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Cast-In-Place Pipe Watermain Rehabilitation – What It's All About

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1. ABSTRACT

Over the past 40 years, the trenchless application for Cast-In-Place Pipe (CIPP) lining extended predominantly to sanitary sewers and storm drains. In the last 10 years, CIPP technology has started to emerge as an alternative for watermain rehabilitation, extending the service life of existing water distribution systems. This paper will examine a case study on a project completed for Kitchener Utilities and will outline the preparation of tender/contract documents for trenchless rehabilitation, discussing the reasoning behind the selection of CIPP watermain lining over traditional open cut installation method.

The paper will examine the process involved in generating the contract documentation “Special Provisions” which include submission requirements; provisions for dealing with less traffic and pedestrian disruption; education and coordination with residents and property owners about the new trenchless construction method; the importance in locating existing services, gate valves, and curb stops; provisions for watermain cleaning and drying; lining design parameters; closed-circuit television (CCTV) inspection; the complexities encountered to reinstate existing service connections; the removal and replacement of existing watermain valves and tees; quality assurance/quality control (QA/QC) procedures introduced to govern the quality of the lining work; dealing with unforeseen circumstances; and, finally, preparing the formulation of a comprehensive bid form document. The paper will summarize the outcome for the CIPP watermain lining project, offer lessons learned, provide a summary on the effect the CIPP trenchless technology has on the feasibility for watermain rehabilitation, performance, complexity, cost and environmental impact.

2. INTRODUCTION

A municipal service that is often taken for granted by the general public is the potable water distribution system that transports safe drinking water for both public and commercial use within our established communities. This includes residential water for drinking, cooking, cleaning, bathing as well as water for commercial/industrial applications for the cleaning and manufacture of food products, which we depend on for daily consumption. The public may not necessarily know—or care—about how the water reaches its taps, but it will demand that when it requires water, that water is available 24/7 and is guaranteed safe for consumption. This is the Scope of Work for CIPP watermain lining systems required by municipalities responsible for supplying potable water to the taxpaying public.

The City of Kitchener (City), Ontario, is one of these municipalities, tasked with managing water distribution lines that provide potable water to City residents. Refer to Figure 1 City of Kitchener. Kitchener Utilities is a municipal entity which is responsible for the distribution of both natural gas and potable water. It is solely owned by the Corporation of the City of Kitchener, a municipality within the Region of Waterloo.



Figure 1 City of Kitchener

In 2010, Kitchener Utilities participated in a pilot project to utilize a CIPP lining technology on up to 1.8 kilometres (1.1 mi.) of existing 150 millimeter (6 in.) diameter residential watermain. The project proved successful, leading to a follow-on 2014 Trenchless Watermain Rehabilitation project (Refer to Figure 2 Watermain Locations), which included CIPP watermain lining on the following City streets:

Location of Defective Watermain	Limit of Watermain Extent	Original Installation Year	Diameter of Watermain	Existing Watermain Material	Length
Greenbrook Dr	Westmount Rd East to Farmbrook Pl	1957	200 mm (8 in.)	Cast Iron	278 m (912 ft)
Lyndhurst Dr	Archer Pl to Burbank Rd	1958	150 mm (6 in.)	Cast Iron	456 m (1496 ft)
Archer Pl	Ottawa St North to Lyndhurst Dr	1962	150 mm (6 in.)	Cast Iron	223 m (731 ft)
Ruskview Rd	Sweetbriar Dr to Greenbrook Dr	1963	150 mm (6 in.)	Cast Iron	372 m (1220 ft)



Figure 2 Watermain Locations

3. CIPP WATERMAIN LINING VERSUS OPEN CUT WATERMAIN REPLACEMENT

When the original watermains on Greenbrook Drive, Lyndhurst Drive, Archer Place, and Ruskview Road were installed in the late 1950s to early 1960s, the City’s practice was to install the watermain at a depth of 1.8 m (6 ft). Common to today’s standards, the alignment of the existing watermain was placed directly underneath the asphalt road surface. This practice was to ensure the City placed the watermain below the frost line ensuring that the water valves could be easily identified, as valve locations were more easily found on the street surface and not hidden under landscaping. Prior to the introduction of trenchless technologies, the only feasible option to repair watermain breakages was to isolate the defective sections of the watermain by shutting off adjacent gate valves, then removing and disposing of surface asphalt, excavating to uncover the defective portion of the watermain, cutting, chlorinating, and completing the repair. This would be followed by backfilling, compacting, resurfacing, and restoration works.

The introduction of Class IV fully structural, NSF 61-certified liners provided a way to limit the need for excessive excavation, providing a rehabilitation method that meets the ASTM F1216 standards to complete full structural repair on fully deteriorated watermain pipe. The CIPP lining process consists of resin impregnation of a woven seamless polyester jacket, of which the inner jacket maintains a polymeric membrane bonded to the interior of the watermain to ensure water tightness. The liner can be installed by inversion method, in accordance with ASTM

F1216, or by pulling the liner in place and pushing a pig through the liner, in accordance with ASTM F1743, using water pressure to press the liner to the wall of the pipe. The circulation of hot water or pressurized steam within the liner at a maintained pressure and temperature, over a calculated time period, facilitates the resin curing process to solidify the structural properties of the standalone liner.

Table 1. The Kitchener Utilities' technical evaluation of CIPP lining over open cut PVC pipe replacement

Project Consideration	CIPP Lining		Open Cut Replacement (with PVC Pipe)	
	Comment	Rating	Comments	Rating
Watermain only utility requiring rehabilitation	<ul style="list-style-type: none"> - Less required excavation/restoration - Adjacent utilities not affected - Services can be reconnected, but not replaced - Multiple breaks that occur on the same watermain will be rehabilitated preventing any future breaks 	<ul style="list-style-type: none"> ● ● ● ● 	<ul style="list-style-type: none"> - More excavation/restoration required - Adjacent utilities require locating and protection - Services can be replaced to property line - Watermain cannot be confidently open cut spot repaired, as the condition of the existing watermain is suspect, requiring full replacement to confirm and prevent further breaks from occurring 	<ul style="list-style-type: none"> ● ● ● ●
Acceptability of service provided	<ul style="list-style-type: none"> - Track record on technology is limited, due to limited job history - Technology considered by City, not applicable to watermain over 70 years, (20 years beyond design life) 	<ul style="list-style-type: none"> ● ● 	<ul style="list-style-type: none"> - Proven track record on installation methodology - Watermain over the age of 70 years can be open cut and replaced 	<ul style="list-style-type: none"> ● ●
Servicing and operational issues	<ul style="list-style-type: none"> - New services off CIPP lined watermains are completed utilizing the same saddle and tapping sleeve for typical cast iron pipe - Cannot identify lead (Pb) services for replacement - Cannot rectify or provide frost protection to shallow buried watermain or services - CIPP liner is defined as a fully structural Class IV continuous pipe installed, covering and waterproofing the joints of the existing segmental cast iron pipe 	<ul style="list-style-type: none"> ● ● ● ● 	<ul style="list-style-type: none"> - New services can be installed from main to property line - Lead (Pb) services able to be replaced - Shallow buried services can be replaced and buried below frost line - Replaced PVC pipe is segmental, containing gasket joints that can provide a potential weakness in the pipe for main breaks if external soil conditions warrant 	<ul style="list-style-type: none"> ● ● ● ●
Watermain capacity requires increasing	<ul style="list-style-type: none"> - CIPP lining not designed to increase the capacity of the existing watermain or services 	<ul style="list-style-type: none"> ● 	<ul style="list-style-type: none"> - Upsizing diameter of the existing pipe can increase capacity of the watermain and services 	<ul style="list-style-type: none"> ●
Geotechnical & Hydrological constraints in area	<ul style="list-style-type: none"> - Greatly reduced fill disposal volumes - Minimized excavation, limits dewatering volume in high groundwater conditions 	<ul style="list-style-type: none"> ● ● 	<ul style="list-style-type: none"> - Potential impacted soils requiring disposal - Longer trench lengths require large scale dewatering, requiring permits 	<ul style="list-style-type: none"> ● ●
Construction and Public Safety	<ul style="list-style-type: none"> - Provides a safer procedure with less excavation, less equipment, and less work in open trenches, resulting in minimal traffic diversion 	<ul style="list-style-type: none"> ● 	<ul style="list-style-type: none"> - Larger construction footprint results in the use of heavy construction equipment with open trenches and traffic diversion 	<ul style="list-style-type: none"> ●

Project Consideration	CIPP Lining		Open Cut Replacement (with PVC Pipe)	
	Comment	Rating	Comments	Rating
Social economic constraints	- Minimal construction footprint results in less disturbance to the social and economic condition of the public	●	- Larger impact due to excavation required, resulting in temporary traffic control, restoration works, and noise	●
Natural constraints (e.g., trees, vegetation)	- Less excavation results in minimal to no effect on trees, vegetation, and landscaping	●	- Trees, vegetation, and landscaping (sidewalks, asphalt, and driveways) will require restoration	●
Utility constraints adjacent/crossing watermain	- Process is completed within the inside of the existing watermain; therefore, no external utilities will be affected	●	- Utility locates, with provisions to support existing utilities, carry the added risk of utility damage during excavation	●
Traffic disruption	- Minimal excavation results in minimal traffic disruption	●	- Open cut excavation requires a traffic control component	●

Note: Advantageous ● Moderately Advantageous ● Least Advantageous ●

For CIPP lining, the scoring totaled to 12 Advantageous, 2 Moderately Advantageous, and 4 Least Advantageous. For open cut replacement, the scoring was 7 Advantageous, 1 Moderately Advantageous, and 10 Least Advantageous. The result from the comparison in Table 1 identifies the selection of CIPP lining as more advantageous than open cut replacement, particularly for instances where all other utility infrastructure is determined to be in proper working order and only the watermain utility requires rehabilitation.

The cost analysis of the two watermain rehabilitation methods compares the City's accepted 2014 cost for open cut watermain replacement at \$850 per linear meter (\$255 per ft.) of watermain (excluding taxes) to the actual CIPP lining cost under \$725 per linear meter (\$217.50 per ft.) excluding taxes. This represents a 15 percent capital cost savings recognized by the City.

4. PREPARATION OF TENDER DOCUMENT

Similar to the practice of other Ontario municipalities, the City has developed its own standard tendering documents that have been formatted based on the Ontario Provincial Standards (OPS) for Roads and Public Works. The City has taken a very systematic approach to developing its document structure by standardizing the document to cover almost all aspects of municipal construction and preparing a detailed Form of Tender (FOT) that includes items referenced to the specifications. The City's tender document is also an evolving document that is updated and revised annually, based on a lessons learned approach, to allow for the introduction of new, proven construction technologies established within the market. The City uses the OPS General Conditions of Contract (GCC), and their specifications include provisions supplied by the Region of Waterloo and Area Municipalities Design Guidelines and Supplemental Specifications for Municipal Services (DGSSMS) and comprise additional provisions provided by the City of Kitchener Standard Specifications (CKSS). The Tendering Information and Form of Agreement are written exclusively to meet the City's requirements.

The trenchless CIPP lining of watermain had been utilized once by the City during the pilot project completed in 2010. The pilot project had been successful in rehabilitating 1.8 km (1.1 mi.) of watermain pipe. Therefore, similar to the City's systematic approach, the same 2010 document prepared for the pilot project was used as a baseline to form the 2014 trenchless watermain relining tender document.

Areas within the City's document format that required updating, to facilitate the inclusion of watermain relining works, include the following:

1. Form of Tender
2. Liquidated Damages
3. Special Provisions

Form of Tender

Certain items within the City's existing FOT were applicable to the proposed CIPP lined watermain rehabilitation works and included the provision of performance, labour, and material payment bonds; provision of traffic control; vehicular and pedestrian signage; and erection, maintenance, and removal of project sign boards as supplied by the City that are found within the FOT under Part A. Other items include the supply, installation, maintenance, and removal of a temporary potable water supply system, including all water quality testing, site mobilization/demobilization, and the supply and installation of gate valves, including a valve box to finished grade, that are located within the FOT under Part D.3. Finally, the items related to coordination with other contractors and utility providers and contingency allowance are located within the FOT under Part G.

To update the FOT to reflect the CIPP lining works, new specific lining items with characteristic descriptions of work and units of measurement specific to the specialized relining work were updated into the existing FOT. These items were all incorporated in the FOT at the end of the City's Part D.3 (for Watermain and Appurtenances) and at the end of Part G (Provisional Items and Contingencies). The new items were added to include the following particular associated Special Provisions and Specifications that have been included in order of precedence, in accordance with the Order of Precedence, under Clause GC 2.02, within the GCC under OPSS.MUNI 100.

New items added for Watermain and Appurtenances include the following:

1. Cut out samples of pipe liner/existing watermain for material testing and repair cut out section, including anode and tracer wire—in accordance with the Special Provisions and OPSS 460.
2. Clean existing watermain and install structural liner within existing watermain, including excavation of required access pits, supply and installation anodes, tracer wire, and required fittings in each access pit, and supply and placing backfill, including all disinfection, backfill, and site restoration—in accordance with the Special Provisions, OPSS 460 and 702.
3. Remove and replace existing watermain tees and bends—in accordance with the Special Provisions and OPSS 701.
4. Inspect watermain using CCTV—in accordance with the Special Provisions, CKSS 409 and OPSS 409.
5. Locate, inspect, and check operation of curb box/valve Box—in accordance with the Special Provisions.

The specifications that include method of measurement and payment details are generally linked with the specific Special Provision included under the Specification No. Section of the FOT.

These new items include the following Provisional Items and Contingencies:

1. Abandon existing service identified on Contract Drawings and supply and install new P.E. water service (by open cut method) to property line—in accordance with CKSS 401, 441, City of Kitchener Development Manual (CKDM) and OPSS 401, 441.
2. Supply and install hydrant set (Century Model), complete with a pumper nozzle, and a Stortz type connection, including 150 mm diameter tee, lead pipe, and valve and box (to K.E.S. M36-1)—in accordance with CKSS 441, CKDM, and OPSS 441.
3. Undertake vacuum excavation for water service—in accordance with CKSS 441, OPSS 441, 450 and 463.
4. Sample test CIPP Liner outside of proposed works identified on the Contract Drawings—in accordance with the Special Provisions.

These new items are provisional and have been maintained within the tender to be used should the need arise.

Liquidated Damages

Liquidated damages (also referred to as liquidated and ascertained damages) are damages whose amount the parties designate during the formation of the contract for the injured party to collect as compensation upon a specific breach (e.g., late performance). Under the current City contract, the liquidated damage amount was derived within the Contract Form of Agreement to be \$1,000 per working day (defined as Monday to Friday), that takes precedence, under the OPSS.MUNI 100, GCC.

Special Provision (SP)

The OPS Construction Specification for Pipeline Rehabilitation by Cured-in-Place Pipe (OPSS 460) had been revised and reissued in November 2010 to include provisions for cured-in-place lining of watermain. This incorporated the water quality requirement to meet NSF 61, Drinking Water System Components—Health Effects. The OPSS 460.09 Measurement for Payment and OPSS 460.10 Basis for Payment sections were considered too

general to cover the specific details the City required under this contract. Therefore, Special Provisions were introduced in the City's contract document providing measurement and payment details to govern payment for the new items that had been included within the FOT.

SP (8) to (11) included provisions for the restoration of watermain access pits, support for existing local utilities, and coordination with residents, property owners, and the Regional District School Board, where works are involved adjacent to schools.

SP (14) is the provision added to instruct the contractor to locate, inspect, and check the operation of existing curb boxes on water services connected to the watermain requiring relining. The location and successful operation of the curb boxes is a critical component for the CIPP lining, as the existing services remain connected to the relined watermain. Prior to decommissioning the watermain, the contractor must ensure that the existing curb stop, located on the property line, is closed to prevent potential contamination of the existing private service from the property line to the building. This SP is not covered under OPSS 460.

SP (15) refers to provisions for the cleaning of existing watermain and CIPP liner installation. This SP expands on the details presented under OPSS 460 and includes the following:

1. The installation of access pits into the watermain
2. Cleaning and preparation of the existing watermain
3. Specifications on the required CIPP Watermain Liner
4. Design parameters and requirements for the CIPP watermain liner
5. Execution of the CIPP Watermain liner installation

It is the responsibility of the contractor to determine the selection of all access pit locations. These are normally selected at existing valve boxes that will require replacement, as the CIPP liners are not compatible with the operation of the gate valves. The spacing between access pits is normally limited to no more than 150 m (500 ft). This provides for a conservative lining distance. Where required, the contractor should be specified to provide shoring, groundwater control, and safety and traffic management control around pit excavations. The size of the excavation will be limited, ensuring that watermain cleaning and lining equipment will have access into the watermain pipe. The unit of measurement for this item is lumped into the linear installation price to install CIPP liner, which includes all access pits, removals, excavation, asphalt, and concrete restoration costs. This approach has the advantage of making it within the contractor's best interest to minimize the area of excavation to save on restoration costs.

Rust, tubercles, deposits, loose or deteriorated remains of any previous watermain coating, and any other foreign materials are required to be removed from inside the pipe by methods such as water-propelled cleaning devices and cable pulled scrapers and rack boring. Where service taps protrude too far into the interior of the existing watermain, the service taps are required to be trimmed back to an acceptable protrusion length. Upon the completion of cleaning, a CCTV inspection of the cleaned watermain is required to establish its baseline condition.

The proposed CIPP liner shall meet the requirement of ASTM F1216 and ASTM F1743 (where required) and be certified under NSF/ANSI Standard 61. The contractor shall be requested for submittals that include a work plan, traffic control plan, lining manufacturer's technical product data/properties, product curing procedures, contingency plans for failed product installation, damaged service connections, or damage to the host pipe. The specification for the required liner includes the requirement to provide a thermally cured epoxy-type resin and a waterproof outer membrane layer to hold the resin. The liner is also required to be capable of withstanding efforts and equipment for the remote reinstatement of service connections from inside the lined watermain pipe.

The CIPP Liner Design Method and Parameters required the following:

- Design Life - 50 years
- Safety Factors - External Loads: 2.0, Internal Pressure: 2.0, and Vacuum: 2.0
- Design Pressure - 862 kilopascals (kPa) internal pressure
- Vacuum Pressure - 50 kPa below atmospheric pressure
- External Hydrostatic Pressure - Based on depth of ground water table at 3 ft below grade
- External Earth Load - 2.0 m over top of pipe crown

- Live Load - AASHTO HS-20
- Ovality - 2 percent
- Acceptable Soil Density and Modulus - 1920 kg/m³ and 4.83 megapascals (MPa)
- Liner Flexural Modulus (ASTM 1216) - 1724 MPa
- Liner Tensile Strength (ASTM 1216) - 21 MPa

The design considerations that govern the required thickness of a Class IV fully structural liner have been taken from ASTM F1216 Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube. The ASTM F1216 equations applicable for a structural liner to repair a fully deteriorated watermain pipe are included as follows:

Equation for External Pressure from Groundwater (Partially Deteriorated Liner)

$$P = \frac{2KE_L}{(1-\nu^2)} \times \frac{1}{(DR-1)^3} \times \frac{C}{N} \quad [1]$$

Equation for Hydraulic, Soil and Live Loads (Fully Deteriorated Liner)

$$q_t = 1 \times [32R_w B' E'_s C (E_L I / D^3)]^{1/2} \quad [2]$$

Equation for Minimum Thickness Fully Deteriorated (SI units)

$$\frac{E}{12(DR)^3} \geq 0.00064 \quad [3]$$

Equation for Internal Pressure by Hoop Stress Resistance

$$P = \frac{2S_{TL}}{(DR-2)N} \quad [4]$$

Where:

P	= groundwater load	q _t	= total external pressure on pipe (soil, live load, water)
K	= enhancement factor of soil and existing pipe	R _w	= water buoyancy factor
E _L	= long-term modulus of elasticity for CIPP	B'	= coefficient of elastic support
ν	= Poisson's ratio	I	= moment of inertia of CIPP
DR	= dimension ratio of CIPP	t	= thickness of CIPP
C	= ovality reduction factor	E' _s	= modulus of soil reaction
N	= factor of safety	D	= mean inside diameter of original pipe
S _{TL}	= long-term (time corrected) tensile strength	D _o	= outside diameter of CIPP
		E	= initial modulus of elasticity
		P	= internal pressure

The Eq. 1, Eq. 2, Eq. 3, and Eq. 4 have been solved by imputing the selected CIPP liner's long-term tensile strength (ie., S_{TL} = 85 MPa) and long-term modulus of elasticity (ie., E_L = 2,000 MPa) factored by 50 percent, and the internal and external pressures applied to the pipe to derive the required thickness (t) of the CIPP liner. The thickness of the liner is evaluated in Eq. 1 based on external pressure from groundwater. In Eq. 2, the liner is evaluated based on hydraulic, soil, and live loads and in Eq. 3 based on minimum thickness for fully deteriorated existing pipe. Eq. 4 is determined based on internal pressure caused by hoop stress resistance to internal pipe pressure. The thickest required "t" value can be determined from the following calculations:

Applying to Eq. 1, Eq. 3, and Eq. 4

$$t = \frac{D_o}{DR} \quad [5]$$

Applying to Eq. 2

$$t = (12I)^{1/3} \quad [6]$$

The specifications require that during the submission stage the design calculations for each individual liner be completed, stamped, and sealed by a professional engineer.

SP (15) also specifies that the execution of the watermain liner installation also follows the requirements under ASTM F1743 for pulled-in-place installed CIPP liners. This is in conjunction with the liner manufacturer's accepted liner installation methodology.

SP (16) is provided to monitor and ensure quality assurance for the completed CIPP liner that includes pressure testing of the liner. Pressure testing of a CIPP liner is completed to a maximum pressure equal to the operating pressure of the existing watermain. This differs from the pressure required to test newly installed main. This is to avoid any additional damage to the existing watermain that surrounds the newly installed liner. Flushing, cleaning, and disinfection of the liner is completed in accordance with the DGSSMS requirements that are based on OPSS 441. This provision also refers to the requirement to furnish a sample of the existing watermain material cut up to 0.1 m in length for the full perimeter of the pipe. Each sample is then required to be tagged with the street location and taken to a certified laboratory to test for measured liner flexural modulus, tensile strength, and wall thickness.

SP (18) refers to the reinstatement of service connection laterals and hydrant leads. This includes for internal reinstatement utilizing a mechanical robot to first insert plugs (made from patented material, compatible with the liner material) into the existing service connection leads. All plugs are inserted prior to the CIPP lining of the existing watermain. Once the main is lined and adequately tested, the robot will locate the connection leads by identifying a bulge in the liner caused by the insert plugs and will then cut into the liner at the connection leads.

Design Drawings

The completion of the design drawings utilized the original as-built drawings prepared during the initial liner installation as the base for the proposed works. The as-built drawings were old, dated from 1957 to 1963, and digitized into the AutoCAD system to prepare the CIPP lining design drawings. The alignment and elevation of the installed liner is identical to the original as-built parameters. The as-built drawings were updated to include existing service locations and any other additional utilities present around the watermain to be relined. This provides the contractor with the necessary information to select proposed access pit locations.

In summary, the Tender/Contract Document was developed based on the City's standard Tendering Information, revised City FOT, and standard City Form of Agreement, OPSS.MUNI 100 GCC, complete with the City's Supplemental General Conditions, Standard Specifications, and inclusion of the noted special provisions. The drawings were based on as-built information provided by the City, and the tender document was revised and updated to meet the requirements for the new CIPP watermain lining technology.

5. CONTRACT ADMINISTRATION/LESSONS LEARNED

The tendering resulted in a total of two returned tenders. The competing watermain liners included Nordipipe™ Fully Structural Cured in Place Pipe Liner and Aqua-Pipe® Liners. Both satisfied ASTM F1216, but unlike Nordipipe™ that utilized an inverted liner installation, Aqua-Pipe® adhered to ASTM F1743 for pulled-in-place installation of cured-in-place thermosetting resin pipe. The City awarded the project to Fer-Pal Construction Limited who used the Aqua-Pipe® Lining system.

The original construction schedule provided for in the contract specified a total time for completion equal to 70 working days. During the contract period, work delays were encountered due to the following:

1. There were unsuccessful attempts at completing chlorine residual and bacteriological testing required for the temporary watermain.
2. There was difficulty locating all service connection curb stops along Ruskview Road, Greenbrook Drive, Lynhurst Drive, and Archer Street. Even with the use of a handheld metal detector, some of the curb stops were buried too deep to locate. This required open cut excavation to locate and replace the service curb stop. Once

curb stops were located, they were tested to ensure that they were working properly. Failed operation of a curb stop also resulted in the required open cut excavation to replace the curb stop.

3. It was discovered that the existing watermain on Ruskview Drive had an existing concrete liner. This information was not known at the time of design, and the City was also unaware of this during the design stage. A period of testing had to be completed to confirm that the existing reduced pipe diameter (150 mm existing diameter) could be lined and provide enough clearance for the robotic cutter to complete service connections. It was confirmed that the robotic equipment could operate within the reduced diameter.
4. The as-built information provided for Archer Street was incorrect. The existing watermain required re-alignment that included an open cut installation of a portion of the main to readjust the alignment.
5. Wrinkles and voids were discovered between the liner and the existing watermain on Lynhurst Drive. The liner was confirmed to be structurally sound, but the internal wrinkle within the liner lapsed over a portion of internal service connections, preventing the robotic cutter from identifying the location of the connection, requiring the open cut excavation and installation of the service connection.
6. The final commissioning of the re-lined watermains was also again delayed due to the many unsuccessful attempts at completing chlorine residual and bacteriological testing. The eventual laboratory certified pass of the newly installed watermain bacteriological testing was finally accomplished.

Lessons learned include the following:

a) Contract—Consistency, Items SP(7) & T(3):

The liquidated damages time period should have stated calendar days within the Form of Agreement. This would have been consistent with SP (7).

A well-written document should be checked prior to its finalization to ensure information within all sections corresponds correctly. The document should be clear to all parties, unambiguous, and clearly describe the rights and responsibilities of each participant of the contract.

b) Add to specification, SP(3):

Temporary watermain shall be installed, tested, and certified prior to excavating access pits.

Once the temporary watermain had been installed (not yet tested), the contractor proceeded with access pit excavation works. It took weeks before the contractor received bacteriological testing certification for Greenbrook Drive, Lyndhurst Drive, and Archer Place (75 percent of the project). No work could be completed on site until the temporary watermain was confirmed safe and operational. The residents along the streets began to raise concerns on whether the project would be completed on time. The asphalt existing around the access pits already excavated by the contractor began to erode, and the excavated pits began to fill with water. The lesson learned included adding an SP requiring the successful testing and certification of the temporary watermain prior to allowing access pit excavation works to commence.

c) Clarification, SP(10) & SGC(22):

SP(10) states prior approval for Saturday work and SGC(22) refers to noise by-law exception. Both of these sections within the contract were not compatible. During construction, there were times when the contractor requested or was requested to work on weekends. There was some confusion when reading the contract with regards to SP (10) and SGC (22). The specification should be modified to clarify the same allowable time periods consistent with allowable working hours and noise by-law hours.

d) Add to specification, SP(19):

For CCTV inspection, the contract should include the provision that all pipe lengths must be cleared of stagnant water to provide full view for inspection. During the pre-cleaning CCTV inspection, significant water was found. The purpose of a pre-cleaning CCTV inspection is to observe the condition of the existing pipe and use the data collected to chart the pre-cleaned condition of the watermain within the area. Observing a CCTV inspection which shows 10 m of submerged video recording defeats the purpose of producing the video.

e) Clarification to SP (18)/Add SP (23) to item D3.19:

SP(18), which is included in D3.19, to reads:

The Contractor will be required to furnish to the City a sample of the lining within the host watermain... removed for inspection and for potential testing purposes. Immediately upon removal the Contractor shall give the samples into the custody of the City.

SP(23), which is included in D3.19, reads:

The work of this item shall include all labour and equipment to complete sample tests as per OPSS 460 in accordance with the requirement of ASTM D790.

The word potential should be removed from SP (18) as it indicates the samples retrieved needs to be requested for testing even though samples must be approved or accepted by the City for payment. The other option is to include SP (23) with item D3.19.

6. CONCLUSIONS

From the evaluation of the CIPP watermain lining over the open cut watermain replacement methodology, the City has concluded that in cases where it identifies scenarios where the water utility is the only utility in need of repair, and watermain improvement is warranted, CIPP watermain lining is a financially viable repair option. The preparation of tender documents should be based in order of precedence to include the document's Special Provisions, followed by the City's specifications, followed by the Region of Waterloo's Specifications, followed by the Ontario Provincial Standards to form a comprehensive lining tender document. Lessons learned during tender preparation, contract administration, and inspection should be revised in any new tender document to improve the quality, clarity, and effectiveness of the CIPP lining project.

In conclusion, the use of CIPP watermain lining was an effective method for successfully completing the CIPP lining of watermain on Greenbrook Drive, Lyndhurst Drive, Archer Place, and Ruskview Road. The per meter cost to complete the CIPP Lining works was less than the 2014 open cut costs to complete full replacement of the existing watermain pipe. Therefore, considering the City's budgetary restrictions, foreseen to occur in the future beyond the present forecasted infrastructure budget, coupled with the anticipated accelerated volume of aging watermain infrastructure closely reaching the end of service life, a logical recommendation for the City is to seriously consider adapting this new watermain rehabilitation technology and invest in completing a serious review on incorporating this trenchless technology into its future tender document standards.

7. REFERENCES

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