FOUNDATION INVESTIGATION AND DESIGN REPORT

REHABILITATION OF HIGHWAY 21
FROM BAYFIELD TO GODERICH, ONTARIO

CULVERT REPLACEMENT AT STATION 12+810

MINISTRY OF TRANSPORTATION ONTARIO - WEST REGION
PURCHASE ORDER NUMBER 3009-E-0022
GWP 834-93-00

MTO GEOCRES NO. 40P12-28

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1.0 INTRODUCTION

AMEC Environment & Infrastructure, a Division of AMEC Americas Limited ("AMEC"), was retained by the Ministry of Transportation Ontario - West Region ("MTO") to provide Detail Design Services for the Rehabilitation of Highway 21, Ontario. The project highway is about 20 km long stretching northerly from about 1.85 km south of Bayfield River Bridge (Bayfield) to about 0.17 km north of Huckins Street (Goderich), Ontario. To provide the required geotechnical information for the Detail Design Services, AMEC conducted foundation investigation at the locations of eight (8) existing culverts identified for rehabilitation / replacement by AMEC Design Team. A site plan showing the culvert locations / stations is presented on Drawing No. 1.

The foundation investigation for the culverts comprised advancing a total of 21 boreholes (BH G1 to BH G21) as listed in Table 1.1. Culvert details, as provided by the Design Team, including the stations, type, dimensions and boreholes drilled are summarized in Table 1.1.

Table 1.1- Culvert Details*

Station	Existing Culvert		Boreholes Drilled	Proposed Work	Remarks
	Type	Dimension			
10+200 to 10+300	Concrete-open rigid frame	1.80 x 1.20 x 34.3 m	BH G1 to BH G6	Replacement or extension	Two culverts at Jowett's Grove Road Intersection with Hwy 21
	Concrete-open	0.91 x 0.91 x 40.0 m			
10+550	CSP	0.61 m diameter and 24.4 m length	BH G7 and BH G8	Replacement	
10+705	CSP	0.61 m diameter and 24.0 m length	BH G9 and BH G10	Replacement	
11+187	CSP	0.46 m diameter and 24.7 m length	BH G11 and BH G12	Replacement	
11+873	CSP	0.61 m diameter and 21.7 m length	BH G13 and BH G14	Replacement	
12+810	CSP	0.61 m diameter and 19.3 m length	BH G15 and BH G16	Replacement	
21+055	Concrete-open rigid frame	1.82 m x 5.49 m x 24.0 m	BH G17, BH G18 and BH G19	Replacement	
22+826	CSP	0.76 m diameter and 21.4 m length	BH G20 and BH G21	Replacement	

* from Culvert Summary Table provided by AMEC Design Team

The purpose of the foundation investigation was to obtain information on the subsurface conditions at the culvert sites by means of boreholes, in-situ tests and laboratory tests on selected samples. Based on AMEC's interpretation of the data obtained in the investigation, recommendations are provided on the geotechnical aspects of replacement of the culverts.

As per Terms of Reference (TOR) in the Request for Proposal (Purchase Order Number: 3009-E-0022, dated March 2010), separate reports have been prepared for each culvert site. This report presents the results of foundation investigation together with design discussion and recommendations for the culvert at Station 12+810.

The factual results of the soil conditions encountered in the boreholes and laboratory tests (without design discussion and recommendations) for the culvert at Station 12+810 are presented in a separate report titled "Foundation Investigation Report".

2.0 SITE AND PROJECT DESCRIPTION

The investigated culvert site (at Station 12+810) is located about 610 m north of Bayfield Road, north of Bayfield, Ontario (refer to Drawing No. 1).

At this location, Highway 21 is a two-lane, asphaltic concrete paved road with gravel shoulders on both sides, and runs on top of an embankment built up above the surrounding grade. The surrounding area is primarily rural in nature, with active agricultural operations and farm houses / vacant lands / wood lots.

The existing culvert at this location has been recommended by AMEC Design Team for replacement. Based on the Culvert Summary Table provided in Table 1.1, the existing culvert at this location is a CSP type, 0.61 m diameter and 19.3 m long. From the drawing provided by MTO (ETR Plate No. 171-21/13-0), the height of fill over the culvert is about 2.0 m ±. The existing culvert has been recommended for replacement by the AMEC Design Team.

Site photographs showing the culvert are presented in Appendix C (Photographs 1 and 2).

3.0 GEOLOGY

Based on Map 2556 (Southern Sheet): 'Quaternary Geology of Ontario' prepared by Ministry of Northern Development and Mines of Ontario (1991), the site is located in an area of transition where the overburden comprises (i) St. Joseph Till (Huron - Georgian Bay lobe) consisting of silt to silty clay matrix, clay content increases southward, clast poor, and (ii) Glaciolacustrine deposits consisting of sand, gravelly sand and gravel; nearshore and beach deposits; and (iii) Glaciolacustrine deposits consisting of silt and clay, minor sand, basin and quiet water deposits.

4.0 INVESTIGATION PROCEDURES

4.1 Field Investigation

In accordance with the Terms of Reference for this investigation, two (2) boreholes were advanced - one on each side of the existing culvert. Borehole BH G15 was drilled near the culvert inlet, while Borehole BH G16 was advanced adjacent to the culvert outlet. The borehole locations are presented on Drawing No. 2.

The fieldwork was performed on 18 May 2011 after acquiring all necessary permits for road occupancy, and obtaining clearance for underground utilities. The ground surfaces at the borehole locations were surveyed with reference to the nearest geodetic benchmark (BM HCP # 102, Sta. 10+449.955, El 197.134).

The boreholes were advanced using solid-stem continuous-flight augers, with a track-mounted power-auger drilling rig under the full-time supervision of experienced geotechnical personnel from AMEC. Soil samples were generally taken at 0.76 m intervals for the initial 3 m of the borehole, and 1.5 m thereafter, while performing the Standard Penetration Test (SPT) in accordance with ASTM D1586. This consisted of freely dropping a 63.5 kg (140 lbs.) hammer for a vertical distance of 0.76 m (30 inches) to drive a 51 mm (2 inches) diameter O.D. split-barrel (split spoon) sampler into the ground. The number of blows of the hammer required to drive the sampler into the relatively undisturbed ground by a vertical distance of 0.30 m (12 inches) was recorded as SPT 'N' value of the soil, which indicated the consistency of cohesive soils or the compactness of non-cohesive soils.

The groundwater conditions were observed in the boreholes during sampling and upon completion of drilling. The groundwater depth measurements are presented on the Record of Boreholes. A single monitoring well was installed in Borehole BH G15 for long term monitoring of groundwater levels by the project hydrogeological team (the hydrogeological report is submitted separately). The groundwater levels were measured within the monitoring well on 14 June and 22 June 2011. The results of measurements are shown on the Record of Boreholes and summarized in Table 5.2 (Section 5.4).

Upon completion of drilling, Borehole BH G16 was backfilled with bentonite in accordance with the general requirements of Ministry of the Environment Regulation 903.

The soil samples were transported to AMEC's Advanced Soil Laboratory in Scarborough (Toronto) for further examination and laboratory soil testing. The program of laboratory testing included, where applicable, the following: grain size analysis, Liquid and Plastic Limit, in-situ water content determination, and soil corrosivity analysis.

The results of the in-situ and laboratory tests are presented in the corresponding Record of Boreholes (Appendix A) and Laboratory Test Results (Appendix B).

4.2 Laboratory Tests

In accordance with the Terms of Reference for this investigation, the following tests were conducted in the laboratory:

- In-situ water content determination (14);
- Grain size distribution analysis (4);
- Atterberg Limit tests (4); and
- Soil corrosivity (1).

The results of in-situ and laboratory tests are presented in the Record of Boreholes in Appendix A. The grain size distribution curves and plasticity chart are shown in Appendix B.

5.0 SUB-SURFACE CONDITIONS

Based on the investigation results, the soil profile consisted of topsoil underlain by native deposit (clayey silt) extending to the termination depths of the boreholes (elevation 189.6 m in BH G15 and 189.7 m in BH G16). In Borehole BH G16, clayey silt fill was encountered between the topsoil and the native clayey silt.

The stratigraphic units and groundwater conditions at the borehole locations are discussed in the following sections. Detailed information is provided in the Record of Boreholes (Appendix A). Interpolated stratigraphical cross sections showing the existing culvert are provided in Drawing No. 3.

Soil and groundwater conditions may vary between and beyond the borehole locations.

5.1 Topsoil

Topsoil was encountered at the existing grade in both boreholes. The measured thickness of topsoil was about 400 mm in Borehole BH G15, and 600 mm in Borehole BH G16. The topsoil consisted primarily of organic matter with some rootlets and soils.

The thickness of topsoil could vary between and beyond the borehole locations. The measured moisture contents in topsoil samples were 22 % and 25 %.

5.2 Clayey Silt Fill

Borehole BH G16 drilled adjacent to the culvert outlet encountered clayey silt fill underneath the topsoil. The clayey silt fill was likely native soil that had been disturbed or reworked possibly as a result of construction. The clayey silt fill extended to about 1.4 m below the existing grade.

The clayey silt fill was dark brown in color and contained some sand, trace rootlets and organic matter.

A single measured SPT ‘N’ value of the clayey silt fill was 6 blows per 0.3 m. The measured moisture content in the clayey silt fill was 26 %.

5.3 Clayey Silt

Native clayey silt was encountered below the topsoil in Borehole BH G15; and underneath the clayey silt fill in Borehole BH G16. The clayey silt extended to the termination depths of both boreholes (elevation 189.6 m ±).

The clayey silt was brown in color, and contained trace sand, gravel and cobbles / boulders. The SPT ‘N’ values of the clayey silt ranged widely from 13 to 72 blows per 0.3 m, indicating a stiff to hard consistency. However, a SPT ‘N’ value of 3 blows per 0.3 m (soft consistency) was measure in Sample SS1 in Borehole BH G15. The measured moisture contents in the clayey silt ranged from 16 % to 22 %.

Grain size analyses and Atterberg Limit tests were completed on 4 samples of the clayey silt, and the results are presented in Table 5.1.

Table 5.1 - Grain Size Distribution Analysis and Atterberg Limit Test Results

Borehole No.	Sample No.	Depth (Elevation) (m)	Grain Size Distribution				Atterberg Limit			USCS Modified Group Symbol
			Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Liquid Limit	Plastic Limit	Plasticity Index	
BH G15	SS 2	0.8 - 1.2 (195.4 - 195.0)	0	3	85	12	25	17	8	CL
BH G15	SS 4	2.3 - 2.8 (193.9 - 193.4)	0	1	68	31	29	16	13	CL
BH G16	SS 4	2.3 - 2.8 (194.0 - 193.5)	0	3	84	13	20	16	4	CL- ML / ML
BH G16	SS 7	6.1 - 6.5 (190.1 - 189.7)	4	14	53	29	28	13	15	CL

The grain size distribution curves are presented in Figure No. B 1 and the plasticity chart is presented in Figure No. B 2, in Appendix B.

5.4 Groundwater Conditions

Groundwater conditions in the open boreholes were observed during and on completion of drilling. Groundwater was measured in open boreholes upon completion of drilling at a depth of about 3.2 m below the existing grade (elevation 193.0 m ±) in Borehole BH G15, and about 4.7 m (elevation 191.5 m ±) in Borehole BH G16.

The groundwater levels were also measured in the monitoring well installed in Borehole BH G15. The results of groundwater measurements are shown on the Record of Boreholes and summarized in Table 5.2.

Table 5.2 - Results of Groundwater Measurements

Borehole	Measured Groundwater Level			Remarks
	Date	Depth (m)	Elevation (m)	
BH G15	18 May 2011	3.2 m ±	193.0 m ±	Completion of drilling
	14 June 2011	0.6 m ±	195.6 m ±	In monitoring well
	22 June 2011	0.8 m ±	195.4 m ±	
	23 June 2011	0.3 m ±	195.9 m ±	
	16 Aug 2011	0.9 m ±	195.3 m ±	
	17 May 2012	0.8 m ±	195.4 m ±	
BH G16	18 May 2011	4.7 m ±	191.5 m ±	Completion of drilling

It should be pointed out that the groundwater at the site would fluctuate seasonally and can be expected to be somewhat higher during the spring months and in response to major weather events.

6.0 DISCUSSION AND RECOMMENDATIONS

In preparation of this report, the following drawings were forwarded to AMEC:

- Hwy 21 Culvert Summary Table, dated 3 January 2011.
- MTO Drawing related to the culvert at Station 12+810 (ETR Plate No. 171-21/13-0).
- Cross-section at Station 12+810.

Based on the Culvert Summary Table provided by the Design Team, the existing culvert at Station 12+810 is CSP type, 0.61 m in diameter and 19.3 m long. The invert elevations of the culvert are 195.93 m (inlet) and 195.82 m (outlet). Based on the ETR Plate for the area, the existing fill cover over the culvert is about 2.0 m. As per recommendation by the AMEC Design Team, the existing culvert would be replaced.

From the investigation results, subsurface conditions at the site comprised predominantly topsoil underlain by native clayey silt deposit to termination depths (elevations 189.6 m in BH G15 and 189.7 m ± in BH G16. In Borehole BH G16, clayey silt fill was encountered between the topsoil and native clayey silt. The groundwater level was encountered at a depth of about 3.2 m below the existing grade(elevation 193.0 m ±) in Borehole BH G15, and about 4.7 m (elevation 191.5 m ±) in Borehole BH G16. Groundwater was measured in the monitoring well installed in Borehole BH G15, about three weeks after installation, the highest level being at 0.3 m ± (elevation 195.9 m ±). Stratigraphic cross-sections at the culvert are shown in Drawing No. 3.

At the time of preparation of this report, no detail design information with regard to the replacement culvert was available. It may be possible that the replacement culvert would be installed at the same location as or parallel and adjacent to the existing culvert. The feasibility of replacing the culvert by means of a trenchless method (e.g., pipe ramming) is considered in this report.

Considering the existing culvert size, location and soil conditions, open cut and trenchless technology (tunnelling) could be considered for the installation of the culvert replacement at the site. The geotechnical considerations for these methods are discussed in the following sections.

6.1 Open Cut Method

The existing culvert could be replaced by the open cut method with the following considerations.

6.1.1 Excavation

All excavations for the proposed replacement culvert should be carried out in accordance with the Occupational Health and Safety Act and Regulations for Construction Projects. The soils to be excavated can be classified as follows:

Clayey silt fill	Type 3
Soft clayey silt	Type 4
Firm to stiff clayey silt	Type 3
Very stiff to hard clayey silt	Type 2

Accordingly, a bank slope of 1H:1V is required for excavations in Type 2 and Type 3 soils in accordance with the Occupational Health and Safety Act and Regulations for Construction Projects. For Type 2 soil, a 1.2 m high vertical cut at the bottom of excavation may generally be constructed. For Type 4 soil, a bank slope of 3H:1V is required from the bottom of the excavation. A flatter slope may be required depending on the site and groundwater conditions. If open cut excavation cannot be carried out due to space restriction, temporary shoring will be required. The temporary shoring is discussed in Section 6.1.4.

Excavated materials should be stockpiled at least 3.0 m from the edge of the excavation to prevent slope instability.

Cobbles and boulders should be expected within the fill and native soils.

There may be underground utilities (gas, water, sewer and telephone) within the road embankment which may be exposed during the excavation. All utilities, if present, should be adequately supported or relocated prior to excavation work. Approval should be sought from relevant authorities and utilities companies regarding excavation works around such services.

6.1.2 Dewatering and Drain / Ditch Diversion

The groundwater levels measured in the boreholes are provided on the Record of Boreholes and Table 5.2 (Section 5.0). The invert of proposed replacement culvert would likely be above or close to the groundwater table, if the new culvert is installed at the same invert level of the existing culvert (invert elevation 196.0 m ±). Groundwater seepage is expected to be slow through the clayey silt soils, and could be dewatered using a system of sumps and pumps. High rate of seepage may occur from surface water and dewatering effort could require an increased number of sumps and pumps.

At the time of field work, water was noted in the drain / ditch. Provision must be made to divert water flows from one side of the highway to the other during construction.

For phased construction (i.e., replace one portion of the culvert at a time), the drain flow can be collected from the upstream side and pumped / diverted to the downstream side. The hoses could be run through the portion of the culvert still in place, and then routed around to the north or south limit of the construction excavation for the portion under construction. If the highway were closed entirely to traffic, the drain flows could be pumped / diverted around the excavation.

Given the variations in drain flow and depending on the extent of the work area, a cofferdam (earth dyke) or sheet-piling could be required to prevent drain flows from entering the work area and/or reducing the groundwater inflow into the excavation.

Dewatering plans must consider any flows from the highway side drains / ditches that enter into the drain / ditch at the culvert location.

Dewatering and drain / ditch diversion activities should proceed ahead of the excavation operation.

6.1.3 Traffic Protection and Temporary Detours

The following scenarios could be considered for construction:

- Scenario 1 - reduction of traffic to one-lane using staged open cut construction and provide a temporary detour;
- Scenario 2 - reduce traffic to one-lane using traffic protection (sheet-piling) with no temporary detour required; or
- Scenario 3 - close the road entirely to traffic and provide an alternate route.

It is recommended that practical aspects including traffic protection and temporary detours for the replacement of culvert should be as per contract design.

6.1.4 Temporary Shoring

The width of the open cut will likely be limited and supporting the sideslopes using a system of shoring may be required. The temporary shoring of the excavation should conform to OPSS 539: "Construction Specification for Temporary Protection Systems".

The temporary shoring system should be designed to resist the lateral earth, surcharge and hydrostatic pressure which could occur during construction. Bracings should also be installed within the shoring system to minimize movements of the soils. The design of temporary shoring should be carried out in accordance with Canadian Foundation Engineering Manual, 4th edition. Soil types and parameters for design considerations are summarized in Table 6.1.

Table 6.1 - Summary of Geotechnical Parameters

Soil Stratum	Bulk Unit Weight of Soil, γ (kN/m^3)	Angle of Internal Friction (degree)	Earth Pressure Coefficient[1]		
			At-rest, K_o	Active, K_a	Passive, K_p
Clayey silt fill	17	25	0.58	0.40	2.0
Clayey silt	20	28	0.53	0.35	2.0

(1) Values based on semi-empirical relationships. The K_p (passive condition) values are reduced in order to limit the lateral soil movement that is required to mobilize the passive resistance.

6.1.5 Bedding

The data from the boreholes suggests that the invert level of the proposed replacement culvert would likely be within the clayey silt soil. The replacement culvert should be founded on undisturbed native clayey silt below any existing fill. Fill soil, if encountered below the proposed culvert invert level, should be removed and replaced with compacted clean fill soils. The replacement culvert should be provided with granular bedding or lean concrete. The bedding material should consist of a well graded granular material such as Granular 'A' or better. The minimum bedding thickness shall be in accordance with OPSD 802.010. The thickness of the bedding may, however, have to be increased if wet or weak (soft to firm or loose) subgrade conditions are encountered. Cut-off walls below the culvert invert should be considered to prevent erosion below the culvert, particularly if granular bedding is used.

6.1.6 Backfilling

Based on visual and tactile examination of the soil samples, and the measured moisture contents of the soil samples, the on-site excavated clayey silt fill and native clayey silt could be generally be re-used as backfill provided their moisture contents at the time of construction are at or near optimum. All soils will likely require reconditioning prior to reuse (i.e. drying of the soil).

Backfill and cover for the replacement culvert should conform to OPSD 802.010 (*Flexible Pipe Embedment and Backfill, Earth Excavation*), while the frost treatment, where required, should follow OPSD 803.030 (*Frost Treatment – Pipe Culverts, Frost Penetration Line Below Bedding Grade*) and OPSD 803.031 (*Frost Treatment – Pipe Culverts, Frost Penetration Line between Top of Pipe and Bedding Grade*).

The reconstruction of the embankment slopes should match the existing slopes, with a maximum slope of 2H:1V.

6.2 Tunnelling Methods

Tunnelling procedures depend upon a number of factors, the most important of which are the groundwater conditions and the soil type through which the tunnel must pass. The following geotechnical factors should be considered for the selection of tunnelling method:

i. The proposed tunnelling method should cause minimal disturbance to the existing highway and its usage.
ii. The proposed tunnelling method would not cause instability of the existing highway embankments.

iii. The proposed tunnelling method should consider suitable means of groundwater dewatering during the tunnelling work, if it is encountered.
iv. A minimum soil cover (height of soil over the culvert crown) of 2.0 m should be maintained during tunneling except at the entrance and exit where applicable.

In view of the short length of culvert and soil conditions encountered at the site, the following two tunnelling methods may be considered, although other tunnelling methods (e.g., horizontal directional drilling) may also be considered, if applicable.

6.2.1 Jacking and Boring

Jacking and boring could be used directly at the existing culvert location by jacking a steel pipe with a larger diameter than the existing culvert, or nearby location.

This technique forms a horizontal bore hole from a drive shaft / pit to a reception shaft / pit by means of rotating cutting head. Spoil is transported back to the drive shaft / pit by helical auger flights rotating inside a steel casing. The casing is jacked in place simultaneously with the augering operation. After the installation of the steel casing, a new culvert pipe will be installed inside the casing and the gap between the casing and the pipe will be grouted.

Based on the soil condition encountered in Boreholes BH G15 and BH G16, the alignment of proposed pipe jacking and boring tunnelling will likely pass through the existing fill soil (clayey silt). The invert level of the replacement culvert is likely to be above or close to the groundwater level (Section 6.1.2). It is cautioned that soil/groundwater condition between and beyond the borehole locations may be different and that cobbles / boulders may be encountered. The groundwater level may also vary seasonally and perched water may be present. The anticipated tunneling condition is ‘firm’ according to Tunnelman’s Ground Classification. Should silt and / or sand seams / lenses or weak zones be encountered during tunnelling, some local instability or seepage could occur.

Provision for handling groundwater seepage during tunneling should be discussed and a contingency plan should be in place prior to commencement of tunnelling work. At this site, groundwater seepage, if any during tunnelling, may be handled by gravity drainage and pumping from open sumps and pumps (Section 6.1.2). The tunnelling alignment should be provided with a gentle gradient so that water seepage into the opening can be directed away from the tunnel face. If there is a possibility of loss of soils due to high groundwater seepage into the tunnel, proper measures(s) should be implemented (e.g., installing a shield or plug at the tunnel face, grouting the soils around the tunnel prior to excavation, etc.). As a minimum and as a preventive measure against development of flowing or running condition and to maintain stability of the tunnel face, a plug of soil should be left inside the front end of the tunnel casing at all times, i.e. the steel casing should advance slightly beyond the excavated soil face. The size of the plug depends on the soil and groundwater condition encountered the time of tunnelling. If unexpected high groundwater flow is encountered and/or loss of soil through the tunnel is excessive, the tunnel operation should be stopped immediately and remedial measures should be taken to stabilize the tunnel face. Potential gap between the tunnel casing and the soil, after the completion of tunnelling, should be grouted to reduce settlements.

Cobbles and boulders should be expected within the fill and native soils.

The construction of the tunnel should comply with OPSS 416: “Construction Specification for Pipeline and Utility Installation by Jacking and Boring”.

The work should be carried out by specialized contractor experienced with such jacking and boring work.

The soil parameters presented in Section 6.1.4 are also applicable with this method. Further, the following soil parameters may be used preliminary design purposes:

- Adhesion between the steel casing and surrounding soil: 50 kPa.
- Modulus of Elasticity, E, for the surrounding soil: 30 MPa.

6.2.2 Pipe Ramming

Pipe ramming could be used directly at the location of the existing culvert or nearby by ramming a steel pipe with a larger diameter than the existing culvert, or nearby location.

The pipe ramming is an established and widely used trenchless method for installation of steel pipes and casings. In operation, pipe ramming method utilizes a pneumatic tool to hammer the pipe into the ground. The spoils inside the pipe can be removed either during or after the installation. The pipe ramming method is applicable in a wide variety of soils and frequently used under railway and road embankments where pipe installation is required for relatively short lengths. Pipe ramming operation generates vibrations to the soil and noise.

This method is feasible for cohesionless and cohesive soils.

Discussion provided for jacking and boring in Section 6.2.1 is also applicable with this method.

6.2.3 Concluding Remarks

Based on the requirements of the project and the soil conditions, any of the two tunnelling methods may be used. The steel casing may be used directly as the new culvert if acceptable by the designer. Tunnelling method to be selected should cause minimum disturbance to Highway 21.

It is recommended that practical aspects for the best suited/economical method of installation be discussed with experienced tunnel contractors prior to commencement of the tunnelling work.

6.3 Comparison of the Construction Techniques

A comparison of the construction techniques (open cut and tunnelling) are provided in Table 6.2.

Table 6.2 - Comparison of Construction Methods

Construction Technique	Description	Advantages	Disadvantages	Risks / Consequences	Cost Comparison
Open Cut	Open cut or shored excavation to replace existing CSP culvert.	Use of standard excavation and construction equipment. - No specialist contractor is required. - Maintain the existing culvert location.	Disruption to traffic by opening only one lane or road closure. - Will require roadside protection (trench box or similar) to maintain traffic flow. A sliding trench box can be used. Traffic signalling will be required for one lane traffic. - Temporary dewatering and / or detouring of the existing water way will be required. - Will require rebuilding of embankment fills and road.	Excavation sideslopes may not be stable during construction due to rainfall, groundwater, etc.	Low to Medium
Tunnelling by Jacking and Boring / Pipe Ramming	- Boring underneath the embankment and jacking/ramming a new pipe into place. - Will require jacking and receiving pits.	- No disruption to traffic flow.	- Requires specialist contractor and specialized equipment. - Will require dewatering of jacking and receiving pits. - Temporary diversion of water way into and out of proposed replacement culvert location.	- Soil condition based on limited borehole data. - Risk of encountering cobbles / boulders, which may complicate jacking and boring / ramming operations. - Jacking and boring / ramming through wet to saturated fine grained soil may result in construction difficulties with the stability of the bore face. - Jacking and boring / ramming below embankment soils may result in settlement within embankment.	Medium to High

Based on the above comparison of the construction techniques, the open cut method would likely be less costly. However, if interrupting the traffic on Highway 21 is to be avoided, tunnelling should be considered.

6.4 Entry / Receiver Pits

In constructing the tunnels, pits are required on both ends. The pits for the liner installation are expected to be at or below a depth of about 1 m to 2 m below the existing culvert invert. The soils to be excavated may consist of fill soils (clayey silt) and native clayey silt deposit. Subgrade materials for supporting tunnelling equipment at the pits would likely consist of native stiff to hard clayey silt. Groundwater and dewatering is discussed in Sections 6.1.1 and 6.1.2 respectively. Geotechnical reaction of 100 kPa (SLS) and geotechnical resistance of 150 kPa (factored ULS) are recommended for consideration when the equipment is founded on native undisturbed soil. The exposed base of the entry / receiver pits should be covered with a mud slab to protect the subgrade from disturbance, and to provide a stable platform for pipe jacking/ramming operation.

6.5 Settlement Monitoring

During tunnelling, the ground over and in the vicinity of the tunnel alignment may experience settlement. Good workmanship and site control is the most effect way to reduce settlements to practical minimum. It is recommended that ground movement during tunnelling be monitored. This is to confirm that the tunnelling process does not cause any significant impact on the existing soil and groundwater conditions. If any adverse effect of tunnelling is identified by the monitoring program, the tunneling process can be modified accordingly.

Settlement monitoring should follow the MTO Settlement Monitoring Guidelines – Tunnelling, which is attached in Appendix D of this report. As per the guideline, a maximum settlement of 10 mm relative to baseline readings should be considered as review level, at which the method, rate or sequence of construction and/or ground stabilization measures should be reviewed and/or modified to mitigate further ground displacement. Furthermore, an alert level of a maximum settlement of 15 mm relative to baseline readings is recommended, at which stage the construction operation should be stopped, and measures to secure the site and to mitigate further movement should be immediately taken to ensure public safety and maintenance of traffic flow.

6.6 Soil Corrosivity

One soil sample (BH G15 - SS 2) was analysed by Maxxam Analytics Laboratory in Mississauga to determine the soil corrosivity potential with respect to concrete and steel. The Certificate of Analysis is included in Appendix B. A summary of the test results is presented in Table 6.3.

Table 6.3 - Results of Corrosivity Test

Soil Sample No.	pH	Electrical Conductivity µmho/cm	Resistivity (ohms-cm)	Chloride (µg/g)	Sulphate (µg/g)
BH G15 - SS 2	7.6	166	6000	<20	<20

The test results have shown that the sulphate content of the soil is <20 ppm (µg/g). As per Table 3 "Additional Requirements for concrete subjected to sulphate attack", Clause 4.1.1.6 of CSA Standards Specification A23.1-09, any soil which has sulphate content below 0.1% (i.e., 1,000 ppm or µg/g) is not considered aggressive with respect to concrete. As such, in accordance with Table 6 of CSA A23.1-09, Type GU (general use) cement can be used for concrete.

Based on the results of soil resistivity of analyzed soil sample, the degree of corrosivity should be considered as "mild" for exposed metallic structures. This is based on a comparison of the test results to literature reference (J.D. Palmer, Soil Resistivity Measurement and Analysis, Materials Performance, Volume 13, 1974).

A corrosion specialist should be retained, if necessary, to review the test results and provide recommendation for the most effective protection solutions.

6.7 Earthquake Considerations

In conformance with the criteria in Clause 4.4.6.2 in Section 4: Seismic Design of the Canadian Highway Bridge Design Code CAN/CSA-S6-06, the Site Soil profile is Type I.

7.0 CLOSURE

The sub-soil information contained in this report should be used solely for the purpose of foundation assessment of the culvert site at Station 12+810 on Highway 21, north of Bayfield, Ontario.

The Limitations of Report is an integral part of this report.

This report was prepared by Mohammad Mollah, M.Eng., P.Eng., and was reviewed by Dr. Prapote Boonsinsuk, Ph.D., P.Eng.

Sincerely,

AMEC Environment & Infrastructure,
a Division of AMEC Americas Limited

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a Division of AMEC Americas Limited

LIMITATIONS OF REPORT

The conclusions and recommendations given in this report are based on information determined at the testhole locations. The information contained herein in no way reflects on the environmental aspects of the project, unless otherwise stated. Subsurface and groundwater conditions between and beyond the testholes may differ from those encountered at the testhole locations, and conditions may become apparent during construction, which could not be detected or anticipated at the time of the site investigation.

The design recommendations given in this report are applicable only to the project described in the text, and then only if constructed substantially in accordance with the details stated in this report.

The comments made in this report relating to potential construction problems and possible methods of construction are intended only for the guidance of the designer. The number of testholes may not be sufficient to determine all the factors that may affect construction methods and costs. The contractors bidding on this project or undertaking the construction should, therefore, make their own interpretation of the factual information presented and draw their own conclusions as to how the subsurface conditions may affect their work. This work has been undertaken in accordance with normally accepted geotechnical engineering practices.

This report was prepared specifically for the culvert at Station 12+810 in Highway 21 north of Bayfield Ontario, as described in the report. Any use which a third party makes of this report, or any reliance on or decisions to be made based on it, are the responsibility of such third parties. AMEC Environment & Infrastructure, a Division of AMEC Americas Limited, accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this report.

List of Construction Specifications and Drawings

Specification / Drawing	Title
Specifications	
OPSS 180 (Nov/11)	General Specification for the Management and Disposal of Excess Materials
OPSS 206 (Nov/09)	Construction Specification for Grading (Re-issued 2010-11)
OPSS 501 (Nov/10)	Construction Specification for Compacting
OPSS 511 (Apr/11)	Construction Specification for rip-rap, rock protection, and granular sheeting
OPSS 539 (Nov/09)	Construction Specification for temporary protection systems
OPSS 572 (Nov/03)	Construction Specification for Seed and Cover
OPSS 802 (Nov/10)	Construction Specification for Topsoil
OPSS 803 (Nov/10)	Construction Specification for Sodding
OPSS 804 (Nov/10)	Construction Specification for Seed and Cover
OPSS 902 (Nov/10)	Construction Specifications for excavating and Backfilling of structures
OPSS 1004 (Nov/06)	Material Specifications for Aggregates - Miscellaneous
OPSS 1010(Apr/04)	Material Specifications for Aggregates – Base, subbase, select subgrade, and backfill material
OPSS 1860 (Apr/12)	Material Specification for Geotextiles
Drawings	
OPSD 208.010	Benching of Earth Slopes
OPSD 802.010	Flexible Pipe Embedment and Backfill, Earth Excavation
OPSD 803.030	Frost Treatment – Pipe Culverts, Frost Penetration Line Below Bedding Grade
OPSD 803.031	Frost Treatment – Pipe Culverts, Frost Penetration Line between Top of Pipe and Bedding Grade
OPSD 810.010	Rip-rap treatment for sewer and culvert outlets

DRAWINGS

DRAWING NO. 1	CULVERT LOCATION PLAN
DRAWING NO. 2	BOREHOLE LOCATION PLAN
DRAWING NO. 3	STRATIGRAPHIC CROSS SECTIONS

SCALE

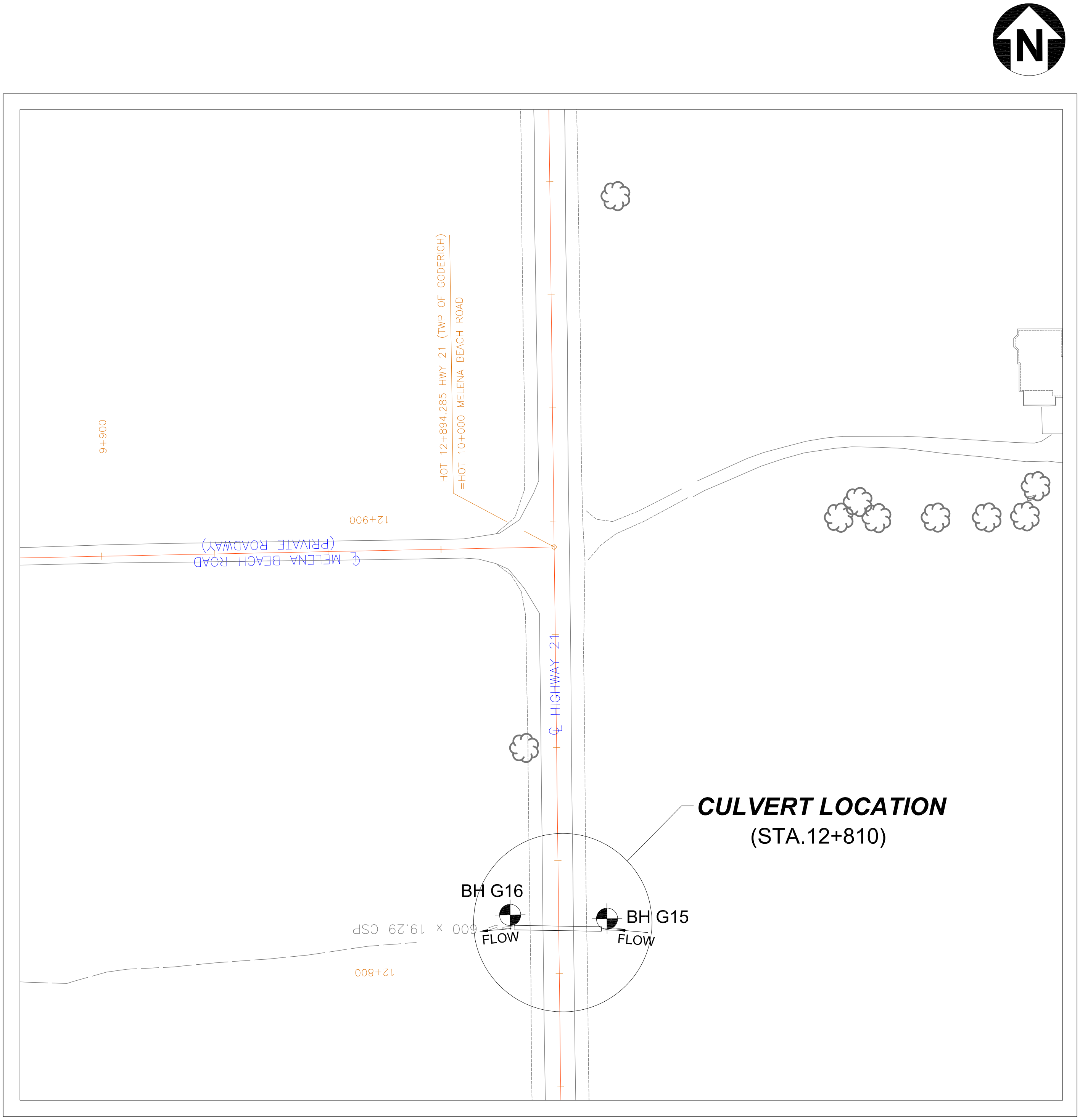
1500m 0 1500 3000 4500 6000m

LEGEND

● CULVERT LOCATION

AMEC Environment & Infrastructure, a Division of AMEC Americas Limited	amec	CLIENT LOGO: Ontario	CLIENT: MINISTRY OF TRANSPORTATION ONTARIO WEST REGION

TITLE: CULVERT LOCATION PLAN	DWN BY: KW	DATUM: -	DATE: JANUARY 2013
PROJECT: REHABILITATION OF HIGHWAY 21 - FROM BAYFIELD TO GODERICH, ONTARIO PURCHASE ORDER NUMBER: 3009-E-0022, WP 834-93-00, GEOCRES No.: 40P12-28	CHK'D BY: PB	REV. NO.: A	PROJECT NO: TP110076
	PROJECTION: -	SCALE: AS SHOWN	DRAWING No. 1



SCALE

15m 0 15 30 45 60m

AMEC Environment & Infrastructure,
a Division of AMEC Americas Limited

amec

CLIENT LOGO: Ontario

CLIENT: MINISTRY OF TRANSPORTATION ONTARIO WEST REGION

TITLE: BOREHOLE LOCATION PLAN	DWN BY: KW	DATUM: -	DATE: JANUARY 2013
PROJECT: REHABILITATION OF HIGHWAY 21 - FROM BAYFIELD TO GODERICH, ONTARIO PURCHASE ORDER NUMBER: 3009-E-0022, WP 834-93-00, GEOCRES No.: 40P12-28	CHK'D BY: PB	REV. NO.: A	PROJECT NO: TP110076
	PROJECTION: -	SCALE: AS SHOWN	DRAWING No. 2

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

PURCHASE ORDER NUMBER: 3009-E-0022

G.W.P. No. 834-93-00

REHABILITATION OF HWY 21 FROM BAYFIELD TO GODERICH
GEOCRES No.40P12-28
CULVERT AT STA 12+810
STRATIGRAPHIC CROSS SECTION

SHEET 1 OF 1

amec
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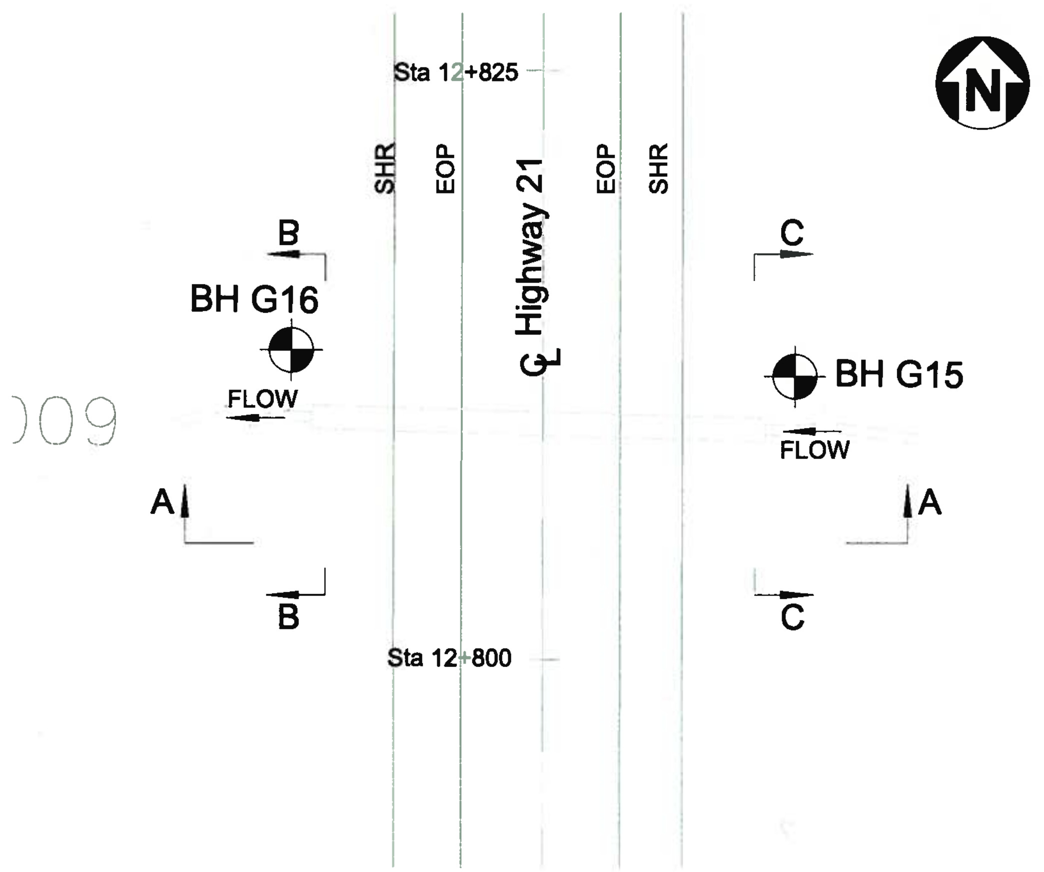
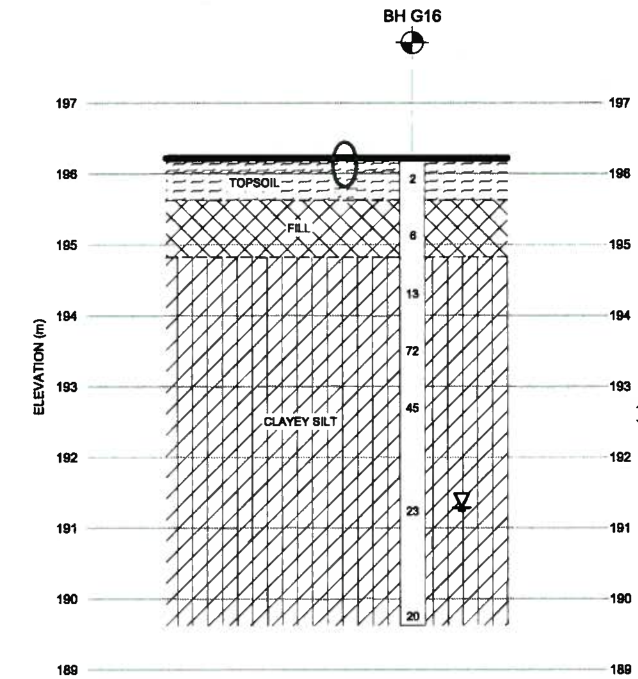
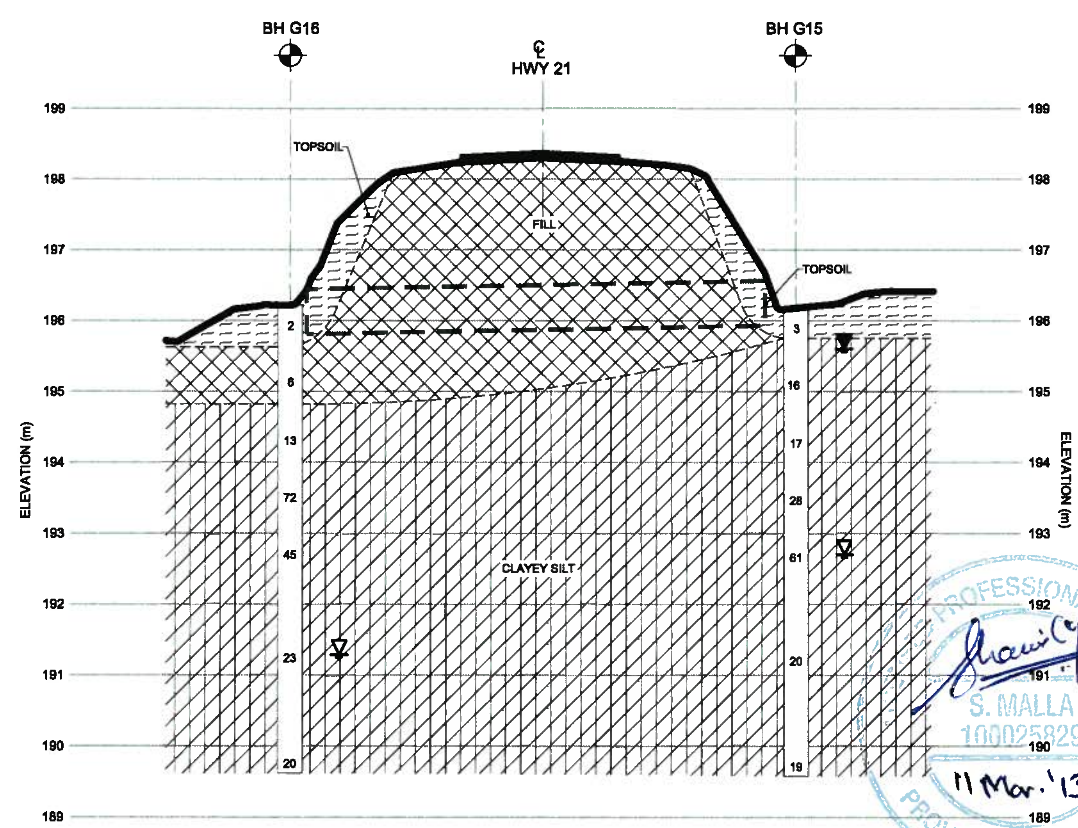


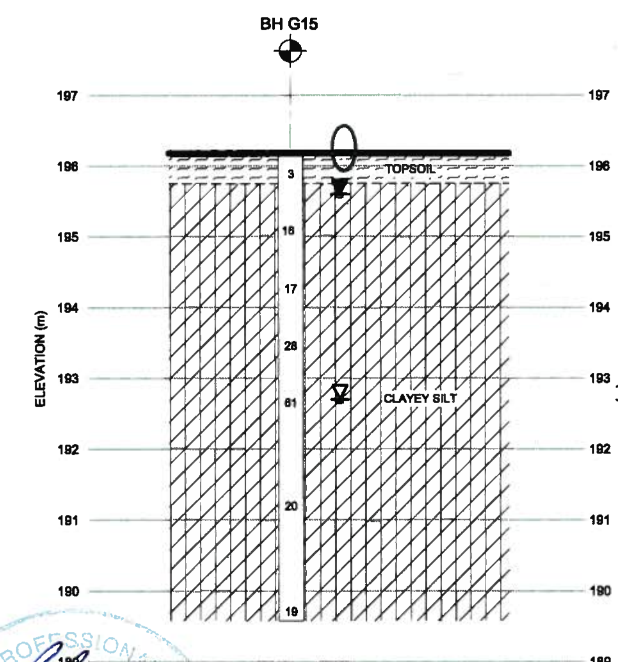
PLAN



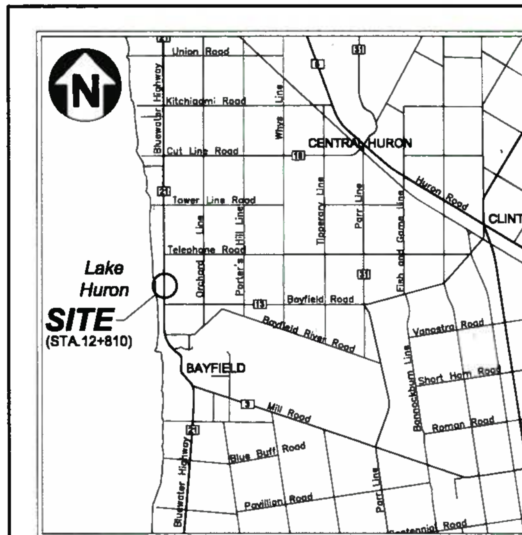
SECTION B-B



SECTION A-A



SECTION C-C



KEY PLAN

Approximate Scale

SCALE
0 4 8 12m HOR
0 1 2 3m VER

LEGEND

- BOREHOLE LOCATION
- GROUNDWATER LEVEL AT TIME OF INVESTIGATION
- GROUNDWATER LEVEL IN MONITORING WELL
- EOP EDGE OF PAVEMENT
- SHR SHOULDER ROUND

DESCRIPTION	UTM COORDINATES NORTHING	UTM COORDINATES EASTING	ELEVATION (m)
BH G15	4826850	443051	196.18
BH G16	4826850	443029	196.22

NOTES:

1. The boundaries between soil strata have been established only at borehole locations. Between boreholes, the boundaries are assumed from geological evidence and may be subject to considerable error.
2. This drawing is for subsurface information only. Surface details and features are for conceptual illustration.
3. Borehole without ▽ ▼ was dry.

SOIL STRATIGRAPHY

- TOPSOIL
- CLAYEY SILT
- FILL

PROFESSIONAL ENGINEER S. MALLA 100025829 11 Mar.'13 PROVINCE OF ONTARIO

LICENSED PROFESSIONAL ENGINEER P. BOONSINSUK 11 Mar '13 PROVINCE OF ONTARIO

REVISIONS

DESIGN PB	CHK PB	CODE CHBDC-06	CL 625-ONT	DATE JAN. 2013
DRAWN KW	CHK HS	SITE 12+810		DWG 3

P:\GEOProjects\2011\TP-Burlington\TP110076\HWY 21105-Foundation\Drawings\TP110076_HWY21_Cul_Sections_and_BHPlans.dwg

APPENDIX A

RECORD OF BOREHOLES

EXPLANATION OF BOREHOLE LOG

This form describes some of the information provided on the borehole logs, which is based primarily on examination of the recovered samples, and the results of the field and laboratory tests. Additional description of the soil/rock encountered is given in the accompanying geotechnical report.

GENERAL INFORMATION

Project details, borehole number, location coordinates and type of drilling equipment used are given at the top of the borehole log.

SOIL LITHOLOGY

Elevation and Depth

This column gives the elevation and depth of inferred geologic layers. The elevation is referred to the datum shown in the Description column.

Lithology Plot

This column presents a graphic depiction of the soil and rock stratigraphy encountered within the borehole.

Description

This column gives a description of the soil stratums, based on visual and tactile examination of the samples augmented with field and laboratory test results. Each stratum is described according to the *MTC Soil Classification Manual*.

The compactness condition of cohesionless soils (SPT) and the consistency of cohesive soils (undrained shear strength) are defined as follows *(Ref. MTC Soil Classification Manual)*:

Compactness of Cohesionless Soils	SPT N-Value*
Very loose	0 to 5
Loose	5 to 10
Compact	10 to 30
Dense	30 to 50
Very Dense	> 50

Consistency of Cohesive Soils	Undrained Shear Strength kPa
Very soft	0 to 12
Soft	12 to 25
Firm	25 to 50
Stiff	50 to 100
Very stiff	100 to 200
Hard	Over 200

* For penetration of less than 0.3 m, N-values are indicated as the number of blows for the penetration achieved (e.g. 50/25: 50 blows for 25 centimeter penetration).

Soil Sampling

Sample types are abbreviated as follows:

SS	Split Spoon	TW	Thin Wall Open (Pushed)	RC	Rock Core	GS	Grab Sample
AS	Auger Sample	TP	Thin Wall Piston (Pushed)	WS	Washed Sample	AR	Air Return Sample

Additional information provided in this section includes sample numbering, sample recovery and numerical testing results.

Field and Laboratory Testing

Results of field testing (e.g., SPT, pocket penetrometer, and vane testing) and laboratory testing (e.g., natural moisture content, and limits) executed on the recovered samples are plotted in this section.

Instrumentation Installation

Instrumentation installations (monitoring wells, piezometers, inclinometers, etc.) are plotted in this section. Water levels, if measured during fieldwork, are also plotted. These water levels may or may not be representative of the static groundwater level depending on the nature of soil stratum where the piezometer tips are located, the time elapsed from installation to reading and other applicable factors.

Comments

This column is used to describe non-standard situations or notes of interest.

MTC SOIL CLASSIFICATION
Based on MTC Soil Classification Manual

Ontario

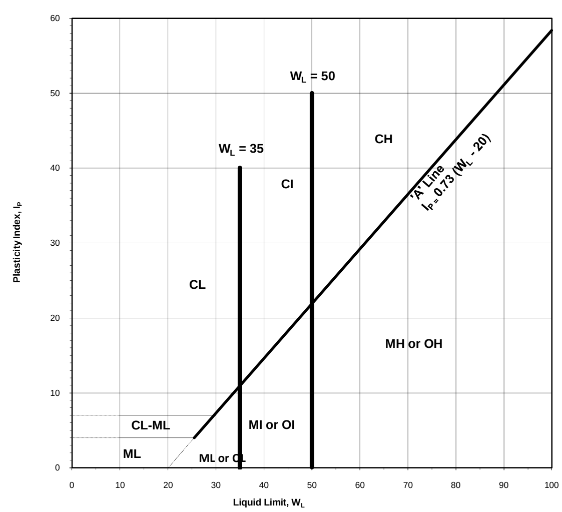
MAJOR DIVISION				GROUP SYMBOL	TYPICAL DESCRIPTION	INFORMATION REQUIRED FOR DESCRIBING SOILS		LABORATORY CLASSIFICATION CRITERIA	
COARSE GRAINED SOILS (MORE THAN HALF BY WEIGHT LARGER THAN 75µm)	GRAVELS MORE THAN HALF THE COARSE FRACTION LARGER THAN 4.75mm	CLEAN GRAVELS (LITTLE OR NO FINES)	WIDE RANGE IN GRAIN SIZE & SUBSTANTIAL AMOUNTS OF ALL INTERMEDIATE PARTICAL SIZE	GW	WELL GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES	GIVE TYPE, NAME, IF NECESSARY, INDICATE APPROX % OF SAND & GRAVEL ; MAX SIZE; ANGULARITY, SURFACE CONDITION, & HARDNESSOF THE COARSE GRAINS, LOCAL OR GEOLOGICAL NAME & OTHER PERTINENT DESCRICTIVE INFORMATION, & SYMBOL IN PARENTHESIS.	USE GRAIN SIZE CURVE IN IDENTIFYING THE FACTORS AS GIVEN UNDER FIELD IDENTIFICATION	$C_u = \frac{D_{60}}{D_{10}}$ GREATER THAN 4; $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ BETWEEN 1 AND 3	
			PREDOMINANTLY ONE SIZE OF A RANGE OF SIZES WITH STONE INTERMEDIATE SIZES MISSING	GP	POORLY GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES				
		GRAVEL WITH FINES (APPLICABLE AMOUNT OF FINES)	NON PLASTIC FINES (FOR IDENTIFICATION PROCEDURES SEE ML BELOW)	GM	SILTY GRAVELS, POORLY GRADED GRAVEL-SAND- SILT MIXTURES				
			PLASTIC FINES (FOR IDENTIFICATION PROCEDURES SEE CL BELOW)	GC	CLAYEY GRAVELS, POORLY GRADED GRAVEL-SAND-CLAY MIXTURES				
	SANDS MORE THAN HALF THE COARSE FRACTION SMALLER THAN 4.75mm	CLEAN SANDS (LITTLE OR NO FINES)	WIDE RANGE IN GRAIN SIZE & SUBSTANTIAL AMOUNT OF ALL INTERMEDIATE PARTICLE SIZES	SW	WELL GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES	FOR UNDISTURBED SOILS ADD INFORMATION ON STRATIFICATION, DEGREE OF COMPACTNESS, CEMENTATION, MOISTURE CONDITION & DRAINAGE CHARACTERISTICS		NOT MEETING ALL GRADATION REQUIREMENTS FOR GW	
			PREDOMINANTLY ONE SIZE OR A RANGE OF SIZES WITH SOME INTERMEDIATE SIZE MISSING	SP	POORLY GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES				
		SANDS WITH FINES (APPLICABLE AMOUNT OF FINES)	NON PLASTIC FINES (FOR IDENTIFICATION PROCEDURES SEE ML BELOW)	SM	SILTY SANDS, POORLY GRADED SAND-SILT MIXTURES			ATTERBERG LIMITS BELOW A-LINE OR Ip LESS THAN 4	ABOVE A-LINE WITH Ip BETWEEN 4 AND 7 ARE BORDERLINE CASES REQUIRING USE OF DUAL SYMBOLS
			PLASTIC FINES (FOR IDENTIFICATION PROCEDURES SEE CL BELOW)	SC	CLAYEY SANDS, POORLY GRADED SAND-CLAY MIXTURES		DETERMINE PERCENTAGE OF GRAVEL & SAND FROM GRAIN SIZE CURVE. DEPENDING ON PERCENTAGE OF FINES (FRACTION SMALLER THAN 75 µm) COARSE GRAINED SOILS ARE CLASSIFIED AS FOLLOWS: LESS THAN 5% GW, GP, SW, SP; MORE THAN 12% GM, GC, SM, SC; 5% TO 12% BORDER LINE CASES REQUIRE USE OF DUAL SYMBOL.	ATTERBERG LIMITS ABOVE A- LINE WITH Ip GREATER THAN 7	

			IDENTIFICATION PROCEDURE ON FRACTION SMALLER THAN 425µm			GROUP SYMBOL	TYPICAL DESCRIPTION	INFORMATION REQUIRED	LABORATORY CLASSIFICATION CRITERIA	
FINE-GRAINED SOILS (MORE THAN HALF BY WEIGHT SMALLER THAN 75µm)	SILT AND CLAYS		DRY STRENGTH (CRUSHING CHARACTERISTICS)	DILATANCY (REACTION TO SHAKING)	TOUGHNESS (CONSISTENCY NEAR PLASTIC LIMIT)					
		LIQUID LIMIT LESS THAN 35	NONE	QUICK	NONE	ML	INORGANIC SILTS & SANDY SILTS OR SLIGHTLY PLASTICITY, ROCK FLOUR	GIVE TYPE, NAME, IF NECESSARY, INDICATE DEGREE AND CHARACTER OF PLASTICITY, AMOUNT AND MAXIMUM SIZE OF COURSE GRAINS, COLOUR IN WET CONDITION, ODOUR, IF ANY, LOCAL OR GEOLOGIC NAME & OTHER PERTINENT DESCRICTIVE INFORMATION & SYMBOL IN PARENTHESIS.	$C_u = \frac{D_{60}}{D_{10}}$ GREATER THAN 6; $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ BETWEEN 1 AND 3	
			MEDIUM TO HIGH	NONE TO VERY SLOW	MEDIUM	CL	SILTY CLAYS (INORGANIC), GRAVELLY CLAYS, SANDY CLAYS, LEAN CLAYS			
			SLIGHT TO MEDIUM	SLOW	SLIGHT	OL	ORGANIC SILT OF LOW PLASTICITY, ORGANIC SANDY SILTS			
		LIQUID LIMIT BETWEEN 35 AND 50	NONE TO SLIGHT	SLOW TO QUICK	SLIGHT	MI	INORGANIC COMPRESSIBLE FINE SANDY SILT WITH CLAY OF MEDIUM PLASTICIT, CLAYEY SILTS			
			HIGH	NONE	MEDIUM TO HIGH	CI	SILTY CLAYS (INORGANIC) OF MEDIUM PLASTICITY		NOT MEETING ALL GRADATION FOR SW	
			SLIGHT TO MEDIUM	VERY SLOW	SLIGHT	OI	ORGANIC SILTY CLAYS OF MEDIUM PLASTICITY	FOR UNDISTURBED SOILS AND INFORMATION ON STRUCTURE, STRATIFICATION, CONSISTANCY IN UNDISTURBED AND REMOLDED STATES, MOISTURE & DRAINAGE CONDITION.		
		LIQUID LIMIT GREATER THAN 50	SLIGHT TO MEDIUM	SLOW TO NONE	MEDIUM	MH	INORGANIC SILTS, HIGHLY COMPRESSIBLE MICACEOUS OR DIATOMECACOUS FINE SANDY SILTS, ELASTIC SILTS		ATTERBERG LIMITS BELOW A- LINE OR Ip LESS THAN 4	ABOVE A-LINE WITH Ip BETWEEN 4 AND 7 ARE BORDERLINE CASES REQUIRING USE OF DUAL SYMBOLS
			HIGH TO VERY HIGH	NONE	HIGH	CH	CLAYS (INORGANIC) OF HIGH PLASTICITY, FAT CLAYS			
			MEDIUM TO HIGH	NONE TO VERY SLOW	SLIGHT TO MEDIUM	OH	ORGANIC CLAYS OF HIGH PLASTICITY		ATTERBERG LIMITS ABOVE A- LINE WITH Ip GREATER THAN 7	
HIGH ORGANIC SOILS			READILY IDENTIFIED BY COLOUR, ODOUR, SPONGY FEEL & FREQUENTLY BY FIBROUS TEXTURE			Pt	PEAT AND OTHER HIGHLY ORGANIC SOILS			

FRACTION		U.S STANDARD SIEVE SIZE		DEFINING RANGES OF PERCENTAGE BY WEIGHT OF MINOR COMPONENTS	
		PASSING	RETAINED	PERCENT	DESCRIPTOR
GRAVEL	COARSE	75 mm	26.5 mm	40-50	AND
	FINE	26.5 mm	4.75 mm	30-40	Y/EY
SAND	COARSE	4.75 mm	2.00 mm	20-30	WITH
	MEDIUM	2.00 mm	425 µm	10-20	SOME
	FINE	425 µm	75 µm	1-10	TRACE
FINES (SILT OR CLAY BASED ON PLASTICITY)		75 µm			

OVERSIZED MATERIAL

ROUNDED OR SUBROUNDED	NOT ROUNDED
ROUNDED OR SUBROUNDED: COBBLES 75 mm TO 200 mm BOULDERS > 200 mm	NOT ROUNDED: ROCK FRAGMENTS > 75 mm ROCKS > 0.76 CUBIC METRE IN VOLUME



PLASTICITY CHART
FOR LABORATORY CLASSIFICATION OF FINE GRAINED SOILS

BOUNDARY CLASSIFICATION: BOUNDARY CLASSIFICATION: SOILS POSSESSING CHARACTERISTICS OF TWO GROUPS ARE DESIGNATED BY COMBINATIONS OF GROUP SYMBOLS FOE EXAMPLE GW-GC WELL GRADED GRAVEL-SAND MIXTURE WITH CLAY BINDER

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www.amec.com

MTC SOIL CLASSIFICATION MANUAL

ENGINEERING PROPERTIES OF SOIL

Ontario

TYPICAL NAMES OF SOIL GROUPS	GROUP SYMBOLS	PERMEABILITY WHEN COMPACTED	STRENGTH WHEN COMPACTED	COMPRESSIBILITY WHEN COMPACTED	WORKABILITY AS A CONSTRUCTION MATERIAL	SCOUR RESISTANCE	SUSCEPTIBI LIIY TO SURFICIAL EROSION	SUSCEPTIBILI TY TO FROST ACTION	DRAINAGE CHARACTERISTICS
WELL-GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES	GW	PERVIOUS	EXCELLENT	NEGLIGIBLE	EXCELLENT	MEDIUM	NEGLIGIBLE	NEGLIGIBLE	EXCELLENT
POORLY GRADED GRAVELS, GRAVEL-SAND MIXTURES, LITTLE OR NO FINES	GP	VERY PERVI0US	GOOD	NEGLIGIBLE	GOOD	MEDIUM	NEGLIGIBLE	NEGLIGIBLE	EXCELLENT
SILTY GRAVELS, POORLY GRADED GRAVEL- SAND-SILT MIXTURES	GM	SEMI-PERVIOUS TO IMPERVIOUS	GOOD	NEGLIGIBLE	GOOD	LOW TO MEDIUM	SLIGHT	SLIGHT	FAIR TO SEMI IMPERVIOUS
CLAYEY GRAVELS, POORLY GRADED GRAVEL-SAND-CLAY MIXTURES	GC	IMPERVIOUS	GOOD TO FAIR	VERY LOW	GOOD	MEDIUM	SLIGHT	NEGLIGIBLE TO SLIGHT	PRACTICALLY IMPERVIOUS
WELL-GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES	SW	PERVIOUS	EXCELLENT	NEGLIGIBLE	EXCELLENT	LOW TO MEDIUM	SLIGHT	NEGLIGIBLE	EXCELLENT
POORLY GRADED SANDS, GRAVELLY SANDS, LITTLE OR NO FINES	SP	PERVIOUS	GOOD	VERY LOW	FAIR TO GOOD	LOW TO MEDIUM	MODERATE	NEGLIGIBLE TO SLIGHT	EXCELLENT
SILTY SANDS, POORLY GRADED SAND-SILT MIXTURES	SM	SEMI-PERVIOUS TO IMPERVIOUS	GOOD	LOW	FAIR	LOW	MODERATE	SLIGHT TO MODERATE	FAIR TO SEMI IMPERVIOUS IMPERVIOUS
CLAYEY SANDS, POORLY GRADED SAND WITH SOME CLAY MIXTURES	SC	IMPERVIOUS	GOOD TO FAIR	LOW	GOOD	VERY LOW TO LOW	MODERATE TO SLIGHT	NEGLIGIBLE	PRACTICALLY IMPERVIOUS
INORGANIC SILTS AND SANDY SILTS OF SLIGHT PLASTICITY, ROCK FLOUR	ML	SEMI-PERVIOUS TO IMPERVIOUS	FAIR	MEDIUM	FAIR	VERY LOW	SEVERE	SEVERE	FAIR TO POOR
INORGANIC CLAYEY SILTS OF LOW PLASTICITY, GRAVELLY CLAYS, SANDY CLAYS, LEAN CLAYS	CL	IMPERVIOUS	FAIR	MEDIUM	GOOD TO FAIR	LOW TO MEDIUM	SLIGHT TO MODERATE	MODERATE TO SEVERE	PRACTICALLY IMPERVIOUS
ORGANIC SILTS OF LOW PLASTICITY	OL	SEMI-PERVIOUS TO IMPERVIOUS	POOR	MEDIUM	FAIR TO POOR	VERY LOW TO LOW	SEVERE	SEVERE	POOR
INORGANIC COMPRESSIBLE SILTS OF MEDIUM PLASTICITY	MI	SEMI-PERVIOUS TO IMPERVIOUS	FAIR	MEDIUM TO HIGH	FAIR TO POOR	LOW	MODERATE	MODERATE TO SEVERE	FAIR TO POOR
INORGANIC SILTY CLAYS OF MEDIUM PLASTICITY	CI	IMPERVIOUS	FAIR TO POOR	HIGH	FAIR	LOW TO MEDIUM	SLIGHT	MODERATE TO SEVERE	SEMI IMPERVIOUS TO PRACTICALL Y
ORGANIC SILTY CLAY OF MEDIUM PLASTICITY	OI	SEMI-PERVI0US TO IMPERVIOUS	POOR	HIGH	POOR	VERY LOW TO LOW	SEVERE	MODERATE TO SEVERE	POOR TO PRACTICALLY IMPERVIOUS
INORGANIC SILTS, MICACEOUS OR DIATOMACEOUS FINE SANDY OR SILTY SOILS, ELASTIC SILTS	MH	SEMI-PERVIOUS TO IMPERVIOUS	FAIR TO POOR	HIGH	POOR	VERY LOW	MEDIUM	SEVERE	POOR
INORGANIC CLAYS OF HIGH PLASTICITY, FAT CLAYS	CH	IMPERVIOUS	POOR	HIGH	FAIR TO POOR	LOW TO MEDIUM	SLIGHT TO NEGLIGIBLE	NEGLIGIBLE	PRACT I.CALL Y IMPERVIOUS
ORGANIC CLAYS OF HIGH PLASTICITY	OH	IMPERVIOUS	POOR	HIGH	POOR	LOW	MODERATE	NEGLIGIBLE TO SLIGHT	PRACTICALLY IMPERVIOUS
PEAT AND OTHER HIGHLY ORGANIC SOILS	Pt	-	-	-	-	LOW	SEVERE	-	FAIR TO GOOD

Ontario

RECORD OF BOREHOLE No. BH G15

G.W.P. 834-93-00 | LOCATION Sta: 12+810, 2.3 m N of Culvert, 10.7 m Rt of CL of Rd, E 443051; N 4826850 | ORIGINATED BY JF

DIST Goderich HWY 21 | BOREHOLE TYPE 150 mm diameter borehole (Solid Stem) | COMPILED BY SAL

DATUM Geodetic | DATE May 18, 2011 - May 18, 2011 | CHECKED BY SM

PROJECT Rehabilitation of Highway 21, from Bayfield to Goderich, Ontario | JOB NO. TP110076

ELEV DEPTH (m)	DESCRIPTION	NUMBER	TYPE	"N" VALUES	NATURAL MOISTURE CONTENT w (%)	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
196.2						
0.0	**about 400 mm TOPSOIL**	1	SS	3	22	Highest groundwater level recorded.
195.8 / 0.4	brown **CLAYEY SILT** trace sand soft to hard	2	SS	16	19	0 3 85 12
		3	SS	17	21	
		4	SS	28	20	0 1 68 31
		5	SS	61	20	
	------ grey					
	trace cobbles/boulders	6	SS	20	17	
		7	SS	19	18	
189.6 / 6.6	**End of Borehole**					

Monitoring well details:
- 50 mm diameter PVC pipe:
- concrete: 0.0 - 0.3 m
- bentonite plug: 0.3 - 1.2 m
- sand pack 1.2 - 1.5 m
- slotted pipe: 1.5 - 4.6 m
- sand pack: 4.6 - 6.1 m
- protective casing: 0.9 m above ground

Groundwater level on
18-May-11 - 3.2 m (EL 193.0 m)
14-Jun-11 - 0.6 m (EL 195.6 m)
22-Jun-11 - 0.8 m (EL 195.4 m)
23-Jun-11 - 0.3 m (EL 195.9 m)
16-Aug-11 - 0.9 m (EL 195.3 m)
17-May-12 - 0.8 m (EL 195.4 m)

Column headings: SOIL PROFILE; SAMPLES; STRAT PLOT; GROUND WATER CONDITIONS; DEPTH m; ELEVATION SCALE m; DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100; SHEAR STRENGTH kPa ○ 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 (%) 20 40 60; SOIL VAPOUR READING PPM.

Depth scale: 1, 2, 3, 4, 5, 6. Elevation scale: 196, 195, 194, 193, 192, 191, 190.

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

Ontario

amec

RECORD OF BOREHOLE No. BH G16

G.W.P. 834-93-00 | LOCATION Sta: 12+810, 2.8 m N of Culvert, 10.7 m Lt of CL of Rd, E 443029; N 4826850 | ORIGINATED BY JF

DIST Goderich HWY 21 | BOREHOLE TYPE 150 mm diameter borehole (Solid Stem) | COMPILED BY SAL

DATUM Geodetic | DATE May 18, 2011 - May 18, 2011 | CHECKED BY SM

PROJECT Rehabilitation of Highway 21, from Bayfield to Goderich, Ontario | JOB NO. TP110076

ELEV DEPTH (m)	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	NATURAL MOISTURE CONTENT w (%)	GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
196.2 / 0.0	**about 600 mm TOPSOIL**	1	SS	2		25	
195.6 / 0.7	dark brown **Clayey Silt FILL** some sand trace rootlets and organic matter	2	SS	6		26	
194.9 / 1.4	brown **CLAYEY SILT** trace sand and gravel stiff to hard	3	SS	13		22	
		4	SS	72		16	0 3 84 13
	------ grey	5	SS	45		22	
		6	SS	23	▽ (4.7 m)	15	
		7	SS	20		17	4 14 53 29
189.7 / 6.6	**End of Borehole** Groundwater level on 18 May 2011 was 4.7 m depth						

DYNAMIC CONE PENETRATION RESISTANCE PLOT: 20 40 60 80 100

SHEAR STRENGTH kPa: ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE; 20 40 60 80 100

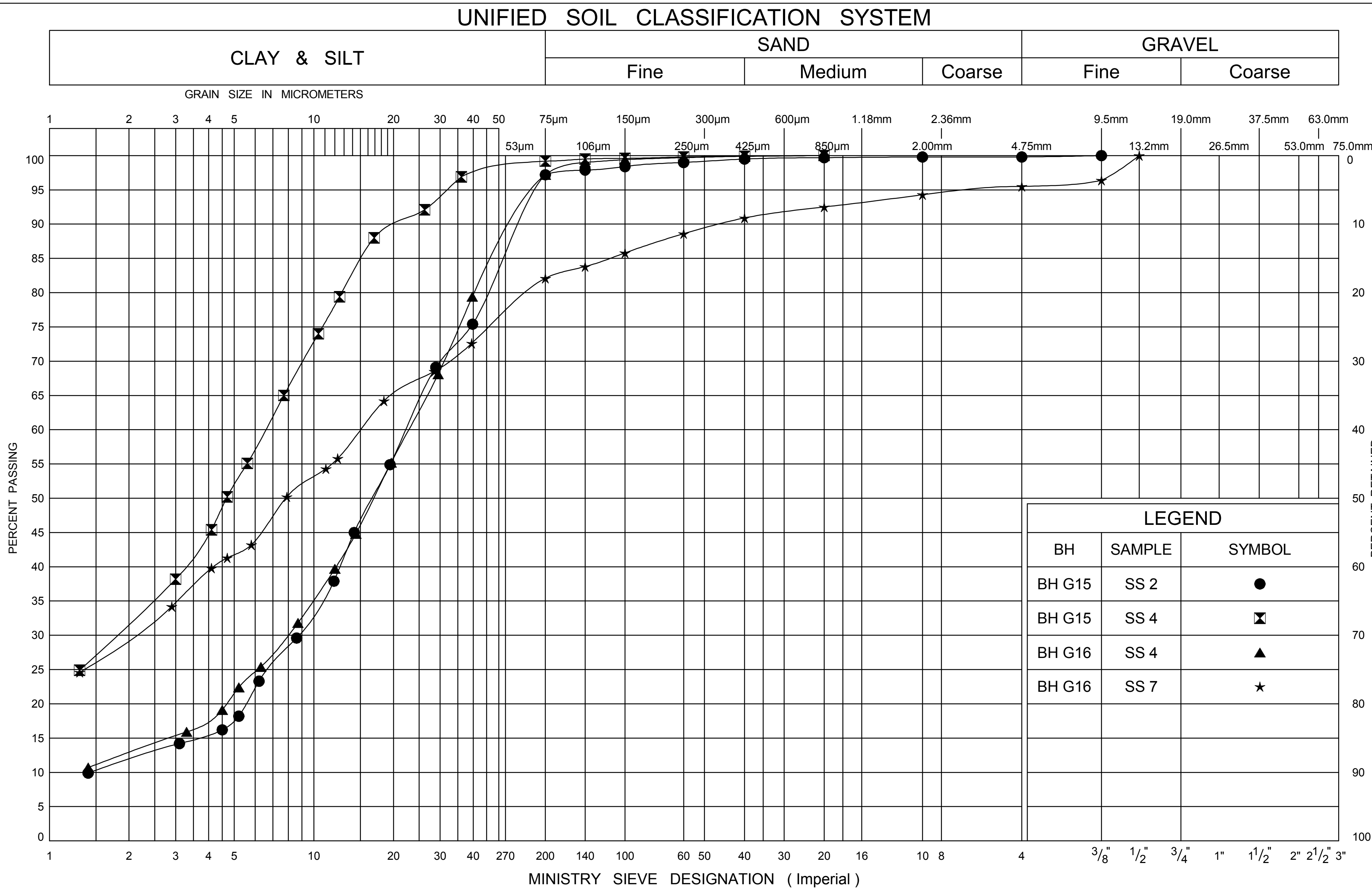
PLASTIC LIMIT W_P — NATURAL MOISTURE CONTENT W — LIQUID LIMIT W_L; WATER CONTENT (%) 20 40 60

SOIL VAPOUR READING PPM; REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL

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

APPENDIX B

LABORATORY TEST RESULTS



BH	SAMPLE	SYMBOL
BH G15	SS 2	●
BH G15	SS 4	⧗
BH G16	SS 4	▲
BH G16	SS 7	★

Ministry of Transportation
Ontario

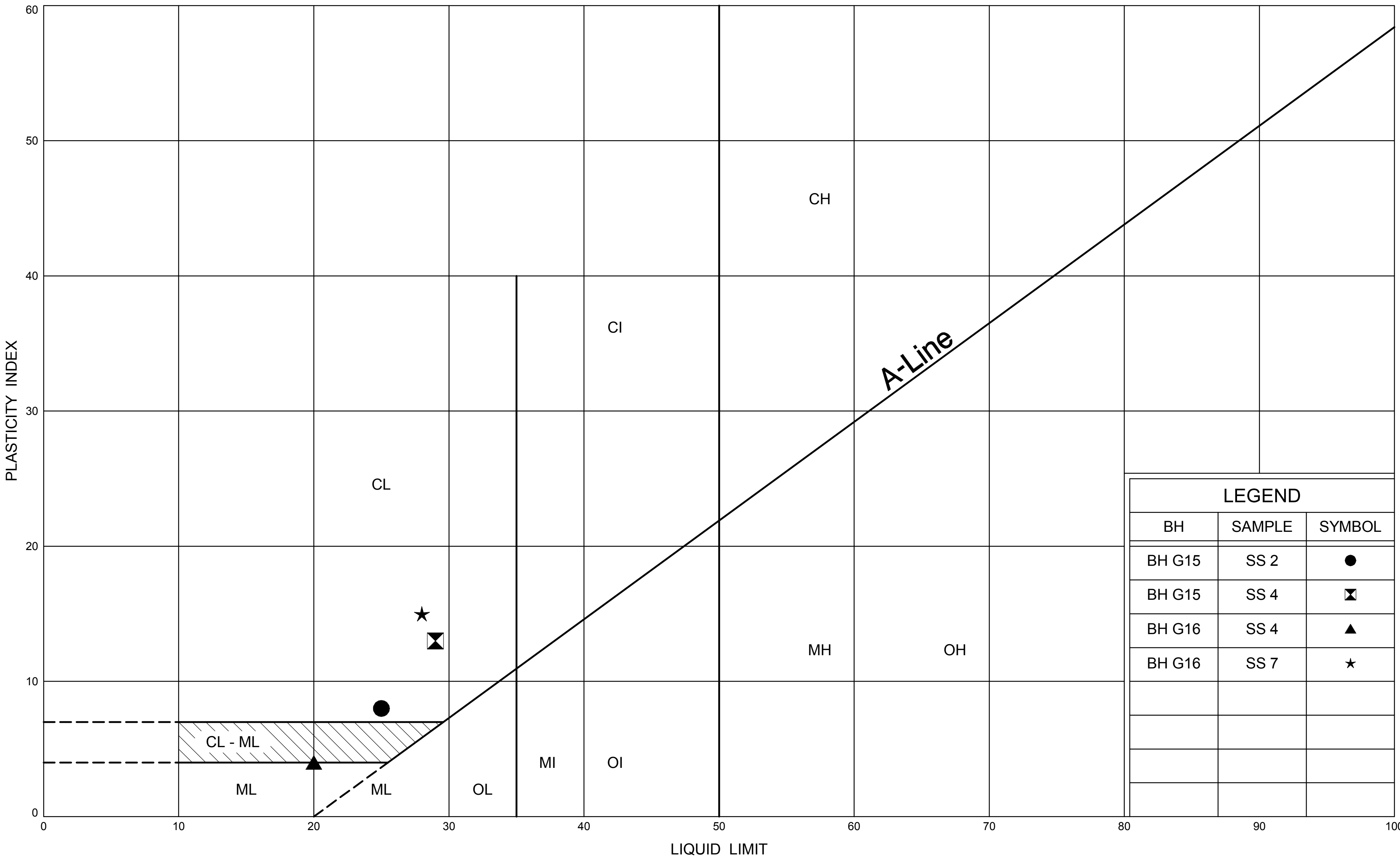
GRAIN SIZE DISTRIBUTION

Clayey Silt

Figure No. B1

G.W.P. 834-93-00

Culvert at Sta. 12+810, Hwy 21, Bayfield to Goderich



LEGEND

BH	SAMPLE	SYMBOL
BH G15	SS 2	●
BH G15	SS 4	⧗
BH G16	SS 4	▲
BH G16	SS 7	★

Ministry of Transportation
Ontario

PLASTICITY CHART

Clayey Silt

Figure No. B2

G.W.P. 834-93-00

Culvert at Sta. 12+810, Hwy 21, Bayfield to Goderich

Your Project #: TP110076.5
Site: HWY21 (7 CULVERTS)
Your C.O.C. #: 32091

Attention: Shami Malla
AMEC Earth & Environmental Ltd
Scarborough
104 Crockford Blvd
Sacroborough, ON
CANADA M1R3C3

Report Date: 2011/06/06

CERTIFICATE OF ANALYSIS

MAXXAM JOB #: B175937
Received: 2011/05/27, 17:25

Sample Matrix: Soil
Samples Received: 7

Analyses	Quantity	Date Extracted	Date Analyzed	Laboratory Method	Method Reference
Chloride (20:1 extract)	4	N/A	2011/06/02	CAM SOP-00463	
Chloride (20:1 extract)	3	N/A	2011/06/04	CAM SOP-00463	
Conductivity	7	N/A	2011/06/02	CAM SOP-00414	APHA 2510
pH CaCl2 EXTRACT	6	2011/06/02	2011/06/02	CAM SOP-00413	SM 4500 H
pH CaCl2 EXTRACT	1	2011/06/03	2011/06/03	CAM SOP-00413	SM 4500 H
Resistivity of Soil	7	2011/05/30	2011/06/02	CAM SOP-00414	APHA 2510
Sulphate (20:1 Extract)	7	N/A	2011/06/04	CAM SOP-00464	EPA 375.4

* RPDs calculated using raw data. The rounding of final results may result in the apparent difference.
* Results relate only to the items tested.

Encryption Key

Please direct all questions regarding this Certificate of Analysis to your Project Manager.

GINA BAYBAYAN,
Email: GBAYBAYAN@maxxam.ca
Phone# (905) 817-5766

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Maxxam has procedures in place to guard against improper use of the electronic signature and have the required "signatories", as per section 5.10.2 of ISO/IEC 17025:2005(E), signing the reports. For Service Group specific validation please refer to the Validation Signature Page.

Total cover pages: 1

Maxxam Job #: B175937
Report Date: 2011/06/06

AMEC Earth & Environmental Ltd
Client Project #: TP110076.5
Project name: HWY21 (7 CULVERTS)

RESULTS OF ANALYSES OF SOIL

Maxxam ID		JQ4509	JQ4510	JQ4511		JQ4512		JQ4513		JQ4514		
Sampling Date		2011/05/16	2011/05/16	2011/05/16		2011/05/16		2011/05/18		2011/05/17		
	Units	**BH G7 / SS2**	**BH G10 / SS4**	**BH G12 / SS4**	**QC Batch**	**BH G13 / SS2**	**QC Batch**	**BH G15 / SS2**	**QC Batch**	**BH G17 / SS3**	**RDL**	**QC Batch**
Calculated Parameters												
Resistivity	ohm-cm	2600	530	1100	2502843	3200	2502843	6000	2502843	3200		2502843
Inorganics												
Soluble (20:1) Chloride (Cl)	ug/g	140	970	470	2508305	120	2506767	<20	2506767	49	20	2506767
Conductivity	umho/cm	389	1870	951	2506690	316	2506690	166	2506690	317	2	2506690
Available (CaCl2) pH	pH	7.61	7.50	7.60	2506893	7.81	2506893	7.61	2508147	7.93		2506893
Soluble (20:1) Sulphate (SO4)	ug/g	<20	<20	<20	2508307	<20	2506764	<20	2506764	120	20	2506764

Maxxam ID		JQ4515		
Sampling Date		2011/05/17		
	Units	**BH G21 / SS2**	**RDL**	**QC Batch**
Calculated Parameters				
Resistivity	ohm-cm	1900		2502843
Inorganics				
Soluble (20:1) Chloride (Cl)	ug/g	270	20	2506767
Conductivity	umho/cm	532	2	2506690
Available (CaCl2) pH	pH	7.74		2506893
Soluble (20:1) Sulphate (SO4)	ug/g	<20	20	2506764

RDL = Reportable Detection Limit
QC Batch = Quality Control Batch

Package 1	20.3°C

Each temperature is the average of up to three cooler temperatures taken at receipt

GENERAL COMMENTS

Maxxam Analytics International Corporation o/a Maxxam Analytics 6740 Campobello Road, Mississauga, Ontario, L5N 2L8 Tel: (905) 817-5700 Toll-Free: 800-563-6266 Fax: (905) 817-5777 www.maxxam.ca

Maxxam Job #: B175937
Report Date: 2011/06/06

AMEC Earth & Environmental Ltd
Client Project #: TP110076.5
Project name: HWY21 (7 CULVERTS)

QUALITY ASSURANCE REPORT

			Matrix Spike		Spiked Blank		Method Blank		RPD		QC Standard	
QC Batch	Parameter	Date	% Recovery	QC Limits	% Recovery	QC Limits	Value	Units	Value (%)	QC Limits	% Recovery	QC Limits
2506690	Conductivity	2011/06/02					<2	umho/cm	2.4	35	103	75 - 125
2506764	Soluble (20:1) Sulphate (SO4)	2011/06/04	102	75 - 125	97	85 - 115	<20	ug/g	NC	35		
2506767	Soluble (20:1) Chloride (Cl)	2011/06/02	109	75 - 125	98	85 - 115	<20	ug/g	NC	35		
2508305	Soluble (20:1) Chloride (Cl)	2011/06/04	95	75 - 125	103	85 - 115	<20	ug/g	5.0	35		
2508307	Soluble (20:1) Sulphate (SO4)	2011/06/04	111	75 - 125	95	85 - 115	<20	ug/g	NC	35		

N/A = Not Applicable
RPD = Relative Percent Difference
Duplicate: Paired analysis of a separate portion of the same sample. Used to evaluate the variance in the measurement.
Matrix Spike: A sample to which a known amount of the analyte of interest has been added. Used to evaluate sample matrix interference.
QC Standard: A blank matrix to which a known amount of the analyte has been added. Used to evaluate analyte recovery.
Spiked Blank: A blank matrix to which a known amount of the analyte has been added. Used to evaluate analyte recovery.
Method Blank: A blank matrix containing all reagents used in the analytical procedure. Used to identify laboratory contamination.
NC (RPD): The RPD was not calculated. The level of analyte detected in the parent sample and its duplicate was not sufficiently significant to permit a reliable calculation.

Maxxam Analytics International Corporation o/a Maxxam Analytics 6740 Campobello Road, Mississauga, Ontario, L5N 2L8 Tel: (905) 817-5700 Toll-Free: 800-563-6266 Fax: (905) 817-5777 www.maxxam.ca

Validation Signature Page

Maxxam Job #: B175937

The analytical data and all QC contained in this report were reviewed and validated by the following individual(s).

Cristina Carriere

CRISTINA CARRIERE, Scientific Services

==

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APPENDIX C

SITE PHOTOGRAPHS

Photograph No. 1: View of inlet/outlet of culvert.

Photograph No. 2: View of road embankment near the culvert.

APPENDIX D

SETTLEMENT MONITORING GUIDELINE

APPENDIX: SETTLEMENT MONITORING GUIDELINES - TUNNELING

The purpose of settlement monitoring is to prevent damage to existing utilities and highway structures along the tunnel alignment. Ground settlement include settlement due to lost ground and dewatering/drainage.

Instrumentation Arrays

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

Surface Monitoring Points

Surface monitoring points will be installed to cover the whole length of the tunnel with in the right of way under the jurisdiction of MTO (Figure 1).

Surface monitoring points will be located at not greater than 5m intervals along the tunnel alignment. The surface monitoring will be identified using paint marks on the pavement. Surface monitoring points installed on the unpaved right of way shall be founded below frost penetration depths. The interval and/or marking of the points should be changed with MTO's approval where traffic disruptions might occur.

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

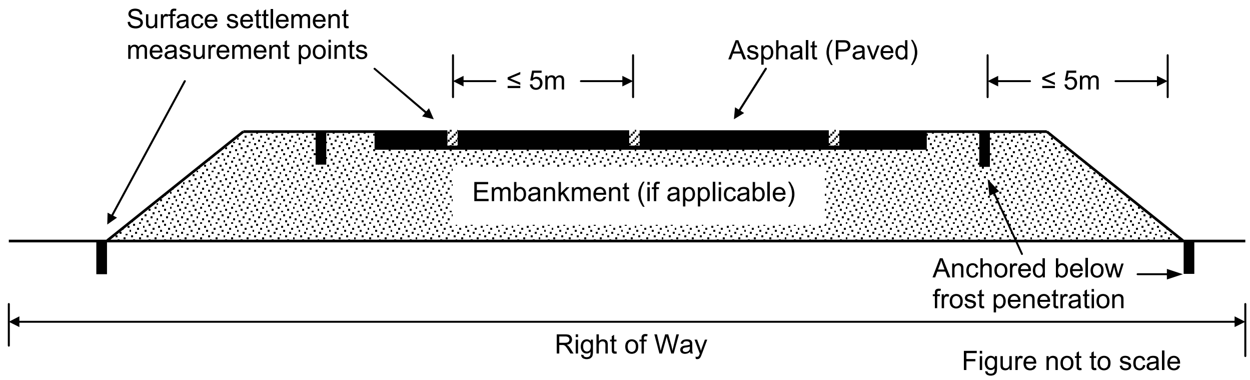

Figure 1: Typical configuration of surface settlement monitoring points along the tunnel alignment.

Condition Survey

A condition survey for the pavement will be carried out prior to commencement of construction and documented for the purpose of requirement of restoration. The condition survey shall document visible flaws such as cracks, distortions and deviations, heaves, and depressions. This surface survey will be completed during the installation of the monitors and again once the tunnel has been completed.

Reading Frequency

An average of at least two readings shall be taken to establish the initial conditions.

The reading and collection of data from the surface monitoring points shall be read and recorded by the Contractor during the construction period and after construction for period of at least 2 weeks provided that further settlement has stopped.

A minimum of three (3) sets of reading be taken daily, provided that movements are within anticipated limits. Otherwise, the frequencies should increase according to a pre-planned interval.

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

Measurements of the monitoring points shall be reported promptly to MTO for review.

Data Collection and Data Transfer

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

Criteria for Assessment

The acceptable surface settlement (or heave) will be according to criteria as specified below.

Baseline Reading – A baseline reading of the instrumentation shall be taken prior to commencement of the work. An average of at least two initial readings shall be recorded as baseline reading.

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

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

Review of Contractor's Proposed Method

MTO, the Proponent's prime consultant and Foundation Engineer should review the Contractor's proposed method of construction. The proposed method should include a description of the potential loss of ground, and calculation of the maximum settlement in relation to the Contractor's procedure and equipment, alternative/remedial measures when review level of measurement is reached; and contingency/remedial measures when alert level of measurement is reached.

Contractor's Responsibility For Restoration and Warranty Provision

In addition to the monitoring program to assess the adequacy of the construction method to control potential ground movements and groundwater, the Contractor is responsible for reinstatement (such as surface paving) should movements or other surface distress occur, and provide a reasonable warranty period acceptable to MTO. Remedial measures shall be approved by MTO; however, MTO maintains the right to perform the maintenance at the proponent's expense.

Construction Monitoring

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