1 INTRODUCTION

The City of Toronto is Canada’s largest municipality. After several years with no tunneling activity in the downtown core, tunnel boring machines have once again come to life. Two recently completed projects include:

- The environmentally award winning chilled water network expansion for Enwave Energy Corporation with C and M McNally Engineering Corporation as the Contractor; and
- The cross-town high voltage primary network reinforcement for Hydro One with DIBCO Underground Ltd as the Contractor.

The following drawing shows the tunnel locations.
2 THE ENWAVE PROJECT

Enwave Energy Corporation has recently completed a major expansion of its chilled water network in downtown Toronto. Enwave is one of the largest District Energy providers in North America. Over the last 25 years they have evolved and grown from the Toronto District Heating Corporation and currently provide chilled water and steam to over 140 buildings in Toronto via 40 kilometres of underground pipes that cover most of the City’s downtown core.

The previously constructed Deep Lake Water Cooling infrastructure comprised three 5-kilometre-long pipelines supplying water from a depth of 83 metres at the bottom of Lake Ontario to a new Chilled Water Plant at Rees Street and Lakeshore Boulevard West in downtown Toronto. Enwave’s cooling source is water from the bottom of Lake Ontario where it is permanently 4 degrees celsius. Enwave uses this cold energy to cool buildings in downtown Toronto by passing it through central heat exchangers to provide chilled water supply to many of Toronto’s high rise office towers for air conditioning. The chilled water is conveyed in a looped supply and return system comprising twin 1200 mm diameter cement lined steel pipes within 3.5 m internal diameter tunnels with access for the Owner’s maintenance forces. A typical tunnel cross-section is shown below.

The recent expansion comprised the extension of the chilled water supply, into Toronto’s downtown core. The expansion was completed over a five-year period, commencing with the preparation of pre-designs in 2003. The pre-design work included an evaluation of open cut and tunnel routing options, as well as an evaluation of the chilled water piping materials and configuration of the pipes within the tunnels.

The MMM Group Limited was retained in 2003 by Enwave as the Engineer to undertake the initial evaluation, subsequent detailed design and contract administration. When it was confirmed that tunneling was the preferred alternative, C&M McNally Engineering Corporation from Burlington, Ontario were retained to work on a uniquely collaborative basis with the Owner and Engineer throughout the design and implementation stages. The initial construction contract was unit price and was awarded on the basis of competitive “indicative bids” prior to the detailed design having been completed. Subsequent phases were negotiated unit price contracts. The southern portion of Toronto’s downtown core is underlain by shale at a relatively shallow depth (±8 to 12 metres). The depth to the top of rock increased to ±18 metres at the northerly limits of the project in the vicinity of Bay and Gerrard Streets. The entire 5.8 kilometres of tunnels were driven through rock.
2.1 DESIGN CHALLENGES

The main design challenges included:

- **Locating Tunnel Boring Machine (TBM) Construction Shafts**

  Locating TBM construction shafts to minimize disruption to vehicular and pedestrian traffic and to existing utilities was generally achieved by locating shafts in the curb lanes, and on the far side of intersections on one-way streets. This provided traffic with the opportunity to merge after the intersection.

  For the TBM shaft, near the northerly limits of the project at the Hayter and Laplante intersection, a location could not be found on the main street without severe disruption to traffic. Consequently a side street adjacent to the main street was utilized. This location, with the associated tunnel routing, is shown on the following drawing.

  ![ENTRY/EXIT SHAFT AT HAYTER AND LAPLANTE](image)

  This location was also utilized for multiple TBM drives, which included:

  - Entry of the 3.55m OD TBM which was launched to the east and south;
  - Removal of the 3.55m OD TBM which had entered the shaft from the south and east;
  - Entry of the 3.00m OD TBM which was launched to the east and north from within the 3.55m tunnel and formed a wye configuration in the tunnel;
  - Removal of the 3.00m OD TBM which was then turned 180 degrees and re-launched to mine to the west; and
  - Final removal of the 3.00m OD TBM

  In large part due to the contractor’s ingenuity and the cooperative nature between the Owner, Contractor and Engineer, the Contractor was able to mine four tunnels with only four entry / exit shafts. Furthermore, two additional tunnels were mined from the Hayter / Laplante shaft.

- **Tunneling in the Toronto Shales**

  Construction challenges associated with tunneling in Toronto’s shale include:

  - the weathering and associated spalling that occurs after the shale is exposed;
  - the stress relief and associated rock squeeze that occurs; and
  - the potential for unexpected rock fracture zones.
The weathering and rock fracture zones were successfully addressed by C&M McNally’s open-faced, rock TBM’s, and their patented roof support system and no delays were encountered. McNally’s roof support system comprises a series of staggered wooden lathes that are extruded from the TBM’s top support, as the machine moves forward. The lathes are held in place by steel ribs anchored to the rock. This system proved to be much more effective than the traditional steel mesh anchored to the tunnel roof. The rock squeeze was successfully mitigated due to the lag time between the mining and the construction of the cast-in-place benching and the final cast-in-place liner in the tunnels. This lag allowed time for the relief of rock stresses. The movement was monitored during construction to confirm that the rock stresses had been adequately relieved.

- **Tunnel Access and Egress Requirements**

Due to the success in being able to reduce the number of intermediate TBM shafts, particular attention was required to ensure that the Owner’s operations personnel had appropriate ongoing access to the tunnels. Access was required not only for future maintenance, but also for the installation of future chilled water service connections, as well as for emergency evacuation purposes. Discussions were held with the Owner’s operations staff and their Health and Safety representatives. It was determined that a maximum in-tunnel distance in the order of 250m was appropriate. Consequently intermediate tunnel access was provided, on average every 500 meters.

The intermediate access chambers generally comprised 1200mm diameter I.D. vertical maintenance holes. They were drilled from the surface with 1800mm corrugated steel pipe (CSP) liners in the overburden, down to the top of rock. Rock drilling then completed the vertical access down to the tunnel obvert elevation.

- **Ventilation and Lighting Considerations**

An analysis of air circulation within the tunnels was undertaken to determine the ventilation requirements for the Owner's Operations and Maintenance personnel. It was determined that the use of portable fans would provide the required ventilation, while avoiding ongoing maintenance issues associated with a permanently installed ventilation system. Protocols were developed for the removal of end-of-tunnel hatches and the installation of portable fans prior to tunnel entry by the Owner’s Operations and Maintenance personnel. For lighting, the Owner was concerned that it not become an ongoing maintenance issue. The final choice was a light emitting diode (LED) system that provides a low, but adequate, level of lighting.

### 2.2 CONSTRUCTION CHALLENGES

The main construction challenges included:

- **Turning 90 Degrees Within 20-metre Road Allowances**

Traditional tunnel design requires that significant changes in the horizontal alignment e.g. 90 degree turns within public rights of way, be accomplished within a shaft. Due to the significant costs and difficulty locating intermediate shafts that are only required to address a change in the tunnel alignment, working within the collaborative nature of the project, the contractor was able to maneuver the TBM and trailing gear around several 90 degree bends without intermediate shafts.

The sharp change in direction required the TBM to make tight “sweep” bends between the outside of the intersecting rights of way. This was achieved by a series of incremental chords. Each chord comprised mining a short distance, hand mining the outside curve at the front of the TBM for a short distance, jacking the TBM into the hand mined cut-out, and then
repeating the cycle. Although each 90 degree bend was labour intensive, the overall project costs were lower than if additional shafts had been used. Also, disruption to pedestrian and vehicular traffic at the surface and disruption to utilities were also avoided. The minimum TBM turning radius that was accomplished for part of the turn using this approach, was 36m. An example of such a turn is shown below.

- **Reducing the Number of TBM Exit Shafts**

  No exclusive TBM exit shafts were required due to C&M McNally’s use of two Robbins Main Beam TBMs (3.5m OD and 3.0m OD) which had the capability to be backed out through the tunnel to re-utilize the entry shaft for TBM removal. This reduced the number of exit shafts that would otherwise have been required by six.

- **Internal Piping Configuration**

  The installation of twin 1200mm diameter cement mortar lined steel pipes within 3.5m OD tunnels required the contractor to establish the optimum pipe lengths and the ability to lower the pipes vertically into the construction shafts and then turn them to horizontal in the tunnel.

  As pipe joints were welded, and mortared insitu i.e. in the tunnels, access for welders was also a major consideration.

  Particular attention was required by the contractor to the piping configuration at two locations:
• The start of construction where the existing 1200mm diameter pipes were vertically stacked and had to transition to being horizontally adjacent and;
• At the intersections of two 3.5m tunnels with interconnecting twin 1200mm pipes.

A series of specially fabricated fittings were used to accomplish the change from vertical to horizontal stacking while the interconnections were achieved by matching the invert of the upper tunnel with the obvert of the lower tunnel, breaking out a rock cavern, providing additional concrete support and fabricating and welding a series of 1200-mm-diameter wyes and bends to connect each pair of chilled water supply and return pipes;

• **Installation of Multiple Chilled Water Building Service Connections**

Configuring and executing the chilled water service connections from the tunnels to the buildings. For vertical connections, this was achieved by pre-drilling over the proposed tunnel alignment and then mining the tunnel through the pre-drilled location. A cap and lag tunnel was mined from the building to the pre-installed vertical riser to complete the connection. For the near horizontal or shallow angle connections, the connection was generally drilled from the lower level in the building's underground parking, to the tunnel obvert within the public right of way, after the tunnel had been mined. This required special attention to the size and weight of the directional drilling equipment to ensure it could be successfully maneuvered within each building’s underground parking structure.

The chilled water supply and return building connections required careful coordination with the property managers, utility companies and the Owner, to minimize disruption to the tenants of the existing high rise towers.

• **Collaborative Approach**

The demand for chilled water connections from the owners and property managers in Toronto’s downtown high rise office towers exceeded the Owner’s initial projections. Consequently, there were a series of very tight deadlines to ensure that chilled water was provided to customers on schedule. Great care was taken to ensure that there would be no unscheduled service interruptions as the highest reliability was a vital part of the Owner’s service.

The overall success of the project was achieved in large part because of the collaborative approach that was maintained throughout the project between Owner, Contractor and Engineer. Weekly team meetings focused on design and construction issues and all issues were resolved amicably with the overall success of the project being the primary goal for all parties.

**3.0 THE HYDRO ONE PROJECT**

In the Province of Ontario, Hydro One is responsible for the distribution of primary (high voltage) power.

In order to improve the security of Hydro One’s 115 KV primary electrical supply in downtown Toronto, Hydro One determined that a link was required between two of their main Transformer Stations. They conducted an Environmental Assessment which concluded that, in order to minimize disruption in the downtown core during construction, the link was best constructed within a tunnel.

A Route Selection Study was undertaken by the Engineer to determine the optimal routing and construction methodology to connect the Esplanade Transformer Station and the John Street
Transformer Station. Detailed design was then completed and included procurement of the high voltage cables.

The as-constructed tunnel was 3.305 metres OD, with a 280-mm-thick cast-in-place liner. The tunnel was 2.1 kilometres long. The tunnel was constructed in the Toronto shale with an invert approximately 30 metres below the surface. The original design included one entry/exit shaft. However, Dibco Underground Ltd. from Bolton, Ontario, the successful tunneling contractor, elected to also construct a separate exit shaft. They utilized a Komatsu rock TBM.

The tunnel routing was primarily under the City's busy Front Street (east and west of Yonge Street). Crossings under, and parallel to, an existing 1,200-mm watermain, also in tunnel, and under a portion of the Toronto Transit Commission's Yonge-University subway line were also required. The tunnel alignment successfully included two 90º bends within 20-metre rights of way, without the need for intermediate shafts. Dibco used a similar approach to C & M McNally to successfully achieve their tight turns.

Although Hydro One required an additional 115 KV link, the cabling was designed to be upgraded in the future to carry 230 KV.

The supply and installation of the 230-kv XLPE high voltage cables was undertaken as a separate contract by Arno from Quebec with cables procured from Silec in France.

The tunnel cross-section allowed for the installation of two primary high voltage circuits now and two additional circuits in the future. Each circuit included three high voltage cables. The tunnel invert included benching for a drainage channel. Provision was also made to install utility ducts in the tunnel invert.

The typical Hydro One tunnel cross section is shown below.

![Typical 3.304M Hydro One Tunnel Diagram]
The Hydro One tunnel civil work was completed in 2007 and the project was successfully commissioned with final cable testing in the summer 2008.

4.0 CONCLUSIONS

Both projects confirmed the benefits of a cooperative spirit between Owners, Contractors and Engineers. They also confirmed that a willingness to push the envelope on “normal” tunneling construction techniques can prove to be beneficial e.g. turning 90 degrees within 20m wide rights-of-way.

5.0 KEY PERSONNEL/ACKNOWLEDGEMENTS

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