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Long Distance Curved Microtunnelling Raises the Bar in Ontario

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Abstract: Prior to 2012, the integration of designed vertical or horizontal curves into microtunnel alignments was unheard of in Ontario. Straight and relatively short microtunnels, less than 200m long, were the local accepted industry standard. Following the release of a large number of infrastructure projects in the suburban Greater Toronto Area (GTA), clients and design consultants encouraged contractors to present value engineered alternatives to proposed project alignments and construction methods. Such an initiative has allowed contractors to develop cost effective solutions, which harnessed the application of state-of-the-art microtunnelling methods and equipment. As a result, several recent projects now feature pre-designed curved microtunnels as part of the tender documents. This paper discusses, in technical detail, three recent projects, whereby, long distance curved microtunnels were successfully constructed. Each of the projects had tunnel drives exceeding 300m in length, ranging in diameter from 1200mm ID to 1500mm ID, incorporating the use of Vertical, Horizontal, and Spatial Curves. Critical parameters such as pre-project planning and engineering are highlighted, while the importance of post-tunnelling assessments is also discussed.

Key words: Long-distance curved microtunnelling, value-engineered solutions, spatial curve integration.

1. Introduction

The construction of curved microtunnels is not a new technical development within the trenchless industry. Historically speaking, the first recorded notable planned and designed curved microtunnel was successfully built by Seibu Construction Company in Chiba, Japan in 1982. The project involved the construction of a 1.8m ID, 847m long gravity sewer beneath the Edo River and the curved portion of the sewer alignment involved the execution of a 300m Radius horizontal curve for a distance of 245m. The success of the Edo River microtunnel project inspired the construction of several curved microtunnels in Japan, with extreme radii of 60-80m being achieved. In Europe, there have been multiple long curved microtunnels, cumulating in the most impressive of them all, the 2,535m, 3.0m ID "Europipe", built in 1992 under the North Sea, Norway.

In North America the history of curved microtunnelling commences within the current decade. In 2010 Northeast Remsco constructed a 1.8m ID 447m radius horizontal curve for a distance of 52.6m as part of the Homestead Ave. Interceptor Expansion Project in Hartford, Connecticut, US. For reference, the current record for long distance non-curved microtunnelling in North America goes to the Kiewit Bilfinger Berger (KBB) JV who constructed a 2.1m ID, 937.87m long microtunnel as part of the City of Portland, Oregons East Side Combined Sewer Overflow Tunnel Project. The success of these projects or indeed any curved or long microtunnel project is due to extensive pre-project planning and the use of state-of-the-art microtunnelling equipment. Since 2012, several significant microtunnelling "firsts" have been achieved in Ontario, following the reintroduction of the method in 2011, each of which will be discussed in this paper [1-9].

2. Characterising Long Distance Curved Microtunnelling

It is important define the parameters which would classify a trenchless project as a "long distance curved

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microtunnel". The authors propose the following criteria:

The microtunnel alignment has been pre-designed or value engineered.

The micro tunnel boring machine (MTBM) is remotely operated from the surface.

The tunnel is constructed by pipe jacking.

The MTBM has the ability to articulate and steer the cutterhead through the ground.

The Internal Diameter (ID) exceeds 1200mm.

The minimum length of the microtunnel drive is 200m.

The tunnel alignment incorporates at least one Horizontal or Vertical Curve or a combination of both (spatial curve).

The tunnel boring machine utilises an advanced guidance system that allows navigation through curves without loss of position information.

2.1 Planning for Success

The American President Abraham Lincoln famously quoted, "Give me six hours to chop down a tree, and I will spend the first four sharping the axe". The level or planning that must be done in advance of a long distance curved microtunnel cannot be overstated. There are several key elements which need to be considered and reviewed prior to the construction in certain situations the tendering of any long distance curved microtunnel. A number of these elements are noted under the following sub-headings.

2.1.1 Site Investigation

A separate technical paper could be written on the subject of site investigations for microtunnelling projects. While the extents and scope of any sub surface site investigation are defined by the project budget, it is paramount that the following subjects be addressed as a minimum:

- Local Landscape Use and Topography
- Local Geology
- Local Hydrogeology
- Engineering Properties for the soil or rock along the proposed alignment
- Chemical Analysis of Soil or Rock
- Study of Past Local Tunnelling Experience in Project Location
- Project Specific Studies, i.e. Contaminated Land
- Sub Surface Risks, i.e. Buried Utilities

The above subjects should be provided in the Project Geotechnical Data Report (GDR), which in turn should be summarised in the Project Geotechnical Baseline Report (GBR). A well written and researched set of geotechnical reports with an unambiguous set of recommendations or statements will often set the tone for the project, and the contractor will assign costs to cover the "ground risk" accordingly.

2.1.2 Specifications

The project specifications define how the project will be administered and also provide the minimum quality, material, and operational standards to which the contractor must follow during the course of the contract. Recent standard specifications written for microtunnelling projects in Canada typically require the contractor to provide detailed and comprehensive tunnelling submissions prior to construction. Such submissions provide the client with evidence that the contractor has theoretically evaluated the project prior to construction. In the case of Long-Distance Microtunnelling, the contractor is required to include additional details such as surveying protocols, interjack spacing, risk assessments and contingency plans.

2.1.3 Equipment Selection

In the 1980's, there were over twelve manufacturers of microtunnelling equipment competing for the small bore trenchless market. Today, there are only five manufacturers of microtunnel boring machines (MTBM) and the associated support equipment. The latest generation of MTBMS, jacking frames, and spoil management systems are modular, highly sophisticated, and are capable of negotiating the most adverse of soil conditions. As with all tunnelling projects, the key to success is detail at micro management level. The selection of the correct equipment is the most important element of the project. In applying this analogy to long distance curved microtunnels, considerable analyses must be contributed towards:

MTBM Selection – The MTBM power system (hydraulically driven or electrically driven), the ability to steer through the curves in the alignment, cutting head configuration, cutting tool configuration, and access capability are important parameters to consider during this process.

Slurry Circuit System – The number, position, and size of slurry pumps and pipework to transfer the drilling fluids to the MTBM and back to the surface needs to be evaluated.

Separation Plant Selection – The separation plant must be able to cope with the volumes of material generated by the selected MTBM. It must never cause delay to the MTBM. Often the separation system is the first system to fail on a microtunnel project.

Jacking frame and Intermediate Jacking Station (IJS) Selection – The jacking forces must be predicted prior to construction and a jacking site specific system must be developed to overcome these estimated forces. The possibility of stoppages due to maintenance and the resulting increase in jacking forces from the stoppage should be included in the analyses.

Lubrication System Selection – The distribution system selected must be capable of minimising jacking forces for the entire length of the tunnel. Like the slurry system, pump and pipe sizing play an important role to the success of this system.

Backup Components - It is inevitable that wear components, particularly in slurry pumps, will need replacement on site. It is important to ensure that sufficient spare parts are kept on site and that the project is staffed with qualified skilled trades to ensure that downtime is kept to an absolute minimum.

2.1.4 Jacking Pipe Selection

There are three primary types of jacking pipes that can be used in microtunnelling projects, namely Precast Reinforced Concrete Pipe, Centrifugally Cast Fiberglass Reinforced Polymer Mortar Pipe (CCFRPM), and Steel Liner Pipe. Since each of these jacking pipes are materially different, it is extremely important that they are designed site specifically. Design criteria such as pipe length, maximum jacking load, maximum earth load, and joint seal rating are all standard specifications that are important. However, in long distance curved microtunnelling, the ability for the pipe string to take the curved alignment and the ability to use IJS units to overcome the jacking force requirement are the overruling design criteria. A curve introduces non concentric loading through the wall of the jacking pipe, therefore, reducing its ability to take load and each pipe joint deflects through a curve. IJS units are essential on long microtunnel drives to permit forward advancement of the MTBM. Therefore, the jacking pipe type selection must be able accommodate curves and IJS units.

2.1.5 Guidance Systems

MTBM guidance systems have been in use in the microtunnelling industry since the mid 1970's. As a rule of thumb, conventional shaft laser based MTBM guidance systems are reliable and accurate up to 250m for straight alignments. Beyond 250m, Electronic Distance Measuring (EDM) Thedolites in conjunction with a tunnel guidance system must be used to maintain the line and level of the MTBM. In the case of long distance curved microtunnels, there are two options available.

The first is a Gyro based tunnel guidance system. They use a North seeking compass as reference to control alignment while grade is controlled by a hydro water level system. The system has been around since 1983 and it has been widely used in the industry.

The second system is a more recent development known as VMT SLS-LT. It uses automated EDM’s to continuously measure MTBM position and reference prisms in the tunnel. The software in the system continuously recalculates the co-ordinates of the reference prisms as they move in the tunnel with the jacking pipe.

Both guidance systems require a physical tunnel survey to confirm accuracy at regular intervals. The interval spacing is usually decided by the alignment tolerances and the accuracy of the guidance system being used. A physical survey in a microtunnel is extremely difficult in sizes smaller than 1200mm ID, therefore, long curved microtunnels are generally equal or greater to this diameter. These current systems allow the MTBM operator to know the real-time and projected position and orientation of the MTBM at all times.

3. Recent Curved Microtunnels - Ontario

Long distance curved microtunnels are site specific and require all of the above points to be addressed to ensure a successful end result. Several such projects have been constructed by Ward and Burke Microtunnelling Ltd., and will now be discussed below.

3.1 Keswick WPCP Effluent Outfall Expansion Project. December 2012- July 2013

This complex project was located along the south-eastern shoreline of Lake Simcoe in the Town of Keswick. The project owner was the Regional Municipality of York who in order to meet the projected demands for the Town of Keswick, issued a tender for the expansion of the Water Pollution Control Plant (WPCP) and the twinning of the existing outfall to Lake Simcoe. A detailed technical account of the project has been written by Gelinas et al., NASTT 2014. McNally Construction Ltd., of Hamilton, Ontario, were the General Contractors for the project and they awarded a sub-contract to Ward and Burke Microtunnelling Ltd. for the construction of the microtunnels and associated shafts required on the project. The original trenchless scope of the project involved the construction of 750m of 750mm ID Sanitary sewer and six tunnelling shafts. Ward and Burke Microtunnelling Ltd. worked closely with the project team and developed a value engineered alternative design alignment using 1.2m ID Reinforced Concrete Pipe, the elimination of two tunnel shafts, and the incorporation of curved microtunnels. The details of the curved microtunnels were as follows (Table 1):

Ward and Burke Microtunnelling utilised the VMT SLS LT MTBM guidance system and both curved microtunnels drives were completed successfully, making the Keswick WPCP project the first trenchless project in Canada to use designed microtunnel curves along its alignment. It is also important to point out that the Keswick WPCP project also involved the "wet" retrieval of the MTBM from the bed of Lake Simcoe. This high-risk tunnel drive was successfully completed, making it the first ever wet retrieval of a MBTM from a lake bed in Canada.

The Keswick WPCP Project was very well planned, designed, and executed. The owner employed a pre-bid qualification process and a highly experienced design team to provide a detailed contract specification for the project. As a result of the achievements on the Keswick

Table 1 Keswick Outfall Expansion - Curved Tunnel Alignment Details.

CURVED DRIVE No. 1	KESWICK WPCP
DRIVE LENGTH	335.984m
INTERNAL DIAMETER	1.2m
VERT. CURVE RADIUS	-
HORZ. CURVE RADIUS	6850m
CURVE LENGTH	295m
MAX. JACKING FORCE	60T
NO. OF INTERJACKS	1
DRIVE DURATION	16 Days
SOIL TYPE	Wet Sand & Silts.
MTBM TYPE	HERRENKNECHT AVN1200
PRIMARY LINING	Reinforced Concrete Pipe

CURVED DRIVE No.2	KESWICK WPCP
DRIVE LENGTH	207.969m
INTERNAL DIAMETER	1.2m
VERT. CURVE RADIUS	6600m
HORZ. CURVE RADIUS	875m
CURVE LENGTH	182.984m
MAX. JACKING FORCE	107T
NO. OF INTERJACKS	0
DRIVE DURATION	11 Days
SOIL TYPE	Wet Sand,Silts, Boulders
MTBM TYPE	HERRENKNECHT AVN1200
PRIMARY LINING	Reinforced Concrete Pipe

WPCP project, the project team was awarded several industry awards, namely:

- Runner Up -Trenchless Technology Project of the Year 2013 (Trenchless Technology Magazine)
- Ontario Public Works Association - 2013 Project of the Year, Structures, $10-50 Million Category
- Irish Buildings and Design Awards 2014 International Engineering Project of the Year.

Elgin Mills PD6 Watermain Project - April 2013 - October 2013

As part of the Regional Municipality of York's Long Term Water and Wastewater Master Plan 2009, the Elgin Mills PD7 watermain was identified as critical infrastructure required in order to strengthen the current water supply network serving the Towns of Richmond Hill and Markham. The PD7 watermain was constructed along Elgin Mills Rd. from Enford Rd. East to Bayview Avenue, with the local streetscape defined as dense suburban residential sub-divisions. Following a Pre-bid Qualification process and tender period, the project was awarded to Drainstar Contracting of Vaughan, Ontario, who then issued a sub-contract to Ward and Burke Microtunnelling Ltd. to construct the trenchless tunnel and launch shaft for the project. The final product pipe for the watermain was specified to be a 600mm ID C301 Concrete Pressure Pipe. In order to install the watermain along Elgin Mills Rd. Ward and Burke proposed to construct a 740m long, 1500mm ID Microtunnel. The design alignment consisted of three horizontal curves with straight tangents in between each individual curve. A total of 4 interjack stations were installed into the pipe string during tunnelling but none were engaged due to the effective and efficient management of lubrication throughout the drive. A VMT SLS LT MTBM guidance system was used during tunnelling. Upon completion, the drive entered the record books for being the longest curved microtunnel ever constructed in North America.

Fig. 1 MTBM Reception - Keswick WPCP.

MULTI-CURVED DRIVE No. 3	ELGIN MILLS PD7
DRIVE LENGTH	740m
INTERNAL DIAMETER	1.5m
VERT. CURVE RADIUS	-
HORZ. CURVE RADIUS	400m - 180m Long 3000m - 83m Long 400m - 80m Long
MAX. JACKING FORCE	150T
NO. OF INTERJACKS	4
DRIVE DURATION	51 Days
SOIL TYPE	Glacial Till, Sands. Silts.
MTBM TYPE	HERRENKNECHT AVN1500
PRIMARY LINING	Reinforced Concrete Pipe

Fig. 2 View inside 1500mm ID Microtunnel - Elgin Mills.

North Don Sanitary Sewer Project - September 2013 - June 2014

The North Don Sanitary Relief Sewer System is located in The Regional Municipality of York and its construction first commenced in 1974. Over the years several extensions were added to the system to accommodate population growth in the Richmond Hill, Aurora, and Newmarket areas of Ontario. The North Don Sanitary Sewer Relief Project involved the construction of 1,704m of 1200mm ID reinforced concrete gravity sewer by microtunnelling and connections to the existing North Don Sanitary Sewer at Carrville Rd and the Bathurst Collector Trunk Sewer at Autumn Hill Boulevard. Following a pre-bid qualification process and tender period the project was awarded Pachino Construction Ltd. of Concord, Ontario. Pachino Const. Ltd., then issued a sub-contract to Ward and Burke Microtunnelling Ltd. to construct the trenchless tunnel and tunnelling shafts for the project.

The sanitary sewer was constructed in three distinct microtunnel drives, with the longest tunnel drive being 635m, making it the current longest 1200mm ID microtunnel drive constructed in North America. The VMT SLS LT MTBM tunnel guidance system was installed to successfully guide the MTBM to each of the reception shafts within project tolerances. It is important to note that these microtunnels were constructed during one of the coldest winters in recent memory. Temperatures regularly plummeted to -20 ^{0}C below making for very challenging tunnelling conditions.

CURVED DRIVE No. 4	NORTH DON SAN. SEWER
DRIVE LENGTH	467.5m
INTERNAL DIAMETER	1.2m
VERT. CURVE RADIUS	-
HORZ. CURVE RADIUS	500m
CURVE LENGTH	57m
MAX. JACKING FORCE	206T
NO. OF INTERJACKS	2
DRIVE DURATION	31 Days
SOIL TYPE	Glacial Till, Sand, Silts.
MTBM TYPE	HERRENKNECHT AVN1200
PRIMARY LINING	Reinforced Concrete Pipe

CURVED DRIVE No. 5	NORTH DON SAN. SEWER
DRIVE LENGTH	600.6m
INTERNAL DIAMETER	1.2m
VERT. CURVE RADIUS	-
HORZ. CURVE RADIUS	650m
CURVE LENGTH	238m
MAX. JACKING FORCE	350T
NO. OF INTERJACKS	3
DRIVE DURATION	56 Days
SOIL TYPE	Saturated Sand and Silts to Clay and Silt.
MTBM TYPE	HERRENKNECHT AVN1200
PRIMARY LINING	Reinforced Concrete Pipe

CURVED DRIVE No. 6	NORTH DON SAN. SEWER
DRIVE LENGTH	635m
INTERNAL DIAMETER	1.2m
VERT. CURVE RADIUS	5800m
VERT CURVE LENGTH	80m
HORZ. CURVE RADIUS	400m
HORZ CURVE LENGTH	129m
MAX. JACKING FORCE	350T
NO. OF INTERJACKS	2
DRIVE DURATION	42 Days
SOIL TYPE	Saturated, Low Shear Strength Sand, Silts.
MTBM TYPE	HERRENKNECHT AVN1200
PRIMARY LINING	Reinforced Concrete Pipe

Kenilworth Ave. Combined Sewer Overflow Project. - February 2014 - July 2014

Located in the City of Hamilton, Ontario, the Keninworth Ave. North Project is unique as it involved a long distance curved microtunnel within the Queenston Shale "soft rock" formation. The objective of the CSO project was to provide storage capacity for the local storms sewers which has reached maximum capacity. The project also involved the upgrading of local watermains and surface infrastructure such as traffic signal systems. Rankin Construction Ltd, were the General Contractors for the Project. The local streetscape around Kenilworth Ave. North is dominated by the Dofasco Steel Processing Plant. Due to the density of sub-surface utilities, the original straight, 177m long microtunnel was extended by an additional 142m to avoid having to open trench across a very busy intersection at Bath Rd. Ward and Burke

Microtunnelling Ltd, switched out the standard ELS MTBM guidance system for a VMT SLS LT system in under 3 days and were able to complete the remainder of the microtunnel drive in under 10days.

CURVED DRIVE No. 7	KENILWORTH AVE. N. CSO
DRIVE LENGTH	319m
INTERNAL DIAMETER	1.5m
VERT. CURVE RADIUS	-
HORZ. CURVE RADIUS	952m
CURVE LENGTH	142m
MAX. JACKING FORCE	90
NO. OF INTERJACKS	1
DRIVE DURATION	35 Days
SOIL TYPE	Queenston Shale
MTBM TYPE	HERRENKNECHT AVN1500
PRIMARY LINING	Reinforced Concrete Pipe

4. Closing Statement/Summary

Through correct planning and use of the latest microtunnelling equipment and technology, long distance curved microtunnelling becomes an economical and safe option to overcome the constraints that are inherent with deep tunnels and congested urban environments. In all projects highlighted, the use of long distance curved microtunnelling saved the construction of shafts that otherwise would have been located on busy roads adjacent to existing services and structures. By utilizing such a system, the workforce exposure to live traffic risk is reduced, traffic disruption is at a minimum, and the client receives cost savings through the elimination of shafts.

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