EBP-TBM tunneling versus Microtunneling – pros and cons to select the right technology

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ABSTRACT

Mechanized tunneling has been rapidly increasing its popularity all over Canada and, in particular, in the Greater Toronto Area (GTA), where the intense urbanization of the last two decades limits the other technologies applicability. In the past, most of the municipal infrastructure tunnels including sewage trunk sewers were built by conventional methods and open cuts requiring significant disturbance to the areas of construction. These methods were chosen as projects were normally located within vacant lands and existing corridors. However, conventional methods and open cuts often associate with multiple impacts including and not limited to dewatering and discharge, property acquisitions, traffic disturbance, significant noise and vibration issues.

RÉSUMÉ

La construction de tunnels mécanisés a rapidement gagné en popularité partout au Canada et, en particulier, dans la région du grand Toronto (RGT), où l'urbanisation intense des deux dernières décennies limite l'applicabilité des autres technologies. Dans le passé, la plupart des tunnels municipaux d'infrastructure, y compris les égouts collecteurs d'eaux usées, étaient construits selon des méthodes conventionnelles et les coupes à ciel ouvert exigeaient des perturbations importantes dans les zones de construction. Ces méthodes ont été choisies, car les projets étaient normalement situés dans des terrains vacants et des corridors existants. Cependant, les méthodes conventionnelles et les coupes ouvertes s'associent souvent à de multiples impacts, y compris, sans s'y limiter, l'assèchement et le déversement, les acquisitions de propriétés, les perturbations du trafic, les problèmes importants de bruit et de vibration.

1 INTRODUCTION

The Regional Municipality of York (York Region), north of the City of Toronto stretches to Lake Simcoe across an area of 1,776 square kilometers (686 square miles). With a population of 1,156,186 residents, it is the sixth-largest municipality in Canada.

York Region together with Peel Region in the west and Durham Region in the east forms the Greater Toronto Area (GTA) surrounding the largest city in Canada, Toronto.

Prior to 2006, York Region constructed most of its infrastructure via open cuts and conventional tunneling. Starting from about 2007 this approach changed as York Region’s urbanization triggered the application of modern tunneling techniques in order to minimize social impacts and impacts to the existing infrastructure. As such, the need to use trenchless technologies including earth pressure tunnel boring machines (EPB TBM) and microtunneling became increasingly necessary.

York Region demonstrates the leading edge innovative approach for underground infrastructure projects by selecting construction methodology that would limit general disruption and direct surface impacts.

2 HISTORICAL TUNNELLING PROJECTS IN THE GREATER TORONTO AREA (GTA)

There are a number of tunnelling projects in the GTA over the last ten years which need to be mentioned as they provide a great reference for future projects including selection of an appropriate tunnelling methodology, including various tunneling (EPB-TBM) and microtunneling in similar geological-geotechnical environment.

2.1 West Trunk Sewer, Peel Region,

As a result of this project, approximately 13,600 m of 3 m diameter sanitary sewer were constructed in 2017 by tunnelling methods. The project was tendered as two separate contracts: Contract 1 with predominant excavation within the bedrock and Contract 2 with tunneling mostly through soft grounds including some bedrocks due to several buried valleys within the tunnel alignment. Tunnel depth varied between 12 m to 56 m below ground surface (bgs) within the Queenston and Georgian Bay Shales. During investigative drilling, natural gas was encountered in 8 of 38 boreholes in the Georgian Bay Shale with maximum pressure of 520 kPa and maximum flow rate of 0.8 L/sec.

The geological and other constraints like fracture zones, loose soils, buried valleys, high groundwater pressures, gassy conditions and lack of land available for construction compounds due to very urbanized areas made the selection of tunneling methodology as the only one feasible. There were two different types of tunneling utilized on each Contract, where Contract 1 was carried out with an open face TBM and Contract 2 was built by a closed phase machine (EPB TBM).

2.2 Herridge Feedermain, Peel Region

The Herridge Feedermain, about 6,500 m long pipe of 3 m diameter to convey portable water was built between 2008 and 2010. The feedermain connects the Lorne Water Treatment Plant and the Herridge Reservoir and pumping station.

Approximately 90% of the feedermain was constructed by tunnelling with the remainder by an open cut. The tunneling portion was managed via three separate contracts, where each one was constructed by an open face hard rock TBM.

Contract 1: approximately 1,420 m long tunnel through the bedrocks of fresh, grey Georgian Bay Shale with relatively strong limestone and siltstone interbeds, which were about 100 mm thick and generally discontinuous. During construction, groundwater infiltration was controlled by gravity drainages and sump pumping from mining shafts. The tunnel's crown was supported by longitudinal wood lagging (steel channels and wood planks) spaced about 0.9 m apart. There were joints and small wedge failures in the lower tunnel's portions observed and managed.

Contract 2: approximately 1,780 m long through the bedrocks supported similar to Contract 1 by longitudinal wood lagging.

Contract 3: about 400 m long tunnel through the bedrocks similar to other two Contracts was supported by steel ribs at 1.2 m spacing and lagging. Groundwater infiltration was controlled by sump-pumping and direct pumping. Geological constraints due to relatively stronger interbedding layers of limestone and siltstone ranging in thickness from 100 mm to 500 mm were encountered.

2.3 Hanlan Feedermain, Peel Region

The Hanlan Feedermain approximately 2,870 m long 3.0 m diameter tunnel through the bedrocks of Georgian Bay Shale Formation was constructed by TBM in the early 1990s. The tunnel's crown was supported by longitudinal steel channels and wire mesh.

In addition to the well-known geological conditions there were two areas where extremely challenging ground movements encountered. As such, the tunnel's intersection with 400 mm watermain, storm and sanitary sewer pipes caused ground's movements above (2 -3 m above) the excavated perimeter triggering groundwater inflow into the tunnel at about 50 to 70 L/ min. This crown's instability issue occurred due to artificial fills including bedding materials, grouting and infill (U-fill) encountered as part of the existing pipes (watermain, storm and sewer). This risk was not properly assessed during design. If such detailed assessment would be completed ahead of the tunneling; a closed-mode tunneling option (EPB TBM) or other soil improvement techniques could be selected. .

2.4 Southeast Collector Trunk Sewer, York Region

The tunnel of about 15 km long and 3 m diameter was constructed between 2011 and 2015. Tunnel's depth varied from 8 m to 45 m bgs through the most recent geological formation of the last glaciation period consisting of glacial till, sands, silts and softer clays. There were 15 shafts built to facilitate construction and future long-term operation and maintenance. .

Tunneling was completed by four York Region's pre-owned EPB TBMs of 3.6 m excavation diameter with 200 mm thick concrete precast liner. Grouting of the annular space was completed with a two-component grout mixture pumped from the tail shield of the EPB TBM behind the front row segments.

2.5 Heart Lake Road Tunnel, Peel Region

The Heart Lake Road Trunk Storm Sewer conveying runoff under the major GTA's highway 401 about 1,470 m long was constructed between 1974 and 1975. This tunnel was built about 1.5 to 10 m deep through dark grey, soft and highly fissile shale and harder bedrocks of Georgian Bay Shale Formation.

This tunnel was constructed using three different tunneling methodology, such as: TBM, drill and blast, and an open cut. The TBM section was of 2.74 m and a drill and blast section was of 3.05 m finished sewer diameter respectively. A 300 mm thick cast-in-place concrete lining was installed in these two sections. This project is interesting due to time-dependent deformation start taking place in the Georgian Bay Shale bedrocks, which affected the tunnel and became a subject for several decades of research on the GTA's bedrocks' squeezing effect.

2.6 9th Line/16th Ave Trunk Sewer, York Region

Construction of this 15 km long tunnel between 2000 and 2007 has been associated with many challenges including tunneling through glacial deposits under up to 5 bar high groundwater pressures.

The project was procured by York Region as a design-build contract. The tunnel was built via two passes by an open face TBM including ribs and lagging with active dewatering as a temporary support first pass followed by a cast-in-place concrete installation as a second pass.

A significant challenge on the project was due to almost 50 m bgs depths of the alignment passing through the water bearing layer (one of the regional aquifer).inter-layered by glacial tills. Groundwater levels along the entire alignment were generally high often at artesian up to 6 m above ground surface, which required significant active dewatering effort. As such, groundwater removals over entire tunneling (time lag between two passes) were enormous reaching to 25,000 l/min sustained for about 5 years of dewatering.

As a result, groundwater drawdown extended greater than 5 km away from the tunnel alignment lowering groundwater levels in the residential and York Region supply wells and demanding York Region to mitigate multiple impacts. Due to some visible surficial impacts like dewatering discharge directly to the nearest creek, tunneling was put on hold by the Ministry of Environment and Climate Change (MOECC) until an environmental mitigation plan was developed and approved. Another challenge was due to a Permit to Take Water's approval for construction dewatering was significantly delayed by MOECC, which in turn delayed the project's commissioning for almost two years.

2.7 Ninth Line Stouffville Extension, York Region

The 9th Line trunk sewer extension to the north was constructed between 2003 and 2006 in three sections of 5.75 km main branch, 1.5 km east branch; and 2.3 km portion connecting main branch to the pumping station, which was also decommissioned as part of this project.

Almost the entire alignment was constructed by an open cut due to relatively shallow depths.

Tunneling section was passing through cohesive glacial till and dense water-bearing granular soils. Active dewatering was required to facilitate shaft and tunnel construction. Approximately 50 percent of the tunnel was constructed using pipe jacking technique followed by 1.5 m diameter TBM. There were multiple challenges caused by a need of active dewatering and by the presence of boulders and cobbles.

The remaining portion was built via conventional tunneling by 2.7 m diameter non-pressurized TBM with steel ribs and temporary lagging liner prior to the cast-in-place permanent concrete liner being installed.

2.8 19th Avenue Interceptor Sewer, York Region

This project was built between 2007 and 2008 via two tunnelling portions of about 2.8 m internal diameter managed by the two EPB TBMs operated in pressurized mode throughout entire tunneling. To connect the new tunnel with the rest of York Region sanitary system, this contract also included an open cut portion in the south end of the alignment.

This project was majorly constructed through two types of soil: a till unit comprised of cohesive and non-cohesive soils consisting of sand, silt and clay materials with traces of gravel and cobbles and boulders; and a sand unit comprised of dense to very dense sand to silt deposits of major regional aquifer. The till unit providing a capping layer to the underneath aquifer thinned out almost midway of the tunneling section outcropping the aquifer unit to the ground surface. This situation created a major challenge of dealing with high groundwater pressures of more than 6 m above ground surface and tunneling under the existing creek with minimum (1 – 1.5 m) of ground cover, which caused few frack-out issues.

2.9 Bathurst/Langstaff Trunk Sewer, York Region

This project procured as design–build was implemented through design and construction of two sanitary trunk sewers in four tunnel drives. It utilized EPB TBM technology with a precast concrete segmental liner of an 2.74m internal diameter.

Once the machine finished the southern drive in January 2007 it was refurbished and returned to the shaft to launch to the north. The west-east tunneling portion was about 3,648 m long.

The tunnels varied from 6 m to 33 m in depth and were constructed through cohesive glacial till, hard silty clay, fine granular soils with groundwater pressures of about 1.5 bar encountered during construction.

There was one major accident where more than 1,000 m3 of water, fine sand, and silt flowed into the tunnel causing a large sink hole on the ground surface. This sink hole triggered a major failure of the adjacent regional road including utility pipes, which in turn caused another project's delay in order to acquire a new PTTW allowing higher dewatering rates. The tunnel alignment at this location was about 22 m bgs through major aquifer unit (1.5 Bar groundwater pressure), which conditions were significantly underestimated through the project's field investigations completed during design.

Due to this accident and to recover some time, the project was modified by launching the second EPB TBM from the downstream shaft to tunnel toward the affected area. Concurrently, a secant pile shaft was constructed at the affected area, and portions of the berried TBM were recovered. However, the tunnel within the affected area was completely rebuilt due to the non-recoverable damages occurred due to the accident.

3 WEST VAUGHAN SEWAGE SERVICING PROJECT TUNNELING METHOD SELECTION

3.1 Project Description and environmental constraints

York Region completed the West Vaughan Sewage Servicing (WVSS) conceptual design identifying a need for about 14km trunk sewer (Figure 1) connecting the Kleinburg Water Resource Recovery Facility (WRRF) with the Humber Sewage Pumping Station (SPS) including its expansion from 1700 L/s to 2400 L/s. A conceptual design was prepared in 2014 outlining the design requirements and specific criteria for the proposed West Vaughan Sewage System Project.

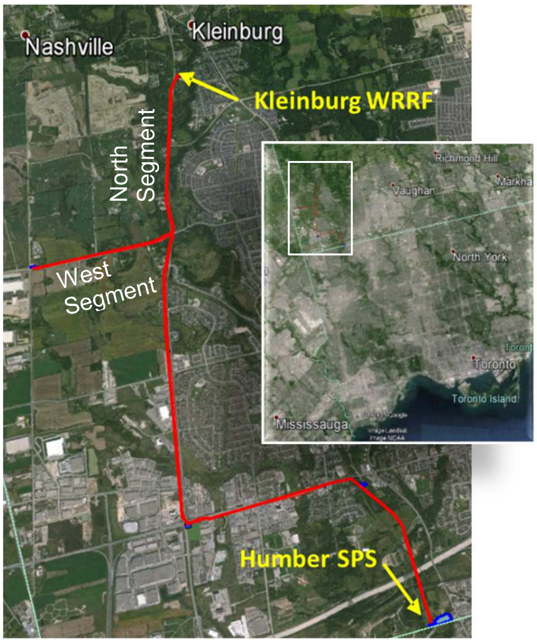

Figure 1. West Vaughan Sewage Servicing Project

The WVSSP's design was procured by York Region selecting Delcan-Geodata Joint Venture as a successful bidder. As part of the preliminary design stage, a detailed analysis was completed in order to minimize environmental impacts, and to review the construction methodology by highlighting risks and benefits of different tunneling options.

A comparison between the conceptual design and other construction alternatives proposed by the Joint Venture was completed in order to move the project into its next design's phase. This comparison was based on a multi-criteria analysis focused on the key elements like technical feasibility in given geological condition, social/environmental impacts, cost and schedule.

3.2 Geological setting

Figure 2 provides schematic views of the geological profiles developed from the preliminary geological interpretation along the North & West tunnel segments.

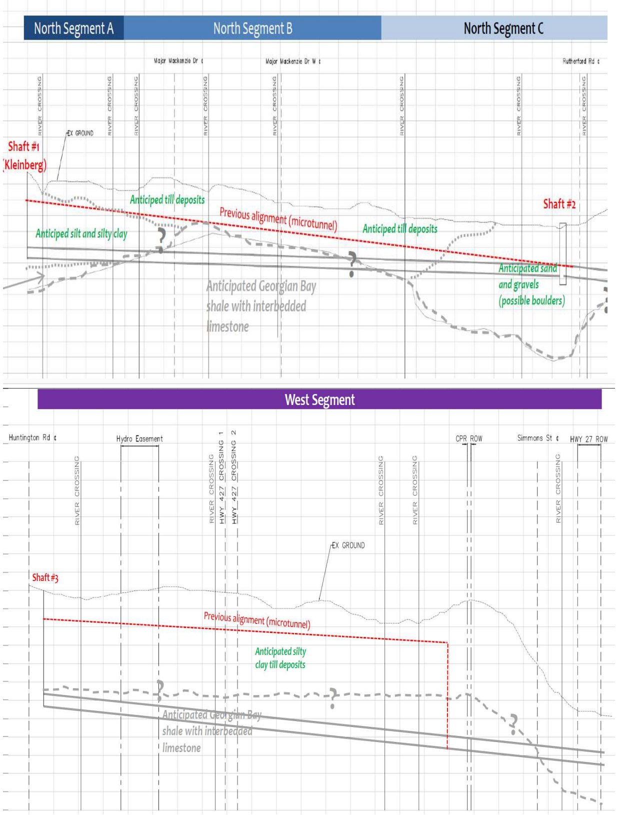

Figure 2. North & West Segments Preliminary Profiles

3.2.1 North Segment

Based on the preliminary geological/geotechnical information, the North segment can be subdivided into three portions A, B, C (Figure 2) where soil characteristics are similar.

North Segment A is about 500 m long immediately south of the Kleinburg WRRF, where till deposits overlay silty clay and silt deposits. Sands with artesian groundwater condition at about 150 m above sea level (asl) just above the bedrocks of Georgian Bay shales (140m asl to 147m asl) were identified.

North Segment B is located further south with the bedrock elevations expected to rise above 155m asl for about next 1000 m south. The bedrocks are overlain by till deposits up to the ground surface. Groundwater levels are relatively shallow at about 0.2m – 0.4m bgs. .

North Segment C is represented by a buried valley where the bedrocks elevations drop to below 120m asl (about 45 m bgs). The buried valley is filled with sand and gravels, which are hydraulically conductive and historically associated with the Scarborough Formation (aquifer unit).

3.2.2 West Segment

This segment (Figure 2), as per preliminary geological investigations is comprised from silty clay till deposits varied in thickness from 22 to 25 m (elevations 165 to 170m asl). The till deposits characterized by very low permeability are considered as an aquitard. The bedrocks of Georgian Bay Shale formation underlay the till unit.
Upon completion of the detailed geological/geotechnical and hydrogeological investigations the 3D Geological Model was developed for the entire alignment (Figure 3). .

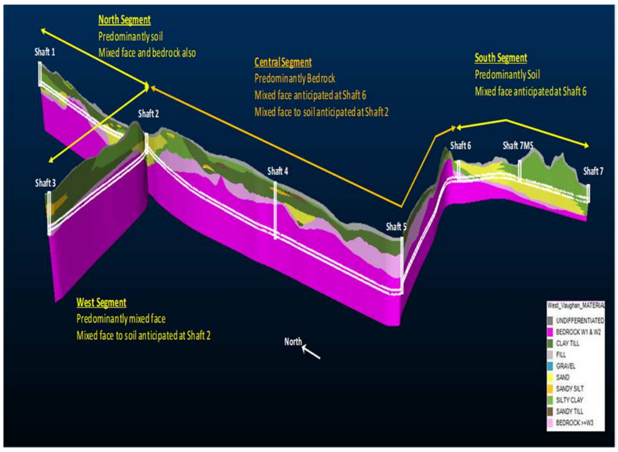

Figure 3. WVSS 3D Geological-Geotechnical Model

3.3 WVSS Conceptual Design and Design

The four different construction methodologies were analyzed as part of the conceptual design by using evaluation criteria such as cost, pipe durability, surface disturbance and environmental impact, as follows:

1. Open cut for West Segment only
2. Horizontal Directional Drilling (HDD) only for the North Segment
3. Microtunneling for both West & North Segments
4. Tunnel boring machine (TBM) only for the North Segment

Through the evaluation, the North Segment 825 mm diameter pipe's most appropriate method was selected as microtunneling feasible to tunnel through varied soils without advanced dewatering, which reduces impact to surface water features. The West Segment 975 mm diameter pipe's recommended construction methodology was selected as a combination of an Open Cut and Microtunneling.

Upon completion of the detailed geotechnical investigation during design, the following construction considerations were additionally analyzed:

- Construction of a launching shaft about 30 m deep locked in bedrocks at Huntington Rd;.
- Lowering the West Segment alignment for deep tunneling through competent bedrocks from the intersection of highway 27 and Rutherford Rd toward the Huntington Rd.shaft;.
- Lowering the North Segment C for deep tunneling through competent bedrocks and soft upper deposits along Hwy 27;.

- Final extraction of the EPB-TBM machine at the Kleinburg WRRF extraction shaft.

Due to the changes in the project's financing and implementation timelines, construction sequencing and tunnel profile required some adjustments, which were captured through field investigations and reflected in the design.

3.4 Microtunneling versus EPB-TBM

3.4.1 Pros and Cons

A larger launching shaft in the intersection of Rutherford Road and Highway 27 required more land and a better location than was proposed at conceptual design, As such, the shaft was moved within the west north corner to the public land owned by the low tier York Region's Town municipality.

In order to avoid a large drop structure in the intersection of Highway 27 and Rutherford Rd, the sewer profile was generally lowered. This should provide a thicker protective layer between the tunnel obvert and river channels at each river crossing and reduce potential risks for frack-out.

In addition, the frack-out potential reduces further with the switch from microtunneling construction method generating significantly higher pressures to EPB-TBM with the controlled pressures.

In fact, microtunneling construction requires application of a slurry-mix under high pressure (up to 15 bar) to facilitate and support excavation, where the risk of the higher not fully controlled pressures from inside out is significant. This high pressure can impact the nearby infrastructures and utilities by potentially misplacing and damaging them, which can be severe.

Lowering the tunnel profile with the application of EPB-TBM significantly reduces the number of shafts (launching and extraction) from planned 23 to 3 along the West and North Segments. The deeper West Segment's alignment also reduces potential interference with the proposed Enbridge's major pipeline and Hwy 427 planned extension.

EPB-TBM tunneling methodology reduces surficial disturbance in general and therefore reduces a number of permits and approvals required for construction. This in turn reduces impacts to roads closure, traffic management and impacts from dust, pollution, noise and vibration.

3.4.2 Cost comparison EPB-TBM and Microtunnel

The linear cost (cost per meter) of EPB-TBM tunneling is about 1.5 times higher than microtunneling due to higher equipment cost and larger diameter of the machine. However, the reduction in the number of shafts, larger drop-structure, and number of construction compounds required for microtunneling should offset the majority of EPB-TBM linear cost.

In addition, special environmental protection and mitigation measures including permits and approvals would be required for the shafts construction and for shallower river crossings, which would increase the project's cost.

A high-level cost estimate was carried out comparing the Microtunneling and EPB-TBM construction methods, which resulted in an insignificant cost difference - <<5% variability.

3.4.3 Multi Criteria Analysis: Criteria and Parameters

A Multi Criteria Analysis (MCA) was carried out in order to better qualify the advantages and disadvantages of selecting either microtunneling and EBP-TBM for the North and West Segments.

The MCA criteria and the parameters are outlined in Table 1.

Table 1. Multi-Criteria Analyses Parameters

Criteria	**Parameter**
Cost	Cost
Schedule	Schedule
Technical	Maintenance Durability
Impact	Traffic Environment Social

Each criterion was individually weighed to address different scenarios, which would reflect the importance of some parameters relative to others.

For example, the Cost Weighted scenario assumes that cost trade-offs are considered the main factor in choosing between the microtunneling and EPB-TBM alternatives.

The five analyzed scenarios are outlined in Table 2. In a second step, a relative score was allocated to the microtunneling and EPB-TBM construction methods and reported in Table 4.

Table 2. Multi-Criteria Analyses Scenarios

Criteria	**Scenario**				
	Cost Weighted	Schedule Weighted	Technical Weighted	Impact Weighted	Neutral
Cost	0.50	0.17	0.17	0.17	0.25
Schedule	0.17	0.50	0.17	0.17	0.25
Technical	0.17	0.17	0.50	0.17	0.25
Impact	0.17	0.17	0.17	0.50	0.25

Table 3. Multi-Criteria Analyses Scoring System

1	better	2	equivalent	3	worse

In the MCA, a lower score indicates the better / preferred alternative. If there is no perceived benefit with either approach, a score of 2 is assumed.

The relative scoring by parameter is summarized in the table and further discussion reported in Table 4.

Table 4. Multi-Criteria Analyses Comparative Results

Criteria	Parameter	West Segment		North Segment	
		Micro	TBM	Micro	TBM
Cost	Cost	2	2	2	2
Schedule	Schedule	2	2	2	2
Technical	Maintenance	3	1	3	1
	Durability	2	2	2	2
Impact	Traffic	3	1	3	1
	Environment	3	1	3	1
	Social	3	1	3	1

3.4.4 Multi Criteria Analysis: Weighted Scenarios

Subsequently to the results obtained in the previous step, all factors involved in the multi-criteria analysis were weighted relative to the two tunneling methods in accordance with the four different scenarios. This was done in order to have a better understanding of the impact of each construction method.

The results reported in Table 4 (neutral scenario) is equivalent to where all families of parameters are equally weighted. In the four scenarios, the weighting is multiplied against the relative score to calculate the weighted score for each alternative. The total score is the sum of the weighted scores.

A lower total score indicates the better / preferred alternative for the given scenario. In the Table 5, different weights adopted for the different scenarios are reported. A summary of total scores for the various scenarios are provided below in Table 6.

The relative lower total score provides indication as to the better / preferred alternative.

Table 5. Multi-Criteria Analyses Scenarios' Weights

Cost Weighted Scenario

Criteria		Parameter	
Cost	0.50	Cost	0.50
Schedule	0.17	Schedule	0.17
Technical	0.17	Maintenance	0.085
		Durability	0.085
Impact	0.17	Traffic	0.057
		Environment	0.057
		Social	0.057

Schedule Weighted Scenario

Criteria		Parameter	
Cost	0.17	Cost	0.17
Schedule	0.50	Schedule	0.50
Technical	0.17	Maintenance	0.085
		Durability	0.085
Impact	0.17	Traffic	0.057
		Environment	0.057
		Social	0.057

Technical Weighted Scenario

Criteria		Parameter	
Cost	0.17	Cost	0.17
Schedule	0.17	Schedule	0.17
Technical	0.50	Maintenance	0.25
		Durability	0.25
Impact	0.17	Traffic	0.057
		Environment	0.057
		Social	0.057

Impact Weighted Scenario

Criteria		Parameter	
Cost	0.17	Cost	0.17
Schedule	0.17	Schedule	0.17
Technical	0.17	Maintenance	0.085
		Durability	0.085
Impact	0.50	Traffic	0.17
		Environment	0.17
		Social	0.17

The results of the MCA under the various weighted scenarios indicated that the EPB-TBM tunneling option is moderately to highly preferable over the microtunneling option for all scenarios.

The results shown in Table 6 highlighted that EPB-TBM is the preferable tunneling method based on technical and impact factors, definitely associated with the specific geological-geotechnical conditions.

It should be noted that the cost weighted scenario did not include the potential cost savings for re-use of the EPB-TBM that can be used in the central and south tunnel segments. Social-cost implications due to traffic congestion, traffic management and other social impacts were also not included in this analysis. .

Table 6. Multi-Criteria Analyses Results for 4 Scenarios

Scenario	West Segment		North Segment	
	Micro	TBM	Micro	TBM
Cost Weighted	2.25	1.75	2.25	1.75
Schedule Weighted	2.25	1.75	2.25	1.75
Technical Weighted	2.42	1.58	2.42	1.58
Impact Weighted	2.58	1.42	2.58	1.42
Neutral	2.38	1.63	2.38	1.63

3.5 The WVSS preferred tunnelling method

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Investigated geological / geotechnical conditions have confirmed the deepening for the West and North Segments' profiles which resulted a significant portion of these segments to be tunneled through the competent bedrocks.

The EPB-TBM option will have fewer social and environmental impacts in comparison to microtunneling due to the significant reduction in the number of shafts, in particularly sensitive conservation authority's lands. The

EPB-TBM alternative will require three shafts versus 23 shafts estimated for microtunneling.

A Multi Criteria Analysis (MCA) was carried out for comparison of the microtunneling and EPB-TBM options, utilizing preliminary assumptions relatively to the cost, schedule, technical and social-enviro factors, with weightings applied to the various parameters.

The analyses was developed at preliminary design stage and then continued through value engineering process confirming that the EPB-TBM construction method is preferred option over microtunneling

As a result of the above analyses, the WVSS alignment and construction method were summarized as outlined on Figure 4. Figure 4 illustrates the change in the alignment compared to the original conceptual design.

The microtunneling shafts, which are smaller and shallower than the maintenance shafts, are not shown on the Figure for clarity, but would typically have been spaced approximately 200 m along the alignment. Note that the Northern and Western Segments were combined into the Northern Segment, due to similarities in the new alignment.

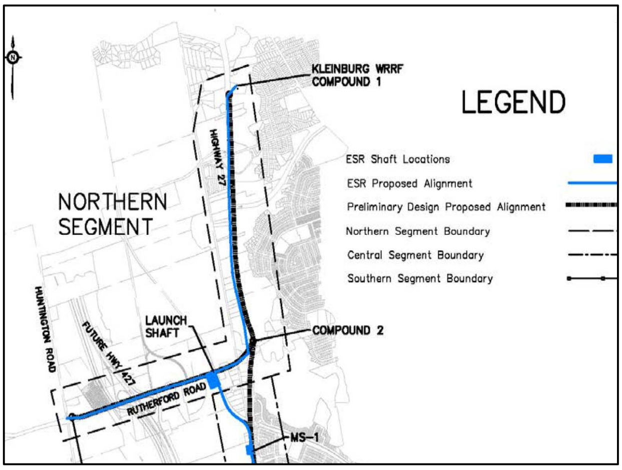

Figure 4. The WVSS Project original conceptual design vs modified alignment

The primary modifications proposed for the Western and Northern Segments resulted in the following overall advantages:

1. Increasing tunnel depth from an average of 5 to 10 meters bgs to an average of 15 to 20 meters bgs will reduce vibration and surface settlements;
2. Removing 17 microtunnel shafts and construction compounds along the Northern Segment alignment and 8 shafts along the Western Segment will significantly reduce surface disturbance;
3. Reducing the number of properties required for construction including general roads closure will reduce traffic impacts and risks of collisions due to fewer shafts and construction zones;
4. Relocating intersection shaft (connection of the Northern/Central segments) from west of Rutherford Road to the northeast corner of Rutherford Road and Highway 27 will reduce impact on Canadian Pacific Rail operations;
5. Relocation the connection shaft to the land owned by the lower tier municipality reduces the general land acquisition cost on the project;
6. Reducing the depth of a drop shaft in the connection shaft reduces potential odour issues and the cost for its mitigation including long term operation and maintenance cost.

4 CONCLUSION

This article provides a comparison based on impacts assessment, risks management and cost estimate on one of the regional project - WVSS used as an example completed with different tunneling methods. References to lessons learned from other projects built within the GTA where information is available to the public are also included in this article.

A risk analysis associated with each of the two (EPB-TBM and microtunneling) construction methodologies on each particular project shall be based on a real case scenario. For instance, the upcoming West Vaughan Sewage Servicing project will utilize the EPB TBM technology. Such decision was made based on a detailed analysis of the existing geological variability, including Georgian Shale bedrock with high potential for swelling and glacial tills at river crossings with high risk of frack-out. Other upcoming projects within the GTA registered however may lead to different risk analysis causing a choice of microtunneling technology versus EPB-TBM.

The Authors recommend using this paper as a basis or guide to develop a specific case-sensitive framework on each project to evaluate different scenarios under different conditions and circumstances. This article is meant to provide an analytical and semi-scientific approach properly weighing all factors and deciding which factor should be weighted the most in order to achieve a safe and cost-effective underground project for sewage systems.

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