The North American Society (NASTT) and the
International Society for Trenchless Technology (ISTT)
International No-Dig Show 2009

Toronto, Ontario Canada
March 29 – April 3, 2009

Paper E-1-03

ON GRADE LARGE DIAMETER DIRECTIONAL DRILLING

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ABSTRACT: Discussion of challenges and success criteria of large diameter, long distance on-grade HDD gravity sewer installations with a case study and trued solutions for design, risk mitigation, communication and configuration management. A contractor's perspective.

In a project that spanned over 5 years from its earliest conception to its final installation, the Fox Hollow Sanitary Sewer HDD HDPE on grade installation proved to be an example of the need for contractor collaboration from the planning and design phase right through to project closeout.

The project was initiated to install 312m of 660mm DIPS DR 9 HDPE at a 1.5%, grade crossing the Fox Hollow Ravine, a main London traffic artery (Wonderland Rd), passing directly adjacent to a 500 year old Attawandaron Indian Village and terminating in the west slope of Medway Creek / Snake Creek confluence (navigable waters) located in the Medway Valley Heritage Forest. The successful gravity installation would enable the decommissioning of an aged pumping station and support continued growth in the northern part of the city.

Utilization of magnetometer in an installation that was at its termination 21m below grade and the affects chamber construction staging had on the HDD process are examined and lessons learned are included in this discussion.

1. INTRODUCTION

In order to address the needs of athe future Fox Hollow housing development and in order to retire the existing Whitehills Pumping Station, a large diameter gravity trunk sewer was proposed. The site of the works was located in the Northwest London, Ontario. Bounded by Fanshawe Park Rd to the north, and book-ended by the Fox Hollow Ravine Park and Medway Valley Heritage Forest, an environmentally sensitive area.

The alignment of the sewer project connected existing sanitary sewers located west of Wonderland Road North to the existing Medway Valley Trunck Sanitary Sewer on the east side of Medway Creek. The route crossed beneath Wonderland Rd and along the north edge of the Museum of Ontario Archaeology parking lot and beneath Medway Creek. (Golders 2007) Wonderland Rd is a majory roadway in the London area connecting the burgeoning residential developments of North London to the commercial and business center in the center and south of the City. The Museum of Archaeology is situated directly adjacent to a 500 year old Atawandaron Indian Village, home of a local summer children's camp.

The trenchless portions of the work were closed to pre-qualified vendors.

This paper presents construction challenges and innovative means and methods used to overcome these challenges resulting in a successful HDD installation. These challenges included managing drilling fluid pressures to prevent hydrofracture in the area immediately adjacent to Medway Creek, issues associated with high torque on the drill string following an extensive delay in the construction process, coordination construction with other project work in the vicinity of the creek, installing the product pipe without the use of buoyancy control measures, and difficulties associated with using a project specified magnetometer guidance tracking system to complete the gravity installation of the sanitary sewer in an area where sheetpiles were to be driven.

2. THE LAYOUT

The layout as earlier referecend included a narrow corridor, through environmentalls sensitve, well travelled public parkland, the backyards of local residents, through an ancient Indian village and terminating in a second environmentally sensitive area.

The varying elevation at first view seems to provide a level of difficulty to the work. The reality is the wear and tear on a walkover technician. While a wireline geomagnetic tracking system was used, walkover readings were planned to confirm line, grade and depth. The utilized system supported this approach. While in field, the depth of the bore proved to exceed the capacity of the system and walkover readings were infrequently made as a the variance in refining was too great to provide satisfactory conclusions. The extreme depth of the bore was beyond the ideal walkover range of available survey equipment.

Based on operator experience with adressing wide variances, affirmation of line and grade was suitable when aligned with the computational results from the geomagnetic tracking software.

Figure 1. Topogorapy of Fox Hollow Sanitary Trunk Sewer (Source Google Maps)

3. EARLY DESIGN CONSIDERATIONS

Trenchless technologies considered as potential methods to construct the proposed sanitary sewer included horizontal directional drilling, microtunneling, pipejacking (using handmining or machine excavation) and conventional tunneling. HDD was selected as the best alternative to complete the installation.

Tunneling / Pipejacking / Microtunneling

An initial consideration was to tunnel the length of the required installation. This approach was deemed costs prohibitive when aspects of lining and retrieval logistics proved overwhelming. Costs estimates escalated to 7 times the final trenchless cost applied to the HDD method.

The distance and varying soils (wet and saturated) to be covered by pipe-jacking also proved cost prohibitive. Coupled with excessive duration requirements and low success rate expectation this method was eliminated from further consideration.

Auger Boring

During the early process, various contractors collaborated with the design team. One contractor suggested the auger bore methodology. This was reviewed and other collaborating contractors advised that the length of the bore was beyond the capabilities of conventional boring equipment when considering the line and grade accuracy requirements of the project. A 1% variance was contractually stipulated.

Additional Soils Reports

Additional soils reports were commissioned, the primary purpose to validate the initial reports and to provide a greater depth analysis of the soils. Earth Boring recommended a second soils report to corroborate the initial report and to enable the design engineer and contractor to develop a more comprehensive tender document

Pre-Qualification

During the early design it was determined that the trenchless sub-contractors would be pre-qualified prior to the release of the tender documents. The successful pre-qualified sub-contractors would be named in the contract documents.

By pre-qualifying the trenchless contractor the owner mitigates several factors of risk. The greatest risk mitigation is that the owner can be satisfied of the technical expertise that is brought to the project. A large diameter on grade installation in an environmentally and historically sensitive area should not be the learning ground for an in-experienced contractor who shows up with an attractive although unrealistic price quote.

In this particular project the following items were considered:

Principal Project History	Provide proof of experience and include reference contacts
Personnel Experience	Sr personnel and experience
Safety	Documented safety policies and procedures
Propose Methodology	Based on supplied information, provide a road map for the proposed work
Equipment	Proposed for the work and whether it is owned or rented

Earth Boring pre-qualified for this work twice. The initial let was never concluded. Of interest was the second let included contractors that had neither similar experince nor suitable equipment.

The process was flawed and resulted in a challenging tender process.

HDD Right of Way in Fox Hollow Valley

Figure 3 and Figure 4 represent the 'business end' layout of the proposed installation. The bore was to originate from S2 and conclude at S3. The intermidate component, just a long sloping line.

Two immediate challeges were prevalent, right of way at S2 and S3. Manhole S2 is situated in the valley immediately to the west of Wonderland Rd., a highly travelled artery for London.

In order to accommodate set back room for the selected HDD equipment (configuraiton used for this work) is 9:1. This ratio, developed in consideration of the work at hand, bend radius of the drill string and company experience, could not be accomodated in the span of the valley. Complicating matters was the existing 1800mm culvert that transversed the pilot bore and the existing sanitary that ran at the west edge of the valley. To address the culvert matter the HDD rig was cut in below grade (Figure 2). The pilot bore was brought to the west edge of the 1800mm culvert. A hole was properly cored through both sides of the culvert and a 12" pipe installed to accodmodate the string through the culvert. Both ends were parged and the area backfilled.

Figure 2. Machine Cut below grade to accommodate short distance to MH

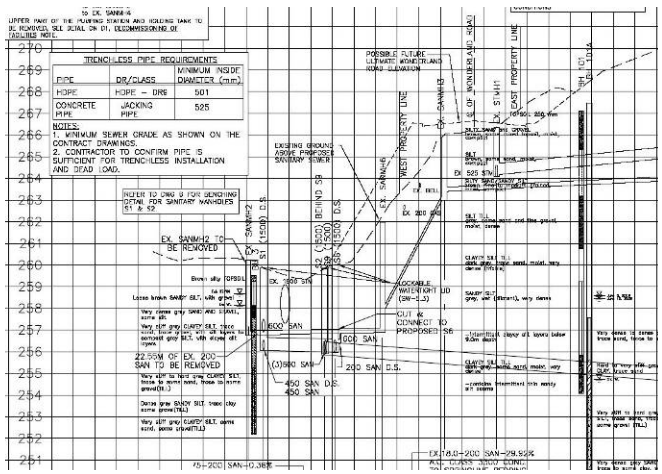

Figure 3. – Plan and Profile for Set-Up (Layout 1.jpg)

4. GETTING STARTED

As Earth Boring Forces were mobilizing to the field, the first pre-construction meeting was in progress. Immediately preceding the meeting, a discussion was held with the contractor, in part to acknowledge appreciation that the shaft at S2 was already installed, and at the same time to remind them that utilization of a magnetometer required a 'steel free' environment for calibration. The steel boxes of the shaft at S2 would adversely impact the calibration of the head. Earth Boring advised that the head could and would be calibrated in the park – some 200m east of the HDD staging area. During the course of the following meeting, Earth Boring advised the stakeholders of the method of installation, staging and expected duration. As that item was covered in the agenda, the next portion included the preparation of S3, the termination of the pilot bore. A detail drawing was presented for a well engineered retaining wall, complete with 20m earth anchors at all manner of angle of installation. The magnetometer would fail on approach.

To summarize a lengthy process, it was determined that sheet piling would begin for S3 but would be limited to perimeter areas. Earth Boring was directed to commence the pilot bore and terminate in a small 3m by 3m excavation. Upon approach, Earth Boring would be required to excavate, burn a hole through the installed sheeting and pass the pilot bore outside the retaining structure. After the completion of the pilot bore and the start of the initial back ream pass, the retaining structure would be completed, and the earth anchors installed.

At right is the Plan and Profile for the outfall to MH S3

Figure 4 and a second drwg (Figure 3) were made available at the time of tender. Other aspects of the dwg package were not released as deemed not relevant to the drilling project. This is a challenging issue – as in many contracts the HDD work consitutes a minor part of the work. At early design phases a timber and steel skeleton support frame was discussed with the design team to accommodate the break out and pullback at S3.

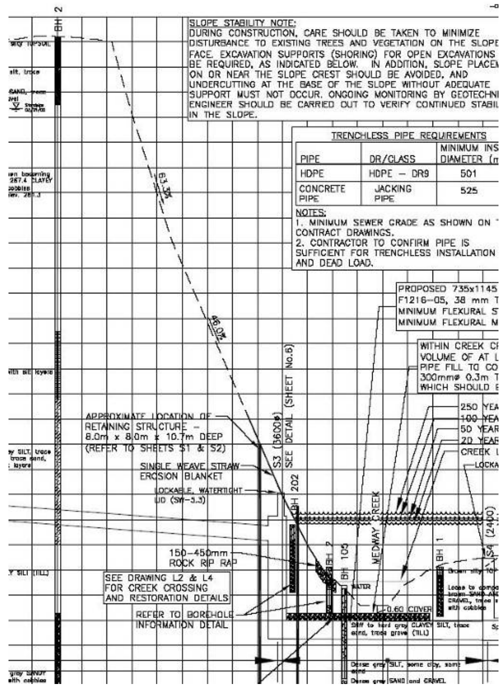

Figure 3. MH S3 – Medway Creek

Earth Boring extended the pilot bore by an additional 30m (accommodate design change) and proceeded with an initial back ream. Size considerations for the initial reamer pass were limited to the confines of the small receiving pit and modified HDD best practices. The project soil engineer directed that the area be backfilled during the back-ream operation. After flow and mud properties were explained (initially outlined by Earth Boring in requisite submittals) the engineer limited the operation to the installation of big ‘O’ pipe for slurry management. A 3.5m section of 600mm big ‘O’ pipe was vertically installed and from this installation the slurry was to be managed. Many of the directions issued by the soils engineer were confounding to HDD experience and best practices.

The Pilot Bore

Utilization of the magnetometer was the atypical aspect of this installation. The steering tool calibration had to be carried out in a remote part of the bore path as the sending trench boxes had already been installed. The project inspector was given a glimpse into the sensitivity of the tool early in the process. As the magnetometer lay beneath Wonderland Rd., (11m below grade) variances in the electronic display of azimuth could be detected. On occasion, the tool would appear to bend south, then to the north. The inspector began to question the integrity of the steering tool. His attention was directed to Wonderland Rd as traffic proceeded. As traffic moved from the south to the north, the electronic representation of the tool head would flicker south then to the north. The opposite happened with traffic moving from north to south. The field forces let him watch for a while, then a look of wonder was noted. It was the steel in the cars causing the sensitive tooling to react as it did. He was amazed at the sensitivity of the tool. There were no further questions with regard to the issue of the earth anchor installation sequence.

As noted previously the extreme depth precluded effective wall over verification once the pilot bore exited the Wonderland Rd ROW. Confidence in location was achieved by the feedback of the magnetometer and its software and Earth Boring locating best practices. Figure 5 profiles the azimuth and grade of the installation.

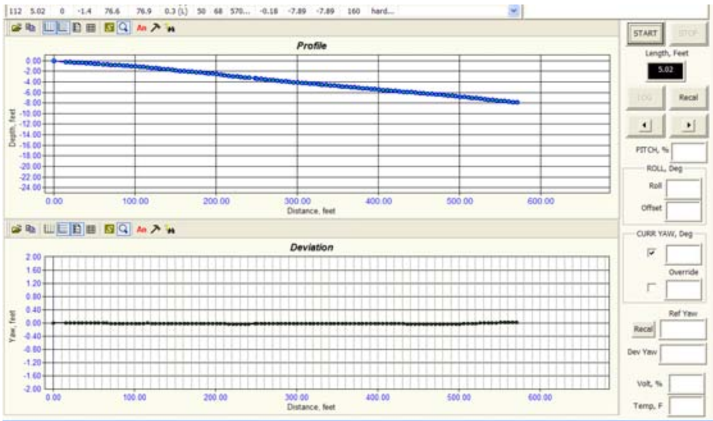

Figure 5 Profile of Bore

Azimuth Deviation and Profile are representative of the bore as the steering tool exited the sending shaft at S2. The last several readings were made at 1.5m intervals as part of Earth Boring best practices.

<u>The Wait</u>

At the completion of the pilot bore and the initial ream, Earth Boring returned the drill string to within 25m of the ongoing retaining works. The work on the retaining structure took 6 weeks to complete. Initially, Earth Boring was assured by all stakeholders that duration would be 2 weeks maximum. During this period of time the drill string was periodically rotated and moved through the initial ream hole. The excessive wait was due to the challenges the earth anchor installation company faced for their work package. In short, the ground was harder than they understood it to be.

The resulting impact was a snapped drive shaft on the HDD rig. The swelling of the hole reached critical mass and caused a squeeze so great as to fail the rotational shaft. Fortunately, the designed failure happened in a planned failure location, saving the drill string from down-hole ruin.

Figure 6 HDPE Pullback

Upon completion of the initial stages of the retaining structure, Earth Boring commenced its final reaming pass and subsequently connected the carrier pipe for pullback. The pullback operation commenced at 10am and was complete at 5pm that evening. Figure 6 shows the pipe in early stages of pullback. The remaining retaining structure would be built around this installation and would extend another 3m below the invert of the pipe pictured.

5. GEOTECHNICAL CONDITIONS

The geotechnical conditions along the alignment were characterized by 13 boreholes, completed to various depths below the proposed sanitary sewer invert. The typical subsurface conditions consisted of surficial deposits of topsoil and fill overlying deposits of sands, sands and gravel, and silt overlying various depositional sequences of glacial till and silt. Alluvial deposits of sand, sand and gravel, and silt were found adjacent to Medway Creek (Golders 2007). The majority of the HDD bore was located within silt, and clayey silt/silty clay layers. The groundwater table was identified as being between 3 and 4 metres above the proposed invert of the sanitary sewer for the majority of the alignment.

As part of the Contractor Submittal Process, a series of design calculations were produced for the project. These include an installation induced load and stress analysis, unconstrained buckling analysis, and a hydrofracture analysis. The pullback force/installation load analysis was determined based on the method proposed by Duyvestyn (2009). This method replaces the hydrokinetic drag component of the drilling fluid/slurry flow with equations characterizing the flow of the drilling fluid within the annular space between the bore and the outer surface of either the product pipe or the drill pipe. Greater detail can be found in Duyvestyn (2009).

Figure 7 summarizes the predicted and observed installation loads for this project. The maximum load observed during installation was approximately 95,000 lbs. Figure 7 also displays predicted loads based on ASTM F 1962 and a method developed for the Pipeline Research Committee at the American Gas Association referred as the AGA method (Huey et al. 1996).

An added benefit of the method found in Duyvestyn (2009) is that the analysis can be tailored to determine the bore pressure throughout any of the drilling process (i.e. pilot bore, reaming or pullback stage) along any portion of the alignment. For this project, this analysis proved valuable in assessing the risk of a hydrofracture during the pilot bore and reaming stages due to the increased hydrofracture risks associated with drilling downslope and the drastic change in depth of cover in the vicinity of Medway Creek. The estimated bore pressures were compared to predictions of the allowable bore pressure for the overlying soils based on the Delft Geotechnics method (Staheli et al. 1998). The allowable bore pressures were divided by the required bore pressure estimates to determine an estimate of the true factor of safety against hydrofracture. The results of this analysis are summarized in Figure 7. During pilot bore drilling care was taken to decrease the volume of drilling fluids injected through the drill pipe and into the bore in the vicinity of Medway Creek. Decreasing the volume of drilling fluid pumped into the bore resulted in no hydrofracture event in the vicinity of Medway Creek. It should be noted that a small hydrofracture was observed in the vicinity of the entry location where lower factors of safety were calculated. However, this hydrofracture event was very short lived.

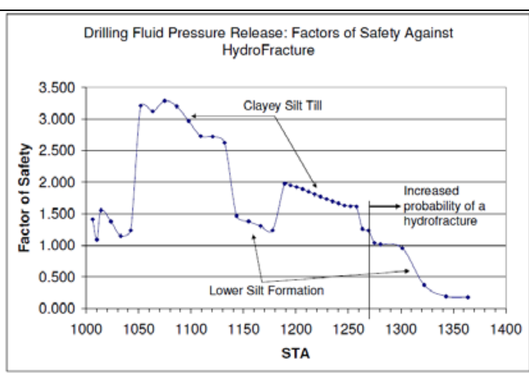

Figure 7. Estimated factor of safety during pilot bore drilling.

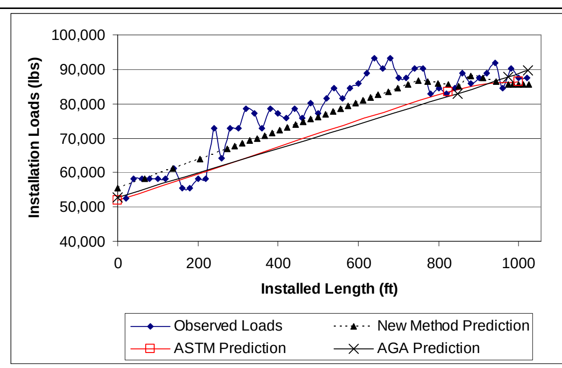

Figure 8. Observed and predicted loads during pullback operations

6. CONCLUSIONS – LESSONS LEARNED AND CONSIDERATIONS FOR SUCCESS

The complete works has not been resolved at the time of writing. Issues are still outstanding with respect to settlement concerns. Other aspects of the works have provided for the following observations:

1. Large scale HDD project owners and designers should seek to include participation from all stakeholders from conceptualization, to plan and design and in field resolution.
    a. Initial efforts for a collaborative approach fell short as key aspects of the design where not shared with the HDD contractor.
    b. Contractor needs to be advised for all related structures and appurtenances related to the general HDD operation

2. Soils Report - Well founded, well documented and well understood by all stakeholders. Money spent on soils reports should be considered sound risk mitigation planning. The relational costs to money spent here v.s. those spent when soils issues are discovered are inverse.

3. Designers of HDD Intensive works must educate and immerse themselves in the planned technology, or contract a reputable firm to provide this function. Simply stating in a tender 'trenchless methods' without the work being let as a design build indicates that the tender author does not know what they want and leaves the process open to error and omission.

4. Contract Administrators should also be educated in the technologies employed within contracts under their domain. A mere familiarity is not sufficient in large diameter on grade installations.

5. Pre-Qualification of Contractors works and should be a consideration in all large scale HDD projects.

    a. References should be checked
    b. Ensure the contractor has the equipment noted
    c. Provide the rating system for the selection criteria

6. Magnetometers have the potential of becoming a key component of on grade large diameter installations

Success is measured in various ways. Typically, schedule, cost and satisfaction are the top indicators of success. This project was in many ways successful despite the differences held by stakeholders. The contractor was able to overcome challenges resulting from the stakeholder's lack of knowledge of the HDD process. The adaptability of experienced HDD contractors figures prominently in the on grade, on line, on time completion of HDD projects.

7. REFERENCES

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