

**Golder Associates Ltd.**

2390 Argentia Road  
Mississauga, Ontario, Canada L5N 5Z7  
Telephone: (905) 567-4444  
Fax: (905) 567-6561



**REPORT ON**

**FOUNDATION INVESTIGATION AND DESIGN  
PRELIMINARY DESIGN  
CULVERT REPLACEMENT AT STATION 10+502.5  
HIGHWAY 7 FROM FOWLERS CORNERS  
SOUTHERLY TO COUNTY ROAD 28  
PETERBOROUGH, ONTARIO  
G.W.P. 73-99-00, SITE NO. 26-186**

Submitted to:

National Capital Engineering Limited  
100 Craig Henry Drive, Suite 202  
Ottawa, Ontario  
K2G 5W3

GEOCRES NO: 31D-429

**DISTRIBUTION**

- 3 Copies - Ministry of Transportation, Ontario,  
Kingston, Ontario (Eastern Region)
- 1 Copy - Ministry of Transportation, Ontario,  
Downsview, Ontario (Foundation Section)
- 2 Copies - National Capital Engineering Limited,  
Ottawa, Ontario
- 2 Copies - Golder Associates Ltd.,  
Mississauga, Ontario

September 2007

04-1111-024D



## TABLE OF CONTENTS

<u>SECTION</u>	<u>PAGE</u>
<b>PART A - PRELIMINARY FOUNDATION INVESTIGATION REPORT</b>	
1.0 INTRODUCTION.....	1
2.0 SITE DESCRIPTION.....	1
3.0 INVESTIGATION PROCEDURES.....	2
3.1 Foundation Investigation .....	2
4.0 SITE GEOLOGY AND SUBSURFACE CONDITIONS.....	3
4.1 Regional Geology.....	3
4.2 Subsoil Conditions .....	4
4.2.1 Topsoil / Peat .....	4
4.2.2 Silty Sand .....	4
4.2.3 Clayey Silt to Silty Clay .....	5
4.2.4 Sandy Silt to Silt .....	6
4.2.5 Groundwater Conditions .....	7
5.0 CLOSURE .....	8
 <b>PART B - PRELIMINARY FOUNDATION DESIGN REPORT</b>	
6.0 PRELIMINARY ENGINEERING RECOMMENDATIONS .....	9
6.1 General .....	9
6.2 Culvert Foundation Options.....	10
6.2.1 Geotechnical Resistance .....	11
6.2.1.1 Preferred Alternative - Box Culvert.....	11
6.2.1.2 Open Footing Culvert .....	12
6.2.2 Resistance to Lateral Loads .....	13
6.2.3 Frost Protection .....	14
6.3 Lateral Earth Pressures for Preliminary Design .....	14
6.4 Settlement.....	17
6.4.1 Culvert Replacement .....	17
6.4.2 Proposed Culvert Under Future Embankment Widening.....	17
6.5 Stability .....	19
6.6 Base Heave .....	19
6.7 Preliminary Considerations for Culvert Construction .....	20
6.7.1 Subgrade Preparation and Excavation .....	20
6.7.2 Groundwater and Surface Water Control .....	20
6.7.3 Bedding and Backfill .....	21
6.7.4 Erosion Protection .....	22
6.8 Closure .....	22

In Order  
Following  
Page 22

References

Table 1

Lists of Abbreviations and Symbols

Record of Borehole Sheets (06-5 to 06-8)

Drawing 1

Appendix A

## **LIST OF TABLES**

Table 1            Evaluation of Culvert Foundation Alternatives

## **LIST OF DRAWINGS**

Drawing 1        Borehole Locations and Soil Strata

## **LIST OF APPENDICES**

Appendix A      Laboratory Test Data

Figure A1        Grain Size Distribution – Clayey Silt to Silty Clay

Figure A2        Grain Size Distribution – Silt

Figure A3        Plasticity Chart – Clayey Silt to Silty Clay

Figure A4        Consolidation Test – Void Ratio vs. Log Pressure – BH 06-5, Sa 4

Figure A5        Consolidation Test – Total Work vs. Pressure – BH 06-5, Sa 4

Figure A6        Oedometer Consolidation Summary

Figure A7        Plots of Consolidation Test Results

**PART A**

**FOUNDATION INVESTIGATION REPORT  
PRELIMINARY DESIGN  
CULVERT REPLACEMENT AT STATION 10+502.5  
HIGHWAY 7 FROM FOWLERS CORNERS  
SOUTHERLY TO COUNTY ROAD 28  
PETERBOROUGH, ONTARIO  
G.W.P. 73-99-00, SITE NO. 26-186**

## **1.0 INTRODUCTION**

Golder Associates Ltd. (Golder) has been retained by National Capital Engineering Limited (NCE) on behalf of the Ministry of Transportation, Ontario (MTO) to carry out preliminary foundation investigation associated with proposed highway operational improvements and future four laning of Highway 7 from Fowlers Corners Southerly to County Road 28 in Peterborough, Ontario.

The terms of reference for the scope of work are outlined in Golder's proposal P31-8197, dated August 2003, that forms part of the Consultant's Agreement (P.O. Number 4005-A-000268). This report addresses the preliminary foundation investigation carried out for the proposed culvert replacement at Station 10+502.5 (Site No. 26-186) as part of the Highway 7 improvement project. Preliminary foundation investigation and design services are required for a total of four structures (i.e. Jackson Creek Bridge, CNR Overhead Site and two structural culvert sites) in four separate reports for this project. The scope of foundations work for this project was expanded to include several swamp areas and a high fill area as outlined in Golder's letter titled "Proposal for Addendum Foundation Investigation", dated April 6, 2006 and approved by MTO on April 8, 2006. The work was carried out in accordance with the Quality Control Plan for this project dated April 20, 2006.

The purpose of this investigation is to establish the subsurface conditions at the proposed culvert replacement site by borehole drilling, dynamic cone penetration testing, in situ testing and laboratory testing on selected samples. A plan drawing of the existing culvert location was provided to Golder by NCE on March 31, 2006.

## **2.0 SITE DESCRIPTION**

The site is located on Highway 7, approximately 0.5 km south of Parkhill Road West (County Road 3) in Peterborough, Ontario (see key plan on Drawing 1). The existing highway in this area has two lanes, one lane each for northbound and southbound traffic.

Within the existing MTO right-of-way, the site generally consists of the raised highway embankment with grass covered embankment side-slopes (sloped at about 2H:1V to 3H:1V) and flat low-lying swampy areas on both sides of the existing highway. There is forest and swamp (wetland) areas located beyond the highway right-of-way on both sides of the existing highway. The existing structure consists of twin corrugated steel pipe arches each measuring 1.5 m wide x 1.2 m high x 24.8 m long. The existing culvert structures allow passage of the Jackson Creek tributary beneath Highway 7 in this area. It is proposed that the existing structures are to be lengthened or replaced as part of highway improvements and to eventually accommodate future four-laning of Highway 7 in this area.

Based on the MTO drawings provided to us titled "Engineering and Title Records", dated May 2001, the existing Highway 7 road surface at the site is at about Elevation 245.8 m and the existing culvert obvert is at about Elevation 244.2 m, with the culvert invert at about Elevation 243.0 m.

### **3.0 INVESTIGATION PROCEDURES**

#### **3.1 Foundation Investigation**

The field work for this culvert investigation was carried out on July 5 and 6, 2006 during which time four (4) boreholes combined with Dynamic Cone Penetration Tests (DCPTs) were advanced. The combined boreholes and DCPTs, numbered 06-5 to 06-8 (inclusive), were advanced at the approximate locations shown in plan on Drawing 1.

The current field investigation was carried out using a track-mounted CME-55 drill rig supplied and operated by Eastern Soil Investigation Limited of Courtice, Ontario. The boreholes were advanced using 107 mm outside diameter (O.D.) solid stem augers. Soil samples were obtained at intervals ranging from 0.75 m to 1.5 m in depth, using a 50 mm outer diameter (O.D.) split-spoon sampler in accordance with Standard Penetration Test (SPT) procedures. Dynamic Cone Penetration Tests (DCPTs) were carried out in all boreholes below a depth of about 9.8 m and were terminated on effective refusal (i.e. greater than 100 blows per 0.3 m of penetration).

The boreholes were advanced to depths of up to about 9.8 m below ground surface. The DCPT's were advanced from the bottom of the boreholes and were terminated at depths ranging from about 14.3 m to 21.6 m below ground surface. The groundwater conditions in the open boreholes were observed during the drilling operations and a piezometer was installed in borehole 06-5 to permit monitoring of the groundwater level at this location. The piezometer consisted of 50 mm diameter PVC pipe, with a slotted screen sealed at a select depth within the borehole. The boreholes and annulus surrounding the piezometer pipe were backfilled to the surface with bentonite pellets in accordance with Ontario Regulation (O.Reg.) 903 amended to O.Reg. 128/03 of the Ontario Water Resources Act. The piezometers will require decommissioning prior to or during construction in accordance with O.Reg. 903. The piezometer installation details and water level readings are described on the Record of Borehole sheets that follow the text of this report.

The field work was supervised by a member of our engineering and technical staff, who located the boreholes, arranged for the clearance of underground services, supervised the drilling, sampling and in situ testing operations, logged the boreholes, and examined and cared for the soil samples. The samples were identified in the field, placed in appropriate containers, labelled and transported to our Mississauga geotechnical laboratory where the samples underwent further detailed visual examination and laboratory testing. All of the laboratory tests were carried out to MTO and/or ASTM Standards as appropriate. Classification testing (water content, Atterberg

limits and grain size distribution) was carried out on select samples. Specialized laboratory consolidation testing was carried out on one sample from borehole 06-5.

The borehole locations were staked in the field by Golder relative to on-site features. Attempts were made by NCE to get permissions to enter private property in order to locate boreholes at the proposed east limit of the proposed culvert extension under the future four-lane widening area; however, permission to enter the private property was not given by the owner. As a result, several boreholes were located along the east limit of the MTO property line. Upon completion of drilling operations, the borehole locations (i.e. MTM NAD83 northing and easting coordinates) and ground surface elevations (referenced to geodetic datum) were surveyed by a licensed surveyor (i.e. Transenco Limited) and are summarized in the following table and on Drawing 1.

<b><i>Borehole Number</i></b>	<b><i>MTM NAD83 Northing (m)</i></b>	<b><i>MTM NAD83 Easting (m)</i></b>	<b><i>Ground Surface Elevation (m)</i></b>
06-5	4905696.0	390739.5	243.5
06-6	4905673.2	390748.7	243.3
06-7	4905705.4	390726.1	244.7
06-8	4905746.5	390721.6	243.1

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

### **4.1 Regional Geology**

As delineated in *The Physiography of Southern Ontario*<sup>1</sup>, the study area for this assignment lies within the physiographic region known as the Peterborough Drumlin Field.

The surficial soils in the Peterborough Drumlin Field consist of drumlinized till. Toward the southwestern portion of this physiographic region, near the Oak Ridges Moraine, the till is typically sandy. Some of the drumlins in this area have shallow coverings of silt and fine sand, between about 0.5 m and 2.5 m in thickness. “Wave-washed” drumlins, with exposed bouldery surfaces, are also present near the Simcoe Lowlands immediately south and east of Lake Simcoe. Localized swampy areas and deposits of silt, clay and peat are found in the low-lying areas between drumlins.

<sup>1</sup> Chapman, L.J. and D.F. Putnam. *The Physiography of Southern Ontario*, Ontario Geological Survey Special Volume 2, Third Edition, 1984. Accompanied by Map P.2715, Scale 1:600,000.

## **4.2 Subsoil Conditions**

The detailed subsurface soil and groundwater conditions as encountered in the boreholes advanced during this investigation, together with the results of the laboratory tests carried out on selected soil samples, are given on the attached Record of Borehole sheets and in Appendix A following the text of this report.

The stratigraphic boundaries shown on the Record of Borehole sheets are inferred from non-continuous sampling, observations of drilling progress and the results of Standard Penetration Tests (SPTs). These boundaries, therefore, represent transitions between soil types rather than exact planes of geological change. Further, subsurface conditions will vary between and beyond the borehole locations. The inferred soil stratigraphy based on the results of the boreholes at the culvert replacement location and future widening location is shown on Drawing 1.

In general, the subsoils at the culvert site consist of a surficial layer of topsoil and/or peat, underlain in places by a layer of silty sand, overlying a deposit of clayey silt to silty clay containing frequent interlayers of silt and sand. The clayey silt/silty clay is underlain by a deposit of sandy silt to silt. A more detailed description of the subsurface conditions encountered in the boreholes is provided in the following sections.

### **4.2.1 Topsoil / Peat**

Topsoil and/or peat was encountered at the ground surface in all of the boreholes (i.e. boreholes 06-5 to 06-8). A surficial layer of topsoil (about 0.8 m thick) was encountered in borehole 06-7, underlain by a 1.5 m thick layer of peat containing wood fragments. Fibrous peat was encountered at the ground surface in the remaining boreholes (06-5, 06-6 and 06-8) and ranged in thickness from about 0.8 m to 2.3 m.

Standard Penetration Test (SPT) 'N' values recorded within the topsoil and peat typically ranged between 0 (i.e. weight of hammer) and 3 blows per 0.3 m of penetration indicating a very soft to soft consistency. One 'N' value of 12 was recorded within the peat in borehole 06-7; however, the higher value is likely attributed to wood fragments present within the peat soil.

### **4.2.2 Silty Sand**

Beneath the peat and topsoil, a layer of silty sand containing trace gravel and clay was encountered in boreholes 06-7 and 06-8. The top of the silty sand layer was encountered at a depth of about 2.3 m and 0.8 m, corresponding to Elevation 242.4 m, at boreholes 06-7 and 07-8, respectively. The thickness of the silty sand layer was about 1.4 m and 1.9 m at boreholes 06-7 and 07-8, respectively.

Standard Penetration Test (SPT) 'N' values recorded within the silty sand layer ranged between 0 (i.e. weight of hammer) and 20 blows per 0.3 m of penetration, but typically between about 3 and 10 blows per 0.3 m of penetration, indicating a generally very loose to compact relative density.

The natural water content measured on two samples of the silty sand layer were 16 per cent and 17 per cent.

#### **4.2.3 Clayey Silt to Silty Clay**

A clayey silt deposit containing trace to some sand, trace gravel was encountered below the peat and/or silty sand in all of the boreholes. In borehole 06-6, the upper portion of this stratum is described as a clayey silt to a silty clay. The clayey silt contained frequent interlayers of sand and silt throughout the deposit. In borehole 06-5, the interlayers of sand and silt were more predominant within the upper metre of the deposit. The top of the clayey silt/silty clay deposit was encountered at depths ranging between about 1.1 m and 3.7 m, corresponding to between about Elevations 240.4 m and 242.4 m. The thickness of the clayey silt/silty clay deposit varied between about 4.6 m and 7.6 m.

Standard Penetration Testing (SPT) 'N' values recorded within the clayey silt/silty clay deposit ranged between 2 blows and 24 blows per 0.3 m of penetration, indicating a soft to very stiff consistency. The large range in 'N' values can be attributed to the presence of frequent silt and sand interlayers.

A field vane test to measure the undrained shear strength of the clayey silt was performed in borehole 06-5 at a depth of 4.1 m (Elevation 239.3 m). The shear strength of the clayey silt was greater than 100 kPa indicating a very stiff consistency at this location. The high measured strength may be attributed to the presence of silt and sand interlayers.

The natural water content measured on select samples of the clayey silt/silty clay deposit ranged between about 18 per cent and 32 per cent. A grain size distribution curve for a select sample of the clayey silt to silty clay is shown on Figure A1 in Appendix A.

The results of Atterberg Limits testing carried out on six samples of the clayey silt/silty clay deposit are illustrated on the plasticity chart on Figure A3 in Appendix A. The test results are summarized below and indicate the clayey silt generally is of low plasticity.

<i>Borehole</i>	<i>Sample</i>	<i>Elevation (m)</i>	<i>Liquid Limit (%)</i>	<i>Plastic Limit (%)</i>	<i>Plasticity Index (%)</i>
06-5	4	239.8 – 240.4	33	17	16
06-5	5	238.3 – 238.9	18	14	4
06-6	4	239.6 – 240.2	26	15	11
06-6	7	235.1 – 235.7	17	11	6
06-7	7	236.5 – 237.1	18	12	6
06-8	6	236.4 – 237.0	18	11	7

A laboratory consolidation test was carried out on a single specimen of the clayey silt deposit obtained from a Shelby tube sample. The results are summarized below.

<b>Borehole/ Sample No.</b>	<b>Sample Depth/Elev.</b>	$\sigma_{vo}'$ (kPa)	$\sigma_p'$ (kPa)	$\sigma_p' - \sigma_{vo}'$ (kPa)	OCR	$C_c$	$C_r$	$e_o$	$c_v^*$ (cm <sup>2</sup> /s)
06-5, Sa#4	3.4 m/240.1 m	25	320	295	13	0.20	0.02	0.71	$4.5 \times 10^{-2}$

Note: \* For stress range of  $20 \leq \sigma_v' \leq 160$  kPa

where:  $\sigma_{vo}'$  is the effective overburden pressure in kPa  
 $\sigma_p'$  is the preconsolidation pressure in kPa  
OCR is overconsolidation ratio  
 $e_o$  is initial void ratio  
 $C_c$  is the compression index  
 $C_r$  is the recompression index  
 $c_v$  is the coefficient of consolidation in cm<sup>2</sup>/s

The clayey silt sample used for the consolidation test (i.e. from borehole 06-5, Sa#4) is considered to be over-consolidated. A bulk unit weight of about 20 kN/m<sup>3</sup> and a specific gravity of 2.76 was measured on the consolidation test specimen. The consolidation test results are shown on Figures A4 to A7 in Appendix A.

#### 4.2.4 Sandy Silt to Silt

A layer of sandy silt to silt, some sand was encountered below the clayey silt deposit in all of the boreholes. The sandy silt to silt contained trace to some gravel and clay. The top of this layer was encountered at depths ranging between about 7.3 m and 8.8 m, corresponding to between about Elevations 234.8 m and 235.8 m. The sandy silt to silt layer was penetrated between about 1.0 m and 2.5 m and all boreholes were terminated within this layer, below which depth Dynamic Cone Penetration Tests (DCPT) were advanced in all boreholes. The DCPTs were terminated upon effective refusal at depths ranging from about 14.3 m (Elevation 228.8 m) to 21.6 m (Elevation 223.1 m). The apparent zig-zag pattern of the DCPTs suggests that interlayers of clayey and granular soils continues with depth.

Standard Penetration Testing (SPT) 'N' values recorded within the sandy silt to silt ranged from 0 (i.e. the weight of hammer) to 18 blows per 0.3 m of penetration, indicating a very loose to compact relative density.

The natural water content measured on four samples of the sandy silt to silt ranged between about 14 per cent and 20 per cent. Grain size distribution curves for two select samples from the silt (to sandy silt) deposit are shown on Figure A2 in Appendix A.

#### 4.2.5 Groundwater Conditions

The water levels were noted within the open boreholes at the time of the drilling operations. A piezometer was installed in borehole 06-5. The piezometer was sealed into the lower sandy silt deposit, below the clayey silt deposit. Details of the piezometer installation are shown on the Record of Borehole Sheet following the text of this report. The water levels measured in the piezometer and open boreholes upon completion of drilling are summarized below.

<i>Borehole</i>	<i>Installation</i>	<i>Ground Surface Elevation (m)</i>	<i>Depth to Water Level(m)</i>	<i>Water Level Elevation (m)</i>	<i>Date</i>
06-5	Piezometer	243.5	7.3	236.2	July 5, 2006
			3.8	239.7	July 6, 2006
			-0.9*	244.4	July 10, 2006
			-0.8*	244.3	July 31, 2006
			-1.0*	244.5	Aug. 18, 2006
06-6	Open Borehole	243.3	0.2	243.1	July 6, 2006
06-7	Open Borehole	244.7	2.3	242.4	July 6, 2006
06-8	Open Borehole	243.1	0.6	242.5	July 6, 2006


Note : \* Artesian Conditions

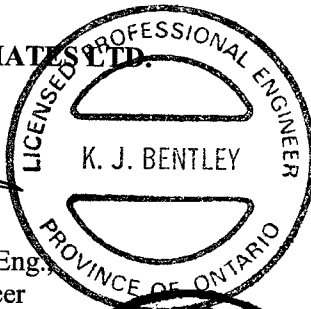
It should be noted that the piezometer readings indicate artesian conditions from within the sandy silt up to about 1 m above the ground surface at borehole 06-5. Groundwater levels at the site of the culvert will depend on rainfall and snowmelt conditions and are expected to fluctuate seasonally.

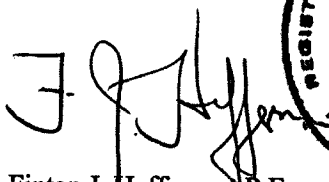
## 5.0 CLOSURE

The field technician supervising the drilling program was Mr. Suresh Bainey. This report was prepared by Mr. Kevin J. Bentley, P.Eng., a geotechnical engineer; the technical aspects were reviewed by Mr. J. Paul Dittrich, P.Eng, an Associate of Golder. Mr. Fintan J. Heffernan, Golder's Designated MTO Contact for this project, conducted an independent quality control review of the report.

**GOLDER ASSOCIATES LTD.**

  
Kevin J. Bentley, P.Eng.,  
Geotechnical Engineer



  
Fintan J. Heffernan, P.Eng.,  
Designated MTO Contact



KJB/JPD/FJH/sm/al

N:\Active\2004\1111\04-1111-024 NCE Hwy 7\Reports\Culvert 26-186\FINAL\04-1111-024D FINAL 07SEPT Final Report Culvert 26-186.doc

**PART B**

**FOUNDATION DESIGN REPORT  
PRELIMINARY DESIGN  
CULVERT REPLACEMENT AT STATION 10+502.5  
HIGHWAY 7 FROM FOWLERS CORNERS  
SOUTHERLY TO COUNTY ROAD 28  
PETERBOROUGH, ONTARIO  
G.W.P. 73-99-00, SITE NO. 26-186**

## **6.0 PRELIMINARY ENGINEERING RECOMMENDATIONS**

This section of the report provides foundation design recommendations for the preliminary design of the proposed culvert replacement and future culvert extension as part of the proposed highway operational improvements and future four laning of Highway 7. The recommendations are based on interpretation of the factual data obtained from the boreholes advanced during the preliminary subsurface investigation at this site. The interpretation and recommendations provided are intended to provide the designers with sufficient information to assess the feasible foundation alternatives and to carry out preliminary design of the proposed culvert foundations. Where comments are made on construction they are provided in order to highlight those aspects which could affect the preliminary design of the project and for which, ultimately, provision will have to be made at the detail design stage of the project as the contract documents are prepared.

Further borehole drilling will be required during the detail design phase of the project, when the details of the culvert replacement and extension and embankment widening are finalized. At that time, further investigation of the thickness of peat and composition of the embankment fills below the existing road surface and extent of clayey silt / silty clay soils will be required to confirm temporary stability concerns during construction, dewatering requirements and excavation / fill requirements. For the proposed culvert extension under the future embankment as part of the four-laning of Highway 7, additional borehole drilling is recommended further into the wetland area (i.e. further east and within the private property) to confirm the consistency and thickness of the cohesive soils and refine the predicted magnitude and time rate of settlement under the new embankment loading and to further assess any stability / settlement mitigation options and develop the necessary operational constraints and/or special provisions for the contract.

### **6.1 General**

Based on the MTO drawings provided to us titled "Engineering and Title Records", dated May 2001, the existing Highway 7 road surface at the culvert site is at about Elevation 245.8 m and the existing culvert obvert and invert is at about Elevation 244.2 m and Elevation 243.0 m, respectively. The exact location of the culvert replacement site and existing or proposed cross-sections were not available at the time of preparation of this preliminary report. The existing culvert consists of two corrugated steel pipe arches that each measure 1.5 m wide x 1.2 m high x 24.8 m long. The existing culvert foundation type was not known at the time of this report and should be confirmed prior to detail design. Based on the results of a visual inspection of the existing culvert structure (performed by Harmer Podolak Engineering Consultants), we understand that the culvert is approaching the end of its service life and will need to be replaced within the next 10 years. Future planning indicates that Highway 7 will be widened to four lanes

in this area (see Drawing 1) and the proposed culvert replacement may need to be extended, reconfigured (re-used) or a new culvert added to accommodate the proposed future widening.

Based on conversations with the designer, the existing roadway elevation will remain unchanged and the height of the future embankments for the four-laning of Highway 7 will likely match the current road elevation. Based on the borehole elevations, embankments heights are expected to be up to about 2.7 m high (i.e. above the existing ground surface) at the culvert location. The culvert should be designed to withstand the maximum anticipated overburden, lateral pressures and live loads. The effects of frost should also be considered in the structural design if frost susceptible soils are located within the depth of frost penetration.

Several material type alternatives (i.e. steel and concrete) for the culvert replacement have been considered based on the information presented in the NCE memorandum titled “ Evaluation of Structural Alternatives, Twin CSPA Culverts MTO Site No. 26-186 Station 10+502.5”, dated November 29, 2006. The preferred culvert replacement structure was established to be a precast concrete box culvert with a buried closed bottom measuring 3 m wide x 1.5 m high x 24.8 m long.

## **6.2 Culvert Foundation Options**

Apart from the existing roadway embankment fill, the shallow subsoils at the culvert location consist of a surficial layer of peat and topsoil, underlain by silty sand and then by a clayey silt deposit with interlayers of silt, sand and silty clay. Underlying the clayey silt deposit, layers of sandy silt to silt were encountered at depth. Groundwater was typically encountered between about 0.2 m and 2.3 m depth (Elevation 242 m to Elevation 243 m) within the open boreholes. However, the piezometer, which was sealed below the clayey silt deposit and within the lower sandy silt layer, measured artesian conditions with water levels up to about 1 m above ground surface (Elevation 244.5 m) in August 2006. It should be noted that water levels in this area will fluctuate on a seasonal basis.

Based on the subsurface information obtained, the native loose to compact silty sand and predominantly firm to very stiff clayey silt soils located below the surficial topsoil and peat deposits are considered suitable for the support of the proposed culvert foundation. From a foundations perspective, consideration could be given to extending the existing culverts on the east side; however, differential settlement/movement between the widened sections and the existing culverts (i.e. at the joints) should be expected. Given that the founding elevation of the existing footings is unknown, there is also risk of undermining the existing footings if culvert extension is being considered. Based on the structural evaluation, the existing culvert is to be replaced in order to meet the design service life for the structure. Table 1 provides a comparison of culvert foundation options based on advantages, disadvantages, risks, relative costs and

consequences. Both closed box and open footing culverts have been included as options. The options also assume that open footings would be cast-in-place and the culvert structure placed or constructed on top of the footing as either a precast or cast-in-place unit. Closed box culverts can be either precast or cast-in-place as a single unit.

From a foundations perspective, the preferred culvert replacement structure type at this location is a closed concrete box culvert. This type of culvert will also accommodate the addition and potential reuse of culvert sections for future highway embankment widening. Some localized stripping of the topsoil, peat and any highly organic soils that are present at this site will be required as part of the construction.

## 6.2.1 Geotechnical Resistance

### 6.2.1.1 Preferred Alternative - Box Culvert

The approximate invert elevation, recommended level of subexcavation, and the founding soil type for box culvert(s) (i.e. concrete box or steel arch supported on a base slab) are presented in the following table.

Approximate Culvert Station	Culvert	Relevant Boreholes	Approximate Invert Elevation (m)	Recommended Subexcavation Level for Proposed Culvert (m)	Founding Soil Type
10+502.5	Culvert Replacement	06-5, 06-7	243.0	242.0	Silty Sand and Clayey Silt containing interlayers of silt and sand
10+502.5	Future Culvert Below Four-Lane Widening	06-5, 06-6, 06-7, 06-8	243.0	241.0 – 242.0	Silty Sand and Clayey Silt to Silty Clay containing interlayers of silt and sand

The above recommended subexcavation levels indicate the estimated maximum target elevation required to reach the appropriate founding soil(s). For the proposed future culvert under the four-lane widening area, the results of boreholes drilled north and south of the existing culvert location (06-6 and 06-8) indicate deeper peat and very loose soil deposits; competent founding soil conditions were not encountered until below about Elevation 241 m, about 2 m below the estimated invert level. The actual founding level of the box culvert will depend on the final location of the culvert, thickness of the bottom of the culvert, design invert level, frost protection requirements, the depth of the granular bedding required under the culvert (see Section 6.7.3) and the results of additional boreholes advanced during detailed design.

Assuming the founding levels noted above, the factored geotechnical resistance at Ultimate Limit States (ULS) and the unfactored geotechnical resistance at Serviceability Limit States (SLS) to be used for preliminary design of the box culvert(s) is given below.

Approximate Culvert Station	Culvert	Total Proposed Culvert Width (m)	Factored Geotechnical Resistance at ULS (kPa)	Geotechnical Resistance at SLS (kPa) for 25 mm settlement
10+502.5	Culvert Replacement	3.0	175	125
10+502.5	Future Culvert Below Four-Lane Widening	3.0	175	125

The geotechnical resistance values assume the culverts are founded on granular bedding soils on approved engineered fill (i.e. Granular 'A' or Granular 'B' Type II, see Section 6.7.3) over undisturbed native silty sand or clayey silt soils which for design may be assumed to extend to the subexcavation levels indicated above. It should be noted that there is expected to be some variation in the subexcavation depth of these deposits at the culvert sites and there must be provision in the contract for dealing with greater or lesser amounts of subexcavation and replacement with compacted granular fill where highly organic soils are encountered and removed. Excavation for and construction of the box culvert structure should be in accordance with Special Provision No. 902S01.

### 6.2.1.2 Open Footing Culvert

As an alternative to using box culverts, open footing culverts (i.e. essentially culvert edges supported on strip footings) could be considered. The approximate invert elevation, recommended footing founding level (i.e. depth of subexcavation), and the founding soil type at the footing level for the culvert(s) are presented in the following table.

Approximate Culvert Station	Culvert	Relevant Boreholes	Approximate Invert Elevation (m)	Recommended Subexcavation Level for Proposed Culvert (m)	Founding Subgrade Soil Type
10+502.5	Culvert Replacement	06-5, 06-7	243.0	241.5	Silty Sand and Clayey Silt containing interlayers of silt and sand
10+502.5	Future Culvert Below Four-Lane Widening	06-5, 06-6, 06-7, 06-8	243.0	241.0 - 241.5	Silty Sand and Clayey Silt to Silty Clay containing interlayers of silt and sand

The above recommended subexcavation level indicates the estimated maximum target elevation

required to reach the appropriate founding subgrade soil(s). As mentioned previously, for the proposed future culvert under the four-lane widening area, the results of boreholes drilled north and south of the existing culvert area (06-6 and 06-8) indicate deeper peat and very loose soil deposits. Depending on the location of the future culvert, competent founding subgrade soils may not be encountered until below about Elevation 241 m, up to about 2 m below the estimated invert level. The actual founding level will depend on the final location of the culvert, the design invert level, frost protection requirements and the results of additional boreholes advanced during detailed design.

Assuming the founding levels noted above, the factored geotechnical resistance at Ultimate Limit States (ULS) and the unfactored geotechnical resistance at Serviceability Limit States (SLS) to be used for preliminary design of the open footing culvert(s) is given below.

Approximate Culvert Station	Culvert	Total Proposed Culvert Footing Width (m)	Factored Geotechnical Resistance at ULS (kPa)	Geotechnical Resistance at SLS (kPa) for 25 mm settlement
10+502.5	Culvert Replacement	0.5	150	150
10+502.5	Future Culvert Below Four-Lane Widening	0.5	150	150

The geotechnical resistance values assume the culverts are founded on the undisturbed native silty sand or clayey silt soils which for design may be assumed to extend to the subexcavation levels indicated above. It should be noted that, due to the narrow footing widths (i.e. compared to the box culvert option), there is a higher risk of post-construction differential settlement along the culvert length due to the anticipated difficulty achieving stable base conditions at the founding level. Given the inherent variability of the clayey silt deposit containing interlayers of variable strength/stiffness silty clay, silt and sand, the artesian groundwater conditions encountered within the lower sandy silt to silt layer (located within 5 m of the proposed founding elevation), and the fact that soil strength does not appear to increase with depth at this location, it is recommended that subexcavation / founding depths be as shallow as possible. For this reason, box culverts are the preferred alternative and are recommended for this site as opposed to open footing culverts.

## 6.2.2 Resistance to Lateral Loads

Resistance to lateral forces (i.e. sliding resistance) between the base of the concrete culvert and the undisturbed native materials should be calculated in accordance with Section 6.7.5 of the *CHBDC*. For the concrete box option, assuming the culvert is precast concrete and is placed on compacted granular bedding, a coefficient of friction value ( $\tan \delta$ ) of 0.5 can be used for design.

The coefficient of friction value can be increased to 0.58 if cast-in-place concrete is placed on compacted granular bedding.

For the open footing culvert option, assuming the footings are cast-in-place and founded on undisturbed clayey silt to silty clay, a coefficient of friction value ( $\tan \delta$ ) of 0.43 can be used for design.

In accordance with the *CHBDC*, a factor of 0.8 is to be applied to the coefficient of friction value when calculating the horizontal resistance.

### **6.2.3 Frost Protection**

The frost penetration depths in the area of the proposed culvert(s) is estimated to be approximately 1.5 m. All shallow foundations should be provided with a minimum of 1.5 m of soil cover or equivalent thermal insulations for frost protection.

## **6.3 Lateral Earth Pressures for Preliminary Design**

The lateral earth pressures acting on the new structure and any associated foundation walls will depend on the type and method of placement of the backfill materials, on the nature of the soils behind the backfill, on the magnitude of surcharge including construction loadings, on the freedom of lateral movement of the structure, and on the drainage conditions behind the walls.

The following recommendations are made concerning the design of the walls. It should be noted that these design recommendations and parameters assume level backfill and ground surface behind the walls. Where there is sloping ground behind the walls, the coefficient of lateral earth pressure must be adjusted to account for the slope.

- Select free-draining granular fill meeting the specifications of Ontario Provincial Standard Specifications (OPSS) Granular 'A' or Granular 'B' Type II, but with less than 5 percent passing the No. 200 sieve, should be used as backfill behind the walls. Longitudinal drains and weep holes should be installed to provide positive drainage of the granular backfill. Other aspects of the granular backfill requirements with respect to sub-drains and frost taper should be in accordance with OPSD 3101.150 and 3121.150.
- A minimum compaction surcharge of 12 kPa should be included in the lateral earth pressures for the structural design of the culvert / wall stem, in accordance with *CHBDC* Section 6.9.3 and Figure 6.9.3. Compaction equipment should be used in accordance with Special Provision 105S10. Other surcharge loadings should be accounted for in the design, as required.

- The granular fill may be placed either in a zone with width equal to at least 1.5 m behind the back of the wall stem (Case I in Figure C6.9.1(l)(i) of the *Commentary to the CHBDC*) or within the wedge-shaped zone defined by a line drawn at 1.5 horizontal to 1 vertical (1.5H:1V) extending up and back from the rear face of the footing (Case II in Figure C6.9.1(l)(ii) of the *Commentary to the CHBDC*).
- For Case I, the pressures are based on the proposed embankment fill materials and the following parameters (unfactored) may be used, assuming the use of Select Subgrade Material (SSM) for the new portions of the approach embankments:

SSM	
Soil unit weight:	20 kN/m <sup>3</sup>
Coefficients of static lateral earth pressure:	
Active, $K_a$	0.33
At rest, $K_o$	0.50

- For Case II, the pressures are based on the granular fill as placed and the following parameters (unfactored) may be assumed:

	Granular 'A'	Granular 'B' (Type II)
Soil unit weight:	22 kN/m <sup>3</sup>	21 kN/m <sup>3</sup>
Coefficients of static lateral earth pressure:		
Active, $K_a$	0.27	0.27
At rest, $K_o$	0.43	0.43

- If the culvert structure allows lateral yielding of the culvert walls, active earth pressures may be used in the geotechnical design of the structure. If the abutment support does not allow lateral yielding (such as typically the case for a rigid concrete box culvert), at-rest earth pressures should be assumed for geotechnical design.
- Seismic loading will result in increased lateral earth pressures acting on the culvert wall and any retaining walls. The walls should be designed to withstand the combined lateral loading for the appropriate static pressure conditions given above, plus the earthquake-induced dynamic earth pressure. According to Table A3.1.1 of the CHBDC, this site is located in Seismic Zone 1. The site-specific zonal acceleration ratio (A) for Peterborough is 0.05. Based on experience, for the overburden soils at the site and embankment heights of up to about 2.5 m, a 10 to 20 per cent amplification of the ground motion may occur, resulting in an increase in the ground surface acceleration from 0.05g to between 0.055g and 0.06g. The seismic lateral earth pressure coefficients given below have been derived based on a design zonal acceleration ratio of A = 0.06.

- In accordance with Sections 4.6.4 and C.4.6.4 of the *CHBDC* and its *Commentary*, for structures which allow lateral yielding, the horizontal seismic coefficient,  $k_h$ , used in the calculation of the seismic active pressure coefficient, is taken as 0.5 times the zonal acceleration ratio (i.e.  $k_h = 0.03$ ). For structures that do not allow lateral yielding,  $k_h$  is taken as 1.5 times the zonal acceleration ratio (i.e.  $k_h = 0.09$ ). The seismic active earth pressure coefficients are also dependent on the vertical component of the earthquake acceleration,  $k_v$ . Three discrete values of vertical acceleration are typically selected for analysis, corresponding to  $k_v = +2.3k_h$ ,  $k_v = 0$ , and  $k_v = -2/3$ .
- The following seismic active earth pressure coefficients ( $K_{AE}$ ) for the two cases (Case I and Case II) may be used in design; these coefficients reflect the maximum  $K_{AE}$  obtained using the  $k_h$  and three values of  $k_v$  as described above. It should be noted that these seismic earth pressure coefficients assume that the back of the wall is vertical and the ground surface behind the wall is flat.

SEISMIC ACTIVE PRESSURE COEFFICIENTS,  $K_{AE}$ 

	<b>Case I (SSM)</b>	<b>Case II</b>	
		<b>Granular A</b>	<b>Granular B Type II</b>
Yielding wall	0.32	0.26	0.26
Non-yielding wall	0.37	0.30	0.30

Note : These CHBDC seismic  $K_{AE}$  values include the effect of wall friction ( $\delta=\phi'/2$ ) and are less than the static values of  $K_a$  and  $K_o$  (i.e. yielding and non-yielding wall) reported above for the very low zonal acceleration ratio for this site.

- The above  $K_{AE}$  values for yielding walls are applicable provided that the wall can move up to 250A (mm), where A is the design zonal acceleration ratio of 0.06. This corresponds to displacements of up to 15 mm at this site.
- The earthquake-induced dynamic active lateral pressure distribution, which is to be added to the static earth pressure distribution, is a linear distribution with maximum pressure at the top of the wall and minimum pressure at its toe (i.e. an inverted triangular pressure distribution). The total pressure distribution (static plus seismic) may be determined as follows:

$$p = K \gamma' d + (K_{AE} - K) \gamma' H$$

Where:  $p$  is the total (static plus seismic) pressure distribution (kPa)  
 $K$  is either the static active earth pressure coefficient ( $K_a$ ) or the static at rest earth pressure coefficient ( $K_o$ );  
 $K_{AE}$  is the seismic active earth pressure coefficient;  
 $\gamma'$  is the effective unit weight of the soil ( $\text{kN/m}^3$ )  
 (given above for fill materials)  
 $d$  is the depth below the top of the wall (m); and  
 $H$  is the height of the wall above the toe (m).

## 6.4 Settlement

### 6.4.1 Culvert Replacement

Provided that the existing Highway 7 embankment is not raised or widened, and that any topsoil, peat, or any loosened, deleterious or other organic material is removed from the culvert replacement footprint and that the underlying bedding material is placed and compacted according to Section 6.7.3, the settlement of the culvert replacement is expected to be less than 25 mm.

### 6.4.2 Proposed Culvert Under Future Embankment Widening

For the proposed new culvert to be installed under the new embankment as part of the future four-laning of Highway 7, some settlement is anticipated due to the loading imposed on the clayey subsoils from the new embankment loading. Based on conversations with the designers, it is understood that the new widened embankment will match the existing Highway 7 road grade (about Elevation 245.8 m), resulting in a new embankment fill height of up to about 2.7 m above the existing ground surface which is as low as about Elevation 243.3 m at the current borehole locations. Assuming the new embankment footprint will be stripped of topsoil and peat (which was up to about 2.3 m thick in borehole 06-6 and 06-7) and replaced with engineered fill and/or bedding, the total thickness of the new embankment fill is anticipated to be up to about 5 m.

A preliminary settlement analysis was performed using the commercially available program UNISETTLE (Version 3.2) produced by Unisoft Limited. The soil parameters used for the analysis were based on the laboratory and in situ test data collected during the current preliminary investigation. The over-consolidation ratio (OCR) required in the settlement analysis was estimated using the results of the borehole and consolidation test data. The total net loading on the foundation soils (after stripping, backfilling and embankment fill construction) was estimated to be about 70 kPa.

The immediate compression of the existing granular fill above the clayey silt to silty clay deposit and the compression of the lower sandy silt to silt below the cohesive deposit were modelled using elastic moduli. The time dependant consolidation settlement of the clayey silt to silty clay deposit was modelled using the following parameters.

<i>Soil</i>	<i>Initial Void Ratio</i> <i>e<sub>o</sub></i>	<i>Recompression Index</i> <i>C<sub>r</sub></i>	<i>Compression Index</i> <i>C<sub>c</sub></i>	<i>OCR</i>
Clayey Silt to Silty Clay	0.71	0.02	0.2	13

The following table summarizes the simplified stratigraphy, unit weights and deformation

parameters (see Chapter 6, “*Commentary to the CHBDC, 2001*”) employed in the settlement analysis:

<i>Soil</i>	<i>Thickness (m)</i>	<i>Bulk Unit Weight (kN/m<sup>3</sup>)</i>	<i>Deformation Properties</i>
Backfill, Bedding and Native Upper Silty Sand	1	20	E' = 10 MPa
Clayey Silt to Silty Clay	6	20	See table above
Lower Sandy Silt to Silty Sand Layer	2	19	E' = 5 MPa
Underlying Interlayered Soil (based on DCPT results)	5	20	E' = 20 MPa

Although the net loading due to the placement of the new culvert itself on the foundation soils is expected to be relatively small, the structural design of the culvert sections should consider resistance to the bending moment anticipated to occur along the centreline of the culvert due to the non-uniform embankment geometry and loading conditions (i.e. vertical settlements and horizontal strains).

The predicted maximum total settlement at the new culvert location (i.e. centreline of the future embankment) is estimated to be about 75 mm due to the loading imposed by the new embankment fill. This total is estimated to be comprised of about 40 mm of immediate settlement due to compression of the cohesionless soils layers and about 35 mm of time dependant settlement of the cohesive soil layers. Based on an estimated coefficient of consolidation ( $c_v$ ) of  $4.5 \times 10^{-2} \text{ cm}^2/\text{s}$  and assuming two-way drainage of the approximately 6 m thick clayey silt to silty clay stratum, it is estimated that about 90% of the consolidation settlement will be complete within about 2 months. Settlement of the granular embankment fill and shallow underlying native granular interlayers is expected to occur rapidly (i.e. during or shortly after construction). The majority of settlement within the deeper sandy silt to silt soils (below the cohesive deposit) are anticipated to occur gradually over about 2 months.

Considering the west portion of the proposed culvert replacement area has been preloaded by the existing roadway embankment, the estimated maximum total settlement of 75 mm at the central portion of the new embankment is anticipated to be differential west portion of the culvert. Based on the anticipated impact to the culvert and roadway due to the settlement of the future embankment, preloading is recommended. The new embankment should be constructed adjacent to the drainage course and allowed to settle at the proposed culvert location for at least 2 months prior to culvert installation. A camber could be incorporated into the design of the culvert to manage the expected settlements after placement of fill above and adjacent to the culvert where preloading may no be practical given the close proximity to the creek.

Other options (other than preloading) to mitigate the impacts of consolidation settlement could include surcharging, use of light weight fill, or partial or full subexcavation, or cambering the culvert with articulating joints. Given the high water level, the deep extent of the clayey deposit and construction issues such as the close proximity of the existing roadway, full or partial subexcavation of the clayey deposit is not considered practical, use of light weight fill too expensive and surcharging not necessary. Cambering of the culvert using articulated joints will require specialized construction and may not be cost effective.

## **6.5 Stability**

Given the fact the existing embankment height and slope will not change at the culvert replacement location, the global stability of the embankment is not considered to be a concern. As previously mentioned, artesian groundwater conditions were encountered within the lower sandy silt layer encountered at a depth of about 8.7 m below ground surface (about Elevation 235 m to Elevation 236 m). For the future culvert extension area as part of the four-laning of Highway 7, a new embankment widening is to be constructed. For preliminary design, assuming the new embankment road grade is at the same level as the existing Highway 7 road grade and side-slopes are not steeper than the existing conditions, stability is not considered to be a concern. The factor of safety of the proposed embankment is estimated to be greater than 1.3, however the global stability should be checked after the detailed design investigation is complete.

## **6.6 Base Heave**

Temporary subexcavations during culvert installation should be maintained as shallow as possible to reduce the risk of basal heave or unstable founding soil conditions within the clayey silt soils containing interlayers of silt and sand. Given the artesian water conditions encountered within the underlying lower sandy silt to silt layer, preliminary calculations indicate that a soil thickness of about 6.5 m must be maintained for a Factor of Safety against basal heave of about 1.5. As such, subexcavation to about Elevation 242 m, as recommended for the closed-bottom culvert replacement, can be carried out with an adequate factor of safety against base heave. However, subexcavation to lower elevations, as recommended for the open-bottom culvert replacement and as may be required for the construction of the future culvert extension, could have a factor of safety less than 1.5 against base heave. The potential for base heave will have to be re-addressed after the detail design investigation is complete. Depending on the detail design, relief wells may be required to lower the artesian water pressures to below the founding level.

## **6.7 Preliminary Considerations for Culvert Construction**

### **6.7.1 Subgrade Preparation and Excavation**

Prior to the placement of any engineered fill, bedding, or new embankment construction, all surficial peat, topsoil, organics, and softened or loosened soils should be stripped from below the proposed culvert sites and wasted/reused for landscaping. All subgrade soils should be proofrolled or inspected prior to fill placement and embankment fill should be placed in accordance with SP206S03.

Based on the preliminary boreholes, it is anticipated that excavations up to about 2.3 m below the existing ground surface (and up to about 3.8 m below the existing road surface for the culvert replacement) will be required to remove the topsoil and peat soils, and expose the native clayey silt and silty sand soils. It is not known whether the peat / organic soils were removed as part of the original culvert / embankment construction, as such, detail design investigation should investigate the subsoil conditions below the existing roadway, directly over the proposed culvert replacement site, in order to more accurately estimate subexcavation depths. Depending on construction staging and sub-excavation depths (after detailed design), the culvert replacement may require temporary shoring or temporary embankment widening placement and culvert extension to maintain two-lanes of traffic on Highway 7 during construction.

Excavation works should be carried out in accordance with the guidelines outlined in the latest edition of the Occupational Health and Safety Act (OHSA) for Construction Activities, and follow the guidelines outlined in OPSS 902.

It is noted that the soils in which the excavations will be formed are susceptible to disturbance due to the highly organic peat, groundwater seepage, upwellings from the underlying artesian water conditions, and construction traffic. Groundwater and surface water control will be required.

### **6.7.2 Groundwater and Surface Water Control**

The founding soils for the culverts are susceptible to disturbance due to seepage, artesian water conditions, water ponding, and / or construction traffic. Provided that the existing culvert is to remain in use during construction of the culvert replacement, the majority of the Jackson Creek tributary can be diverted around the construction area. If the existing culvert is to be removed prior to completion of the new culvert, a system of sumps and pumps or a temporary CSP will be required to divert the creek from one side of the road to the other. Groundwater seepage into the excavations is expected. The severity of the groundwater conditions is dependent upon many factors including the season during which construction occurs and the flow rate of the Jackson

Creek tributary. In general, pumping using properly filtered sumps, and/or filtered drains placed along the base of the excavation should provide sufficient groundwater control during foundation works unless dewatering is required to maintain base stability during excavation. Ditches to divert perched water and/or storm water flows around the construction area will also be required to help permit construction in the dry.

### **6.7.3 Bedding and Backfill**

Based on the subsurface information obtained from the boreholes, the native loose to compact silty sand and firm to very stiff clayey silt soils located below the surficial topsoil and peat deposits are considered suitable for the support of the bedding for the proposed culvert replacement and future culvert as part of the four-lane widening. Stripping of the topsoil, peat and highly organic soils will be required.

For the box culvert options, the bedding, leveling pad, and backfill requirements for the culvert replacement and future culvert should be in accordance with OPSS 422 for precast concrete rigid frame culverts. The box culvert should be provided with at least 150 mm of OPSS Granular 'A', or Granular 'B' Type 2 (OPSS 1010) material if in wet ground conditions, for bedding purposes and partial frost protection. If Granular 'B' Type 2 is used, the placement of a geotextile filter between the bottom of the bedding/engineered fill and native soils may be required depending on the actual in situ ground and water conditions. The bedding should be placed in lifts not exceeding 200 mm in loose thickness, and compacted to at least 95 per cent of the Standard Proctor maximum dry density. In addition, for closed box culverts, a minimum 75 mm thick uncompacted leveling pad of Granular 'A' or fine aggregate (OPSS 1002) should be provided.

Frost treatment for the culvert structure should follow the guidelines provided in OPSD 803.010 for box and open footing culverts. In order to reduce the potential for frost damage to the culvert (i.e. differential heave and settlement), the combined thickness of backfill and bedding should be at least 1.5 m (i.e. equal to the depth of frost penetration).

For the culvert extension to be constructed for the future four-laning of Highway 7 and possibly for the replacement culvert (depending on the culvert base thickness), the borehole information indicates that after stripping of the topsoil and peat soils, the subgrade will likely require placement of engineered fill to raise grades to the bedding level. This can be achieved by placing additional lifts of the properly placed and compacted bedding material (i.e. Granular 'A' or Granular 'B' Type II).

Compaction equipment should be used in accordance with Special Provision No. 105S10. Inspection and field density testing should be carried out by qualified geotechnical personnel

during all engineered fill placement operations to ensure that appropriate materials are used, and that adequate levels of compaction have been achieved.

#### 6.7.4 Erosion Protection

Typically, the existing subsoils at the invert level of the culvert sites consist of peat, sandy silt and clayey silt deposits. It is assumed that all peat and highly organic soils will be removed and replaced with engineered fills within the culvert footprint. At the culvert inlet and outlet locations, if the anticipated water flow velocities are sufficiently high, provision should be made for scour and erosion protection.

In order to prevent water from flowing either beneath the culvert (potentially causing undermining and scouring for box culverts) or around the culvert (creating seepage through the embankment fill and potentially causing erosion and loss of fine particles), a clay seal or cut-off headwall should be provided at the upstream end of the culvert.

Erosion protection should be provided upstream and downstream of the culvert as appropriate. Consideration could be given to the use of suitable non-woven geotextiles and rip-rap to provide erosion protection based on hydraulic requirements.

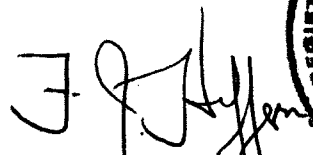
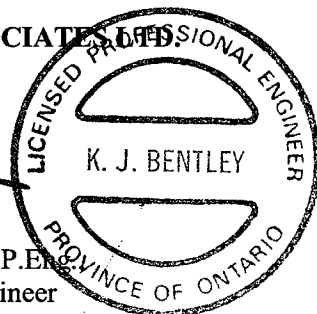
#### 6.8 Closure

This report was prepared by Mr. Kevin Bentley, P.Eng., a geotechnical engineer and the technical aspects were reviewed by Mr. J. Paul Dittrich, P.Eng., an Associate and senior geotechnical engineer. Mr. Fintan J. Heffernan, a Designated MTO Contact with Golder, conducted a quality control review of the report.

GOLDER ASSOCIATES LTD.



Kevin J. Bentley, P.Eng.  
Geotechnical Engineer



Fintan J. Heffernan, P.Eng.,  
Designated MTO Contact



KJB/JPD/FJH/al

N:\Active\2004\1111\04-1111-024 NCE Hwy 7\Reports\Culvert 26-186\FINAL\04-1111-024D FINAL 07SEPT Final Report Culvert 26-186.doc

## REFERENCES

Canadian Geotechnical Society. 1992. "Canadian Foundation Engineering Manual (CFEM) - Third Edition", Technical Committee on Foundations.

Canadian Standards Association. 2001. "Canadian Highway Bridge Design Code (CHBDC) and Commentary", CAN/CSA-S6-00, CSA Special Publication, S6.1-00.

Ministry of Transportation Ontario. 2004. "Special Provision No. 105S10 – Construction Specification for Compaction", November. Amendment to OPSS 501, Feb. 1996.

Ministry of Transportation Ontario. 2004. "Special Provision No. 206S03 – Earth Excavation, Grading-Item No., Excavation for Pavement Widening-Item No., Rock Excavation, Grading-Item No., Rock Face-Item No., Rock Embankment-Item No.", January.

Ministry of Transportation Ontario. 2006. "Special Provision No. 902S01 – Earth Excavation For Structure, Rock Excavation For Structure, Unwatering Structure Excavation, Clay Seal", June.

Ontario Provincial Standards. 2004. "Ontario Provincial Standard Specification OPSS 422 - Construction Specification For Precast Reinforced Concrete Box Culverts And Box Sewers in Open Cut", April.

Ontario Provincial Standards. 2002. "Ontario Provincial Standard Specification OPSS 902 – Construction Specification For Excavation and Backfilling – Structures", November.

Ontario Provincial Standards. 2004. "Ontario Provincial Standard Specification OPSS 1002 – Material Specification for Aggregates - Concrete", April.

Ontario Provincial Standards. 2004. "Ontario Provincial Standard Specification OPSS 1010 – Material Specification For Aggregates – Base, Subbase, Select Subgrade, and Backfill Material", April.

Ontario Provincial Standards. 2006. "OPSD 803.010 – Backfill and Cover for Concrete Culverts", November, Rev.1.

Ontario Provincial Standards. 2005. "Ontario Provincial Standard Drawing OPSD 3101.150 – Walls, Abutment, Backfill Minimum Granular Requirement", November.

Ontario Provincial Standards. 2005. "Ontario Provincial Standard Drawing OPSD 3121.150 – Walls Retaining, Backfill Minimum Granular Requirement", November

Ontario Regulation 213/91. "Occupational Health and Safety Act - Construction Projects", Amended to O. Reg. 527/00.

**TABLE 1**  
**EVALUATION OF CULVERT FOUNDATION ALTERNATIVES**  
**HIGHWAY 7 CULVERT REPLACEMENT (SITE NO. 26-186)**  
**G.W.P. 73-99-00**

<i>Option</i>	<i>Rank/ Option</i>	<i>Advantages</i>	<i>Disadvantages</i>	<i>Relative Costs</i>	<i>Risks/Consequences</i>
Closed Concrete Box or Steel Arch with Base Slab	1	<ul style="list-style-type: none"> <li>• Routine excavation and construction procedure;</li> <li>• Shallow sub-excavation depth compared to open / strip footing;</li> <li>• Construction time reduced if precast culvert units are used.</li> </ul>	<ul style="list-style-type: none"> <li>• Dewatering required to place and compact bedding layer;</li> </ul>	<ul style="list-style-type: none"> <li>• Comparable cost to Option No. 2 due to costs associated with placing/compacting bedding layer and dewatering.</li> </ul>	<ul style="list-style-type: none"> <li>• Risk of shifting / heaving of culvert sections due to frost action;</li> <li>• Reduced risk of disturbing base founding level due to shallower excavation (i.e. minimize excavation into clayey silt deposit and reduce risk of encountering water seepage from artesian water conditions;</li> <li>• If steel arch used, extra care and time required to compact backfill in close proximity to steel structure.</li> </ul>
Open Footing Culvert or Steel Arch with Strip Footing	2	<ul style="list-style-type: none"> <li>• Foundations will be located below frost depth;</li> <li>• Construction time reduced if precast culvert units are used.</li> </ul>	<ul style="list-style-type: none"> <li>• Dewatering required (i.e. more extensive than box culvert) in order to place footings on competent founding soils;</li> <li>• Deeper excavation into native soils with high / artesian groundwater conditions present within underlying granular layers. Shallower founding levels could be considered; however, founding levels will be located within frost penetration depth;</li> <li>• Longer construction time for cast-in-place procedure.</li> </ul>	<ul style="list-style-type: none"> <li>• Comparable costs to Option No. 1 due to deeper excavation depths with high/artesian water levels and more intensive dewatering efforts.</li> </ul>	<ul style="list-style-type: none"> <li>• High risk of disturbing founding soils due to deeper excavation (i.e. excavations will penetrate deeper into clayey silt deposit and increased risk of encountering water seepage from artesian water conditions;</li> <li>• Disturbance to founding soils may lead to differential settlement;</li> <li>• Risk of problems during dewatering which may lead to construction delays;</li> <li>• Risk of base heave with deeper excavations;</li> <li>• If steel arch used, extra care and time required to compact backfill in close proximity to steel structure.</li> </ul>
Deep Foundations (i.e. Piles or Caissons)	NP		<ul style="list-style-type: none"> <li>• Pile/caisson tip elevations anticipated to be in excess of 15 m below ground surface.</li> </ul>	<ul style="list-style-type: none"> <li>• Much higher costs than Option No. 1 and No. 2.</li> </ul>	

NP = not feasible or not practical

Additional Notes:

1. Preferred option as determined from structural, drainage, and fisheries issues is a Closed Concrete Box (i.e. Closed Footing).

## 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

### III. SOIL DESCRIPTION

#### (a) Cohesionless Soils

Density Index (Relative Density)	N Blows/300 mm or Blows/ft.
Very loose	0 to 4
Loose	4 to 10
Compact	10 to 30
Dense	30 to 50
Very dense	over 50

### 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.) drive open sampler for a distance of 300 mm (12 in.)

#### Consistency

	<u>kPa</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

#### (b) Cohesive Soils

$c_u, s_u$

#### 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.).

**PH:** Sampler advanced by hydraulic pressure

**PM:** Sampler advanced by manual pressure

**WH:** Sampler advanced by static weight of hammer

**WR:** 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.

### IV. SOIL TESTS

w	water content
$w_p$	plastic limit
$w_l$	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>
$D_R$	relative density (specific gravity, $G_s$ )
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
$SO_4$	concentration of water-soluble sulphates
UC	unconfined compression test
UU	unconsolidated undrained triaxial test
V	field vane (LV-laboratory vane test)
$\gamma$	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
F	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 ( $\sigma' = \sigma - u$ )
$\sigma'_{vo}$	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
u	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
*	Density symbol is $\rho$ . Unit weight symbol is $\gamma$ where $\gamma = \rho g$ (i.e. mass density x acceleration due to gravity)

#### (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)

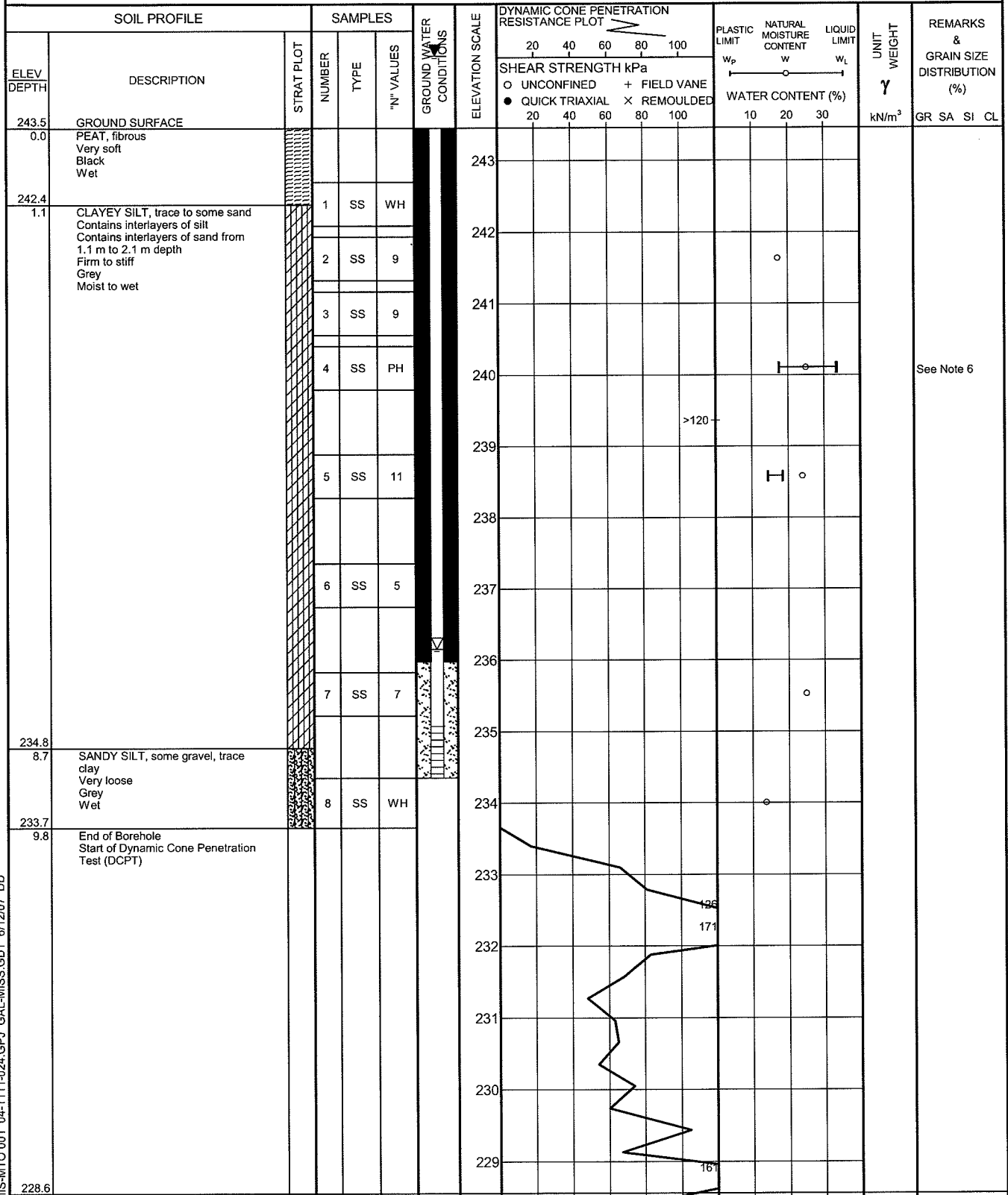
$C_c$	compression index (normally consolidated range)
$C_r$	recompression index (over-consolidated range)
$C_s$	swelling index
$C_a$	coefficient of secondary consolidation
$m_v$	coefficient of volume change
$c_v$	coefficient of consolidation
$T_v$	time factor (vertical direction)
U	degree of consolidation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

#### (d) Shear Strength

$\tau_p, \tau_r$	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

- Notes:** 1  $\tau = c' + \sigma' \tan \phi'$   
2 Shear strength = (Compressive strength)/2

<b>PROJECT</b> 04-1111-024D		<b>RECORD OF BOREHOLE No 06-5</b>		1 OF 2 <b>METRIC</b>	
W.P. 73-99-00		LOCATION N 4905696.0 ; E 390739.5		ORIGINATED BY SB	
DIST _____ HWY 7		BOREHOLE TYPE Power Auger, 101 mm O.D. Solid Stem Augers		COMPILED BY DD	
DATUM Geodetic		DATE July 5, 2006		CHECKED BY SLP	



See Note 6

Continued Next Page

+ 3, X 3: Numbers refer to Sensitivity      ○ 3% STRAIN AT FAILURE

MIS-MTO 001 04-1111-024.GPJ GAL-MISS.GDT 6/12/07 DD



PROJECT		RECORD OF BOREHOLE No 06-5				2 OF 2 METRIC																	
W.P. 73-99-00		LOCATION N 4905696.0 ; E 390739.5				ORIGINATED BY SB																	
DIST HWY 7		BOREHOLE TYPE Power Auger, 101 mm O.D. Solid Stem Augers				COMPILED BY DD																	
DATUM Geodetic		DATE July 5, 2006				CHECKED BY SLP																	
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	20	40						60	80	100	20	40	60	80	100	10
14.9	End of DCPT  Notes:  1. Water level measured in piezometer at 7.3 m depth (Elevation 236.2 m) upon completion of installation on July 5, 2006.  2. Water level measured in piezometer at 3.8 m depth (Elevation 239.7 m) on July 6, 2006.  3. Water level measured in piezometer at 0.9 m above ground surface (Elevation 244.4 m) on July 10, 2006.  4. Water level measured in piezometer at 0.8 m above ground surface (Elevation 244.3 m) on July 31, 2006.  5. Water level measured in piezometer at 1.0 m above ground surface (Elevation 244.5 m) on August 18, 2006.  6. Laboratory consolidation (oedometer) test performed on Sample No. 4.																						



1 OF 2 **METRIC**

ORIGINATED BY SB

COMPILED BY DD

CHECKED BY \_\_\_\_\_ SLP

+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity      ○<sup>3%</sup> STRAIN AT FAILURE

MIS-MTO 001 04-1111-024.GPJ GAL-MISS.GDT 6/12/07 DD

Continued Next Page



+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity      ○<sup>3%</sup> STRAIN AT FAILURE



1 OF 2 **METRIC**

ORIGINATED BY SB

COMPILED BY DD

CHECKED BY \_\_\_\_\_ SLP

MIS-MTO 001 04-1111-024.GPJ GAL-MISS.GDT 6/12/07 DD

+<sup>3</sup>, X<sup>3</sup>: Numbers refer to Sensitivity      ○<sup>3%</sup> STRAIN AT FAILURE



PROJECT 04-1111-024D		RECORD OF BOREHOLE No 06-7				2 OF 2 METRIC				
W.P. 73-99-00		LOCATION N 4905705.4 ; E 390726.1		ORIGINATED BY SB						
DIST _____ HWY 7		BOREHOLE TYPE Power Auger, 101 mm O.D. Solid Stem Augers		COMPILED BY DD						
DATUM Geodetic		DATE July 6, 2006		CHECKED BY SLP						
SOIL PROFILE		SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × REMOULDED	PLASTIC LIMIT W <sub>P</sub> NATURAL MOISTURE CONTENT W LIQUID LIMIT W <sub>L</sub> WATER CONTENT (%)	UNIT WEIGHT γ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE						
15.0	— CONTINUED FROM PREVIOUS PAGE —									
223.1										
21.6	End of DCPT  Note: 1. Water level measured in open borehole at 2.3 m depth (Elevation 242.4 m) upon completion of drilling. 2. SPT N-Value for Sample # 1 affected by presence of wood fragments.						Effective Refusal - 208 blpws/0.3m			

MIS-MTO 001 04-1111-024.GPJ GAL-MISS.GDT 6/12/07 DD



1 OF 2 **METRIC**

PROJECT 04-1111-024D

W.P. 73-99-00

LOCATION N 4905746.5 ;E 390721.6

ORIGINATED BY SB

DIST \_\_\_\_\_ HWY 7

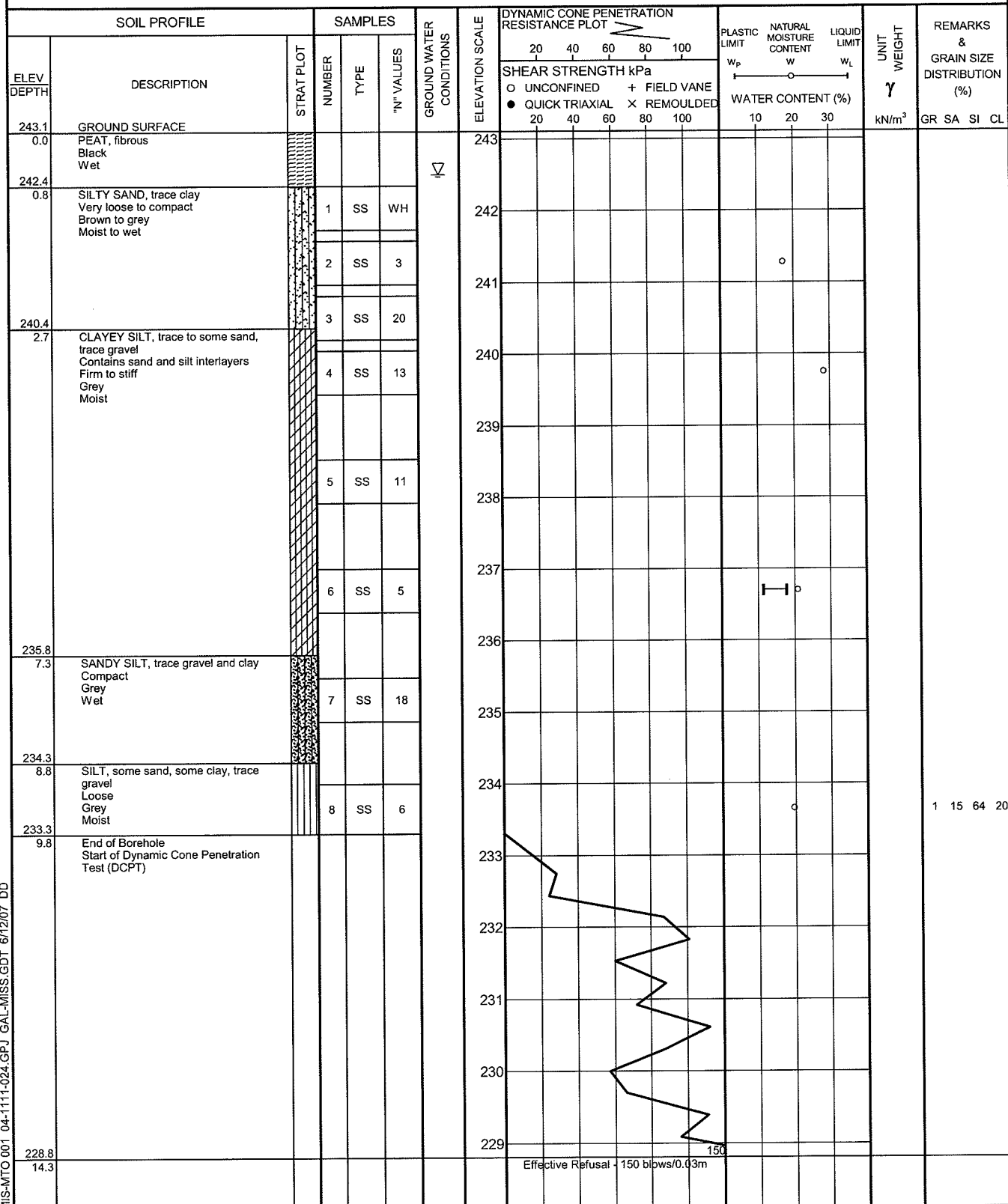
BOREHOLE TYPE Power Auger, 101 mm O.D. Solid Stem Augers

COMPILED BY DD

DATUM Geodetic

DATE July 6, 2006

CHECKED BY      SLP

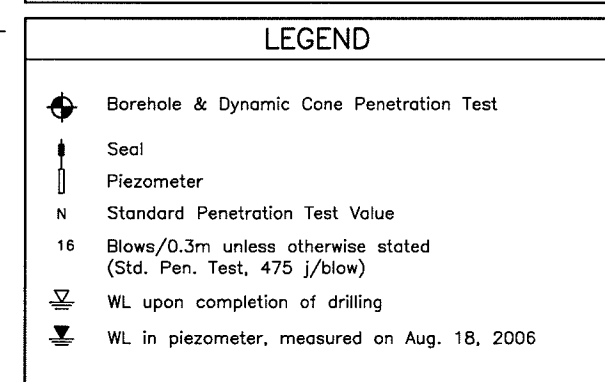
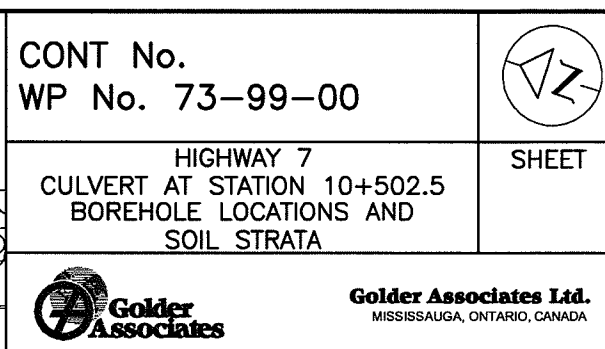


Continued Next Page

+<sup>3</sup>, X<sup>3</sup>: Numbers refer to Sensitivity      ○<sup>3%</sup> STRAIN AT FAILURE



+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity      ○<sup>3%</sup> STRAIN AT FAILURE



No.	ELEVATION	CO-ORDINATES	
		NORTHING	EASTING
06-5	243.5	4905696.0	390739.5
06-6	243.3	4905673.2	390748.7
06-7	244.7	4905705.4	390726.1
06-8	243.1	4905746.5	390721.6

**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.

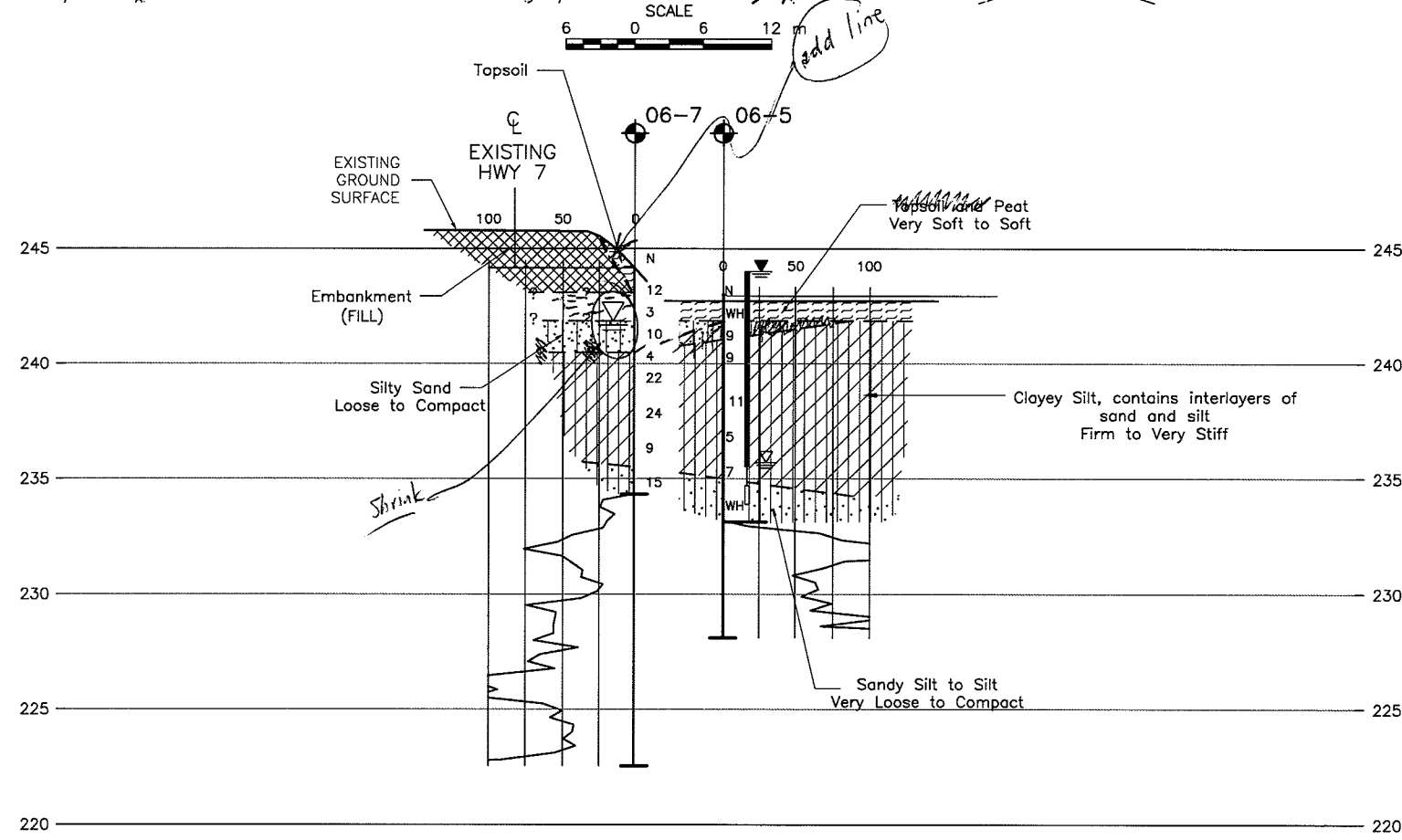
The boundaries between soil strata have been established only at borehole locations. Between Boreholes the boundaries are assumed from geological evidence.

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 plans provided in digital format by NCE, drawing file no. 2004-002 recommended plan.dwg, received March 31, 2006.

NO.		DATE		BY		REVISION									
Geocres No. 31D-429															
HWY. 7				PROJECT NO. 04-1111-024D						DIST.					
SUBM'D. SLP				CHKD. KJB				DATE: Aug. 9, 2007				SITE: 26-186			
DRAWN: MSM				CHKD. KJB				APPD.				DWG. 1			



**A-A'**  
**1**

**EXISTING HIGHWAY 7 CULVERT (STATION 10+502.5)**

**HOR SCALE**  
6 0 6 12 m

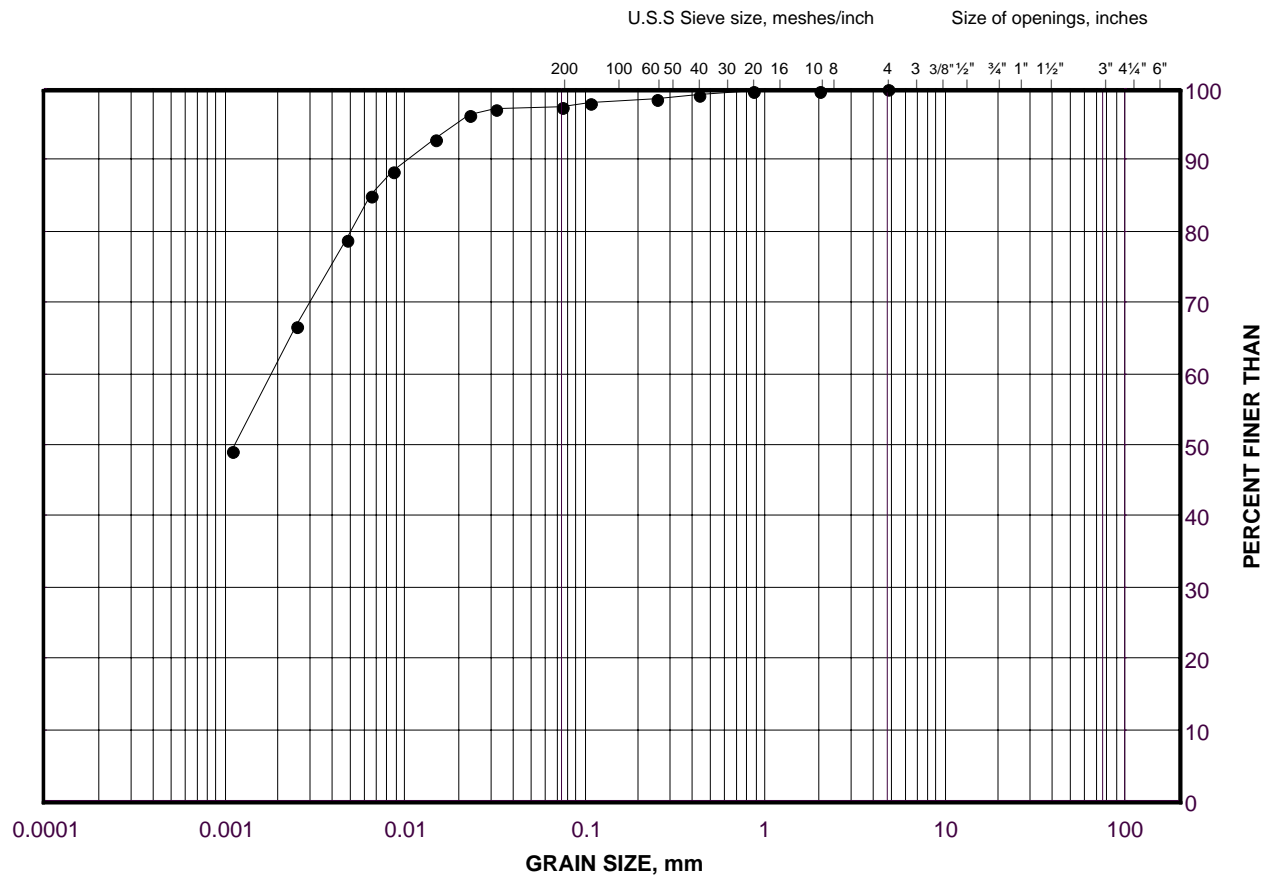
**VER SCALE**  
3 0 3 6 m

**APPENDIX A**  
**LABORATORY TEST DATA**

# GRAIN SIZE DISTRIBUTION

Silty Clay

FIGURE A1



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

## LEGEND

SYMBOL	BOREHOLE	SAMPLE	DEPTH(m)
•	06-6	5	4.60 - 5.20

Project Number: 04-1111-024D

Checked By: \_\_\_\_\_

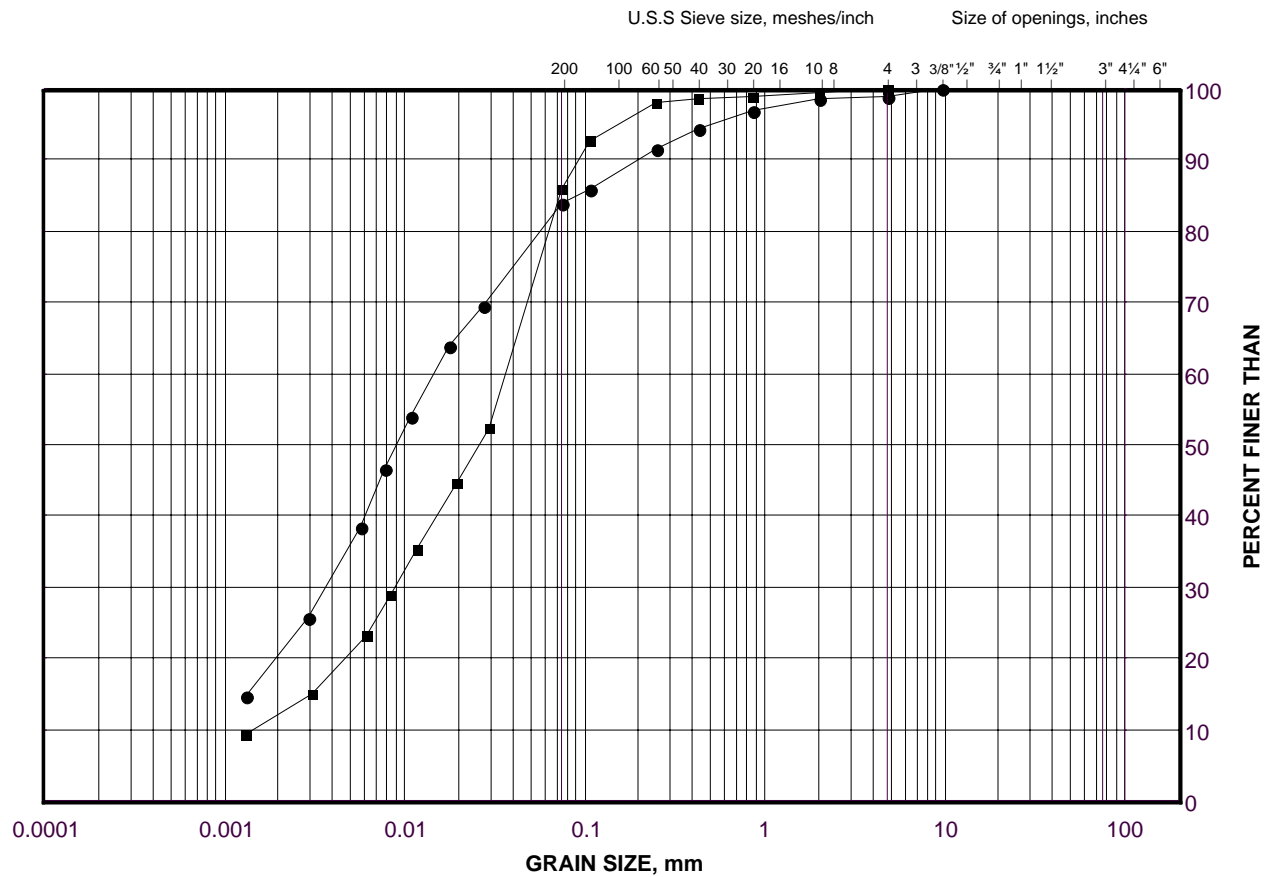
**Golder Associates**

Date: 24-Jan-07

# GRAIN SIZE DISTRIBUTION

Silt

FIGURE A2



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

## LEGEND

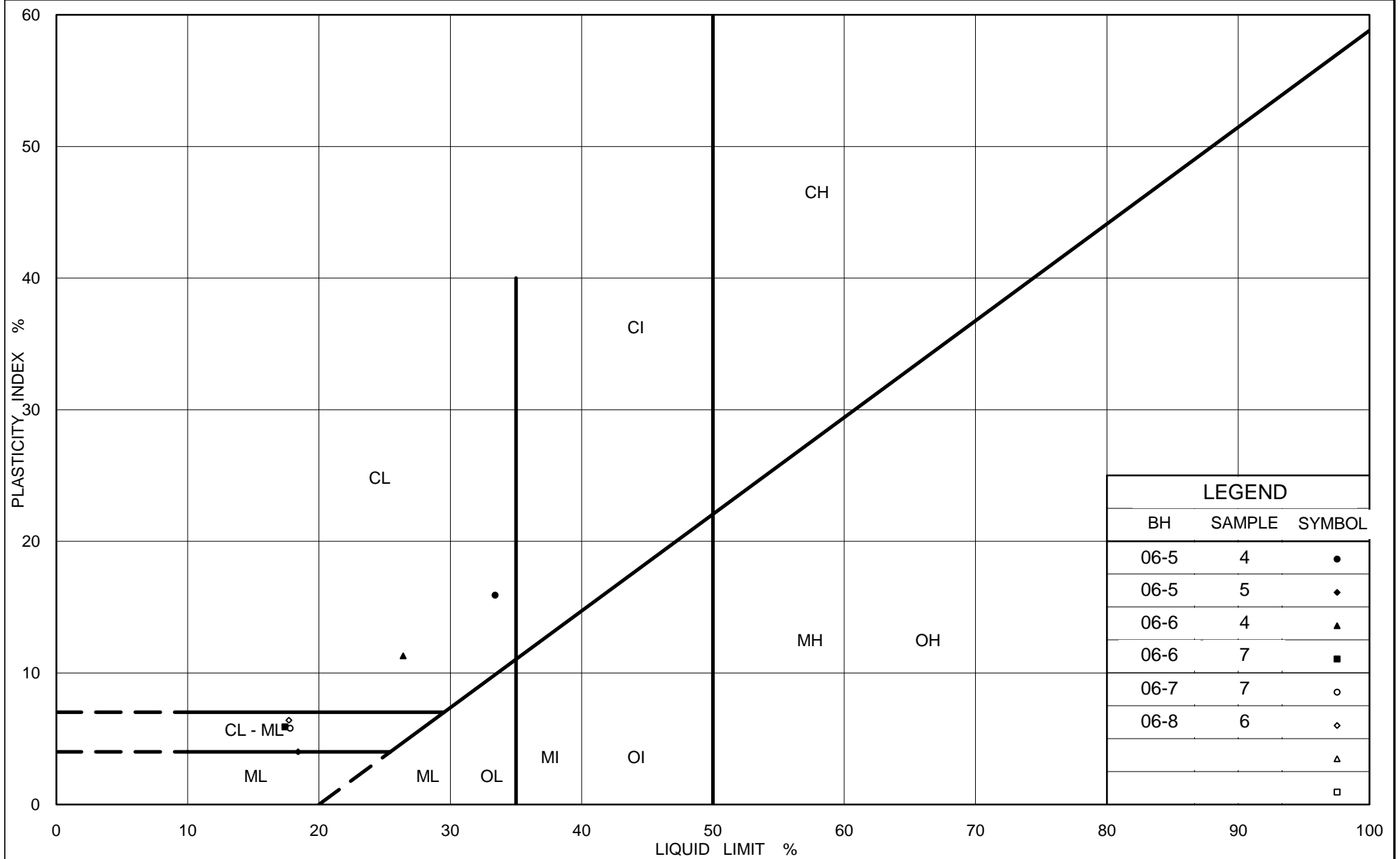
SYMBOL	BOREHOLE	SAMPLE	DEPTH(m)
●	06-8	8	9.10 - 9.80
■	06-7	8	9.10 - 9.80

Project Number: 04-1111-024D

Checked By: \_\_\_\_\_

**Golder Associates**

Date: 24-Jan-07



Ministry of Transportation

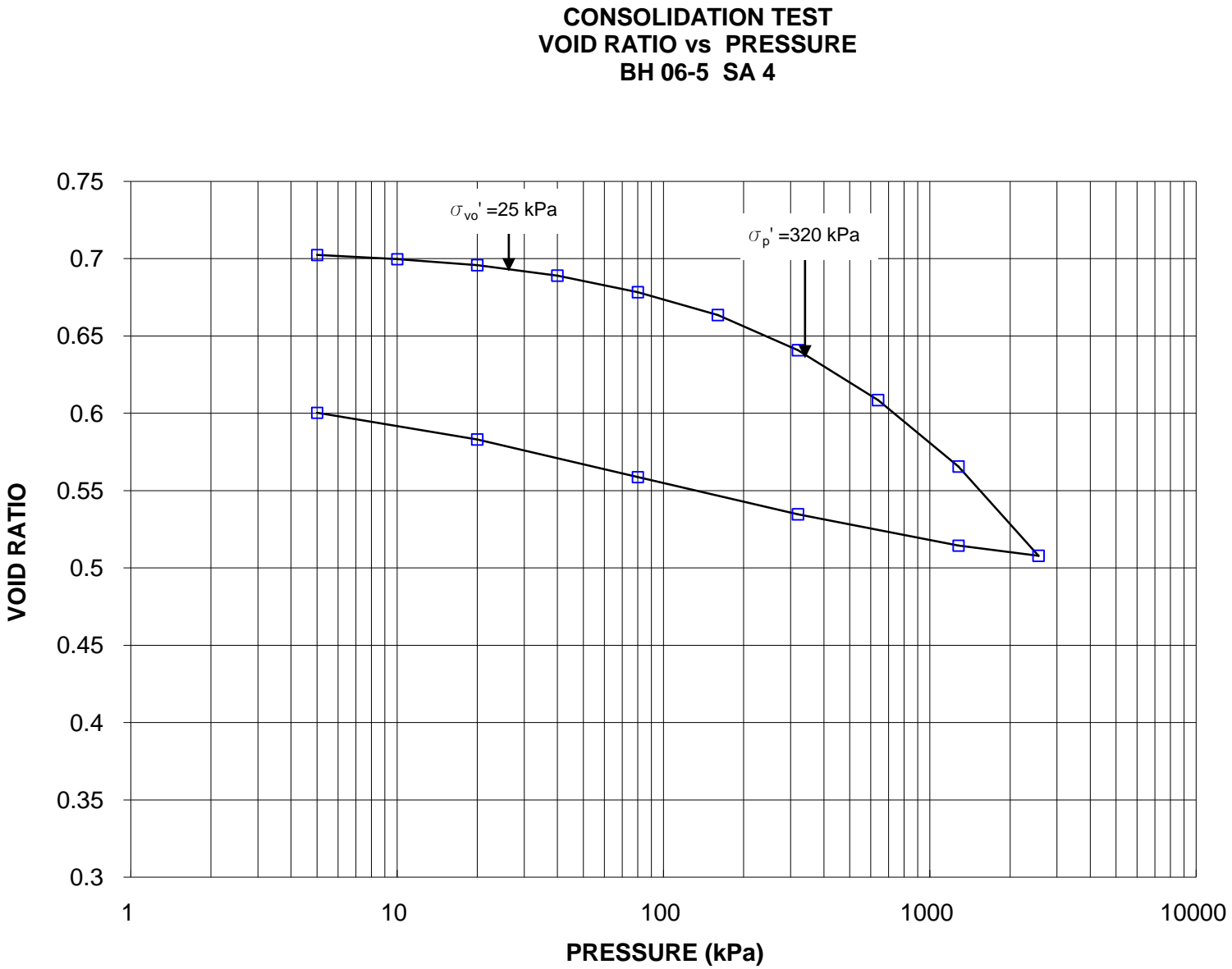
Ontario

# PLASTICITY CHART Clayey Silt

FIG No. A3

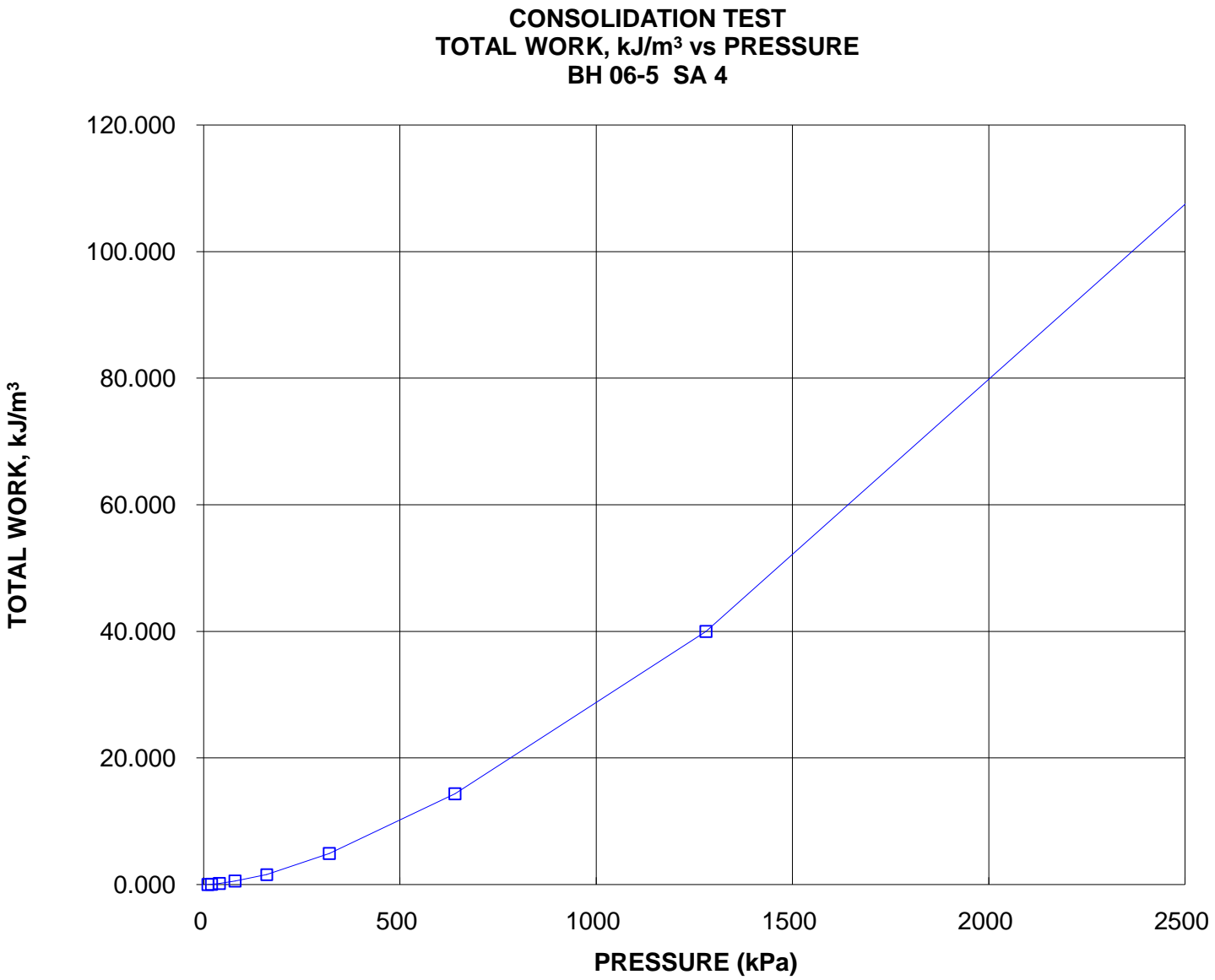
Project No. 04-1111-024

Checked By: KJB



CONSOLIDATION TEST  
TOTAL WORK VS. PRESSURE

FIGURE A5



**OEDOMETER CONSOLIDATION SUMMARY****FIGURE A6****SAMPLE IDENTIFICATION**

Project Number	04-1111-024	Sample Number	4
Borehole Number	5	Sample Depth, m	3.0-3.7

**TEST CONDITIONS**

Test Type	Standard	Load Duration, hr	24
Oedometer Number	5		
Date Started	08/29/2006		
Date Completed	09/11/2006		

**SAMPLE DIMENSIONS AND PROPERTIES - INITIAL**

Sample Height, cm	1.27	Unit Weight, kN/m <sup>3</sup>	19.84
Sample Diameter, cm	4.95	Dry Unit Weight, kN/m <sup>3</sup>	15.87
Area, cm <sup>2</sup>	19.21	Specific Gravity, measured	2.76
Volume, cm <sup>3</sup>	24.39	Solids Height, cm	0.745
Water Content, %	25.00	Volume of Solids, cm <sup>3</sup>	14.30
Wet Mass, g	49.35	Volume of Voids, cm <sup>3</sup>	10.09
Dry Mass, g	39.48	Degree of Saturation, %	97.9

**TEST COMPUTATIONS**

Pressure kPa	Corr. Height cm	Void Ratio	Average Height cm	t <sub>90</sub> sec	cv, cm <sup>2</sup> /s	mv m <sup>2</sup> /kN	k cm/s
0.00	1.270	0.705	1.270				
5.00	1.268	0.702	1.269	2	1.71E-01	3.15E-04	5.27E-06
10.00	1.266	0.700	1.267	2	1.70E-01	3.15E-04	5.25E-06
20.00	1.263	0.696	1.265	3	1.13E-01	2.36E-04	2.62E-06
40.00	1.258	0.689	1.261	10	3.37E-02	1.97E-04	6.50E-07
80.00	1.250	0.678	1.254	17	1.96E-02	1.57E-04	3.03E-07
160.00	1.239	0.664	1.245	23	1.43E-02	1.08E-04	1.51E-07
320.00	1.222	0.641	1.231	23	1.40E-02	8.37E-05	1.14E-07
640.00	1.198	0.608	1.210	37	8.39E-03	5.91E-05	4.85E-08
1280.00	1.166	0.565	1.182	34	8.71E-03	3.94E-05	3.36E-08
2560.00	1.123	0.508	1.145	40	6.94E-03	2.65E-05	1.80E-08
1280.00	1.128	0.514	1.126				
320.00	1.143	0.535	1.136				
80.00	1.161	0.559	1.152				
20.00	1.179	0.583	1.170				
5.00	1.192	0.600	1.186				

Note:  
k calculated using cv based on t<sub>90</sub> values.

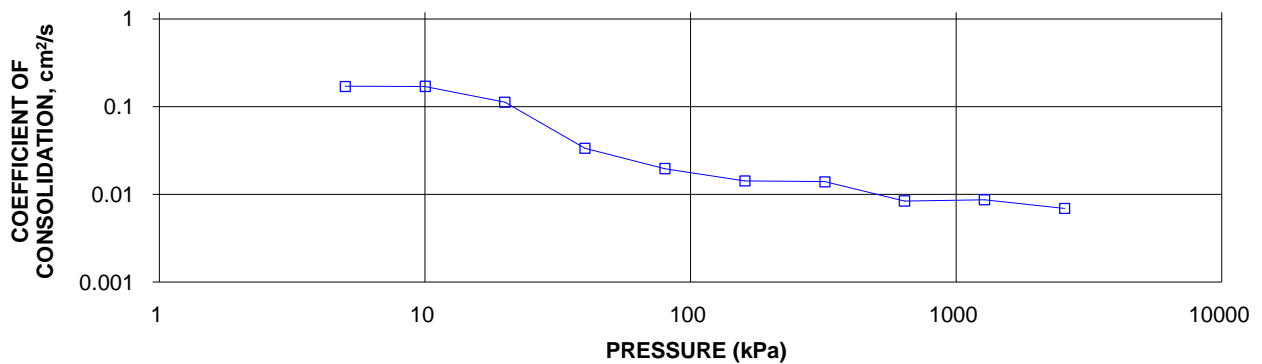
**SAMPLE DIMENSIONS AND PROPERTIES - FINAL**

Sample Height, cm	1.19	Unit Weight, kN/m <sup>3</sup>	20.70
Sample Diameter, cm	4.95	Dry Unit Weight, kN/m <sup>3</sup>	16.91
Area, cm <sup>2</sup>	19.21	Specific Gravity, measured	2.76
Volume, cm <sup>3</sup>	22.89	Solids Height, cm	0.745
Water Content, %	22.39	Volume of Solids, cm <sup>3</sup>	14.30
Wet Mass, g	48.32	Volume of Voids, cm <sup>3</sup>	8.59
Dry Mass, g	39.48		

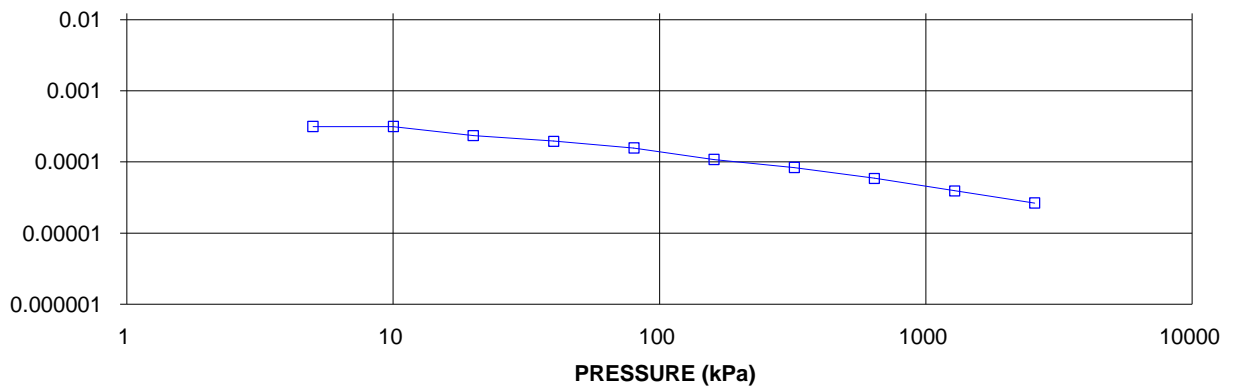
# **PLOTS OF CONSOLIDATION TEST RESULTS** **Cv, Mv, and K VS. PRESSURE**

**FIGURE A7**

**CONSOLIDATION TEST**  
**CV cm<sup>2</sup>/s VS PRESSURE (kPa)**  
**BH 5 SA 4**



**CONSOLIDATION TEST**  
**MV m<sup>2</sup>/kN vs PRESSURE (kPa)**  
**BH 5 SA 4**



**CONSOLIDATION TEST**  
**HYDRAULIC CONDUCTIVITY vs PRESSURE**  
**BH 5 SA 4**

