Coxwell Bypass Tunnel—Project Update Mid-Construction

M. Bruder, T. Chiesa, and D. Cressman

1 Project Overview

In 1987, an International Joint Commission designated the City of Toronto's waterfront an Area of Concern (AOC) in the Great Lakes Basin [2], due largely to degraded environmental conditions in the Lower Don River (one of Toronto's largest watersheds) and along Toronto's Inner Harbour as a result of storm sewer and combined sewer overflow (CSO) discharges.

The City of Toronto developed a comprehensive Wet Weather Flow Master Plan [1] to address these impacts. The Plan includes an integrated system of tunnels and storage tanks to intercept these wet weather flows, along with key infrastructure upgrades at Ashbridges Bay Treatment Plant (ABTP). It is referred to as the Don River and Central Waterfront and Connected Projects (DRCW Project). Once fully implemented, it is expected to lead to the "de-listing" of Toronto as an AOC.

The DRCW Project consists of five substantial infrastructure projects that, working together, will significantly improve the water quality in the Lower Don River, Taylor-Massey Creek and along Toronto's Inner Harbour. The five projects include: Don River and Central Waterfront Wet Weather Flow System; Ashbridges Bay Landform Project/site of the future high-rate treatment facility; the new integrated pumping system; a new 3.5 km outfall; and a new ultraviolet disinfection wastewater treatment system.

M. Bruder (✉)
R.V. Anderson Associates Limited, London, ON, Canada
e-mail: mbruder@rvanderson.com

T. Chiesa
City of Toronto, Toronto, ON, Canada

D. Cressman
Black & Veatch, Toronto, ON, Canada

S. Walbridge et al. (eds.), *Proceedings of the Canadian Society of Civil Engineering Annual Conference 2021*, Lecture Notes in Civil Engineering 239,
https://doi.org/10.1007/978-981-19-0503-2_3

The backbone of the DRCW project is the three tunnels: the 10.5 km long by 6.3 m diameter Coxwell Bypass Tunnel (CBT); the interconnected 5.6 km long by 6.3 m diameter Inner Harbour West Tunnel (IHWT); and the 6.0 km long by 4.4 m diameter Taylor-Massey Tunnel. See Fig. 1 for an Isometric of the CBT and a stratigraphic profile.

The overall system will include 12 large diameter shafts for access and additional wet weather flow (WWF) storage, 27 connections from existing sewer outfalls to the tunnels, seven offline wet and dry weather flow detention tanks ranging in size from 900 to 20,500 m^3, real-time control to regulate flows in the sewer system,

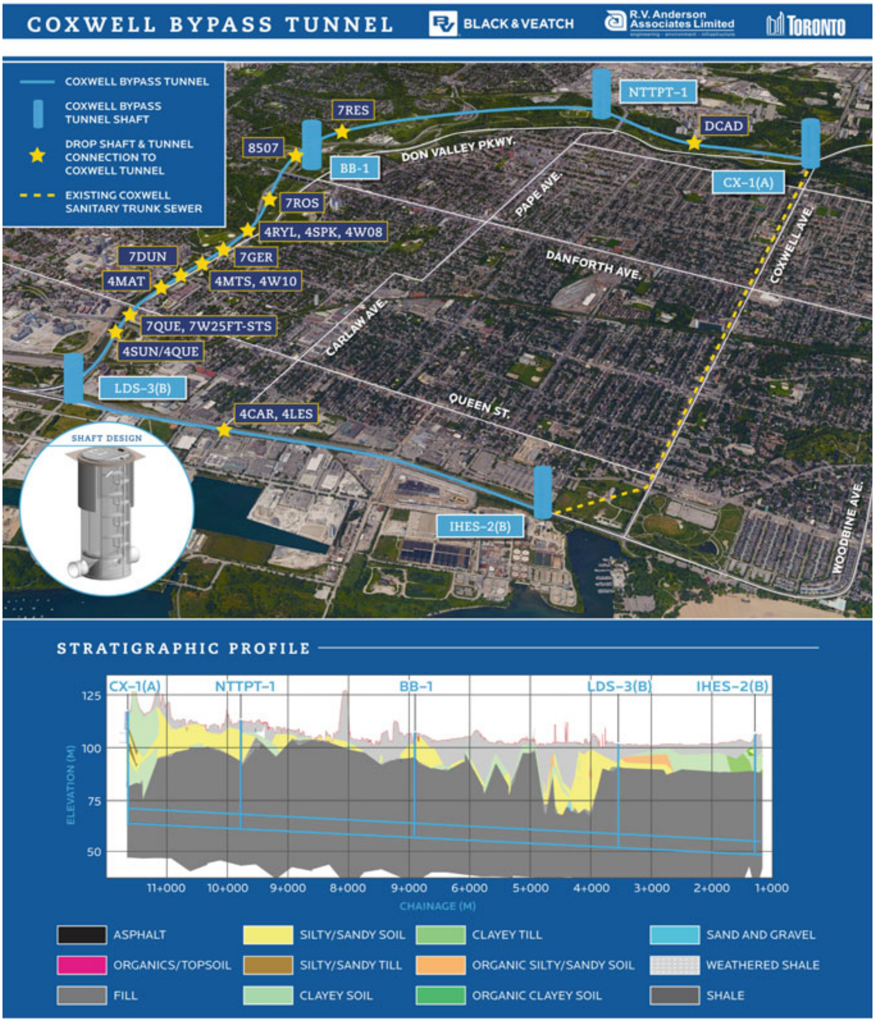

Fig. 1 CBT aerial isometric and stratigraphic profile

a new High-Rate Treatment Facility to treat flows from the tunnel system; and, the Integrated Pumping Station (IPS) at the ABTP which will pump flows from the tunnel system to the new High-Rate Treatment Facility. The DRCW Project is expected to cost more than $3 billion.

2 Design of the Coxwell Bypass Tunnel

2.1 Design Process

The CBT is the first stage of the overall DRCW Project. It will facilitate a bypass of the existing Coxwell Sanitary Trunk Sewer from Cowell Ravine Park north of O'Connor Drive and Coxwell Avenue to the ABTP. Design and construction of this stage will help establish a framework for completing future stages of the DRCW Project.

The CBT is a fully deep-rock tunnel 10.5 km long by 6.3 m finished diameter. It will be constructed with a Tunnel Boring Machine (TBM) in a single pass with a precast concrete tunnel lining (PCTL). The CBT includes five deep-rock WWF storage shafts, 11 deep-rock drop shafts and deaeration/adit tunnels; and, two at-grade sewer connection structures. On average, the five WWF shafts are 20 m inner diameter (ID) by 50 m deep.

The City of Toronto engaged Black & Veatch, in association with R.V. Anderson Associates Limited (BV/RVA) and North Tunnel Constructors (NTC) (comprised of JayDee Canada, Michels Canada, and C&M McNally Tunnel Constructors) to deliver the CBT project. The preliminary design of all five stages of the DRCW Project began in early-2014, and detailed design of the CBT began in late-2015. The CBT was tendered in late-2017 and awarded in early-2018.

2.2 Geotechnical Investigation

A geotechnical field program was undertaken to collect sufficient information to inform detailed design of the overall DRCW Project. This program included drilling over 250 boreholes with a comprehensive sampling/testing schedule to define the subsurface conditions and mitigate risk with the design/construction of the tunnels/shafts. In total, the program had approximately 6.2 km of vertical soil drilling, 3.2 km of vertical deep-rock drilling and 1 km of inclined deep-rock drilling in shale of the Georgian Bay Formation (GBF), and over 150 piezometers and monitoring wells. In addition to routine rock and soil testing, the program included specialized sampling and advanced field tests to define the geotechnical parameters that are critical in the design of tunnels/shafts. Some of the specialized work included in-situ stress measurements and swell testing of the rock.

2.3 Hydraulic Design

A key feature of the Stage 1 CBT and the Stage 4 IHWT is capturing/storing both stormwater and CSO from outfalls along the Don River and the Inner Harbour. The tunnels work together, where the IHWT feeds into the CBT, which will flow through the IPS at ABTP for treatment once the wet weather storm event has subsided.

Detailed transient analysis allowed the number and size of shafts to be significantly optimized from the original conceptual design presented in an Environmental Assessment study leading to the development of the DRCW Project. The CBT and IHWT will provide 78% of the total required storage volume of the DRCW Project, where the shafts are sized to mitigate transient effects from rapid filling of the tunnels.

Most existing sewers will be connected to the CBT using tangential vortex drops to safely convey flows approximately 50 m to tunnel below. Deaeration chambers are based on the tunnel system in Milwaukee Wisconsin and will remove the majority of air entrained by the vortex drops. Smaller diameter adits will connect the deaeration chambers to the tunnel invert. This will direct the remaining air releases to the larger shafts on the tunnel alignment to minimize the risk of geysering. See Fig. 2 for a Computational Fluid Dynamics (CFD) rendering of the interception chamber and tangential vortex drop to the deeper CBT.

Sewers next to large shafts will have their flow conveyed to the CBT through baffle drops within the shafts. The City recognized the importance of physical modelling and prioritized it as a part of the BV/RVA scope. Physical modelling was completed for the four baffle drops on the CBT using 1:10 Froude scale models. These confirmed the designs that were previously developed through Computational Fluid Dynamics and allowed optimisation of benching to prevent material accumulation. See Fig. 3 for a CFD rendering of the baffles drops within a shaft.

The CBT gradient is a consistent 0.15% to maximise sediment transport whilst maintaining sub-critical flow conditions. Sediment will be deposited during large

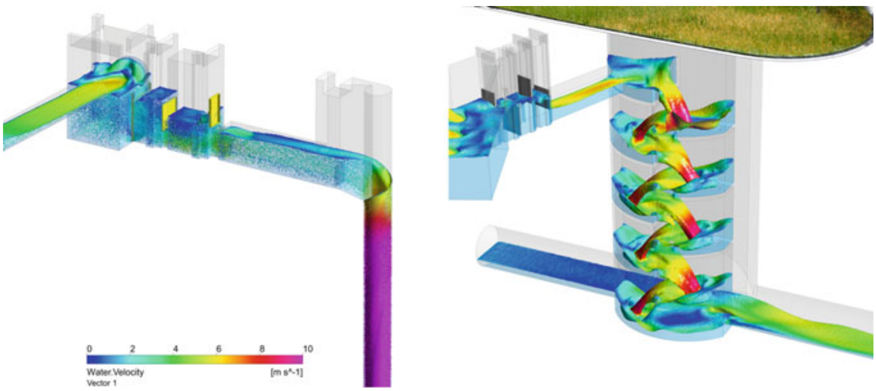

Fig. 2 CFD rendering of interception chamber and tangential vortex drop to CBT (left) and baffle drops within the shaft (right)

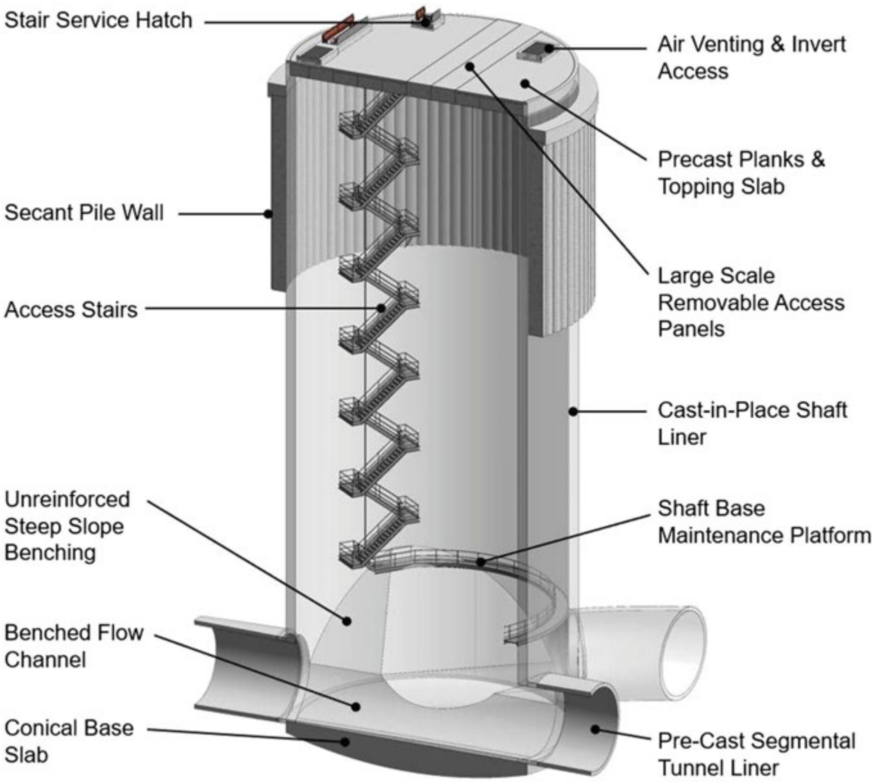

Fig. 3 Structural and operational components of a typical non-baffle shaft

rainfall events that will fill the tunnel, but it will be remobilised during the more numerous low flow events. Analysis of a typical year's rainfall showed that the CBT should be broadly 'self-cleansing' at an average sediment depth in the order of 2%.

2.4 Tunnel Alignment

The CBT is 6.3 m ID and at a consistent 0.15% slope. The total WWF storage capacity of the tunnel and shafts is approximately 500,500 m^3. The lowest tunnel invert has roughly 20 m of soil and 40 m of bedrock cover.

The CBT alignment generally follows the City's right of way to reduce the impact tunnel construction could have on properties. Shaft 1 starts at the ABTP and the tunnel travels south-west along Lake Shore Boulevard East to Shaft 2 at the Keating Railyard. The tunnel crosses under the Don River and two rail corridors before heading north-west along Bayview Avenue towards Shaft 3 where it crosses under the Prince Edward Viaduct bridge. Past Shaft 3, the tunnel sweeps north-east in a near straight-shot towards Shaft 4 at the North Toronto Treatment Plant. Between Shafts 3 and 4, the tunnel crosses under land predominantly managed by the Toronto and Region Conservation Authority (TRCA). The tunnel then heads east towards Shaft 5 at Coxwell Ravine Park.

2.5 Shaft Design

The CBT has five deep-rock shafts strategically placed along the alignment to reduce the impact tunnel construction could have on properties. The range of shaft IDs is 19 m to 22 m, and the average shaft depth is 50 m through both soil and rock profiles.

Several challenging constraints were addressed during detailed design. While the rock behaviour at each shaft site was similar, the soil and above-grade features were highly distinct. For instance, Shaft 2 had a large unbalanced soil load case to address potential future high-rise construction immediately adjacent to the shaft. Shaft 3 is located within the Don River's flood plain, and the design had to account for four metres of hydrostatic uplift acting on the precast concrete roof from a one in 100-year flood load case. As for Shaft 5, due to its depth and ground conditions, BV/RVA required the Contractor to utilize a drilling guidance software that monitors the verticality and alignment of secant piles.

All shafts will have cast-in-place concrete base slabs and walls. The shaft roofs are composite slabs consisting of precast panels topped with 200 mm thick cast-in-place concrete. This solution includes removable panels for maintenance access, and the composite nature simplifies construction by avoiding the erection of elaborate false work inside the shaft. Due to the additional concrete cover, the topping also provides long-term durability during harsh Canadian winters. The base slab reinforcement is hemispherical with bundled 35 M bars in each direction and a maximum concrete slab thickness of 3 m at the centre. This was required to resist a significant hydrostatic uplift force. See Fig. 3 for some of the structural and operational elements of a shaft without baffles inside.

2.6 Precast Concrete Tunnel Lining

The 300 mm thick PCTL is a universal ring assembly comprised of four 67.5° rhomboidal segments and two 45° trapezoidal segments. The segments are 1.8 m in length to facilitate longer excavation cycles and improve production. The PCTL has been designed to facilitate ring build in a turning radius of 197 m, the concrete compressive strength is 50 MPa, and the steel fibers provided a minimum residual flexural strength of 3.4 MPa at L/150 of beam deflection in accordance with ASTM C1609. The gaskets are designed to handle 12 bar of hydrostatic load. Time dependant deformation of GBF shale was not found to increase the PCTL axial force and bending moment.

Fig. 4 Shaft 1 looking up showing secant piles and rock bolts

3 Construction of the Coxwell Bypass Tunnel

The CBT construction commenced in August 2018 with expected completion in 2024. The total capital cost of the project is approximately $400 M excluding taxes. The following project status update is per the end of January 2021.

3.1 Shaft Construction

All shafts utilize secant piles keyed into the shale bedrock for temporary soil support, and welded-wire-mesh complete with rock bolts is used for temporary rock support as required. Shaft 1, 3, 4, and 5 are fully excavated with temporary works installed. Shaft 1 is being used as the main entry/exit shaft for personnel and equipment. Shafts 3 to 5 have base slabs poured. For the final concrete wall lining, Shaft 3 is complete, Shaft 4 is nearing completion, and Shaft 5 will start in March, 2021. See Figs. 4, 5 and 6 for photos of the shafts under construction.

3.2 Starter and Tail Tunnels

The starter/tail tunnels are complete and accommodated the assembly/launch of the tunnel boring machine (TBM). The tail tunnel will facilitate connection of the CBT to the future IPS. NTC extended the length of the starter tunnel to 117 m long to fully assemble the TBM underground without the need for setup change. The tail tunnel is 74 m long. Rock support ribs, bolts, welded-wire-mesh, and 100 mm of shotcrete were used for temporary support, and the base was finished with a mud slab.

Fig. 5 Shaft 3 base slab reinforcement

Fig. 6 Shaft 3 finished cast-in-place concrete and steel formwork supported by strand jacks

Excavation was completed with a road header, top/bottom bench rock support was installed by utilizing an electric drilling unit, and shotcrete was applied by utilizing an automated shotcrete sprayer. See Figs. 7 and 8 for the starter/tail tunnels.

Dust control and timely conveyance of muck away from the excavation face was essential to maintain production. Combination of skid steers and scoop trams were used to carry the muck to the centre of Shaft 1 where the excavated material were lifted using a muck box. In anticipation of launching the TBM, a thrust frame was installed behind the trailing shield, concrete eco-blocks were placed throughout the starter tunnel, and steel rails were mounted to the blocks in order to accommodate the TBM gantries during the launch phase.

Fig. 7 Looking down the tail tunnel from within Shaft 1

Fig. 8 Looking down the starter tunnel prior to TBM assembly

3.3 Excavated Tunnel

NTC procured a new convertible TBM, named Donnie, to complete excavation of the CBT. The TBM is designed to operate in open mode during rock excavation and will utilize a muck ring and belt conveyor to remove rock from the excavation chamber. The TBM is also capable of operating in closed mode with excavation controlled through the earth pressure balance method up to six bar design pressure. The earth pressure balance mode utilizes a continuous flighted auger screw conveyor to remove muck from the excavation chamber. TBM manufacturing was completed by Lovsuns, and all components were delivered to Shaft 1. Final testing/commissioning of the TBM was completed in early 2020 and the TBM pushed off in March 2020. Per the end of January 2021, the TBM has advanced 4.1 of 10.5 km (39%). See Fig. 9 for the TBM at the Lovsuns manufacturing facility assembled for commissioning prior to delivery.

Fig. 9 TBM at Lovsuns manufacturing facility

The PCTL is being manufactured by CSI Tunnel Systems in a joint venture with Forterra Precast—in a local facility in Whitby, ON. PCTL manufacturing is ongoing and delivery of rings commenced in February 2020. Rubber Tired Vehicles (RTVs) are being utilized to transport precast concrete segmental linings to the TBM heading. This will be the first project in Ontario that utilizes RTVs in lieu of conventional Loci's. See Fig. 10 for an RTV transporting the PCTL to the tunnel heading, and see Fig. 11 for a section of the tunnel with multiple completed PCTL rings.

To transport muck generated during tunnelling operations, NTC procured a continuous conveyor which consists of multiple components including a horizontal discharge conveyor to provide flexibility for muck handling in the long and narrow Shaft 1 site, an inclined conveyor, a vertical shaft conveyor; and, a tunnel conveyor system. The entire generated muck along the length of the project will be transported to the Shaft 1 site which makes the design and operation of the conveyor system

Fig. 10 RTV transporting PCTL to the tunnel heading

Fig. 11 Completed PCTL rings

Fig. 12 Aerial of the vertical shaft conveyor and muck storage at Shaft 1

quite challenging. See Fig. 12 for an aerial of the vertical shaft conveyor and muck storage at Shaft 1.

3.4 *Geotechnical Monitoring*

Time dependent deformation of the GBF shale, a well-researched behavior, was considered during detailed design through in-situ stress tests, swell tests, and numerical modelling. Swelling of the shale is stress-dependent and triggered immediately upon excavation. The stress field effects of a 22 m OD excavation can be measured several shaft diameters away.

During construction, four 10 m-long borehole extensometers were installed in Shaft 3. This will help validate previous design assumptions, refine shaft lining designs, and improve the overall schedule, should rebar reinforcement be reduced based on extensometer observations. The length of the extensometers were as long as practical to capture the deformation, and instrument heads were surveyed regularly as an additional check. Load cells were also installed to measure radial pressure between the final lining and the bedrock walls. Monitoring of the extensometers began at the end of July 2019 and Shaft 3 excavation was completed one month later.

4 Closure

Planning and executing the DRCW Project is a landmark achievement for the City of Toronto. It demonstrates the City's commitment to eliminate CSOs, improve aquatic habitat in Lake Ontario, and de-list Toronto's waterfront as an Area of Concern.

Acknowledgements The authors would like to acknowledge all the dedicated people who are working hard to deliver this project.

References

1. City of Toronto (2021) The City's wet weather flow master plan. https://www.toronto.ca/services-payments/water-environment/managing-rain-melted-snow/the-citys-wet-weather-flow-master-plan/. Accessed 28 Apr 2021
2. MMM Group Limited (2012) Don River and Central Waterfront Project–Municipal Class EA–Environmental Study Report, Prepared for the City of Toronto