directional drilling (HDD) during the design phase as part of site investigation work helped mitigate some of these risks. However, other risks were realized during construction and made shaft construction challenging. The paper will also describe a significant value engineering proposal made by the contractor that offered cost and schedule benefits and minimized disruption to the Belt Parkway, and how teamwork between the client, resident engineer, contractor, and designer led to a successful modification of the design. Finally, the use of customized launch and reception seals in lieu of ground treatment outside the microtunneling shafts will be discussed as an innovation and proof of concept for future projects.

2. INTRODUCTION

The Bergen Basin Sewer project consists of the construction of a new 48-inch parallel interceptor across the Belt Parkway at 150th Avenue. The project is intended to reduce combined sewer overflow (CSO) discharges into Bergen Basin and Jamaica Bay by relieving an existing hydraulic bottleneck in the West Interceptor Sewer to the Jamaica Wastewater Treatment Plant (see Figure 1). The new interceptor sewer will parallel existing twin 36-inch sewers under the Belt Parkway at 150th Avenue and will activate in wet weather (see Figure 2). The project is being undertaken by the New York City Department of Environmental Protection (NYCDEP).
Figure 1. Overall Location Plan Showing Existing Twin 36-inch Sewer Bottleneck (courtesy Hazen & Sawyer).

Figure 2. Location Plan Showing New Sewer Alignment per Contract Documents (courtesy Hazen & Sawyer).
3. DESIGN PHASE

The facility planning phase of the project considered numerous alternatives for augmenting the existing interceptor sewer conveyance system. Trenchless methods were indicated as preferable due to the need to minimize disruption to the Belt Parkway. Site investigations were performed in a number of phases to support the various stages of facility planning and design development, as described below.

Site Investigation
An initial boring program included eight soil borings ranging from 51 to 71 feet in depth. This program included seven observation wells along with geotechnical and environmental laboratory testing programs. A second phase of soil borings was performed to focus on the preferred alternative, and included an additional seven borings up to 62 feet in depth, blind drilled borings to locate abandoned infrastructure, and vacuum-excavated test pits to locate a critical water main. Lastly, horizontal directional drilling techniques were used to install sub-horizontal investigation holes to mitigate the risk of unknown obstructions along the microtunnel alignment beneath the Belt Parkway (described in more detail later in this paper).

Geotechnical Conditions
The regional geology of the project site consists of numerous layers of different glacial outwash material overlain on very deep gneiss bedrock. The bedrock in this region is between 600 and 700 feet below ground surface. The primary strata include the following:

- **Topsoil.** Topsoil is generally 1 to 2 feet thick at the ground surface where asphalt or pavement was not encountered. The topsoil is generally described as very loose to loose, dark brown, poorly graded silt with sand and some organics.
- **Artificial Fill.** Artificial fill consists of glacial outwash deposits excavated during construction of the surrounding utilities and structures and then used as backfill. Based on the presence of numerous utilities at the project site that were likely constructed by open cut and backfilled, the depth of artificial fill was anticipated to be up to 27 feet in some areas.
- **Glacial Outwash Deposits.** Glacial outwash deposits include loose to medium dense fine to medium sand with traces of silt and fine gravel, and medium dense to very dense fine to medium sand with traces of silt and fine gravel.

Based on the results of the geotechnical exploration and the observation wells, the average groundwater elevation at the project site is at elevation +0.0 with fluctuations between elevation +3 feet and elevation -1 feet.

Horizontal Direction Drilling for Risk Reduction
Extensive desktop and field surveys were performed to identify potential obstructions to the construction of the microtunnel drive beneath the Belt Parkway. In spite of these efforts, there was still a potential that an unknown obstruction could be encountered during construction. The microtunnel drive beneath the Belt Parkway presented the greatest risk if an impenetrable obstruction were encountered, given the potential impact to the operation of the Belt Parkway if a recovery shaft had to be constructed to rescue a stalled microtunnel boring machine.

To address this risk, two horizontal directional drill (HDD) investigation probes were performed along the alignment of the microtunnel drive beneath the Belt Parkway, to determine the presence of any unknown obstructions in advance of performing this drive. A Vermeer D24x40 rig was used (see Figure 3) and a 4 3/4-inch drill bit was deployed to drill the pilot holes (see Figure 3). The holes were located at approximately 2 o’clock and 7 o’clock of the proposed drive.

The two HDD investigation probes were drilled beneath the Belt Parkway without encountering any impenetrable obstructions. The rate of progress of the drilling operation varied slightly as the density and nature of the soils changed along the alignment. The HDD rig operator did not observe a noticeable increase in torque or thrust that would indicate the presence of an obstruction of significance. On completion of the HDD probes, the probe holes
were grouted with a low-strength cement-bentonite grout. Full grouting of the probe holes ensured that no preferential flow paths for slurry were present during the subsequent microtunneling process.

Although the HDD investigation probes represented a significant cost for the overall site investigation program, this risk-reduction measure proved out the planned alignment. The success of the investigation assured the key stakeholders that the planned microtunnel could be installed as shown without encountering any significant obstructions.

Figure 3. HDD Drill Rig and Drill Bit.

**Crossing the 42-inch Storm Sewer**
The alignment of the new interceptor sewer, coupled with the requirement to assure gravity flow of the new interceptor sewer, created a conflict with an existing 42-inch storm sewer beneath the shoulder of the Belt Parkway. To address this conflict, and to minimize the impacts to the Belt Parkway, a series of excavations were planned to reroute the 42-inch storm sewer in a permanent diversion off the Belt Parkway.

The diversion would include temporary bypass pumping of the storm sewer during microtunneling, then reinstatement of the storm sewer. A short section of elliptical pipe would be installed along the new microtunnel alignment to provide adequate separation between the two sewers (see Figure 4). This portion of the work would require multiple phased lane closures of the Belt Parkway, installation of secant piles for a rigid support of excavation system, extensive grouting, and use of temporary steel roadway decks to span the excavations, and much of the work would have to be performed during night-time closures.

Figure 4. Plan of Excavations in Belt Parkway for 42-inch Storm Sewer Diversion.
**Value Engineering Proposal by Contractor**

Following the award of the construction contract, the contractor explored alternatives to eliminate the complex excavation and sequencing required to cross the 42-inch storm sewer and reinstate the new and existing sewers on completion of construction. The concept of using smaller pipelines to avoid the conflict with the 42-inch storm sewer had been discussed in the preliminary planning stage, but was not pursued due to unknowns concerning the existing storm sewer, its exact elevation, whether it had been built with a cradle, and whether it was supported on piles. The risks due to these unknowns resulted in the option being eliminated during the planning stage. Once the project was in construction, the contractor was in a position to undertake more invasive investigations and confirm the viability of using twin 36-inch crossings in lieu of the single 48-inch crossing.

The contractor was granted access to the existing 42-inch storm sewer and performed test drills to confirm that the storm sewer had not been built with a cradle that would impede the progress of the MTBM. Survey work was performed, including at the intersection points with the proposed microtunnel drives to confirm the exact elevations. Additional HDD investigation probes along the alignment of the second pipe run mirrored the investigations performed during the design phase, providing greater certainty of no obstructions along both microtunnel drives.

The results of all the investigations provided assurance to the designers, owner, and the contractor that the concept of twin 36-inch pipes to replace the single 48-inch pipe was viable. The two drives provided approximately 10.5 inches of clearance between the microtunnel cutterhead and the invert of the storm sewer pipe (see Figure 5). The designer required a zone of grouted soil around the crossing point to mitigate the risk of unacceptable deformation of the storm sewer.

![Figure 5. Value Engineering Proposal – Twin 36-inch Pipes.](image)

Due to the hydraulic capacity benefits of the twin 36-inch pipes, the upstream microtunnel drive running parallel to the Belt Parkway was upsized from 48-inch to 54-inch to improve the system’s capacity to capture CSOs.
4. CONSTRUCTION

Shaft Construction
Three construction shafts (the jacking shaft, the north receiving shaft, and the south receiving shaft) were required to install the new interceptor sewer and tie-in to the existing system and relieve the upstream hydraulic bottleneck. All three shafts were designed and constructed to resist hydrostatic pressures below the groundwater table in the geologic conditions identified above.

The primary shaft was the jacking shaft, a fully enclosed sheet pile cofferdam driven to a depth that reduced considerably the amount of dewatering efforts required to construct the shaft. Once the excavation was “bottomed out,” a concrete manhole chamber designed to withstand the pressure of the maximum jacking loads was constructed inside the sheet pile cofferdam. Once all microtunnel pipe jacking was completed, the transition invert between the 54-inch reinforced concrete pipe (RCP) and the two 36-inch RCP pipes was constructed, using styrofoam forms for the flow channels and building out the permanent manhole structure, identified as Transition Chamber SMH-N1 (shown in Figure 6).

The north receiving shaft was originally designed as a three-sided sheet pile cofferdam, installed against the existing upstream manhole chamber SMH-23. The shaft design allowed for a raised window opening in the sheet piles to maintain an existing 24-inch sanitary sewer connected into the SMH-23 chamber. Various areas such as the openings between the existing chamber and the sheet pile cofferdam, the area beneath the SMH-23 chamber, and the raised window opening around the existing 24-inch sewer were to be sealed via grouting with a sodium silicate permeation grout.

During preliminary site investigations at the north receiving shaft location, it was discovered that two rows of abandoned sheet piling likely used to construct the original SMH-23 chamber had been left in place and directly
interfered with the new construction shaft. The abandoned sheet piling could not be removed, and this unforeseen field condition halted construction and prompted a redesign of the north receiving shaft.

The redesign of the cofferdam left gaps in the sheet piling on either side of the abandoned left-in-place sheeting, which added three additional openings in an already non-enclosed cofferdam (see Figure 7). To close the penetrations of the cofferdam, additional permeation grouting columns sealed each opening against the abandoned sheet piling. This provided a zone of treated ground to prevent groundwater infiltration and stabilize the soil. During the excavation of the shaft, the abandoned sheet piling within the excavation was removed and disposed of in lifts until construction reached the final elevation, enabling the installation of a concrete bottom plug. Once the concrete bottom plug was installed, work proceeded and was completed successfully.

Figure 7. Location of Abandoned Steel Sheet Piling at North Receiving Shaft.

The most challenging shaft construction was for the south receiving shaft. The shaft was designed to be constructed around a live 72-inch RCP interceptor sewer that carried daily average flows of 25 million gallons per day (MGD) to the Jamaica Wastewater Treatment Plant. The contract-required tie-in point was at an existing cast-in-place manhole on the 72-inch sewer line. This had to be demolished and connected to the new twin 36-inch sewers by constructing a new transition chamber SMH-73A. To add to the complexities, an existing live 10-inch Extra Strength Vitrified Pipe (ESVP) sanitary sewer was tied into the same manhole at a higher elevation. The contractor designed a fully continuous sheet pile cofferdam driven to the required toe elevation except for the pipe penetrations, where the sheet piles would be intentionally left above the existing pipes to create a window opening in the cofferdam around the two 72-inch RCP and the 10-inch ESVP locations. The pipe penetrations would then be sealed off with jet grouting as a means of ground improvement (see Figure 8). To minimize the reliance on dewatering, the shaft was designed to be watertight and included a 12-foot-thick jet-grouted bottom plug to resist the hydrostatic uplift.
Before installing the sheet pile cofferdam, the contractor investigated the existing condition of the 72-inch and 10-inch sewers. While the existing 72-inch sewer was found to be in good condition, the existing 10-inch sewer showed signs of cracking and was in poor condition. The contractor determined that to prevent any issues with the existing 10-inch sewer during the sheet pile and jet grouting installation, the existing sewer should be replaced with a new 10-inch ductile iron pipe (DIP) sewer that could withstand the vibrations of sheet pile installation and the high pressures of jet grouting.

The sheet pile cofferdam installation and jet grouting work was successfully performed per the original design, and excavation of the shaft commenced. Due to the project’s tight timeline and to remain on schedule, the contractor excavated one section of the shaft to grade to receive the microtunnel drives before excavating around the 72-inch sewer. Upon excavating the section of the shaft to grade it was observed that a minimal amount of groundwater, about 5 gallons per hour, was infiltrating from a location beneath the 72-inch sewer. The quantity of groundwater infiltration was considered minimal and was temporarily dealt with, as the focus was on receiving the microtunnel drives beneath the Belt Parkway.

Once all microtunnel work was completed successfully, excavation under the 72-inch pipe continued. A significant breach in the jet grouting plug was found to be causing groundwater to infiltrate into the shaft at an uncontrollable rate. Attempts to seal the breach with remedial grouting were helpful, but were not totally successful given the high groundwater pressure outside the cofferdam.

To seal the breach in the jet grout plug, the contractor drilled three dewatering wells to 90 feet deep and installed 75 HP pumps. The dewatering efforts effectively drew down the groundwater table where the breach in jet grouting could be sealed successfully to allow construction to continue. The contractor was able to excavate to grade and install a hydraulic telescoping flume in the 72-inch sewer to convey the 25 MGD of interceptor sewer flows to the treatment plant (see Figure 8).
**Microtunnel Construction**
Pressurized face microtunnel boring machines were required to minimize any chances of ground settlement at the surface during the microtunnel drive. The contractor used two Herrenknecht brand AVN microtunnel machines suitably sized to install the 36-inch and 54-inch RCP direct jacked pipe. The face of the microtunnel machine was pressurized with a bentonite-based slurry, allowing the machine to recirculate the slurry to a separation plant where solids were separated from the slurry mixture.

The slurry separation plant was a Derrick brand system with multiple hydrocyclones and an integrated flow-line cleaner that used vibrating motors to filter the solids from the slurry mixture through urethane screens. Once the solids were removed from the slurry mixture, the clean circulating slurry was repumped to the face of the microtunnel machine to complete the circulating slurry system. The equipment chosen for the project resulted in three very successful microtunnel drives.

**Microtunnel Launch and Reception**
The contract design for the launch and reception of tunneling equipment required a large zone of treated ground outside the shaft to minimize any infiltration of groundwater and soil, which could potentially cause settlement on or adjacent to the Belt Parkway or surrounding roads. The contractor proposed an alternate method of groundwater and soil control, using a double row of sheet piles and specially designed launch and reception seals that could resist high hydrostatic pressures.

The double row of sheet piles allowed the shaft’s innermost sheet pile to be grouted and cut before removing the outer row of sheet piles when the microtunnel machine was advanced out of the shaft. Both of the 36-inch microtunnels were advanced out of the shaft on an angle, requiring a third row of sheet piles to be installed to allow the cutter wheel of the microtunnel machine to be driven into a uniform and perpendicular face of undisturbed soil. The launch seals used dual lip seals and an inflatable bladder that could be pressurized if any infiltration of groundwater or soils was observed. During the tunneling operation the air bladders were inflated to 40 PSI. However, they could have been inflated to 160 PSI if required (see Figure 9).

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*Figure 9. Microtunnel Launch Seal Shop Drawing.*
Similar to the launch shaft setup, the reception shafts used a double row of sheet piles, with the outer row removed before receiving the microtunnel machine. In lieu of a zone of treated ground, a special mechanical seal with preinstalled cartridge was installed as an additional safety measure, preventing the standard rubber lip seal from being damaged (see Figure 10). The preinstalled cartridge was particularly effective at providing a controlled entry of the microtunnel machine into the shaft. It prevented chunks of concrete from the headwall causing damage to the lip seals during breakthrough and before the seal was engaged onto the shield.

This methodology proved successful for all three microtunnel drives. One concern was the presence of timber piles during the 54-inch microtunnel drive, which were described in the Geotechnical Baseline Report. During the reception of the machine, construction workers noticed that the pipe jacking operation came to a halt about 1 foot short of the reception shaft. At first the concern was that the equipment had missed the shaft entry portal, but after further investigation of the slurry return at the separation plant it was determined that the machine was excavating through abandoned timber piles. Once the machine mined through the timber piles, it entered the cartridge, where it was successfully recovered in the shaft.

![Figure 10. Reception Seal with Preinstalled Cartridge Braced for MTBM Reception.](image-url)
Grouting Beneath Existing Utilities
Other project concerns included advancing each of the 36-inch microtunnel drives beneath an existing 42-inch storm sewer running parallel with the Belt Parkway and a live 72-inch water main running adjacent to the South Conduit Avenue. The primary concern was at the 42-inch sewer, where the new 36-inch microtunnels were to pass beneath the pipe by approximately 10 inches, as described above.

To prevent any settlement at this location and to provide a stabilized means of ground improvement, the design required installation of permeation grouting under the 42-inch sewer coupled with EPDM seals inside the storm sewer to prevent fugitive grout from entering the sewer. These seals were removed upon completion of the works. The grouting performed effectively, as evidenced by the utility monitoring devices located above the 42-inch storm sewer, which indicated negligible movements.

The design of ground improvement in these two locations identified a potential conflict: the angle of the microtunnel machine was planned to enter the zone of treated ground at an angle that could have caused the machine to veer off its intended line and grade, or to result in unintended overexcavation. To mitigate this risk, the location of grout pipes were staggered to allow a roughly perpendicular face for the microtunnel equipment to enter and exit the zone of treated ground.

The contractor also identified a risk that tunneling through the PVC grout tubes could potentially clog the circulating slurry lines. To address this, the contractor designed the placement of the grouting pipes on either side and above the theoretical microtunnel envelope, and targeted some inclined pipes to grout beneath the storm sewer (see Figure 11). During the microtunnel operation, a few pieces of PVC were recovered at the slurry separation plant. However, the amount was negligible and the mining operations were not impacted as a result.

Figure 11. Grout Pipe Layout at the 42-inch Storm Sewer.
5. CONCLUSIONS

For a small total length of sewer, this project included numerous challenges for both design and construction. The use of HDD in the design phase was seen as a valuable tool in risk mitigation and provided assurances to key stakeholders that the proposed alignment and methodology was viable. The use of innovative launch and reception seals for the microtunnel machine eliminated the need to install extensive ground treatment works and provided a robust mechanical seal system to prevent uncontrolled ground and water inflow.

The contractor’s value engineering proposal required significant additional investigations to verify that it was a viable proposal and would not jeopardize the project’s overall approach to risk mitigation and schedule certainty. The owner, contractor, construction manager, and designer developed good working relationships and the success of the value engineering proposal was largely the result of good teamwork and partnering (see Figure 12).

Grouting of the 42-inch storm sewer was seen to be a valuable risk reduction measure and prevented any appreciable movement of the storm sewer during microtunneling beneath the sewer, with a clear separation of only about 10 inches between the extrados of the existing sewer and the cut diameter of the new sewer. EPDM seals located at the joints inside the storm sewer prevented any fugitive grout from fouling the sewer during the permeation grouting operations.

Figure 12. Teamwork was a Key Success Factor.