# DIRECT COMPARISON OF HDD AND OPEN-CUT PIPE INSTALLATION UNDERNEATH FLEXIBLE PAVEMENT: PAVEMENT AND PIPE PERFORMANCE EVALUATION

Adedamola Adedapo (Graduate student, Department of Civil Engineering, University of Waterloo, Waterloo, ON, N2L 3G1, Canada.)

## ABSTRACT

A comprehensive study is being conducted to develop a better understanding of mechanisms that influence high density polyethylene (HDPE) pipe behavior and road deterioration when conventional open cut-and-cover and horizontal directional drilling (HDD) techniques are used to install utility pipes under flexible pavements. For direct comparison, two instrumented 200mm SDR-17 DIPS HDPE pipes were installed 1.5m beneath an asphalt paved roadway. Details of the construction and instrumentation are described. Some preliminary results are also presented and discussed.

## INTRODUCTION

Many of the underground utility networks in most urban areas have been functioning longer than their intended design life, with little or no maintenance. They are now in a state of serious deterioration. In Canada for instance, the estimated cost to bring the water mains and sewers to an acceptable level of service is 11.5 billion and 47 billion CDN, respectively. Despite the advantages and availability of many trenchless technology techniques for pipe installations and maintenance, 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. One of the reasons identified for the limited use of trenchless technologies by municipalities is limited or lack of documentation/information on the short and long term performance of trenchless technology installed utility pipes and their effect on adjacent utilities and structures such as pavement. Project owners, municipalities and decision makers are more familiar and comfortable using conventional cut-and-cover pipe installation technique even though many studies have suggested that utility cuts on flexible pavements reduce the pavement life and increase pavement maintenance and rehabilitation costs significantly. Trenchless construction techniques provides 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).

One of the goals of a new research initiative at the University of Waterloo is to promote the use of trenchless technology by demonstrating it viability and benefits for the replacement of utility pipe in urban areas thereby preventing the adverse effect of traditional installation technique of pavement infrastructure. A comprehensive study is being conducted to develop a better understanding of mechanisms that influence high density polyethylene (HDPE) pipe behavior and road deterioration when conventional cut-and-cover and horizontal directional drilling (HDD) methods are used to install utility pipes under flexible pavements. The research will provide project owners and municipal engineers with useful quantitative data on the performance and impact of the of the two installation techniques on pipe and pavement behavior.

Three primary objectives have been identified for the research. The first objective is to document HDPE pipe and soil response 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 Centre for Pavement and Transportation (CPATT) and the Centre for Advancement Trenchless Technologies (CATT). The field investigation program is described in this paper.

## DESCRIPTION OF PIPE INSTRUMENTATION AND INSTALLATIONS

Two instrumented 200mm SDR-17 DIPS HDPE pipes were installed 1.5m beneath an asphalt paved roadway, 16.7m (~55ft) apart. The pipe placement locations were selected to have similar vehicle speed, drainage and subsurface conditions.

The pipes consist of three instrumented test sections each fused with other pipe sections to form a longer string. The test sections were fused into the pipe sections so that they would be located under the West and East wheel path lanes (WL and EL) and a control test section (CO) located 2m outside the West traffic lane. In addition to these instrumented sections; the HDD pipe has a fourth test section located directly behind the pull head (PH). Using state-of-the-art data acquisition systems, HDD drill rig, pipe and pavement responses were measured every 10 seconds during pipe installation using 61 sensors. Post construction monitoring consisted of monitoring the pipe, soil and asphalt pavement performance using 56 sensors recording data at one minute intervals.

***HDD pipeline instrumentation***

The HDD pipe sensors, shown in Figure 1, consisted of six pressure transducers, nine linear displacement transducers, four strain gauges, one thermistor and a load cell. The linear displacement transducers measure pipe ring deflections, pressure transducers mounted flush with the outside of the pipe wall at 90 degree intervals records the bore slurry annulus pressure adjacent to the pipe and strain gauges were placed at the pipe crown, invert and at the springlines as shown in Figure 2(b) to record pipe tension and flexure. The 222kN pulling head load cell 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.

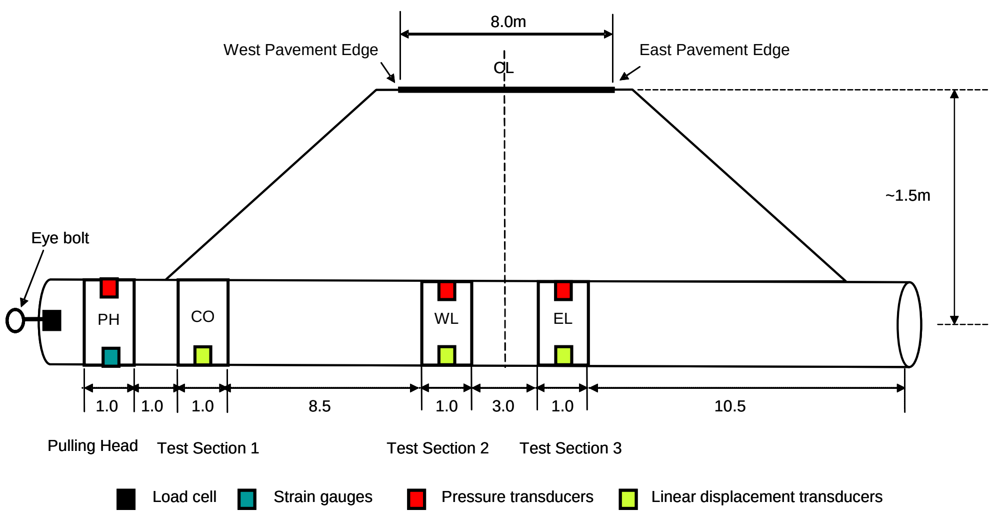



**Figure 1:** Layout of the 20 sensors placed inside the HDD installed pipe.

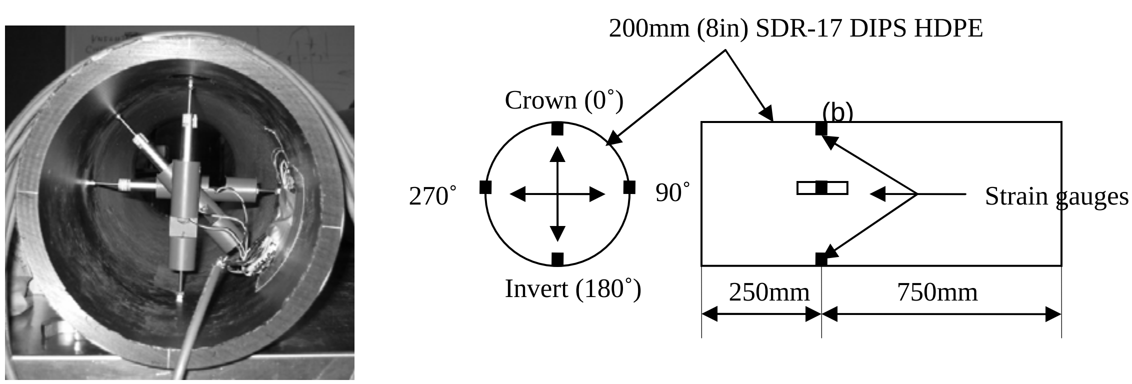



**Figure 2**: Position of Linear Displacement Transducers and Strain Gauges in the Test Sections.

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.

### *Conventional Cut-and-cover Pipeline instrumentation*

The Ontario Provincial Standard Specifications for Pipe Sewer Construction by Open Cut Method (OPSS 410) were followed for the conventional open-cut installation.

To determine HDPE pipe performance during and following construction, linear displacement transducers, strain gauges, and a temperature probe similar to HDD pipe instrumentation were installed inside the pipe. Figure 3 shows the location of the test sections. One temperature probe was also placed inside Test Section 2 to record pipe temperature changes. 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.

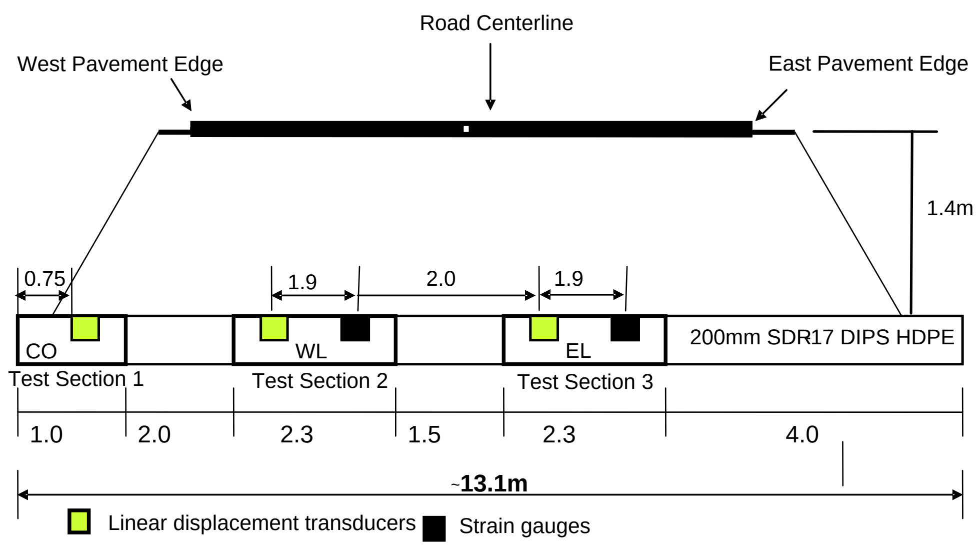



**Figure 3:** Open trench pipe installation test section and instrumentation locations.

## PAVEMENT PERFORMANCE MONITORING

To determine the influence of the pipe installations on the road performance International Roughness Index (IRI) survey, detailed GPR survey and FWD tests were completed on the pavement prior to and subsequently following the pipe installations. An elevation survey grid was also setup on the asphalt pavement surface; the grid was surveyed prior to, during, and following the completion of the pipe installations.

## PIPE DEFLECTION MEASUREMENTS DURING CONSTRUCTION

The change in pipe diameter recorded during the HDD and cut-and-cover installations are presented in Figures 4 and 5 respectively. Positive and negative deflection readings indicate outward and inward pipe movement.

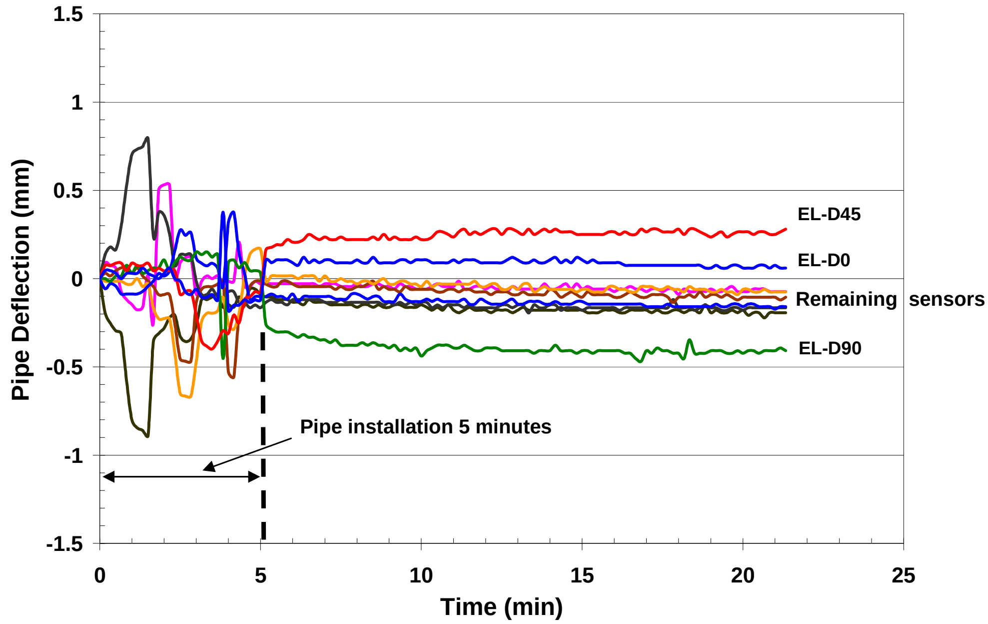



**Figure 4**: Horizontal directional drilled HDPE installation ring deflections.

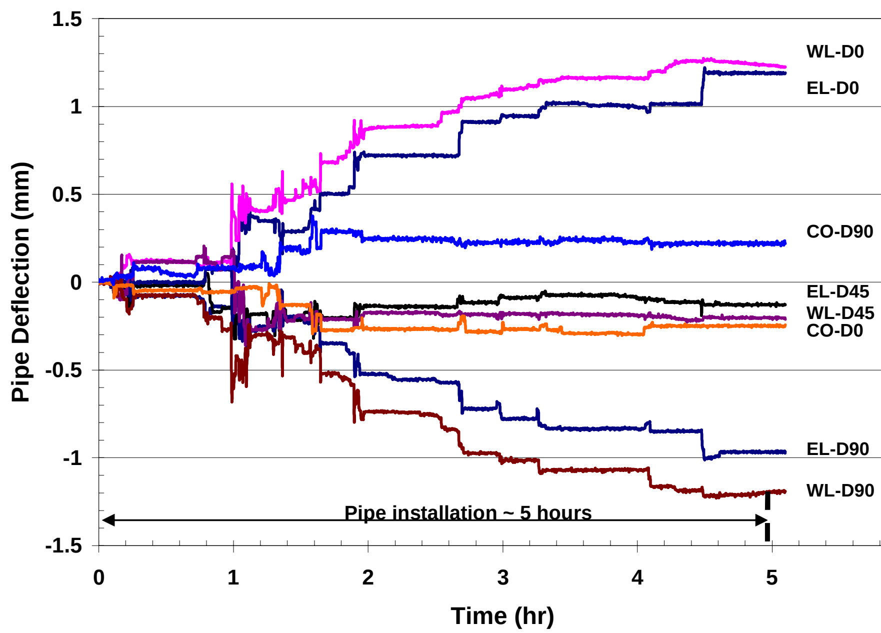



**Figure 5**: Open cut HDPE installation ring deflections.

Pipe deflection labeling scheme:

EL - D90

Sensor location: West Lane, East Lane, or Control section (WL, EL and CO respectively)

Sensor orientation: In degrees with respect to the pipe crown (0 = vertical, 45 = oblique, and 90 = horizontal).

For the directional-drilled pipe, maximum pipe deflections (± 0.85mm) were observed in test section 1 located behind the pulling head. These peak deflections are attributed to the bending of the pipe as it climbed up the road slope and curved to enter the bore path. It should be noted that the pipe deflected uniformly vertically and horizontally, then returned nearly to its pre-installation shape.
Pipe diameter reduced uniformly by approximately 0.2mm resulting from the tensile force imparted by the drill rig and drill fluid/soil friction in control test section and test section 2. 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. Deflection measurements in test section 3 suggest that pipe diameter decreased horizontally and increased vertically by approximately 0.3mm. Thus, its cross section became oval shaped during installation.

The pipe response to construction loading observed during open-cut installation differs from HDD; the step-like pattern shown in Figure 5 resulted from trench restoration backfill lifts and compaction. The maximum pipe deflections recorded are between ±1.2mm and appears to progressively increase with backfill height. At the end of construction, the control test section had significantly less pipe deflection (±0.3mm) than the test section located underneath the West and East traffic lanes (±1.2mm); the lower deflection is attributed to additional stiffness provided by a water tight plug/seal inserted at the pipe ends.

The deflection data suggest that construction induced pipe deflections in HDD pipe are approximately one-quarter smaller than those induced during open cut-and-cover installation. Both measured pipe deflections are small and within acceptable limits. It is also seen that the mechanism that control pipe ring deflection in directional–drilled and buried pipe differs significantly.

## CONSTRUCTION INDUCED PIPE STRAIN

Strain induced on the HDD and open cut installed pipes during construction are presented in Figures 6 and 7 respectively.

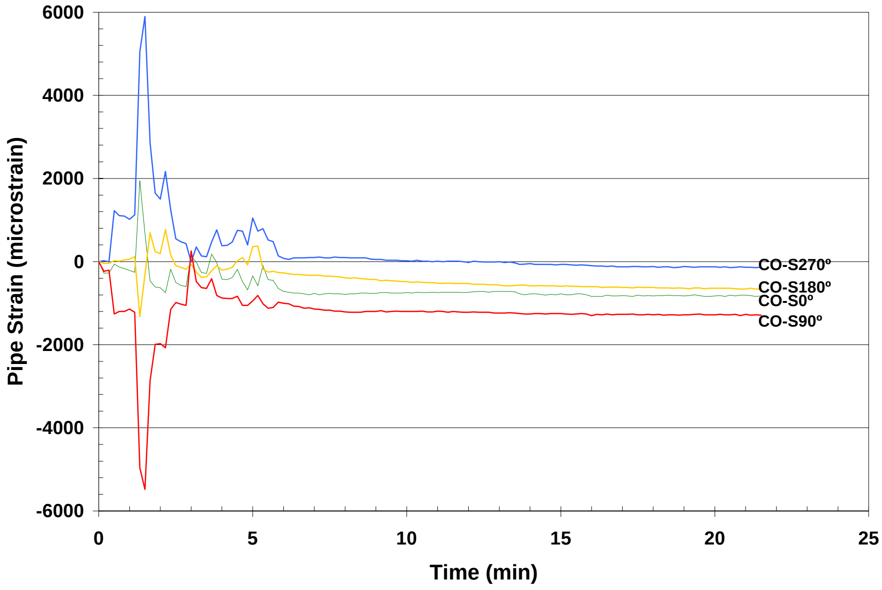



**Figure 6**: Horizontal directional drilled HDPE installation induced pipe strain.

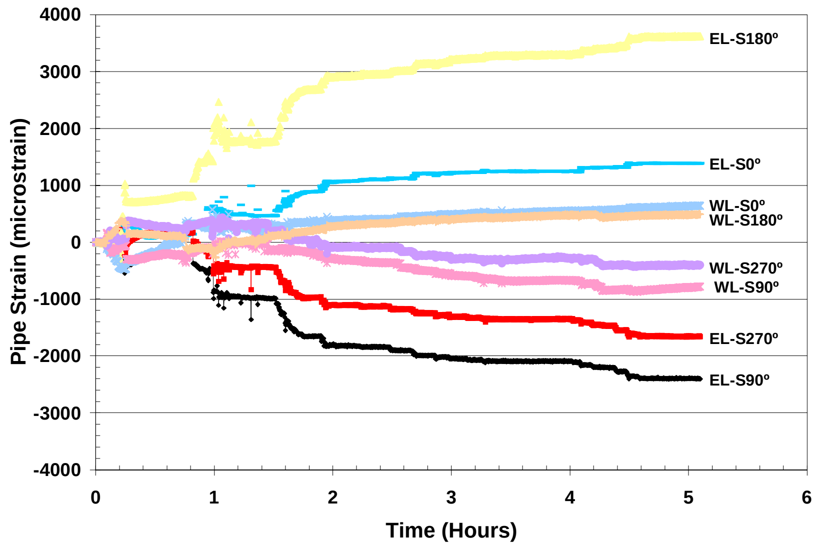



**Figure 7**: Open cut HDPE installation induced pipe strain.

Figure 6 shows the response of strain gauges located directly behind the butt cap. Axial and bending strains are induced as the pipe is pulled into the bore during HDD installation; the axial strains develop in response to axial loading (pulling forces) imparted by the drill rig while bending strains develop as the pipe is forced to negotiate changes in bore trajectories. As the pipe passed through entrance curve, strain gauges inferred to be at the top and bottom of the pipe (0˚ and 180˚ gauges) recorded strains that are about 0.15 and 0.2 percent, respectively. The strain gauges inferred to be along the pipe neutral bending axis (90˚ and 270˚ gauges) recorded strains as high as 0.55 and 0.6 percent, respectively. The slight difference in the magnitude each pair can be attributed to pipe rotation and the strain gauges not being located exactly at the top and bottom of the pipe. The bending strains were eliminated after the pipe completed the entrance curve leaving the pipe with mainly axial strain.

Pipe strains recorded during the open trench installation are shown in Figure 7. The mechanism that produced strain in open cut is very different from that of HDD. There is no axial load imposed on open-cut installed pipe and the pipe does not negotiate any bore trajectories. The bending strains experienced by the pipe are due to the overburden stress and compaction during trench restoration. The gauges were fixed appropriately unto the pipe to capture the strain resulting from the anticipated stress.
Unlike the observations reported during HDD, oppositely placed gauges (0˚/180˚ and 90˚/270˚ gauges) show similar trends, same signs and slightly different magnitude. Test Section 3 located under the East lane showed relatively higher strain, gauges placed 0˚ and 180˚ recorded maximum strain of about 0.14 and 0.36 percent, respectively and 90˚ and 270˚ gauges recorded 0.16 and 0.25 percent strain, respectively. Strain gauges in Test Section 2 underneath the West lane showed lower strains, gauges placed 0˚ and 180˚ recorded maximum strain of about 0.06 percent and gauges at 90˚ and 270˚ recorded 0.04 and 0.08 percent strain, respectively.

Similar to pipe deflections, pipe strain showed a step-like pattern; where each step corresponds to a backfill lift placement during trench restoration. Strain data showed that the crown and invert of the pipe are in tension inside while the springline was in compression inside during trench restoration and backfilled compaction.

The difference in magnitude of the pair gauges (0˚/180˚ and 90˚/270˚ gauges) can be a result of lack of symmetry of the compaction loading, heterogeneity or irregularity of the bedding, support and backfill material.

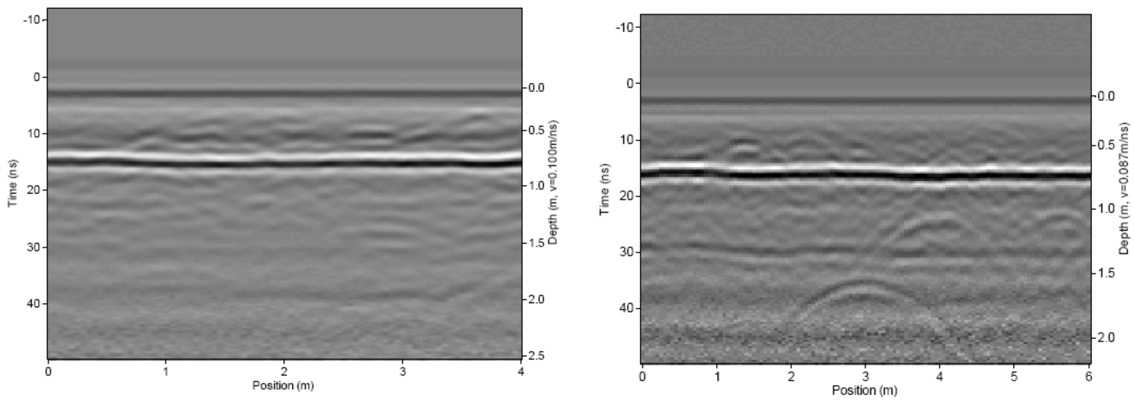
## ASPHALT PAVEMENT RESPONSE TO CONSTRUCTION LOADING

### *Ground Penetration Radar (GPR) Survey Data*

A SmartCart profiling system, which comprises of a Noggin 1000 and a Noggin 250 production control unit equipped with a Digital Video Logger (DVL-IIG) was used to acquire GPR data over the installations.

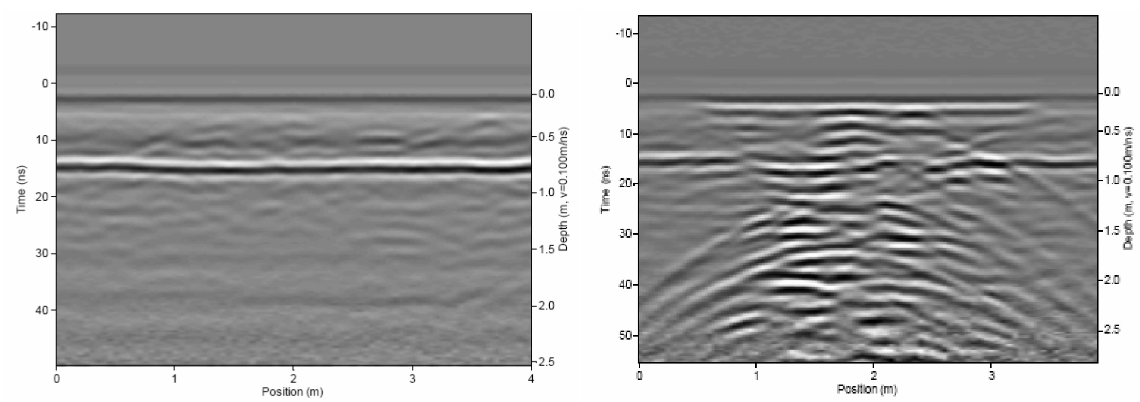
Grid surveys performed over the location of the HDD installed pipe are presented in Figure 8. Note the hyperbolic response from buried pipe at 1.5 m depth in Figure 8 (b). There appears to be no disturbance to the soil structure observable in the GPR data from the pipe installation.

GPR grid surveys performed at the location of the buried pipe prior and after the installation are presented in Figure 9. The GPR data collected at 250 MHz (Noggin 250) suggest that there is clear disturbance in the pavement structure resulting from the conventional buried pipe installation.




(a) Before installation (b) After installation

**Figure 8**: GPR section at the location of the HDD installed pipe




(a) Before installation (b) After installation

**Figure 9:** GPR section at the location of the open-cut buried pipe

***Surface distress survey data***

Visual examination of pavement surface distress or cracks at the vicinity of the pipe installations are conducted periodically. There have been no crack or other visible pavement distress at the HDD pipe location; the pavement surface condition remained unchanged two years after the installation.

There was a 24mm (~1inch) hump developed over the pavement as a result of trench restoration. The patch area has also started to show signs of distress after two winter seasons. As shown in Figure 10, the edge of the patch area is already detached form the rest of the pavement, infiltration of water into the pavement through the 12mm (0.5 inches) wide crack could subsequently leads to alligator cracking and cause structural damage.

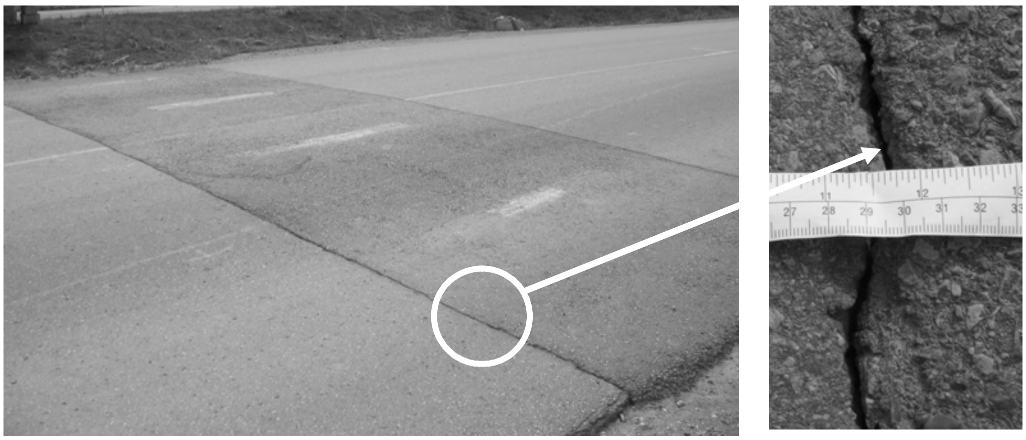


**Figure 10**: Pavement distress at the location of the pipe installed by conventional open-cut technique.

***Surface Elevation Survey Data***

Elevation surveys were conducted prior and after the installations to identify any pavement movement or deformation resulting from pipe installations. Pavement elevations surveys are also conducted periodically to monitor the long-term pavement deformation that may occur with time. Till date, there has been no significant change in the pavement elevation at the vicinity of the HDD installed pipe. There pavement elevation above the buried pipe has also not shown any substantial change, apart from the 24mm (~1inch) hump developed during construction. The serviceability and riding comfort of the roadway is affected by this hump. There has been a change in the pavement roughness at this location due to the hump.

**CONCLUSIONS**

A comprehensive study is been conducted to develop a better understanding of HDPE pipe performance under roadways and pavement deterioration when pipes are installed using horizontal directional drilling and conventional cut-and-cover construction techniques.

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 whiles the cut-and-cover pipe decreased in vertical diameter while its horizontal diameter increased.

The processes producing deformation and the pattern of stress/strain in Flexible PE pipes installed using HDD construction practices differs from those associated with buried pipe applications. During HDD installation pipe deformation is due to axial loading (pulling forces) and changes in bore trajectories as

pipe negotiates the entrance curve. Hence, axial strains develop in response to axial loading imparted by the drill rig while bending strains develop as the pipe is forced to negotiate changes in bore trajectories.
In the conventional cut-and-cover construction method pipe deformation is mainly due to backfill overburden and the compaction loadings resulting mainly in bi-axial deformation around the pipe.

GPR subsurface exploration data showed HDD did not caused any visible disturbance in the pavement structure while conventional pipe installation caused noticeable disturbance of the pavement structure.

Surface distress and elevation survey data indicated there has been no change in elevation, no crack or other visible pavement distress at the HDD installed pipe location; the pavement surface condition remained unchanged two years after the installation. The conventional buried pipe installation resulted in a noticeable hump in the pavement section; this resulted in the change of the International Roughness Index (IRI) which is a measure of the serviceability and riding comfort of the pavement.

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