Record-Setting Tunnel Boring Below Lake Ontario at the Ashbridges Bay Outfall Tunnel

Doug Harding
Robbins

Joe Savage
Southland Contracting

ABSTRACT

The 3.5 km long Ashbridges Bay Outfall in Toronto, Ontario, Canada was a challenging drive set below Lake Ontario. After a remote machine acceptance due to the global pandemic, an 8 m diameter Single Shield machine launched in March 2021 from an 85 m deep shaft and began its bore in shale with limestone, siltstone and sandstone. During excavation, the TBM and its crew bored a city-wide record of 30 rings in one day, or 47 m of advance. This paper will cover the unique project, from TBM acceptance through to launch, tunneling in difficult conditions, and completion in 2022.

INTRODUCTION

The Ashbridges Bay Treatment Plant Outfall (ABTPO) project in Toronto, Ontario, Canada involves construction of a new 3.5 km long TBM-driven outfall in sedimentary rock. The completed outfall connects to fifty (50) in-lake risers to enable efficient dispersion of treated secondary effluent over a wide area of Lake Ontario, making this project the largest outfall in the country. The project for the City of Toronto improves the city's shoreline and Lake Ontario's water quality by replacing a 70-year-old existing outfall.

Outfall components (see overview map in Figure 1 and Figure 2) consist of an 85 m deep, 16 m diameter onshore shaft constructed adjacent to the shoreline; a 3,500 m long, 8 m diameter segmentally lined tunnel constructed through rock beneath the lakebed; and fifty (50) 1,000 mm diameter risers with 830 mm diameter ports installed in line with the tunnel and extending from the tunnel horizon to the lakebed at equal spacing along the diffuser (Solecki et. al., 2022).

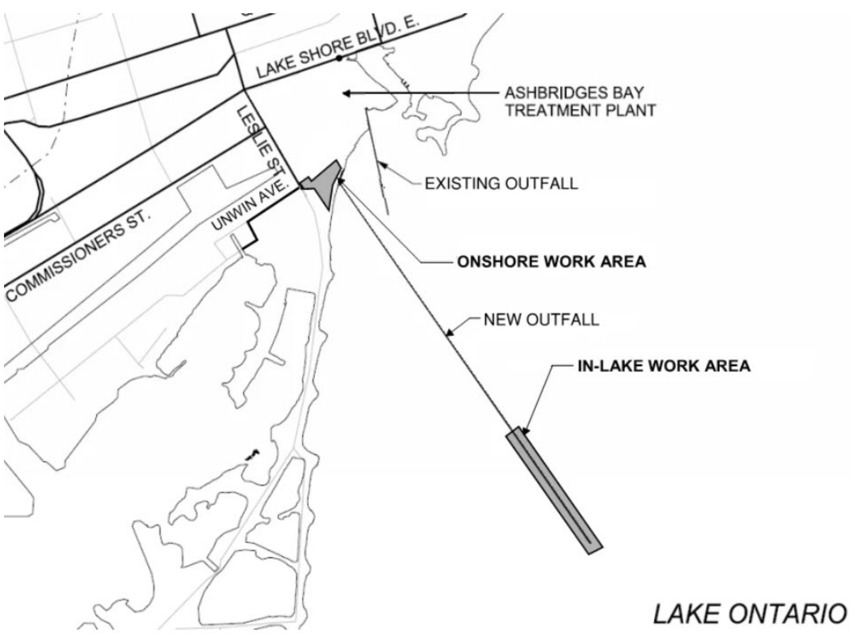

Figure 1. Ashbridges Bay Outfall map of works. (Image: http://tunnelingworld.com/project-show-case/ashbridges-bay-wastewater-outfall-tunnel/)

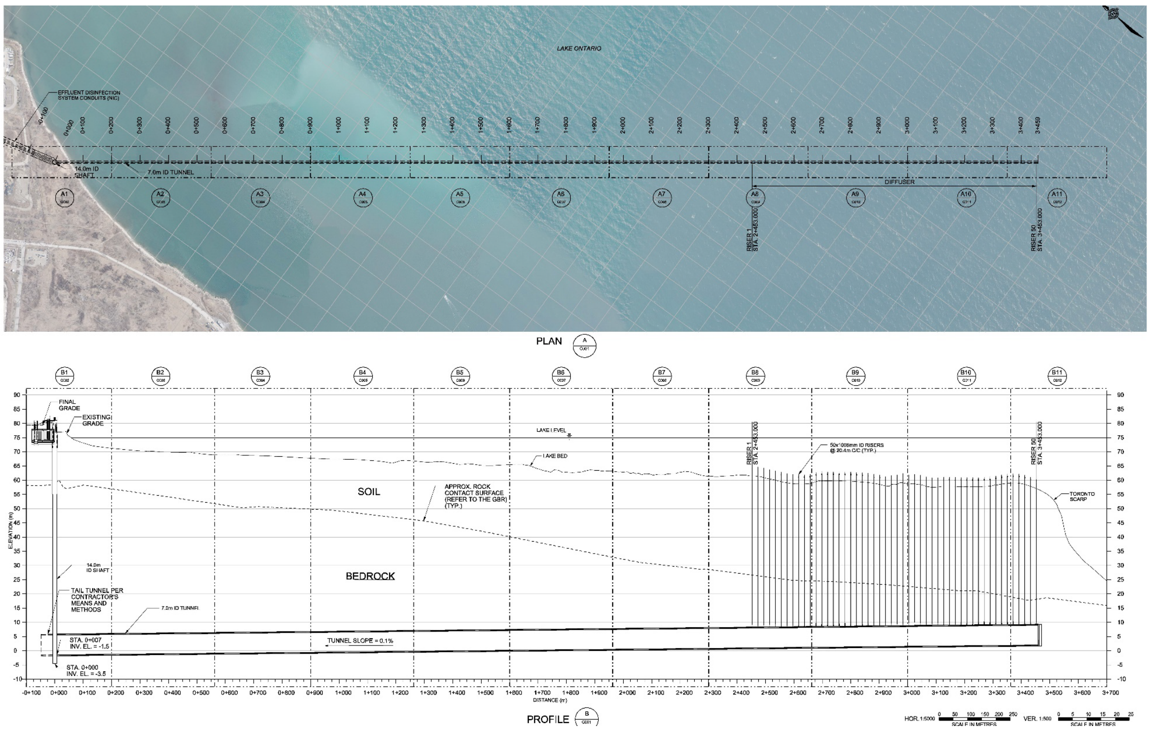

Figure 2. Ashbridges Bay Outfall profile – running tunnel and diffuser shafts at end of tunnel drive

The project also includes the construction of a new effluent conduit that will convey treated and disinfected effluent from the ABTP to the new outfall for dispersion into Lake Ontario through the risers. Construction of the ABTPO project commenced in 2019 and is anticipated to be completed by the end of 2024. The main parties involved for the City of Toronto project include consultants Hatch/Jacobs/Baird and Contractor JV Southland/Astaldi. In 2022, the shaft and starter/tail tunnel were excavated, the tunnel was completed by TBM tunnelling, and all 50 risers were pre-installed from the lakebed. Work remaining on the project includes completing all tunnel riser connections, final cast-in-place lining for the shaft and starter tunnel, and conduit connections with the treatment plant.

Geology

The tunnel alignment (see Figure 3) is situated entirely within the Georgian Bay Formation Shale (GBFS) which is described as a greenish to bluish grey non-calcareous shale. The shale is a fissile rock with widely spaced vertical or inclined jointing and closely spaced sub-horizontal bedding planes interbedded with limestone, siltstone and sandstone. As per the GBR, the average UCS values along the tunnel alignment baselined that the GBFS on average is 'weak', according to the ISRM Classification System. In addition, specific groundwater baselines during TBM tunneling were stated in the GBR as follows 1) 100 L/min transient inflow and 2) 15 L/min steady state conditions measured after 48 hours from initial excavation (Solecki et. al., 2022).

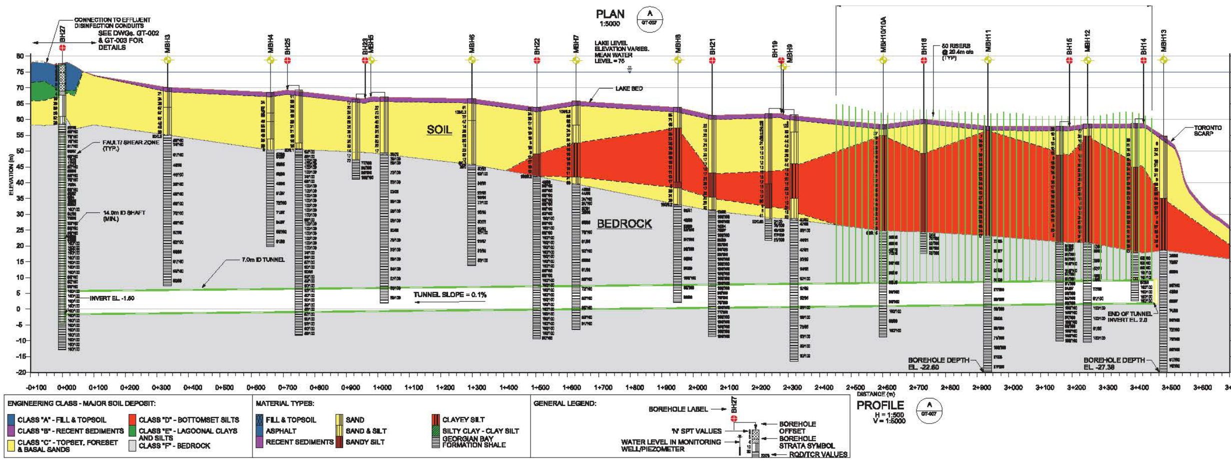

Figure 3. Geology along the tunnel alignment - Ashbridges Bay Outfall profile

Project Sequence

The outfall construction sequencing involved, among other elements, sinking a shaft adjacent to the shoreline and then mining a tunnel through rock beneath the lakebed below Lake Ontario. The most important construction sequencing constraint required all risers to be installed, grouted, and tested for leaks before tunneling within 100 m of any riser (see Figure 4). Another constraint involved probing ahead of the TBM to assess the potential for water inflows. If flows were encountered during this probing, pre-excavation grouting would be performed to improve rock quality and limit water ingress into the tunnel. Following TBM mining, connections to the pre-installed risers would be made prior to outfall tunnel flooding.

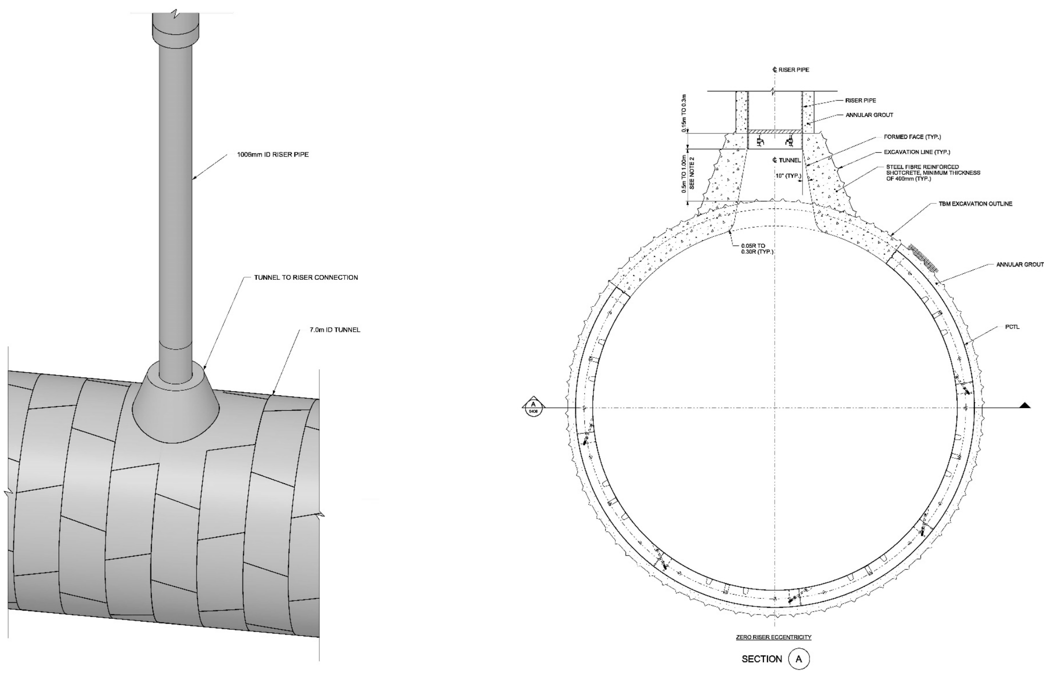

Figure 4. Riser connections to main tunnel

TBM PROCUREMENT & REBUILD

A Single Shield TBM type was decided on due to the requirement for a single-pass Precast Concrete Tunnel Lining. Other minimum TBM & tunnel requirements including TBM advance probing, two-component annular grouting injected from the TBM tail-shield, gas monitoring, refuge chamber and provisions for TBM pre-excavation grouting, Class 1, Division 2 compliance, CSA and Canadian Electrical and Safety compliance and certification were also specified to manage the anticipated conditions and potential project risks.

Per the contract design the tunnel would be a “dead end tunnel” and the TBM was to be abandoned after completion of the 3.5km long tunnel drive. There were provisions in the TBM design to remove the usable components should there be time in the schedule to do so.

Upon contract award, the contractor procured a 7.95 m diameter Single Shield, High Performance (HP) Tunnel Boring Machine (TBM) manufactured by Robbins. The tender specifications allowed for use of a rebuilt TBM, and one was selected that was previously used at an 8.7 m excavated tunnel diameter in a Crossover XRE TBM configuration for both rock and soft ground excavation at the Túnel Emisor Poniente (TEP) II project located in Mexico City, Mexico (see original configuration in Figure 5 below) Design of the machine allowed both excavation in rock “open mode” and then converted to EPB "closed mode”. The machine was converted to EPB mode for its final section of tunnel.

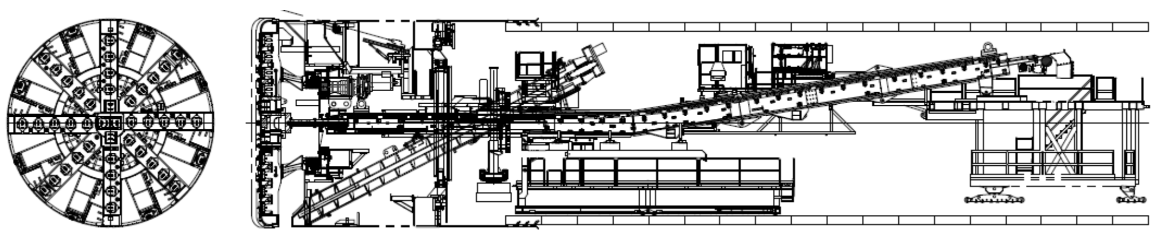

Figure 5. The TBM in EPB Mode after completion of the Túnel Emisor Poniente (TEP) II project.

Robbins began remanufacturing and modifying the TBM for Ashbridges in the Robbins Mexico facility located just outside Mexico City. The Ashbridges machine incorporated new TBM shields and a 17-inch disc cutterhead as well as utilizing components from the previous project in Mexico. Robbins USA and Robbins Mexico worked together to perform the refurbishment work, which occurred directly before and during the height of the COVID-19 pandemic.

Tender specifications required that if a rebuilt machine was to be utilized, as a minimum the following major components had to be installed as “brand new”: the main bearing, cutterhead electric drive motors, cutterhead gear drives and main bearing sealing system. In addition, the remanufactured machine had to comply with ITAtech Guidelines on Rebuilds of Machinery for Mechanized Tunnel Excavation - ITAtech Report No. 5, May 2015 and a new machine warranty had to be provided.

Additional machine features were added to comply with the TBM specification, and as the project was determined to be in “potentially gassy” conditions included the machine being fitted with gas monitors and supplied to Class 1, Division 2 specifications. In addition, due to the concern that water might leak into the tunnel from Lake Ontario, extra capacity for probing and grouting was built in around the machine shield periphery and through the face of the machine. Onboard drilling and grouting capabilities gave 360-degree ground detection capabilities as well as capacity to treat the ground if water was detected (see Figures 6 and 7).

In addition, remote data monitoring was enabled on the machine, for performance and drilling data, that was accessible from any location. Robbins monitored this data and worked with the contractor to troubleshoot any issues encountered during boring.

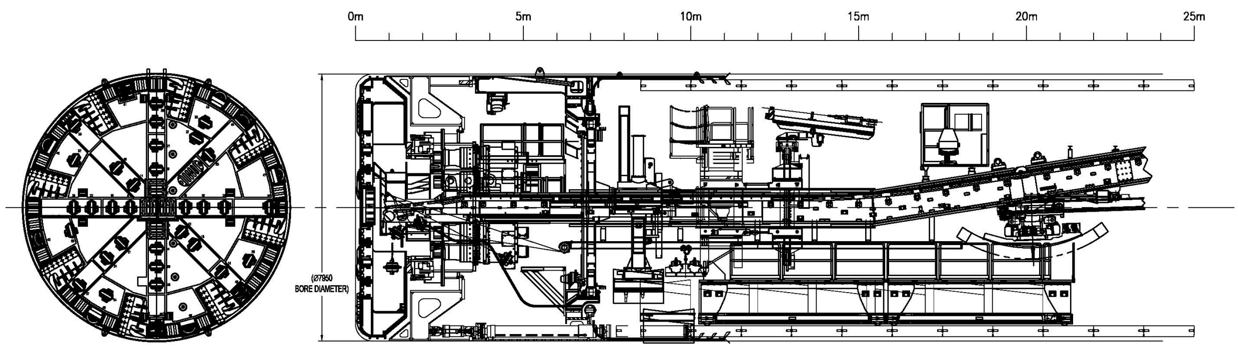

Figure 6. TBM configuration for the Ashbridges Tunnel project

GENERAL SPECIFICATIONS	
TRC PROJECT NUMBER	15889
MACHINE NUMBER	SS234-280-4
SEGMENT LINING	
DIAMETER (OUTER / INNER)	7,660 mm / 7,000 mm
NOMINAL LENGTH / THICKNESS	1,500 mm / 330 mm
NUMBER OF SEGMENTS IN RING	6
MAXIMUM SEGMENT WEIGHT	5,400 kg
CUTTERHEAD	
BORE DIAMETER (NEW CUTTERS)	7,950 mm
CUTTER TYPE	Ø17 in, BACKLOADING
CUTTER QUANTITY	49
BUCKET QUANTITY	8
WATER SPRAY NOZZLES	6
MAIN BEARING	
DIAMETER, TYPE	3,910 mm, 3-AXIS
RATED L10 LIFE	+12,000 HOURS

MAIN THRUST	
MAXIMUM THRUST FORCE	46,694 kN @ 345 bar
EXCEPTIONAL THRUST FORCE	56,845 kN @ 420 bar
RECOMMENDED OPERATING THRUST	6,464 kN
THRUST CYLINDER STROKE	2,500 mm
STROKE SENSOR QUANTITY	4
ARTICULATION	
ARTICULATION CYLINDER FORCE	23,683 kN @ 345 bar
ARTICULATION CYLINDER STROKE	250 mm
STROKE SENSOR QUANTITY	4
CUTTERHEAD DRIVES	
TOTAL POWER	7 x 330 kW = 2,310 kW
NOMINAL CUTTERHEAD SPEED	0 - 7.1 RPM
MAXIMUM TORQUE	3,410 kNm @ 0 - 6.5 RPM
EXCEPTIONAL (BREAKOUT) TORQUE	5,116 kNm

Figure 7. TBM Specifications

Virtual Factory Acceptance Testing

By the time the assembly team reached the factory acceptance testing phase, much of the world was on Covid lockdown and travel was restricted between the U.S., Canada, and Mexico where the teams were based. Because of this a virtual TBM factory acceptance test was performed online for the first time ever, where personnel walked through the machine while it was in Mexico and showed each component performing the required testing (see Figure 8).

The virtual testing required coordination by all involved—consultant Hatch provided a virtual testing platform via Onsite Librestream software and Microsoft Teams, while Robbins and Southland/Astaldi secured fast broadband connections and set up multiple video feeds on the TBM for concurrent testing capabilities. The virtual testing also allowed more individuals including those from the project owner to take part in the test.

Figure 8. The Ashbridges TBM during the virtual machine acceptance in Mexico.

TBM LAUNCH & PERFORMANCE

Once the machine had been shipped to Canada from Mexico via ocean freight, it had to be hoisted and lowered in pieces down the 14m diameter x 85 m deep shaft, which was located on the shores of Lake Ontario. TBM Assembly (see figure 9) then commenced in the starter tunnel which was constructed to facilitate the TBM at shaft bottom.

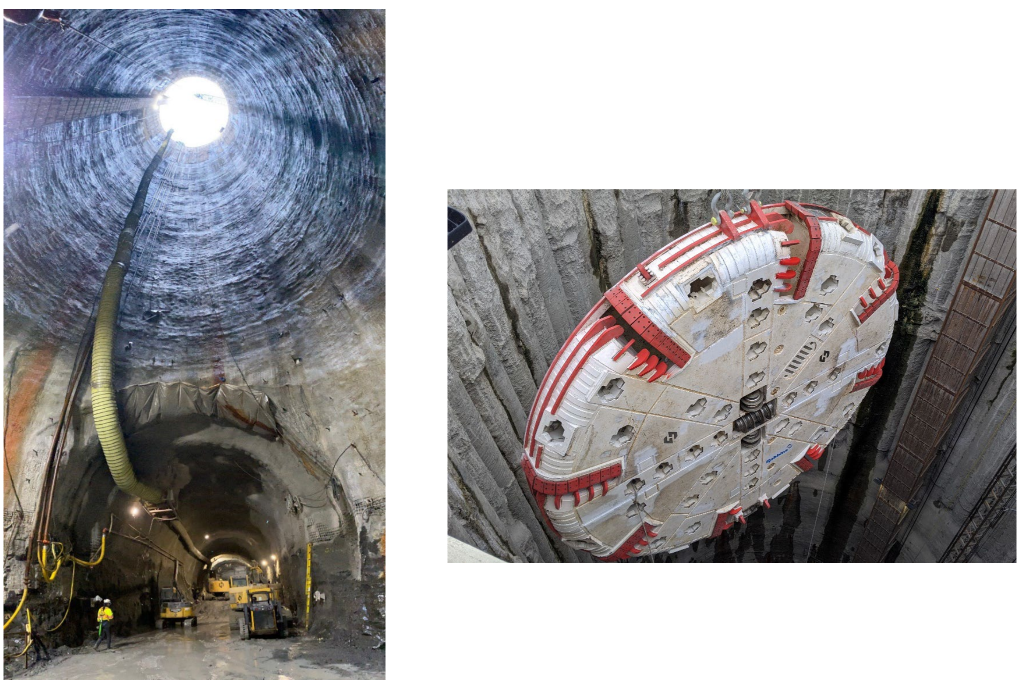

Figure 9. Starter tunnel at shaft bottom and cutterhead being lowered down shaft

Robbins conveyor systems were supplied and included the 3.5km long tunnel conveyor, vertical conveyor installed in the shaft, and a stacker conveyor on the surface for muck storage and haulage—the system would need to move over 174,000 cubic meters of material to build the tunnel. A large grout plant was also built at the surface to support the significant grouting operation behind the TBM tail shield while placing segments. Each ring required well over 5 cubic meters of grout material per ring (see Figure 10).

Figure 10. Project site at the surface with continuous conveyor configuration.

At the same time that the launch and initial tunneling were underway, crews were working to install the 50 in-lake risers from barges on the surface of Lake Ontario. Due to the weather conditions in the Northeast, there was a limited time to install the risers before winter and storm season set in.

Encountering High Groundwater Inflows

The machine was officially launched in March 2021, and began boring in good ground conditions. The machine achieved a city-wide record of 30 rings in one day, or about 47 m of advance. The machine and crew surpassed a previous best day of 21 rings at a project with similar specifications (see Figure 11).

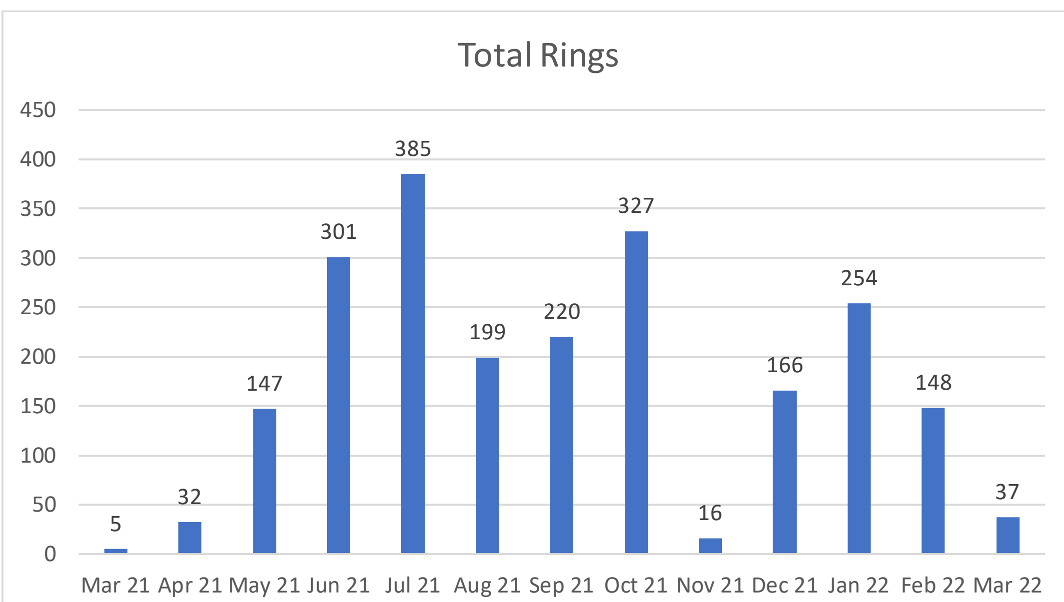

Figure 11. Total rings erected during tunneling (each ring is 1.5 m long).

About 2.5 km into the tunnel, the machine hit its first section of significant groundwater. This was followed by another section about 3.2 km in. Both sections had high enough water inflows (>400 lpm) to significantly damage the pre-cast concrete lining. In one instance a sustained water inflow in excess of 100 lpm was measured per hole (see Figure 12). The holes were left to drain and there was no evidence of reduced flow over a period of time. It was therefore contemplated that water inflows could have a direct connection to the lake above the tunnel alignment. At these locations, the ground conditions consisted of approximately 15m of GBSF rock cover above the tunnel and 35m of overburden deposits. The distance from tunnel springline to lake level was approximately 70m. In some holes, packers were installed to confirm groundwater pressures ranging between 1.7 to 3.1 Bar. When these conditions were first encountered, damage to the pre-cast concrete lining occurred in the crown of the tunnel consisting of structure cracks (>25mm in thickness) and movement to the rings (steps & lips).

Figure 12. Significant, sustained water inflows from the rock formation above the tunnel crown (Solecki et. al., 2022).

Solutions and Remediation Work

Once the high-water inflows and initial pre-cast concrete lining damages were encountered, the contractor was directed to temporarily stop TBM mining to allow the designer to assess the conditions and integrity of the tunnel. It was determined that additional segmental lining repair was necessary consisting of crack repairs, channel installation within the crown, and rock bolt installations. The rationale for this required repair was to stabilize the rings to ensure axial load transfer was restored in the ring. Two channels per segment (C150x12.2), nominally spanning between the 10o'clock to 2o'clock position, were installed to temporarily stabilize the segments. Depending on the damaged segment and the orientation of the installed ring, up to 6 bolts per segment (1.8m in length and 32mm OD injectable anchors using TPH TD Solid Seal TX Resin) were installed.

Once the segments were repaired, the focus was then shifted to ensure that the annular gap between the lining and excavated rock was fully filled. Various check holes completed and numerous gaps (voids) in the shoulders and crown of the tunnel were discovered. The re-use of the two-component cement grout used during TBM mining was unlikely to be able to withstand the water inflows and pressure. Implementing an alternative PCTL annular grouting method was deemed necessary.

After contemplating several products that would meet the project requirements, a polyurethane chemical grout was selected as the preferred annular backfill grout. This chemical grout was a closed cell polyurethane foam used for filling voids, sealing larger volume leaks, and stabilizing the ground. Field trials were performed to select the necessary dosage of accelerant. The chemical grout was injected at closely spaced ports (3/8" diameter holes) around the periphery of the pre-cast concrete lining to completely fill the annular gap.

Ultimately, the following methods were successfully adopted to get through the sections of groundwater and to mitigate risk during the rest of tunneling:

1. Install a chemical grout collar (see Figure 13) around the first ring immediately outside the TBM shield. In total approximately 50-70 drill holes were installed around the complete ring, with approximately 2 to 4 liters of chemical grout injected per hole.
2. Mine and build the next ring while carefully examining movements and damages to nearby rings. During TBM mining, continue with injecting two-component annulus grout through the TBM shield while increasing the B-component accelerant.
3. Pre-install channel supports on the ring built within the TBM shield. It was determined that the pre-installation of channel supports prior to the ring leaving the TBM mitigates segment damage, and damage to lips and steps in the event that the lining moves further due to lack of annular confinement.
4. Monitor pre-cast concrete lining damage and have material and equipment available to repair segments as needed (crack repairs, rock bolts, additional channels, etc.).
5. Perform additional check holes and proof grouting using both the two-component grout and chemical grout. Ensure all segments are stable and the annular gap is full prior to mining the next ring set.
6. Repeat the pattern until the TBM successfully mines through the encountered ground feature.

Figure 13. Chemical grout collar radial injection ports to stabilize ring along with steel channel.

Breakthrough and Beyond

Upon breakthrough in March 2022, the machine shields and other components were left in place at the end of the tunnel, as there was no way retrieve them through the lined tunnel. Along with the good excavation rates in areas of good ground, cutter wear was low as the rock hardness was relatively weak; in fact only eight cutters were changed during the course of boring.

Work remained after the initial excavation: the contractor was required to excavate through the segmental lining and rock to connect the tunnel to the bottom of each of the 50 risers. Several mobile, working gantries are being used in this process with platforms to support specialized demolition equipment, as well as equipment to support the ground and perform final shotcrete lining in those 50 riser areas.

CONCLUSIONS

Before and during tunneling, the Ashbridges Bay Outfall tunnel met with challenges – these challenges were met head-on by the team and innovative solutions developed. Whether a new way of virtually testing a TBM, or a solution for sections of water inflows, the project team quickly reacted to the situation by working closely together to develop a plan. The successful implementation of the plans demonstrates that challenging and adverse conditions can be safely and efficiently overcome by working closely as one diverse team.

REFERENCES

Solecki, A., Waher, K., and Kramer, G. 2022. TBM Tunnelling Challenges and Managing High Water Groundwater Inflows on the Ashridges Bay Treatment Plant Outfall Project. *Proceedings of the Tunnelling Association of Canada (TAC) 2022 Conference.*