Rescue and Refurbishment of a TBM inundated with Flood Waters at the New York City Harbor Siphon Project

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ABSTRACT

In October 2012, New York City's Harbor Siphons Project and its 3.6 m CAT EPB ground to a halt when hit by Superstorm Sandy. Despite contractor Tully/OHL JV's best efforts to mitigate anticipated flood risks, the launch shaft was inundated with seawater, flooding the tunnel and TBM just 460 m into the 2.9 km long drive. A team of Robbins and OHL personnel were able to document, reverse engineer, and refurbish severely corroded components of the TBM while in the tunnel, resulting in a successful re-launch in April 2014. This paper will document the incredible efforts of the team to rescue and refurbish the TBM, and its performance since the restart.

INTRODUCTION

The ongoing success of the New York City Harbor Siphons Project is a testament to commitment and perseverance. The project, which is owned by The New York City Economic Development Corporation's (NYCEDC), was started in August 2011 to replace two shallow water lines across the New York Harbor between Staten Island and Brooklyn (see Figure 1).

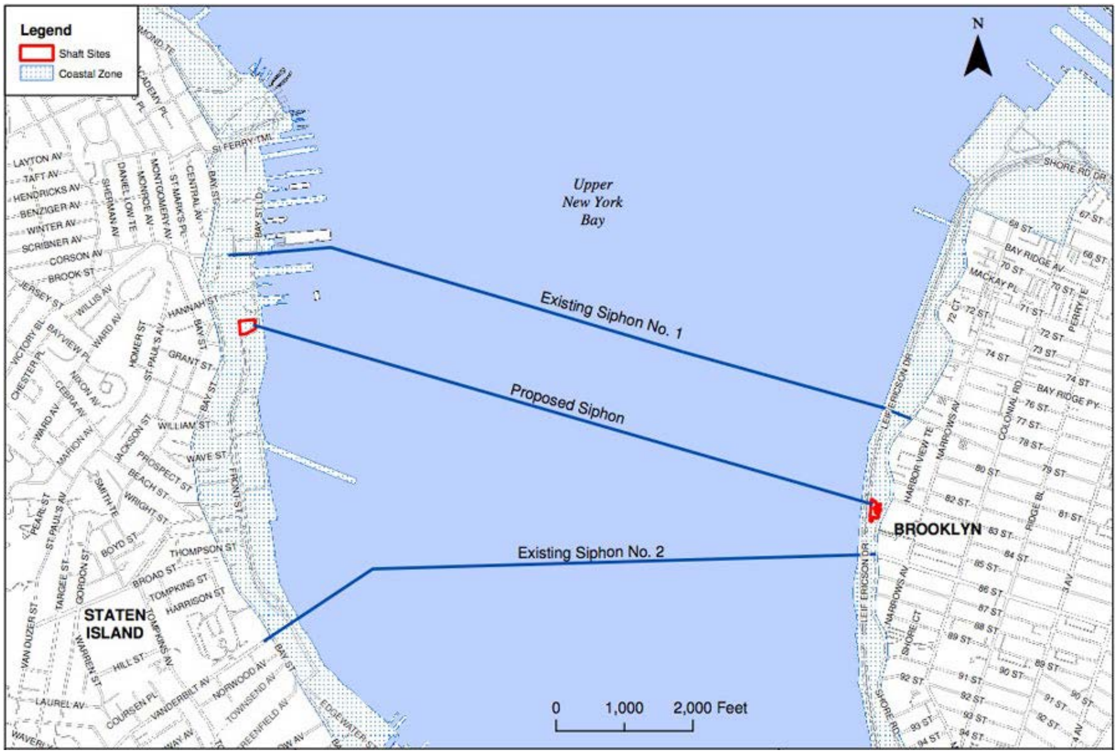

Figure 1. Existing and new siphons. Image: tunneltalk.com.

The Anchorage Channel, an integral part of the shipping trade with access to New York Harbor and the rest of the Port of New York and New Jersey, is one of the more heavily used water transportation arteries in the world. Future cargo volumes are expected to double over the next decade and possibly quadruple in 40 years. The channel must be deepened in order to accommodate the new generation of cargo mega-ships, which have drafts that exceed 14 m (the present depth of Anchorage Channel), and ensure the City's ability to benefit from the anticipated increase in this sector of the economy.

Using funding authorized by the Federal government, the Port Authority of New York New Jersey (PANYNJ) and the United States Army Corps of Engineers (USACOE) proceeded with dredging operations to deepen the Anchorage Channel to 15 m below mean low water over a length of 5,800 m, from the Verrazano-Narrows Bridge to the channel's confluence with the Port Jersey Channel.

In order to complete their project, however, the two existing siphons owned by NYCEDC had to be removed, ultimately requiring replacement by a larger tunnel. The new siphon requires a 3.6 m diameter, 2,883 m long tunnel. NYCEDC is responsible for the construction of the USD $300 million project on behalf of the New York City Department of Environmental Protection.

Designed by CDM/Hatch Mott McDonald, subsurface investigations for the new siphon included 38 marine borings, 36 shaft and land side borings, pressuremeter tests at nine locations, and field vane shear tests at eight locations along the alignment.

The new siphon will be finished with a backfilled 1.2 m welded-steel water pipe. Full backfill around the riser pipes in the shafts will also be installed. Water transmission mains connecting the tunnel to the existing system will be constructed in open cut. Microtunneling will drive two additional crossings, about 99m and 37m long, under the Staten Island Railroad.

Once the new tunnel is complete, the existing siphons will be decommissioned and abandoned. The new tunnel will serve as a backup to the 900ft deep Richmond main water tunnel that was built under the harbor between Brooklyn to Staten Island in the 1960s through hard rock.

TUNNEL BORING MACHINE

The tunnel subcontractor, Tully/OHL USA JV, procured a 3.6 m diameter EPB TBM from Caterpillar in 2012. The TBM, dubbed "Pat", was designed to drive through highly variable clays and sands under full hydrostatic conditions. The machine was designed specifically for the difficult undersea drive and to withstand potential hydrostatic pressures of up to 8 bar. It was launched from the 35 m deep, 8.5 m i.d. Staten Island shaft to drive toward the 24.3 m deep, 7.3 m i.d. Brooklyn shaft. The contractor anticipated average advance rates of 17 m per day (see Figures 2-3).

Figure 2. Side view of CAT TBM.

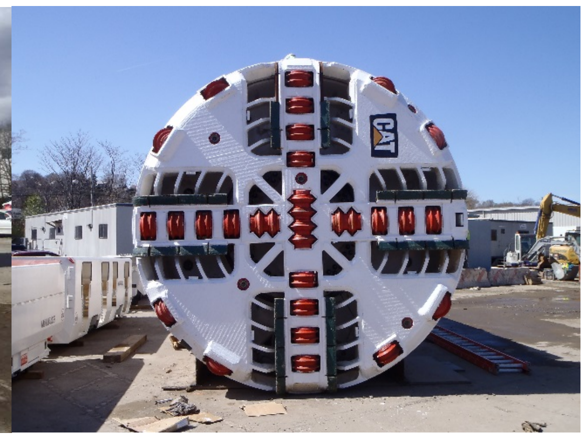

Figure 3. CAT TBM Cutterhead.

HURRICANE AND FLOOD

Unfortunately, a major setback was dealt to the owners of the Siphons project and Tully/OHL USA JV when in late October 2012, Superstorm Sandy brought flood waters to New York City and hurricane force winds of 145 kph. On October 29th, Superstorm Sandy drove water levels at the Staten Island site to three feet above the one hundred year flood level. The protective concrete barriers around the shaft and sandbags at the mouth of the tunnel were overcome and the nearly 113 m long machine was entirely submerged under sea water after boring only 460 m (see Figures 4-5).

Figure 4. Tunnel after the flood.

Figure 5. Inside the TBM, looking forward at the drive motors and man lock, partially submerged.

Following the storm, water was pumped from the TBM and crews were sent into the tunnel to perform essential maintenance. Workers representing the New York City's Local 147 laborers union (affectionately referred to as 'sandhogs') and mechanics from local 15 IOUE under the direction of Tully/OHL USA management protected critical bearing components by ensuring that the bearing cavity was fully immersed in clean oil. The machine then sat idle until late July 2013 when TBM manufacturers were contacted for proposals to refurbish the machine so work on the project could continue (see Figure 6).

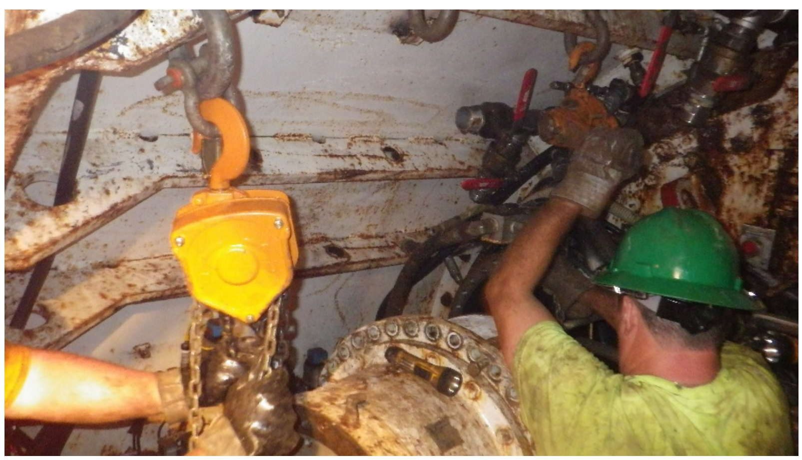

Figure 6. The Crew Inspect Gearboxes on the stranded TBM.

TBM REWORK

Among the prospective candidates for TBM refurbishment were Herrenknecht of Germany, Caterpillar (CAT) Tunnelling Company of Canada, who manufactured the TBM, and the Robbins Company based in Solon, Ohio. Robbins travelled to Staten Island in late July 2013 and performed a comprehensive survey of the heavily corroded machine, which had been extensively damaged by salt water, and prepared a detailed proposal (see Figure 7). The proposal provided detailed descriptions of the scope of work and included a clause establishing a bonus or penalty condition for the completion of the refurbishment in mid-December

2013. During that time, CAT made the announcement that they would be closing their Tunneling Division. The Robbins Company was selected to perform the refurbishment and immediately a team was dispatched to the Staten Island site to begin. The team included a field service site supervisor, technicians, and a project manager.

Figure 7. Example of salt water corrosion – segment unloader controls.

Refurbishment Strategy

The general plan for the refurbishment centered on removing the rear eleven gantries and belt conveyor from the tunnel and shipping them by truck to Robbins' Solon facility where the backup gear could be completely cleaned, evaluated and repaired (see Figures 8-9). The remaining two gantries, screw conveyor, segment erector, stationary shield and forward shield would have to be refurbished onsite in the tunnel. The segmented concrete tunnel lining would not permit the removal of these items.

Per the scope of work, the cutterhead and main bearing of the TBM were excluded from the refurbishment, as they were under earth pressure and not accessible. The Robbin team would need to complete the refurbishment taking into account unknowns, such as the condition of the cutterhead. Thankfully, the contractor had completed a hyperbaric intervention replacing the cutting tools just two weeks before the storm, so it was assumed to be in reasonably good shape.


Figure 8. Back-up system being shipped to Solon, Ohio.

Figure 9. Substation rework in Solon, Ohio.

The parties involved set about immediately on a two-pronged approach of shipping the removed equipment to Solon, and organizing a plan for the onsite refurbishment of the remaining items. By early August, the gantries were back in Solon and production was proceeding to inspect and disassemble equipment in order to evaluate and order items where necessary. Onsite, local 15 mechanics and local 147 sandhogs worked diligently identifying, disassembling and evaluating system components. Major failed components, such as grout pumps, drive motors and propulsion hydraulic blocks were shipped by truck back to Solon for repair, while less complicated items were ordered for shipment directly to site. Additionally, a local hydraulic supply house was selected to provide onsite hose making capabilities up through 2 inches diameter. In this way, replacement of worn hoses could be produced as needed saving precious time.

By September, 2013, the gantries in Solon were being refitted, onsite the bulk of the evaluations were complete and workers turned to cleaning and re-hosing the forward shields and first two gantries. Steel components of the machine were stripped with abrasives, then sanded and repainted.

Rework Challenges

The Robbins crew was contracted to guide onsite personnel in replacing corroded hydraulic components and all new electrical—from Variable Frequency Drives to PLCs and wiring—inside the small tunnel under a water pressure of 3 bar. As such, the earth pressure had to be constantly monitored during the refurbishment. The machine had been stopped with its thrust cylinders in, and thus certain components could not be replaced or evaluated before the machine started up.

Introduction of the gantries began in early November and work continued coordinating and installing all the replaced components in the forward shields as well as interconnecting electrical and hydraulic leads between the gantries and the TBM. By mid-December 2013 all gantries and equipment had been returned to the Staten Island site and the majority of the components were reintroduced into the tunnel.

Meanwhile, the TBM's control system was being reversed engineered. The team understood early on that the previous control programming would be unusable given the PLC change and an elite team of Robbins PLC technicians were assembled to recode the machine onsite.

Because the team only had limited assembly drawings from the CAT manual, much of the refurbishment, including the PLC system, had to be built from the ground up. The team at site observed how the machine worked in order to build the correct PLC system, working backwards to set up an all new system. One crew member was dedicated full-time to documentation, observing and photographing various parts so that they could be reverse engineered in order to create the best possible software.

Much of the rework occurred because the manufacturer of the PLC system was switched to Mitsubishi from its original manufacturer Allen-Bradley. Components as small as the flowmeters responsible for monitoring critical flow in the lube system had to be reformatted. The flowmeters communicate with the PLC through a card, and that card had to be replaced with one that could communicate with a Mitsubishi system. Many components required a similar reformatting, from the segment erector to the 16 thrust cylinders of the machine, which operated individually rather than being controlled in quadrants as a standard Robbins EPB would have been.

Work continued at a feverish pace through the holiday season as Tully/OHL USA prepared to return to mining. By January 2014, the majority of physical systems were in place in the tunnel and the Robbins PLC technicians began the monumental task of bringing the newly reassembled machine back to life electrically. The Mitsubishi PLC was initially set up by Robbins Electrical Engineers. Several Robbins field service electrical technicians were brought to site to help guide electrical connections, and supervise installation of the many network communication lines (see Figure 10).

Figure 10. Technicians bring the TBM back online after reverse engineering electrical and computer systems.

Despite all of the challenges, the refurbishment project was a success. It was a monumental task, and took four months, ultimately finishing up on schedule. The dogged determination and commitment of the assembled staff of technicians and local tradesmen paid dividends as the customer's milestone dates set forth in the initial proposal were met.

LAUNCH AND MINING

In the final phase of the refurbishment, a Robbins PLC technician was able to complete the commissioning of the TBM and on April 14, 2014 the machine officially returned to mining. To ensure continued success, the team remained on site to support ongoing maintenance of the TBM. In the coming months, the machine performance steadily increased, eventually reaching as high as 108 ft (32.9 m) per day. This result—the equivalent of 27 rings in 24 hours—significantly outperformed the machine as designed before the flood, which had a maximum of 16 rings per day (segment rings are 5+1 precast concrete, 1.2 m in length). By August, the project appeared to be on target for a mid-September completion. However, in early September, ground conditions changed from a silty clay to sand and suddenly the Tully/OHL USA management team found the machine struggling with excessive water ingress and extremely slow propulsion rates.

After brainstorming, the management team installed four, 50 ton auxiliary cylinders in the lower propulsion system and were able to re-establish forward progress but at a reduced rate. The TBM pushed on, but in early October the project was faced with another hurdle. As the soil changed the machine encountered a pocket of glacial soils comprised of larger, hard stones. The hardened material led to tool failure and the TBM was stalled for the majority of November while a hyperbaric intervention was performed to install new tooling. With the intervention complete and a new dressing of rippers installed, the TBM began mining again in late November.

Once mining was reestablished, the TBM faced a final critical crossing beneath Belt Parkway, a busy thoroughfare built on sensitive soils. Monitors were installed in the roadway and around critical utilities including a high-pressure gas line to make sure settlement remained within the set parameters as the machine passed 34 m below. As crews mined, they injected polymer to maintain a smooth flow of muck and consistent earth pressure, while pre-mixed single component grout was used for backfill of the annular gap. The grout was delivered via grout pumps to ports behind the segments at the edge of the tail shield. Ultimately, the crossing was successful and monitored settlement was well within specified limits.

As of January 24, 2015, the machine had mined through the first 1 m thick slurry wall of the exit shaft, having bored a total of 2,882 m. Its completion point is just beyond the exit shaft, past a second slurry wall where the TBM will be buried. The exit shaft has been backfilled with sand. The completion of this project marks the first successful excavation by an EPB in the NYC area, and will serve as a tribute to the determination and perseverance of the entire Harbor Siphons project team.