Stantec

Foundation Investigation and Design Report

Highway 24
Alder Creek Culvert
Partial Replacement and Rehabilitation
Station 11+650
Township of North Dumfries
Site No. 33-489/C

G.W.P. 3055-03-00

Geocres No. 40P8-197

Project No. 165000768

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FOUNDATION INVESTIGATION REPORT
For
G.W.P 3055-03-00

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1.0 Introduction

Stantec Consulting Ltd. (Stantec) was retained by the Ministry of Transportation, Ontario (MTO) to undertake the detailed design for resurfacing of Highway 24 from 0.3 km north of Glen Morris Road northerly to 0.33 km south of Footbridge Road and from 0.23 km north of Footbridge Road northerly to the south limits of Cambridge. This project also includes the partial replacement and rehabilitation of the existing Alder Creek Culvert (Site No. 33-489-C) at approximate Station 11+650 on Highway 24, south of the Town of Cambridge, in the Township of North Dumfries, Ontario.

This Foundation Investigation Report has been prepared specifically and solely for the partial replacement and rehabilitation of the Alder Creek Culvert.

2.0 Site Description and Geology

Site Location

The site location is shown on the Key Plan inset to Drawing No. 1, provided in Appendix A. The existing Alder Creek Culvert crosses beneath Highway 24 at Station 11+650, approximately 100 m south of Maple Manor Road East.

General Site Description

It is noted that Highway 24 runs approximately north-south at the project location with chainage increasing from south to north. In the vicinity of the culvert, Highway 24 has a two lane rural cross-section with approximately 3 m wide shoulders (see Photo 1 in Appendix A).

Alder Creek flows to the Grand River which is located approximately 80 m west of Highway 24.

A recreational trail (part of the Grand River Trail System) runs along a former railway embankment approximately 25 m west of and parallel to Highway 24. The top of the trail embankment is approximately 4 m wide and has a gravel surface (Photo No. 2 in Appendix A). The trail embankment has side slopes of approximately 2H:1V.

The Alder Creek Culvert extends in an east-west orientation from the east side of Highway 24 to the west side of the recreational trail.

Drainage of the highway is provided via ditches leading to the culvert at the inlet and to an opening in the side of the culvert between Highway 24 and the recreational trail.

At the inlet of the culvert (east end), the Highway 24 paved surface is approximately 3.8 m higher than streambed and the embankment has 2.5H:1V side slopes. At the west side of Highway 24, the embankment is approximately 1.1 m high above the top of the culvert with a side slope of 2H:1V.

The area between Highway 24 and the recreational trail is covered with brush and small trees (see Photos No 1 and 3 in Appendix A).

<u>Existing Culvert</u>

The existing culvert consists of three sections:

1. The original culvert constructed to support the former railway and consisting of a 27.1 m long rigid frame open footing concrete culvert with encased steel beams. This section extends beneath the trail embankment and terminates approximately 1.5 m west of the centerline of Highway 24. This section has an approximate span of 3.1 m and a height of approximately 1.8 m. It is understood that the footings for this culvert are at elevation 252.1 m. This section of the culvert has been identified as requiring replacement.

2. The first extension consisting of an 8.7 m long non-rigid frame open footing concrete culvert which abuts the east (inlet) end of the original culvert.

3. The second extension consisting of a 7 m long concrete rigid frame box culvert constructed in 1990 at the east (inlet) end of the first extension. It is understood that the second extension has a span of 3.05 m and an interior height of 1.85 m.

The approximate alignment of the existing culvert is shown on Drawing No. 1 in Appendix A. Flow in the culvert is from east to west, toward the Grand River.

The outlet of the culvert is visible at the base of the trail embankment on the west side, approximately 2.1 m below the trail surface (see Photo 4 in Appendix A). Signs of erosion and concrete deterioration of the underside of the culvert are visible on the south side of the outlet. A concrete headwall is present at the outlet.

<u>Physiographic Description</u>

The site is located within a physiographic region known as the Waterloo Hills Region (Chapman and Putnam, 1984). In this region, the surface is generally composed of sandy hills, some of them being ridges of sandy till. The extensive area adjoining the hilly regions forms the alluvial terraces of the Grand River spillway. This area is relatively flat and contains similar but more uniform sandy and gravelly materials.

Drainage is generally toward the west toward the Grand River. In the immediate vicinity of the site, drainage is provided via drainage ditches and culverts.

3.0 Method of Investigation

3.1 DRILLING INVESTIGATION

A field investigation consisting of five boreholes was carried out for this assignment. The boreholes were designated BH10-1 through BH10-5 and their locations are shown on the Borehole Location Plan, Drawing No.1 in Appendix A.

Prior to carrying out the investigation, Stantec contacted the public utility authorities to clear the borehole locations of public utilities.

The field drilling program was carried out from November 30 to December 2, 2010. Three boreholes (BH10-1, BH10-2 and BH10-4) were advanced with solid-stem augers using a truck mounted Dietrich D-90 drill rig equipped for soil and bedrock sampling. BH10-3 was advanced with the same drill rig but with a hollow-stem auger. BH10-5 was advanced using portable drilling equipment having drive and flush casing. Both drill rigs were owned and operated by Walker Drilling Ltd. of Utopia, Ontario.

The subsurface stratigraphy encountered in each borehole was recorded in the field by an experienced Stantec Field Technologist. Split spoon samples were collected at regularly spaced intervals (typically every 760 mm) during the course of Standard Penetration Testing (ASTM D1586). All samples recovered were returned to Stantec’s Ottawa laboratory for detailed classification and testing. Boreholes were backfilled with auger cuttings mixed with bentonite and road holes were topped with cold patch asphalt.

3.2 SURVEY

Borehole locations were established in the field by Stantec personnel relative to the centerline of the existing alignment and the existing culvert. The ground surface elevation at each borehole location was surveyed by Stantec personnel with reference to a Geodetic Benchmark provided by MTO. The benchmark was located at the top of the northwest concrete headwall of the outlet at Station 11+650.4, approximately 28.5 m west of Highway 24 centerline. The Geodetic elevation of this benchmark is reported to be 256.029 m. Table 3-1 summarizes the borehole information.

Table 3.1: Borehole Summary

	Boreholes				
	BH10-1	**BH10-2**	**BH10-3**	**BH10-4**	**BH10-5**
MTM Zone 10 Coordinates Northing Easting	 4796848.1 239160.1	 4796840.1 239152.9	 4796841.1 239134.2	 4796851.0 239134.3	 4796851.5 239125.7
Station	11+651.4	11+643.3	11+643.9	11+654.5	11+655.0
Offset	2.0 m RT	5.3 m Lt	24.7 m LT	24.4 m LT	33.2 m LT
Ground Surface Elevation, m	257.5	257.1	256.9	256.9	254.6
Total Depth Drilled, m	9.4	9.8	9.1	8.9	2.9
End of Borehole Elevation, m	248.1	247.4	247.7	248.0	251.7
Depth Augered, m	9.4	9.8	9.1	5.2	2.9
Number of Soil Samples	10	11	10	6*	5
Depth Cored, m	0	0	0	3.7*	0

*Three NQ-size cores were retrieved from a boulder(s) in addition to the six soil samples within the overburden.

3.3 LABORATORY TESTING

All samples were taken to our Ottawa laboratory where they were subjected to a detailed visual examination by a Geotechnical Engineer. Selected soil samples underwent plasticity testing (2 samples), gradation analysis (16 samples) and moisture content testing (21 samples). Two samples were submitted to Parcel Laboratories of Ottawa for analysis of pH, soluble sulphate content, chloride content and resistivity.

Samples remaining after testing will be placed in storage for a period of one year after issuance of the final report. After the storage period, the samples will be discarded unless we are directed otherwise by MTO.

4.0 Subsurface Conditions

4.1 SUBSURFACE PROFILE

The subsurface conditions observed in the boreholes are presented in detail on the Borehole Records provided in Appendix B. An explanation of the symbols and terms used to describe the Borehole Records is also provided.

In general, the subsurface stratigraphy consisted of a pavement structure over a silty sand with gravel fill material overlying a silty sand with gravel to silty gravel with sand till deposit.

Borehole location plans and stratigraphic sections of the soils encountered within the boreholes are provided on Drawing No. 1 and 2 in Appendix A.

4.1.1 Pavement Structure

The pavement structure observed in Borehole BH10-1 consisted of the following

HM Asphalt	200 mm
PCC Concrete	150 mm
Base Gravel	none observed

The shoulder granular fill material observed in Borehole BH10-2 was 0.9 m thick. A grain size distribution test was carried out on a sample of the shoulder granular fill, indicating the following composition

- 32% Gravel
- 58% Sand
- 10% Fines (silt and clay size particles)

This material is classified as well-graded sand with silt and gravel (SW-SM); a grain size distribution curve is presented on Figure 1 in Appendix C.

4.1.2 Highway Embankment Fill

The highway embankment fill extends to 4.0 m below the road profile (to elevation 253.1 m to 253.4 m) and generally consists of silty sand with gravel (SM).

The results of moisture content and grain size distribution tests carried out on the highway embankment fill are summarized below.

- 0 to 34% Gravel
- 42 to 51% Sand
- 24 to 55% Fines (silt and clay size particles)
- Moisture Content 8 to 27%

The higher moisture content and fines content observed are associated with a sandy silt pocket noted in BH10-2. The grain size distribution curves are plotted on Figure 2 in Appendix C.

Standard Penetration Test (STP) N-values observed within the highway embankment fill ranged from 4 to 35 blows per 0.3 m suggesting variable states of compactness ranging from loose to dense.

Atterberg limits tests on one representative sample from the embankment fill indicated that the fill was non-plastic.

Organic Layer

It is noted that an approximately 100 mm thick layer of organic material consisting of dark brown sandy silt with plant remains was encountered beneath the shoulder granular fill in BH10-2 and immediately beneath the embankment fill in BH10-1 and BH10-2. Moisture content testing on one sample of this material yielded a value of 48%. The latter organic material was likely left in place during the placement of the embankment.

4.1.3 Granular Railway Ballast

Approximately 1.0 m of granular fill associated with the former railway was encountered beneath the recreational trail in BH10-3 and BH10-4 (extending to elevation 255.7 m to 256.0 m). One SPT N-value measurement in this layer indicated 39 blows per 0.3 m, suggesting a dense state. One representative sample obtained from this layer revealed the following:

- 59% Gravel
- 33% Sand
- 8% Fines (silt and clay size particles)
- Moisture content 4%

According to USCS, the material can be classified as poorly graded gravel with silt and sand (GP-GM). The grain size distribution test result for this material is provided in Figure 3 in Appendix C.

4.1.4 Recreational Trail Embankment Fill

Embankment fill material was encountered immediately beneath the railway ballast in BH10-3 and BH10-4. The thickness of the embankment fill was 1.4 to 2.2 m (extending to elevation 253.8 m to 254.3 m). The SPT N-values for this layer ranged between 5 and 17 blows per 0.3 m suggesting a loose to compact state. Three representative soil samples retrieved from this layer revealed the following results:

- 0% to 4% Gravel
- 20 to 36% Sand
- 61 to 80% Fines (silt and clay size particles)
- Moisture Content 14 to 18%

The material can be classified as sandy silt with gravel (ML). The grain size distribution test results for this material are provided in Figure 4 in Appendix C.

An Atterberg Limits test conducted on one cohesive sample from this fill layer indicated a plasticity index of 8% suggesting low plasticity (Figure 6 in Appendix C).

4.1.5 Topsoil

Approximately 300 mm of brown sandy silt topsoil was encountered at the ground surface in BH10-5. The bottom elevation of the topsoil was approximately 254.3 m. A 100 mm thick sandy silt with organic material was noted beneath the fill in BH10-3. Testing on samples from BH10-3 revealed:

- 0% Gravel
- 44% Sand
- 56% Fines (silt and clay size particles)
- Moisture Content 21 to 24%

4.1.6 Silty Gravel with Sand to Silty Sand with Gravel Till

A deposit of silty gravel with sand (GM) to silty sand with gravel (SM) was encountered beneath the fill layers in BH10-4 and beneath the topsoil and organic layers in BH10-1, BH10-2, BH10-3 and BH10-5. The top elevation of this deposit ranged between 253.0 to 254.3 m. The boreholes penetrated into the till to depths ranging from 2.6 m (BH10-5) to 6.3 m (BH10-4). It is noted that drilling was terminated in this layer at all borehole locations at elevation between 251.7 m and 247.4 m and hence the actual thickness for the till deposit was not established. It is further noted that frequent cobbles and boulders were encountered within this deposit.

The SPT N-values for this deposit ranged between 16 blows per 0.3 m to well over 100 (split-spoon refusal) suggesting a compact to very dense state. Testing on seven representative samples obtained from this layer revealed the following:

- 18 to 56% Gravel
- 31 to 63% Sand
- 12 to 51% Fines (silt and clay size particles)
- Moisture Content 8 to 14%

Representative grain size distribution plots for this material are indicated on Figure 5 in Appendix C.

Two soil samples retrieved immediately beneath the existing fill at the site were submitted to Paracel Laboratories in Ottawa, Ontario, for analysis of pH, water soluble sulphate and chloride concentrations, and resistivity. The analysis results are provided in Table 4.1.

Table 4.1: Results of Chemical Analysis

Borehole No	Sample No.	Depth (m)	pH	Chloride (µg/g)	Sulphate (µg/g)	Resistivity (Ohm-m)
BH10-2	SS6	3.8 to 4.4	7.69	264	9	20.4
BH10-4	SS4	3.1 to 3.7	7.89	30	7	55.6

4.2 BEDROCK

Bedrock was not encountered within the depth of exploration of this investigation.

4.3 GROUNDWATER

Groundwater was encountered in all the boreholes at the time of drilling, between November 30 and December 2, 2010. The observed groundwater levels are summarized in Table 4.2 as “inferred” groundwater level.

Table 4.2: Inferred Groundwater Levels (time of drilling)

Borehole No	Ground Surface Elevation (m)	Groundwater	
		Depth (m)	Elevation (m)
BH10-1	257.5	4.9	252.6
BH10-2	257.1	4.0	253.1
BH10-3	256.9	3.2	253.7
BH10-4	256.9	3.4	253.5
BH10-5	254.6	1.5	253.1

Fluctuations in the groundwater and culvert water level due to seasonal variations or in response to a particular precipitation event should be anticipated.

The water level elevation in the culvert at the inlet (east) and outlet (west) was 254.00 and 253.96 m, respectively, as surveyed on December 3, 2010.

5.0 Closure

A subsurface investigation is a limited sampling of a site. The subsurface conditions given herein are based on information gathered at the specific borehole locations. Should any conditions at the site be encountered which differ from those at the borehole locations, we request that we be notified immediately in order to assess the additional information.

This report has been prepared by Simon Gudina and Paul Carnaffan and reviewed by Raymond Haché and Fred Griffiths.

Respectfully Submitted;

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FOUNDATION DESIGN REPORT
For
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6.0 Discussion

6.1 PROJECT DESCRIPTION & BACKGROUND

Project Purpose/Justification

The culvert at the site consists of three segments, namely, the original 27.1 m long culvert and two subsequent extensions 8.7 and 7 m long, respectively. While the two culvert extensions are in satisfactory condition, the original culvert has been identified as requiring replacement.

Performance of Existing Foundations

The bottom of the culvert near the south side at the outlet displays signs of erosion, undermining and deterioration (see Photo No 4 in Appendix A). In addition, there are some signs of red staining indicative of rusting of the steel beams encased in the original culvert.

No contract documents or foundation investigation and design reports were available for the original culvert section however it is understood that the footings are founded at approximate elevation 252.1 m. Based on the borehole data, it appears likely that the culvert is supported on strip footings bearing on the silty sand with gravel (till) deposit.

Visual inspection of the culvert inlet and outlet at the time of the investigation did not reveal any indications of significant settlement or cracking.

Proposed Structures

It is understood that the two extensions of the existing culvert are in a satisfactory condition and will be retained. However, the joint between the two extensions at the top of the culvert is to be exposed and sealed. Several replacement options were considered for the original 27.1 m long section of the culvert. The replacement options included:

- Replacement of the entire 27.1 m long original culvert with a single closed box or open footing culvert;
- Replacement of the original culvert with two shorter structures, one approximately 13.2 m long culvert from near the centerline of Highway 24, west to the toe of the highway embankment and the other beneath the recreational trail.

- The Highway 24 replacement structure would be either a rigid frame box culvert or a rigid frame open footing culvert.
- The trail structure would be a rigid frame box culvert, a rigid frame open footing culvert, a pedestrian bridge or open bottom steel arch culvert with concrete footings. The bridge would be 4 m wide and have a single span of approximately 13.6 m. The culverts would be approximately 4.9 m wide and 12.7 m long.

Key elevations associated with the proposed culvert replacement are as follows:

Pavement Elevation	257.50 m (approximately near C/L of Highway 24)
Trail Elevation	256.7 m
Invert Elevation	253.21 m
Streambed Elevation	253.66 m
Water Elevation:	254.00 m at time of Foundation Investigation (December 3, 2010)
25 Year Water Level:	254.86 m
Founding Elevation	252.1 m existing 27.1 m long Rigid Frame Open Footing Culvert 252.9 m Proposed Precast Rigid Frame Box Culvert 252.4 m Proposed Rigid Frame Open Footing Culvert Option 254.2 m Proposed Pedestrian Bridge 252.3 m Proposed Open Bottom Steel Arch Culvert with Concrete Footings

The founding elevation for the precast rigid frame box culvert has been determined based on the assumption that the base of the culvert will be 300 mm thick. The founding elevation for the rigid frame open footing culvert has been selected to achieve adequate frost cover below the stream bed.

It is understood that no wingwalls or headwalls will be required for the proposed Highway 24 culvert replacement. The proposed replacement for the trail culvert option is anticipated to include a Retained Soil System (RSS) over the culvert and extending 3 m beyond both sides of the upstream end.

<u>Construction Staging & Detours</u>

It is understood that a short term local road detour is not anticipated for the culvert partial replacement and rehabilitation works.

It is further understood that a one lane traffic condition is acceptable for the brief period required to repair the joint between the two existing culvert extensions.

Two lanes of traffic are to be maintained during the longer duration required for the replacement of the western portion of the Highway culvert. The available Highway 24 cross-section is not sufficient to enable open cut excavation for the culvert replacement with two lanes of traffic. Therefore roadway protection will be required. In addition, the proposed work will require a minor widening of the existing Highway 24 cross-section to the east.

Replacement of the culvert segment beneath the recreational trail will require a temporary closure of the trail. Construction can proceed with open excavation in the trail embankment.

6.2 SOIL SUMMARY

The soil conditions at this site generally consist of fill over compact to very dense glacial till.

For design purposes, the following soil models will be used:

Table 6.1: Geotechnical Model (beneath Highway 24)

Elevation (m)		Soil Type	Design Properties
From	To		
257.5	253.0	FILL: Silty Sand with gravel, loose	Total Unit Weight = 21.0 kN/m^3 Friction Angle, ϕ = 33°
253.0	<248.0	Silty sand with gravel (SM) to silty gravel with sand (GM), compact to very dense, (TILL) Frequent cobbles and boulders	Total Unit Weight = 22 kN/m^3 Friction Angle, ϕ = 38º E' = 150 MPa

Table 6.2: Geotechnical Model (beneath recreational trail)

Elevation (m)		Soil Type	Design Properties
From	To		
257.0	256.0	FILL: Gravel with silt and sand, compact	Total Unit Weight = 22.0 kN/m^3 Friction Angle, ϕ = 38°
256.0	254.0	FILL: Sandy silt (ML), loose to compact	Total Unit Weight = 19.0 kN/m^3 Friction Angle, ϕ = 30°
254.0	252.5	Sandy silt with gravel (ML), compact (TILL)	Total Unit Weight = 21.5 kN/m^3 Friction Angle, ϕ = 32º E' = 20 MPa
252.5	<248.0	Silty sand with gravel (SM) to silty gravel with sand (GM), dense to very dense (TILL) Frequent cobbles and boulders	Total Unit Weight = 22.0 kN/m^3 Friction Angle, ϕ = 38º E' = 150 MPa

Note: A design water level corresponding to the 25 year water level of 254.86 m will be used.

6.3 SEISMIC DESIGN CONSIDERATIONS

It is recommended that a Soil Profile I as defined in CHBDC (CHBDC, 2006) Section 4.4.6 be used in the seismic design of this site.

Table A3.1.1 of the CHBDC indicates that the Zonal Acceleration Ratio (ZAR) for Cambridge, Ontario, is 0.05. A seismic hazard calculation for the site was obtained from Natural Resources Canada (copy attached in Appendix F). It indicates that for this site, the peak ground acceleration (PGA) value corresponding to 10% exceedance in 50 years is 0.062, which is slightly larger than the ZAR for Cambridge. Hence, ZAR of 0.062 should be used for this site.

Even though it is not likely very significant, seismically induced lateral earth pressures should be considered for this project with a Zonal Acceleration Ratio of 0.062.

Liquefaction of the foundation soils is not a concern for this project due to the compact to very dense soil conditions and the relatively low Zonal Acceleration Ratio.

7.0 Structure Foundations

7.1 STRUCTURE/FOUNDATION OPTIONS

It is understood that the following optional structure types are being considered for the culvert partial replacement on this project.

- Rigid Frame Box Culvert
- Rigid Frame Open Footing Culvert
- Pedestrian Bridge Structure (for the trail only)
- Open Bottom Steel Arch with Concrete Footings (for the trail only)

All of the above options are being considered for the recreational trail crossing whereas only the two Rigid Frame Culvert options are being considered at Highway 24. The soil conditions at this site are suitable to support the culvert options and a pedestrian bridge option on shallow foundations.

It is noted that regardless of the option selected, the existing 27.1 m long original culvert is to be removed. This will require excavation down to the existing founding elevation of 252.1 m for all options. This suggests the need for groundwater control as detailed in Section 8.4.

Table 7.1 compares the possible replacement options for the original culvert.

Table 7.1: Comparison of the Replacement Options for the Original Culvert

Option	Advantages	Disadvantages	Relative Cost	Risk/ Consequences
One long culvert from Highway 24 centreline to the outlet	• A single structure / operation required	• Installation of long culvert can be difficult and time consuming • More extensive (deeper and longer duration) unwatering required • Requires ditch inlets into culvert between Highway and trail embankments	Medium	• Possibly exposed culvert section between Highway 24 and trail embankments with accelerated degradation
Two separate short culverts (beneath Highway 24 and the trail)	• Use of shorter precast sections for culvert can reduce construction period • No exposed culvert section between Highway 24 and trail embankments • Both segments independent	• Poorer hydraulic performance	High	• Possible erosion issues between the two embankments
Short culvert beneath Highway 24 and Pedestrian Bridge for the trail	• Use of shorter precast culvert section can reduce construction period • No exposed culvert section between Highway 24 and trail embankments • Pedestrian bridge with prefab trusses will have lower cost and shorter construction period	• Possibly higher maintenance requirements for the pedestrian bridge	Medium	• Possible erosion issues between the two embankments
Short culvert beneath Highway 24 and open bottom steel arch with concrete footings for the trail	• Readymade steel arch sections will have lowest material and installation cost • No exposed culvert section between Highway 24 and trail embankments • Both segments independent		Low	• Possible erosion issues between the two embankments

This comparison would suggest that the replacement should consist of two separate structures. It is noted that from a geotechnical perspective, all options are suitable for this project.

Table 7-2 compares the culvert structure options considered from a foundations design and constructability perspective for the segment to be replaced beneath Highway 24.

Table 7.2: Comparison for Highway 24 Culvert Replacement

Option	Advantages	Disadvantages	Relative Cost	Risk/ Consequences
Precast Rigid Frame Box	• Use of precast sections reduces construction period • Slightly less unwatering volume	• Needs heavy lifting equipment • Does not match adjacent culvert type	Low	
Rigid Frame Open Footing	• Matches adjacent culvert foundations	• Slower construction process • Greater unwatering volume required	High	• Higher risk of unwatering related issues

Table 7.3 compares the foundation options for the segment beneath the recreational trail.

Table 7.3: Comparison for Recreational Trail Options

Option	Advantages	Disadvantages	Relative Cost	Risk/ Consequences
Precast Rigid Frame Box	• Use of precast sections reduces construction period • Slightly less unwatering volume	• Needs heavy lifting equipment • Poorer hydraulic performance • Requires RSS at inlet	Medium	
Rigid Frame Open Footing		• Slower construction process • Greater unwatering volume require • Poorer hydraulic performance • Requires RSS at inlet	High	• Higher risk of unwatering related issues
Pedestrian Bridge on Spread Footing	• Shorter length of footings • Less risk of erosion problems • Higher founding levels are possible	• Possibly higher maintenance requirements	Low	
Open Bottom Steel Arch with Concrete Footing	• Low material and installation cost	• Requires RSS at inlet	Low	

The foundation soils at the site are generally good and can provide adequate support for all options listed in Table 7.2 and Table 7.3 above. Therefore, the lowest cost options should be carried forward for design.

The following design recommendations are provided for:

- 13.2 m long rigid frame box culvert for the segment beneath Highway 24; and

- An open bottom steel arch culvert with concrete footings for the segment beneath the trail. The proposed open bottom arch culvert is approximately 12.7 m long. RSS walls will be included at the inlet.

7.2 FOUNDATION RECOMMENDATIONS

7.2.1 Geotechnical Resistances

The following geotechnical resistances are provided for a variety of cases covering the possible options described above. It is recommended that the replacement culvert(s) be founded on the native glacial tills. In all instances the existing footings must be removed. The excavations should be backfilled with compacted OPSS Granular A. For the Highway 24 rigid frame box culvert, a 200 mm layer of OPSS Granular A should be placed and compacted beneath the culvert for bedding purposes.

For the trail open bottom steel arch culvert, it is anticipated that the spread footings will be founded at the elevation required to provide adequate frost protection. After removal of the existing footing OPSS Granular A will need to be provided as a structural fill pad beneath the footing down to competent till. The edges of the pad should extend at least 300 mm horizontally away from the footing in all directions. The Granular A should be placed within the influence zone of the footing which is defined by a 1:1 line extending down and away from the top of the pad in all directions.

The geotechnical resistances provided in Table 7.4 may be used in the design provided the footings are placed on undisturbed native till or granular bedding over undisturbed native till as described above.

Table 7.4: Recommended Spread Footing Design Parameters

Founding Element	Founding Elev. (m)	Footing Size (m x m)		Factored Geotechnical Resistance at ULS (kPa)	Geotechnical Reaction at SLS (kPa)
		Width (m)	Length (m)		
Hwy 24 Rigid Frame Box Culvert on Till	252.9	3.0 3.5 4.0	13.2	700 800 900	600 500 400
Open Bottom Steel Arch Culvert Footing on Granular A	252.3	1.0 1.2 1.5	12.7	270 280 300	270* 280* 300*

Notes:

(1) In accordance with Section 6.6.1 of the CHBDC, a resistance factor of 0.5 has been applied to calculate the factored geotechnical resistance at ULS.

(2) The geotechnical reaction at SLS typically corresponds to a maximum settlement of 25 mm. Geotechnical reaction at SLS values marked with an asterisk (*) correspond to conditions where the factored geotechnical resistance at ULS is reached prior to

undergoing 25 mm of total settlement. These foundation conditions have been assigned a geotechnical reaction at SLS equal to the factored geotechnical resistance at ULS.

(3) The use of OPSS Granular A material beneath the open bottom steel arch culvert foundation is not for the purpose of achieving high bearing resistances or reactions but rather to ensure that the foundations are supported on a consistent engineered structural fill once the existing footings and embankment fills have been removed from beneath the influence zone of the open bottom arch culvert footings.

7.2.2 Sliding Resistance

The unfactored horizontal resistance of spread footings may be calculated using the following unfactored coefficients of friction:

0.55 between OPSS Granular A and pre-cast concrete

0.45 between silty sand with gravel (till) and cast-in-place concrete

In accordance with Table 6.1 of the CHBDC CAN/CSA-S6-06, a resistance factor against sliding of 0.8 should be applied to obtain the resistance at ULS.

7.2.3 Frost Protection

The design frost penetration depth for foundations, f, at the site is 1.3 m based on OPSD 3090.101. Spread footings should be provided with 1.3 m of earth cover or equivalent insulation for frost protection.

This depth of frost penetration should also be used in the design of frost tapers for the culvert backfill.

7.2.4 Lateral Earth Pressures

7.2.4.1 Lateral Earth Pressures under Static Conditions

Earth pressures will need to be considered in the design of the culvert walls, RSS walls, as well as for roadway protection systems.

Computation of earth pressures should be in accordance with Section 6.9 of the CHBDC. For walls that are designed to allow rotation, active earth pressure may be used for design. For rigidly tied and unyielding structures, the at-rest earth pressure should be used for design. For a rigid frame box culvert, the walls are considered to be unyielding and the at-rest earth pressure should be used for design. The unfactored soil parameters provided in Table 7.5 may be used for design of walls with a horizontal backfill and those provided in Table 7.6 for walls with a 2H:1V backfill. The effects of compaction should be accounted for by applying a compaction surcharge as shown in Figure 6.6 of the CHBDC.

The total active (P_A) and passive (P_P) thrusts can be calculated using the following equations:

$P_A = ½ K_a \gamma H^2$

$P_P = ½ K_p \gamma H^2$

Where H is the height of the wall. Values for K_a, K_p, K_o and γ are provided in Tables 7.5 and 7.6 below. The thrust acts at a point one third up the height of the wall.

Table 7.5: Recommended Non-Seismic Earth Pressure Parameters (Horizontal Backfill)

Parameter	OPSS Gran B Type I	OPSS Gran A and Gran B Type II	Existing Embankment Fill	Sandy Silt with Gravel (Till)	Silty Sand with Gravel (Till)
Bulk Unit Weight, γ (kN/m^3)	21.2	22.0	19.0	21.5	22
Effective Friction Angle	32º	35º	30º	32°	38°
Coefficient of Earth Pressure at Rest (K_o)	0.47	0.43	0.50	0.47	0.38
Coefficient of Active Earth Pressure (K_a)	0.31	0.27	0.33	0.31	0.24
Coefficient of Passive Earth Pressure (K_p)	3.2	3.7	3.0	3.2	4.2

Table 7.6: Recommended Non-Seismic Earth Pressure Parameters (2H:1V Backfill)

Parameter	OPSS Gran B Type I	OPSS Gran A and Gran B Type II	Existing Embankment Fill	Sandy Silt with Gravel (Till)	Silty Sand with Gravel (Till)
Bulk Unit Weight, γ (kN/m^3)	21.2	22.0	19.0	21.5	22
Effective Friction Angle	32º	35º	30º	32°	38°
Coefficient of Earth Pressure at Rest (K_o)	0.47	0.43	0.50	0.47	0.38
Coefficient of Active Earth Pressure (K_a)	0.47	0.39	0.54	0.47	0.33

7.2.4.2 Lateral Earth Pressures under Seismic Conditions

The culvert walls and RSS walls should also be designed to resist the earth pressures induced under seismic loading conditions. The seismic earth pressures may be calculated using the parameters detailed in Tables 7.7 and 7.8 below.

The total active and passive thrusts under seismic loading conditions can be calculated using the following equations:

- $P_{AE} = ½ K_{AE} \gamma H^2 (1 - k_V)$
- $P_{PE} = ½ K_{PE} \gamma H^2 (1 - k_V)$

where:

- K_{AE} = active earth pressure coefficient (combined static and seismic)
- K_{PE} = passive earth pressure coefficient (combined static and seismic)
- H = height of wall

- k_h = horizontal acceleration coefficient
- k_v = vertical acceleration coefficient
- γ = total unit weight

For this site, the following design parameters were used to develop the recommended K_{AE} and K_{PE} values. A site specific Seismic Hazard Calculation sheet prepared by Natural Resources Canada is provided in Appendix F. For transportation structures the PGA value corresponding to a 10% probability of exceedence in 50 years is typically selected.

- Zonal Acceleration Ratio, A or PGA 0.062
- Horizontal Acceleration Coefficient, kh 0.031 yielding 0.093 non-yielding
- Vertical Acceleration Coefficient, kv 0.021 yielding 0.062 non-yielding
- Horizontal Backslope to wall
- Vertical back of wall

The above k_h value corresponds to ½ of the A value for yielding walls and 1.5 times for non-yielding walls. The k_v value corresponds to 0.67 of the k_h value. The angle of friction between the soil and the wall has been set at 0° to provide a conservative estimate.

Table 7.7: Recommended Seismic Earth Pressure Parameters (Horizontal Backfill)

Parameter	OPSS Gran B Type I		OPSS Gran A and Gran B Type II		Existing Embankment Fill		Sandy Silt with Gravel (Till)		Silty Sand with Gravel (Till)	
Bulk Unit Weight, γ (kN/m^3)	21.2		22.0		19.0		21.5		22	
Effective Friction Angle	32º		35º		30º		32°		38°	
	Yielding wall	Non-yielding	Yielding wall	Non-yielding	Yielding wall	Non-yielding	Yielding wall	Non-yielding	Yielding wall	Non-yielding
Active Earth Pressure (K_{AE})	0.33	0.37	0.29	0.33	0.35	0.40	0.33	0.371	0.25	0.29
Height of Application of P_{AE} from base as a ratio of wall height, (H)	0.343	0.362	0.344	0.364	0.342	0.361	0.343	0.362	0.345	0.367
Passive Earth Pressure, (K_{PE})	3.20	3.07	3.63	3.50	2.94	2.82	3.20	3.07	4.14	4.00
Height of Application of P_{PE} from base as a ratio of wall height, (H)	0.323	0.299	0.323	0.300	0.323	0.298	0.323	0.299	0.323	0.301

Table 7.8: Recommended Seismic Earth Pressure Parameters (2H:1V Backfill)

Parameter	OPSS Gran B Type I		OPSS Gran A and Gran B Type II		Existing Embankment Fill		Sandy Silt with Gravel (Till)		Silty Sand with Gravel (Till)	
Bulk Unit Weight, γ (kN/m^3)	21.2		22.0		19.0		21.5		22	
Effective Friction Angle	32º		35º		30º		32°		38°	
	Yielding wall	Non-yielding	Yielding wall	Non-yielding	Yielding wall	Non-yielding	Yielding wall	Non-yielding	Yielding wall	Non-yielding
Active Earth Pressure (K_{AE})	0.53	Note 1	0.43	0.56	0.62	Note 1	0.53	Note 1	0.36	0.45
Height of Application of P_{AE} from base as a ratio of wall height, (H)	0.356	Note 1	0.353	0.399	0.362	Note 1	0.356	Note 1	0.352	0.391
Passive Earth Pressure, (K_{PE})	8.56	8.41	10.76	10.59	7.41	7.28	8.56	8.41	13.81	13.61
Height of Application of P_{PE} from base as a ratio of wall height, (H)	0.325	0.308	0.326	0.309	0.325	0.308	0.325	0.308	0.326	0.310

Note 1 Under seismic conditions these materials are not suitable for retaining wall backslopes constructed at 2H:1V. Either flatter backslopes or the use of OPSS Granular B Type II or Granular A would be required.

7.2.5 Retained Soil System (RSS)

A Retained Soil System (RSS) retaining wall is being considered at the inlet end of the proposed open bottom steel arch culvert to replace the existing G.R.C.A. Recreational Trail culvert. The RSS will be constructed over the inlet side (east side) of the trail culvert (the side nearest Highway 24) and will extend immediately from the face of the steel arch at 30° (in the horizontal plane) away from the face of the culvert in both directions. The proposed length of RSS walls on each side of the arch is 3 m.

Retained soil systems are listed in the Ministry of Ontario (MTO) Designated Sources for Materials (DSM) and under Special Provisions 599S22 and 599S23. The RSS should be tendered with the following attributes:

Application: Wall/Slope

Geometry: Vertical (GV)

Performance: Low

Appearance: Low

Site Specific Geotechnical Considerations

A 300 mm thick Granular A Leveling Pad should be constructed beneath the RSS.

The factured geotechnical resistance at ULS for an RSS wall wider than 1.0 m constructed on the site soils would be 200 kPa. The SLS geotechnical reaction for 25 mm total settlement was estimated to be much greater than 200 kPa for an RSS wall of 3.0 m or less; therefore, an SLS geotechnical reaction of 200 kPa, matching the ULS value, is recommended for design.

The minimum soil cover to the underside of the leveling pad should be 900 mm. The minimum soil cover to the top of the leveling pad should be 600 mm.

Unit weight values and effective friction angles provided in Section 6.2 of this report may be used for design of the RSS.

7.2.6 Embankment Design

A slope stability evaluation was carried out for the reinstatement of the Highway 24 embankment. The evaluation was carried out using a commercial program Slope/W (Geo-Slope, 2010). A traffic load equivalent to 0.8 m of fill has been included in the analyses. Figures 7 and 8 in Appendix E show the static and seismic slope stability analysis results for the proposed slope. The analysis results indicate that the proposed slope of 2H:1V is appropriate if constructed using Select Subgrade Material, Granular A, Granular B I or Granular B II. Reinstatement of the downstream slope of the trail embankment should also be constructed to 2H:1V with a Select Subgrade Material, Granular A, Granular B I or Granular B II.

8.0 Construction Considerations

8.1 CONSTRUCTION STAGING

The partial replacement/rehabilitation of the culvert in this project is anticipated to involve a staged construction. It is understood that a one lane traffic condition is acceptable for the brief period required to repair the joint between the two existing culvert extensions.

Two lanes of traffic are to be maintained during the longer duration required for the replacement of the western portion of the Highway culvert. The available Highway 24 cross-section is not sufficient to enable open cut excavation for the culvert replacement with two lanes of traffic. Therefore roadway protection will be required. In addition, the proposed work will require a minor widening of the existing Highway 24 cross-section to the east.

Replacement of the culvert segment beneath the recreational trail will require a temporary closure of the trail. Construction can proceed with open excavation in the trail embankment.

8.2 EXCAVATION AND BACKFILLING

Excavation and backfill for the new culverts should be carried out in accordance with OPSS 902 Construction Specification for Excavation and Backfilling – Structures.

All vegetation, fill, organic soils and other deleterious materials must be removed from beneath the proposed box culvert foundation. Where deleterious materials are encountered, the material should be excavated, wasted and replaced. The lateral extent of such excavation should include all deleterious material within the influence zone of the foundations.

Side slopes for open cut excavations should conform to the Occupational Health and Safety Act (OHSA) regulations for Construction Projects. The soils encountered at the site may be classified in accordance to the OHSA as follows:

Existing Embankment Fills	Type 3 Soil
Native Till above Water Table	Type 2 Soil
Native Till below Water Table	Type 3 Soil

Generally, it is anticipated that construction requirements for temporary open excavations will include 1H:1V side slopes extending from the base of the excavation.

Grading work for reinstatement of the highway and recreational trail embankments along the existing culvert alignment should be carried out in accordance with OPSS 206 Construction Specification for Grading and SP 206S03. Backfilling of the culvert should be carried in accordance with OPSD 803.010.

Bedding, leveling and cover material for the culverts should consist of OPSS Granular A.

8.3 ROADWAY PROTECTION SYSTEM

It is understood that two traffic lanes are required to be open during the partial culvert replacement for Highway 24. The available embankment width will not allow open cut slopes. Hence, a temporary roadway protection is required along with widening of the pavement at the inlet side.

The roadway protection for the culvert replacement will necessitate excavation below the groundwater levels. As such, unwatering of the excavation will be required for the culvert replacement, and may also be required during installation of the roadway protection system.

The following table compares the available roadway protection options considered for the culvert replacement:

Table 8.1: Comparison of Roadway Protection Systems

Option	Advantages	Disadvantages	Relative Cost	Risk & Consequences
H-Piles with timber lagging; struts/rakers	• simple installation	• more difficult to control unwatering	Low	• No significant risk anticipated
Steel sheet pile (SSP)	• no unwatering required during roadway protection installation	• difficult to drive/install in dense till with frequent cobbles boulders (see Section 4.1.6)	High	• Damage or loss of sheet pile walls during driving

H-piles with Timber Lagging presents itself as the most viable option for roadway protection at the site. This will be supported with struts or rakers from the construction side.

A conceptual drawing showing the location of the roadway protection is provided on Drawing No. 3 in Appendix D.

The contractor will ultimately be responsible to develop and implement a roadway protection system meeting the requirements of OPSS 539, including establishing appropriate geotechnical design parameters.

Shoring design should meet the requirements of Performance Level 2 as per OPSS 539 and should consider traffic loading. Performance Level 2 specifies a Maximum Angular Distortion of 1:200 and a Maximum Horizontal Displacement of 25 mm. Pile and raker spacing must be designed not to exceed these limits. Horizontal movement should be monitored throughout the culvert replacement process as described in OPSS 539. The monitoring requirements outlined in OPSS 539 are considered to be appropriate for this project.

8.4 UNWATERING

Removal of the underside of the existing foundations of the original 27.1 m long culvert will require excavation to 252.1 m or 1.9 m below the water level observed at the time of the investigation and 2.8 m below the 25 year water level.

Control of the water flow in the stream will require a cofferdam or an aquadam to prevent stream flow into the excavations. Given that cobbles and boulders were encountered in the till, an aquadam would provide a less risky option. It is anticipated that creek flow will be diverted using pumps to allow construction of the replacement culverts.

The native soils within the anticipated depth of excavation have a low to moderate hydraulic conductivity. The estimated hydraulic conductivity for the native soil at the site is expected to range from $1x10^{-8}$ m/s (Sandy Silt with Gravel Till) to $1x10^{-5}$ m/s (Silty Sand with Gravel Till). Unwatering of the structure excavations using conventional sump and pump techniques should be adequate.

8.5 EROSION AND SCOUR PROTECTION

Scour protection will be required to ensure the long-term surficial stability of the embankment slopes and adjacent stream banks. All slopes within 3 m of the culvert inlets and outlets should be surfaced with rip-rap at least 300 mm thick placed on a Class II non-woven filter fabric. For the trail crossing, scour protection should also be applied over the stream bed to protect the proposed arch culvert footings; the footing embedment depth may be considered as secondary scour protection.

Normal slope vegetation should be established as soon as possible after completion of the embankment fills in order to control surficial erosion.

The contractor should provide silt fences and erosion control blankets, as required, throughout the duration of the construction to prevent silt/sediments from running off the site.

8.6 CEMENT TYPE AND CORROSION PROTECTION

Two samples of the native soil was submitted to Paracel Laboratories in Ottawa, Ontario for analysis of pH, water soluble sulphate and chloride concentrations, and resistivity. The testing was completed to determine the potential for degradation of the concrete in the presence of soluble sulphates and the potential for corrosion of exposed steel used in foundations and buried infrastructure. The analysis results are summarized in Table 4.1.

The concentration of soluble sulphate provides an indication of the degree of sulphate attack that is expected for concrete in contact with soil and groundwater at the site. The soluble sulphate concentrations for the two samples were 7 and 9 µg/g. Soluble sulphate concentrations less than 1000 µg/g generally indicate that a low degree of sulphate attack is expected for concrete in contact with soil and groundwater. Type GU (General Use) Portland Cement should therefore be suitable for use in concrete at this site.

The pH, resistivity and chloride concentration provide an indication of the degree of corrosiveness of the sub-surface environment. The soil pH values were 7.7 and 7.9 which are within what is considered the normal range for soil pH of 5.5 to 9.0. The pH levels of the tested soil do not indicate a highly corrosive environment. The test results provided in Table 4.1 may be used to aid in the selection of coatings and corrosion protection systems for buried steel objects.

9.0 Specifications

The following specifications are referenced in this report:

Table 9.1: Specifications Referenced in Report

Document	Title
OPSS 206	Construction Specification for Grading
OPSS 539	Construction Specification for Temporary Protection System
OPSD 803.010	Backfill and Cover for Concrete Culverts with Spans Less Than or Equal to 3.0 m
OPSS 902	Construction Specification for Excavation and Backfilling - Structures
OPSD 3090.101	Foundation Frost Depths for Southern Ontario
OPSD 3101.150	Walls, Abutment, Backfill Minimum Granular Requirements
SP 206S03	Earth Excavation, Grading
SP599S22	Retained Soil System, Wall/Slope
SP599S23	Retained Soil System, Wall/Slope

10.0 References

ASTM. 1999. Standard Test Method for Penetration Test and Split-Barrel Sampling of Soils (ASTM D1586). ASTM International, West Conshohocken, PA.

ASTM. 2000. Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System) (ASTM D2487). ASTM International, West Conshohocken, PA.

Chapman, L.J., and Putnam, D.F. 1984. The physiography of Southern Ontario, Ontario Geological Survey Special Volume 2. Ontario Research Foundation, Toronto, Ontario.

CHBDC. 2006. Canadian Highway Bridge Design Code. Canadian Standards Association, Mississauga, Ontario.

Geo-Slope International, Ltd. 2010. GeoStudio 2007 (Slope/W 2007), Calgary, Alberta.

Ontario Ministry of Transportation (MTO). 2007. RSS Design Guidelines. Engineering Standards Branch, St. Catharines, Ontario.

11.0 Closure

A soil investigation is a limited sampling of a site. The conclusions given herein are based on information gathered at the specific borehole locations. Should any conditions at the site be encountered which differ from those at the borehole locations, we request that we be notified immediately in order to assess the additional information and its effects on the above recommendations.

We trust the information presented herein meets your present requirements. Should you have any questions or require additional information, please do not hesitate to contact us.

This report has been prepared by Simon Gudina and Paul Carnaffan and reviewed by Raymond Haché and Fred Griffiths.

Respectfully submitted,

STANTEC CONSULTING LTD.

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Designated Principal MTO Foundation Contact

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APPENDIX A

Drawing No. 1 and 2 – Borehole Location Plan and Soil Strata Plot

Site Photos

METRIC

DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN

PLATE No

CONT WP 3055-03-00

SHEET

HWY 24, CAMBRIDGE, ON

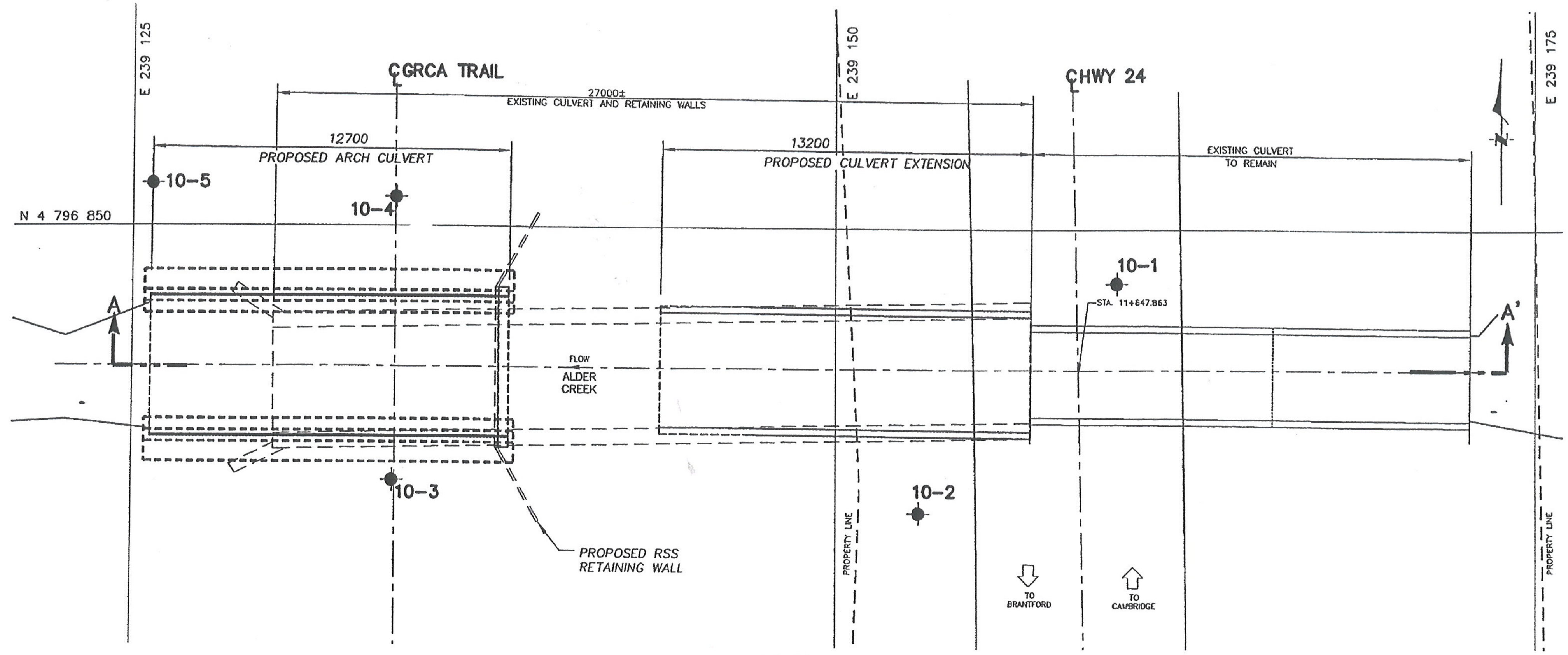
STA TO STA

BOREHOLE LOCATIONS & SOIL STRATA

Stantec

LICENSED PROFESSIONAL ENGINEER — F.J. GRIFFITHS — PROVINCE OF ONTARIO — Oct 14/11

LICENSED PROFESSIONAL ENGINEER — J.G.A.R. HACHÉ — PROVINCE OF ONTARIO — Oct 14/11



PLAN

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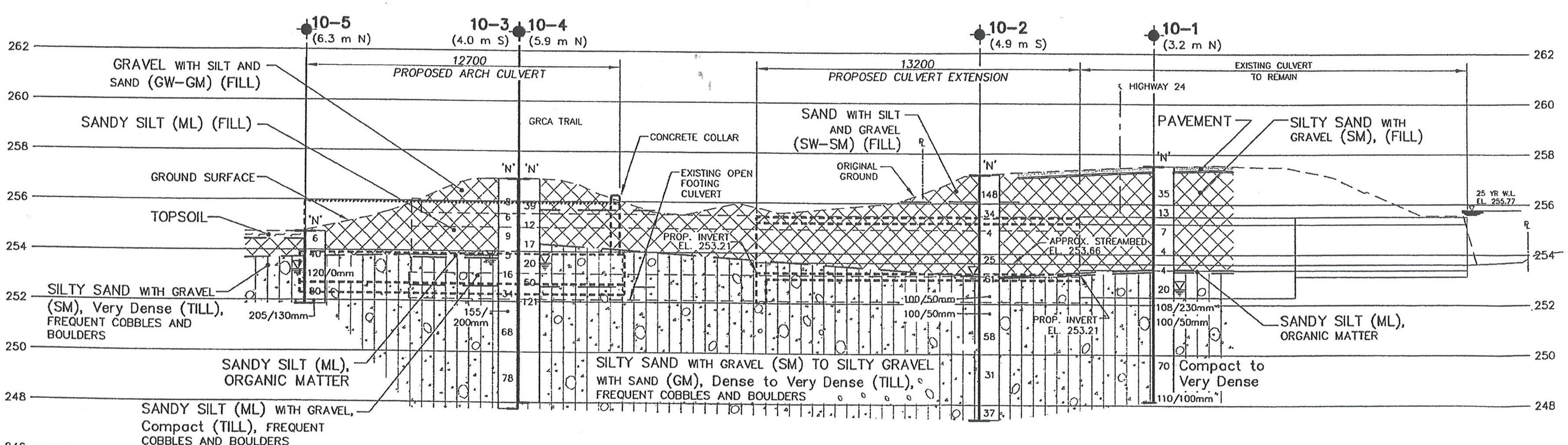

CROSS SECTION A–A'

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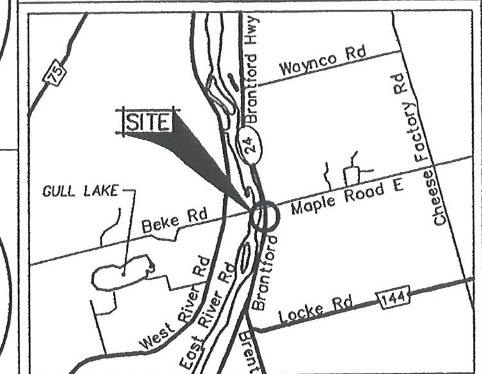


KEY PLAN

1 km 0 1 2 km

LEGEND

⊕	Bore Hole
N	Blows/0.3m (Std Pen Test, 475 J/blow)
▽	WL at Time of Investigation Dec 2010
△ BM	Benchmark (Top NW Corner of Concrete HD Wall, 28.5 LT, STA 11+650.4) Elev. = 256.029 m Geodetic
(3.2 m N)	Offset from Cross Section Line

No	ELEVATION	MTM ZONE 10 COORDINATES NORTH	EAST
10-1	257.5	4 796 848.1	239 160.1
10-2	257.1	4 796 840.1	239 152.9
10-3	256.9	4 796 841.1	239 134.2
10-4	256.9	4 796 851.0	239 134.3
10-5	254.6	4 796 851.5	239 125.7

NOTES

This drawing is for subsurface information only. Surface details and features are for conceptual illustration.

The boundaries between soil strata have been established only at Bore Hole locations. Between Bore holes the boundaries are assumed from geological evidence.

NOTE: The complete foundation investigation and design report for this project and other related documents may be examined at the Engineering Materials Office, Downsview. Information contained in this report and related documents is specifically excluded in accordance with the conditions of Section 102-2 of Form 100.

REVISIONS	DATE	BY	DESCRIPTION

GEOCRES No 40P8-197

HWY No			DIST
SUBM'D SG	CHECKED	DATE 2011/03/07	SITE
DRAWN GBB	CHECKED	APPROVED	DWG 1

DRAWING NAME: 165000768-1 (SEPT).DWG CREATED: GBB MODIFIED: 11/09/15 Printed: Sep 15, 2011

T:\Autocad\Drawings\Project Drawings\2011\165000768\Final (Sept)\165000768-1 (Sept).dwg (PLAN & A-A')

METRIC

DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN

PLATE No

CONT WP 3055–03–00

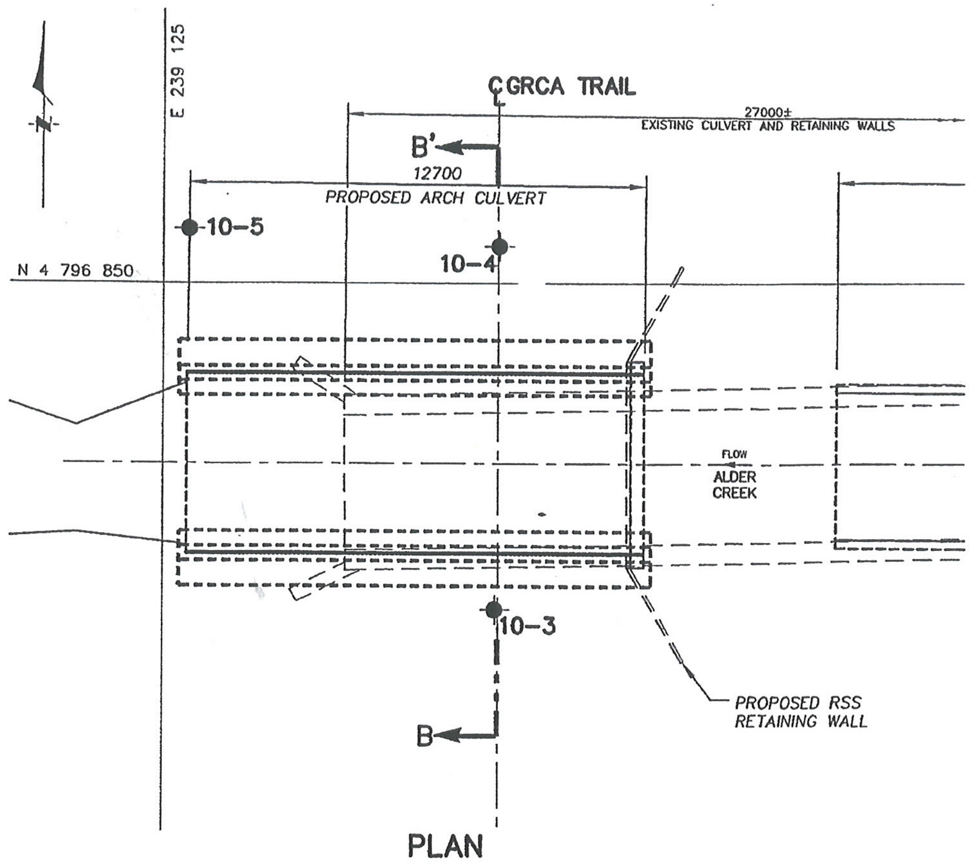
HWY 24, CAMBRIDGE, ON

STA TO STA

SHEET

BOREHOLE LOCATIONS & SOIL STRATA

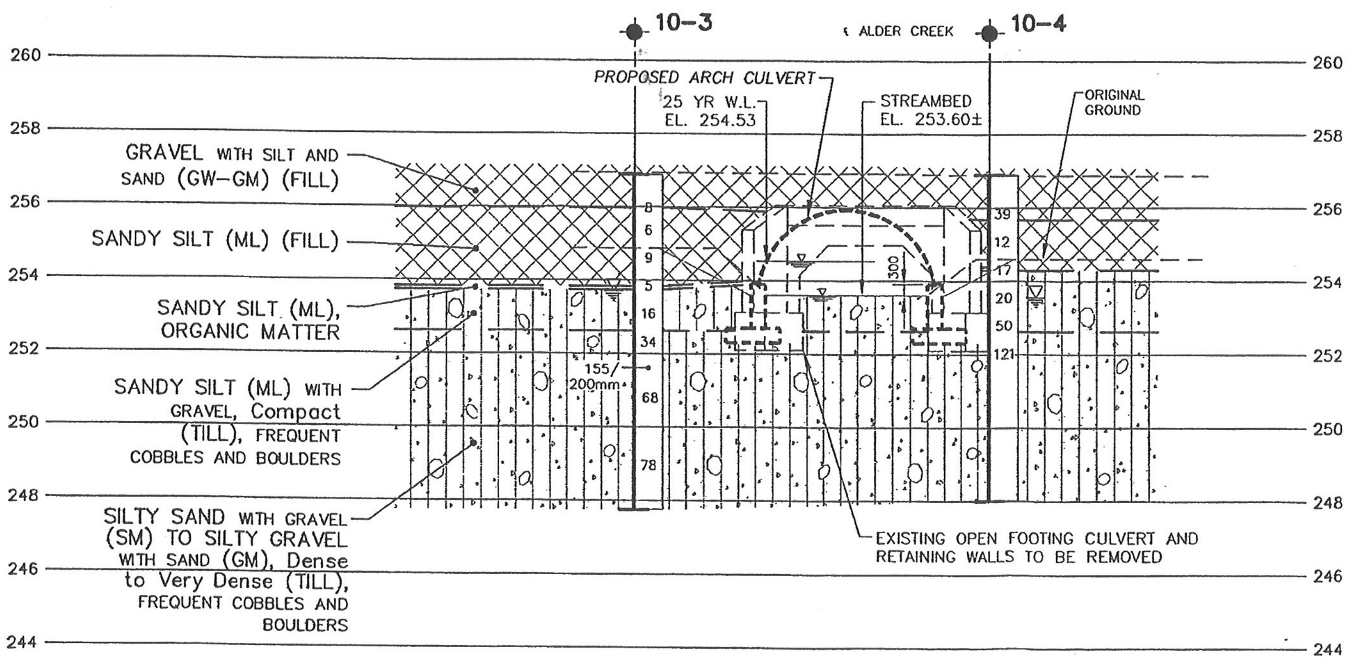
Stantec



PLAN

SCALE

2 m 0 2 4 m



CROSS SECTION B–B'

SCALE

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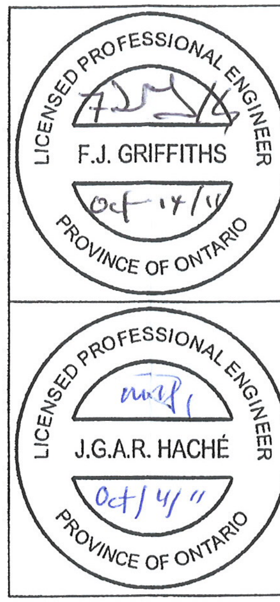

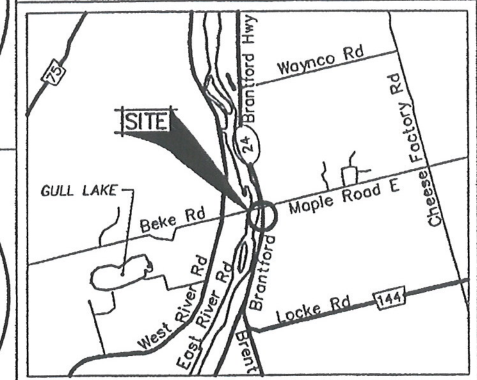

KEY PLAN

1 km 0 1 2 km

LEGEND

- Bore Hole
- N Blows/0.3m (Std Pen Test, 475 J/blow)
- WL at Time of Investigation Dec 2010
- BM Benchmark (Top NW Corner of Concrete HD Wall, 28.5 LT, STA 11+650.4) Elev. = 256.029 m Geodetic

No	ELEVATION	MTM ZONE 10 COORDINATES NORTH	EAST
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10–2	257.1	4 796 840.1	239 152.9
10–3	256.9	4 796 841.1	239 134.2
10–4	256.9	4 796 851.0	239 134.3
10–5	254.6	4 796 851.5	239 125.7

NOTES

This drawing is for subsurface information only. Surface details and features are for conceptual illustration.

The boundaries between soil strata have been established only at Bore Hole locations. Between Bore holes the boundaries are assumed from geological evidence.

NOTE: The complete foundation investigation and design report for this project and other related documents may be examined at the Engineering Materials Office, Downsview. Information contained in this report and related documents is specifically excluded in accordance with the conditions of Section 102-2 of Form 100.

REVISIONS	DATE	BY	DESCRIPTION

GEOCRES No 40P8–197

HWY No			DIST
SUBM'D SG	CHECKED	DATE 2011/03/07	SITE
DRAWN GBB	CHECKED	APPROVED	DWG 2

Photo No. 1: Hwy 24 looking south at culvert site.

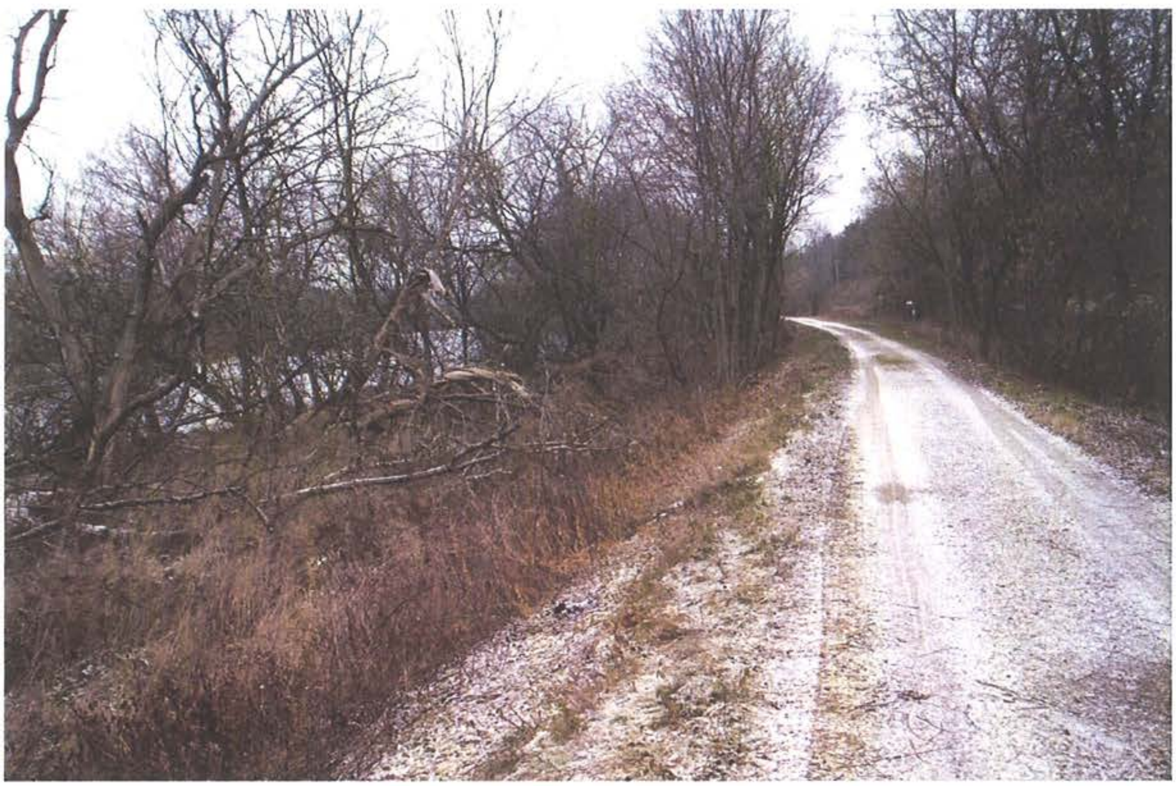


Photo No. 2: Recreational trail looking north at culvert site.

Photo No. 3: View from recreational trail toward Hwy 24 with exposed culvert section in between.

Photo No. 4: Culvert outlet with signs of erosion and deterioration at the south side.

APPENDIX B

Symbols and Terms Used on Borehole Records

Borehole Records

SYMBOLS AND TERMS USED ON BOREHOLE AND TEST PIT RECORDS

SOIL DESCRIPTION

Terminology describing common soil genesis:

Topsoil	- mixture of soil and humus capable of supporting vegetative growth
Peat	- mixture of visible and invisible fragments of decayed organic matter
Till	- unstratified glacial deposit which may range from clay to boulders
Fill	- material below the surface identified as placed by humans (excluding buried services)

Terminology describing soil structure:

Desiccated	- having visible signs of weathering by oxidization of clay minerals, shrinkage cracks, etc.
Fissured	- having cracks, and hence a blocky structure
Varved	- composed of regular alternating layers of silt and clay
Stratified	- composed of alternating successions of different soil types, e.g. silt and sand
Layer	- > 75 mm in thickness
Seam	- 2 mm to 75 mm in thickness
Parting	- < 2 mm in thickness

Terminology describing soil types:
The classification of soil types are made on the basis of grain size and plasticity in accordance with the Unified Soil Classification System (USCS) (ASTM D 2487 or D 2488). The classification excludes particles larger than 76 mm (3 inches). The USCS provides a group symbol (e.g. SM) and group name (e.g. silty sand) for identification.

Terminology describing cobbles, boulders, and non-matrix materials (organic matter or debris):
Terminology describing materials outside the USCS, (e.g. particles larger than 76 mm, visible organic matter, construction debris) is based upon the proportion of these materials present:

Trace, or occasional	Less than 10%
Some	10-20%
Frequent	> 20%

Terminology describing compactness of cohesionless soils:
The standard terminology to describe cohesionless soils includes compactness (formerly "relative density"), as determined by the Standard Penetration Test N-Value (also known as N-Index). A relationship between compactness condition and N-Value is shown in the following table.

Compactness Condition	SPT N-Value
Very Loose	<4
Loose	4-10
Compact	10-30
Dense	30-50
Very Dense	>50

Terminology describing consistency of cohesive soils:
The standard terminology to describe cohesive soils includes the consistency, which is based on undrained shear strength as measured by *in situ* vane tests, penetrometer tests, or unconfined compression tests.

Consistency	Undrained Shear Strength	
	kips/sq.ft.	kPa
Very Soft	<0.25	<12.5
Soft	0.25 - 0.5	12.5 - 25
Firm	0.5 - 1.0	25 - 50
Stiff	1.0 - 2.0	50 – 100
Very Stiff	2.0 - 4.0	100 - 200
Hard	>4.0	>200

ROCK DESCRIPTION

Terminology describing rock quality:

RQD	Rock Mass Quality
0-25	*Very Poor*
25-50	*Poor*
50-75	*Fair*
75-90	*Good*
90-100	*Excellent*

Rock quality classification is based on a modified core recovery percentage (RQD) in which all pieces of sound core over 100 mm long are counted as recovery. The smaller pieces are considered to be due to close shearing, jointing, faulting, or weathering in the rock mass and are not counted. RQD was originally intended to be done on NW core; however, it can be used on different core sizes if the bulk of the fractures caused by drilling stresses are easily distinguishable from *in situ* fractures. The terminology describing rock mass quality based on RQD is subjective and is underlain by the presumption that sound strong rock is of higher engineering value than fractured weak rock.

Terminology describing rock mass:

Spacing (mm)	Joint Classification	Bedding, Laminations, Bands
> 6000	*Extremely Wide*	-
2000-6000	*Very Wide*	*Very Thick*
600-2000	*Wide*	*Thick*
200-600	*Moderate*	*Medium*
60-200	*Close*	*Thin*
20-60	*Very Close*	*Very Thin*
<20	*Extremely Close*	*Laminated*
<6	-	*Thinly Laminated*

Terminology describing rock strength:

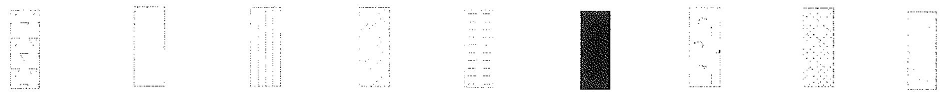
Strength Classification	Unconfined Compressive Strength (MPa)
Extremely Weak	< 1
Very Weak	1 – 5
Weak	5 – 25
Medium Strong	25 – 50
Strong	50 – 100
Very Strong	100 – 250
Extremely Strong	> 250

Terminology describing rock weathering:

Term	Description
Fresh	No visible signs of rock weathering. Slight discolouration along major discontinuities
Slightly Weathered	Discolouration indicates weathering of rock on discontinuity surfaces. All the rock material may be discoloured.
Moderately Weathered	Less than half the rock is decomposed and/or disintegrated into soil.
Highly Weathered	More than half the rock is decomposed and/or disintegrated into soil.
Completely Weathered	All the rock material is decomposed and/or disintegrated into soil. The original mass structure is still largely intact.

STRATA PLOT

Strata plots symbolize the soil or bedrock description. They are combinations of the following basic symbols. The dimensions within the strata symbols are not indicative of the particle size, layer thickness, etc.



Boulders Cobbles Gravel | Sand | Silt | Clay | Organics | Asphalt | Concrete | Fill | Bedrock

SAMPLE TYPE

SS	Split spoon sample (obtained by performing the Standard Penetration Test)
ST	Shelby tube or thin wall tube
DP	Direct-Push sample (small diameter tube sampler hydraulically advanced)
PS	Piston sample
BS	Bulk sample
WS	Wash sample
HQ, NQ, BQ, etc.	Rock core samples obtained with the use of standard size diamond coring bits.

WATER LEVEL MEASUREMENT

▼ measured in standpipe, piezometer, or well

▽ inferred

RECOVERY

For soil samples, the recovery is recorded as the length of the soil sample recovered. For rock core, recovery is defined as the total cumulative length of all core recovered in the core barrel divided by the length drilled and is recorded as a percentage on a per run basis.

N-VALUE

Numbers in this column are the field results of the Standard Penetration Test: the number of blows of a 140 pound (64 kg) hammer falling 30 inches (760 mm), required to drive a 2 inch (50.8 mm) O.D. split spoon sampler one foot (305 mm) into the soil. For split spoon samples where insufficient penetration was achieved and N-values cannot be presented, the number of blows are reported over sampler penetration in millimetres (e.g. 50/75). Some design methods make use of N value corrected for various factors such as overburden pressure, energy ratio, borehole diameter, etc. No corrections have been applied to the N-values presented on the log.

DYNAMIC CONE PENETRATION TEST (DCPT)

Dynamic cone penetration tests are performed using a standard 60 degree apex cone connected to A size drill rods with the same standard fall height and weight as the Standard Penetration Test. The DCPT value is the number of blows of the hammer required to drive the cone one foot (305 mm) into the soil. The DCPT is used as a probe to assess soil variability.

OTHER TESTS

S	Sieve analysis
H	Hydrometer analysis
k	Laboratory permeability
γ	Unit weight
G_s	Specific gravity of soil particles
CD	Consolidated drained triaxial
CU	Consolidated undrained triaxial with pore pressure measurements
UU	Unconsolidated undrained triaxial
DS	Direct Shear
C	Consolidation
Q_u	Unconfined compression
I_p	Point Load Index (I_p on Borehole Record equals $I_p(50)$ in which the index is corrected to a reference diameter of 50 mm)

	Single packer permeability test; test interval from depth shown to bottom of borehole
	Double packer permeability test; test interval as indicated
	Falling head permeability test using casing
	Falling head permeability test using well point or piezometer

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RECORD OF BOREHOLE No BH 10-1

METRIC

W.P. 3055-03-00 | LOCATION Alder Creek Culvert | N: 4 796 848 E: 239 160 | ORIGINATED BY JF

DIST London HWY 24 | BOREHOLE TYPE Split-spoons, Solid-stem Augers | COMPILED BY JF

DATUM Geodetic | DATE 2010 12 02 - 2010 12 02 | CHECKED BY PC

SOIL PROFILE

ELEV / DEPTH	DESCRIPTION
257.5	Asphalt
257.3 / 0.0	200 mm ASPHALT
257.3 / 0.2	150 mm CONCRETE
0.4	Silty sand with gravel (SM), brown to reddish brown, FILL
253.4	
253.3 / 4.1	Sandy silt (ML), dark brown, wet, ORGANIC matter
4.2	Silty sand with gravel (SM) to silty Gravel with sand (GM), compact to very dense, brown, TILL - frequent cobbles and boulders
248.1 / 9.4	End of Borehole

SAMPLES

NUMBER	TYPE	"N" VALUES	WATER CONTENT (%)	GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
1	SS	35	o	34 42 (24)
2	SS	13		
3	SS	7		
4	SS	4		
5	SS	4	48	
6	SS	20		
7	SS	108/ 230mm		
8	SS	100/ 50mm		
9	SS	70		
10	SS	110/ 100mm		

GROUND WATER CONDITIONS: water level symbol (∇) at approximately elev. 253.0 (at sample 6)

ELEVATION SCALE: 257, 256, 255, 254, 253, 252, 251, 250, 249

DYNAMIC CONE PENETRATION RESISTANCE PLOT: 20 40 60 80 100

SHEAR STRENGTH kPa: O UNCONFINED, ✱ FIELD VANE, ● QUICK TRIAXIAL, × LAB VANE: 20 40 60 80 100

PLASTIC LIMIT W_P — NATURAL MOISTURE CONTENT W — LIQUID LIMIT W_L

WATER CONTENT (%): 10 20 30

UNIT WEIGHT γ kN/m³

REMARKS & GRAIN SIZE DISTRIBUTION (%): GR SA SI CL

✱3, ×3: Numbers refer to Sensitivity   O 3% STRAIN AT FAILURE

Stantec

RECORD OF BOREHOLE No BH 10-2

METRIC

W.P. 3055-03-00 LOCATION Alder Creek Culvert N: 4 796 840 E: 239 153 ORIGINATED BY JF

DIST London HWY 24 BOREHOLE TYPE Split-spoons, Solid-stem Augers COMPILED BY JF

DATUM Geodetic DATE 2010 12 01 - 2010 12 01 CHECKED BY PC

ELEV / DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
257.1	Gravel Shoulder						
0.0	Well graded sand with silt and gravel (SW-SM), brown to dark grey, FILL	1	BS			257	32 58 (10)
		2	SS	148			
256.2 / 256.0 / 1.1	Sandy silt (ML), dark brown, wet, ORGANIC matter					256	
	Silty sand with gravel (SM), grey to reddish brown, FILL	3	SS	34			25 51 (24)
	- Sandy silt pocket at 2.4 m - Very little gravel below 2.4 m	4	SS	4		255	0 45 (55)
		5	SS	25		254	
253.1 / 253.0 / 4.1	Sandy silt (ML), dark brown, wet, ORGANIC matter	6	SS	61	∇	253	
	Silty sand with gravel (SM) to silty gravel with sand (GM), dense to very dense, brown to grey, TILL - frequent cobbles and boulders	7	SS	100/ 50mm		252	38 33 (29)
		8	SS	100/ 50mm		251	
		9	SS	58		250	56 32 (12)
		10	SS	31		249	23 63 (14)
		11	SS	37		248	
247.4 / 9.8	End of Borehole						

DYNAMIC CONE PENETRATION RESISTANCE PLOT: 20 40 60 80 100

SHEAR STRENGTH kPa: O UNCONFINED, ✖ FIELD VANE, ● QUICK TRIAXIAL, × LAB VANE; 20 40 60 80 100

PLASTIC LIMIT W_P, NATURAL MOISTURE CONTENT W, LIQUID LIMIT W_L; WATER CONTENT (%) 10 20 30

UNIT WEIGHT γ kN/m³

✖ 3, × 3: Numbers refer to Sensitivity   O 3% STRAIN AT FAILURE

Stantec

RECORD OF BOREHOLE No BH 10-3

METRIC

W.P. 3055-03-00 | LOCATION Alder Creek Culvert N: 4 796 841 E: 239 134 | ORIGINATED BY JF

DIST London HWY 24 | BOREHOLE TYPE Split-spoons, Hollow-stem Augers | COMPILED BY JF

DATUM Geodetic | DATE 2010 11 30 - 2010 12 01 | CHECKED BY PC

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	WATER CONTENT (%) / PLASTIC LIMIT – LIQUID LIMIT	GR	SA	SI	CL
256.9	Gravel Trail										
0.0	Poorly graded gravel with silt and sand (GW-GM), brown, FILL	1	BS				o	59	33	(8)	
256.0 / 0.9	Sandy silt (ML), reddish brown, FILL - Clayey pocket at 1.0 m	2	SS	8		256	●–●	0	20	(80)	
		3	SS	6		255	o				
		4	SS	9		254	o	3	36	(61)	
253.8	Sandy silt (ML), dark brown, wet, ORGANIC matter	5	SS	5	▽		o	0	44	(56)	
253.7 / 3.2	Sandy silt (ML), compact, brown to greyish brown, TILL - With gravel below 3.5 m	6	SS	16		253					
252.6 / 4.3	Silty sand with gravel (SM) to silty gravel with sand (GM), dense to very dense, grey, TILL - frequent cobbles and boulders	7	SS	34		252					
		8	SS	155/200mm		251					
		9	SS	68		250	o	45	39	(16)	
		10	SS	78		249					
						248					
247.7 / 9.1	End of Borehole										

DYNAMIC CONE PENETRATION RESISTANCE PLOT: 20 40 60 80 100

SHEAR STRENGTH kPa: O UNCONFINED; ✖ FIELD VANE; ● QUICK TRIAXIAL; × LAB VANE — 20 40 60 80 100

UNIT WEIGHT γ kN/m³

REMARKS & GRAIN SIZE DISTRIBUTION (%)

✖3, ×3: Numbers refer to Sensitivity   O3% STRAIN AT FAILURE

Stantec

RECORD OF BOREHOLE No BH 10-4

METRIC

W.P. 3055-03-00 LOCATION Alder Creek Culvert N: 4 796 851 E: 239 134 ORIGINATED BY JF

DIST London HWY 24 BOREHOLE TYPE Split-spoons, Solid-stem Augers COMPILED BY JF

DATUM Geodetic DATE 2010 12 02 - 2010 12 02 CHECKED BY PC

ELEV / DEPTH	SOIL PROFILE – DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
256.9	Gravel Trail					
0.0	Poorly graded gravel with silt and sand (GP-GM), brown, FILL	1	SS	39		
255.7 / 1.2	Sandy silt (ML), reddish brown, FILL	2	SS	12		4 35 (61)
		3	SS	17		
254.3 / 2.6	Sandy silt with gravel (ML), compact to dense, greyish brown to brown, TILL	4	SS	20	∇	
		5	SS	50		18 31 (51)
252.6 / 4.3	Silty sand with gravel (SM), dense to very dense, brown, TILL - frequent cobbles and boulders - coring carried out to advance through boulder	6	SS	121		
		7	NQ			
		8	NQ			
		9	NQ			
248.0 / 8.9	End of Borehole					

ELEVATION SCALE: 256, 255, 254, 253, 252, 251, 250, 249

DYNAMIC CONE PENETRATION RESISTANCE PLOT: 20 40 60 80 100

SHEAR STRENGTH kPa: O UNCONFINED ✖ FIELD VANE ● QUICK TRIAXIAL × LAB VANE — 20 40 60 80 100

PLASTIC LIMIT W_P — NATURAL MOISTURE CONTENT W — LIQUID LIMIT W_L; WATER CONTENT (%) 10 20 30

UNIT WEIGHT γ kN/m³

✖³, ×³: Numbers refer to Sensitivity O 3% STRAIN AT FAILURE

Stantec

RECORD OF BOREHOLE No BH 10-5

METRIC

W.P. 3055-03-00	LOCATION Alder Creek Culvert	N: 4 796 852 E: 239 126	ORIGINATED BY JF
DIST London HWY 24	BOREHOLE TYPE Portable Equipment, Split-spoons		COMPILED BY JF
DATUM Geodetic	DATE 2010 12 02 - 2010 12 03		CHECKED BY PC

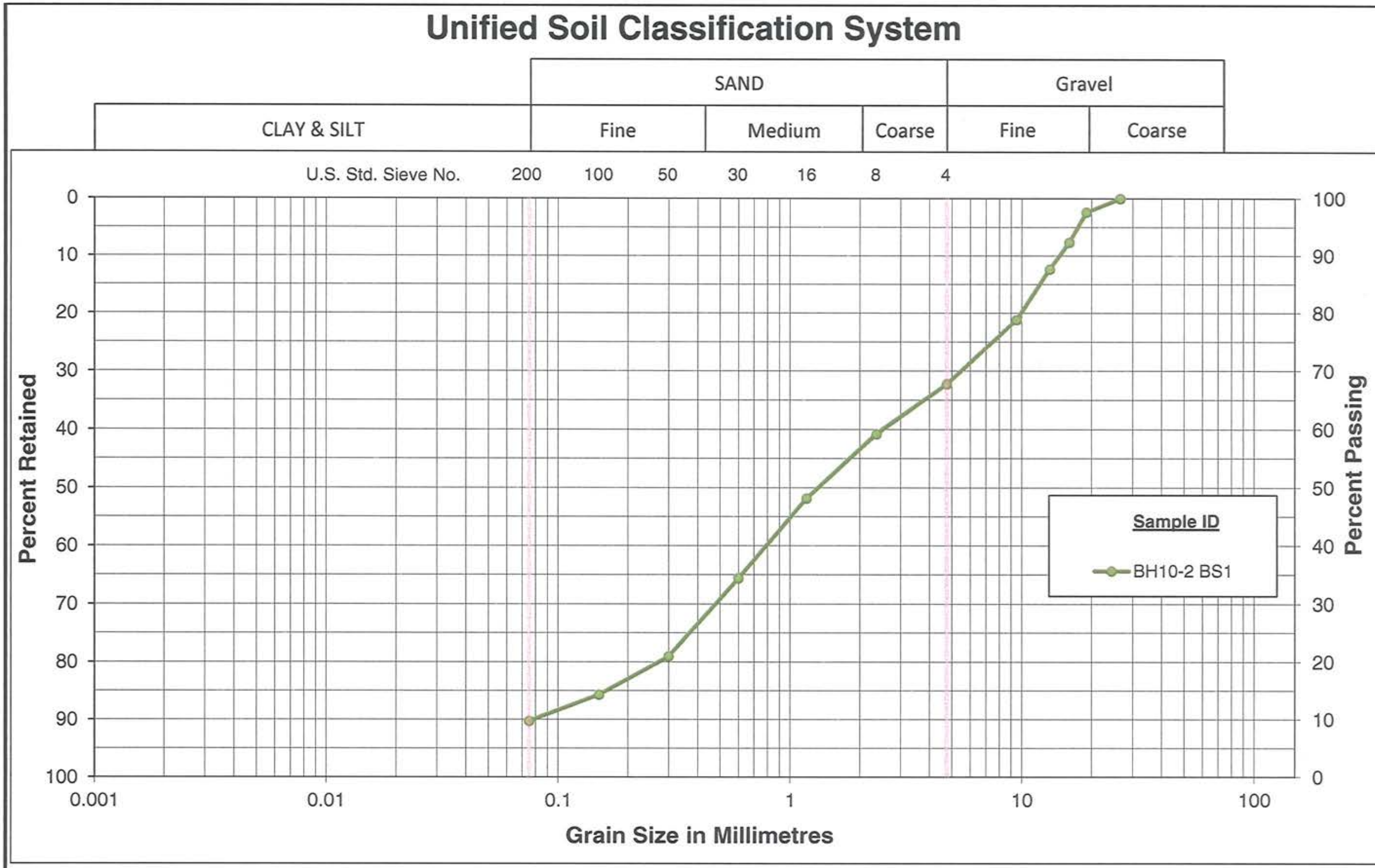
ELEV DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	NATURAL MOISTURE CONTENT w (%)	GR	SA	SI	CL
254.6	Low grass										
0.0	TOPSOIL										
254.3 0.3	Silty sand with gravel (SM), very dense, brown, TILL - frequent cobbles and boulders	1	SS	6		254					
		2	SS	40			o	30	36	(34)	
		3	SS	120/ ,0mm	▽	253					
		4	SS	80		252	o	32	40	(28)	
251.7		5	SS	205/ 130mm							
2.9	End of Borehole										

Legend: DYNAMIC CONE PENETRATION RESISTANCE PLOT (20, 40, 60, 80, 100); SHEAR STRENGTH kPa: O UNCONFINED, ✱ FIELD VANE, ● QUICK TRIAXIAL, × LAB VANE (20, 40, 60, 80, 100); PLASTIC LIMIT W_P, NATURAL MOISTURE CONTENT W, LIQUID LIMIT W_L; WATER CONTENT (%) (10, 20, 30); UNIT WEIGHT γ kN/m³; REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL

✱3, ×3: Numbers refer to Sensitivity   O 3% STRAIN AT FAILURE

APPENDIX C

Laboratory Test Results



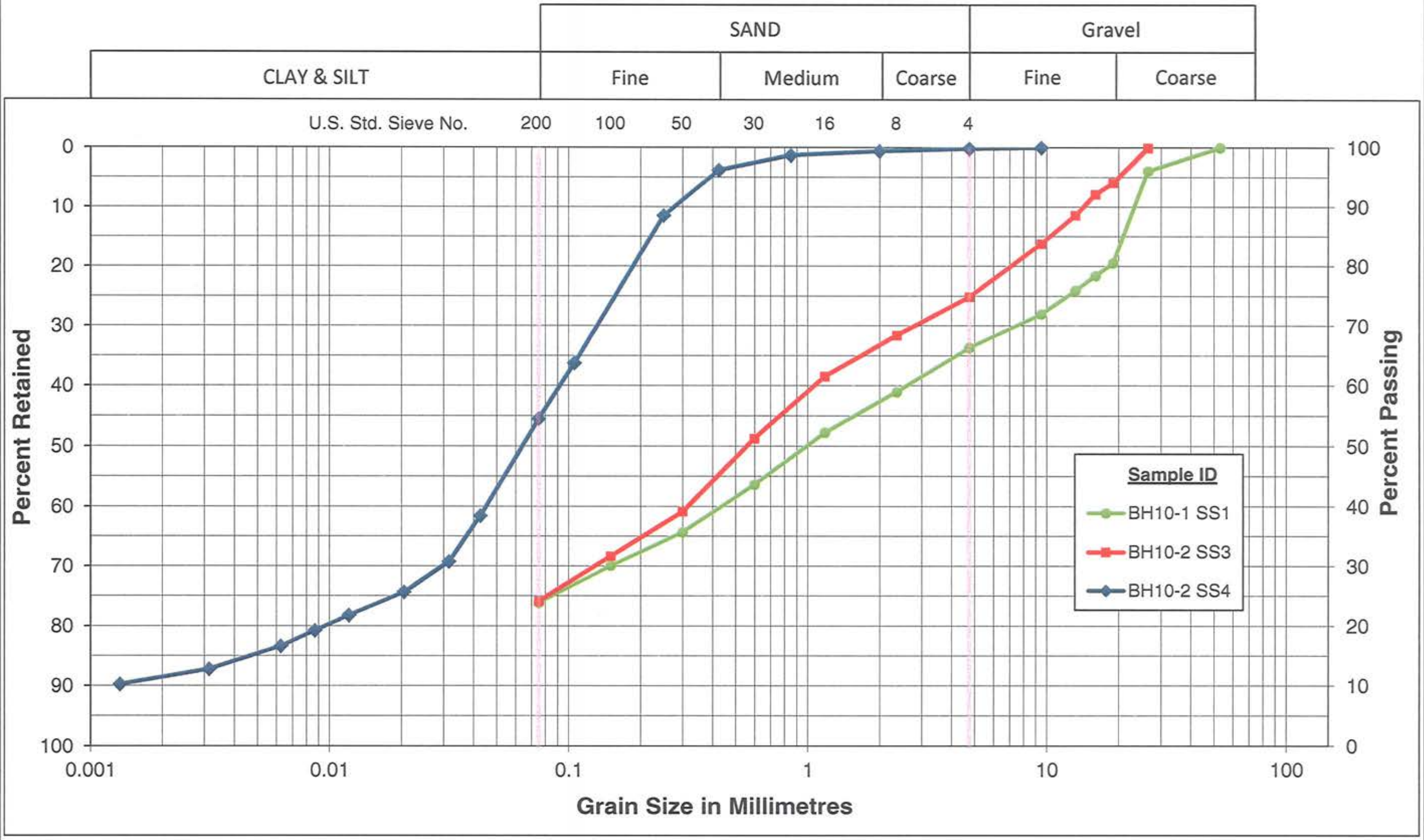
GRAIN SIZE DISTRIBUTION

Hwy 24 Shoulder Granular Fill

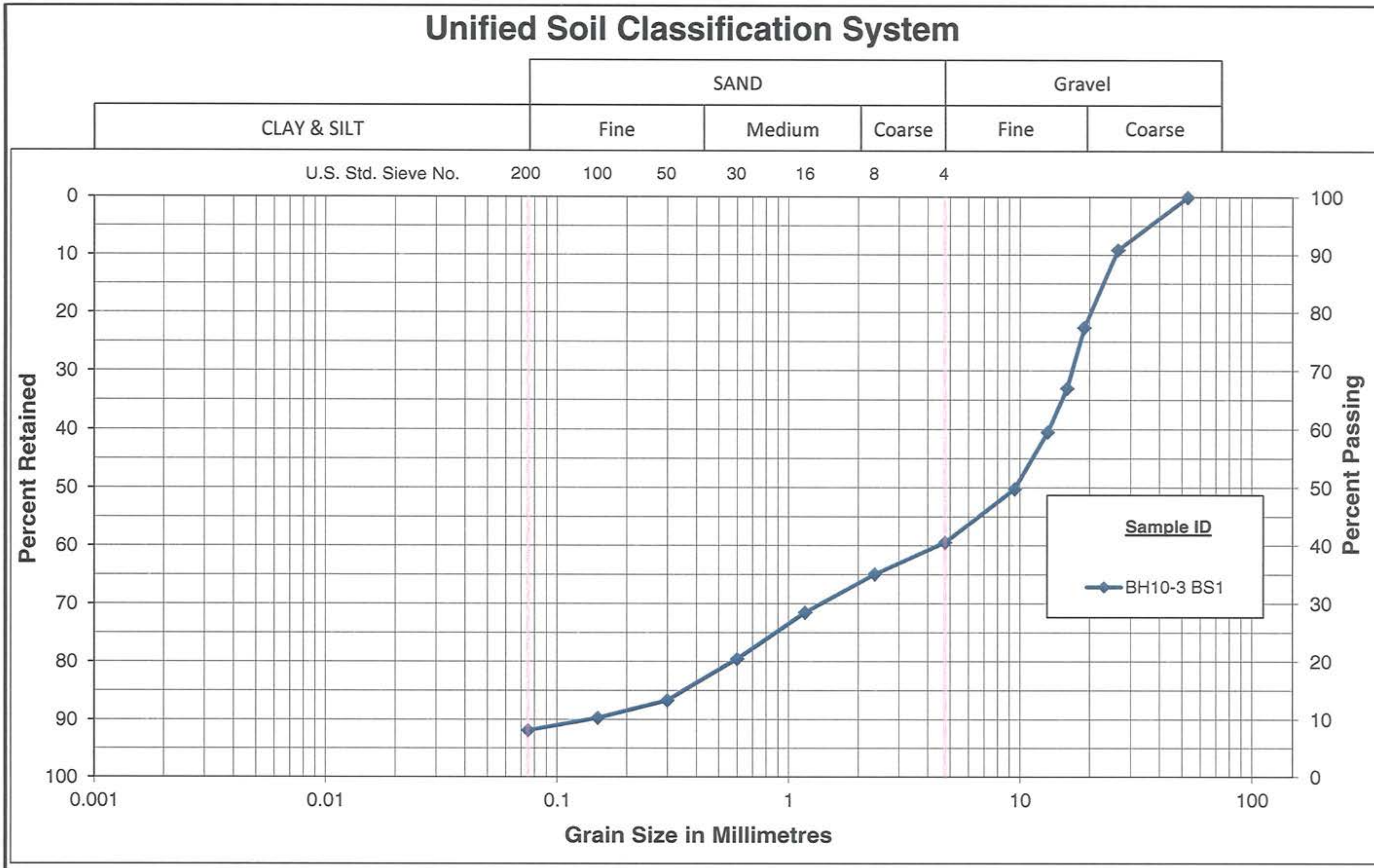
Figure No. 1

Project No. 165000768

Unified Soil Classification System



GRAIN SIZE DISTRIBUTION Hwy 24 Embankment Fill	Figure No. 2
	Project No. 165000768



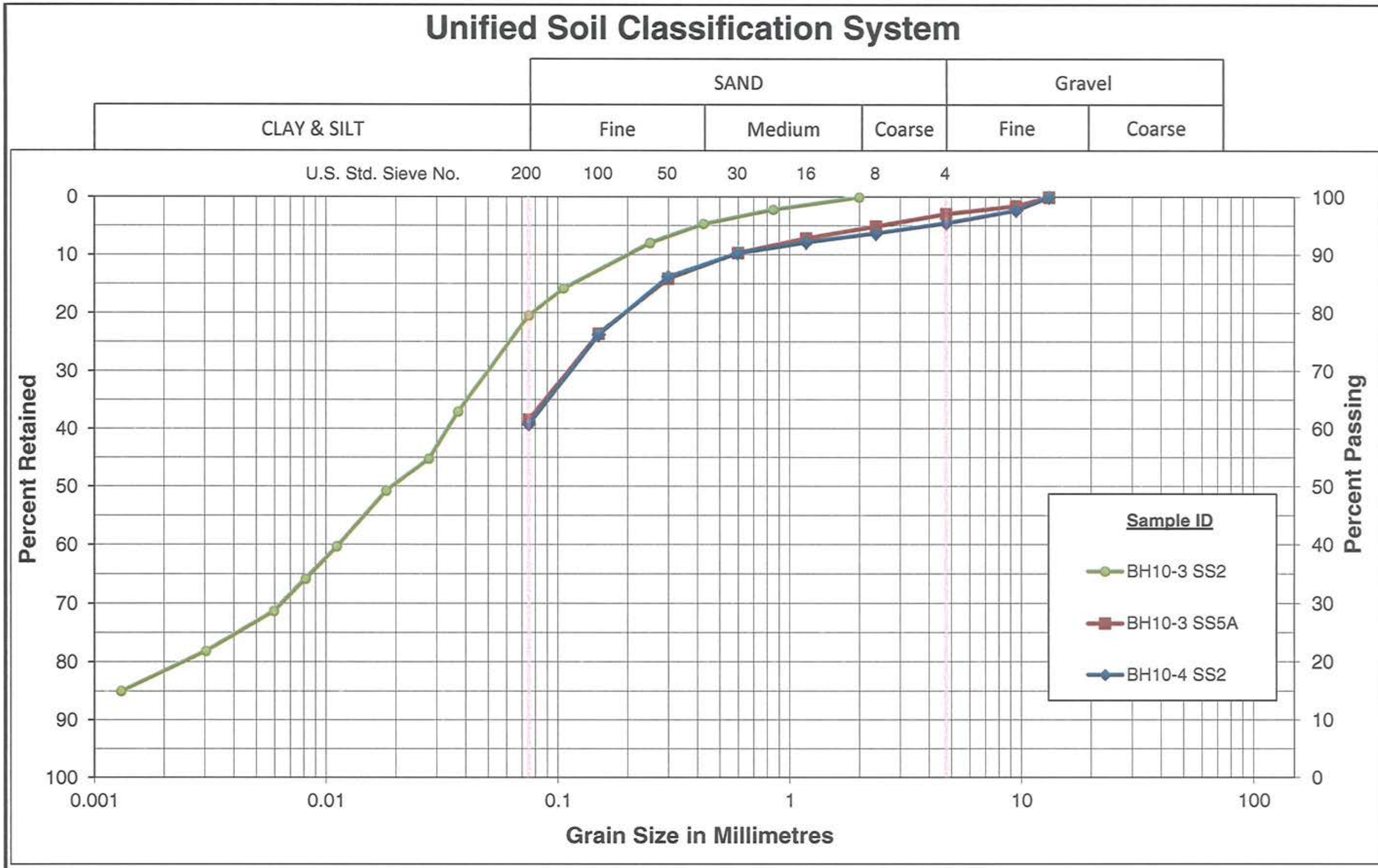
GRAIN SIZE DISTRIBUTION

Granular Railway Ballast

Figure No. 3

Project No. 165000768

Stantec

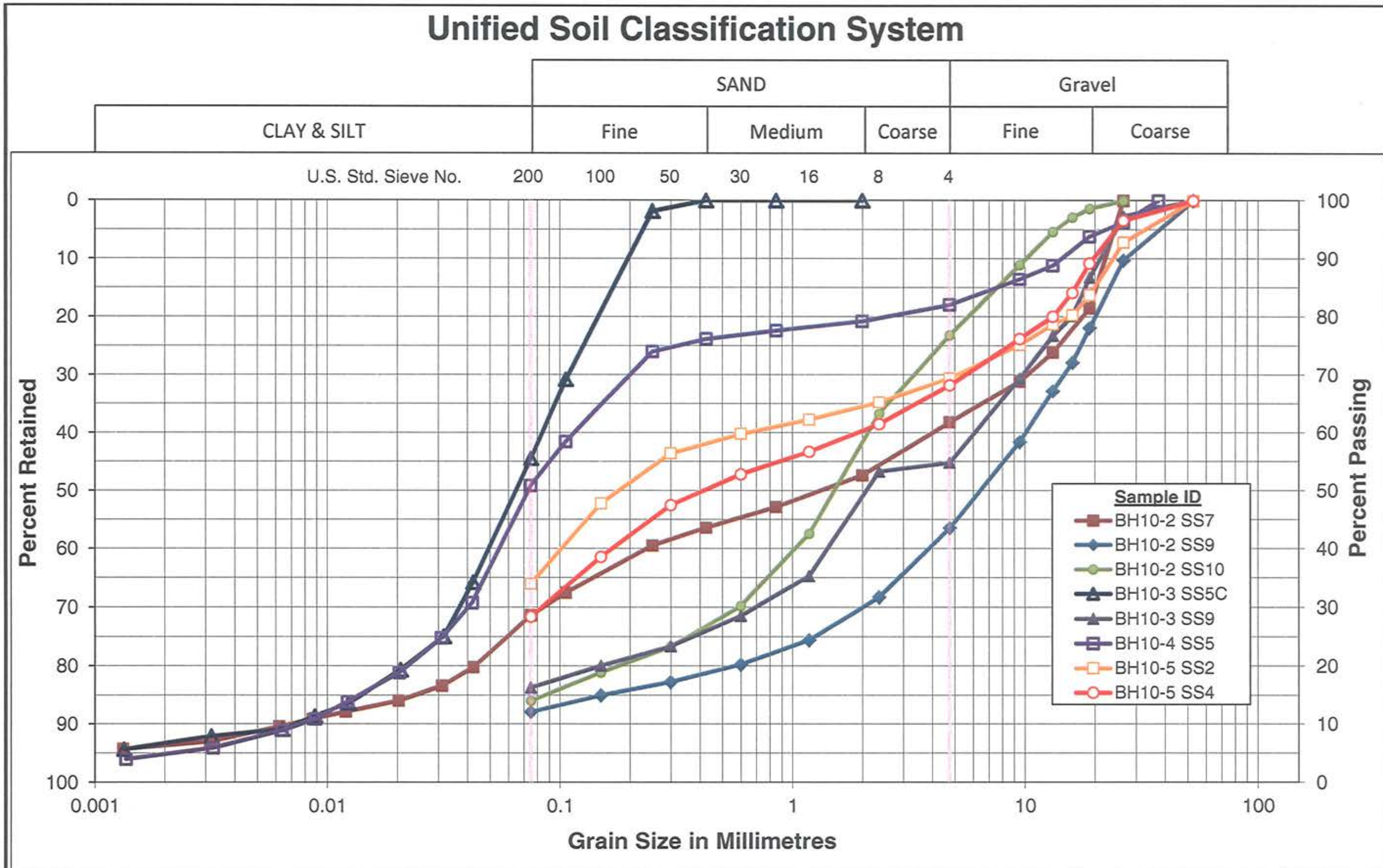


GRAIN SIZE DISTRIBUTION

Recreational Trail Embankment Fill

Figure No. 4

Project No. 165000768



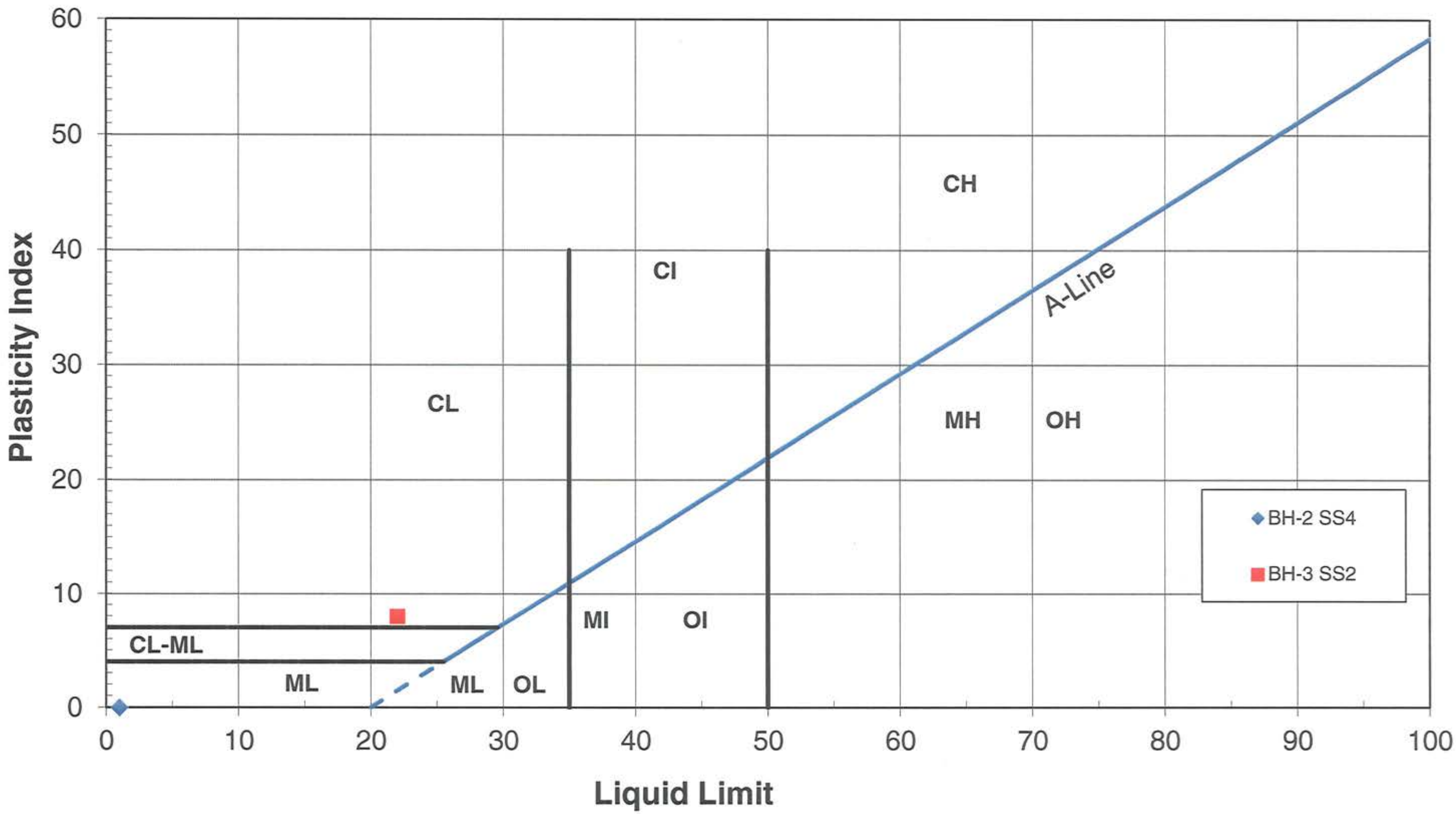
Stantec

GRAIN SIZE DISTRIBUTION

Native TILL (ML, SM and GM)

Figure No. 5

Project No. 165000768



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PLASTICITY CHART

Figure No. 6

Project No. 165000768

APPENDIX D

Drawing No.3 – Schematic of Roadway Protection System Location

METRIC

DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN

PLATE No

CONT 2012-
WP 3055-03-00

HWY 24, CAMBRIDGE, ON — SHEET

STA TO STA

ROADWAY PROTECTION SYSTEM LOCATION

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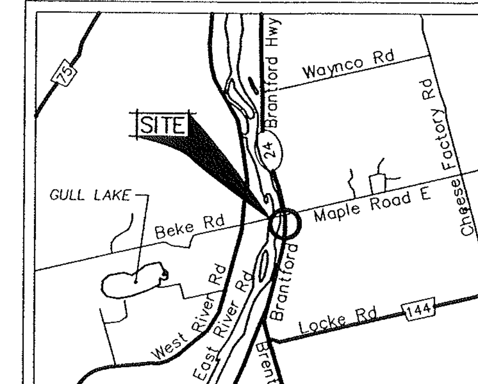
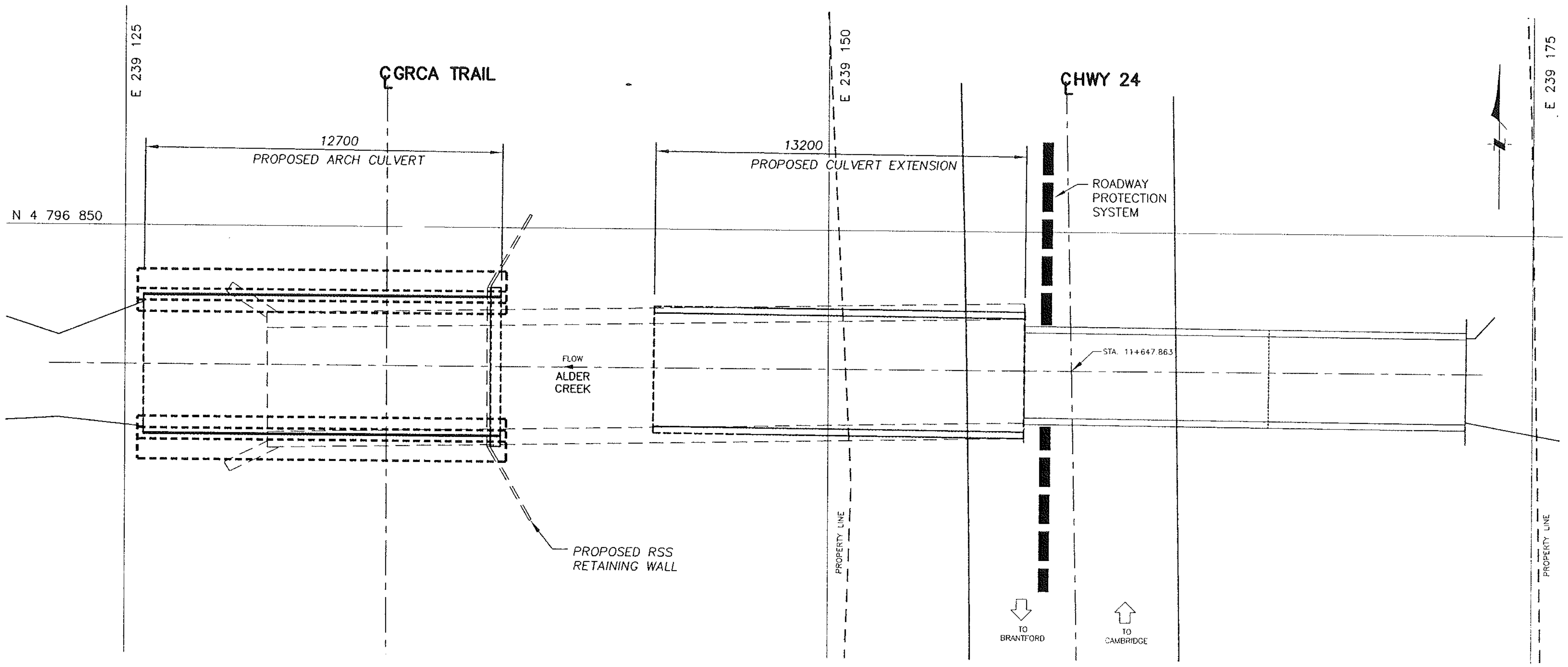


KEY PLAN

1 km 0 1 2 km



PLAN

SCALE

2 m 0 2 4 m

=NOTE=

This drawing is for subsurface information only. Surface details and features are for conceptual illustration.

NOTE: The complete foundation investigation and design report for this project and other related documents may be examined at the Engineering Materials Office, Downsview. Information contained in this report and related documents is specifically excluded in accordance with the conditions of Section 102-2 of Form 100.

REVISIONS	DATE	BY	DESCRIPTION

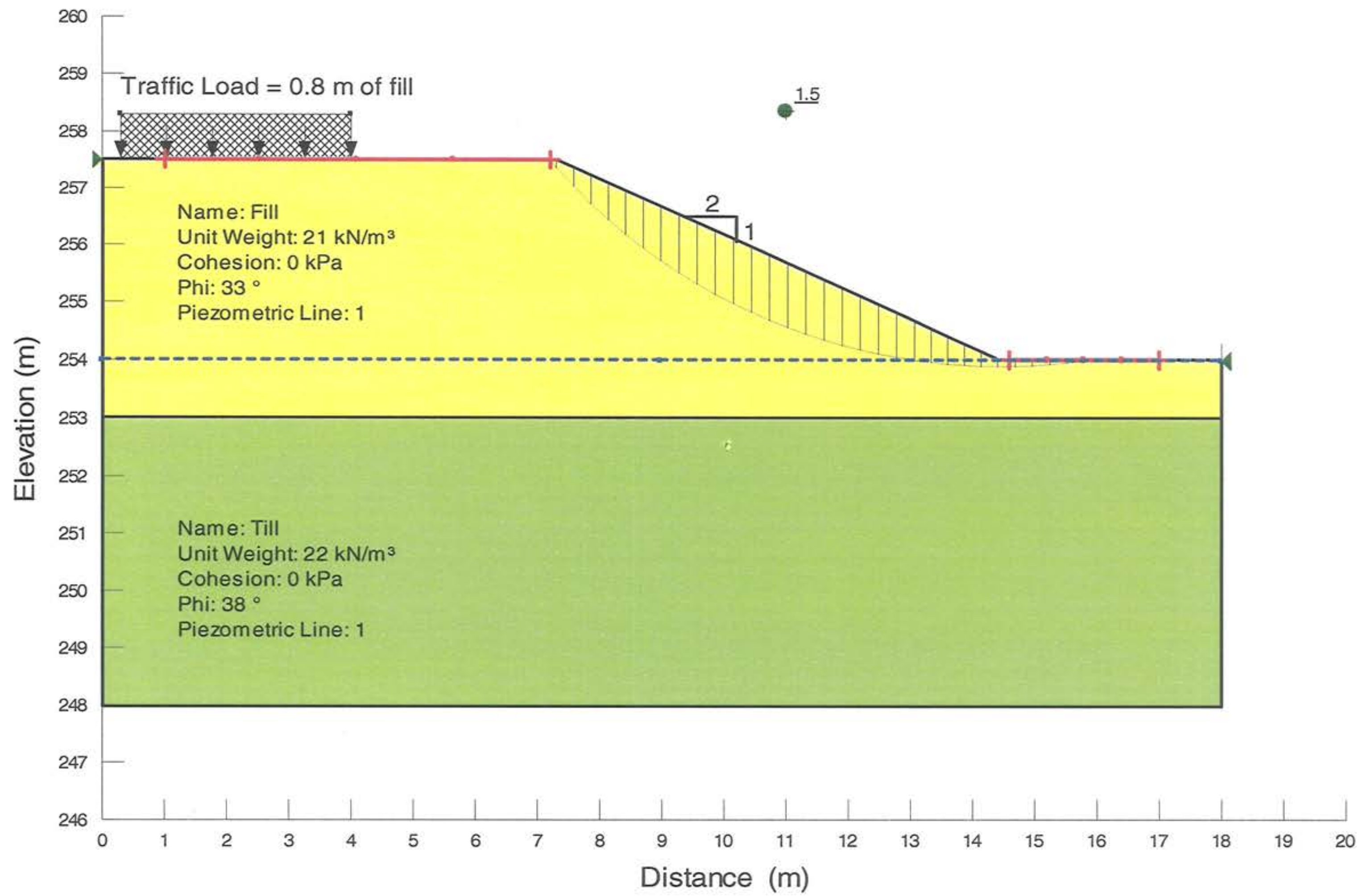
GEOCRES No 40P8-197

HWY No			DIST
SUBM'D SG	CHECKED	DATE 2011/03/15	SITE
DRAWN GBB	CHECKED	APPROVED	DWG 3

DRAWING NAME: 165000768-1 (Sept).DWG
CREATED: GBB MODIFIED: 11/09/16
T:\Autocad\Drawings\Project Drawings\2011\165000768\Final (Sept)\165000768-1 (Sept).dwg (ROADWAY PROTECTION) Printed: Sep 16, 2011

APPENDIX E

Slope Stability Analysis Results



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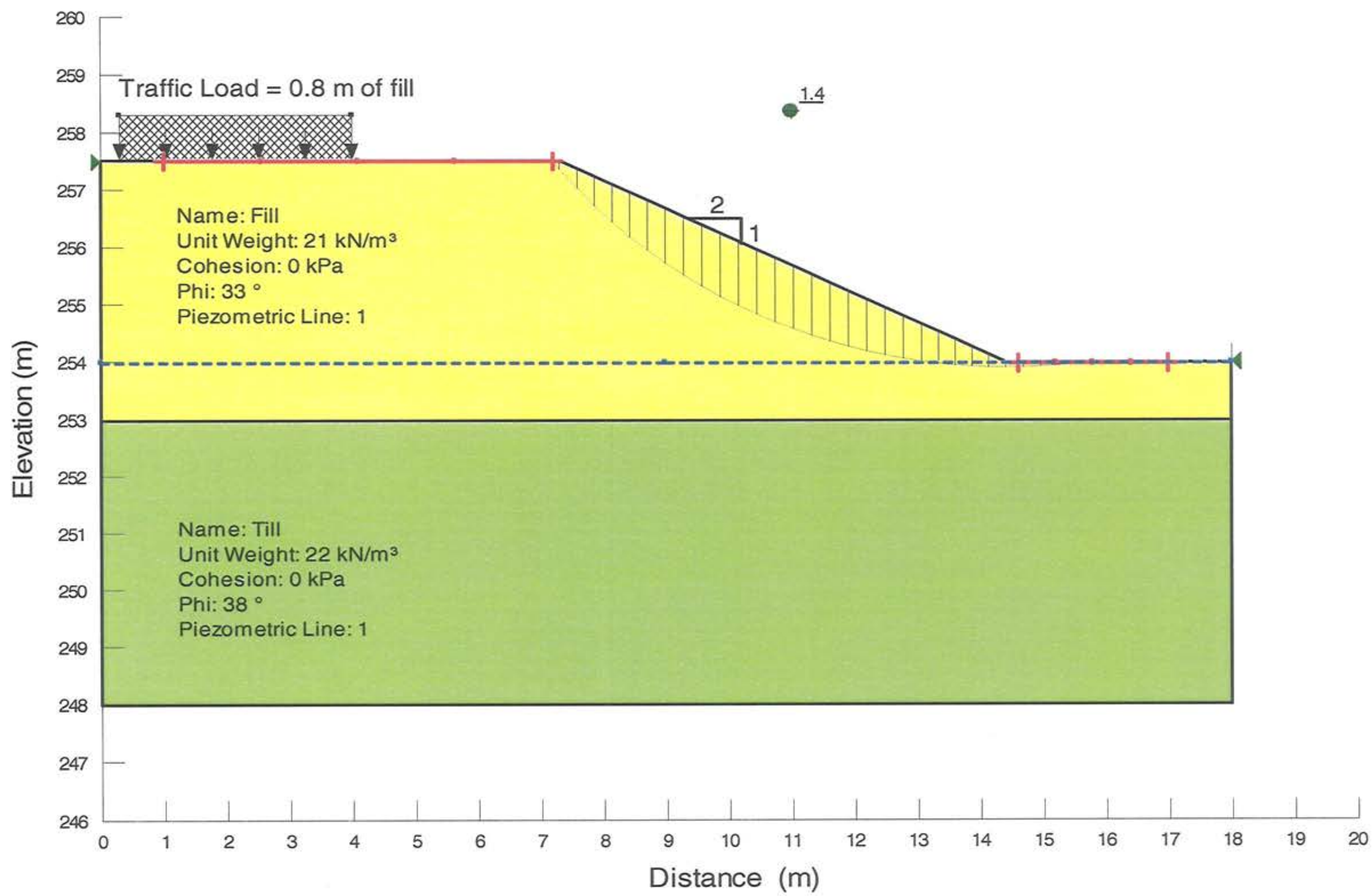
Static Stability Analysis

Highway 24 - Alder Creek Culvert Partial Replacement and Rehabilitation

Figure 7

Project No. 165000768



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Seismic Stability Analysis

Highway 24 - Alder Creek Culvert Partial Replacement and Rehabilitation

Figure 8

Project No. 165000768

APPENDIX F

2005 NBC Seismic Hazard Calculation

2005 National Building Code Seismic Hazard Calculation

INFORMATION: Eastern Canada English (613) 995-5548 français (613) 995-0600 Facsimile (613) 992-8836
Western Canada English (250) 363-6500 Facsimile (250) 363-6565

Requested by: Simon Gudina, Stantec — December 17, 2010

Site Coordinates: 43.3085 North 80.3091 West

User File Reference:

National Building Code ground motions:
2% probability of exceedance in 50 years (0.000404 per annum)

Sa(0.2)	Sa(0.5)	Sa(1.0)	Sa(2.0)	PGA (g)
0.227	**0.109**	**0.051**	**0.014**	**0.147**

Notes. Spectral and peak hazard values are determined for firm ground (NBCC 2005 soil class C - average shear wave velocity 360-750 m/s). Median (50th percentile) values are given in units of g. 5% damped spectral acceleration (Sa(T), where T is the period in seconds) and peak ground acceleration (PGA) values are tabulated. Only 2 significant figures are to be used. ***These values have been interpolated from a 10 km spaced grid of points. Depending on the gradient of the nearby points, values at this location calculated directly from the hazard program may vary. More than 95 percent of interpolated values are within 2 percent of the calculated values.***

Ground motions for other probabilities:

Probability of exceedance per annum	0.010	0.0021	0.001
Probability of exceedance in 50 years	40%	10%	5%
Sa(0.2)	0.033	0.091	0.144
Sa(0.5)	0.016	0.044	0.067
Sa(1.0)	0.006	0.019	0.031
Sa(2.0)	0.002	0.006	0.009
PGA	0.019	0.062	0.093

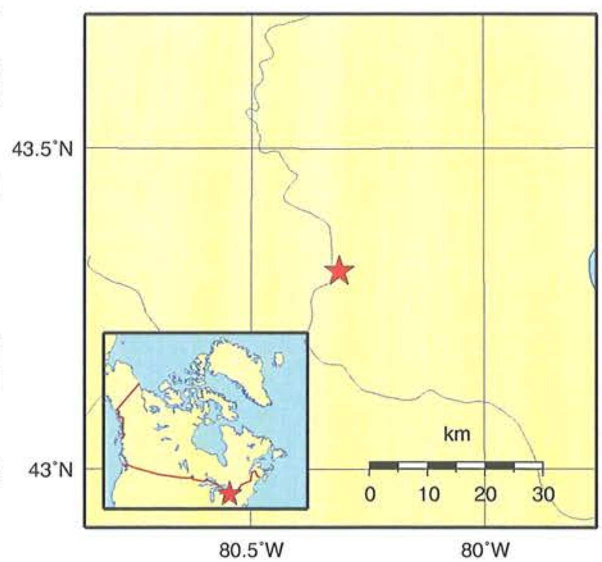
References

National Building Code of Canada 2005 NRCC no. 47666; sections 4.1.8, 9.20.1.2, 9.23.10.2, 9.31.6.2, and 6.2.1.3
Appendix C: Climatic Information for Building Design in Canada - table in Appendix C starting on page C-11 of Division B, volume 2

User's Guide - NBC 2005, Structural Commentaries NRCC no. 48192
Commentary J: Design for Seismic Effects

Geological Survey of Canada Open File xxxx
Fourth generation seismic hazard maps of Canada: Grid values to be used with the 2005 National Building Code of Canada (in preparation)

See the websites *www.EarthquakesCanada.ca* and *www.nationalcodes.ca* for more information



Aussi disponible en français