Trenchless Installations Preserve Pavement Integrity

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ABSTRACT

Horizontal directional drilling (HDD) has been successfully used to perform trenchless pipeline installations under highways, roads, waterways, and various other situations where traditional open cut-and-cover methods will results in significant traffic disruptions and/or environmental damage. In the case of pavements, utility and pipeline cuts have been shown to accelerate pavement deterioration and create significant user delays. Initially trenchless pipeline construction bids were higher than open cut-and-cover methods. However, if full life cycle costing methods are used trenchless construction methods are more cost-effective than the low bid open cut.

This is the first known study that investigates the comparative impacts of directional drilled and conventional open cut and cover pipeline installations on pavement integrity and performance. Obtaining such comparisons under the same levels of subgrade type, pavement structure, traffic, and environmental conditions is unique and will provide field data that will be important to both the trenchless and pavement industries.

This paper reports on a joint effort between The Centre for Advancement of Trenchless Technologies (CATT) and The Centre for Pavement and Transportation Technology (CPATT), both located in the University of Waterloo Department of Civil Engineering, to carry out the foregoing comparisons. CPATT's test site at The Regional Municipality of Waterloo's waste management facility (reported at TAC's 2003 Conference) was used for the research. The trenchless and open-cut installations were placed in a clayey till subgrade about 2m from the surface, which is overlain by 300mm of granular B subbase, 150mm of granular A base and 100mm of hot mix asphalt. The open-cut installation was restored to pre-cut conditions using current best practices. During trench re-instatement field instrumentation was installed to measure soil backfill and pavement response to traffic loading. Strain gauges were installed at the bottom of the asphalt layer to measure the pavement response to traffic loading and environmental changes. The pipes, 200mm SDR-17 high-density polyethylene (HDPE) were instrumented to measure pipe short and long-term behaviour (strains and deflections). Other data collected includes the construction progression and comprehensive materials characterization data that includes the slurry used for the directional drilled pipe installation.

This paper provides an overview of the University of Waterloo Centre for Pavement and Transportation (CPATT) research program and test track facility. It also discusses the research program designed to quantify pavement deterioration and polyethylene pipe performance when pipes are installed under flexible pavements using a directional drill and open cut-and-cover construction methods. Details of the construction and instrumentation are presented. Directionally drilled and open cut pipe construction induced pipe deflections are also discussed as an example of the quality of data being collected in this study.

INTRODUCTION

Municipal roads and highways are being excavated to install utility pipeline networks, to replace or expand existing municipal water and wastewater distribution and collection systems, gas distribution networks, and high-speed data and communication transmission networks. Studies by Tighe et al. (2002), Humphrey and Parker (1999), Papoutsis et al. (2000), Tarakji (1995), and Shanin and Crovetti (1987) indicate that utility cuts in flexible pavements significantly reduce the pavement life and significantly increase pavement maintenance and rehabilitation costs.

Trenchless construction methods are rapidly becoming an economic alternative to cut-and-cover construction due to lower reconstruction costs, shorter construction periods, and lower social costs due to reduced user traffic delays [Tighe et al. (2002) and Tighe et al (1999)].

2 CPATT

The technological challenges in roads and pavements are substantial and include not only the need for asset preservation but also the provision of adequate levels of service and safety and the need for continuing innovation and advancement in all areas. It is these challenges that have formed the basis for a new research initiative in Canada – the University of Waterloo Centre for Pavement and Transportation Technology (CPATT) integrated laboratory and field-test facility. Support for the initiative came from a three-way partnership of the public sector (Federal, Provincial, Regional and Municipal), private sector (contractors, consultants, suppliers and manufacturers) and academia. The Canada Foundation for Innovation (CFI) and Ontario Innovation Trust (OIT) and private sector are providing $6.0 million over four years for research infrastructure. An additional $3.0 million was provided by the Ontario Research Development and Challenge Fund (ORDCF), the Ministry of Transportation of Ontario, the University of Waterloo, and a group of private sector partners in terms of cash, material, equipment and time donations.

3 CPATT FIELD-TEST FACILITY

The field site is located at the Regional Municipality of Waterloo's waste management site located in Waterloo, Ontario. The landfill site contains a torture test track that has truck monitoring and weighing capabilities, access to utilities, and a building to house test and data acquisition equipment.

The 709m (2326ft) long and eight meter (26.2ft) wide test track was constructed in the summer of 2002 along the southeast boundary of the Regional Municipality of Waterloo's waste management site (Figure 1). The two lane test track is composed of a standard binder mix Hot Laid 4 (HL4)) and four different surface mixes: namely Hot-Laid 3 (HL3), Polymer-Modified Asphalt (PMA), Stone Mastic Asphalt (SMA) and Superpave, as shown in Figure 2. The binder course consisted of a standard municipal mix which was HL4. Two control sections HL3-1 and HL3-2 were placed at each end of the test track. The test track pavement structure consists of 300mm of Granular B subbase, overlaid by 200mm Granular A base and 100mm of asphalt overlay (binder HL4 plus one type of surface mix). The three surface mixes that are being tested at this site will be examined using roughness characteristics, structural adequacy, skid properties, pavement resistance to fatigue cracking and rutting, thermal cracking and traffic noise reduction.

Figure 1: CPATT Field Torture Test Track Facility at the Region of Waterloo Municipal Landfill Site.

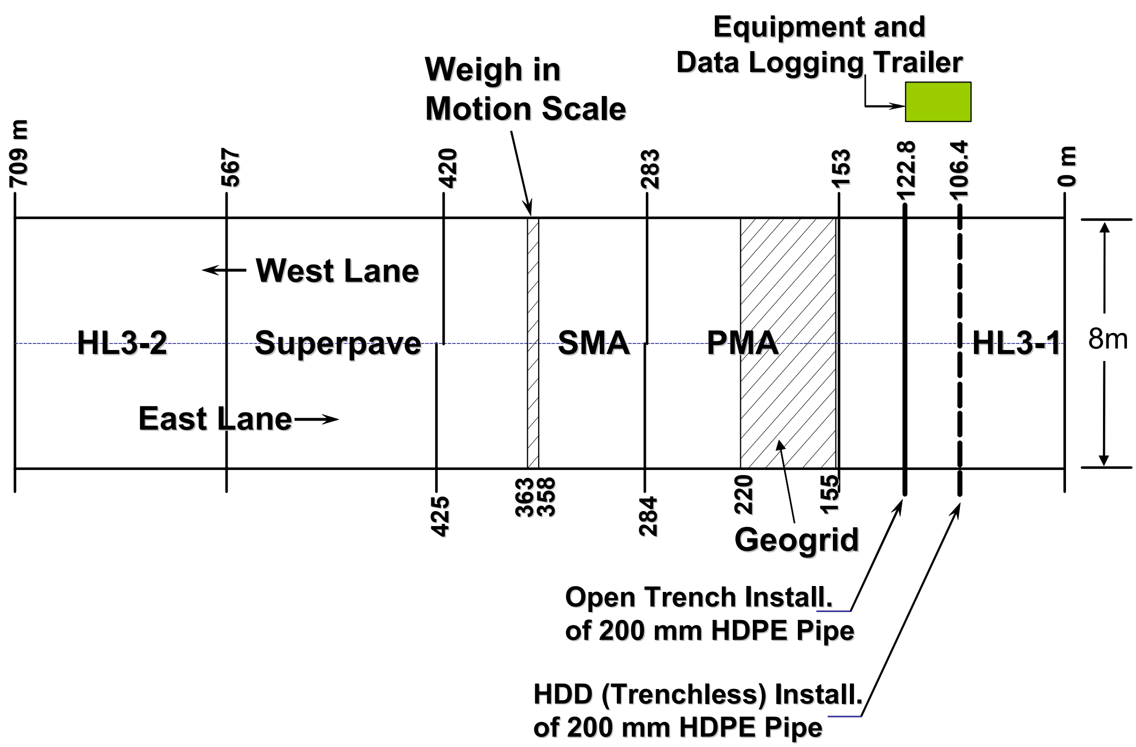

Figure 2: Test track layout.

The test track is an access road that connects the impermeable clay liner borrow pit to the solid waste storage cells. In the Summer of 2004, a new waste storage cell was constructed. Cell construction will consist of transporting impermeable clay along the test track using 80 tonne heavy off road haul vehicles. Unloaded and loaded haul trucks contribute approximately 40 and 80 Equivalent Single Axle Loads (ESALs) respectively. The total ESALs experienced by the test track in 2002 were calculated to be about 296,000. Most of these ESAL's were applied over a one month period when a clay haul occurred. During the summer of 2003 a weigh in motion was installed in the test track pavement to measure track weights and traffic counts.

Falling Weight Deflectometer (FWD) pavement load/deflection testing and International Roughness Index (IRI) surveys were taken both prior to and immediately following construction and following the in-service phase. Distress surveys were also performed both prior to and following the clay haul. Results of the initial pavement performance are reported in Tighe et al. (2003).

4 HDD VS OPEN CUT PIPELINE INSTALLATIONS

A current CPATT research project is to develop a better understanding of mechanisms that influence PE pipe behavior and road deterioration when open cut-and-cover and directional drilling methods are used to install utility pipes under flexible pavements. Three research objectives have been identified. The first objective is to document PE pipe and soil forces during and following pipe installation. The second is to develop a fuller understanding of the time-dependent pipe-soil behavior, while the third objective is to measure flexible pavement deterioration rate when best practices are used for the pipe installation. The research program consists of an integrated field, laboratory and numerical investigation supported by the CPATT and the Centre for Advancement Trenchless Technology.

In April, 2003, a 200mm (8in) instrumented SDR-17 Ductile Iron Pipe Size (DIPS) high density polythene pipe was installed 1.52m (5ft) below the HL3-1 control test section using a horizontal directional drill. In October, 2003, a second 200 mm (8in) instrumented SDR-17 high density polythene was installed 1.67m (5.5ft) below the track HL3-1 control test section using open cut-and-cover construction.

The locations of the two pipe installations are shown in Figure 2. The pipe placement locations were selected to have similar vehicle velocities, drainage conditions and subsurface conditions.

5 HDD PIPE INSTALLATION

The HDD pipe was installed on April 30, 2003 by T.W. Johnston Ltd., London Ontario. Four instrumented test sections, each approximately one meter (3.28ft) long, were fused with other pipe sections to form a 22.9m (75ft) long continuous length of PE pipe. Pipe fusion and connection of sensor wires took approximately six hours to complete.

Using a Ditch Witch 2040 drill rig, a 125mm (5in) pilot bore was completed in 50 minutes. The drill was set back to ensure that the bore path under the test track was horizontal and at the specified depth of 1.52m (5ft) and that the bore was below a methane gas PE pipe collection conduit. The pilot bore was pre reamed using a 300mm OD Kodiak reamer. The 200mm (8in) DIPS HDPE pipe was installed behind the second pass of the 300mm (12in) Kodiak reamer. Drill fluid was pumped into the bore during the pilot bore and pipe installation. The drill fluid mixture consisted of mixing 225kg (500lbs) of Boregel, 1.8 kg (4lbs) of No Sag, and 5.4kg (12lbs) of QuikTrol mixed in 1400 litres (3700 gal) of water. The HDPE pipe installation was completed in approximately 5 minutes.

A total of twenty four sensors were installed inside the HDPE pipe and on the drill rig to measure the pipe performance, bore annulus slurry pressure and drill rig response during and following pipe installation. The pipe sensors, shown in Figure 3, consisted of six pressure transducers, nine linear displacement transducers, four strain gauges, one thermistor and a load cell. Four 1.0m (3 feet) long PE pipe test sections were instrumented in the laboratory. The pull head test section (PH) contains a load cell, two pressure transducers and four strain gauges. Test Section 1, the control test section (CO), contained three linear displacement transducers. Test Section 2 installed under the West traffic lane (WL) and Test Section 3 installed under the East traffic Lane (EL) each contained three linear displacement transducers and two pressure transducers.

Three linear displacement transducers were placed inside the test sections (CO, WL, and EL) to measure pipe diameter changes. A linear transducer was connected to the pipe crown and invert (0) to record pipe vertical diameter changes. The second transducer connected the pipe springlines (90) to measure horizontal pipe diameter changes. The third transducer was placed 45 degrees clockwise from the crown transducer and measured oblique pipe deflections (45). All deflection sensors were calibrated to +/- 0.05mm. To record the bore slurry annulus pressure adjacent to the pipe, pressure transducers were mounted flush with the outside of the pipe wall at 90 degree intervals. To record pipe tension and flexure, strain gauges were placed at the pipe crown, invert and at the springlines. A 222kN load cell, located in the pulling head, was designed to record the axial load imparted to the pipe by the drill rig via an eyebolt with a backing plate and bearing assembly installed inside the pull head. The eye bolt was connected to the drill string via a swivel. Pipe temperature was measured using a temperature probe placed inside Test Section 2 (WL).

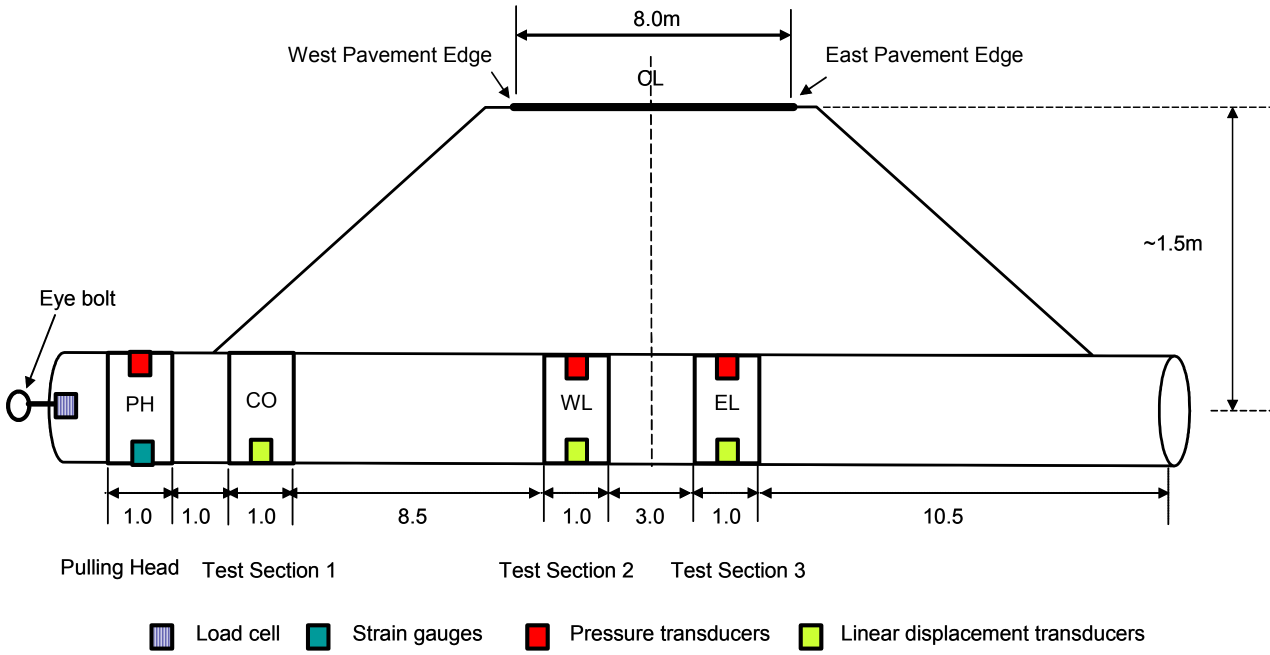

Figure 3: Layout of the 20 sensors placed inside the HDD installed pipe.

To monitor drill rig performance during pilot bore drilling and pipe installation, pressure transducers were installed on the drill rig to record the drill rig feed and return hydraulic pressures. A transducer installed in the drill fluid tank recorded the height of fluid in the drill fluid tank so that the volume of drilling fluid consumed during drilling and pipe installation could be determined.

Two Somat 2100 field computer data acquisition systems were used to record the pipe ring deflections, bore slurry pressure and pipe strain. A Campbell Scientific CRX10 data logger was used to monitor the temperature probes and a Lakewood data logger was used to record load cell readings. The Somat, Campbell and Lakewood data acquisition systems were placed inside the pipe during pipe fusion. Drill rig and the drill fluid tank pressure transducers were recorded using a second Lakewood data logger. All loggers were set to record and store sensor readings at 10-second intervals.

Following the pipe installation ring deflections and bore slurry pressure readings were obtained continuously at one minute intervals. Temperature readings were obtained at 15 minutes intervals. A deep-cycle battery continuously recharged by a solar panel powers the data acquisition systems.

To determine the influence of the pipe installations on the road performance an IRI survey was completed on the entire test track prior to and following the pipe installation and a elevation survey grid 0.5 by 0.5m (1.5 by 1.5 feet) was setup on the asphalt surface. The survey baseline was set along centre line of the pipe installation. The grid was surveyed using a Total Station prior to, during, and following the completion of the drilling process and pipe installation.

6 OPEN CUT INSTALLATION

On October 15 and 16, 2003, T.W. Johnston Ltd., London, Ontario installed the second 200mm (8in) DIPS HDPE pipe 13.1m (43ft) long 1.68m (5.5ft) below control test section HL3-1. The centerline of the pipe is at station 122.8m which is 16.7m (54.7 feet) west of the HDD installation (Figure 2). Ontario Provincial Standard Specifications for Pipe Sewer Construction by Open Cut Method (OPSS 410) were followed.

Pipe fusion started on October 15 and was completed in approximately four hours. The pavement was cut 1.37m (4.5ft) on both sides of the proposed pipe centerline location using a gas powered circular saw. Pavement layers and site soils were excavated using a rubber tire backhoe to a depth of 1.82m (6ft) below the pavement surface. Excavation took approximately four hours to complete. The subgrade, clayey silt with sand and gravel (TILL), was compacted and leveled using a hand operated tamping plate.

Two 150mm (6in) thick lifts of compacted granular “A” material were placed after a thermistor was installed on the subgrade. The fused HDPE pipe was placed and set in position within the trench with the backhoe. All pipe sensors were connected to data acquisition system located inside the site trailer and initialized.

During the evening of October 15, 42mm of rain was recorded at the site. This heavy rainfall caused the walls of the open trench to slump onto the HDPE pipe during the night and water to pond inside the trench. The trench was drained by opening the east end of the trench. Soil on the top of the pipe was removed and the pipe was taken out of the trench. All wet and soft soil was excavated until undisturbed subgrade was exposed. This excavation resulted in the trench wall to be widened and deepened to the geometry shown in Figure 4.

Granular “A” material was placed and compacted to a depth of 1.68m (5.5ft) below existing pavement grade. The pipe was placed back in the trench and all pipe sensors were checked and initial values recorded. Granular “A” material was placed over and around the pipe. To ensure that material was properly installed under the pipe haunches, granular material was rodded along the pipe sides. Using 150 to 200mm (6 to 8in) thick lifts, “Granular A” material, was compacted in the trench to subbase elevation - 600mm (2ft) below the pavement surface.This was followed by 300mm (12in) of compacted Granular B subbase placed using two lifts and 200mm (8in) of compacted Granular A. Trench reconstruction took approximately five hours. Due to the small quantity of asphalt required for the pavement restoration and year end commitments by the pavement contractor, pavement restoration was not completed until November 12, 2003. Final trench reconstruction consisted of compacting the Granular A base material and laying 100mm (4in) of HL3 asphalt in a single lift.

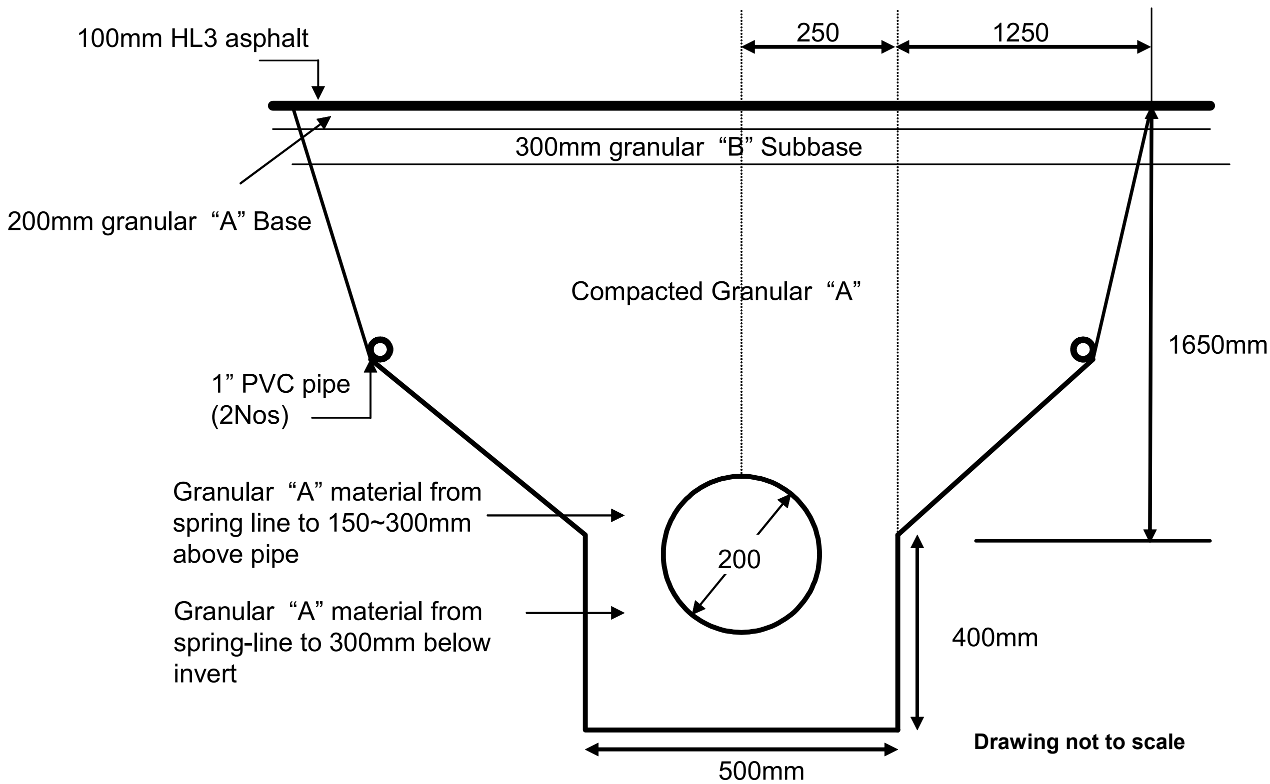

Figure 4: Open cut trench construction geometry and pipe location.

A detailed survey grid that extended 1.5m beyond the area of the pavement excavation (3m from the pipe centerline) was setup on the asphalt East and West lanes to measure pavement movements. The grid was surveyed prior to commencement of excavation and immediately following asphalt restoration.

To determine HDPE pipe performance during and following construction, linear displacement transducers, strain gauges, and a temperature probe were installed inside the pipe. Two 2m (6.6ft) long and one 1m (3.3ft) long PE pipe test sections were instrumented in the laboratory. Figure 5 shows the location of the test sections. Test sections were fused into the pipe sections so that they would be located under the East and West wheel path lanes (WL and EL) and the control test section (CO) would be located 2m outside the West traffic lane. One temperature probe was also placed inside Test Section 2 to record pipe temperature changes.

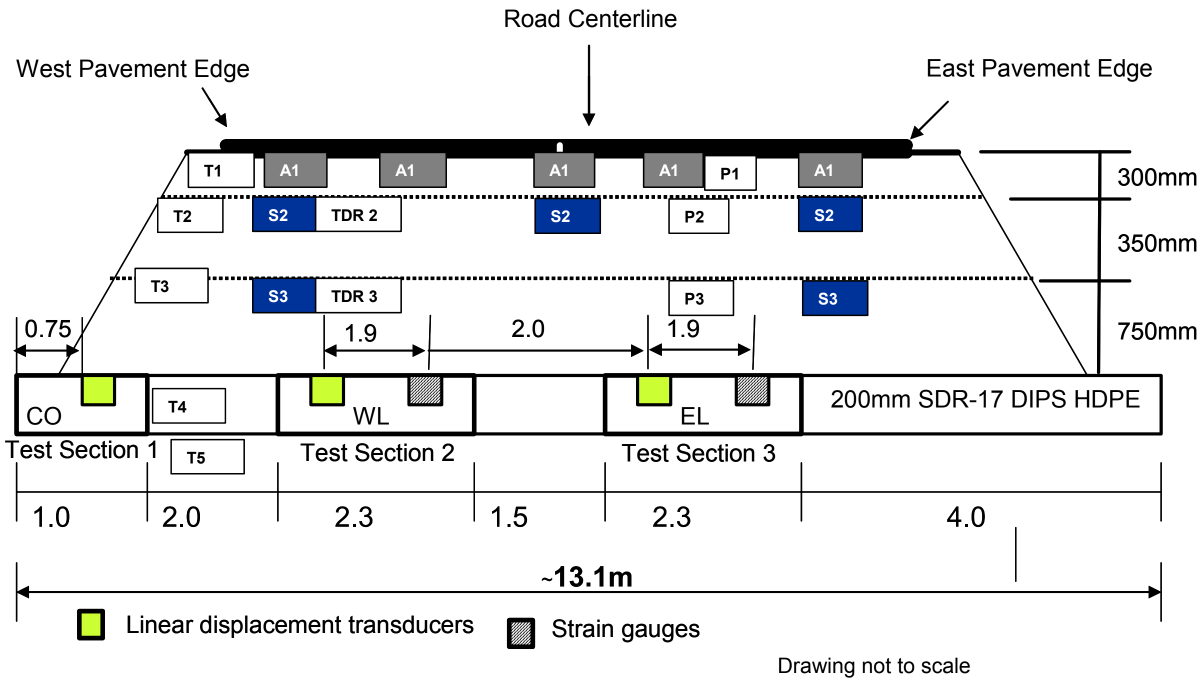

Figure 5: Open trench pipe installation test section and instrumentation locations

Eighteen sensors were installed in the pipe to monitor pipe deflections, temperatures changes and pipe strains during and following pipe installation and during traffic loading. Pipe vertical (0), horizontal (90) and oblique (45) deflections were monitored using three linear displacement transducers with a sensitivity of +/- 0.005mm. Test Sections 2 and 3 each contained strain gauges placed at the pipe crown, invert and at springlines. To determine temperature influences on strain gauge readings, one unconnected strain gauge was placed inside the pipe.

To measure, asphalt and soil strain, water content, ground temperature, and the traffic load vertical distribution, 19 sensors were installed in the trench backfill during reconstruction. Figure 5 shows the vertical and transverse distribution of the monitoring sensors installed under the West and East lanes at 150, 300 and 650mm below the asphalt surface. Earth pressure cells (P1 to P3) were installed to monitor the total vertical pressure on pavement layers and also to capture the dynamic stress response of the base and subgrade. Two RST TPC-9-S and one TP-12-S pressure cells (690, 345 and 172 kPa capacity) earth pressure cells were selected due to their small imprint size, measurement range, and capability to withstand hot mix asphalt temperature. To measure soil strains at the base/subbase interface and the subbase/subgrade interface, Geokon 3900 aggregate strain gages were installed (S2 and S3). To determine backfill volumetric water content, Campbell Scientific CS616 water content reflectometer probes (TDR 1 to TDR3) were installed. To measure soil temperature, Campbell Scientific Temperature probe 107B (T1 to T5) were installed. To determine asphalt strains, four Construction Technology Laboratory (CTL) H-type asphalt strain gages (A1) were installed at the base of the asphalt layer. All sensors were calibrated in the laboratory prior to installation.

All pipe sensor wires exit the west end of the trench and were fed through a 50mm plastic pipe vertical riser that was sealed water tight. Both ends of the HDPE pipe were also sealed water tight using rubber end plugs. All sensors, except for the water content reflectometer and temperature probes, are monitored using a SOMAT E-DAQ field computer data acquisition system. The water content and temperature probes are connected to a Campbell CR10X data acquisition system. During trench reconstruction, instrumentation readings were recorded at 10-second intervals. A deep-cycle battery continuously recharged by a solar panel powers the E-DAQ and CR10X field computer data acquisition system and the wireless router.

7 PAVEMENT DETERIORATION MONITORING

Pavement deterioration performance measures consisted of conducting distress, asphalt grid surveys, IRI road roughness profiles and FWD deflection surveys. In early October, 2003, Sensor & Software Inc. completed a ground penetrating radar (GPR) survey over HL3-1 prior to the open cut pipe installation. A second GPR survey was completed on November 26, 2003. Additional post pipe installation performance surveys are planned prior to and following seasonal events and clay hauls.

8 CONSTRUCTION HDPE RING DEFLECTIONS

Figures 6 and 7 show the HDPE pipe response during the HDD and open cut installation respectively.

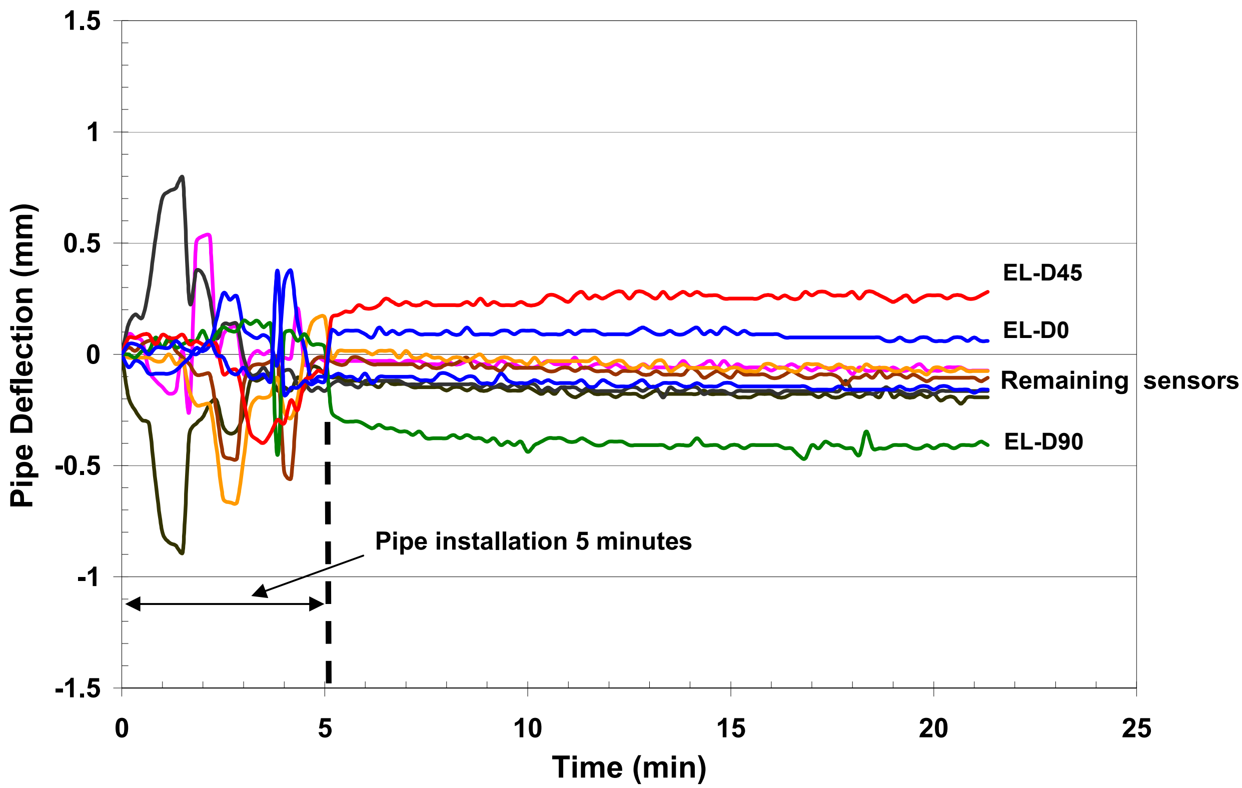

Figure 6: Horizontal directional drilled HDPE installation ring deflections.

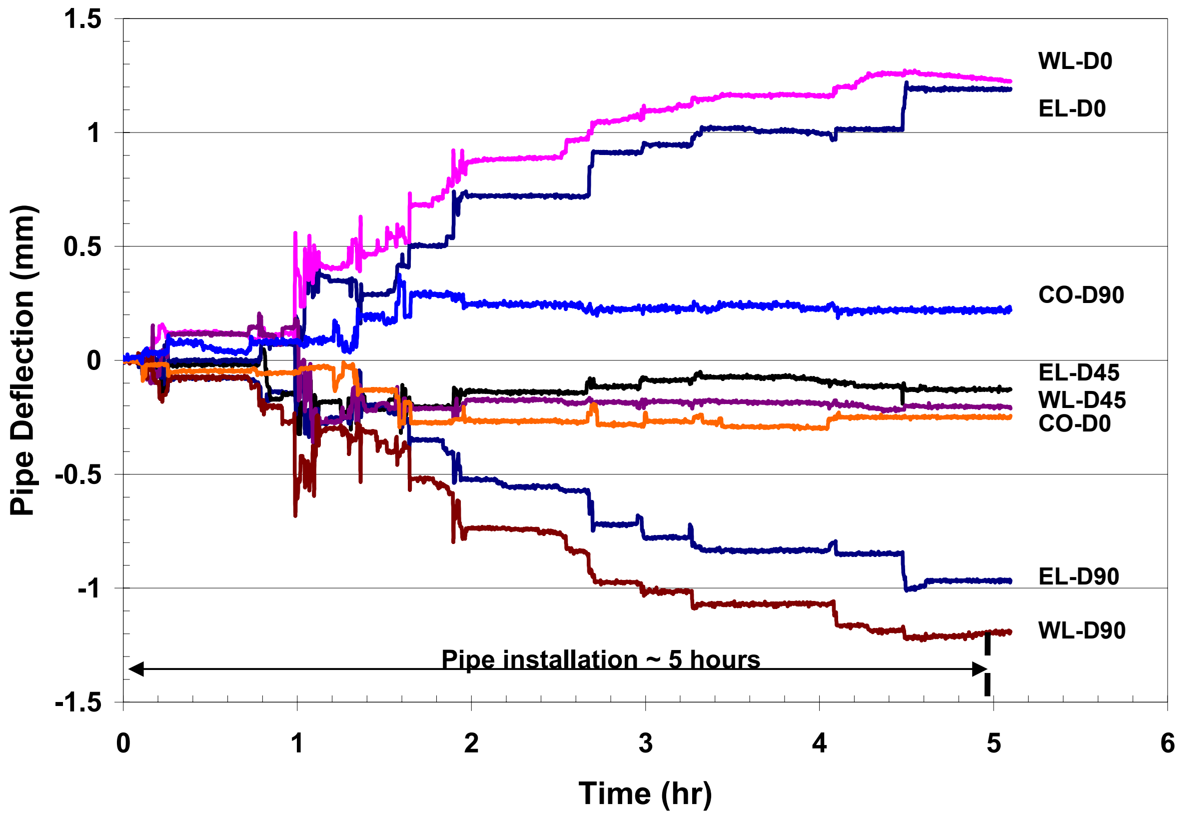

Figure 7: Open cut HDPE installation ring deflections.

Pipe deflection sensors are labeled using the labeling scheme:
EL - D90: Sensor location such as West or East Lane, (WL and EL respectively) or Control (CO) – sensor orientation in degrees with respect to the pipe crown (0 = vertical, 45 = oblique, and 90 = horizontal). Thus, deflection sensor EL-D90 is located under the east traffic lane and measures pipe horizontal ring deflection.

All deflection sensors were initialized to read zero prior to pipe installation. Positive and negative deflection readings indicate outward and inward pipe movement.

Figure 6 show pipe deflections during installation with a directional drill. Pipe deflections can be seen to be increase to a peak reading between ± 0.3 to 0.9mm then to decrease to zero during the first five minutes. Positive and negative pipe deflections are attributed to the bending of the pipe as it climbed up the road slope and curved to enter the bore path. Maximum pipe deflections were observed in Test section 1 (± 0.85mm). The symmetrical sinusoidal shape of the deflection readings indicate that the pipe deflected uniformly vertically and horizontally then returned nearly to its pre-installation shape.

After five minutes, all the deflection sensor readings became constant. The control test section and Test Section 2 located under the West traffic lane section indicate that the pipe diameter reduced uniformly by approximately 0.2mm due to the tensile force imparted by the drill rig and drill fluid/soil friction. This observation is consistent with pipe deflection data reported by Knight et al. 2002. Sensors under the East traffic lane (Test Section 3) show the greatest pipe deflection readings (EL-D45 = 0.3mm, EL-D0 = 0.1mm and EL D90 = -0.4mm). Test Section 3 was observed to rotate during installation approximately 45 degrees counter clockwise. This rotation resulted in sensors D0 and D45 rotating to measure oblique and vertical pipe deflections respectively. Pipe deflection measurements indicate that Test Section 3 diameter decreased horizontally and increased vertically by approximately 0.3mm. Thus, its cross section became oval shaped during installation.

Pipe deflections recorded during the open trench installation are shown in Figure 7. It should be noted that the time scale for the open-cut installation is hours compared to minutes for the HDD pipe installation. Based on Figure 7, the following observations were made:

- Pipe deflections are between ±1.2mm.
- Test sections under the West and East lanes show deflection with similar magnitudes and trends.
- At the end of construction, the control test section had significantly less pipe deflection (±0.3mm) than the West and East traffic lanes (±1.2mm).
- Pipe deflections occurred in steps. These steps correlate with trench restoration backfill placement.
- During pipe installation and trench restoration the pipe vertical diameter decreased while the horizontal diameter increased.

The control test section is located 0.75m from the pipe west end. The lower magnitude of pipe deflection in the controlled test section is attributed to the placement of the water tight plug into the pipe end.

Comparison of Figure 6 with Figure 7 suggests that HDD induced pipe deflections are approximately one-quarter smaller than those induced during open cut-and-cover installation. Both measured pipe deflections are small and within acceptable limits.

9 SUMMARY AND CONCLUSIONS

Two 200mm SDR-17 DIPS HDPE pipes were installed approximately 1.5m below the CPATT test track located at the Region of Waterloo waste management site. The objectives of these two pipe installations are to develop a better understanding of HDPE pipe performance under roadways and pavement deterioration when pipes are installed under roadways using horizontal directional drilling and open cut-and-cover pipe installation methods.

In April 2003, a 27m long HDPE pipe was installed using a horizontal directional drill. In October 2003, a second pipe was installed using conventional open cut-and-cover. During the HDD pipe installation, 24 sensors were monitored at 10-second intervals to record pipe performance (load, strain, temperature, and deflection), bore slurry annulus pressures, and the drill rig response. In October 2003, a second HDPE pipe was installed under the CPATT test track. To monitor the pipe performance, eighteen sensors were installed inside the pipe to monitor pipe deflections, strain and temperature. To monitor the soil backfill above the pipe 19 additional sensors were installed to measure the soil response to traffic loads. Using state-of-the-art data acquisition systems, a total of 61 sensor readings were recorded at 10-second intervals during the pipe installations. Post construction monitoring of the pipe, soil and asphalt pavement performance is carried out by monitoring 56 sensors at one-minute intervals. Pavement deterioration is quantified by completing IRI roughness profiles, FWD deflection, GPR, pavement elevation and distress surveys prior to and following construction.

Field monitoring results indicate that the HDD installed pipe has significantly lower ring deflection when compared to the open cut-and-cover pipe installation and that the HDD and open cut pipe deflection are very different – the HDD pipe decreased uniformly in diameter while the cut-and-cover pipe decreased in vertical diameter while its horizontal diameter increased.

10 ACKNOWLEDGEMENTS

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