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**PRELIMINARY FOUNDATION  
INVESTIGATION AND DESIGN REPORT  
CULVERT EXTENSION AND/OR REPLACEMENT  
HIGHWAY 400 WIDENING  
FROM YORK / SIMCOE BOUNDARY  
TO 1 KM SOUTH OF HIGHWAY 89  
G.W.P. 40-00-00**

Submitted to:

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**PART A**

**PRELIMINARY FOUNDATION INVESTIGATION REPORT  
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HIGHWAY 400 WIDENING  
FROM YORK / SIMCOE BOUNDARY  
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## **1.0 INTRODUCTION**

Golder Associates Ltd. has been retained by URS Cole, Sherman (Cole, Sherman) on behalf of the Ministry of Transportation, Ontario (MTO) to provide preliminary foundation engineering services for the ultimate widening of Highway 400 from the York / Simcoe Boundary northerly to 1 km south of Highway 89, in Simcoe County, Ontario. Foundation engineering services are required for the widening and / or replacement of six existing overpass and underpass structures, as well as four structural culverts.

This report addresses the four structural culverts. A foundation investigation has been carried out, in which two boreholes were advanced at each culvert location and in-situ and laboratory testing were conducted, to determine the subsurface conditions at the sites for this preliminary design study.

The terms of reference for the scope of work are outlined in the MTO's Request for Quotation (RFQ) dated September 5, 2000, and in Golder Associates' subsequent letters dated December 13, 2000 and February 15, 2001.

## 2.0 SITE DESCRIPTION

Four structural culverts are present in this section of Highway 400. Their locations, types, dimensions and channel invert elevations are summarized in the following table:

<i><b>Culvert Location</b></i>	<i><b>Culvert Type</b></i>	<i><b>Culvert Dimensions</b></i>	<i><b>Channel Invert Elevation</b></i>	<i><b>Highway 400 Elevation</b></i>
10+065 (Holland River)	Concrete Rigid Frame	3.05 m x 1.5 m	East: 215.9 m West: 216.0 m	221.5 m
13+740	Concrete Arch	7.3 m x 3.65 m	East: 221.8 m West: 221.6 m	227.0 m
17+820	Concrete Box	3.65 m x 1.4 m	East: 253.1 m West: 252.5 m	255.5 m
23+010	Concrete Box	3.05 m x 1.8 m	East: 258.6 m West: 257.5 m	271.5 m

### 3.0 INVESTIGATION PROCEDURES

Subsurface investigations at the four culvert sites were carried out in December 2000 and January 2001, at which time a total of eight boreholes were advanced. The following table summarizes the locations and depths of the boreholes:

<i><b>Borehole</b></i>	<i><b>Culvert Location</b></i>	<i><b>Borehole Location Along Highway 400</b></i>	<i><b>Depth</b></i>
C-1	Station 10+065 (Holland River)	Station 10+065, East Side of Highway 400	14.3 m
C-2	Station 10+065 (Holland River)	Station 10+065, West Side of Highway 400	14.3 m
C-3	Station 13+740	Station 13+730, East Side of Highway 400	18.9 m
C-4	Station 13+740	Station 13+730, West Side of Highway 400	11.3 m
C-5	Station 17+820	Station 17+825, East Side of Highway 400	14.3 m
C-6	Station 17+820	Station 17+795, West Side of Highway 400	11.3 m
C-7	Station 23+010	Station 23+010, East Side of Highway 400	11.0 m
C-8	Station 23+010	Station 23+020, West Side of Highway 400	11.3 m

The borehole locations and elevations were surveyed by Callon Dietz, Ontario Land Surveyors. The borehole elevations are referenced to geodetic datum, and the northing and easting co-ordinates are referenced to the MTM NAD83 survey system. The borehole locations, together with elevations and northing and easting coordinates, are shown on the attached Drawings 1 to 4.

The investigation was carried out using bombardier-mounted B-57 and D-50 drill rigs supplied and operated by Master Soil Investigations Ltd. of Weston, Ontario. The boreholes were advanced using 108 mm diameter solid stem and 162 mm diameter hollow stem augers. Samples of the overburden were obtained at 0.75 m to 3 m intervals of depth using 50 mm outside diameter split-spoon samplers in accordance with the Standard Penetration Test (SPT) procedure. In-situ vane shear strength testing was carried out at selected locations using an 'N' size vane. The water levels in the open boreholes were observed throughout the drilling operations, and piezometers were installed in Boreholes C-1, C-4, C-5 and C-7 to permit monitoring of the groundwater levels at the site.

The field work was supervised on a full-time basis by a member of our 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 Associates' laboratory in Mississauga for further examination. Index and classification tests consisting of water content determinations, Atterberg Limits tests and grain size distribution analyses were carried out on selected soil samples.



## **4.0 SITE GEOLOGY AND STRATIGRAPHY**

### **4.1 Regional Geological Conditions**

This 15 km section of Highway 400 traverses, from south to north, the following physiographic regions as delineated in *The Physiography of Southern Ontario* (Chapman and Putnam, Third Edition, 1984): the Simcoe Lowlands; the Schomberg Clay Plains; the Peterborough Drumlin Field; and a second lobe of the Simcoe Lowlands. Along Highway 400, the southern lobe of the Simcoe Lowlands is present at the North Canal / Canal Road site. The Schomberg Clay Plains are present north of this site, to 2 km north of Simcoe Road 88 (formerly Highway 88). The Peterborough Drumlin Field extends from 2 km north of Simcoe Road 88 to about 3 km south of Highway 89. The northern lobe of the Simcoe Lowlands extends from about 3 km south of Highway 89 to beyond the northern limit of this project.

The southern lobe of the Simcoe Lowlands, at the southern end of this project, is comprised of the Holland River valley. The culvert at Station 10+065 is located within this valley. The valley extends southwest from Cook Bay, at the south end of Lake Simcoe; it was once a shallow extension of the lake. The floor of the valley is covered by extensive deposits of loose silts and soft clays, which overlie a till sheet. In localized areas, these silts and clays are overlain by a thin, poorly graded sand of deltaic origin. Because the valley is depressed and poorly drained, a surficial cover of peat has formed in many areas.

The surficial soils in the Schomberg Clay Plains, in which the culverts at Stations 13+740 and 17+820 are located, consist primarily of clay and silt deposits. These deposits overlie till within drumlins as found in the Peterborough Drumlin Field. The drumlins are completely or partially buried by the clay and silt deposits, depending on the size of the drumlin. The varved clay and silt deposits are typically about 5 m thick, although deeper deposits have been found in some locations.

The surficial soils in the Peterborough Drumlin Field, in which the culvert at Station 23+010 is located, consist primarily of gravelly sand till or sand and gravel deposits. Deposits of silt, clay or peat may be found in the low-lying areas between drumlins.

At the northern end of this project, the Simcoe Lowlands include the shores of Kempenfelt Bay, the Nottawasaga River, and Innisfil Creek. The surficial soils of the northern lobe of the Simcoe Lowlands consist primarily of sand, although silt, clay or peat may be found in low-lying areas.

## **4.2 Site Stratigraphy**

The detailed subsurface soil and groundwater conditions encountered in the boreholes, together with the results of the laboratory testing carried out on selected soil samples, are given on the Record of Borehole sheets and Figures 1 to 4. The locations of the borings are shown on the attached Drawings 1 to 4. 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. Subsoil conditions will vary between and beyond the borehole locations.

## **4.3 Holland River Culvert at Station 10+065**

Boreholes C-1 and C-2 were drilled near the east and west ends of the existing Holland River culvert which extends under Highway 400 at about Station 10+065. At the site, the Highway 400 grade is at about Elevation 221.5 m, and the existing channel invert is at about Elevation 216 m. The ground surface at the borehole locations is at about Elevation 218.6 m and 219.2 m on the east and west sides of Highway 400, respectively.

The subsoils encountered in the boreholes consist of fill overlying a thin peat layer, in turn underlain by an interlayered sequence of clayey silt, sandy silt to sand and silt, and silty sand deposits. A more detailed description of the subsurface conditions encountered in Boreholes C-1 and C-2 is provided in the following subsections.

### **4.3.1 Fill**

About 0.8 m of compact sand and gravel fill was encountered in both boreholes, overlying about 1.2 m to 1.3 m of clayey silt fill. The clayey silt fill is firm to stiff, based on measured Standard Penetration Test (SPT) 'N' values of 7 to 15 blows per 0.3 m of penetration. The base of the fill was encountered at Elevation 216.5 m in Borehole C-1 on the east side of the highway, and at Elevation 217.2 m in Borehole C-2 on the west side of the highway.

### **4.3.2 Peat**

A 200 mm to 300 mm thick layer of peat was encountered immediately below the clayey silt fill in both boreholes. The peat was encountered between Elevations 216.5 m and 216.2 m in Borehole C-1 on the east side of the highway, and between Elevations 217.2 m and 216.9 m in

Borehole C-2 on the west side of the highway. It is noted that the base of the peat layer as encountered at these borehole locations is about 0.2 m to 1.2 m above the existing culvert invert level.

#### **4.3.3 Upper Clayey Silt**

A deposit of clayey silt was encountered immediately below the peat layer in both boreholes. The surface of the deposit was encountered at Elevation 216.2 m in Borehole C-1, where the clayey silt is about 1.4 m in thickness. In Borehole C-2, the clayey silt is about 2.6 m thick, extending between Elevations 216.9 m and 214.3 m.

This upper clayey silt deposit is soft to stiff, based on measured SPT 'N' values of 3 to 14 blows per 0.3 m of penetration. Atterberg limits testing carried out on one sample measured a plastic limit of 16 per cent, a liquid limit of 24 per cent, and a plasticity index of 8 per cent, indicating that this clayey silt deposit is inorganic and of low plasticity. The measured natural water contents range from 15 to 20 per cent.

#### **4.3.4 Upper Sandy Silt to Sand**

The upper clayey silt is underlain by a deposit which ranges in composition from sandy silt, to sand and silt, to sand containing trace silt. The results of two grain size distribution tests are shown on Figure 1. The surface of this cohesionless deposit was encountered in the boreholes at Elevations 214.9 m and 214.3 m on the east and west sides of Highway 400, respectively. The deposit base is at about Elevations 212 m to 211.6 m as encountered in these boreholes.

The measured SPT 'N' values range from 9 to 56 blows per 0.3 m of penetration, but are typically between 9 and 23 blows per 0.3 m of penetration, indicating that the upper sandy silt to sand deposit has a generally compact relative density.

#### **4.3.5 Lower Clayey Silt**

A 1.2 m to 1.5 m thick clayey silt stratum underlies the upper sandy silt to sand stratum. The surface of this cohesive unit was encountered at about Elevation 212 m and 211.6 m in Boreholes C-2 and C-1, respectively, and its base was encountered at about Elevation 210.5 m.

The consistency of this material ranges from very stiff to hard, based on two measured SPT 'N' values of 24 and 144 blows per 0.3 m of penetration. Atterberg limits testing measured a plastic limit of 12 per cent, a liquid limit of 19 per cent, and a plasticity index of 7 per cent, indicating that the clay material is inorganic and of low plasticity. The water content measured on this sample was about 14 per cent, near the plastic limit of the material.

#### **4.3.6 Lower Sand to Silty Sand**

Both boreholes were terminated in a lower cohesionless deposit, the surface of which was encountered at about Elevation 210.5 m. This deposit extended to the maximum depth of investigation, at about Elevation 204.3 m on the east side of the highway, and about Elevation 204.9 m on the west side of Highway 400.

This deposit ranges in composition from sand containing trace to some silt, to silty sand. It has a dense to very dense relative density, based on measured SPT 'N' values of 36 to 74 blows per 0.3 m of penetration.

#### **4.4 Culverts at Stations 13+740 and 17+820**

Boreholes C-3 and C-4 were drilled on the east and west sides of the existing culvert that extends under Highway 400 at Station 13+740. At this site, the Highway 400 grade is at about Elevation 227 m, and the existing channel invert is at Elevation 221.8 m to 221.6 m, declining from east to west. The ground surface at the borehole locations is at Elevation 222.6 m and 222.7 m on the east and west sides of Highway 400, respectively.

Boreholes C-5 and C-6 were drilled near the east and west ends of the existing culvert that extends under Highway 400 at Station 17+820. At this site, the Highway 400 grade is at about Elevation 255.5 m while the culvert invert is at about Elevation 253.1 m to 252.5 m, declining from east to west. The ground surface at Borehole C-5, on the east side of the highway, is at about Elevation 254.1 m, while the ground surface at Borehole C-6 is at about Elevation 253.5 m.

Both of these culverts are located within the Schomberg Clay Plain physiographic region. The subsoils encountered in the boreholes consist of fill and / or topsoil overlying a deposit of clayey silt. A more detailed description of the subsurface conditions encountered at these culvert sites is provided in the following subsections.

#### **4.4.1 Topsoil and Fill**

At Station 13+740, Borehole C-3 encountered about 0.8 m of firm clayey silt fill overlying the native clayey silt deposit. Borehole C-4 at this site encountered about 600 mm of topsoil overlying the native soils.

In the boreholes advanced at Station 17+820, 500 mm to 600 mm of topsoil was encountered immediately below the ground surface.

#### **4.4.2 Clayey Silt**

An extensive clayey silt deposit is present at these two culvert sites, below the topsoil and fill. The surface of the clayey silt was encountered at about Elevation 222 m in Boreholes C-3 and C-4, and at about Elevation 253 m to 253.5 m at Station 17+820. The clayey silt deposit extended to the maximum depth investigated: about Elevation 203.7 m at Station 13+740, and about Elevation 239.8 m at Station 17+820.

The clayey silt deposit contains trace to some sand and trace gravel. Faint layering was observed in some samples. Sand seams were encountered within the deposit below Elevation 245 m (about 9 m depth) in Borehole C-6. Grain size distribution test results for representative samples of this glaciolacustrine deposit are shown on Figures 2 and 3.

The natural moisture contents measured on samples of the clayey silt range from about 10 to 28 per cent, but are typically between 15 and 25 per cent. Atterberg limits testing measured plastic limits of 13 to 20 per cent, liquid limits of 21 to 34 per cent, and plasticity indices of 8 to 14 per cent. The limits test results indicate that the clayey silt is inorganic and of low plasticity.

In Boreholes C-3 and C-4 at Station 13+740, the clayey silt soils above about Elevation 217 m have SPT 'N' values that range from 6 to 36 blows per 0.3 m of penetration; the measured 'N' values are typically between 13 and 27 blows per 0.3 m of penetration, indicating that the upper portion of the deposit at this site has a predominantly stiff to very stiff consistency. Below Elevation 217 m, the measured SPT 'N' values range from 8 to 22 blows, but are typically between 8 and 15 blows per 0.3 m of penetration. In-situ vane shear testing carried out below Elevation 217 m measured undrained shear strengths of about 40 kPa to 65 kPa. These test results confirm that the lower portion of the deposit has a firm to stiff consistency.

In Boreholes C-5 and C-6 at Station 17+820, the measured SPT 'N' values in the upper 1 m to 2 m of the deposit range from 4 to 8 blows per 0.3 m of penetration, indicative of a firm consistency. Below this, down to about Elevation 247 m (about 7 m depth), the measured SPT 'N' values range

from 11 to 20 blows per 0.3 m of penetration, indicative of a stiff to very stiff consistency. Below Elevation 247 m down to Elevation 240 m (the maximum depth of investigation), the SPT 'N' values range from 5 to 9 blows per 0.3 m of penetration; this portion of the deposit has a firm to stiff consistency.

#### **4.5 Culvert at Station 23+010**

Boreholes C-7 and C-8 were drilled near the east and west ends of the existing culvert which extends under Highway 400 at Station 23+010, just south of the West Gwillimbury Twelfth Concession. At this site, the Highway 400 grade is at about Elevation 271.5 m, and the existing culvert invert is at Elevation 258.6 m to 257.5 m, declining from east to west. The ground surface at the borehole locations is at Elevation 263.5 m and 260.3 m on the east and west sides of Highway 400, respectively.

This culvert is located within the Peterborough Drumlin Field physiographic region. The subsoils encountered in the boreholes consist of fill and / or topsoil overlying a sand and silt till deposit. A more detailed description of the subsurface conditions encountered at this culvert site is provided in the following subsections.

##### **4.5.1 Topsoil and Fill**

In Borehole C-7 on the east side of the highway, about 600 mm of topsoil was encountered immediately below ground surface. On the west side of the highway, Borehole C-8 encountered about 2.3 m of clayey silt fill containing some sand and trace gravel. The measured SPT 'N' values in this fill are 10 and 11 blows per 0.3 m of penetration, indicating that the clayey silt fill has a stiff consistency.

##### **4.5.2 Sand and Silt Till**

The surface of the sand and silt till deposit was encountered at about Elevation 263 m in Borehole C-7 on the east side of Highway 400, and at about Elevation 258 m in Borehole C-8 on the west side of the highway. This till deposit extended to the maximum depth of investigation, corresponding to Elevation 252.5 m and 249 m on the east and west sides of the highway, respectively.

The result of a grain size distribution test carried out on a representative sample of this till material is shown on Figure 4. Atterberg limits testing measured plastic limits of about 12 per cent, liquid limits of 13 to 15 per cent, and plasticity indices of 1 to 3 per cent. The measured water contents range from 9 to 10 per cent.

The SPT 'N' values measured in the sand and silt till deposit range from 3 to greater than 100 blows per 0.3 m of penetration, but are typically between about 10 and 50 blows per 0.3 m of penetration. Based on these 'N' values, the till deposit has a predominantly compact to dense relative density.

#### 4.6 Groundwater Conditions

The water levels in the boreholes were observed during and upon completion of drilling. Piezometers were installed in one borehole at each culvert site; the details of the piezometer installations are shown on the Record of Borehole sheets. The results of the water level readings at each of the culvert locations are summarized in the following table.

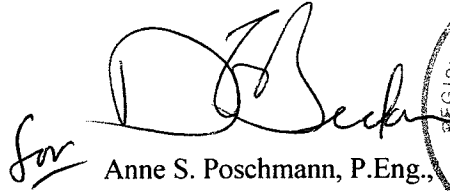
<i>Culvert Location</i>	<i>Culvert Invert Elevation</i>	<i>Borehole Number</i>	<i>Water Elevation on Completion of Drilling</i>	<i>Water Elevation in Piezometer</i>	
				<i>Jan 18, 2001</i>	<i>Mar 20, 2001</i>
10+065 (Holland River)	216.0 m – 215.9 m	C-1	N/A	216.8 m	217.0 m
		C-2	216.5 m	N/A	N/A
13+740	221.8 m – 221.6 m	C-3	N/A	N/A	N/A
		C-4	216.6 m	221.2 m	221.8 m
17+820	253.1 m – 252.5 m	C-5	248.0 m	253.3 m	253.6 m
		C-6	250.8 m	N/A	N/A
23+010	258.6 m – 257.5 m	C-7	N/A	258.7 m	260.6 m
		C-8	257.9 m	N/A	N/A

It should be noted that groundwater levels are expected to fluctuate seasonally and are expected to be higher during wet periods of the year.

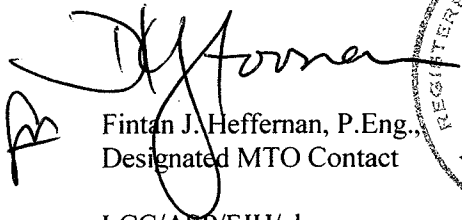
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LCC/ASP/FJH/clg

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**PART B**

**PRELIMINARY FOUNDATION DESIGN REPORT  
CULVERTS  
HIGHWAY 400 WIDENING  
FROM YORK / SIMCOE BOUNDARY  
TO 1 KM SOUTH OF HIGHWAY 89  
G.W.P. 40-00-00**

## **5.0 ENGINEERING RECOMMENDATIONS**

### **5.1 General**

This section of the report provides preliminary foundation design recommendations for the extension and / or replacement of four structural culverts, associated with the widening of this section of Highway 400. The recommendations are preliminary only and are based on interpretation of the factual data obtained from a limited number of boreholes advanced during the subsurface investigation at this site. The interpretation and recommendations provided are intended for planning purposes only, to provide the information necessary at this stage of the study. As such, where comments are made on construction they are provided only in order to highlight those aspects which could affect the planning of the project. Further foundation investigation will be required at these culvert sites as part of the detailed design stage of the project.

It is understood that Highway 400 will be widened from its existing six-lane configuration to an ultimate configuration of ten lanes. The primary options under consideration involve widening into the median, or using a 22 m wide open median with widening on the outside of the existing highway. Depending on which option is adopted, it is expected that the existing highway will be widened by between 10 m and 29 m, necessitating extension or replacement of the existing structural culverts.

### **5.2 Foundation Options for Holland River Culvert at Station 10+065**

The existing Holland River culvert is a 3.05 m x 1.5 m concrete rigid frame, with channel invert at about Elevation 216 m. Box culverts extend under the service roads on either side of Highway 400 and are structurally separate from the rigid frame culvert. It is not known whether the widening will require replacement of the service road culverts, and these have not been addressed in this report.

The founding conditions of the existing rigid frame culvert are not known. If the existing culvert is to be extended, it is recommended that the foundation type be determined prior to (or as part of) final design. If the existing culvert is supported on piles, the culvert extension should also be supported on piles. If the existing culvert is supported on the shallow foundations, the culvert extensions could be supported on either shallow or deep foundations; however, substantial groundwater control will likely be required in either case to permit excavations for pile cap or shallow foundation construction. This groundwater lowering / cut-off must be carried out prior to foundation excavation in order to maintain the integrity of the founding soils under the existing culvert footings and ensure that the founding soils for the proposed footings are not disturbed.

It is understood that the most likely option for the Highway 400 widening in this area will be widening into the median. In this event, there will likely be no requirement for extension of the culvert. Assessment will be required, however, of the existing culvert and its foundations with respect to the additional loading which would be applied over the portion of the culvert within the median.

### **5.2.1 Shallow Foundations**

Shallow foundations should be placed at least 1.5 m below the lowest surrounding grade to provide adequate protection against frost penetration. The soils at and immediately below founding level (approximately Elevation 214.5 m) are expected to consist generally of compact, water-bearing sand and silt to sandy silt. Assuming that the existing structure is founded at this level, there will be a requirement to implement groundwater control measures to permit excavation for the new footings without having adverse impact on the existing footings and to maintain the integrity of the founding soils for the new footings.

For preliminary design, spread footings placed on the properly prepared, undisturbed sand and silt to sandy silt soils, at or below Elevation 214.5 m, may be designed using a factored geotechnical resistance at Ultimate Limit States (ULS) of 250 kPa, assuming a 2 m wide footing. For preliminary design, the geotechnical resistance at Serviceability Limit States (SLS) may be taken as 200 kPa. The embankment widening could require up to about 4.5 m of fill placement. The magnitude of settlement of the culvert extensions will depend on the configuration of this widening in relation to the existing embankment and the consequent consolidation settlement of the founding soils. Based on the subsoil conditions at this site, the settlement will occur during construction of the embankment and will be less than 25 mm. The geotechnical resistance at SLS should be reviewed following the detailed design stage of subsurface investigation, once the footing / culvert size, embankment and culvert configuration and loadings are determined.

Resistance to lateral forces / sliding resistance between the concrete footing and the subsoils should be calculated in accordance with Section 6-8.4.3 of the Ontario Highway Bridge Design Code (OHBDC). The angle of friction between the concrete footings and the undisturbed compact sand / silt deposits should be taken as 22 degrees. The corresponding coefficient of friction,  $\tan \delta$ , would be 0.4.

### **5.2.2 Driven Steel H-Piles**

Alternatively, the culvert extensions could be supported on driven steel H-piles. Assuming a required pile cap depth of 1.5 m, similar groundwater control measures will be required as for

spread footings in order to ensure that the existing footings are not undermined during pile cap construction.

Steel H-piles or pipe piles, driven into the compact to very dense sand deposit that was encountered below about Elevation 210.5 m, could be used for support of the rigid frame culvert extensions. Based on the borehole information to date, a pile tip level at Elevation 205 m may be assumed for preliminary design. Assuming that the pile caps would be placed at about Elevation 214.5 m, the piles would be about 9.5 m long.

For preliminary design, and subject to confirmation following the detailed design stage of subsurface investigation, the factored axial resistance at ULS for steel HP 310 x 79 piles may be taken as 500 kN. The corresponding axial resistance at SLS for 25 mm of settlement may be taken as 400 kN.

Lateral loading could be resisted fully or partially by the use of battered piles. If vertical piles are used, the resistance to lateral loading will have to be derived from the soil in front of the piles. The resistance to lateral loading in front of the pile may be calculated using subgrade reaction theory where the coefficient of horizontal subgrade reaction,  $k_h$ , is based on the equations given below.

For clayey silt soils:

$$k_h = \frac{k_{s1}}{5B} \quad \text{where } B \text{ is the pile diameter (m) and}$$

$k_{s1}$  is the coefficient of horizontal subgrade reaction, as given below.

For the upper sandy silt to sand and lower sand to silty sand deposits:

$$k_h = \frac{n_h z}{B} \quad \text{where } n_h \text{ is the constant of subgrade reaction, as given below;}$$

$z$  is the depth (m); and

$B$  is the pile diameter (m<sup>2</sup>).

The following ranges for the value of  $n_h$  and  $k_{s1}$  may be assumed in the structural analysis; these values will have to be confirmed following the detailed design stage of subsurface investigation.

<i>Soil Unit</i>	<i>n<sub>h</sub></i>	<i>k<sub>sl</sub></i>
Upper sand and silt to sand layer, between Elevation 214.5 m and 212 m	2 to 5 MPa/m	—
Lower clayey silt, between Elevation 212 m and 210.5 m	—	25 to 50 MPa/m
Lower sand to silty sand, below Elevation 210.5 m	5 to 15 MPa/m	—

Group action for lateral loading should be considered when the pile spacing in the direction of the loading is less than six to eight pile diameters. Group action can be evaluated by reducing the coefficient of lateral subgrade reaction in the direction of loading by a reduction factor, *R*, as follows:

<i>Pile Spacing in Direction of Loading (d = Pile Diameter)</i>	<i>Subgrade Reaction Reduction Factor, R</i>
8d	1.00
6d	0.70
4d	0.40
3d	0.25

### 5.3 Foundation Options for Culvert at Station 13+740

The existing culvert at Station 13+740 is a concrete arch culvert, with channel invert at about Elevation 221.8 m to 221.6 m. The soils below the channel level, as encountered in Boreholes C-3 and C-4, consist of an extensive deposit of clayey silt, which ranges in consistency from firm to hard.

The foundation system for the existing culvert is not known. It is recommended that the type of foundation be established prior to or as part of the detailed design stage in order to assess the most feasible type of foundation for the culvert extensions. The following summarizes the options together with the consequences depending on the foundation conditions of the existing culvert.

Construction of the widened highway embankment sections will induce consolidation settlement of the clayey silt stratum underlying the site. Shallow spread footings could be used for the culvert extension; however, the new embankment loading could result in differential settlement along the extensions and may also cause some settlement of the ends of the existing culvert if the existing culvert is supported on spread footings.

Alternatively, the new sections of arch culvert could be supported on pile foundations. If the existing culvert is also supported on deep foundations, this option would minimize differential settlement along the full length of the culvert and its extensions. However, if the existing culvert is supported on shallow foundations, then loading due to construction of the widened

embankment would induce additional consolidation settlement of the soils under the ends of the existing culvert resulting in differential settlement between the old and new culverts.

### **5.3.1 Shallow Foundations**

Shallow foundations should be founded at least 1.5 m below the lowest surrounding grade to provide adequate protection against frost penetration. Spread footings placed on the properly prepared clayey silt deposit, at or below Elevation 220.5 m to 220 m, may be designed using a factored geotechnical resistance at ULS of 325 kPa, assuming a 2 m wide footing.

Settlement of the footings will be dependent on the footing size, configuration and applied loads and, in addition, settlement of the footings will occur due to consolidation of the founding soils under the additional embankment loading. For a grade raise of up to about 5 m, it is estimated that up to about 50 mm of consolidation settlement of the firm to stiff clayey silt soil could occur below the extensions, and up to about 25 mm of settlement could occur below the ends of the existing culvert. For preliminary design, the geotechnical resistance at SLS may be taken as 250 kPa; however, it should be noted that the settlement of the culvert footings will be up to 50 mm due to the embankment loading as noted above. The settlement and SLS resistance should be confirmed at the final design stage, once the footing size, configuration and loadings are known, to assess whether this spread footing option is feasible. Additional field and laboratory testing should be carried out to determine compressibility characteristics of the subsoils to refine the settlement predictions.

Resistance to lateral forces / sliding resistance between the concrete footing and the subsoils should be calculated in accordance with Section 6-8.4.3 of the OHBDC. The angle of friction between the concrete footings and the undisturbed, firm to stiff clayey silt should be taken as 24 degrees. The corresponding coefficient of friction,  $\tan \delta$ , would be 0.45.

### **5.3.2 Driven Steel H-Piles**

Steel H-piles could be used for support of the arch culvert extensions. The piles should be driven into the very stiff portion of the clayey silt deposit below Elevation 207 m in the borehole on the east side of the highway. For preliminary design, a tip elevation of about 205 m may be assumed which results in approximately 15 m long piles assuming that the new pile caps are placed at about Elevation 220.5 m to 220 m.

For preliminary design, and subject to confirmation following the detailed design stage of subsurface investigation, the factored axial resistance at ULS for steel HP 310 x 79 piles driven to

a tip elevation of 205 m may be taken as 250 kN. The corresponding axial resistance at SLS for 25 mm of settlement may be taken as 200 kN.

Placement of additional fill for the embankment widening will induce consolidation settlement of the clayey silt soils. This consolidation will induce a downward movement of the soils adjacent to the piles, and negative skin friction will develop along the pile shaft. The magnitude of the downdrag load acting on the pile is a function of the skin friction that develops between the pile and the consolidating clayey silt, the surface area of the pile within these deposits, and the settlement induced by embankment loading. The load calculated in this manner is a nominal (unfactored) load. The structural engineer must multiply this load by a load factor of 1.25 and include it as part of the dead load effects acting on the pile, as described in the OHBDC. For preliminary design, the negative skin friction load on a single pile may be taken as 100 kN. The downdrag load will have to be reassessed during the detailed design stage, using shear strength and consolidation data which should be determined at the extension locations.

Lateral loading could be resisted fully or partially by the use of battered piles. If vertical piles are used, the resistance to lateral loading will have to be derived from the soil in front of the piles. The resistance to lateral loading in front of the pile may be calculated using subgrade reaction theory where the coefficient of horizontal subgrade reaction,  $k_h$ , for the clayey silt soils is based on the following equation:

$$k_h = \frac{k_{s1}}{5B} \quad \text{where } B \text{ is the pile diameter (m) and } k_{s1} \text{ is the coefficient of horizontal subgrade reaction, as given below.}$$

The following ranges for the value of  $k_{s1}$  may be assumed in the structural analysis; these values will have to be confirmed following the detailed design stage of subsurface investigation.

<i>Soil Unit</i>	<i>k<sub>s1</sub></i>
Clayey silt between Elevation 220.5 m and 218 m	25 to 60 MPa/m
Clayey silt between Elevation 218 m and 208 m	10 to 20 MPa/m
Clayey silt below Elevation 208 m	25 to 60 MPa/m

Group action for lateral loading should be considered when the pile spacing in the direction of the loading is less than six to eight pile diameters. Group action can be evaluated by reducing the coefficient of lateral subgrade reaction in the direction of loading by a reduction factor,  $R$ , as follows:

<i>Pile Spacing in Direction of Loading (d = Pile Diameter)</i>	<i>Subgrade Reaction Reduction Factor, R</i>
8d	1.00
6d	0.70
4d	0.40
3d	0.25

## **5.4 Foundation Options for Culvert at Station 17+820**

The existing culvert at Station 17+820 is a closed concrete box with channel invert at about Elevation 253.1 m to 252.5 m. The soils below this level, as encountered in Boreholes C-5 and C-6, consist of an extensive deposit of clayey silt that ranges in consistency from firm to very stiff. Based on these subsurface conditions, the use of box culvert extensions or a box culvert replacement placed at shallow depth is considered suitable at this site.

It should be noted that construction of the widened portions of the Highway 400 embankment will induce differential settlement between the existing box culvert and its extensions. In addition, the existing portions of the culvert which are beneath the present embankment side slopes will undergo further settlement due to the superimposed load of the widened portion of the embankment. Suitable construction joints will be required to accommodate the anticipated settlements of the existing culvert and its extensions.

### **5.4.1 Box Culvert Foundations**

For the box culvert extensions placed on the undisturbed clayey silt deposit at or below Elevation 251.5 m to 251 m, a factored geotechnical resistance at ULS of 200 kPa may be used for preliminary design.

The settlement of the box culvert extensions will be dependent on the culvert size and applied loads. The majority of the settlement of the extensions will occur due to consolidation of the founding soils under the widened embankment loading. For a 3.5 m high embankment widening, it is estimated that up to 50 mm of consolidation settlement of the clayey silt deposit could occur; this would affect both the extensions and the ends of the existing box culvert. For preliminary design purposes, the geotechnical resistance at SLS may be taken as 150 kPa; however, it should be noted that the settlement of the culvert will be up to 50 mm due to the embankment loading, as noted above. The settlement and the SLS resistance should be reviewed at the detailed design stage, once the embankment and culvert configuration and loadings are established. Additional field and laboratory testing should be carried out to determine compressibility characteristics of the subsoils to refine the settlement predictions.

Resistance to lateral forces / sliding resistance between the concrete footing and the subsoils should be calculated in accordance with Section 6-8.4.3 of the OHBDC. The angle of friction between the concrete footings and the undisturbed sand and silt till founding soil should be taken as 25 degrees; the corresponding coefficient of friction,  $\tan \delta$ , would be 0.45.



## **5.5 Foundation Options for Culvert at Station 23+010**

The existing culvert at Station 23+010 is a closed concrete box with channel invert at about Elevation 258.5 m to 257.5 m. The soils below this level, as encountered in Boreholes C-7 and C-8, consist of compact to very dense sand and silt till. Based on these subsurface conditions, the use of box culvert extensions, or a box culvert replacement if rehabilitation of the existing structure is not feasible, placed at shallow depth is considered suitable at this site.

The excavation for culvert extensions or replacement will extend to about Elevation 258 m to 257 m, up to 3.5 m below the highest measured water level at the site. There will be a requirement for groundwater control / foundation protection measures to permit excavation within the granular till, without having an adverse impact on the existing box structure and to maintain the integrity of the founding soils for the extensions. Given the relatively fine-grained nature of the sand and silt till at this site, eductor wellpoints placed at close spacing would be required for lowering of the groundwater level. Alternatively, depending on the water level existing at the time of construction, it may be feasible to carry out the excavation to the founding level in short sections with immediate placement of a mudcoat after reaching the founding level. This alternative should be assessed further at the final design stage once the extent of culvert lengthening is established.

### **5.5.1 Box Culvert Foundations**

For the box culvert placed on the undisturbed sand and silt till at or below Elevation 258 m and 257 m on the east and west sides of Highway 400, respectively, a factored geotechnical resistance at ULS of 425 kPa may be used. For preliminary design purposes, the geotechnical resistance at SLS may be taken as 350 kPa.

Resistance to lateral forces / sliding resistance between the concrete footing and the subsoils should be calculated in accordance with Section 6-8.4.3 of the OHBDC. The angle of friction between the concrete and the undisturbed sand and silt till founding soil should be taken as 26 degrees; the corresponding coefficient of friction,  $\tan \delta$ , would be 0.48.

## **5.6 Bedding and Backfill**

The bedding, backfill and levelling pad requirements for the culvert extensions / replacements should be in accordance with OPSD 803.01 and 803.02. The culvert extensions or replacements should be designed for the full overburden pressure and live load, assuming an embankment fill unit weight of 21 kN/m<sup>3</sup>.

The culverts should be provided with at least 400 mm of OPSS Granular 'A' bedding. The bedding should be compacted to at least 95 per cent of the Standard Proctor maximum dry density (provided that proper groundwater control is in place where necessary, to avoid "pumping" of water into the fill during compaction).

Backfill to the culvert walls should consist of granular fill meeting the specifications for OPSS Granular 'A' or Granular 'B', Type II (but with less than 5 per cent passing the 200 sieve). The backfill should be placed in lifts not exceeding 200 mm loose thickness and compacted to 95 per cent Standard Proctor dry density. The fill depth during placement should be maintained equal on both sides of the culvert with one side not exceeding the other by more than 400 mm.

## **5.7 Lateral Earth Pressures**

The lateral pressures acting on the culvert extensions / replacements will depend on the type and method of placement of the backfill materials, on the nature of the embankment fill behind the backfill, on the magnitude of surcharge including construction loadings, and on the subsequent lateral movement of the structures. The following recommendations are made concerning the design of the walls, in accordance with the OHBDC:

- Select free-draining granular fill meeting the specifications of OPSS Granular 'A' or Granular 'B' but with less than 5 per cent passing the 200 sieve should be used as backfill behind the walls. This fill should be compacted in loose lifts not greater than 200 mm in thickness to 95 per cent of the material's Standard Proctor maximum dry density, in accordance with OPSS 501. Longitudinal drains and weep holes should be installed to provide positive drainage of the granular backfill. Other aspects of the culvert granular backfill requirements with respect to sub-drains and frost taper should be in accordance with OPSD 803.010 and 803.02.
- A compaction surcharge equal to 16 kPa should be included in the lateral earth pressures for the structural design of the culvert, in accordance with OHBDC Figure 6-7.4.3. Compaction equipment should be used in accordance with OPSS 501.06.
- The granular fill may be placed either in a zone with width equal to at least 1.5 m behind the back of the walls (Case I from OHBDS Figure 6-7.4.1) 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 footing (Case II from OHBDC Figure 6-7.4.3).

- For Case I, the pressures are based on the existing and proposed embankment fill materials and the following parameters (unfactored) may be assumed:

Soil unit weight:	20 kN/m <sup>3</sup>
Coefficients of lateral earth pressure:	
Active, $K_a$	0.35
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:

	<b>Granular 'A'</b>	<b>Granular 'B'</b> <b>Type II</b>
Soil unit weight:	22 kN/m <sup>3</sup>	21 kN/m <sup>3</sup>
Coefficients of lateral earth pressure:		
Active, $K_a$	0.27	0.31
At rest, $K_o$	0.43	0.47

- If lateral yielding of the culvert walls is allowed, active earth pressures may be used in the design of the structure. If the culvert support / wall does not allow lateral yielding, at-rest earth pressures should be assumed for design.

It should be noted that the above design recommendations and parameters assume level backfill and ground surface behind the culvert walls. Where there is sloping ground behind the walls (i.e. sloping upwards away from the culvert), the coefficient of lateral earth pressure must be increased to account for the slope.

## 5.8 Erosion Protection

Erosion protection should be provided to the culverts as appropriate. Consideration could be given to use of suitable non-woven geotextiles and rip-rap to provide erosion protection based on hydraulic requirements. The soils at the invert level of the rigid frame culvert consist of soft to stiff clayey silt which would be classified as medium to high scourability. The firm to stiff clayey silt at the arch culvert invert level would be classified as low to medium scourability.

An upstream clay seal and / or a cut-off wall should be provided to control seepage through the bedding below the box culverts. The material specification for a clay seal should be in accordance with the requirements of OPSS 1205. In addition, sediment control such as silt fences and / or erosion control blankets may be required during construction and diversion of the rivers, creeks or ditches, to mitigate migration of fine soil particles into the water courses.

## **5.9 Construction Considerations**

### **5.9.1 Groundwater and Surface Water Control**

At the Holland River culvert, a dewatering scheme will be necessary to facilitate footing / pile cap excavation and concrete placement in dry conditions. In this regard, the groundwater level should be lowered to at least 0.5 m below the founding level prior to excavation and construction of the footings or pile caps. Alternatively, interlocking steel sheeting may be driven around the foundation areas to a depth below founding level equal to the height of the groundwater above the founding level. A cut-off to groundwater inflow may be achieved if the sheet piling is driven into the clayey silt deposit which was encountered below about Elevation 211.5 m. It must be ensured that a full enclosure is achieved around the footing / pile cap area in order for the steel sheeting option to provide the required groundwater control.

At the concrete box culvert at Station 23+010, measures will be required to ensure that the sand and silt till founding soils are not disturbed due to upward seepage through the deposit during excavation, which will extend up to 3.5 m below the groundwater level. Due to the fine-grained nature of the deposit, groundwater lowering may not be feasible. Consideration could be given to carrying out the excavation in short sections with placement of a lean concrete mud coat immediately after reaching the founding level.

At the other two culvert sites, groundwater seepage should be expected during excavation, particularly where water-bearing fill or native soils are present. In general, pumping from properly-filtered sumps or a filtered drain placed at the base of the excavation should provide sufficient groundwater control during foundation works. The creek / ditch waters may have to be diverted in order to permit construction in the dry.

### **5.9.2 Excavation**

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. The following table summarizes the expected soils, OHSA soil types, and temporary open-cut slope configurations. Where space restrictions dictate, in particular adjacent to the existing highway embankment, the footing or pile cap excavations will have to be carried out within a braced excavation.

<i>Culvert Location</i>	<i>Anticipated Soils</i>	<i>OHSA Soil Type</i>	<i>Temporary Cut Slope Configuration</i>
10+065	Embankment Fill	Type 3	2H:1V
	Peat	Type 3	2H:1V
	Soft to Stiff Clayey Silt	Type 2	1.5H:1V
	Compact Sand / Silt	Type 2*	1H:1V
13+740	Embankment Fill	Type 3	1.5H:1V
	Firm to Very Stiff Clayey Silt	Type 3	1.5H:1V
17+820	Embankment Fill	Type 3	1.5H:1V
	Firm Clayey Silt	Type 3	2H:1V
23+010	Embankment Fill	Type 3	1.5H:1V
	Compact Sand and Silt Till	Type 2	2H:1V

\* Assuming proper groundwater control is in place.

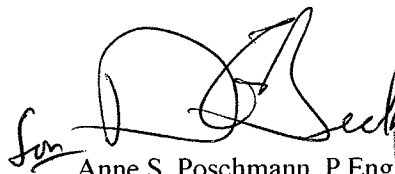
### 5.9.3 Subgrade Protection

It is noted that the soils in which the footing or pile cap excavations will be formed are susceptible to disturbance from ponded water and construction traffic. For protection of the founding soils, a working mat of lean concrete should be placed as soon as practical after reaching the base of the excavation and following inspection by qualified geotechnical personnel. This mat could be 150 mm thick and could serve as the bedding for the culvert provided drainage under the culvert is not required and provided that an adequate level surface can be achieved with the lean concrete. Where drainage is required or where additional levelling is required, granular bedding should be provided.

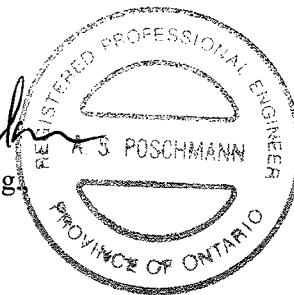
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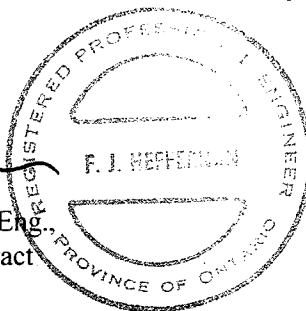
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## LIST OF ABBREVIATIONS

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.)

#### (b) Cohesive Soils

Consistency	$c_u, s_u$	psf
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

#### 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 <sub>4</sub>	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.

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## 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 stresses (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 (con't.)

$w$	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)

#### (c) 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

#### (d) Consolidation (one-dimensional)

$C_c$	compression index (normally consolidated range)
$C_r$	recompression index (overconsolidated 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	Overconsolidation ratio = $\sigma'_p / \sigma'_{vo}$

#### (e) 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

PROJECT 001-1151

# RECORD OF BOREHOLE No C-1

1 OF 1

METRIC

W.P. 40-00-00

LOCATION N 4878798.4; E 296307.9

ORIGINATED BY PKS

DIST SW HWY 400

BOREHOLE TYPE 162mm Diameter Hollow Stem Augers

COMPILED BY LCC

DATUM Geodetic

DATE December 4, 2000

CHECKED BY ASP

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT      NATURAL MOISTURE CONTENT      LIQUID LIMIT			UNIT WEIGHT  $\gamma$  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)			
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa		WATER CONTENT (%)							
								20   40   60   80   100		w <sub>p</sub> w      w <sub>L</sub>							
								○ UNCONFINED      + FIELD VANE									
								● QUICK TRIAXIAL      x REMOULDED									
218.6	GROUND SURFACE							20	40	60	80	100	10	20	30	2   91   7	
0.0	Sand and Gravel (Fill) Compact Brown Moist		1	SS	13												
217.8			2	SS	15												
0.8	Clayey Silt, trace to some sand, trace gravel (Fill) Firm to stiff Brown Moist		3	SS	7												
216.5																	
2.3	Peat Black		4	SS	14												
	Clayey Silt, some sand Stiff Grey-brown Moist		5	SS	12												
214.9																	
3.7	Sandy Silt, trace clay Compact Grey Wet		6	SS	23												
214.0																	
4.6	Sand, trace gravel, trace silt Compact to very dense Grey Wet		7	SS	17												
			8	SS	56												
211.6																	
7.0	Clayey Silt, trace sand Hard Brown Moist		9	SS	144												
210.4																	
8.2	Sand, trace to some silt to Silty Sand, trace gravel Compact to dense Brown Wet		10	SS	15												
	SPT "N" values are considered to be impacted by blowing sands (See Note 1)																
			11	SS	40												
																</	

Notes:  
1. The borehole was advanced using drilling mud below 4.6m depth (Elev.214.0m). However, some "blow-back" of sands occurred after auger advance. This material was washed out of the hollow stem augers prior to sampling.  
2. The water level in the piezometer was measured at 1.8m depth (Elev.216.8m) on January 18, 2001 and at 1.6m depth (Elev.217.0m) on March 20, 2001. This is approximately coincident with the water level in the Holland River.

ON\_MOT 001-1151.GPJ ON\_MOT.GDT 7/12/01



PROJECT 001-1151				RECORD OF BOREHOLE No C-2				1 OF 1		METRIC			
W.P. 40-00-00				LOCATION N 4878756.0; E 296237.6				ORIGINATED BY PKS					
DIST SW HWY 400				BOREHOLE TYPE 162mm Diameter Hollow Stem Augers				COMPILED BY LCC					
DATUM Geodetic				DATE December 5, 2000				CHECKED BY ASP					
SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT		UNIT WEIGHT $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa		WATER CONTENT (%)			
219.2	GROUND SURFACE												
0.0	Sand and gravel (Fill)		1	SS	13	V	219						7 40 43 10
218.4	Compact Brown Moist		2	SS	10		218						
0.8	Clayey Silt, some sand, trace gravel (Fill)		3	SS	8		217						
217.2	Stiff Brown Moist		4	SS	3		216						
2.3	Peat Black/brown		5	SS	6		215						
	Clayey Silt, trace to some sand		6	SS	9		214						
214.3	Soft to stiff Grey Moist		7	SS	20		213						
4.9	Sand and Silt, trace gravel		8	SS	9		212						
	Loose to compact Grey Wet		9	SS	24		211						
212.0	Clayey Silt with sand, trace gravel		10	SS	49		210						
7.2	Very stiff Grey Moist		11	SS	36		209						
210.5	Sand, trace to some silt to Silty		12	SS	74		208						
8.7	Sand, trace gravel		13	SS	56		207						
	Dense to very dense Grey Wet					206							
204.9						205							
14.3	END OF BOREHOLE												
Note: The water level in the open borehole on completion of drilling was at 2.7m depth (Elev.216.5m).													

ON\_MOT\_001-1151.GPJ ON\_MOT.GDT 7/12/01

PROJECT <u>001-1151</u>		<b>RECORD OF BOREHOLE No C-3</b>		1 OF 1	<b>METRIC</b>
W.P. <u>40-00-00</u>		LOCATION <u>N 4882055.6; E 294769.6</u>		ORIGINATED BY <u>PKS</u>	
DIST <u>SW</u> HWY <u>400</u>		BOREHOLE TYPE <u>108mm Diameter Solid Stem Augers</u>		COMPILED BY <u>LCC</u>	
DATUM <u>Geodetic</u>		DATE <u>December 7 &amp; 8, 2000</u>		CHECKED BY <u>ASP</u>	

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL			
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa							WATER CONTENT (%)		
222.6	GROUND SURFACE																
0.0	Clayey Silt, some sand, trace gravel (Fill)		1	SS	7												
221.8	Firm		2	SS	10												
0.8	Brown/grey		3	SS	6												
	Clayey Silt, trace to some sand, trace gravel		4	SS	27												
	Firm to hard		5	SS	36												
	Grey		6	SS	21												
	Moist		7	SS	26												
			8	SS	15												
			9	SS	11												
			10	SS	8												
			11	SS	9												
			12	SS	8												
			13	SS	24												

ON\_MOT\_001-1151.GPJ ON\_MOT.GDT 7/12/01

PROJECT 001-1151				RECORD OF BOREHOLE No C-4				1 OF 1		METRIC				
W.P. 40-00-00				LOCATION N 4882043.3; E 294714.7				ORIGINATED BY PKS						
DIST SW HWY 400				BOREHOLE TYPE 108mm Diameter Solid Stem Augers				COMPILED BY LCC						
DATUM Geodetic				DATE December 11, 2000				CHECKED BY ASP						
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 kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa						
222.7	GROUND SURFACE													
0.0	Topsoil		1	SS	19									
222.1			2	SS	13									
0.6	Clayey Silt, trace to some sand, trace gravel Stiff to very stiff Brown becoming grey below 1.5m depth Moist		3	SS	15									
			4	SS	17									
			5	SS	30									
			6	SS	20									
			7	SS	14									
			8	SS	14									
			9	SS	17									
			10	SS	14									
			11	SS	22									
211.4	END OF BOREHOLE													
11.3	Notes: 1. The water level in the open borehole on completion of drilling was at 6.1m depth (Elev.216.6m). 2. The water level in the piezometer was measured at 1.5m depth (Elev.221.2m) on January 18, 2001, and at 0.9m depth (Elev.221.8m) on March 20, 2001.													

ON\_MOT\_001-1151.GPJ ON\_MOT.GDT 7/12/01

[illegible]

PROJECT <u>001-1151</u>		<b>RECORD OF BOREHOLE No C-6</b>		1 OF 1	<b>METRIC</b>
W.P. <u>40-00-00</u>	LOCATION <u>N 4886046.3; E 294006.2</u>	ORIGINATED BY <u>GPD</u>			
DIST <u>SW</u> HWY <u>400</u>	BOREHOLE TYPE <u>108mm Diameter Solid Stem Augers</u>	COMPILED BY <u>LCC</u>			
DATUM <u>Geodetic</u>	DATE <u>December 13, 2000</u>	CHECKED BY <u>ASP</u>			

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT			PLASTIC NATURAL LIQUID LIMIT MOISTURE CONTENT			UNIT WEIGHT $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL		
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa			W <sub>p</sub>	W	W <sub>L</sub>				
								○ UNCONFINED	+ FIELD VANE	● QUICK TRIAXIAL						× REMOULDED	
253.5	GROUND SURFACE							20 40 60 80 100									
0.0	Topsoil		1	SS	3	▽	253										
252.9							252										
0.6	Clayey Silt, trace sand and gravel Firm to very stiff Brown becoming grey below 4.6m depth Moist		2	SS	4		251										
			3	SS	8		250										
			4	SS	14		249										
			5	SS	20		248										
			6	SS	18		247										
			7	SS	14		246										
			8	SS	12		245										
			9	SS	7		244										
			10	SS	5		243										
			11	SS	8												
242.2	END OF BOREHOLE																
11.3	Note: Water level in open borehole on completion of drilling at 2.7m depth (Elev.250.8m).																

ONL MOT 001-1151.GPJ ONL MOT.GDT 7/12/01

PROJECT 001-1151		<b>RECORD OF BOREHOLE No C-7</b>		1 OF 1	<b>METRIC</b>
W.P. 40-00-00		LOCATION N 4891212.0; E 293386.2		ORIGINATED BY PKS	
DIST SW HWY 400		BOREHOLE TYPE 108mm Diameter Solid Stem Augers		COMPILED BY LCC	
DATUM Geodetic		DATE December 21 & 22, 2000		CHECKED BY ASP	

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			20 40 60 80 100	20 40 60 80 100	W <sub>p</sub>	W	W <sub>L</sub>		
263.5	GROUND SURFACE													
0.0	Topsoil		1	SS	10									
262.9			2	SS	8									
0.6	Sand and Silt, trace clay, trace to some gravel (Till) Loose to very dense Brown to grey brown Moist		3	SS	11									
			4	SS	46									
			5	SS	55									
			6	SS	34									
			7	SS	37									
			8	SS	25									
			9	SS	85									
			10	SS	50									
252.5			11	SS	116/23									
11.0	END OF BOREHOLE													
	Note: The water level in the piezometer was measured at 4.8m depth (Elev.258.7m) on January 18, 2001, and at 2.9m depth (Elev.260.6m) on March 20, 2001.													

ON MOT 001-1151.GPJ ON MOT.GDT 7/12/01

PROJECT 001-1151

# RECORD OF BOREHOLE No C-8

1 OF 1

METRIC

W.P. 40-00-00

LOCATION N 4891222.1; E 293294.1

ORIGINATED BY GPD

DIST SW HWY 400

BOREHOLE TYPE 108mm Diameter Solid Stem Augers

COMPILED BY LCC

DATUM Geodetic

DATE January 4, 2001

CHECKED BY ASP

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT			UNIT WEIGHT  $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL		
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa						
								20 40 60 80 100						
								20 40 60 80 100						
						PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT w <sub>p</sub> w w <sub>L</sub>								
						○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL x REMOULDED			WATER CONTENT (%)					
260.3	GROUND SURFACE													
0.0	Clayey Silt, some sand, trace gravel (Fill) Stiff Brown Moist		1	SS	10		260							
			2	SS	11		259							
258.0			3	SS	12		258							
2.3	Sand and Silt, trace clay, trace gravel (Till) Very loose to very dense Brown becoming gray below 10.7m depth Moist becoming wet below 3m depth		4	SS	48		257							
			5	SS	3		256							
			6	SS	55		255							
			7	SS	42		254							
			8	SS	32		253							
			9	SS	21		252							
			10	SS	40		251							
249.0							250							
11.3	END OF BOREHOLE  Note: Water level in open borehole on completion of drilling at 2.4m depth (Elev.257.9m).													

ON MOT 001-1151.GPJ ON MOT.GDT 7/12/01

DIST HWY 400  
CONT. No.  
GWP No. 40-00-00

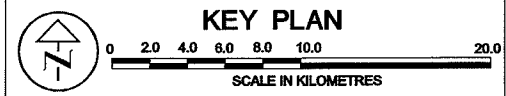
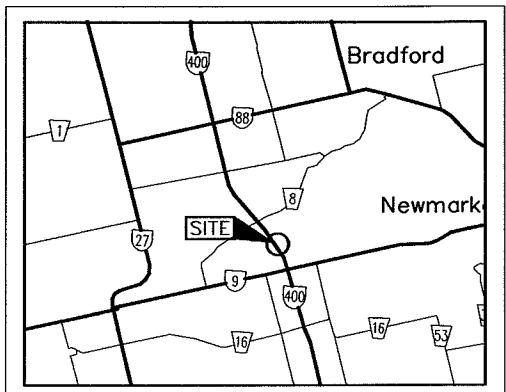


HOLLAND RIVER CULVERT AT  
STATION 10+065 - HWY 400  
BOREHOLE LOCATION PLAN

SHEET



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



LEGEND

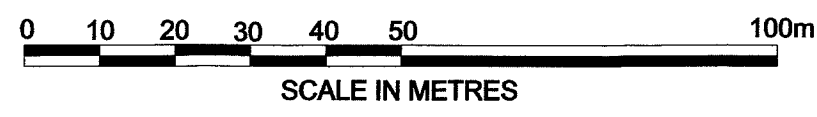
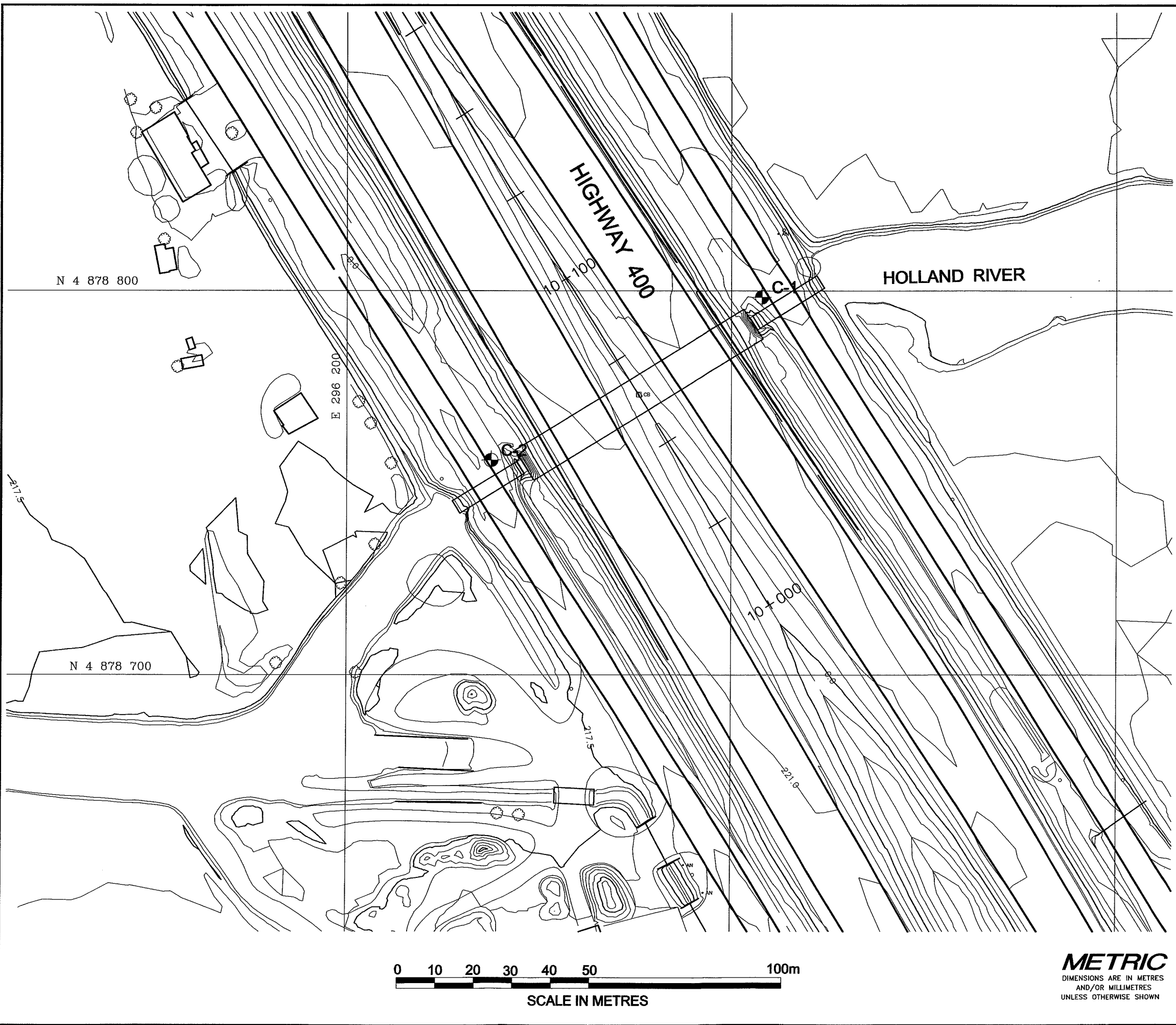
- Borehole, previous investigation
- Borehole, present investigation

No.	ELEVATION	LOCATION	
		NORTHING	EASTING
C-1	218.6	4,878,798.4	296,307.9
C-2	219.2	4,878,756.0	296,237.6

REFERENCE

This drawing was created from digital file "33823.dwg"  
provided by URS Cole Sherman

NO.	DATE	BY	REVISION
Geocres No.			
HWY. No. 400		PROJECT NO.: 001-1151	
SUBM'D. LCC	CHKD: ASP	DATE: JANUARY 2001	SITE
DRAWN: MHW	CHKD. LCC	APPD. ASP	DWG. 1

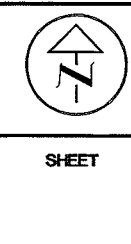


**METRIC**  
DIMENSIONS ARE IN METRES  
AND/OR MILLIMETRES  
UNLESS OTHERWISE SHOWN

P1151010.DWG

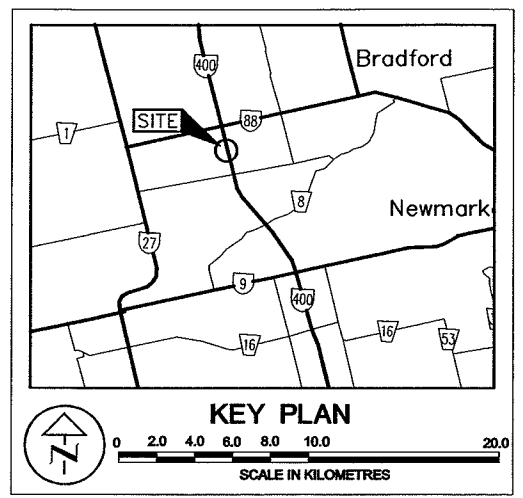




DIST HWY 400  
CONT. No.  
GWP No. 40-00-00  
CULVERT AT STATION 13+740  
HWY 400  
BOREHOLE LOCATION PLAN



**Golder Associates**

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



LEGEND			
	Borehole, previous investigation		
	Borehole, present investigation		
No.	ELEVATION	LOCATION	
		NORTHING	EASTING
C-3	222.6	4,882,055.6	294,769.6
C-4	222.7	4,882,043.3	294,714.7


REFERENCE  
This drawing was created from digital file "33820.dwg"  
provided by URS Cole Sherman

NO.	DATE	BY	REVISION
Geocres No.			
HWY. No. 400		PROJECT NO.: 001-1151	
SUBM'D. LCC	CHKD: ASP	DATE: JANUARY 2001	SITE
DRAWN: MHW	CHKD. LCC	APPD. ASP	DWG. 2



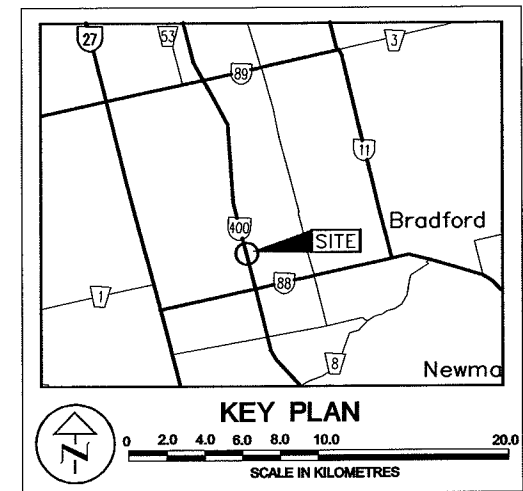
**METRIC**  
DIMENSIONS ARE IN METRES  
AND/OR MILLIMETRES  
UNLESS OTHERWISE SHOWN



P1151007.DWG

DIST HWY 400		
CONT. No.		
GWP No. 40-00-00		SHEET
CULVERT AT STATION 17+820		
HWY 400		
BOREHOLE LOCATION PLAN		



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 MISSISSAUGA, ONTARIO, CANADA

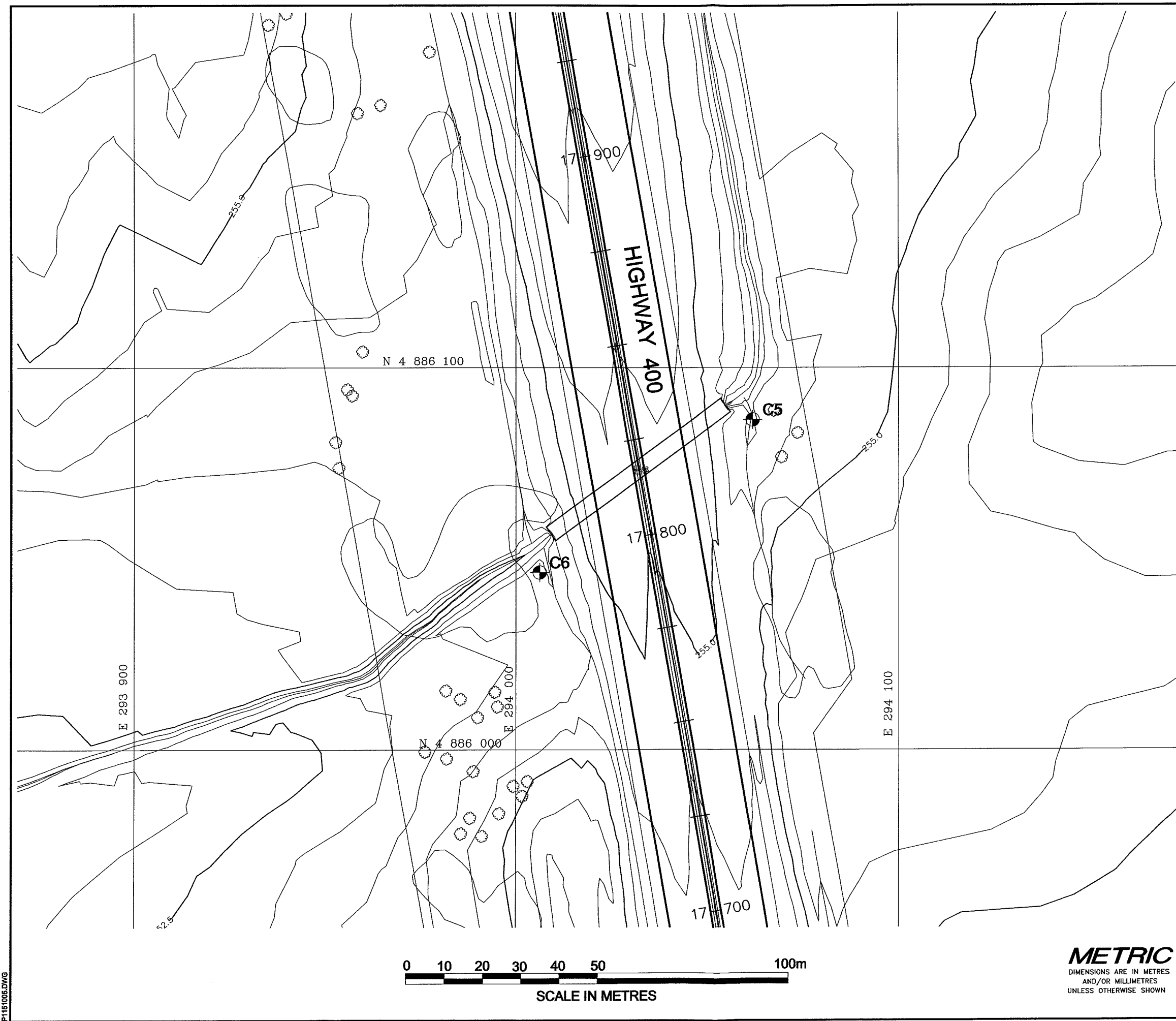


LEGEND			
	Borehole, previous investigation		
	Borehole, present investigation		
No.	ELEVATION	LOCATION	
		NORTHING	EASTING
C-5	254.1	4,886,086.4	294,062.0
C-6	253.5	4,886,046.3	294,006.2

**REFERENCE**

This drawing was created from digital file "33818.dwg" provided by URS Cole Sherman

NO.	DATE	BY	REVISION
Geocres No.			
HWY. No. 400		PROJECT NO.: 001-1151	
SUBM'D. LCC	CHKD: ASP	DATE: JANUARY 2001	SITE
DRAWN: MHW	CHKD. LCC	APPD. ASP	DWG. 3



P1181005.DWG

DIST HWY 400

CONT. No.

GWP No. 40-00-00

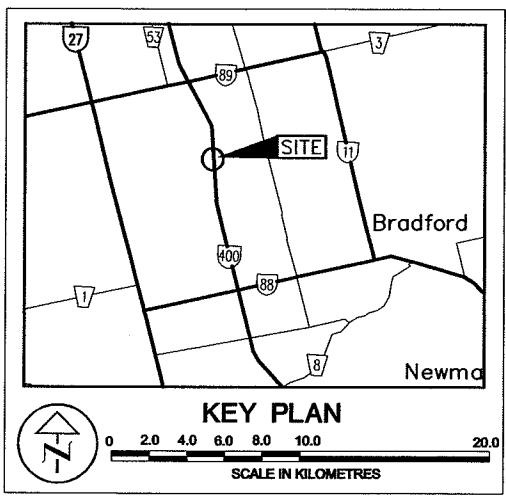
CULVERT AT STATION 23+010

HWY 400


BOREHOLE LOCATION PLAN


SHEET

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LEGEND

 Borehole, previous investigation

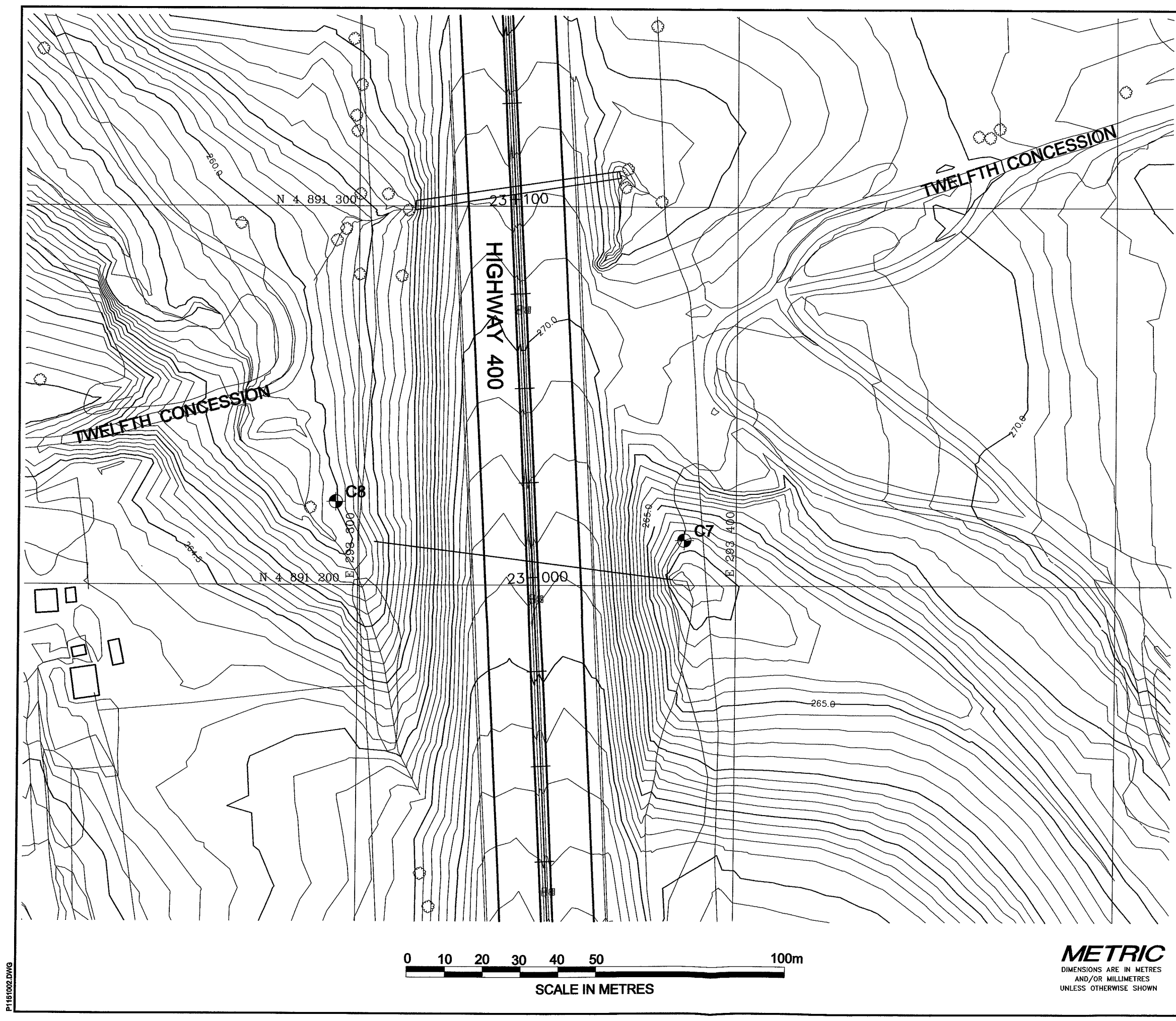
 Borehole, present investigation

No.	ELEVATION	LOCATION	
		NORTHING	EASTING
C-7	263.5	4,891,212.0	293,386.2
C-8	260.3	4,891,222.1	293,294.1

REFERENCE

This drawing was created from digital file "33814.dwg"  
provided by URS Cole Sherman

NO.	DATE	BY	REVISION
Geocres No.			
HWY. No. 400		PROJECT NO.: 001-1151	
SUBM'D.	LCC	CHKD: ASP	DATE: JANUARY 2001 SITE
DRAWN:	MHW	CHKD. LCC	APPD. ASP DWG. 4



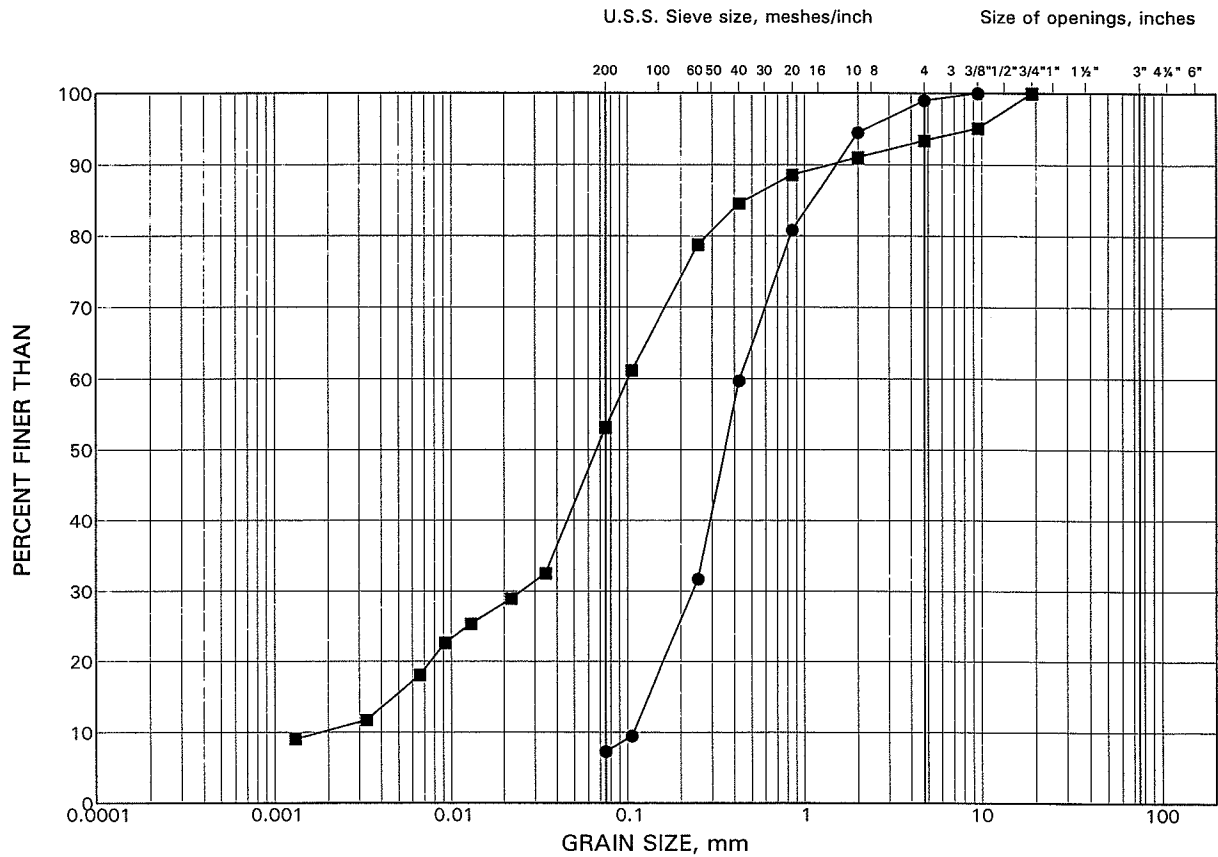
P1151002.DWG

# GRAIN SIZE DISTRIBUTION TEST RESULTS

Holland River Culvert at Station 10 + 065

Sand to Sand and Silt

FIGURE 1



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

## LEGEND

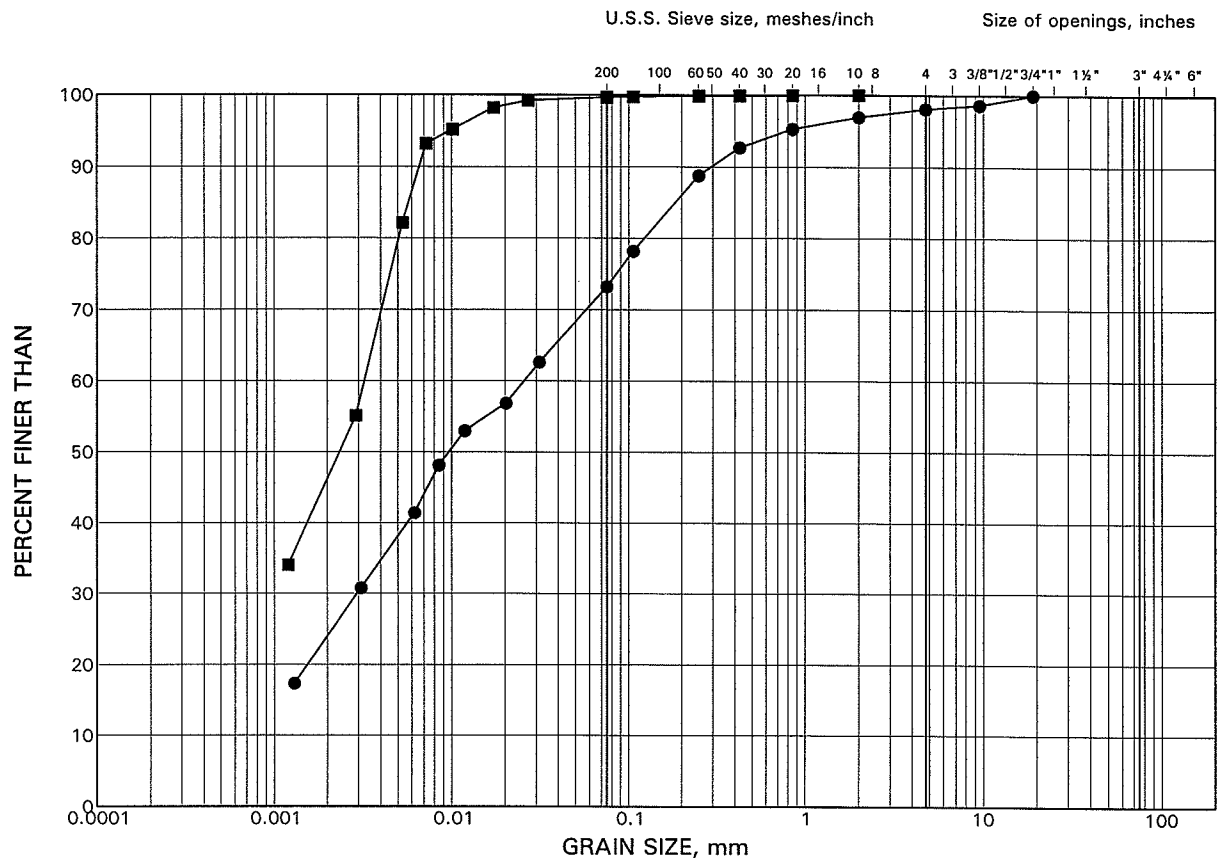
SYMBOL	BOREHOLE	SAMPLE	ELEVATION (m)
●	C-1	7	213.4
■	C-2	7	213.9

# GRAIN SIZE DISTRIBUTION TEST RESULTS

Culvert at Station 13 + 740

Clayey Silt

FIGURE 2



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

## LEGEND

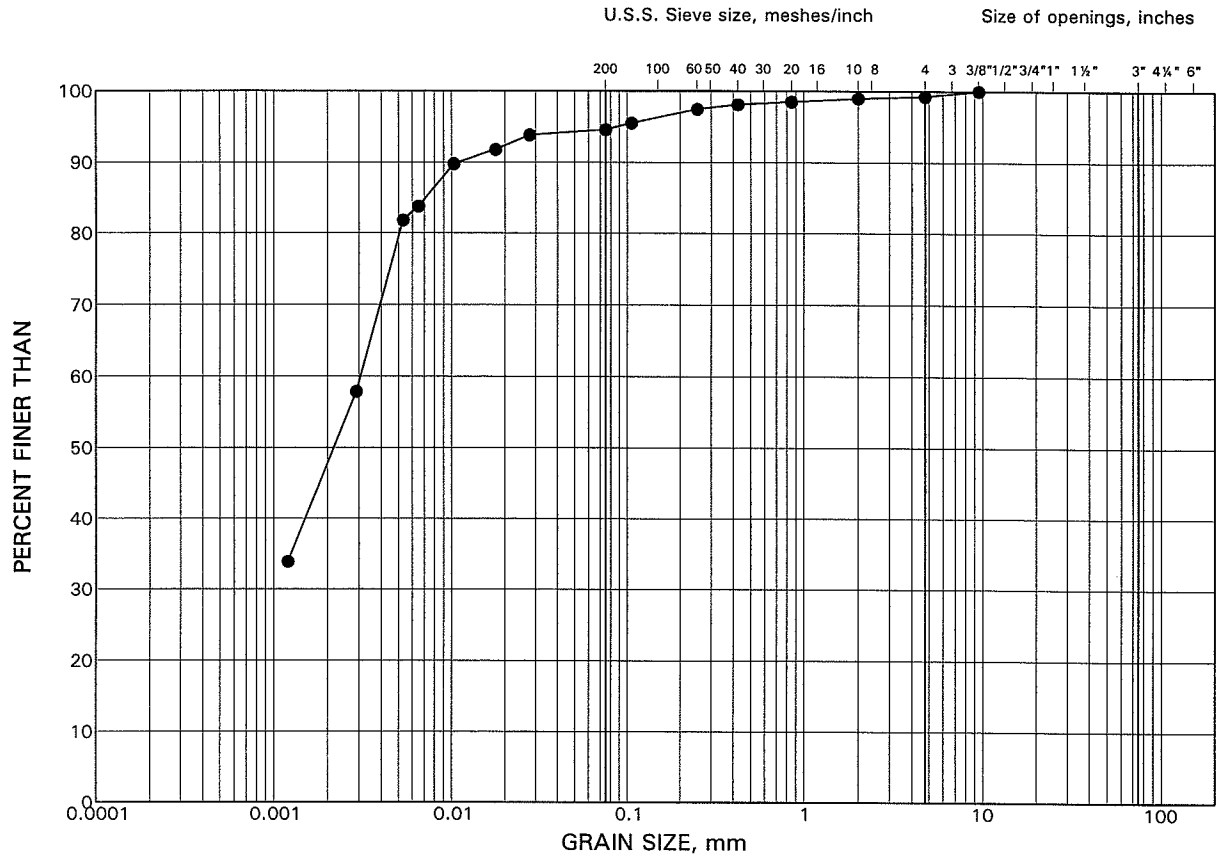
SYMBOL	BOREHOLE	SAMPLE	ELEVATION (m)
●	C-3	6	218.2
■	C-3	10	212.8

# GRAIN SIZE DISTRIBUTION TEST RESULT

Culvert at Station 17 + 820

Clayey Silt

FIGURE 3



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

## LEGEND

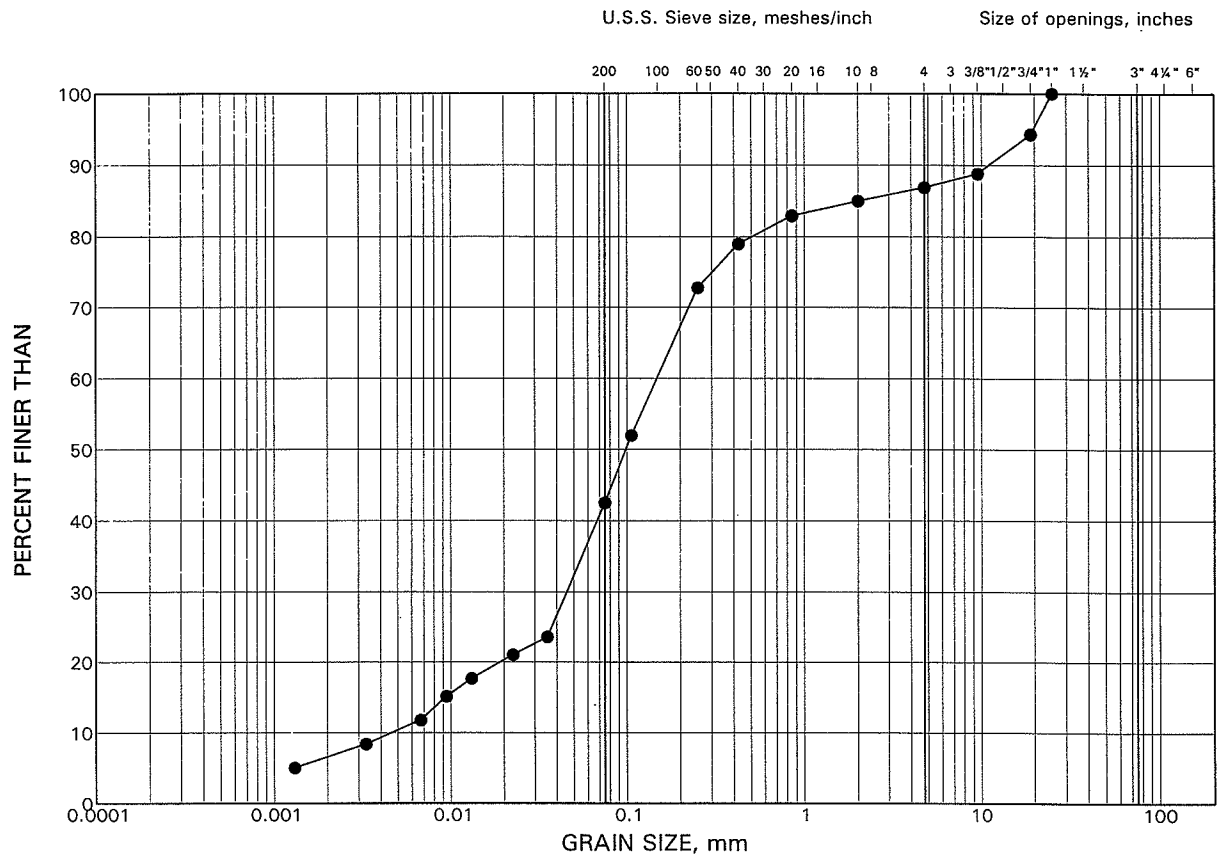
SYMBOL	BOREHOLE	SAMPLE	ELEVATION (m)
•	C-5	4	250.6

# GRAIN SIZE DISTRIBUTION TEST RESULT

Culvert at Station 23 + 010

Sand and Silt Till

FIGURE 4



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

## LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION (m)
•	C-7	6	259.0