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## FOUNDATION INVESTIGATION AND DESIGN REPORT

**Sewer Replacement at Station 23+134, Highway 400  
NBL Rehabilitation Between Highway 11 and Highway  
93, Simcoe County, G.W.P. 2039-06-00**

**Submitted to:**  
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REPORT



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# **PART A**

**FOUNDATION INVESTIGATION REPORT  
SEWER REPLACEMENT AT STATION 23+134  
HIGHWAY 400 NBL REHABILITATION  
BETWEEN HIGHWAY 11 AND HIGHWAY 93  
SIMCOE COUNTY  
G.W.P. 2039-06-00**



## **1.0 INTRODUCTION**

Golder Associates Ltd. (Golder) has been retained by Morrison Hershfield Limited on behalf of the Ministry of Transportation, Ontario (MTO) to provide foundation engineering services in support of the rehabilitation of Highway 400 northbound lanes (NBL) between Highway 11 and Highway 93 in Simcoe County, Ontario. Foundation engineering services are required for the following elements on this project:

- Culvert extensions and replacements;
- Replacement of a sewer crossing by trenchless (tunnelling) methods; and
- Widening of deep cuts and high fill embankments.

This report addresses the replacement of an existing storm sewer, located at Station 23+134 in Vespra Township, using trenchless methods.

The terms of reference and scope of work for the foundation investigation are outlined in MTO's Request for Proposal (RFP) dated May 2008, and in Section 6.8 of MH's *Technical Proposal* for this assignment (Golder's Proposal No. P81-1610).

## **2.0 SITE DESCRIPTION**

The sewer crossing at Station 23+134 is located under the Highway 400 northbound lanes, approximately 2 km north of Partridge Ski Trail Road and 2.2 km south of County Road 11 (Forbes Road) in Vespra Township, in Simcoe County, Ontario.

The existing sewer at this site crosses under the Highway 400 NBL, extending from the centre median to the east side of the highway embankment. The existing sewer is 610 mm in diameter and 26.5 m in length. The invert elevation of the existing sewer is understood to be at approximately Elevation 286.4.

In general, the terrain in this area is relatively flat and poorly drained. The natural ground surface in the immediate vicinity of the site varies from about Elevation 285 m to 286 m. The Highway 400 NBL embankment is up to about 3 m in height, with the pavement grade at approximately Elevation 288.4 m at the sewer crossing site.

## **3.0 INVESTIGATION PROCEDURES**

The field work for this subsurface investigation was carried out in October 2009, at which time two boreholes (Boreholes 09-S-01 and 09-S-02) were advanced using a Diedrich D-125 track-mounted drill rig, supplied and operated by Walker Drilling of Utopia, Ontario. Boreholes 09-S-01 and 09-S-02 were advanced at the locations shown on Drawing 1, in the median and on the east side of Highway 400 NBL, respectively.

Soil samples were obtained at 0.75 m and 1.5 m intervals of depth in the boreholes, using a 50 mm outside diameter split-spoon sampler in accordance with the Standard Penetration Test (SPT) procedure. The groundwater conditions in the open boreholes were observed during the drilling operations. The boreholes were



backfilled to ground surface using bentonite, in accordance with Ontario Regulation 128 (amendment to Ontario Regulation 903).

The field work was supervised full-time by a member of Golder's technical staff who located the boreholes in the field, directed the drilling, sampling, and in situ testing operations, and logged the boreholes. The soil samples were identified in the field, placed in labelled containers and transported to Golder's laboratory in Mississauga for further examination and laboratory testing. Index and classification tests (water contents, Atterberg limits and grain size distributions) were carried out on selected soil samples. All geotechnical laboratory testing was completed to ASTM and MTO LS standards, as applicable.

The borehole locations and ground surface elevations were measured by Sharon Layout & Design Ltd. of Sharon, Ontario. The borehole locations, including MTM NAD83 northing and easting coordinates and ground surface elevations referenced to geodetic datum, are summarized in the following table and are shown on Drawing 1.

Borehole No.	MTN NAD83 Northing	MTN NAD83 Easting	Ground Surface Elevation	Borehole Depth
09-S-01	4,924,459.7 m	290,426.7 m	287.9 m	6.6 m
09-S-02	4,924,469.7 m	290,449.0 m	286.5 m	9.8 m

## **4.0 SITE GEOLOGY AND SUBSURFACE CONDITIONS**

### **4.1 Regional Geology**

This section of Highway 400 is located within the physiographic region known as the Simcoe Uplands, according to *The Physiography of Southern Ontario* (Chapman and Putnam, 1984).

The general topography within the Simcoe Uplands consists of sloping till (moraine) plains. The surficial soils in this region consist of sandy silt to sand and gravel, representing shoreline deposits of a former glacial lake that once flooded the area, overlying a glacial till deposit. Surficial deposits of clayey silt to silty clay are also present adjacent to current and former streams.

### **4.2 Subsurface Conditions**

Two boreholes were advanced to investigate the subsurface conditions at the sewer crossing site. The detailed subsurface soil and groundwater conditions encountered in the boreholes and the results of in situ and laboratory testing are given on the borehole records following the text of this report; the results of laboratory testing are also presented on Figures B1 to B6, which are contained in Appendix B following the text of this report. The stratigraphic boundaries shown on the borehole records are inferred from non-continuous sampling and, therefore, represent transitions between soil types rather than exact planes of geological change. The subsoil conditions will vary between and beyond the borehole locations.

The interpreted stratigraphic conditions at the sewer crossing site are shown on Drawing 1. In general, the soils encountered at the site consist of embankment fill overlying a deposit of very stiff to hard clayey silt till, which is underlain by an interlayered deposit of silt and clayey silt. In Borehole 09-S-01 in the centre median, thin



surficial deposits of stiff clayey silt and compact to dense sand and silt were encountered below the fill and on top of the clayey silt till.

A more detailed description of the subsurface conditions encountered in the boreholes is provided in the following sections.

#### **4.2.1 Topsoil**

Approximately 100 mm to 200 mm of topsoil was encountered immediately below the existing ground surface in both boreholes.

#### **4.2.2 Sand to Silty Sand Fill**

Fill associated with the existing Highway 400 NBL embankment was encountered below the topsoil in both boreholes. The fill is about 1.9 m and 1.3 m in thickness in Boreholes 09-S-01 and 09-S-02, respectively, with the base of the fill encountered at Elevations 285.8 m and 285.1 m.

The fill consists of sand containing trace to some silt to silty sand, containing trace to some gravel. The fill also contains organic materials, and pockets and/or layers or lenses of clayey silt. The results of grain size distribution tests carried out on two selected samples of the fill are shown on Figure B1 in Appendix B. The natural water content measured on selected samples of the fill ranges from 11 to 20 percent.

The Standard Penetration Test (SPT) “N” values measured within the fill range from 3 to 26 blows per 0.3 m of penetration, indicating a variable, loose to compact relative density.

#### **4.2.3 Upper Clayey Silt**

A 0.8 m thick layer of clayey silt was encountered below the fill in Borehole 09-S01. The surface of this deposit was encountered at a depth of 2.1 m below ground surface (Elevation 285.8 m).

The deposit consists of clayey silt with sand, containing trace gravel and seams of sand and silt; the result of a grain size distribution test conducted on the recovered sample of the clayey silt deposit is provided on Figure B2 in Appendix B. Atterberg limits testing carried out on the recovered sample of this deposit measured a plastic limit of 10 per cent, a liquid limit of 15 per cent, and a corresponding plasticity index of 5 per cent. These results, which are plotted on a plasticity chart on Figure B3 in Appendix B, indicate that the deposit consists of clayey silt of low plasticity. The natural water content measured on the sample of clayey silt was 11 per cent.

The measured SPT “N” value within the clayey silt was 13 blows per 0.3 m of penetration, suggesting a stiff consistency.



#### **4.2.4 Upper Sand and Silt**

A 1.5 m thick layer of sand and silt was encountered underlying the fill and upper clayey silt at a depth of 2.9 m below ground surface (Elevation 285.0 m) in Borehole 09-S-01. The base of the sand and silt deposit extended to Elevation 283.5 m in this borehole.

The sand and silt contains trace clay and trace gravel; the results of grain size distribution tests carried out on two samples of the sand and silt deposit are provided on Figure B4 in Appendix B. The natural water contents measured on the recovered samples of the sand and silt deposit were 7 and 11 percent.

The measured SPT “N” values were 11 and 45 blows per 0.3 m of penetration, indicating that the sand and silt deposit has a compact to dense relative density.

#### **4.2.5 Clayey Silt Till**

A deposit of clayey silt till was encountered at a depth of 4.4 m (Elevation 283.5 m) below the sand and silt deposit in Borehole 09-S-01, and directly below the fill at a depth of 1.4 m (Elevation 285.1 m) in Borehole 09-S-02. Borehole 09-S-01 terminated within this deposit; penetrating it for a thickness of 2.2 m. The deposit is 6.7 m thick in Borehole 09-S-02, where it was fully penetrated.

This till deposit consists of clayey silt with sand, containing trace to some gravel; the result of a grain size distribution test carried out on one selected sample of the till is provided on Figure B5 in Appendix B. Atterberg limits testing was carried out on three selected samples of this deposit and measured plastic limits varying from 11 to 12 per cent, liquid limits varying from 19 to 28 per cent, and plasticity indices varying from 9 to 15 per cent. These results, which are plotted on a plasticity chart on Figure B6 in Appendix B, indicate that the till deposit generally consists of clayey silt of low plasticity. The natural water content measured on selected samples of the clayey silt till ranged from 7 to 14 percent.

The measured SPT “N” values within the clayey silt till range from 20 to 127 blows per 0.3 m of penetration, suggesting a very stiff to hard consistency.

#### **4.2.6 Interlayered Silt and Clayey Silt**

An interlayered silt and clayey silt deposit was encountered underlying the clayey silt till in Borehole 09-S-02. The surface of this deposit was encountered at a depth of 8.1 m below ground surface (Elevation 278.4 m). The borehole terminated in this deposit after penetrating it for a thickness of 1.7 m.

The natural water content measured on a sample of the interlayered silt and clayey silt was 11 per cent.

The measured SPT “N” value within this material was 71 blows per 0.3 m of penetration, indicating a very dense relative density/hard consistency.





#### 4.2.7 Groundwater Conditions

The open boreholes were observed to be dry immediately following completion of drilling. However, "perched" groundwater conditions were observed near the base of the fill in Borehole 09-S-01, with wet sand to silty sand fill materials encountered between approximately Elevation 286.9 m and 285.8 m. In addition, some perched groundwater should be anticipated within the sand and silt deposit that was encountered in Borehole 09-S-01, particularly during wet periods of the year.

Based on the observed colour change from brown to grey in the boreholes, it is anticipated that the groundwater level associated with the clayey silt till deposit at this site is at approximately Elevation 283.5 m; this depth is consistent with the water level measured in wells and piezometers installed in other boreholes in this area of the project.

The water level(s) at the sewer crossing site should be expected to fluctuate seasonally in response to changes in precipitation and snow melt, and should be expected to be higher during the spring season or during any period of heavy precipitation.

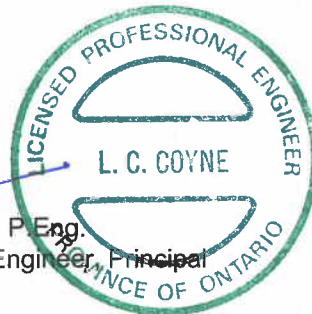
#### 5.0 CLOSURE

This Foundation Investigation Report was prepared by Ms. Nikol Kochmanová, EIT, and reviewed by Ms. Lisa Coyne, P.Eng., a geotechnical engineer and Principal with Golder. Mr. Fin Heffernan, P.Eng., a Designated MTO Contact for Golder, conducted an independent review of this report.

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# **PART B**

**FOUNDATION DESIGN REPORT  
SEWER REPLACEMENT AT STATION 23+134  
HIGHWAY 400 NBL REHABILITATION  
BETWEEN HIGHWAY 11 AND HIGHWAY 93  
SIMCOE COUNTY  
G.W.P. 2039-06-00**



## **6.0 DISCUSSION AND ENGINEERING RECOMMENDATIONS**

### **6.1 General**

This section of the report provides geotechnical/foundation design recommendations for the proposed replacement of the sewer crossing located at Station 23+134 in Vespra Township under the Highway 400 northbound lane between Highways 11 and 93. The recommendations are based on interpretation of the factual data obtained from the boreholes advanced during the subsurface investigation at the sewer crossing site. The interpretation and recommendations are intended to provide the designers with sufficient information to assess feasible crossing methods, and to design the sewer crossing. Where comments are made on construction, they are provided to highlight those aspects that could affect the design of the project, and for which special provisions or operational constraints may be required in the Contract Documents. Those requiring information on aspects of construction should make their own interpretation of the factual information provided as it may affect equipment selection, proposed construction methods, scheduling and the like.

### **6.2 Sewer Crossing Alignment and Pipe Material Options**

The new 600 mm sewer pipe is proposed to be installed over a total length of approximately 26.5 m extending from the median to the east side of the highway embankment. The invert of the existing sewer is understood to be at approximately Elevation 286.4 m, and it is understood that the replacement sewer could be installed at a similar elevation provided that appropriate cover can be achieved for trenchless methods. The interpreted stratigraphic conditions at the proposed sewer crossing location are shown on Drawing 1. Based on the borehole results, it is anticipated that the proposed sewer crossing will be installed through loose to compact sand to silty sand fill. Some “perched” groundwater was observed near the base of the fill, between approximately Elevation 286.9 m and 285.8 m, in Borehole 09-S-01.

MTO requires that the portion of the sewer pipe beneath the paved lanes and shoulders be installed within a larger diameter steel casing. Where jack and bore methods or pipe ramming methods are used, a steel casing would be used over the full length of the trenchless installation. To accommodate pipe installation and potential misalignment during casing advance, it is understood that the steel casing would typically be about 1.5 times the diameter of the sewer pipe; therefore, for a 600 mm diameter sewer pipe, a 900 mm diameter steel casing would be installed.

Based on MTO's Guideline for Foundation Engineering – Tunnelling Speciality, a minimum cover depth of 1.5 m is required for trenchless technologies to be implemented under 400-series highways. The Highway 400 NBL pavement grade is at approximately Elevation 288.4 m at the sewer crossing site. Therefore, to achieve a minimum cover depth of 1.5 m above the top of the 900 mm diameter steel casing, the proposed sewer should be installed with its invert at Elevation 286.0 m. Allowing for a 0.5 per cent cross fall from the median to the east ditch outlet, it is anticipated that the sewer crossing invert would have to be at approximately Elevation 286.1 m at the median inlet, and 285.9 m at the east ditch outlet.

The 900 mm diameter steel casing will remain in place, with the 600 mm diameter sewer pipe installed within the casing, and grout injected into the annular space between the sewer pipe and steel casing. The steel casing must be selected to support overburden and highway loads, hydrostatic pressures (if applicable), and to withstand the grouting pressure and installation forces. The overburden pressure may be calculated using a soil



unit weight of  $21 \text{ kN/m}^3$ . Hydrostatic (groundwater) pressures are not applicable at this site as the groundwater level is below the proposed sewer invert level.

### **6.3 Sewer Installation Methods**

It is understood that the Contractor will be responsible for choosing the method and equipment for the sewer crossing installation. The ground behaviour will be, in part, dependent on the installation method adopted, and this report provides guidance on the influence of ground behaviour on some possible sewer installation methods. It should not be construed that the Contractor is restricted to the particular methods considered herein, and in the event of alternative methods, the Contractor must make his own interpretation of the anticipated ground behaviour, based on the factual information provided in the contract Foundation Investigation Report (Part A of this report).

Based on MTO's Request for Proposal (RFP) dated May 2008, it is understood that it is preferable that the sewer replacement be installed using trenchless methods under the Highway 400 NBL (i.e. between the west and east shoulders) to minimize impacts to traffic, while both trenchless and open-cut installation methods may be considered in the centre median and east ditch areas.

However, if permitted by MTO with respect to traffic impacts (which would be similar to construction staging for culvert replacements), the open-cut method is feasible for construction of the full length of length of the sewer crossing. With this option, the sewer alignment could potentially be maintained higher than for a trenchless installation.

Possible trenchless installation methods include jacking and boring, pipe ramming, using a remotely-operated micro-tunnel boring machine (MTBM), or horizontal directional drilling (HDD). HDD uses drilling fluid under pressure to create the pilot hole, and typically for diameters of 375 mm to 600 mm, the recommended minimum soil cover would be approximately 3.0 m; for larger diameters (as for the installation of a steel casing at this site), even greater soil cover would be recommended. For the overburden cover depth of only about 1.5 m at this sewer crossing site (to suit the drainage ditch grading), the HDD method would not be suitable. Therefore this alternative is not considered further in this report.

The following sections of the report discuss the installation methods, anticipated ground behaviour and feasibility of tunnelling methods, and address construction issues for the two main types of construction: conventional open-cut excavation, and trenchless installation (by jack and bore, pipe ramming or MTBM methods). Table 1, following the text of this report, provides a comparison of the advantages, disadvantages, costs and risks associated with these installation methods.

Based on the comparison and discussion of the possible installation methods, the geotechnically preferred method is an open-cut installation. In this method, the depth of the excavation could be minimized as compared with the installation depths that are recommended for trenchless installation, and regrading of the drainage ditch along the east side of Highway 400 NBL would not be required. However, if trenchless installation is required to minimize impacts on traffic and construction staging requirements, then pipe ramming is the geotechnically preferred method given the subsurface conditions at the sewer crossing location. Some groundwater control may be required for both the open-cut installation and the trenchless installation alternatives, to handle the



“perched” groundwater that was encountered near the base of the fill, perched on top of the underlying cohesive soils.

### **6.3.1 Open-Cut Excavation**

Open-cut trenching across the active highway would include pavement structure demolition and restoration, trench excavation including installation of temporary protection systems for support of excavation sides; steel casing and sewer pipe installation; and trench backfilling including removal of temporary protection system elements. The open-cut excavation method would offer the best control of gradient and alignment for the sewer, reduced potential for delays resulting from encountering obstructions, and the least risk of unanticipated damage to the active highway. The major disadvantages with open-cut installation of the sewer pipe are the requirement for lane closures resulting in complex traffic staging and disruptions/delays, pavement reconstruction, and the potential for post-construction settlement of the backfill materials (although such post-construction settlement could be minimized by using unshrinkable fill to backfill the trench around and above the steel casing).

The open-cut excavation method is feasible at the sewer crossing location, provided that it is acceptable with respect to traffic staging impacts and permitted by MTO. It is noted that culvert replacements will be required approximately 2 km south and 2 km north of this sewer crossing site, and these are expected to be constructed in two halves using open-cut excavation methods, with traffic staging and temporary protection systems to maintain at least one lane of NBL traffic at all times during construction. If the lane reductions will extend through the sewer crossing site, it may be both efficient and cost effective to replace this sewer at the same time using open-cut excavation.

Further discussion on construction considerations related to open-cut excavations is provided in Section 6.5.1.

### **6.3.2 Jacking and Boring/Horizontal Auger Boring**

Jacking and boring, and/or horizontal auger boring, are methods of forming a near-horizontal bore from a jacking/drive pit. The boring is undertaken with a rotating cutter head and a continuous welded casing is jacked through reaction against a thrust block located within the jacking pit. Spoil from the tunnel excavation is transported to the jacking pit along helical auger flights, and following completion the new sewer pipe is installed within the casing. The casing may be lubricated to reduce the frictional forces between the casing and the surrounding soil.

This method is generally suitable for penetrating cohesive soils and cohesionless soils above the water table that are well-graded (i.e. broadly graded). However, if boulders and cobbles are encountered, their removal may result in loss of ground at the face and ground settlement at the ground/pavement surface, depending on the soil conditions. Difficulties may also be encountered in maintaining alignment control of the tunnel as it advances due to the presence of stiffer or more compact/dense soils ahead of the face, cobbles or boulders at the face, or due to mixed face conditions.

The size of the jacking pit is controlled by the equipment size and the length of the casing sections that are being installed. Typically, a working area of about 10 m long by about 3 m to 5 m wide is required to accommodate the jacking/drive pit for jack and bore operations. The receiving pit is typically about 3 m square.



### **6.3.3 Pipe Ramming**

Pipe ramming involves the use of a percussive hammer to advance a steel casing with a cutting shoe attached at the front end of the casing. The casing is generally advanced open-ended and the soil within the casing is typically removed after the casing has been driven the entire length of the installation, thereby reducing the potential for ground loss into the casing during driving. As each casing length is installed the rammer is removed, the next casing is welded in place and the rammer replaced and restarted. On completion of the bore, compressed air or water, pressure jetting or augering is used to remove the spoils from within the casing.

Pipe ramming is best suited for soft to firm clays and very loose to compact sands above the water table. Pipe ramming methods are also better suited than the jack and bore method for penetrating or displacing obstructions such as cobbles and boulders. However, difficulties in maintaining alignment control of the tunnel as it advances can still occur if cobbles and boulders are encountered. Vibrations from the pipe ramming operations may result in settlement of very loose to loose materials in the immediate vicinity of the installation. Furthermore, a “plug” of soil may form at the head of the casing, inducing surficial heave as the pipe is advanced, although this can be controlled by stopping the operation and removing spoil from within the pipe before advancing further. Compared to the jack and bore method, an advantage of pipe ramming is that there is no need for a thrust block in the entrance pit; therefore a smaller pit size can be used for pipe ramming, which is an advantage at space-constrained sites.

### **6.3.4 Micro-Tunnel Boring Machine (MTBM)**

Remotely operated micro-tunnel boring machines (MTBM) use pressurized bentonite slurry to counterbalance the earth and water pressures acting at the tunnel face. The excavated soil is withdrawn in a controlled manner to prevent loss of ground during tunnel advance, with the slurry circulated back through the tunnel to transport cuttings to a settling tank. Given the machine’s ability to control soil and water pressures at the face, dewatering of any water-bearing soils prior to advancing the tunnel is not necessary with this tunnelling method. The MTBM can also be specified to have the capability to crush boulders if these are anticipated along the proposed tunnel alignment.

Typically this method would be considered to minimize the risk of loss of ground and ground surface settlement, particularly where water-bearing soils are anticipated. However, because the tunnel face is pressurized, there is potential for the bentonite slurry to migrate to the surface causing hydraulic fracture (or “frac-out”) of the overlying soils. If this occurs during tunnelling, the bentonite slurry pressure is reduced at the face of the tunnel, and the soils at the tunnel face may become unstable. To avoid “frac-out”, it is considered that the MTBM method is not suitable where the cover depth over the tunnel installation is less than 2.5 m; where the cover depth is between 2 m and 2.5 m, the use of MTBM may be considered, depending on the soil conditions at the site and the consequence(s) of frac-out.

## **6.4 Anticipated Soil Behaviour and Feasibility of Tunnelling Methods**

The anticipated soil and groundwater conditions at the proposed sewer crossing horizon are described in Section 6.1. As discussed in Section 4.2.7, the boreholes were dry upon completion of drilling operations, although wet fill materials (considered to represent groundwater “perched” within the fill on top of the underlying





cohesive soil deposit) were observed near the base of the fill in Borehole 09-S-01, between approximately Elevation 286.9 m and 285.8 m; in addition, some perched groundwater could occur near the base of the sand and silt deposit that was encountered in the same borehole. In general, it is expected that the main groundwater level at this site is below the proposed sewer invert, at approximately Elevation 283.5 m, but that perched groundwater may be encountered between approximately Elevation 286.9 m and 285.8 m within the fill. Due to seasonal fluctuations and the potential for perched groundwater particularly following wet periods, it is recommended that groundwater control be provided to permit the use of auger jack and bore or pipe ramming installations.

Based on the fines content, the coefficient of uniformity<sup>1</sup> and the SPT “N” values, the soil has been classified according to the Tunnelman’s Ground Classification System (Terzaghi, 1950). This system is commonly used to describe the potential behaviour of an unsupported tunnel face during excavation and uses qualitative “stand-up time” criteria to classify the ground at and above the tunnel face into the following principal categories: firm, slowly ravelling, rapidly ravelling, cohesive running and running.

The soil conditions within the tunnel horizon have been classified in the following table:

<b>Borehole No.</b>	<b>Soil Conditions<sup>1</sup></b>	<b>Fines Content<sup>2</sup></b>	<b>SPT ‘N’ Values (per 0.3 m of penetration)</b>	<b>Coefficient of Uniformity</b>	<b>Behaviour</b>
09-S-01	Sand to Silty Sand Fill	36 %	9, 10, 16	44	Slow/Rapid Ravelling
09-S-02	Sand to Silty Sand Fill	25 %	3	100	Slow/Rapid Ravelling

**NOTES:**

1. The listed soil conditions and properties extend from ground surface to the proposed invert level.
2. Fines content is the percentage by weight passing the No. 200 sieve.

Based on the soil conditions and behaviour described above, the soils at and above the tunnel horizon are expected to exhibit rapid ravelling, and/or chunks or flakes of material may begin to drop out of the roof or sides of the tunnel within a few minutes of exposure of the tunnel heading after the ground has been exposed, provided that appropriate groundwater control is in place. These conditions are considered suitable for installation using jack and bore methods or pipe ramming. As discussed in Sections 6.3.4 and 6.4.3, the use of MTBM is considered unsuitable for the proposed sewer crossing due to the shallow cover depth available within the constraints of the drainage ditch grading. A summary comparison of the advantages, disadvantages, costs and risks associated with these sewer installation methods is presented in Table 1, following the text of this report.

A construction specification for trenchless sewer installation is provided in Appendix C, for inclusion with the Contract Documents if trenchless installation is included on this contract. Regardless of which trenchless installation technique is used, ground movements on the highway surface should be monitored during pipe installation to confirm that the permissible ground surface movement (i.e. settlement/heave) tolerances are not exceeded; further discussion on this aspect is given in Section 6.5.4.

<sup>1</sup> The coefficient of uniformity indicates whether the soil is well-graded, and is expressed as the ratio of the particle size at which 60 per cent of the particles are finer over the particle size at which 10 per cent are finer.



### **6.4.1 Jack and Bore/Horizontal Auger Boring Considerations**

Typically with jack and bore operations in cohesionless soils, the specifications require that a “plug” of spoil material remain in the casing at all times. A soil plug can be achieved by maintaining the cutting head at an appropriate distance behind the leading edge of the casing or retracting it into the casing during the jacking operations, the objective being to balance the potential inflow of material into the casing to minimize ground loss and consequent settlement. Once started, the jack and bore or horizontal auger boring operation should continue without stoppage until completed.

Obstructions were not specifically encountered within the fill or native soils in the boreholes advanced at this site; however, given the variable nature of fill and the glacial origin of the native soils, there is a risk that boulders or nests of cobbles will be present. If such obstructions are encountered, it would be necessary to remove the augers and soil plug to access the face and break up the obstruction(s). For cohesionless soil above the water table, the greater the fines content and the more broadly graded the soil is, the greater the stand-up time will be. For the slow to rapidly ravelling soil conditions at the proposed tunnel horizon at the sewer crossing site, the stand-up time may not be sufficient to allow removal of the augers and soil plug without ground loss.

Difficulties may also be encountered in maintaining alignment control of the tunnel as it advances due to the potential presence of cobbles or boulders, stiffer or more compact/dense soils ahead of the face, or mixed face conditions. There is an increased risk of difficulty with the tunnel alignment as the installation length increases – for example, if the jack and bore operation is used in the median west of the west shoulder of the highway. However, it is feasible to construct the median portion of the sewer replacement in open-cut to minimize this risk.

### **6.4.2 Pipe Ramming Considerations**

Obstructions were not specifically encountered within the fill or native soils in the boreholes advanced at this site; however, given the variable nature of fill and the glacial origin of the native soils, there is a risk that boulders or nests of cobbles will be present. Pipe ramming methods are better suited than the jack and bore method for penetrating or displacing such obstructions, though it may still be necessary to clean out the casing to allow access for equipment to break up the obstructions, which could result in loss of ground at the face of the casing given the slow to rapidly ravelling soil conditions at the proposed tunnel horizon.

As with the jack and bore/horizontal auger bore methods, the tunnel alignment may be difficult to control during pipe ramming if cobbles/boulders or mixed face conditions are encountered. Also, there would be an increased risk of difficulty with alignment control if the tunnelled portion is extended beyond the west shoulder into the median, owing to the increased installation length; however, it is feasible to construct the median portion of the sewer replacement in open-cut to minimize this component of risk.

### **6.4.3 MTBM Considerations**

As discussed in Section 6.3.4, there is potential for the bentonite slurry to migrate up to the surface, reducing the bentonite slurry pressure at the tunnel face, and potentially destabilizing the soils at the tunnel face. To avoid “frac-out”, it is considered that the MTBM method is not suitable where the cover depth is less than 2.5 m; where the cover depth is between 2 m and 2.5 m, the use of MTBM is questionable, and may be considered only where suitable soil and groundwater conditions existing at and above the proposed tunnel horizon.





The cover depth at this sewer crossing site is expected to be approximately 1.5 m based on the median inlet and potential east ditch outlet grades; this is less than the recommended 2 m to 2.5 m. The use of MTBM is not considered feasible at this site due to unacceptable risk of “frac-out” and resulting loss of ground at and above the tunnel face, unless the sewer invert level can be lowered by an additional 0.5 m to 1 m. In addition, it is relatively expensive to mobilize micro-tunnel boring machines, and the availability of machines with a suitable diameter bore and the mobilization costs for such equipment may constrain their use on this project.

## **6.5 Design and Construction Considerations**

### **6.5.1 Excavation and Groundwater/Surface Water Control**

Excavations will be required for the jacking and receiving pits for a trenchless installation, or if the replacement sewer is installed using open-cut methods. Entry and exit pits are expected to be located at or near the median and east ditches (i.e., low-lying areas), and all surface water including water within the existing ditches should be directed away from the open excavations.

Based on the borehole results, the excavations are expected to extend through the loose to compact sand to silty sand fill, and potentially into the underlying native clayey silt or sand and silt if the tunnel alignment is deepened. Excavations should be carried out in accordance with the guidelines outlined in the latest edition of the Occupational Health and Safety Act (OHSA) for Construction Projects. The fill materials and any firm to stiff or loose to compact native soils are classified as Type 3 soil, according to the OHSA. Very stiff to hard and dense to very dense portions of the native soils would be classified as Type 1 or 2 soils. At this site, temporary excavations (i.e. those which are only open for a relatively short period) within these overburden soils should be made with side slopes not steeper than 1 horizontal to 1 vertical (1H:1V).

As presented in Section 4.2.7, the boreholes were dry upon completion of drilling operations, although some “perched” groundwater was observed near the base of the fill in Borehole 09-S-01, and some perched groundwater could occur near the base of the sand and silt deposit that was encountered in the same borehole. It is anticipated that seepage into open-cut excavations from zones of perched groundwater can be handled by pumping from properly filtered sumps located in the base of the excavation. Shallower excavation side slopes may be required to minimize surficial sloughing.

If a trenchless installation is adopted for the sewer replacement, groundwater control will be required if perched groundwater conditions persist in the sand to silty sand fill materials, to minimize the potential for wet cohesionless soils to flow into the tunnel during auger jack and bore or pipe ramming operations.

#### **6.5.1.1 Permit to Take Water (PTTW) Requirements for Dewatering**

The potential daily pumping rate to dewater the excavations associated with the installation of the sewer crossing has been assessed, to determine whether a Permit to Take Water (PTTW) will be required for dewatering at this site. The Ministry of Environment requires a PTTW for any site for which the dewatering volume exceeds 50,000 litres (50 cubic metres) per day.



The assessment of potential dewatering volumes was completed based on the borehole information (soil type and deposit thickness, and groundwater elevation) and geotechnical laboratory testing (grain size distribution test results), together with the proposed sewer invert elevation. Based on this information, it is expected that a PTTW will not be required for groundwater control at the sewer crossing site.

### **6.5.2 Temporary Excavation Support**

Temporary protection systems may be required at the entry and exit pit work areas if sufficient space is not available to permit open-cut excavations. Based on the subsurface conditions at the crossing location and the likely excavation geometry, it is expected that either a soldier pile and lagging system or a driven, interlocking sheetpile system would be suitable, using internal bracing (struts), anchors or rakers to provide lateral support. An interlocking sheetpile system has an advantage with respect to controlling groundwater seepage where zones of perched groundwater are present. However, groundwater seepage and the potential loss of fine soil particles can be mitigated if a soldier pile and lagging system is adopted, by backing the lagging with filter cloth in areas where the temporary shoring intercepts zones of perched groundwater.

The lateral support elements should be designed to accommodate the loads applied from pressures and surcharge pressures from area, line or point loads as well as the impact of sloping ground behind the system. The temporary excavation support system should be designed and constructed in accordance with OPSS 539 (*Construction Specification for Temporary Protection Systems*). The lateral movement of the temporary shoring system should meet Performance Level 2 as specified in OPSS 539.

### **6.5.3 Pipe Bedding and Trench Backfill**

In areas where the sewer is installed in an open-cut excavation, at least 150 mm of Granular “A” meeting Ontario Provincial Standard Specification (OPSS) 1010 (*Material Specification for Aggregates – Base, Subbase, Select Subgrade and Backfill Material*) should be used as bedding for the sewer casing; the bedding material should extend to the spring line of the pipe. Sand cover material should be used from the spring line of the pipe to at least 300 mm above the obvert of the casing. Clear stone should not be used as bedding or cover material unless a complete, stitched geotextile surround is provided. All bedding and cover material should be placed in loose lifts and uniformly compacted to at least 95 percent of material’s Standard Proctor Maximum Dry Density, in accordance with MTO’s SP 105S10 (*Amendment to OPSS 501*).

If open-cut excavation is used to install the sewer across Highway 400, it is recommended that the trench below the highway pavement and shoulders be backfilled with unshrinkable fill to minimize post-construction settlement.

Beyond the shoulder of Highway 400, select subgrade material or native site soils may be used for trench backfill, provided they are free of significant amounts of topsoil, organic material or other deleterious materials. Such trench backfill should be placed and compacted in accordance with MTO’s SP 105S10 (*Amendment to OPSS 501*). Normal post-construction settlement of the compacted trench backfill should be anticipated, with the majority of such settlement taking place within about six months following the completion of trench backfilling operations.



#### **6.5.4 Instrumentation and Monitoring**

An instrumentation and monitoring program is recommended at the sewer crossing location for the following purposes:

- To document the effects of the sewer installation on the overlying roadway, and any adjacent structures or utilities;
- To obtain prior warning of ground movements that could occur arising from the construction methods and equipment, encountering cobbles and/or boulders, or encountering unforeseen ground conditions;
- To verify the Contractor's compliance with the settlement limits imposed in the Contract Documents; and
- To allow adjustments to be made to the sewer installation methods such that the settlement limits are not exceeded.

Monitoring of settlement instruments on this project will be constrained by the continuous and high traffic volume and the limited periods during which access to the highway can be obtained. By necessity, settlement points on the road must be read remotely and the use of electromagnetic distance measuring (EDM) equipment is recommended, with reading reflectors installed on the highway. A specialist surveying firm should be retained to confirm the set-up and to carry out the settlement monitoring during construction; their equipment and procedures must be capable of surveying the settlement point elevations to within  $\pm 2$  mm of the actual elevation.

In addition, the installation of in-ground settlement points (consisting of sleeved iron bars set 0.3 m above the tunnel obvert elevation) should be also considered at accessible locations, such as on the highway shoulders. The elevation of the top of the bar would be read using conventional precision levelling equipment. The in-ground monitoring points provide the best measure of the ground settlement effects of tunnelling, as they are generally unaffected by frost heave, thaw settlement or the bridging action of the pavement structure.

All monitoring points should be read at least three times (on separate days) before the start of sewer installation to establish a pre-construction baseline. All points behind the face of the excavation and those within 10 m of the front of the face should be read every 4 hours over the duration of the tunnel drive. The effectiveness of this monitoring method could be impacted by weather conditions if the work is undertaken during the winter months.

A settlement monitoring plan should be established as part of the Contract Administration for construction. The settlement monitoring plan should be consistent with the requirements in the "Appendix: Settlement Monitoring Guideline – Tunnelling" of MTO's *Guideline for Foundation Engineering – Tunnelling Speciality for Corridor Encroachment Permit Application*. A copy of this MTO settlement monitoring guideline is provided in Appendix D for reference.



### 6.5.5 Grouting

After the permanent sewer pipe is installed within the jacked or rammed casing, post-installation grouting should be carried out to fill the annular space between the pipes. This is addressed in the specification provided in Appendix C, for inclusion in the Contract Documents.

For any installations at which the settlement monitoring indicates that pavement settlement has occurred, or where signs of ground loss have been observed, provision should be made for a program of compensation grouting above the pipe.

## 7.0 CLOSURE

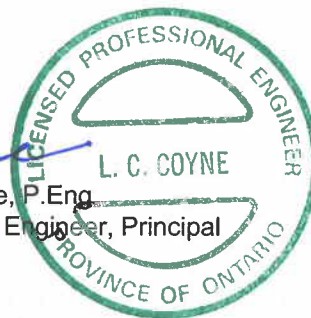
This Foundation Design Report was prepared by Ms. Nikol Kochmanová, EIT, and reviewed by Ms. Lisa Coyne, P.Eng., a geotechnical engineer and Principal with Golder. Mr. Fin Heffernan, P.Eng., a Designated MTO Foundations Contact and one of Golder's registered tunnelling specialists for MTO assignments, conducted an independent technical and quality control review of this report.

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NK/LCC/FJH/jl

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- Peck, R.B., Hanson, W.E., and Thornburn, T.H., 1974. *Foundation Engineering*, Second Edition, John Wiley and Sons, New York.
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### Ontario Provincial Standard Specifications (OPSS)

- OPSS 539 Construction Specification for Temporary Protection Systems
- OPSS 1010 Material Specification for Aggregates – Base, Subbase, Select Subgrade and Backfill Material

### Special Provisions (SP)

- SP105S10 Amendment to OPSS 501, Construction Specification for Construction



## FOUNDATION REPORT FOR SEWER CROSSING, HIGHWAY 400 NBL REHABILITATION, G.W.P 2039-06-00

**TABLE 1**  
**COMPARATIVE ASSESSMENT OF SEWER INSTALLATION METHODS**

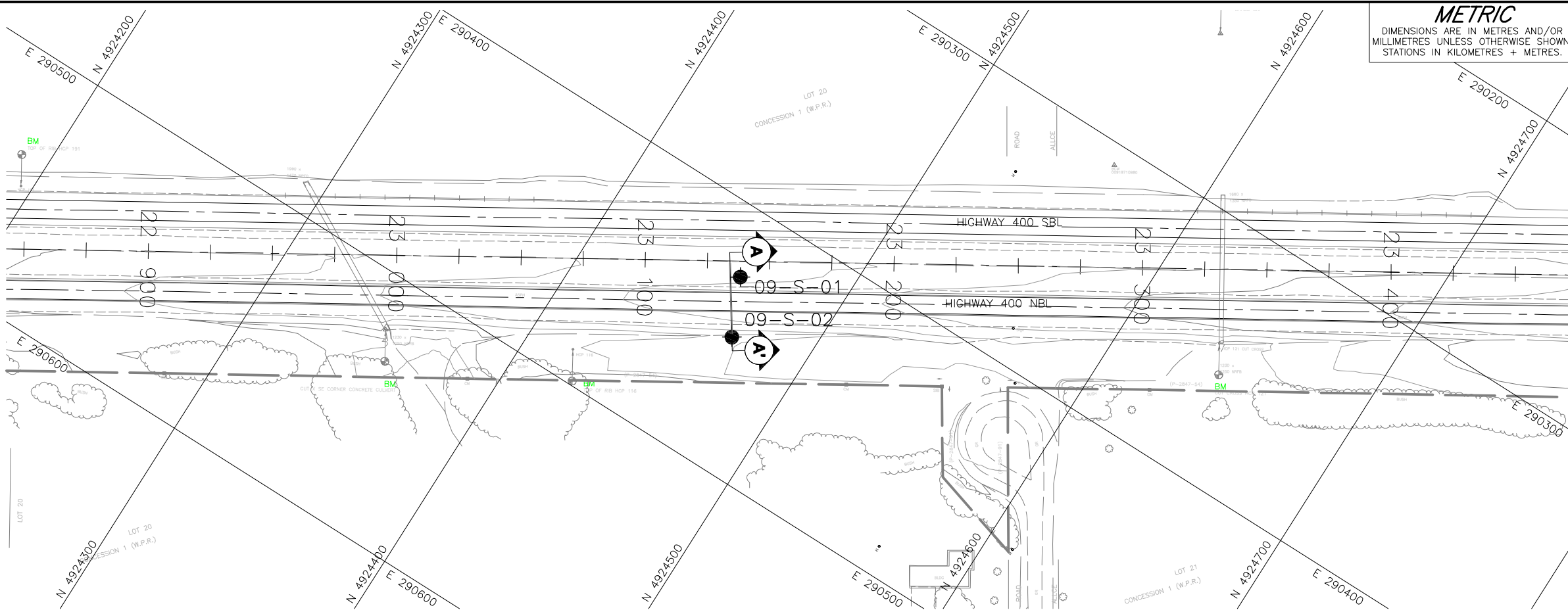
Installation Method	Advantages	Disadvantages	Estimated Cost/m of Sewer Installation	Risk/Consequences
Open-Cut Installation (OPSS 410)	<ul style="list-style-type: none"> <li>Best control of gradient and alignment of sewer</li> <li>Reduced potential of difficulties due to obstructions</li> <li>Least risk of unanticipated impact on active highway</li> <li>Could permit higher invert elevation than trenchless</li> </ul>	<ul style="list-style-type: none"> <li>Requires lane closures and pavement reconstruction</li> <li>Some groundwater control required to handle perched groundwater condition within sand to silty sand fill</li> <li>Potential post-construction settlement of trench backfill, although this could be mitigated using unshrinkable fill</li> </ul>	\$250/m + traffic control costs	<ul style="list-style-type: none"> <li>Greater impact on traffic than trenchless technologies, but negligible risk of unanticipated ground loss/surface settlement</li> </ul>
Jack and Bore Installation (OPSS 416)	<ul style="list-style-type: none"> <li>Sewer can be installed without lane closures resulting in minimal traffic disruption</li> </ul>	<ul style="list-style-type: none"> <li>Large work area required for jacking pit.</li> <li>Some groundwater control required to handle perched groundwater condition within sand to silty sand fill</li> <li>Obstructions (e.g. cobbles or boulders) may result in alignment deviation and/or halt the bore</li> <li>Greatest risk of ground surface subsidence particularly if obstructions are encountered or if wet granular soils are encountered</li> </ul>	Approximately \$1,600/m	<ul style="list-style-type: none"> <li>Risk of misalignment of casing/sewer if obstructions are encountered within the fill</li> <li>Potential for loss of ground into casing particularly if granular soils are encountered</li> <li>Risk of ground surface subsidence increases with decreasing cover</li> </ul>



## FOUNDATION REPORT FOR SEWER CROSSING, HIGHWAY 400 NBL REHABILITATION, G.W.P 2039-06-00

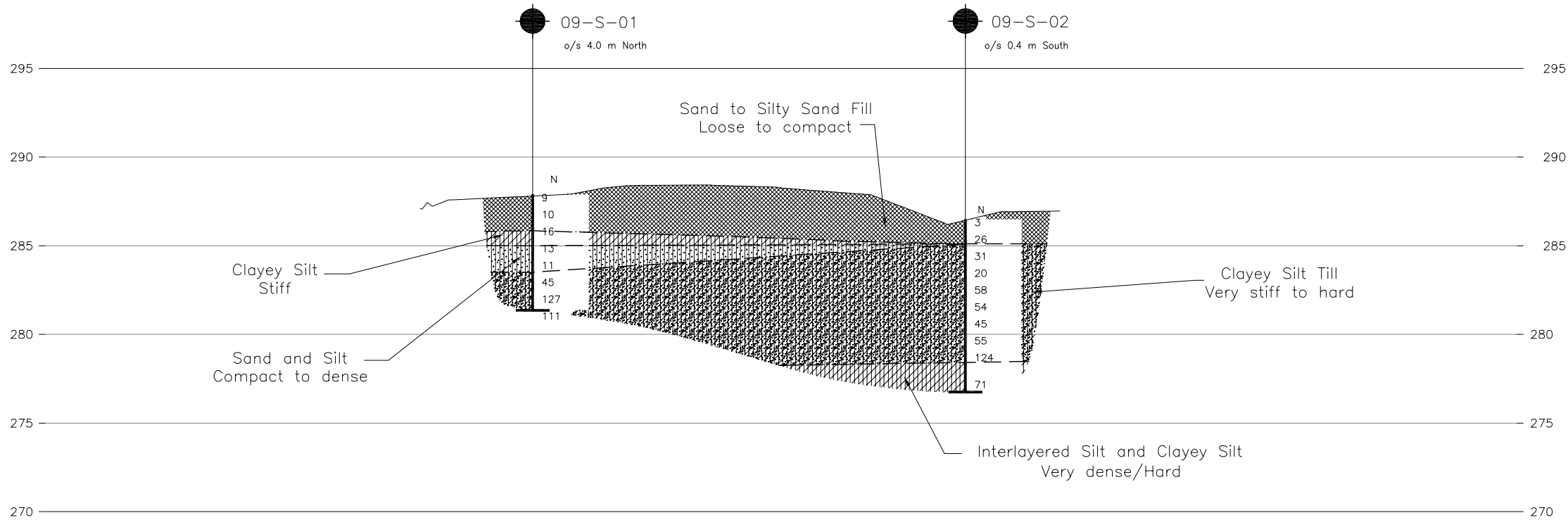
Installation Method	Advantages	Disadvantages	Estimated Cost/m of Sewer Installation	Risk/Consequences
Pipe Ramming Installation	<ul style="list-style-type: none"> <li>Sewer can be installed without lane closures resulting in minimal traffic disruption.</li> <li>Less risk of subsidence above pipe alignment than jack and bore installation method</li> </ul>	<ul style="list-style-type: none"> <li>Large obstructions can deflect casing</li> <li>Some groundwater control required to handle perched groundwater condition within sand to silty sand fill</li> <li>Potential for heaving at ground surface</li> <li>Vibration from pipe ramming may induce settlement of surrounding loose soils</li> </ul>	Approximately \$2,700/m	<ul style="list-style-type: none"> <li>Lower risk of misalignment of casing/sewer or loss of ground, as compared with jack and bore installation method</li> <li>Low risk that vibration from pipe ramming will induce settlement of surrounding loose fill material at this site</li> </ul>
MTBM	<ul style="list-style-type: none"> <li>Machine is able to counterbalance earth and water pressures in a controlled manner, thereby reducing the risk of ground losses during tunnelling</li> <li>Machine can also be specified to have the capability to crush boulders and nests of cobbles</li> </ul>	<ul style="list-style-type: none"> <li>Lack of availability of machines with a suitable diameter bore.</li> <li>Relatively expensive, with high mobilization cost relative to this single short crossing</li> <li>Potential for hydraulic fracture particularly where soil cover over installation is less than 2.5 m</li> </ul>	Estimated to be greater than \$100,00 for this sewer crossing	<ul style="list-style-type: none"> <li>High risk of hydraulic fracture (frac-out) at this sewer crossing location due to shallow cover depth, resulting in an unsupported face and potential ground loss/surface subsidence</li> </ul>





PLAN

SCALE  
20 0 20 40 m



SECTION A

SCALE  
3 0 3 6 m

**METRIC**  
DIMENSIONS ARE IN METRES AND/OR  
MILLIMETRES UNLESS OTHERWISE SHOWN.  
STATIONS IN KILOMETRES + METRES.

CONT No.  
GWP No. 2039-06-00

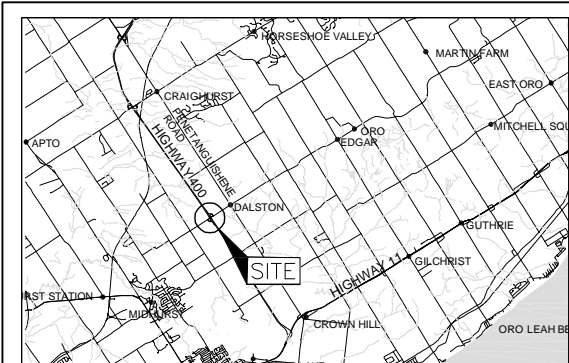


HIGHWAY 400 NBL  
SEWER CROSSING  
BOREHOLE LOCATIONS AND SOIL STRATA

SHEET



**Golder Associates Ltd.**  
MISSISSAUGA, ONTARIO, CANADA



KEY PLAN

SCALE  
3.5 0 3.5 7 km

LEGEND

- Borehole - Current Investigation
- N Standard Penetration Test Value
- 16 Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
- WL upon completion of drilling

BOREHOLE CO-ORDINATES

No.	ELEVATION	NORTHING	EASTING
09-S-01	287.9	4924459.7	290426.7
09-S-02	286.5	4924469.7	290449.0

NOTES

This drawing is for subsurface information only. The proposed structure details/works are shown for illustration purposes only and may not be consistent with the final design configuration as shown elsewhere in the Contracts Documents.

The boundaries between soil strata have been established only at borehole locations. Between Boreholes the boundaries are assumed from geological evidence.

The complete Foundation Investigation and Design Report for this project and other related documents may be examined at the Materials Engineering and Research Office, Downsview. Information contained in this report and related documents is specifically excluded in accordance with Section GC 2.01 of OPS General Conditions.

REFERENCE

Base plan provided in digital format by Morrison Hershfield (drawing file x84117Base.dwg, received January 29, 2010).



NO.	DATE	BY	REVISION
Geocres No. 31D-505			
HWY. 400		PROJECT No. 09-1111-0022	DIST. CENTRAL
SUBM'D. NK	CHKD. LCC	DATE: 8/11/2010	SITE:
DRAWN: JFC	CHKD. NK	APPD. LCC	DWG. 1





# **APPENDIX A**

## **Borehole Records**



## LIST OF ABBREVIATIONS

The abbreviations commonly employed on Records of Boreholes, on figures and in the text of the report are as follows:

### I. SAMPLE TYPE

AS	Auger sample
BS	Block sample
CS	Chunk sample
SS	Split-spoon
DS	Denison type sample
FS	Foil sample
RC	Rock core
SC	Soil core
ST	Slotted tube
TO	Thin-walled, open
TP	Thin-walled, piston
WS	Wash sample

### II. PENETRATION RESISTANCE

#### Standard Penetration Resistance (SPT), N:

The number of blows by a 63.5 kg. (140 lb.) hammer dropped 760 mm (30 in.) required to drive a 50 mm (2 in.) split-spoon sampler for a distance of 300 mm (12 in.)

#### Dynamic Cone Penetration Resistance; $N_d$ :

The number of blows by a 63.5 kg (140 lb.) hammer dropped 760 mm (30 in.) to drive uncased a 50 mm (2 in.) diameter, 60° cone attached to "A" size drill rods for a distance of 300 mm (12 in.).

<b>PH:</b>	Sampler advanced by hydraulic pressure
<b>PM:</b>	Sampler advanced by manual pressure
<b>WH:</b>	Sampler advanced by static weight of hammer
<b>WR:</b>	Sampler advanced by weight of sampler and rod

#### Piezo-Cone Penetration Test (CPT)

A electronic cone penetrometer with a 60° conical tip and a project end area of 10 cm<sup>2</sup> pushed through ground at a penetration rate of 2 cm/s. Measurements of tip resistance ( $Q_t$ ), porewater pressure (PWP) and friction along a sleeve are recorded electronically at 25 mm penetration intervals.

### III. SOIL DESCRIPTION

#### (a) Cohesionless Soils

	<b>N</b>
Density Index	
Relative Density	<u>Blows/300 mm or Blows/ft</u>
Very loose	0 to 4
Loose	4 to 10
Compact	10 to 30
Dense	30 to 50
Very dense	over 50

#### (b) Cohesive Soils Consistency

	<u>kPa</u>	<u>C<sub>u</sub>, S<sub>u</sub></u>	<u>psf</u>
Very soft	0 to 12		0 to 250
Soft	12 to 25		250 to 500
Firm	25 to 50		500 to 1,000
Stiff	50 to 100		1,000 to 2,000
Very stiff	100 to 200		2,000 to 4,000
Hard	over 200		over 4,000

### IV. SOIL TESTS

w	water content
w <sub>p</sub>	plastic limit
w <sub>l</sub>	liquid limit
C	consolidation (oedometer) test
CHEM	chemical analysis (refer to text)
CID	consolidated isotropically drained triaxial test <sup>1</sup>
CIU	consolidated isotropically undrained triaxial test with porewater pressure measurement <sup>1</sup>
D <sub>R</sub>	relative density (specific gravity, G <sub>s</sub> )
DS	direct shear test
M	sieve analysis for particle size
MH	combined sieve and hydrometer (H) analysis
MPC	Modified Proctor compaction test
SPC	Standard Proctor compaction test
OC	organic content test
SO <sub>4</sub>	concentration of water-soluble sulphates
UC	unconfined compression test
UU	unconsolidated undrained triaxial test
V	field vane (LV-laboratory vane test)
γ	unit weight

**Note:** 1 Tests which are anisotropically consolidated prior to shear are shown as CAD, CAU.



## LIST OF SYMBOLS

Unless otherwise stated, the symbols employed in the report are as follows:

### I. GENERAL

$\pi$	3.1416
$\ln x$ ,	natural logarithm of x
$\log_{10}$	x or log x, logarithm of x to base 10
g	acceleration due to gravity
t	time
FoS	factor of safety
V	volume
W	weight

### II. STRESS AND STRAIN

$\gamma$	shear strain
$\Delta$	change in, e.g. in stress: $\Delta \sigma$
$\epsilon$	linear strain
$\epsilon_v$	volumetric strain
$\eta$	coefficient of viscosity
$\nu$	poisson's ratio
$\sigma$	total stress
$\sigma'$	effective stress ( $\sigma' = \sigma - \mu$ )
$\sigma'_{vo}$	initial effective overburden stress
$\sigma_1, \sigma_2, \sigma_3$	principal stress (major, intermediate, minor)
$\sigma_{oct}$	mean stress or octahedral stress $= (\sigma_1 + \sigma_2 + \sigma_3)/3$
$\tau$	shear stress
$\mu$	porewater pressure
E	modulus of deformation
G	shear modulus of deformation
K	bulk modulus of compressibility

### III. SOIL PROPERTIES

#### (a) Index Properties

$\rho(\gamma)$	bulk density (bulk unit weight*)
$\rho_d(\gamma_d)$	dry density (dry unit weight)
$\rho_w(\gamma_w)$	density (unit weight) of water
$\rho_s(\gamma_s)$	density (unit weight) of solid particles
$\gamma'$	unit weight of submerged soil ( $\gamma' = \gamma - \gamma_w$ )
$D_R$	relative density (specific gravity) of solid particles ( $D_R = \rho_s / \rho_w$ ) (formerly $G_s$ )
e	void ratio
n	porosity
S	degree of saturation

#### (a) Index Properties (continued)

w	water content
$w_l$	liquid limit
$w_p$	plastic limit
$I_p$	plasticity index $= (w_l - w_p)$
$w_s$	shrinkage limit
$I_L$	liquidity index $= (w - w_p) / I_p$
$I_C$	consistency index $= (w_l - w) / I_p$
$e_{max}$	void ratio in loosest state
$e_{min}$	void ratio in densest state
$I_D$	density index $= (e_{max} - e) / (e_{max} - e_{min})$ (formerly relative density)

#### (b) Hydraulic Properties

h	hydraulic head or potential
q	rate of flow
v	velocity of flow
i	hydraulic gradient
k	hydraulic conductivity (coefficient of permeability)
j	seepage force per unit volume

#### (c) Consolidation (one-dimensional)

$C_c$	compression index (normally consolidated range)
$C_r$	recompression index (over-consolidated range)
$C_s$	swelling index
$C_a$	coefficient of secondary consolidation
$m_v$	coefficient of volume change
$c_v$	coefficient of consolidation
$T_v$	time factor (vertical direction)
U	degree of consolidation
$\sigma'_p$	pre-consolidation pressure
OCR	over-consolidation ratio $= \sigma'_p / \sigma'_{vo}$

#### (d) Shear Strength

$T_p, T_r$	peak and residual shear strength
$\phi'$	effective angle of internal friction
$\delta$	angle of interface friction
$\mu$	coefficient of friction $= \tan \delta$
$c'$	effective cohesion
$c_u, s_u$	undrained shear strength ( $\phi = 0$ analysis)
p	mean total stress $(\sigma_1 + \sigma_3)/2$
$p'$	mean effective stress $(\sigma'_1 + \sigma'_3)/2$
q	$(\sigma_1 + \sigma_3)/2$ or $(\sigma'_1 + \sigma'_3)/2$
$q_u$	compressive strength $(\sigma_1 + \sigma_3)$
$S_t$	sensitivity

\* Density symbol is  $\rho$ . Unit weight symbol is  $\gamma$  where  $\gamma = \rho g$  (i.e. mass density multiplied by acceleration due to gravity)

Notes: 1  $\tau = c' + \sigma' \tan \phi'$   
2 shear strength = (compressive strength)/2

PROJECT		09-1111-0022		<b>RECORD OF BOREHOLE No 09-S-01</b>				1 OF 1 <b>METRIC</b>								
G.W.P.		2039-06-00		LOCATION		N 4924459.7 ; E 290426.7		ORIGINATED BY								
DIST		Central HWY 400		BOREHOLE TYPE		D-125 Track-Mount, 200 mm Diameter Hollow Stem Augers		COMPILED BY								
DATUM		Geodetic		DATE		October 26, 2009		CHECKED BY								
								LCC								
SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				PLASTIC LIMIT W <sub>p</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa								
287.9	GROUND SURFACE															
0.0	TOPSOIL															
0.2	Sand, trace to some silt to silty sand, trace to some gravel, containing pockets and layers of clayey silt (FILL) Loose to compact Brown to brown-black Moist becoming wet at 1.0 m depth		1	SS	9											
			2	SS	10											
			3A													
			3B	SS	16											
285.8																
2.1	CLAYEY SILT with sand, trace gravel, containing seams of sand and silt Stiff Brown Moist		4	SS	13											
285.0																
2.9	SAND and SILT, trace clay, trace gravel Compact to dense Brown Moist		5	SS	11											
			6	SS	45											
283.5																
4.4	CLAYEY SILT, with sand, trace gravel (TILL) Hard Grey Moist		7	SS	127											
281.4			8	SS	111											
6.6	END OF BOREHOLE															
	NOTE: 1. Borehole dry on completion of drilling.															

PROJECT		09-1111-0022		<b>RECORD OF BOREHOLE No 09-S-02</b>		1 OF 1 <b>METRIC</b>								
G.W.P.		2039-06-00		LOCATION		N 4924469.7 ; E 290449.0								
DIST		Central HWY 400		BOREHOLE TYPE		D-125 Track-Mount, 200 mm Diameter Hollow Stem Augers								
DATUM		Geodetic		DATE		October 26, 2009								
						ORIGINATED BY AB								
						COMPILED BY NLP								
						CHECKED BY LCC								
SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT W <sub>p</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT γ	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa						
286.5	GROUND SURFACE							20 40 60 80 100	20 40 60 80 100	10 20 30				
0.9	TOPSOIL		1	SS	3		286							
	Sand, some silt to silty sand, trace to some gravel, containing organics and pockets and layers of clayey silt (FILL) Loose to compact Brown-black Moist		2	SS	26									8 67 16 9
285.1							285							
1.4	CLAYEY SILT with sand, trace to some gravel (TILL) Very stiff to hard Brown becoming grey below 3.0 m Moist		3	SS	31									2 47 34 17
			4	SS	20		284							
			5	SS	58		283							
			6	SS	54		282							
			7	SS	45		281							
			8	SS	55		280							
			9	SS	124		279							
278.4							278							
8.1	Interlayered SILT and CLAYEY SILT Very dense/hard Grey Moist		10	SS	71		277							
276.8														
9.8	END OF BOREHOLE													
	NOTE: 1. Borehole dry on completion of drilling.													

MIS-MTO.001 09-1111-0022.GPJ GAL-MISS.GDT 11/8/10 DD/SAC



# **APPENDIX B**

## **Laboratory Test Results**

### Sand to Silty Sand Fill

U.S.S Sieve size, meshes/inch

Size of openings, inches

PERCENT FINER THAN

GRAIN SIZE, mm

SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	09-S-02	2	285.4
■	09-S-01	3A	286.3

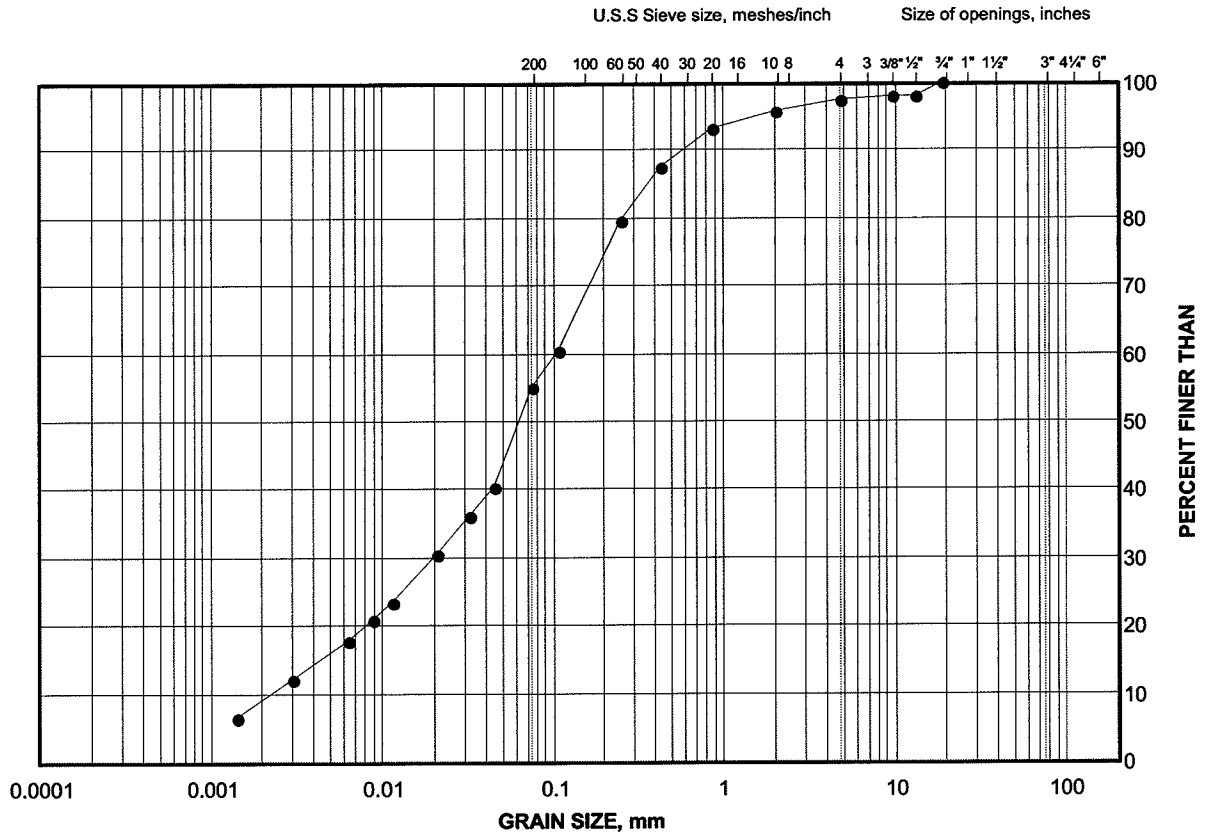
Checked By: Wayne

Date: 31-May-10

# GRAIN SIZE DISTRIBUTION TEST RESULT

Clayey Silt

FIGURE B2



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

## LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
•	09-S-01	4	285.4

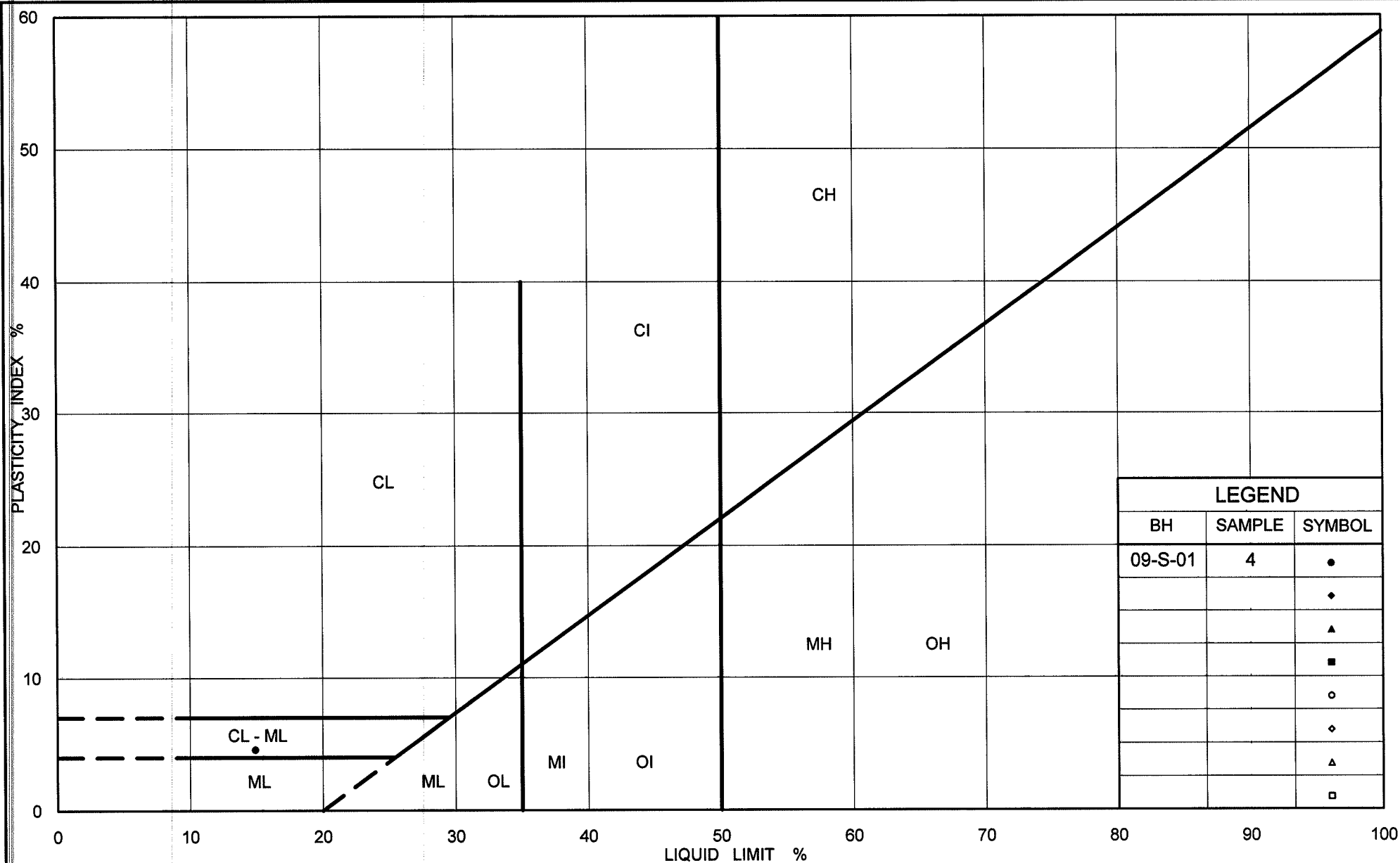
Project Number: 09-1111-0022

Checked By: *[Signature]*

Golder Associates

Date: 31-May-10





Ministry of Transportation

Ontario

# PLASTICITY CHART Clayey Silt

Figure No. B3

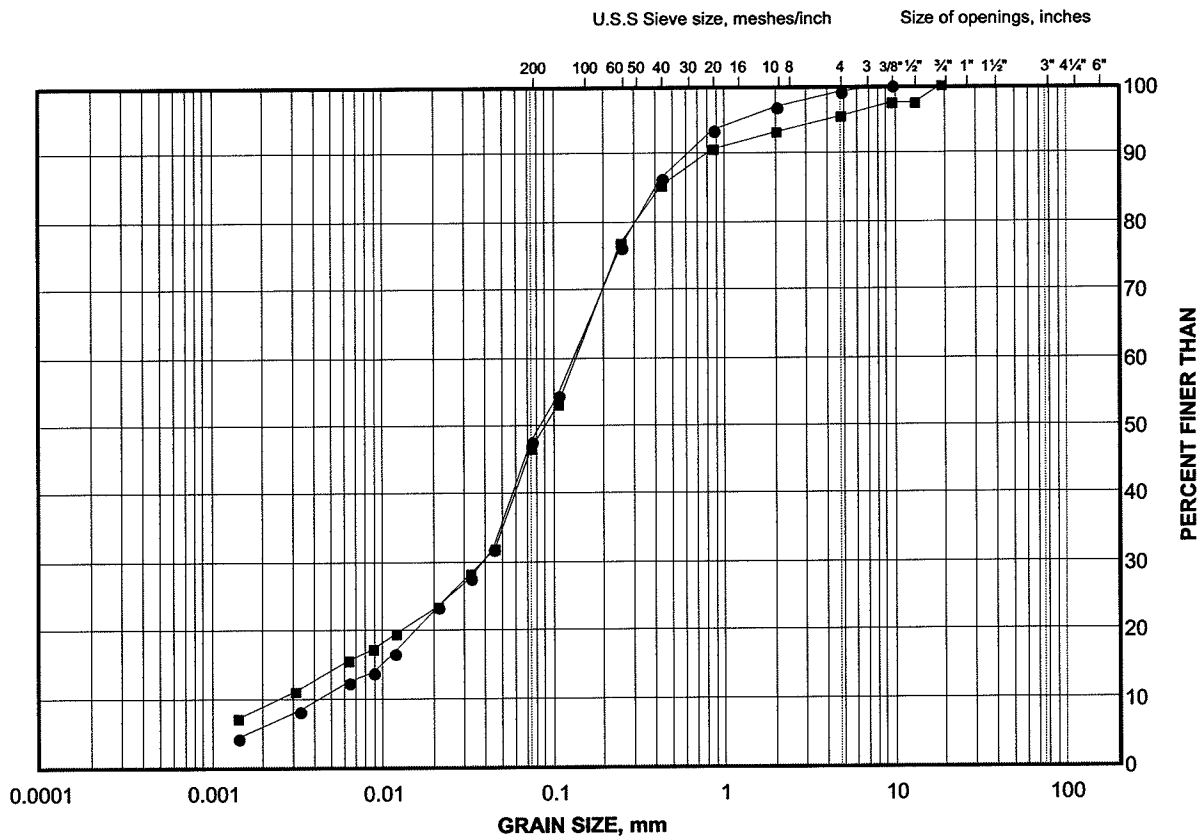
Project No. 09-1111-0022

Checked By: *Maye*

# GRAIN SIZE DISTRIBUTION TEST RESULTS

Sand and Silt

FIGURE B4



SILT AND CLAY SIZES	FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED	SAND SIZE			GRAVEL SIZE		SIZE

## LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	09-S-01	5	284.7
■	09-S-01	6	283.9

Project Number: 09-1111-0022

Checked By: *Wayne*

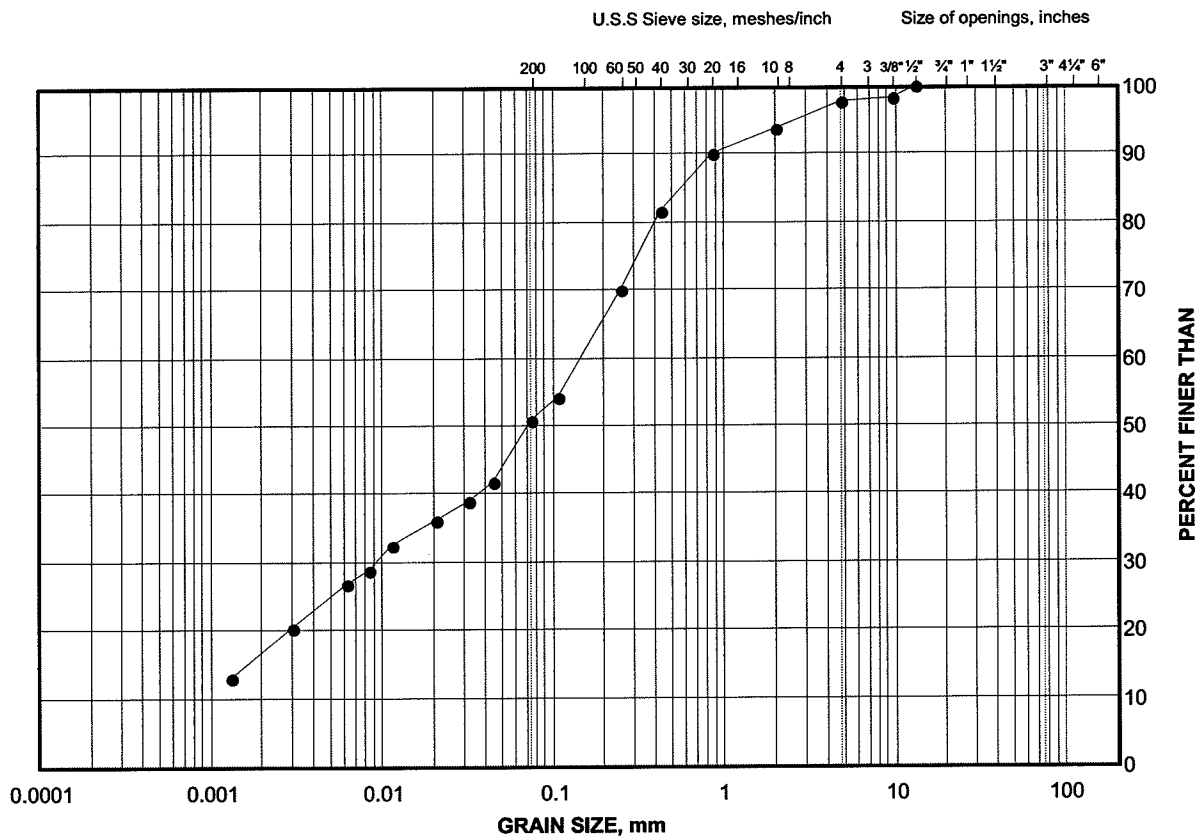
Golder Associates

Date: 31-May-10

# GRAIN SIZE DISTRIBUTION TEST RESULT

Clayey Silt Till

FIGURE B5



SILT AND CLAY SIZES		FINE	MEDIUM	COARSE	FINE	COARSE	COBBLE
FINE GRAINED		SAND SIZE			GRAVEL SIZE		SIZE

## LEGEND

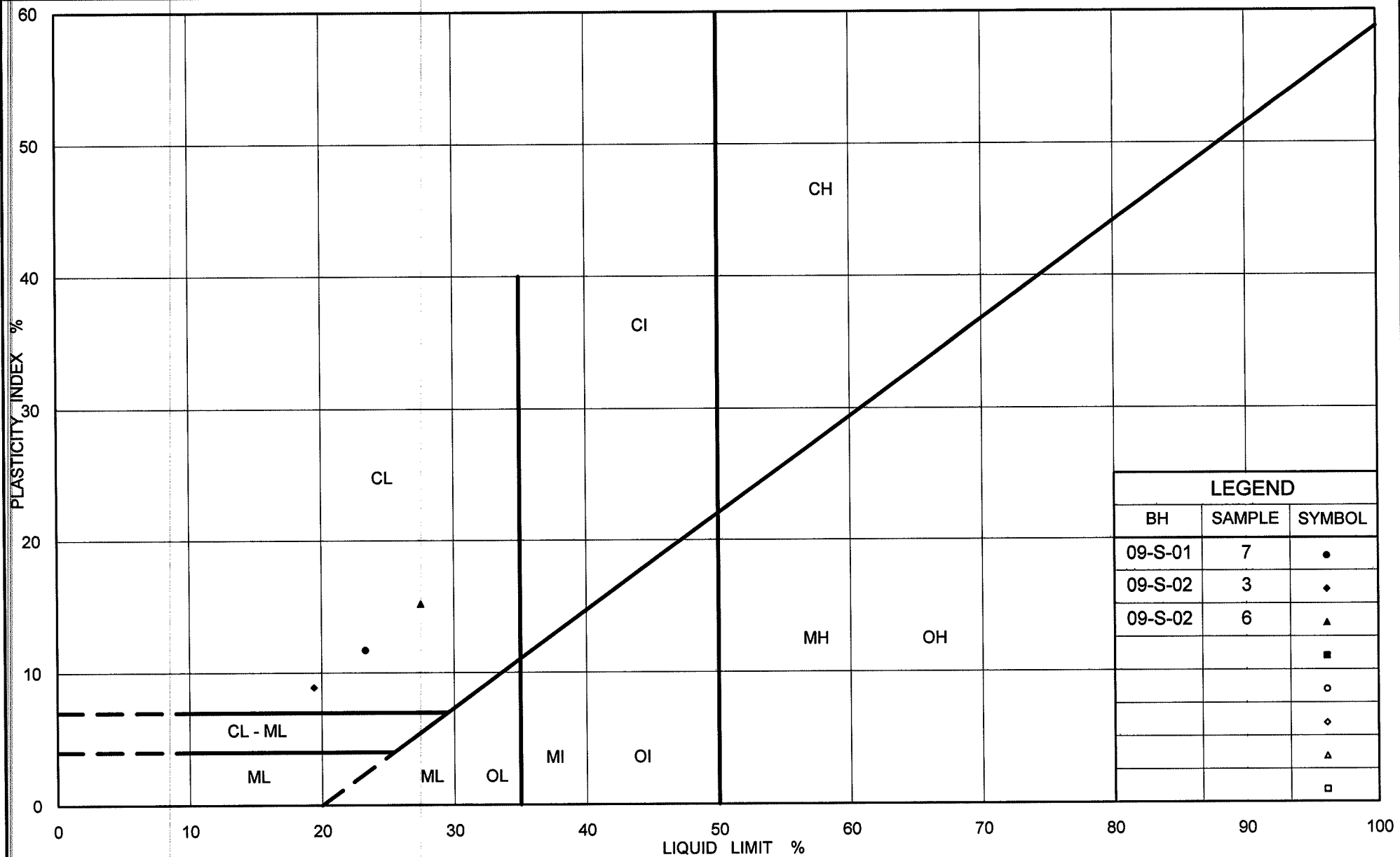
SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
•	09-S-02	3	284.7

Project Number: 09-1111-0022

Checked By: *Wage*

Golder Associates

Date: 31-May-10



Ministry of Transportation

Ontario

# **PLASTICITY CHART** **Clayey Silt Till**

Figure No. B6

Project No. 09-1111-0022

Checked By: *W. J. [Signature]*



# **APPENDIX C**

## **Non-Standard Special Provisions**



### SPECIFICATION FOR SEWER INSTALLATION VIA TRENCHLESS TECHNOLOGY

#### Special Provision

OPSS 415 (Construction Specification for Pipeline and Utility Installation by Tunnelling), OPSS 416 (Construction Specification for Pipeline and Utility Installation by Jacking and Boring) and OPSS 450 (Construction Specification for Pipeline and Utility Installation in Soil by Horizontal Directional Drilling) are deleted and replaced with the following:

#### 1. SCOPE

This specification covers the general requirements for the installation of sewers by trenchless methods.

The Contractor shall determine the most appropriate method of installation. Specifications for Jack and Bore, Pipe Ramming, Directional Drilling, and Tunnelling are provided herein, and shall be applied to the installation method considered feasible by the Contractor.

#### 2. REFERENCES

This specification refers to the following standards, specifications, or publications:

- “Foundation Investigation Report, Sewer Replacement at Station 23+134, Highway 400 NBL Between Highway 11 and Highway 93, Simcoe County, Ontario, G.W.P. 2039-06-00”, by Golder Associates Ltd. Reference No. 09-1111-0022-2.

##### **Ontario Provincial Standard Specifications, General**

OPSS 180 Management and Disposal of Excess Material

##### **Ontario Provincial Standard Specifications, Construction**

OPSS 504 Preservation, Protection, and Reconstruction of Existing Facilities  
OPSS 507 Site Restoration Following Installation of Pipelines, Utilities and Associated Structures in Open Cut  
OPSS 514 Trenching, Backfilling, and Compaction  
OPSS 517 Dewatering of Pipeline, Utility, and Associated Structure Excavation  
OPSS 538 Support Systems  
OPSS 539 Protection Schemes

##### **Ontario Provincial Standard Specifications, Material**

OPSS 1004 Aggregates - Miscellaneous  
OPSS 1350 Concrete - Materials and Production  
OPSS 1440 Steel Reinforcement for Concrete  
OPSS 1802 Smooth Walled Steel Pipe

##### **MTO Specifications**

Form 1820 Concrete Pipe  
Form 1840 Polyethylene Pipe  
SP 105S19 Construction Specification for Protection Systems



## SPECIAL PROVISION

### American Society for Testing and Materials (ASTM) International Standards

ASTM A252-93	Welding and Seamless Steel Pipe Piles
ASTM D2657-03	Standard Practice for Heat Fusion Joining of Polyolefin Pipe and Fittings
ASTM D3350	Standard Specification for Polyethylene Plastics Pipe and Fittings Materials
ASTM F894	Polyethylene Large Diameter Profile Wall Sewer and Drain Pipe

### Canadian Standards Association Standards:

CSA B182.6	Profile Polyethylene Sewer Pipe and Fittings.
CAN/CSA A5-93	Portland Cement
CSA W59	Welded Steel Construction (Metal Arc Welding)

### 3. DEFINITIONS

For the purpose of this specification, the following definitions apply:

**Auger Jack & Bore:** a method of forming a horizontal bore in the subsurface by essentially simultaneously jacking ahead and rotating a cutter head, followed by removal of material from inside the bore by using an auger.

**Backreamer:** a cutting head suitably designed for the subsurface conditions that is attached to the end of a drill string to enlarge the pilot bore during a pullback operation.

**Bore Path:** a drilled path according to the grade and alignment tolerances specified in the Contract Documents.

**Design Engineer:** means the Engineer retained by the Contractor who produces the original design and working drawings. The design engineer shall be licensed to practice in the Province of Ontario.

**Design Checking Engineer:** means the Engineer retained by the Contractor who checks the original design and working drawings. The design checking engineer shall be licensed to practice in the Province of Ontario.

**Digger Shield/Hand Mining:** a method of forming a horizontal bore in the subsurface by essentially simultaneously jacking ahead while tunnelling advances using hand-mining (man-entry operation or "Jack and Mine) or a "digger" type shield with a hydraulic excavator arm to remove materials from inside the liner pipe.

**Drilling Fluids:** a mixture of water and additives, such as bentonite, polymers, surfactants, and soda ash, designed to block the pore space on a bore wall, reduce friction in the bore, and to suspend and carry cuttings to the surface.

**Drilling Fluid Fracture or Frac Out:** a condition where the drilling fluid's pressure in the bore is sufficient to overcome the in situ confining stress, thereby fracturing the soil and/or rock materials and allowing the drilling fluids to migrate to the surface at an unplanned location.

**Engineer:** a Professional Engineer licensed by the Professional Engineers of Ontario to practice in the Province of Ontario.

**Excavation:** includes all materials encountered regardless of type and extent. Excavation shall include removal of natural soil, large boulders, cobbles, wood and fill regardless of means necessary to break consolidated materials for removal.



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## SPECIAL PROVISION

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**Environmentally Sensitive Area (ESA):** areas adjacent to construction that are off limits to the Contractor as specified elsewhere in the Contract.

**Fill:** man-made mixture of previously placed/handled materials such as sand, clay, silt, gravel, broken rock, sometimes containing organic and/or deleterious materials, placed in an excavation or other area to raise the surface elevation.

**Grouting:** injection of grout into voids.

**Guidance System:** an electronic system capable of locating the position, depth and orientation of the drill head during the directional drilling process.

**Directional Drilling (DD):** directional boring or guided boring.

**HDPE:** high density polyethylene.

**Inadvertent Returns:** the flow of unexpected fluids, saturated materials (or running soil) towards the drilling rig that typically originated from an artesian aquifer encountered during the drilling process.

**Loss of Circulation:** the discontinuation of the flow of drilling fluid in the bore back to the entry or exit point or other planned recovery points.

**Pilot Bore:** the initial bore to set directional controlled horizontal and vertical alignment between the connecting points.

**Pipe Jacking:** a method for installing steel casing or concrete pipe in the subsurface utilizing hydraulically operated jacks of adequate number and capacity to ensure smooth and uniform advancement without overstressing the liner/pipe.

**Pipe Ramming:** a method for installing steel casings utilizing the energy from a percussion hammer to advance a steel casing with a cutting shoe attached at the front end of the casing.

**Primary Liner (Support):** system installed prior to or concurrent with excavation, to maintain stability of an excavation and to support earth or rock and any structure utilities or other facilities in or on the supported earth or rock mass, until the excavation is completed.

**Product:** pipelines, conduits, cable, or ducts.

**Pullback:** that part of the DD method in which the drill string is pulled back through the bore path to the entry point.

**Quality Verification Engineer (QVE):** an Engineer who has a minimum of five (5) years experience in the field of pipe installation using trenchless methods or alternatively has demonstrated expertise by providing satisfactory quality verification services for the work at a minimum of two (2) projects of similar scope to the contract. The Quality Verification Engineer shall be retained by the Contractor to certify that the work is in general conformance with the contract documents and to issue Certificate(s) of Conformance.

**Reaming:** a process for pulling a tool attached to the end of the drill string through the bore path to enlarge the bore and mix the cuttings with the drilling fluid. This typically includes multiple passes.





## SPECIAL PROVISION

**Rock:** natural beds or massive fragments, or the hard, stable, cemented part of the earth's crust, igneous, metamorphic, or sedimentary in origin, which may or may not be weathered and includes boulders having a size equivalent to 0.3 m in diameter or greater.

**Secondary Liner:** concrete pipe, HDPE pipe or un-reinforced cast-in-place concrete, installed subsequent to tunnel excavation.

**Shaft:** vertically sided excavation used as entry and/or exit points from which the trenchless method is initiated or directed for the installation of product.

**Strike Alert:** a system that is intended to alert and protect the operator in the case of inadvertent drilling into an electrical utility cable. The strike alert system consists of a sensor and an alarm connected to the drill rig and a grounding stake. The alarm may be audio or visual or both.

**Slurry:** a mixture of soil and/or rock cuttings, and drilling fluid.

**Soil:** all materials except those defined as rock, and excludes stone masonry, concrete, and other manufactured materials; includes rock fragments having an equivalent size less than 0.3 m in diameter.

**Tunnelling:** an underground method of constructing a passage open at both ends that involves installing a pipe. For the purpose of this specification, the pipe may be installed by any of the various methods defined above such as Auger Jack & Boring, Pipe Ramming, Directional Drilling or using hand mining methods

## 4. DESIGN AND SUBMISSION REQUIREMENTS

### 4.01 General

The Contractor's documentation, submission requirements and installation methods shall specifically consider and address the subsurface conditions at the sewer crossing as identified in the geotechnical information. The subsurface conditions at the sewer crossing alignment are presented in "Foundation Investigation Report, Sewer Replacement at Station 23+134, Highway 400 NBL Between Highway 11 and Highway 93, Simcoe County, Ontario, G.W.P. 2039-06-00", by Golder Associates Ltd. Reference No. 09-1111-0022-2.

### 4.02 Working Drawings

Three copies of stamped working drawings for portal or shaft construction, primary liner, excavation, secondary lining, dewatering and groundwater control and grouting shall be submitted to the Contract Administrator (CA) at least one (1) week prior to the commencement of the work for information purposes. All submissions shall bear the seal and signature of the Design Engineer and Design Checking Engineer. The Contractor shall have a copy of the stamped working drawings at the site during construction.

As a minimum, working drawings/details pertaining to the tunnel design and construction shall include the following (as appropriate):

#### a) Plans, Elevations and Details:

- A work plan outlining the materials, procedures, methods and schedule to be used to execute the work;
- A list of personnel, including backup personnel, and their qualifications and experience;
- A safety plan including the company safety manual and emergency procedures;
- The work area layout;
- An erosion and sediment control plan that includes a contingency plan in the event the erosion and sediment control measures fail;



## SPECIAL PROVISION

- A drilling fluid management plan, if applicable, that addresses control of frac-out pressures, any potential environmental impacts and includes a contingency plan detailing emergency procedures in the event that the fluid management plan fails;
- Lighting, ventilation and fire safety details as may be required by applicable occupational health and safety regulations; and
- Excavated materials disposal plan.

b) Design Criteria:

- Primary liner design details, if applicable; and
- Design assumption and material data when materials other than those specified are proposed for use; and
- Drill path design, details of alignment and alignment control, maximum curvature and reaming stages.

c) Materials:

- Certification from the manufacturer that the product furnished on the contract meets the specifications cited in the manufacturer's product specification and that the materials supplied are suitable for the application; and
- Material mixture for filling voids and installation procedures.

d) Upstream/Downstream Portal Installation Procedure:

- The access shaft or entry/exit pit details designed and stamped/signed by the Design Engineer, as applicable; and
- Face support and other temporary support details, if applicable.

e) Primary Liner/Secondary Liner Installation and Grouting Procedure:

- Excavation and pipe jacking procedures, including methodology to handle obstructions and preventing soil cave-in; and
- Details of tunnelling equipment/methods to be used for the works.

f) Excavation and Dewatering:

- Ground control and dewatering details, as applicable, describing the proposed method for control, handling, treatment, and disposal of water.

g) Monitoring Method

- The methods to be employed to monitor and maintain the alignment of the installation.

### 4.02 Site Survey

Prior to commencing the work, the Contractor shall, at each sewer pipe location, lay out the alignment and install settlement monitoring points.

### 4.03 Certificate of Conformance

The Contractor shall submit details of the sequence and method of construction to the Quality Verification Engineer for review, prepared and stamped by the Design Engineer. The Contractor shall submit to the Contract Administrator a Certificate of Conformance sealed and signed by the Quality Verification Engineer a minimum of one week prior to commencement of work under this item. The Certificate shall state that the construction procedures are in conformance with the requirements and specifications of the contract documents.

The Contractor shall submit to the Contract Administrator a Certificate of Conformance sealed and signed by the Quality Verification Engineer upon completion of each of the following operations and prior to commencement of each subsequent operation for each sewer installation:



## SPECIAL PROVISION

Site Surveying (as noted in Section 4.02)  
Excavation for pits including dewatering of excavation  
Jacking/Ramming/Directional Drilling of Casing/Liner  
Excavation and Dewatering  
Installation of Sewer  
Grouting Operations

Each Certificate of Conformance shall state that the work has been carried out in general conformance with the contract documents, specifications and/or stamped working drawings.

In addition, upon completion of the installation of the sewer pipe at each location, the Contractor shall submit to the Contract Administrator a final Certificate of Conformance sealed and signed by the Quality Verification Engineer. The Certificate shall state that the sewer pipe has been installed in general conformance with the Contractor's Submission and Design Requirements, stamped working drawings and contract documents.

The Design Engineer will not be permitted to carry out the work of the Quality Verification Engineer.

### **5. MATERIALS**

#### **5.01 Sewer Pipe**

The sewer pipes shall be concrete pipe or high density polyethylene pipe as specified.

#### **5.02 Concrete**

Concrete shall be according to OPSS 1350. The concrete strength shall be as specified in the Contractor's design submission.

#### **5.03 Concrete Reinforcement**

Steel reinforcing for concrete work shall be according to OPSS 1440.

#### **5.04 Timber**

Timber shall be sound, straight, and free from cracks, shakes and large or loose knots.

#### **5.05 Grout**

The Contractor shall submit the proposed grout mix design for grouts to be used for lubricating jacking pipe and for filling of voids and annular spaces. Parging grout shall consist of a mixture of one part Portland cement conforming to the requirements of CAN/CSA A5-93 and two parts mortar sand conforming to OPSS 1004 wetted with only sufficient water to make the mixture plastic.

#### **5.06 Auger Jack & Bore Materials**

##### **5.06.01 Pipe Materials**

Steel pipe shall conform with ASTM A252-95 welded joints suitable for jacking operations. The Contractor shall select pipe class for pipe jacking.

Concrete pipe as per MTO Form 1820.



## SPECIAL PROVISION

Fittings shall be suitable for and compatible with the class and type of pipe with which they will be used.

### **5.07 Pipe Ramming Materials**

#### **5.07.01 Pipe Materials**

Steel pipe shall conform with ASTM A 252-93 welded joints.

New steel casing when specified shall be smooth wall carbon steel pipe according to ASTM A252-93 Grade 2.

Used steel casing can be used provided that the steel casing can resist the applicable static and dynamic loadings.

Pipe wall thickness shall be determined by the Contractor based on static and dynamic loads from traffic loading and anticipated ramming forces for selected pipe and driven pipe lengths. The wall thickness shall be increased as required to ensure the casing is not damaged during handling and installation.

Pipe segments shall be determined by the Contractor.

Steel pipe joints shall be pressure fit type or welded.

All steel casing pipe shall be square cut.

Steel casing pipe shall have roundness such that the difference between the major and minor outside diameters shall not exceed 1% of the specified nominal outside diameter or 6 mm, whichever is less.

Steel casing pipe shall have a minimum allowable straightness of 1.5 mm maximum per metre of length.

#### **5.07.02 Mill Certificates**

For permanent casing, the Contractor shall submit to the Contract Administrator at the time of delivery one copy of the mill certificate, indicating that the steel meets the requirements for the appropriate standards for casings.

Where mill test certificates originate from a mill outside Canada or the United States of America the Contractor shall have the information on the mill certificate verified by testing by a Canadian laboratory. The laboratory shall be accredited by a Canadian National Accreditation Body to comply with the requirements of ISO/IEC Guide 25 for the specific tests or type of tests required by the material standard specified on the mill test certificate. The mill test certificates shall be stamped with the name of the Canadian testing laboratory and appropriate wording stating that the material conforms to the specified material requirements. The stamp shall include the appropriate material specification number, the date and the signature of an authorized officer of the Canadian testing laboratory.

### **5.08 Directional Drilling Materials**

#### **5.08.01 Drilling Fluids**

The drilling fluids shall be mixed according to the manufacturer's recommendations and be appropriate for the anticipated subsurface conditions.

#### **5.08.02 Pipe Materials**



## SPECIAL PROVISION

High Density Polyethylene (HDPE) pipe as per MTO Form 1840 shall be used in accordance with ASTM D3350.

The requirements for fittings shall be suitable for and compatible with the class and type of pipe with which they will be used and in according to CAN/CSA-B182.6 or ASTM F894.

The Contractor shall determine the required dimensional ratio (DR) of the HDPE pipe to support all subsurface conditions and hydrostatic pressures, and to withstand the grouting pressure and installation forces. The Contractor shall identify these forces in his submission requirements.

The Contractor's submission shall demonstrate, in conjunction with the manufacturer's specifications, that the heat resistance of the pipe material is sufficient to tolerate without damage the heat of hydration generated by grout curing.

Fittings shall be suitable for and compatible with the class and type of pipe with which they will be used.

Joining of HDPE piping shall be completed by thermal butt fusion in accordance with manufacturer's recommended procedures and as outlined in the latest revision of ASTM D2657. All manufacturer's recommendations and procedures shall be followed during the joining process.

Joining of HDPE piping to other piping materials or appurtenances shall be completed using flanged connections.

### **5.09 Tunnelling Materials**

#### **5.09.01 Primary Liner**

Tunnelling methods will require installation of a primary liner. The primary liner shall be designed by the Contractor and the design/drawings shall be stamped/signed by the Design Engineer. The design shall be submitted to the Contract Administrator as specified herein.

#### **5.09.02 Secondary Liner**

Concrete or High Density Polyethylene Pipe shall be used according to the following requirements.

##### **5.09.02.01 Concrete Pipe**

Concrete pipe as per MTO Form 1820 shall be used. The Contractor shall select the pipe class to withstand grouting pressure and installation forces. The Contractor shall identify these forces in his submission requirements.

Fittings shall be suitable for and compatible with the class and type of pipe with which they will be used.

##### **5.09.02.02 High Density Polyethylene (HDPE)**

High Density Polyethylene (HDPE) pipe as per MTO Form 1840 shall be used in accordance with ASTM D3350.

The requirements for fittings shall be according to CAN/CSA-B182.6 or ASTM F894.

The Contractor shall determine the required dimensional ratio (DR) to withstand the grouting pressure and installation forces. The Contractor shall identify these forces in his submission requirements.

Fittings shall be suitable for and compatible with the class and type of pipe with which they will be used.



## SPECIAL PROVISION

Joining of HDPE piping shall be completed by thermal butt fusion in accordance with manufacturer's recommended procedures and as outlined in the latest revision of ASTM D2657. All manufacturer's recommendations and procedures shall be followed during the joining process.

Joining of HDPE piping to other piping materials shall be completed using flanged connections.

### **6. EQUIPMENT**

#### **6.01 Auger Jack & Bore Equipment**

Pipe auger jack & bore equipment shall be determined by the Contractor and shall be identified in the submission requirements specified herein.

Specific details of the manner in which rock or boulders will be broken and removed from the face and the face will be protected to prevent soil loss into the liner shall be submitted to the Contract Administrator for information purposes prior to proceeding with the works.

#### **6.02 Pipe Ramming Equipment**

Pipe ramming equipment shall be determined by the Contractor and shall be identified in the submission requirements specified herein.

The pipe ramming hammer(s) shall be capable of driving the pipe casing from the drive pit through the existing subsurface conditions at the site.

Specific details of the manner in which rock or boulders will be broken and removed from the face and the face will be protected to prevent soil loss into the pipe shall be submitted to the Contract Administrator for information purposes prior to proceeding with the works.

#### **6.03 Directional Drilling Equipment**

##### **6.03.01 General**

The directional drilling equipment shall consist of a directional drilling rig and a drilling fluid mixing and delivery system of sufficient capacity to successfully complete the product installation without exceeding the maximum tensile strength of the product being installed.

##### **6.03.02 Drilling Rig**

The directional drilling rig shall:

- consist of a leak free hydraulically powered boring system to rotate, push, and pull hollow drill pipe into the ground at a variable angle while delivering a pressurized fluid mixture to a guideable drill head;
- contain a guidance system to accurately guide boring operations;
- be anchored to the ground to withstand the rotating, pushing, and pulling forces required to complete the product installation; and
- be grounded during all operations unless otherwise specified by the drilling rig manufacturer.

##### **6.03.03 Drill Head**

The drill head shall be steerable by changing its rotation, be equipped with the necessary cutting surfaces and drilling fluid jets, and be of the type for the anticipated subsurface conditions,



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## **SPECIAL PROVISION**

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### **6.03.04 Guidance System**

The guidance system shall be setup, installed, and operated by trained and experienced personnel. The operator shall be aware of any magnetic or electromagnetic anomalies and shall consider such influences in the operation of the guidance system when a magnetic or electromagnetic system is used.

### **6.03.05 Drilling Fluid Mixing System**

The drilling fluid mixing system shall be of sufficient size to thoroughly and uniformly mix the required drilling fluid.

### **6.03.06 Drilling Fluid Delivery System**

The delivery system shall have a means of measuring and controlling fluid pressures and be of sufficient flow capacity to ensure that all slurry volumes are adequate for the length and diameter of the final bore and the anticipated subsurface conditions. Connections between the delivery pump and drill pipe shall be leak-free.

## **6.04 Tunnelling Equipment**

Tunnelling equipment shall be determined by the Contractor and shall be identified in the submission requirements specified herein.

Specific details of the manner in which rock or boulders will be broken and removed from the tunnel face shall be submitted to the Contract Administrator information purposes. Use of explosives or rock fracturing chemicals shall only be considered subject to a field demonstration satisfactory to the Ministry prior to its use.

## **7. CONSTRUCTION**

### **7.01 General**

The Contractor shall notify the Contract Administrator at least 48 hours in advance of starting work. The proposed method of sewer pipe installation to be used by the Contractor shall be submitted to the Contract Administrator for information purposes prior to commencing the work and shall be subject to the limitations presented in the following subsections.

#### **7.01.01 Layout, Alignment and Depth Control**

The location of the installation shall be established from the lines, elevations and tolerances specified in the Contract Documents. The sewer pipe installation shall be to the horizontal and vertical alignments specified in the Contract Drawings. Deviations from location, alignment, grades and/or invert levels shall be corrected by the Contractor at no cost to the Ministry.

All reference points necessary to construct the sewer pipe installation and appurtenances shall be laid out.

The Contractor shall calibrate tracking and locating equipment at the beginning of each work day, and shall monitor and record the alignment and depth readings provided by the tracking system at every 5 m in normal conditions and every 2 m where precise alignment control is necessary;

The Contract Administrator shall be provided with the assistance and access necessary to check the layout of the pipe installation and associated appurtenances.





## SPECIAL PROVISION

All excavations shall be carried out in accordance with the Occupational Health and Safety Act (OHSA) of Ontario.

For directional drilling, the contractor shall ensure that during pilot hole drilling the maximum degree of deviation or “dog-leg” shall be 2.5 degrees per 9m drill pipe length. Any deviation exceeding 2.5 degrees will necessitate a pull-back and straightening of the alignment at the Contractor’s sole expense. The pilot hole exit location shall be within 0.5m of the target location.

### **7.01.02 Construction Shafts**

Construction shafts shall be specified in the Contractor's submission. The boundaries and protection of these shall be as required to contain all disturbances to areas outside of the ESA limits.

Shafts shall be maintained in a drained condition.

A minimum 2.4 m high secure fence shall be installed around the perimeter of the construction shaft area with gates and truck entrances. The fence shall be removed on completion of the work.

### **7.01.03 Protection Schemes**

The construction of all protection schemes shall be according to OPSS 539. Where the stability, safety, or function of an existing roadway, watercourse, other works, proposed works or ESA's may be impaired due to the method of operation, protection shall be provided. Protection may include sheathing, shoring, and piles where necessary to prevent damage to such works or proposed works.

### **7.01.04 Settlement or Heave**

Any disturbance to the ground surface (settlement or heave) as a result of the pipe installation shall be immediately corrected by the Contract, at no additional cost to the Ministry.

### **7.01.05 Stability of Excavation**

The construction methods, plant, procedures, and precautions employed shall ensure that excavations are stable, free from disturbance, and maintained in a drained condition.

The construction methods, plant, and materials employed shall prevent the migration of soil and/or rock material into the excavation from adjacent ground.

### **7.01.06 Preservation and Protection of Existing Facilities**

Preservation and protection of existing facilities shall be according to OPSS 504.

Minimum horizontal and vertical clearances to existing facilities as specified in the Contract Documents shall be maintained. Clearances shall be measured from the nearest edge of the largest cut diameter required to the nearest edge of the facility being paralleled or crossed.

Existing underground facilities shall be exposed to verify its horizontal and vertical locations when the outlet sewer pipe path comes within 1.0 m horizontally or vertically of the existing facility. Existing facilities shall be exposed by non-destructive methods. The number of exposures required to monitor work progress shall be as specified in the Contract Documents.

### **7.01.07 Transporting, Unloading, Storing and Handling Materials**





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## **SPECIAL PROVISION**

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Manufacturer's handling and storage recommendations shall be followed.

### **7.01.08 Trenching, Backfilling and Compacting**

Trenching, backfilling, and compacting for entry and exit points or other locations along the sewer pipe path shall be according to OPSS 514.

### **7.01.09 Support Systems**

Support systems shall be according to OPSS 538.

If any open excavation will encroach into the highway embankment the protection system shall satisfy the requirements for Performance Level 2 as specified in SP105S19.

### **7.01.10 Dewatering**

The work of this Section includes control, handling, treatment, and disposal of groundwater. The Contractor shall review the foundation investigation report for reference to soil and groundwater conditions on the project site and plan a dewatering scheme accordingly.

The Contractor shall control groundwater inflows to excavations to maintain stability of surrounding ground, to prevent erosion of soil, to prevent softening of ground exposed in the excavation, and to avoid interfering with execution of the work.

The Contractor shall maintain excavations free of standing water at all times during excavation, including while concrete is curing.

Should water enter the excavation in amounts that could adversely affect the performance of the work or could cause loss of ground, the Contractor shall take immediate steps to control the inflow.

The Contractor is alerted that seepage zones of perched water within the fill materials should be expected, particularly where granular materials are excavated.

Dewatering shall be according to OPSS 517.

### **7.01.11 Removal of Boulders**

The Contractor is alerted that cobbles and boulders should be anticipated in the soil deposits at the site. Accordingly, the Contractor shall address the removal of cobbles and boulders in the proposed method of construction. The Contractor shall immediately inform the Contract Administrator of any obstruction encountered.

### **7.01.12 Record Keeping**

Verification record requirements of the alignment and depth of the installation shall be as specified in the Contract Documents. A copy of the verification records shall be given to the Contract Administrator at the completion of the installation.

### **7.01.13 Testing**



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Testing of the product installation shall consist of verifying the specified grade between the two ends of the sewer pipe and passing of water from the median end of the pipe to the outlet end to confirm gravity flow conditions.

### **7.01.14 Management and Disposal of Excess Material**

Management and disposal of excess material shall be according to OPSS 180. Satisfactory re-usable excavated material required for backfill shall be separated from unsuitable excavated material.

### **7.01.15 Site Restoration**

Site restoration shall be according to OPSS 507.

### **7.01.16 Supervision**

A qualified individual, who is experienced in the construction of sewer pipe installation by trenchless methods shall supervise the work at all times.

## **7.02 Auger Jack & Bore Installation**

### **7.02.01 Method of Installation Procedure**

The installation procedure to be used shall be subject to the following limitations:

- Hydraulically operated jacks of adequate number and capacity shall be provided to ensure smooth and uniform advancement without over-stressing of the pipe.
- A suitably padded jacking head or collar shall be provided to transfer and distribute jacking pressure uniformly over the entire end bearing area of the pipe.
- The jacking pipe shall be fully supported in the jacking pit at the specified line and grade.
- Selection of the excavation method and jacking equipment shall take into consideration the conditions at each sewer crossing.

### **7.02.02 Pipe Installation**

Concrete pipe joints shall be water tight and according to OPSS 1820 and must withstand jacking forces, determined by the Contractor.

During the jacking of the liner the space between the liner and the wall of the excavation shall be kept filled with bentonite slurry. Upon completion of jacking, the space between the liner and the wall of the excavation shall be filled with grout.

The annular space between the liner and the product shall be fully grouted with a water tight, expandable and stable grout.

## **7.03 Pipe Ramming Installation**

For pipe ramming installation the following requirements apply:

Only smooth walled steel pipe shall be used. But welding of pipe joints shall conform to CAS W59.

Ramming equipment of adequate capacity shall be provided to ensure smooth and uniform advancement without over-stressing of the pipe. Delays shall be avoided between ramming operations.



## **SPECIAL PROVISION**

A ramming head shall be provided to transfer and distribute jacking pressure uniformly over the entire end bearing area of the pipe.

Two or more lubricated guide rails or sills shall be provided of sufficient length to fully support the pipe at the specified line and grade in the ramming pit. Pipe shall be installed to the line and grade specified.

Following installation of the pipe, all material shall be removed from the pipe to the satisfaction of the Contract Administrator. Any voids remaining between the pipe and the excavation wall shall be grouted as soon as the pipe is rammed. The annular space between the liner pipe and the product shall be fully grouted with a water tight, expandable and stable grout.

### **7.04 Directional Drilling Installation**

#### **7.04.01 General**

When strike alerts are provided on a drilling rig, they shall be activated during drilling and maintained at all times.

#### **7.04.02 Site Preparation**

The work site shall be graded or filled to provide a level working area for the drilling rig. No alterations beyond what is required for DD operations are to be made. All activities shall be confined to designated work areas.

#### **7.04.03 Pilot Bore**

The pilot bore shall be drilled along the bore path in accordance with the grade, alignment, and tolerances as indicated on the Contractor's submitted drilling plan to ensure that the product is installed to the line and grade shown on the Contract Drawings. The Contractor's methods shall take into consideration the conditions at each sewer crossing within the pipe alignment and shall be suitable to advance through such obstructions such as cobbles and boulders and address the potential for deflection off these obstruction and/or soil conditions.

In the event the pilot bore deviates from the submitted path, the Contract Administrator shall be notified. The Contract Administrator may require the Contractor to pullback and re-drill from the location along the bore path before the deviation.

In the event that a drilling fluid fracture, inadvertent returns, or loss of circulation occurs during pilot bore drilling operations, the Contract Administrator shall be advised of the event and action shall be taken in accordance with the Contractor's submitted contingency plan.

At the entry and exit points, there is potential for ravelling of the existing soil, fill and or weathered rock areas along the alignment. This is conventionally addressed by the use of drilling fluid. However, casing may be required. The Contractor's methods shall take into consideration the potential need to install sections of casing to manage ravelling at or near ground surface.

If a drill hole beneath the highway must be abandoned, the hole shall be backfilled with grout or bentonite to prevent future subsidence.

The Contractor shall maintain drilling fluid pressure and circulation throughout the DD process, including during the initial pilot bore and during the reaming process.

The Contractor shall at all times and for the entire length of the installation alignment be able to demonstrate the horizontal and vertical position of the alignment, the fluid volume used, return rates and pressures.



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## SPECIAL PROVISION

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### **7.04.04 Drilling Fluid Fracture (Frac-Out)**

In order to reduce the potential for hydraulic fracturing of the hole during directional drilling, a minimum depth of cover of 5m is normally maintained between the pipe and the ground surface. Sections of the pipe close to the exit pit with less than 5m cover shall be cased. The Contractor shall ensure that drilling fluid pressures are properly set and controlled to prevent frac-out, for the depth of cover available between the bottom of the pavement structure (bottom of the subbase material) and the top of the bore.

Since fluid loss normally occurs in fault zones, fracture zones, or seams of coarse material, fluid migration does not always gravitate to the surface, thus making detection difficult. Once a fluid loss is detected, the Contractor shall halt operations immediately and conduct a detailed examination of the drill path and implement measures to mitigate fluid loss. If no surface migration is evident, resume operation while paying particular attention to fluid monitoring.

In the event of a fluid migration to the surface occurring, the Contractor shall halt all operations immediately, isolate the migration site, and recover fluids. Once the fracture is controlled, continue drilling operations with the operator paying particular attention to the fracture points

### **7.04.05 Reaming**

The bore shall be reamed using the appropriate tools to a diameter at least 50% greater than the outside diameter of the product.

### **7.04.06 Product Installation**

#### **7.04.06.01 General**

The product shall be jointed according to manufacturer's recommendations. The length of the product to be pulled shall be jointed as one length before commencement of the continuous pulling operation.

The product shall be protected from damage during the pullback operation.

The minimum allowable bending radius for the product shall not be exceeded.

Product shall be allowed to recover before connections to new or existing facility are made. Product recovery time shall be according to manufacturers recommendations.

#### **7.04.06.02 Pullback and Grouting**

After successfully reaming the bore to the required diameter, the product shall be pulled through the bore path. Once the pullback operation has commenced, it shall continue without interruption until the product is completely pulled into bore unless otherwise approved by the Contract Administrator.

A swivel shall be used between the reamer and the product being installed to prevent rotational forces from being transferred to the product. When specified in the Contract Documents, a weak link or breakaway connector shall be used to prevent excess pulling force from damaging the product.

The product shall be inspected for damage where visible at excavation pits and where it exits the bore. Any damage noted shall be rectified to the satisfaction of the Contract Administrator,

The pull back and reaming operations shall not exceed the fluid circulation rate capabilities. Reaming and back pulling operations shall be planned to insure that, once started, all reaming and back pulling operations are completed without stopping and within the permitted work hours.



The space between the pipe and the excavation walls shall be filled with grout.

### **7. 05 Tunnelling Installation**

#### **7.05.01 General**

The method of tunnelling shall be selected by the Contractor and shall be submitted to the Contract Administrator prior to commencement of the work for information purposes.

Excavation of native soil and fill shall be done in a manner to control groundwater inflow to the excavation and to prevent loss of ground into the excavation.

Methods of excavating the tunnel shall be capable of fully supporting the face and shall accommodate the removal of boulders and other oversize objects from the face. Continuous ground support shall be maintained during excavation.

As the excavation progresses, the Contractor shall continuously monitor (every 2m) indications of support distress, such as cracking, deflection or failure of support system and subsidence of ground near the excavation.

The Contractor shall advance the ventilation system as a regular part of the normal excavation cycle.

The Contractor shall provide lighting in accordance with OSHA requirements for the entire length of the tunnel.

The tunnel is to be kept sufficiently dry at all times to permit work to be performed in a safe and satisfactory manner.

The Contractor shall maintain clean working conditions at all times in tunnels.

In the event that excavation threatens to endanger personnel, the Work, or adjacent property, the Contractor shall cease excavation. The Contractor shall then evaluate methods of construction and revise as necessary to ensure the safe continuation of the work.

The Contractor shall maintain tunnel excavation line and grade to provide for construction of final lining within specified tolerances.

#### **7.05.02 Tunnelling Method**

The tunnelling method shall be suitable to provide face support in changing ground conditions that may be encountered during the progress of the work. The selection of the tunnelling method should consider the soil conditions at each sewer crossing and the presence of obstructions, such as cobbles and boulders, with respect to the tunnel alignment.

#### **7.05.03 Primary Liner (Support System)**

Primary support systems shall prevent deterioration, loosening, or unravelling of ground surfaces exposed by excavation.

The primary liner support system shall be designed and installed to achieve the intended performance requirements.

Primary liner support system shall maintain the safety of personnel, minimize ground movement into the excavation, ensure stability and maintain strength of ground surrounding the excavation.



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## SPECIAL PROVISION

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The primary liner shall be designed to support all subsurface conditions and hydrostatic pressures and to withstand any additional loads caused by installation and grouting, and shall ensure that no ground loading or other loading will be placed on the new work until after design strength has been reached.

The primary liner shall be installed so that the exterior is as tight as possible to the excavated surface of the tunnel and allows the placement of the full design thickness of the secondary lining.

Primary support systems shall be compatible with the encountered ground conditions, with the method of excavation, with methods for control of water, and with placement of the permanent lining.

All voids between the primary lining and the surface of the excavation shall be filled with cement grout. If an unexpanded liner is used, the space outside the liner plates shall be grouted at least daily.

### **7.05.04                      Secondary Liner**

#### **7.05.04.01                  Placing of Grout**

The void outside the finished secondary liner shall be filled with cement grout according to the Contractor's submission.

Grout shall not be placed until the lining has achieved 85% of its specified strength or 30 MPa. Grouting shall be limited to such sequences and programs as are necessary to avoid damaging any part of the works or any other structure or property.

### **7.06      Instrumentation Monitoring**

The work specified in this Section includes furnishing and installing instruments for monitoring of settlement and ground stability.

Surface settlement markers for monitoring ground stability shall be installed at the pavement/ground surface level on the shoulder, side slope and pavement at not greater than 5 m intervals along the tunnel alignment and as an array of three in ground (1.5 m depth) measurement points on the shoulder of the highway perpendicular to the alignment. The equipment and procedures used for settlement monitoring during construction must be capable of surveying the settlement point elevations to within  $\pm 1$  mm of the actual elevation.

Surface settlement markers shall be hardened steel markers treated or coated to resist corrosion, with an exposed convex head having a minimum diameter of 12 mm and similar to surveyor's PK nails. Markers shall be rigidly affixed so as not to move relative to the surface to which it is attached. Traffic shall be managed by the contractor using short-term lane closures in accordance with the Ontario Traffic Manual (OTM).

In general, settlement monitoring points shall be 12-18 mm rebar encased in a 50-70 mm, Schedule 40 PVC pipe, set to a depth of 1.5 m below ground surface. The assembly shall be placed in a drill hole and backfilled with uniform sand as shown on the Contract Drawings.

The Contractor shall install all surface settlement instruments a minimum of one week prior to the start of works.

The surface settlement instruments shall be clearly labelled for easy identification.

The Contractor shall submit to the Contract Administrator a site plan showing the locations of the monitoring points, a geodetic survey of the settlement monitoring points including station, offset and elevation recorded at the following time intervals:



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- Three consecutive readings at least one week prior to commencement of the work (Baseline Reading);
- Two times per shift during tunnelling operations period; and
- Weekly after completion of the work for one month, or until such time at which all parties agree that further movement has stopped.

All readings shall be submitted to the Contract Administrative for information purposes on a weekly basis. Each report shall include all survey data collected in tabular and graphical format as plots of time versus settlement in comparison to survey data collected prior to commencement of the work.

### 7.07 Criteria for Assessment of Roadway Subsidence/Heave

Based on the monitoring of ground movement as specified in Subsection 4.02, the following represents trigger levels that define magnitude of movement and corresponding action:

- Review Level: If a maximum value of 10 mm relative to the baseline readings is reached, the Contractor shall review or modify the method, rate of sequence of construction or ground stabilization measures to mitigate further ground displacement. If the Review Level is exceeded, the Contractor shall immediately notify the CA and review and discuss response actions. The Contractor shall submit a plan of action to prevent Alert Levels from being reached. All construction work shall be continued such that the Alert Level is not reached.
- Alert Level: If a maximum value of 15 mm relative to the baseline readings is reached, the Contractor shall cease construction operations, inform the Contract Administrator and execute pre-planned measures to secure the site, to mitigate further movements and to assure safety of public and maintain traffic.

No construction shall take place until all the following conditions are satisfied:

- The cause of the settlement has been identified.
- The Contractor submits a corrective/preventive plan.
- Any corrective and/or preventive measure deemed necessary by the Contractor is implemented.
- The CA deems it is safe to proceed.

The Contractor shall avoid damaging instrumentation during construction. Instrumentation that is damaged as a result of the Contractor's operation shall be repaired or replaced by the Contractor within one business day. The costs for replacement/repair shall be borne by the Contractor.

At the completion of the job, the Contractor shall abandon all instrumentations installed during the course of the Work.

## 8. MEASUREMENT FOR PAYMENT

Measurement shall be by Plan Quantity Payment as may be revised by Adjusted Plan Quantity Payment in metres, following along the centre line of the sewer pipes from centre to centre of maintenance holes or chambers (catch basins) or from/to the end of the pipe where no maintenance hole or chamber is installed, of the actual length of sewer installed by trenchless methods.

## 9. BASIS OF PAYMENT

Payment at the contract price shall be full compensation for providing all labour, equipment and materials required for excavation (regardless of material encountered), dewatering, sheathing and shoring, supply and installation of primary liners, supply and installation of the sewers, site restoration and for all other work necessary to complete the sewer as specified.



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## SPECIAL PROVISION

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Where a protection system is made necessary because of the Contractor's operations (e.g. choice of trenchless installation method), the cost shall be included in this item and shall be full compensation for all labour, equipment and materials required to carry out the work including subsequently removing the temporary protection system and performing any necessary restoration work.

Payment for connecting intercepted drains and service connections into the sewer system shall be made on the following basis:

- (a) Where such drains and service connections are shown on the contract drawings the cost of connections shall be included in the contract price for installation of sewers.
- (b) Where such drains and service connections are not shown on the contract drawings, the cost of connections will be considered an allowable extra to the contract.

Payment for removal of boulders/obstructions greater than an equivalent 0.3 m in diameter shall be on a time and materials basis. The Contractor shall inform the Contract Administrator when boulders/obstructions are encountered and prior to removal to allow for proper and accurate tracking of time and material charges.





# **APPENDIX D**

**Settlement Monitoring Guideline – Tunnelling  
(from MTO’s Guideline for Foundation Engineering – Tunnelling  
Speciality for Corridor Encroachment Permit Application)**

## **APPENDIX: SETTLEMENT MONITORING GUIDELINE - TUNNELLING**

### **Instruments**

Two types of settlement monitoring points are required:

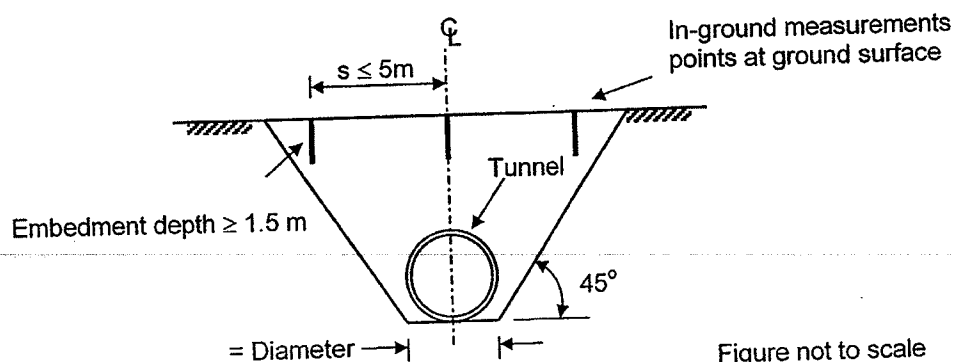
- Surface points are placed along the tunnel alignment at maximum intervals of 5 m.
- In-ground points, approximately 1.5m to 1.8m deep, are proposed for the shoulders (and within the guardrail). The in-ground points are important for detecting settlements before they are transferred to the surface.

### **Instrumentation Arrays**

All measurement points shall be installed and surveyed before the start of excavation to establish benchmarks/baseline.

#### **In-ground Monitoring Points**

One array of three measurement points is to be installed on each shoulder of both directional lanes of the highway. Center point of the array should be directly over the centreline of the tunnel; whereas, the other two points will be at a maximum distance of  $s = 5\text{m}$  on either side of the center point perpendicular to the centerline of the tunnel. The spacing  $s$  between the measurement points may be adjusted to install all the three points within the extents of surface zone defined by a  $45^\circ$  line from the invert of the tunnel as shown in Figure 1.



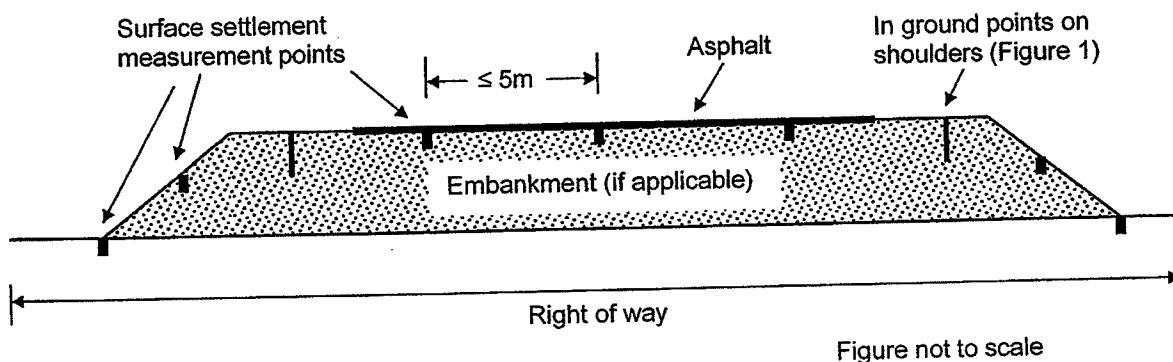
**Figure 1:** Definition of extents of the surface zone

### Surface Monitoring Points

Surface monitoring points will be installed on the pavements, shoulders (every shoul) and side slope of the highway embankments to cover the whole length of the tunnel with in the right of way under the jurisdiction of MTO (Figure 2).

Surface monitoring points will be located at not greater than 5m intervals along the tunnel alignment. The surface monitoring will be identified using paint marks on the pavement.

The final instrumentation plan should be finalised when Contractor's proposed construction method is available.



**Figure 2:** Typical configuration of surface settlement measuring points along the tunnel alignment.

### **Condition Survey**

A condition survey for the pavement will be carried out prior to commencement of construction and documented for the purpose of requirement of restoration, if necessary. The condition survey will be carried out using the surface monitoring points installed on each travelled lane. This surface survey will be completed during the installation of the in-ground monitors and again once the tunnel has been completed. Interim surveys will be required should movement be detected in the in-ground monitoring points.

### **Reading Frequency**

The reading and collection of data from the in-ground and surface monitoring points shall be read and recorded continually by the Contractor during the construction period and after construction to a time at which all parties agreed that further movement has stopped.

It is recommended that at least three (3) sets of reading be taken during each shift, provided that movements are within anticipated limits. Otherwise, the frequencies should increase according to a pre-planned interval.

Monitoring of movements is required during work stoppages, such as during non-operation period (off-shifts) or weekends. At least three (3) sets of readings should be taken daily.

### **Data Collection and Data Transfer**

A procedure is required to be established in consultation with MTO so that the monitoring data and the interpreted data will reach all parties as soon as necessary. The responsible prime Consultant and the Contractor should interpret monitoring data as needed for the purpose of on-going construction. The Geotechnical Engineer should be contacted for technical support to the prime Consultant in the interpretation of ground movements and review of the Contractor's response when Review and Alert Levels are reached.

### **Criteria for Assessment**

The suggested acceptable surface settlement (or heave) is 25mm, or at criteria specified by MTO. The baseline reading, alert level and review level should be established with input from the MTO.

**Baseline Reading** – A baseline reading of the instrumentation shall be taken prior to commencement of the work. All parties should recognize and accept the baseline level in writing.

**Review Level** – A maximum value of 10 mm relative to the baseline readings is suggested for this project. If this level is reached, the method, rate or sequence of construction, or ground stabilization measures should be reviewed or modified to mitigate further ground displacements.

**Alert Level** – A maximum value of 15mm relative to the baseline readings is suggested for this project. If this level is reached, the Contractor shall cease construction operations and to execute pre-planned measures to secure the site, to mitigate further movements and to assure safety of public and maintain traffic.

### **Review of Contractor's Proposed Method**

MTO, the Proponent's prime consultant and Geotechnical Engineer should review the Contractor's proposed method of construction. The proposed method should include a description of the potential loss of ground, and calculation of the maximum settlement in relation to the Contractor's procedure and equipment, alternative/remedial measures

when review level of measurement is reached; and contingency/remedial measures when alert level of measurement is reached.

### **Contractor's Responsibility For Restoration and Warranty Provision**

Notwithstanding the monitoring program to assess the adequacy of the tunnelling construction method to control potential ground movements and groundwater, the Contractor is responsible for reinstatement (such as surface paving) should movements or other surface distress occur, and provide a reasonable warranty period acceptable to MTO.

### **Construction Monitoring**

The Proponent shall retain a qualified Geotechnical Consultant to supervise the installation of surface settlement points on site and to provide direction, technical input and field inspection on this project.

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