Lessons Learned Installing a Critical Large-Diameter Spiral Welded Steel Water Pipe under New York Harbor

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Abstract

The Port of New York and New Jersey (PANYNJ) owns one of the most heavily used water transportation corridors in the World. It takes in nearly 1/3 of all the Eastern US shipping trade. The Anchorage Channel is the main “road-way” into the Metro New York Harbor from the Verrazano Narrows Bridge to the channel’s confluence with the Port Jersey Channel. In 2014, $125 Billion Dollars worth of goods and commodities were shipped into this Port. In the late 1990’s the Port Authority recognized that cargo volumes could double within the next 20 years and along with that the usage fees generated by the increased cargo. To accommodate the larger “mega” ships that were being designed and built for the 21st Century for these increased loads, the Anchorage Channel needed to be dredged to accommodate ships with drafts exceeding 50 feet.

Project History

The Anchorage Channel as it is known sits between two of the New York City boroughs: Staten Island and Brooklyn. All of New York City’s high-quality drinking water is collected in protected reservoirs located 125 miles north of the City. From there the water travels south through aqueducts to the Hillview Reservoir in Yonkers. There, it enters City Water Tunnels Nos. 1, 2 and 3. These tunnels are located roughly 500 feet beneath street level and travel through the boroughs of the Bronx, Manhattan, Queens and Brooklyn. In 1917 (36”) and 1925 (48”) two water main siphons were built approximately 50 feet beneath New York Harbor to connect Staten Island to Brooklyn, and the City’s upstate water supply system (see Figure 1). As Staten Island’s population and its demand for water grew, in 1970 a 10-foot diameter tunnel (Richmond Tunnel) was built deep in the bedrock beneath New York harbor and became the primary water conduit to Staten Island. The original water siphons have since been kept in service as a back-up connection to ensure a 50 MGD supply of drinking water for the half million residents on Staten Island.

To be able to dredge the Channel to accommodate the larger “mega” ships these two older NYC Department of Environmental Protection (NYC DEP) water transmission mains needed to be removed and replaced with a larger (72” diameter) transmission trunk main which would serve as the new back-up if the Richmond Tunnel were to go down. In 2004 the services of Camp Dresser McKee/Hatch Mott McDonald Joint Venture (CDM/HMM JV) was engaged by the NYC EDC

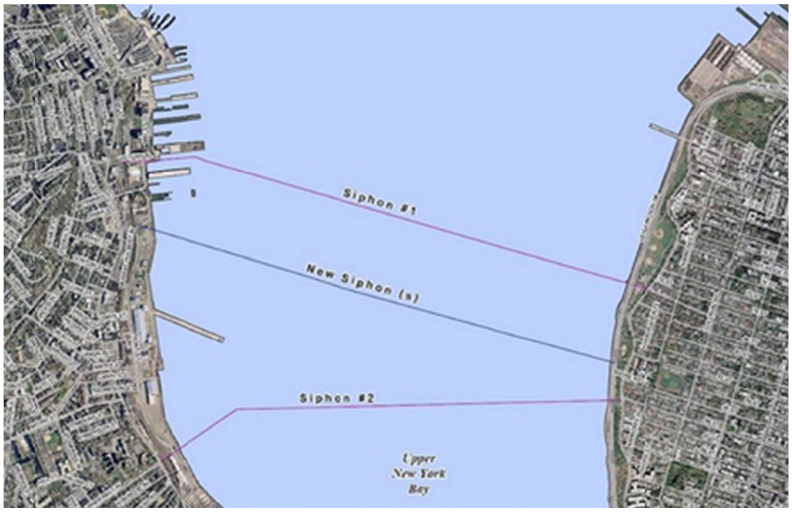

Figure 1. Anchorage Channel Overview.

(Economic Development Corporation managing this project for the NYC DEP) to provide engineering services in connection with the old pipe removal and design and construction of a new deep buried 72” siphon replacement.

A study initiated by CDM/HMM JV evaluated the options to replace the existing pipeline siphons. The study involved a comprehensive evaluation of the alternatives of:

- Dredging and use of Coffer Dams
- Micro-tunneling
- Horizontal directional drilling
- Conventional boring using a tunnel boring machine (TBM)

The Study compared the methods under these criteria:

- Schedule
- Constructability
- Construction Risks
- Environmental Impact
- Cost
- Navigational Costs and Impact

The evaluation components and criteria pointed to the process of conventional TBM approach.

The next study evaluated carrier pipe material options, including:

- Pre-stressed Concrete Cylinder Pipe
- Fiberglass Reinforced Pipe
- Spiral Weld Steel Pipe (AWWA C 200)

The evaluation included these considerations:

- Operational
- Maintenance
- Construction Logistics
- Long Term Life Cycle Performance
- Price of materials

Once the study was completed, spiral welded steel water pipe (AWWA C200) was selected. AWWA C200 Spirally Welded Steel Water pipe has been the primary large diameter “go to” direct bury and tunnel pipe material for the City. This is due primarily to steel pipes: flexibility, corrosion resistance with the use of coatings and cathodic protection (CP), its tensile strength, inherent toughness (compared to other materials) and superior bottle tight lap welded restrained joint.

The City has used lap welded field joints for over 50 years and recognizes that this connection system is the best choice for their applications. The bell and spigot ends allow for some angular deflection and provide easier assembly and fit up in the field compared to a butt weld joint. When completed the lap welded joint will resist thrust from maximum pressures, thermal loadings and bending. During installation the spigot end of the pipe extends into the 4 inch deep bell with a nominal overlap of 2.25 inches but has the flexibility to extend less to allow for angular deflection.

The Engineering team designed the steel pipe system based on key parameters such as working and surge pressure, thrust and thermal loadings, installation and jacking force loadings, grouting pressures, and external buckling. Final design and specification was for a spiral welded steel pipe 72 inch ID cylinder (73.25” OD) with .625 inch wall thickness and a single lap welded bell by spigot joint. The interior of the steel pipe was cement mortar lined per AWWA C205 at the factory.

Pipe Manufacture

Northwest Pipe Company was chosen to supply the AWWA steel water pipe for this siphon project. The welded steel pipe was manufactured from steel coils formed helically into cylinders and double submerged arc welded as they are being formed. This continuous process allows the pipe to be manufactured to any length and most diameters which provides flexibility to the designer and installer. On the pipe mill, cylinders are cut to their desired lengths using a plasma torch. As required by AWWA C200 each length of pipe is hydrostatically tested to 75% of the specified minimum yield and held for a minimum of 30 seconds or as long as needed to perform visual inspection to comply with AWWA C200. In this case the test pressure for 72” pipe with a .625 wall was 538 psi.

The design engineer and owner evaluated various pipe joint designs to determine the optimum joint for performance and constructability. As described in the paragraph above, a single welded, bell and spigot lap joint configuration was determined to be the best option. Bell and spigot joints are provided by precision expanding one pipe end to form a bell and the spigot is simply the cut end of the pipe.

Tunnel Size and Depth

Theoretically a ten foot diameter TBM would have provided sufficient space between the 9,460 lineal feet of concrete tunnel liner and the 72 inch steel carrier pipe however this minimized diameter would have made tunneling and steel pipe installation more complicated. Hence a twelve foot diameter TBM was utilized which resulted in a 10 foot clear opening after the concrete liner sections were placed. This larger bore greatly enhanced the project logistics and productivity. The tunnel depth ranged from 65 feet below grade at the Staten Island shaft to 110 feet below grade at the Brooklyn shaft.

Tully/OHL JV was low bidder and the prime contractor. The low bid came in at just under $300 million. National Welding Corporation was chosen to install and weld the pipe joints in the tunnel as well as the welded steel construction in the launch shaft.

Launch Pit Construction, Excavation and Welding

There were two shafts designed for this project: The launch pit/shaft was located in a vacant lot on Staten Island and was the starting location for the tunneling and for most surface operations. The receiving shaft was located across New York harbor in a Brooklyn park between the Belt Parkway and Shore Road. Access at this location was only available on a limited basis.

Construction began with building a slurry wall launch shaft in August 2011. National Welding Corp. mobilized for the Siphon project in February 2012 where we joined Local 15 Operating Engineers out of New York to perform welding of the shaft whalers that supported the slurry walls against the immense pressure created by the New York harbor just a few hundred feet away. As the excavation progressed additional whalers were added until reaching the bottom where these became the walls of the launch pit for the Tunnel Boring Machine (TBM) (see Figures 2a and 2b). The launch pit consisted of 6 courses of steel whalers varying from a single W36 beam at the top of the launch pit to a triple stacked W36 beam at the base with increasing web and flange thicknesses at lower depths. The walls were supported with W14 spreader beams on every course. Ground freezing was employed to stabilize the liquefied soil at the shafts during construction. The 300 foot long launch shaft would be the assembly location for the TBM and the only access into the tunnel until the machine holed-thru in the Brooklyn shaft over 9,000 feet away on the other side of the Anchorage Channel in an area of Brooklyn called Bay Ridge.

Figures 2a and 2b. Launch Shaft excavation.

Tunnel Boring Machine Begins Mining

A 300 foot-long, 110 ton pressurized TBM was selected for this project. It was designed for soft ground as opposed to bedrock. The machine was lowered into the Staten Island shaft and assembled in July 2012. During TBM operations segmented concrete rings were placed behind the machine thereby reducing the 12 foot diameter excavation to a 10 foot diameter finished tunnel behind the TBM (see Figure 3) that would later house the steel pipeline.

Figure 3. TBM leaves 10 foot diameter segmented tunnel

At the early stages of mining the TBM was to proceed slowly downwards from the 65 foot deep launch shaft at a 2.5% grade to a depth of 100 feet below the surface towards Brooklyn. After reaching the desired depth the TBM would level out and make a slight change in direction and proceed almost horizontally underneath the channel (see Figure 4).

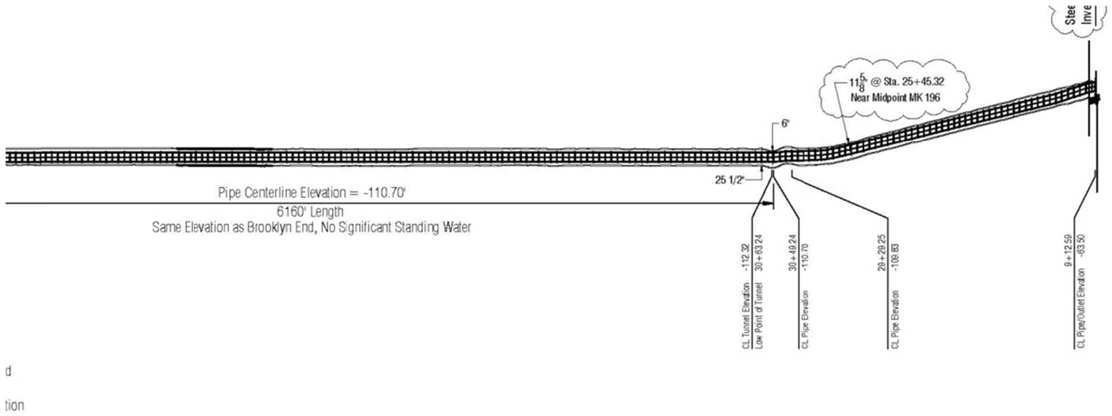

Figure 4. TBM descends to 100 feet.

Soil conditions caused the machine to continue its downward progression beyond the planned depth requiring a correction. This maneuver created a low spot in the tunnel referred to as “the dip” (see Figure 5).

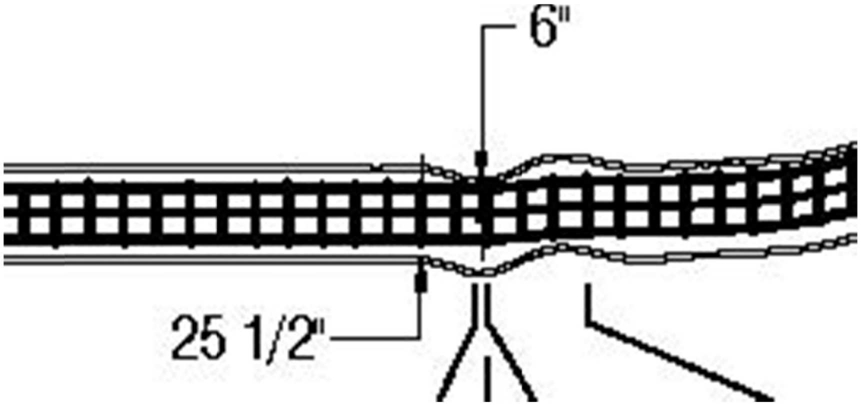

Figure 5. “The Dip”.

The TBM progressed approximately 1,600 feet from the launch shaft in Staten Island towards Brooklyn when operations were suspended on the evening of October 28, 2012 in advance of the approach of Hurricane Sandy. The historic storm surge caused by Sandy flooded the Staten Island shaft and filled the tunnel with sea water. The TBM remained submerged for several months after the storm which severely damaged the hydraulic and electrical components in the machine. After the tunnel and shafts were dewatered and damage assessments were completed, months of repairs and testing of the TBM followed.

On April 14, 2014, the TBM resumed work and continued excavation of the tunnel without problems until the last 700 feet before the hole-thru on the Brooklyn side. Once again, liquefiable soil conditions were believed to cause the front of the TBM to dip downwards twice creating “the second and third dip”.

When the tunnel was completed in February 2015 the pipe installation start date was almost 3 years behind schedule and had gone through multiple design changes. The “dips” presented numerous challenges to both the design and installation teams. Every deviation in the tunnel created a need for more flexibility with the joint design as well as installation means and methods to minimize low spots in the completed tunnel liner.

Evolution of Pipe Carrier Design

The new design called for the steel pipe to be installed at a different slope than the mined tunnel. The pipe installation elevation from invert of tunnel to invert of pipe now varied from 19 inches up to 35 inches. The design continued to evolve as the TBM experienced difficulties maintaining grade and the installation team was required to modify the pipe blocking and carrier design several times just weeks before starting the work. Ultimately the tunnel pipe installation was required to be adjustable throughout the tunnel length undulating from 17 inches to nearly 43 inches in height.

The pipe installation design team utilized the rail previously used for the mining operations as the method of transporting the steel pipe. The pipe was installed with the first piece being set in Brooklyn then progressing back towards the Staten Island access one 40 foot piece at a time. A diesel Locomotive pushed a cradle style pipe carrier (see Figure 6) designed with pneumatic lifting devices to position the pipe at the correct elevations engaging the bell and spigot joints. Polyurethane wheels mounted on the carrier allowed clocking of the new pipe. The design team had used similar pipe carriers successfully numerous times in the past, however those projects were installed to a single elevation but allowing for a slight variation of + or – 4 inches.

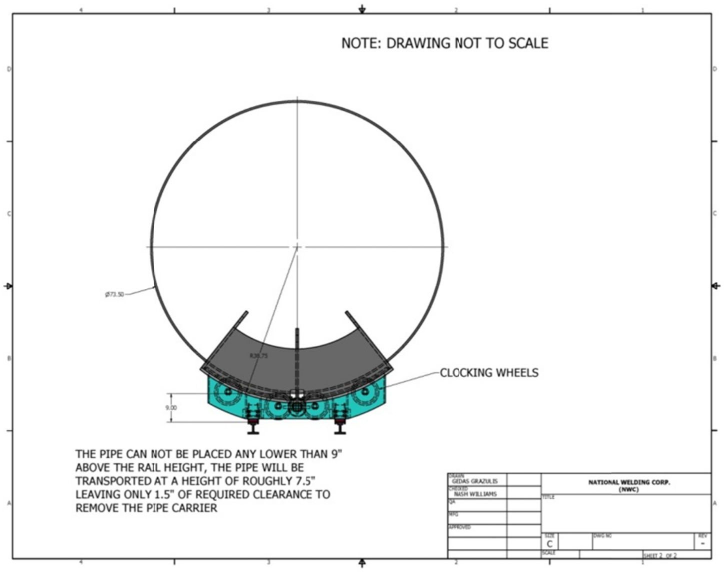

Figure 6. Pipe Carrier rough design.

The tunnel rail had been submerged in salt water and used to transport thousands of tons of muck and concrete segments during mining leaving it in relatively poor shape. The mining contractor consequently experienced numerous derailments during their operations which required a solution. An extra wide rail wheel was machined specifically for the project to prevent the pipe carrier and its 24,000 pound load from derailment. The rail wheels used for the pipe carrier were approximately 2 inches wider than those used on the locomotive.

The pneumatic lifting devices were only capable of raising the pipe 7" above the carrier therefore an innovative solution was needed to install pipe over 2 feet above the pipe carrier as well as allowing rotational clocking of the pipe. To achieve the required installation heights a stackable spacer system was designed to fit the pipe carrier. The spacers were referred to as "stackers" and could be stacked on top of one another until reaching the required height before the pipe was lowered into the shaft (see Figure 7). The stackers allowed the pipe to be transported just below the installation elevation then raised to the final elevation utilizing the pneumatic lifting devices for small elevation adjustments. In multiple areas the pipeline elevation differed dramatically at both ends of the same pipe. In this instance a different quantity of stackers could be used on the front and back of the pipe carrier to achieve the required elevations.

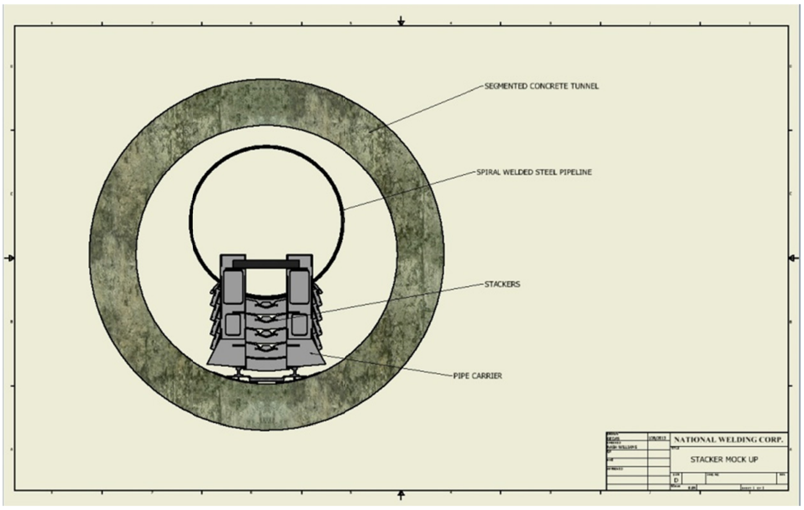

Figure 7. Stackers on Pipe Carrier.

A roller chain was designed to sit over the top stacker allowing for clocking of the pipe (see Figure 8).

Figure 8. Roller Chain for clocking.

Adjustable Pipe Bracing

Once the Bell and Spigot joints were engaged and set to the proper elevation a bracing system was needed to support the pipe while the Pipe Carrier was retracted. The pipe braces would hold the load of the new liner until they were encased during the annulus grouting operations. The pipe braces also needed to adjust for varying pipe elevations quickly at the installation location. Once the pipe was transported into the tunnel there was limited access except at the exposed pipe end, therefore a system that supported the pipe at just one end was preferred. The pipe support system was subject to the pipe dead load plus buoyant forces during the grouting operations. To handle these apposing stresses "ears" or flat plates were welded near the exposed end of each steel liner piece. The pipe bracing was cut to length and welded to the "ears" once the pipe was installed at location. Three different lengths of bracing were manufactured to accommodate the varying installation heights quickly while limiting waste.

The final bracing design consisted of a steel channel leg connected via bolt to a steel plate foot with a UHMW isolation pad between the foot and tunnel wall. During the installation, the crews would set the pipe then measure the required leg length. An oxy acetylene torch was then used to trim the bottom legs to length. Once the legs were welded in place (see Figures 9a and 9b) the lifting devices were lowered and the locomotive pulled the pipe carrier to the launch shaft to receive the next piece of pipe while welding crews stayed behind to install the top bracing.

Figures 9a and 9b. Pipe Bracing and Swivel Foot Design.

Welding and Inspection

With such a tight schedule to install, fit and weld 237 pieces of pipe in under 9 weeks this became a major undertaking. Field adapted high production welding processes were needed to deposit over 4,000 pounds of required weld metal. The Fluxed Core Arc Welding (FCAW) method was selected for the welding due to its high deposition rate and low fume emission characteristics. A high voltage cable running from Brooklyn transmitted 13,700 volts to a mobile step down transformer producing 480 volt 3 phase power inside the new pipeline, high voltage was required to limit line loss due to the length of the tunnel. Four inverter type welding power sources were mounted to a custom built tunnel cart (figure 10) that included a step down transformer that provided power for small hand tools and workspace lighting. Shielding gas for the FCAW process was also supplied from the Brooklyn side via pressure hose.

Figure 10. Welding Cart

Welding inspection was performed by a third party inspection company. The specifications required Magnetic Particle (MT) inspection for every girth weld performed. Welds were required to conform to the acceptance criteria listed in AWS D1.1 Structural Welding Code-Steel 2004, Table 6.1.

Accelerated Installation and Welding

With the project being so far behind, an accelerated installation schedule was required. Crews worked day and night 6 days a week to complete the installation and welding within the 9 week timeframe. Installation was halted several times due to the tunnel flooding (see Figure 11), ventilation and power issues.

Figure 11. Flooded Tunnel at 2nd Dip.

Overview

This project showcases just how adjustable bell and spigot welded joints are in tunnel and other applications. This adjustability frequently becomes a necessity as mining or excavations deviate from the planned alignment. The pipe is manufactured well before the completion of tunneling and in most cases numerous headaches and delays can be avoided with adjustable joint designs, installation methods, bracing and a team willing to adapt to changing conditions. Even with all the difficulties experienced, the pipe installation and welding was completed within the 9 week window and the entire run of pipe under New York Harbor passed the pressure test on January 22, 2016.