FOUNDATION INVESTIGATION AND DESIGN REPORT

REHABILITATION OF HIGHWAY 21
FROM BAYFIELD TO GODERICH, ONTARIO

CULVERT NO. 20 AT STATION 15+205

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

MTO GEOCRES NO. 40P12-21

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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, as shown in Drawing No. 1.

In May 2011, AMEC conducted a foundation investigation comprising 21 boreholes (BH G1 to BH G21) at the locations of eight existing culverts identified for rehabilitation / replacement. The design reports for these culverts have been submitted to MTO separately.

In March 2012, AMEC conducted additional foundation investigations at the locations of 11 additional existing culverts, as shown on Drawing No. 1. The number of boreholes and locations of the boreholes were based on the Highway 21 Culvert Recommendations Table (dated 18 January 2012). The details of the additional culverts investigated, and the boreholes advanced at each location, are summarized in Table 1.1.

Table 1.1 - Culvert Details for Additional Foundation Investigations (March 2012)*

Station	Existing Culvert		Boreholes Drilled	Proposed Work	Foundation Investigation Requirement
	Type	Dimension			
10+267	Concrete Rigid Frame - Open Footing	0.9 x 0.9 x 38.5 m	BH G22 and BH G23	Extend culvert and clean out	Two boreholes for extension
11+691	Concrete Rigid Frame Box	3.75 x 2.30 x 68.4 m	BH G24 and BH G25	Rehabilitate and install RSS to stabilize steep roadway embankment	Foundations for RSS / slopes and protection system to stage the construction
12+138	Concrete Box	1.2 x 1.2 x 24.2 m	BH G26 and BH G27	Rehabilitate inlet, remove outlet precast block wing walls, place gabion wingwalls at east end. Construct CIP wingwalls at west outlet, including scour protection.	Two boreholes at outlet end for retaining wall foundations
13+835	Concrete Box	1.2 x1.2 x 27.05 m	BH G28 and BH G29	Replace south west concrete retaining wall with CIP concrete retaining walls. Construct CIP concrete wingwall at northeast.	Two boreholes (southwest and northeast retaining walls)

Station	Existing Culvert		Boreholes Drilled	Proposed Work	Foundation Investigation Requirement
	Type	Dimension			
15+205	Concrete Arch - Open Footing	7.16 x 3.66 x 29.6 m	BH G30	Rehabilitate and install RSS to stabilize steep roadway embankment. Replace southwest wingwall.	Foundations for RSS / slopes (both sides of the roadway) and protection system for construction. Protection will be installed. One borehole for southwest wingwall.
18+380	Rigid Frame Box	3.66 x 1.52 x 21.4 m	BH G31, BH G32, BH G32A, BH G33 and BH G34	Rehabilitate concrete at both ends and soffit and add wingwalls or extend culvert	Boreholes required for a retaining wall between culverts 12-422, and 12-424 on Highway 21 and 12-423 on Cut Line Road , southeast of Intersection. Or lengthening of the culvert. (min. 4 BH for these 3 culverts total)
18+393		3.05 x 0.91 x 15.3 m		Rehabilitate and construct wing walls between this culvert and 12-422/C	
18+409		3.66 x 1.52 x 21.4 m		Rehabilitate and construct wing walls between this culvert and 12-423/C	
18+843	Concrete Frame - Open Footing	1.5 x 1.1 x 24.7 m	BH G35 and BH G36	Rehabilitate ends and replace wingwalls with CIP concrete. Repair culvert interior. Extend inlet end.	Two boreholes (one at each end)
25+232	Concrete Frame - Open Footing	2.9 x 0. 9 x 20.8 m	BH G37	Replace sandbag wingwalls with gabions at west end and CIP concrete retaining wall at east end. Repair outlet concrete. Place scour protection.	One Foundation borehole (east end)
26+521	Concrete Frame - Open Footing	1.8 x 1.2 x 23.5 m	BH G38 and BH G39	Rehabilitate ends and replace sand bag retaining walls with CIP concrete retaining walls	Two Foundation boreholes (one at each end)

* Based on Hwy 21 Culvert Summary Table (dated 13 December 2011), and Hwy 21 Culvert Recommendations Table (dated 18 January 2012).

The purpose of the additional foundation investigation was to obtain information on the subsurface conditions at the additional culvert sites (Table 1.1) by means of boreholes, in-situ tests and laboratory tests on selected soil samples. Based on AMEC's interpretation of the data obtained in the investigation, recommendations are provided on the geotechnical aspects of replacement / rehabilitation / extension of the culverts.

As per the Terms of Reference (TOR) in the Request for Proposal (Purchase Order Number: 3009-E-0022, dated March 2010), separate reports have been prepared - one for each culvert site, except at the intersection of Highway 21 and Cut Line Road, where one report has been prepared for the three culverts located at the intersection.

This report presents the results of foundation investigation together with design discussion and recommendations for the rehabilitation of existing culvert at Station 15+205 (Culvert No. 20).

The factual results of the soil conditions encountered in the boreholes and laboratory tests (without design discussion and recommendations) for the rehabilitation of existing culvert at Station 15+205 are presented in a separate report titled “Foundation Investigation Report”.

2.0 SITE AND PROJECT DESCRIPTION

The investigated culvert site (at Station 15+205) is located at the existing watercourse (Gully Creek) crossing Highway 21, about 25 m north of Telephone Road, between Bayfield and Goderich, Ontario (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 wooded areas on both sides of the culvert. The embankment slopes were covered with tall and overgrown vegetation and trees at the time of the fieldwork.

As noted in Table 1.1 (Section 1.0), the existing culvert (No. 20) is a 7.16 m wide x 3.66 m high x 29.6 m long concrete, rigid arch structure with open footing. Preliminary Drawing No. S1 (Sheet ST2), indicates that the height of the existing embankment at the culvert location is up to about 10.5 m above the surrounding grade. The embankment slope inclination is 1.5H:1V (approximate).

As per the design recommendation, the existing concrete retaining wall at southwest corner of the culvert would be replaced. The recommendation also includes installation of retaining wall to stabilize the steep embankment slope on the west side of Highway 21.

Site photographs showing the culvert are presented in Appendix C (Photograph Nos. 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 highway 21 Culvert Recommendations Table, one (1) borehole (BH G30) was advanced at mid-shoulder on the west side of Highway 21 extending to a depth of 18.5 m below the existing granular surface (from elevation about 194.4 m to 176.0 m). The borehole was drilled at this location to obtain information regarding the existing fill material, and soil conditions below the culvert footing level. The as-drilled borehole location is presented on Drawing No. 2.

The fieldwork was performed on 14 March 2012, 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 (GBM 0011989U064, Sta. 18+377.189, El 203.775).

The borehole was advanced using hollow-stem augers, with a track-mount power-auger drilling rig under the full-time supervision of experienced geotechnical personnel from AMEC. The drilling, sampling and in-situ testing operations were conducted by using a track-mount drill rig owned and operated by Drilltech Drilling Inc., Newmarket, Ontario.

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 borehole during sampling and upon completion of drilling. The groundwater depth measurement, wherever encountered, is presented on the Record of Borehole.

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

Upon recovery, all soil samples were screened using a hand-held hydrocarbon surveyor (RKI Eagle), the results of which are presented on the Record of Borehole.

One selected sample was tested for soil corrosivity potential with respect to concrete and steel, the results of which are discussed in Section 6.5.

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 grain size analysis, Liquid and Plastic Limit, in-situ water content determination, and soil corrosivity analysis, which was subcontracted to Maxxam Analytics, an accredited CAEL laboratory located in Mississauga, Ontario.

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

AMEC will retain the soil samples for a period of one year after completion of the project, unless otherwise advised in writing by MTO.

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 (15);
- Grain size distribution analysis (2);
- Atterberg Limit tests (2); and
- Soil corrosivity (1).

The results of in-situ and laboratory tests are presented in the Record of Borehole in Appendix A. The grain size distribution curve and plasticity chart, and result of soil corrosivity test are shown in Appendix B.

5.0 SUB-SURFACE CONDITIONS

Based on the investigation results, the soil profile at the borehole location consisted predominantly of surficial sand and gravel fill underlain by fill soils (silty sand and silty clay) overlying the native clayey silt / silty clay deposit extending to the termination depth of the borehole (elevation 176.0 m).

The stratigraphic units and groundwater conditions at the borehole location is discussed in the following sections. Detailed information is provided in the Record of Borehole in Appendix A. Interpolated stratigraphical cross sections through the existing culvert are provided in Drawing No. 3.

It should be noted that the soil and groundwater conditions may vary beyond the borehole location.

5.1 Sand and Gravel Fill

Sand and gravel fill was encountered at the existing grade in the borehole drilled through the existing shoulder. The measured thickness of sand and gravel fill was about 600 mm.

A single SPT N-value measured in the sand and gravel fill was 11 blows per 0.3 m. The measured moisture content in the sand and gravel fill was 5 %.

5.2 Fill Soils

Silty Sand Fill

Silty sand fill was encountered below the sand and gravel fill in the borehole. The silty sand fill extended to about 2.9 m below the existing grade (elevation 191.5 m). The silty sand fill was brown in color, and contained trace organic matter, and trace to some clay.

The SPT 'N' values of the silty sand fill ranged from 4 to 5 blows per 0.3 m. The measured moisture contents in the silty sand fill ranged from 9 % to 17 %.

Silty Clay Fill

The silty sand fill was underlain by silty clay fill, which extended to a depth of 8.7 m below the existing grade (elevation 185.7 m).

The silty clay fill was brown in color, and contained trace gravel and organic matter, and some sand.

The SPT 'N' values of the silty clay fill ranged from 4 to 15 blows per 0.3 m. The measured moisture contents in the silty clay fill ranged from 11 % to 19 %.

5.3 Clayey Silt / Silty Clay

Native clayey silt / silty clay was encountered below the silty sand and silty clay fill in the borehole. The clayey silt / silty clay extended to the termination depth of the borehole (elevation 176.0 m).

The clayey silt / silty clay was grey in color, and contained some sand and trace gravel. The SPT 'N' values of the clayey silt / silty clay ranged widely from 14 to 79 blows per 0.3 m indicating stiff to hard consistency. The measured moisture contents in the clayey silt / silty clay ranged from 12 % to 17 %. Traces of cobbles / boulders were encountered in the clayey silt / silty clay.

Grain size analyses and Atterberg Limit tests were completed on 2 samples of the clayey silt / silty clay, and the results are presented in Table 5.1.

Table 5.1 - Grain Size Distribution Analyses and Atterberg Limit Test Results (Clayey Silt / Silty Clay)

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 G30	SS 9	9.2 - 9.6 (185.2 - 184.8)	4	17	45	34	26	13	13	CL
	SS 13	15.3 - 15.7 (179.2.- 178.8)	-	5	52	43	27	15	12	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 condition in the open borehole was observed during and on completion of drilling. Borehole BH G30 was dry on completion of drilling.

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.

5.5 Limited Environmental Investigation

In accordance with the Terms of Reference and AMEC proposal, soil samples obtained during the geotechnical field drilling program were field screened for evidence of environmental impact. The field screening activities included measuring the combustible organic vapours (COV) in the headspace of samples with a portable hydrocarbon surveyor instrument (RKI Eagle).

No visual or olfactory evidence of environmental impact was observed in the fill and native soil samples recovered from the borehole. The measured COV concentrations in all soil samples were relatively low, ranging from non-detect to 50 ppm as shown in the Record of Boreholes. The COV results are semi-quantitative at best and are generally used only for relative sample comparison purposes when selecting samples for laboratory analysis. Based on the field screening results, evidence of environmental impact is not suspected.

6.0 DISCUSSION AND RECOMMENDATIONS

In preparation of this report, the following information was considered:

I. Highway 21 Culvert Recommendation Table, dated 18 January 2012.
II. Highway 21 Culvert Summary Table, dated 13 December 2011.
III. AMEC Preliminary Drawing No. S1 (Sheet No. ST2), dated April 2012, for Culvert No. 20 at Station 15+205.
IV. Contract Drawings (CS Submission), Contract No. 2012-3028

The existing culvert is an open footing, concrete, arch type structure, which is 7.16 m wide, 3.66 m high and 29.6 m long. Highway 21, at this culvert location, is a two lane asphalt concrete paved road about 7 m wide, which runs on top of an embankment built up above the surrounding grade with an approximate fill cover above the culvert of about 6.5 m. The invert of the culvert lies at elevation of about 183.9 m and about 184.0 m, at inlet and outlet, respectively.

The project comprises the following components:

- Replacement of southwest retaining wall; and
- Stabilization of steep embankment slopes.

Southwest Retaining Wall

Based on the drawing, two concrete retaining walls are currently in place at the southeast and southwest corner areas of the culvert. The retaining wall (approximately 5.0 m long x 1.0 - 1.7 m high) at the southwest corner is in poor condition and is recommended for replacement, whereas the retaining wall (approximately 8.0 m long x 2.0 m high) at the southeast corner is in fair condition and is to be rehabilitated. No design information was available at the time of writing this report. The replacement retaining wall at the southwest corner could comprise gravity type or cast-in-place concrete type retaining wall.

Embankment Slope Stabilization

The cross-section drawing shows that the sideslopes of the road embankments on both sides of Highway 21 are approximately 1.5H:1V, which is steeper than the typical minimum slope gradient of 2H:1V (per OPSD 203.010). Additionally, the investigation showed that embankment fill consisted of loose fill soils (silty sand and silty clay), which extended to about 8.7 m below the road surface (elevations 194.4 m to 185.7 m) at the culvert location. The design recommendation is to stabilize the steep slope, which may be done by flattening (reducing) the slope to the minimum inclination of 2H:1V or flatter, which could be achieved by:

- Installing a retaining wall at or near the slope toe to allow for flattening of the slope; or
- Widening the slope toe without a retaining wall, together with extending the existing culvert.

The following sections discuss the geotechnical aspects of various types of replacement walls at the southwest corner of the culvert, and embankment slope flattening options.

6.1 Replacement of Southwest Retaining Wall

Based on the drawing, a concrete retaining wall is currently in place at the southwest corner of the culvert. The height of the retaining wall ranges from about 1.0 m (at outlet end) to about 1.7 m (far end). The founding elevation of the retaining wall ranges from an approximate elevation of 182.67 to 184.00 m, while, the invert elevation of the culvert at outlet end is about 183.96 m. No other design information was available at the time of writing this report.

6.1.1 Retaining Wall Options

The replacement retaining wall at the southwest corner of the culvert could be gravity type or cast-in-place concrete retaining wall.

A comparison of the feasible retaining wall structures is provided in Table 6.1.

Table 6.1 - Comparison of Retaining Wall Structure Options

Option	Description	Advantages	Disadvantages	Risks / Consequences	Cost Comparison
Cast-in-place concrete retaining wall	Typically, cantilevered, reinforced-concrete, retaining wall.	Durable and low maintenance. Not susceptible to erosion by water flow and ice forces. No specialized contractor is needed.	Rigid structure which may show minor cracks. Labour intensive for placing reinforcing bars and formwork. Possible need more time for construction to allow for curing concrete.	Temporary slope excavated into the existing road embankment may have to stand up longer before backfilling.	Medium to high

Option	Description	Advantages	Disadvantages	Risks / Consequences	Cost Comparison
Gravity Type Retaining Wall - Gabion	Gabions are rectangular steel baskets filled with stone and stacked on one another.	Construction is relatively simple. Flexible type of structure Drain freely.	Gabions are labour-intensive in order to properly place stones inside the gabion baskets. Steel baskets may not be stable in long term. Gabion may be subject to erosion by creek water flow and ice forces.	Maintenance or replacement may be frequent.	Medium to low
Gravity Type Retaining Wall - Armourstone	Armourstones are large-sized stones, typically up to 1 m wide by 1 m high by 1.5 m long.	Construction is relatively simple. Flexible type of structure. Drain freely. Good resistance to water flow and ice forces. Possibly less installation time.	Source and transportation to site may be high		Medium to low
Retained Soil System (RSS)	Stone/concrete facade in front of soil mass reinforced with metal strips or geogrids.	Flexible type of structure	RSS requires specialised contractor according to MTO's DSM. Facade material has to be properly selected to prevent erosion by water flow and ice forces. Labour intensive for construction. Reinforcing strips may not be durable.	May require some maintenance	Medium

Considering that the length and height of retaining wall at this site, gravity-type retaining wall (e.g. gabion wall, armourstone, etc) would be the better option from the geotechnical viewpoint, because of relatively simple construction and flexible structure.

6.1.2 Foundations

Based on the cross-section drawing, the founding elevation of existing concrete retaining wall ranges from an approximate elevation of 182.67 to 184.00 m. The new retaining wall is anticipated to be installed at the same elevation.

The investigation indicated that stiff to very stiff clayey silt / silty clay is likely to be encountered at the retaining wall founding elevation. Sub-excavation may be required to remove any topsoil, loose / soft soils, and / or otherwise deleterious materials, if any. If sub-excavation is required, the grade could be restored by placing lean concrete or compacted 20 mm crusher-run limestone (or approved similar) up to the proposed founding elevation.

The geotechnical Ultimate Limit State (ULS) / Serviceability Limit State (SLS) values provided in Table 6.2 and geotechnical parameters in Table 6.3 should be used for the design of the proposed retaining wall. The recommended SLS bearing value is based on a total settlement of up to 25 mm. Detailed foundation analysis will be necessary if accurate values of settlement are required.

Table 6.2 - SLS and ULS Values for Design

Borehole No.	Founding Stratum	Depth below existing grade (m)	Approximate Elevation (m)	Geotechnical Reaction at SLS (kPa)	Factored Geotechnical Resistance at ULS[1] (kPa)
BH G30	Stiff clayey silt / silty Clay	8.7 - 12.2 m (±)	185.7 - 182.2 m (±)	150	225
	Hard clayey silt	12.2 m (±) and below	182. m (±) and below	250	375

Note: [1] A resistance factor of Φ = 0.5 has been applied to the values provided.

The soil parameters in Table 6.3 may be used for design.

Table 6.3 - Summary of Geotechnical Parameters

Soil Stratum	Bulk Unit Weight of Soil, γ (kN/m^3)	Angle of Internal Friction (degree)	Earth Pressure Coefficient		
			At-rest, K_o	Active, K_a	Passive, K_p*
Existing cohesive fill	18	28	0.53	0.36	2.0
Existing non-cohesive fill	18	30	0.47	0.30	2.0
Clayey Silt / Silty Clay	20	30**	0.50	0.33	2.0
Granular B	21	32	0.47	0.30	2.0
Granular A	22	35	0.41	0.26	2.0

* The K_p (passive condition) values are reduced in order to limit the lateral soil movement that is required to mobilize the passive resistance.

** Long-term (effective stress)

The design frost penetration depth of 1.2 m should be considered in the design of the retaining wall.

For sliding resistance, the unfactored coefficient of friction 0.35 with a resistance factor of 0.8 should be considered at the base of retaining wall.

The retaining wall should be backfilled with granular soil (OPSS 1010 granular 'A' or granular 'B') and compacted to maximum dry density in conformance to OPSS 501 (Method A).

The retaining wall should be provided with a positive drainage system to prevent the built up of hydrostatic pressure. It is recommended that a suitable nonwoven Class II geotextile (with a FOS of 75 - 150 µm according to OPSS 860) be installed between the free draining granular backfill and earth fill / native soils, or immediately behind (and underneath the wall if gabion is used), to prevent migration of fines into the system.

If the retained soil system (RSS) wall is selected, the design of the RSS wall should be carried out as per the manufacturer's specifications based on the type of wall selected. Ministry of Transportation's (MTO) RSS Design Guidelines, including the Non Standard Special Provision for RSS (January 2008) included therein, and/or Standard Special Provision to OPSS - SSP 599S23, should be used for the design, supply and construction of the RSS, in addition to any contract requirements and RSS manufacturer's standards.

The existing retaining should be demolished and completely removed. All excavations should be carried out in accordance with the Occupational Health and Safety Act and Regulations for Construction Projects. The excavation and dewatering are discussed in details in Section 6.3.

A small cofferdam (earth dyke) may be required to keep water flows from entering the work area. Dewatering plans must also consider any flows from the road side ditches that enter into the culvert.

Excavation for retaining wall foundations should comply with OPSS 902 (Nov/10) (*Construction Specifications for Excavating and Backfilling* - Structures) should be followed. Backfill should be placed according to OPSS 206 (*Construction Specification for Grading*), and compacted according to OPSS 501 (*Construction Specification for Compacting*). Backfill for the retaining wall should conform to OPSD 3121.150 (*Minimum Granular Backfill Requirement - Walls Retaining*).

Materials for gabion wall, if used, must comply with OPSS 1430 (Material Specification for Gabion Baskets and Mats).

6.1.3 Temporary Shoring

Temporary shoring may be required during the demolition of the existing retaining wall and excavation work of the new retaining wall. The temporary shoring 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. The design of temporary shoring should be carried out in accordance with Canadian Highway Bridge Design Code CAN/CSA-S6-06 (May 2010). Soil parameters given in Table 6.3 may be used for design considerations.

6.2 Embankment Slope Stabilization

Based on the drawing, the height of the existing embankment at the culvert location is up to about 10.5 m higher than the surrounding grade, and the slope of the embankment is 1.5H:1V. The borehole investigation revealed that the embankment comprised loose fill soils (sand and gravel, silty sand and silty clay) extending to about 8.7 m below the road surface (Elevation 185.7 m) at the culvert location.

Considering the fact that the existing road embankment has been in use for many years, its stability should not be an immediate concern. Nevertheless, its slope stability has been assessed by slope stability analysis as discussed in Section 6.3.

The following feasible options can be considered to stabilize the existing embankment slope:

- With retaining walls ;
- Without retaining wall, and with culvert extension.

6.2.1 Comparison of Embankment Slope Stabilization Options

A comparison of embankment slope stabilization options is provided in Table 6.4.

Table 6.4 - Comparison of Slope Stabilization Options

Option	Description	Advantages	Disadvantages	Risks / Consequences	Cost Comparison
With retaining wall	Retaining wall will be constructed at about 8.7 m below the existing grade on native soil. Additional fill placement at the top of the retaining wall.	Will help preserve the environment, because it involves no major tree/vegetation cutting beyond the embankment slope	Excavation over the existing culvert will be required Require lane closure and roadway protection Add more loads to the slope	Increase in stress on the existing culvert foundation May require special permits from the related conservation authority	Medium to high
Without retaining wall and with culvert extension	Will require new fill placement beyond the existing slope toe and additional fill placement over the existing slope Will require extension of culvert	No specialized equipment other than excavation and compaction Minimum excavation of the existing slope	Excavation around the existing culvert inlet and outlet will be required. Will involve cutting and removal of existing trees / vegetation around the culvert ends Existing culvert structure will have to be extended.	Increase in stress on the existing culvert foundation Will disturb the existing environment due to cutting of trees and vegetation May require special permits from the related conservation	High

Both options have advantages and disadvantages. Due to the lesser environmental impact and possibly lower cost, the construction of the retaining wall may be the preferred option from the geotechnical viewpoint.

6.2.2 With Retaining Wall

If the retaining wall option is chosen to stabilize the embankment slope, the following retaining wall types should be considered.

- Cast-in-place Concrete Retaining wall;
- Gravity Type Retaining Wall;
- Retained Soil System.

A comparison of the possible retaining wall structures is provided in Table 6.1.

Considering that the length and height of retaining wall at this site, RSS would be the better option from the geotechnical viewpoint, because of relatively simple construction and flexible structure. It is likely that a roadway protection system will be required.

6.2.2.1 Foundations

The investigation indicated that the existing fill is loose and therefore, incompetent to support the retaining wall. The retaining wall should be placed within native very stiff to hard clayey silt / silty clay below the fill soil at or below a depth of about 8.7 m below the existing grade (elevation about 185.7 m).

The geotechnical Ultimate Limit State (ULS) / Serviceability Limit State (SLS) values provided in Table 6.2 and geotechnical parameters in Table 6.3 should be used for the design of the proposed retaining wall.

All other recommendations for retaining wall in sub-section 6.1.2 should be considered. The excavation and dewatering is provided in Section 6.3.

The new fill placement would increase the stress on the existing culvert foundation. If this option is selected, a detailed foundation and settlement analysis may be required once the design details are available in order to estimate the increase in stress to the existing culvert foundations and the corresponding settlement. Further, a slope stability analysis for the proposed retaining should be carried out.

A roadway protection may be required for installation of the retaining wall, if constructed, and is discussed in Section 6.2.2.3.

6.2.2.2 Slope Restoration

The final embankment slope restoration to proper highway cross-sections should be carried out using compacted engineered fill at 2H:1V (or flatter) side slopes. The construction should be carried out in accordance with OPSS 206 (*Construction Specification for Grading*), and compacted according to OPSS 501 (*Construction Specification for Compacting*). Bonding between the existing embankment fill and new fill should be achieved as per OPSD - 208.010 (*Benching of Earth Slopes*). The selection, placement and compaction of the fill should be carried out under a geotechnical control program.

The fill soils used for the proposed embankment widening should consist of approved, clean soil earth fill free from topsoil, organic matter etc. The compaction should comply with OPSS 501.

Provided that the new fill is properly compacted on the existing embankment side slope, its long-term settlement should not be significant. If this option is selected, a settlement analysis should be carried out.

The final slope areas and retained soils behind the retaining walls should be covered with topsoil and seeded in accordance OPSS 802 and OPSS 804, as soon after grading as possible to prevent erosion. Additional erosion control measure, if required, should be assessed using erodibility factor of 0.2 (sand) and 0.3 (silt).

6.2.2.3 Roadway Protection

Roadway protection may be required during installation of retaining wall to support the walls of excavation and adjacent traffic lane. The roadway protection scheme designed for performance level 2 system, according to OPSS 539, is recommended to prevent excessive lateral and/ or vertical movement of the existing embankment during construction.

According to OPSS 539, the contractor is responsible for the selection, performance and detailed design of the roadway protection scheme. To meet the performance level 2, the maximum lateral displacement should be limited to 25 mm with maximum allowable angular distortion of 1:200.

A monitoring system should be implemented to check the horizontal and vertical displacements of the roadway surface during construction.

Roadway protection system may comprise sheet piling or soldier piles with lagging. Both systems can be anchored for additional support, if required. Typically, sheet piling can be used to reduce loss of native soils below the water table. Soldier piles with lagging are generally considered suitable for applications above the groundwater table in cohesionless soils or cohesive soils.

Table 6.5 presents a comparison between the two roadway protection systems.

Table 6.5 - Comparison between Sheet Piling and Soldier Piles with Lagging

Option	Description	Advantages	Disadvantages	Risks / Consequences	Cost Comparison
Sheet piles	Closely set piles of timber, steel, etc, driven vertically into the ground in a line to hold back soil and water	Sheet piles are interlocked, therefore, loss of soils will be negligible. Suitable for high water table	May require soil anchors / rakers for lateral support	The surrounding soil may get disturbed during installation of the sheet piles, which may cause failure in unstable slopes	Medium to high
Soldier piles with lagging	Soldier piles (H - steel section) driven first, and horizontal laggings or sheeting placed behind the piles	Can be installed in bored caisson, which significantly reduces disturbance to surrounding soil	May require anchors High risk of soil loss	Excessive settlement may occur due to loss of cohesionless soils under high water table	low to medium

For the existing site condition at the culvert, the soldier piles with lagging may be the preferred roadway protection system. The bottom of the protection system (sheet pile/H-Pile/Caisson) should be extended minimum to an elevation of about 182.0 m. For design purposes, the soil parameters provided in Table 6.2 and 6.3, and the horizontal modulus of Subgrade Reaction (k_s) provided in Table 6.6 may be used for design.

Table 6.6- Horizontal Modulus of Subgrade Reaction

Soil	Horizontal Modulus of Subgrade Reaction[(1)] (kN/m^3)
Existing fill (below 1.2 m frost penetration depth)	3,000
Stiff to hard, clayey silt / silty clay	30,000 - 35,000

(1) k_s estimated based on CFEM.

6.2.3 Embankment Widening Without Retaining Wall and With Culvert Extension

A flatter embankment slope may be achieved without construction of a retaining wall, if the slope is allowed to extend beyond the existing toe of slope, i.e. the base of the embankment is widened. However, this will necessitate the extension of the culvert. The embankment widening, if chosen, should be constructed with compacted engineered fill at 2H:1V (or flatter) side slopes. The construction should be in accordance with OPSS 501 (Construction

Specification for Compacting) and OPSS 206 (Construction Specification for Grading). Bonding between the existing embankment fill and new fill should be achieved as per OPSD - 208.010 (Benching of Earth Slopes). The selection, placement and compaction of the fill should be carried out under a geotechnical control program

At the time of field work, the areas beyond the existing culvert were covered with trees and tall vegetation. All trees should be cut and removed. All topsoil, organic matters, soft / loose and unsuitable soils should be removed from the footprint of the proposed widening areas. Topsoil should also be stripped from existing slope prior to placement of new embankment fill.

After stripping, the exposed subgrade for new fill should be inspected. Based on the investigation results, native very stiff clayey silt / silty clay is anticipated at the founding grade which should be capable of supporting the new fill loads.

The fill soils to be used for the proposed embankment widening should consist of approved, clean earth and compacted as per OPSS 501.

Provided that the widened embankment is founded on stiff to very stiff native clayey silt / silty clay soils, and the new fill is properly compacted on the existing embankment side slope, its long-term settlement should not be significant.

If this option is selected, a detailed foundation and settlement analysis may be required once the design details are available in order to estimate the increase in stress to the existing culvert foundations and the corresponding settlement.

For the culvert extension, the geotechnical Ultimate Limit State (ULS) / Serviceability Limit State (SLS) values provided in Table 6.2 and geotechnical parameters in Table 6.3 may be used for the design. All other recommendations for retaining wall in sub-section 6.1.2 may be used, as necessary. The excavation and dewatering is provided in Section 6.3.

6.3 Proposed Rehabilitation Work

As per the final design recommendation and contract drawings (Sheet 208), slope stabilization with a retaining wall at the toe or by flattening the side slope (with culvert extension) was not considered necessary. Nevertheless, for widening the existing road embankment, a RSS wall, varying in height from about 0.9 m to 2.7 m and with a minimum embedment of 0.3 m into the existing slope surface, is proposed from Sta 15+180 to Sta 15+325 along the west slope at the top of slope, as shown in Sheet 208. The embankment will be widened by about 1.3 m after construction of the wall.

Slope stability analyses were carried out on the existing slope at the culvert location (Station 15+205) with and without the proposed RSS wall for design, and to compare the change in stability of the existing embankment, if any, due to the addition of the wall.

6.3.1 Slope Stability

Global slope stability analyses were carried out at the location of the culvert at approximate Station 15+205, for the existing slope (with and without RSS wall), using GeoStudio 2007 Slope/W software (Version 7.17) employing the Morgenstern-Price method. The analysis was carried out for the slope over the culvert, as well as for the slope immediately adjacent to the culvert. Potential slip surfaces using a grid-based search were considered to determine the critical slip surface (with the lowest factor of safety against slope instability). Both short-term (undrained / end of construction) and long-term (drained) conditions were considered. Additional stability analyses for non-circular slip surfaces along the culvert top were also carried out.

As per Sheet 208 (General Arrangement, Retained Soil System, Sta. 15+180 to 15+325) of the Contract Drawing prepared in April 2012, the height of the proposed RSS wall will vary from 0.9 m to 2.7 m and the embankment will be widened by about 1.3 m at the top. For the analysis at this location, the maximum height of 2.7 m and the width (i.e. the reinforcing strip length) equal to the height has been considered. For internal stability of the RSS wall including overturning and sliding, the width of reinforcing strip within the RSS wall is to be designed by the RSS wall supplier/designer. Design of the RSS wall should be carried out as per the manufacturer's specifications based on the type of wall selected. The Ministry of Transportation's (MTO) RSS Design Guidelines should be used for the design, supply and construction of the RSS, in addition to any contract requirements and RSS manufacturer's standards. RSS Wall requires specialised contractor according to MTO's DSM.

Table 6.7 summarizes the soil parameters used for the global stability analysis. These soil parameters were selected based on the soil conditions encountered in Boreholes BH G30. Groundwater was not encountered in the boreholes during the field investigation. For the slope stability analyses, the groundwater was assumed to be at the culvert invert level, which would be at an elevation of about 182.0 m. Granular fill has been considered behind the proposed wall. Proper drainage system should be constructed to avoid additional accumulation of water behind the wall.

For live loads (traffic loads), a surcharge of 16 kPa was applied on the pavement areas.

Table 6.7 - Summary of Soil Parameters

Soil Type	Unit Weight (kN/m^3)	Total Stress		Effective Stress	
		c (kPa)	Φ (deg)	c' (kPa)	Φ' (deg)
Existing cohesive fill	18	50	0	0	28
Existing non-cohesive fill	18	0	30	0	32
Stiff to hard clayey silt/ silty clay	20	75	0	0	30
Granular Fill	21	0	32	0	32
Retaining Wall*	23	200	36	200	36
Culvert*	24	500	38	500	38

* The parameters for culvert and retaining were assumed only for slope stability modelling to disregard slip surface through the culvert/wall.

The results of the slope stability analysis are presented in Appendix D. Table 6.8 summarizes the results of slope stability analysis.

Table 6.8: Results of Slope Stability Analysis

Analyzed Section (Station)	Calculated Minimum Factor of Safety	
	Total Stress Analysis (Short Term)	Effective Stress Analysis (Long Term)
15+205 (existing condition at culvert location)	-	1.0 (Figure No. D1) (soil parameters used are reasonable and likely conservative)
15+205 (existing condition beside culvert location)	-	1.0 (Figure No. D2) (soil parameters used are reasonable and possibly conservative)
15+205 (with addition of RSS wall at culvert location)	1.9 (Figure No. D3)	1.0 (Figure No. D4) (slightly lower the existing factor of safety)
15+205 (with addition of RSS wall beside culvert location)	1.7 (Figure No. D5)	1.0 (Figure No. D6) (slightly lower the existing factor of safety)

Analyzed Section (Station)	Calculated Minimum Factor of Safety	
	Total Stress Analysis (Short Term)	**Effective Stress Analysis (Long Term)**
15+205 (existing condition at culvert location) (non circular slip with reduced soil strength parameters)	-	1.0 (Figure No. D7)
15+205 (with addition of RSS wall at culvert location) (non circular slip with reduced soil strength parameters)	2.2 (Figure No. D8)	1.0 (Figure No. D9) No significant change in the factor of safety.

A factor of safety (FOS) of slightly higher than 1.0 was calculated for the existing slope at and beside the culvert (most critical condition). Generally, a factor of safety (FOS) of 1.3 is considered for a stable slope. However, it should be noted that the soil parameters used for the analysis which areselected on the basis of published empirical values are conservative. As the existing slope has been in use for a long period of time without any apparent sign of distress during the field investigation, the FOS of the existing slope should be higher than the calculated FOS of 1.0. All FOS's calculated from the various analyses (with and without the proposed RSS wall) are equal to or higher than 1.0, as listed in Table 6.8, without significant reduction (up to one decimal point) in the calculated FOS. As such, the embankment slope with the proposed RSS wall should be stable, provided that any existing loose soils exposed during the construction of the RSS wall are replaced with compacted soils.

The proposed RSS wall will increase the soil pressure on the existing slope by approximately an average of 10 kPa over a distance of about 2 m. The existing embankment is founded on stiff to hard clayey silt / silty clay which should be capable of supporting the slight increase in soil pressure without significant long-term settlement. As a result, the long-term settlement of the road embankment with the RSS wall should be negligible. This is also confirmed by the negligible reduction of the factor of safety against slope instability for the existing embankment.

6.3.2 Design Considerations

The proposed RSS wall should be designed with the following considerations:

- At the borehole location (BH G30), the upper part of the fill (to a depth of about 5.5 m) consisted of loose silty sand underlain by firm silty clay. A bearing capacity of about 30 - 40 kPa (SLS) may be used for the fill at the founding depth of the proposed RSS wall. . The bearing capacities for the native soil are provided in Table 6.2. However, the soil condition noted in the borehole cannot and should not be extrapolated to the total length of the retaining wall, which is about 145 m long. The RSS wall foundation subgrade should be inspected and verified by the contractor administrator during construction phase. Soft spots, if encountered, should be sub-excavated and backfilled with compacted soil. Furthermore, it is recommended that the entire wall footing subgrade be re-compacted prior to construction of the RSS wall.

- For global slope stability, the minimum width of the RSS wall, i.e., the reinforcing strip, should be equal to the height of the wall, and the embedment of the wall (i.e. the depth of wall below ground) should be a minimum of 0.3 m. The RSS wall design should be carried out as per the manufacturer's specifications based on the type of wall selected. In addition to any contract requirements and the RSS manufacturer's standards, MTO's "*RSS Design Guidelines*", including the Non Standard Special Provision for RSS (January 2008) included therein, and/or Special Provision to OPSS - SSP599S23, should be used for the design, supply and construction of the RSS. It should be noted that RSS wall requires specialised contractor listed in MTO's DSM.
- Adequate and proper drainage system should be provided behind the RSS wall to prevent accumulation of water behind wall. Otherwise, the minimum reinforcing strip length may have to be increased.
- *The RSS wall design was revised on May 9, 2013 (Drawing 208A), according to which the proposed RSS wall will vary from 0.4 m to 1.4 m in height and the embankment will be widened by about 1.0 m at the top. The slope stability analysis discussed above was carried out based on Drawing 208 with a maximum wall height of 2.7 m. As the revised design has lower RSS wall height and lower width of embankment to be widened, the maximum 1.4 m high RSS wall should be stable , as noted in Section 6.3.1. However, as recommended earlier, the minimum width of the RSS wall, i.e., the reinforcing strip, should be equal to the height of the wall, and the embedment of the wall (i.e. the depth of wall below slope surface at the RSS wall toe) should be a minimum of 0.3 m.*

6.4 Excavation and Dewatering

All excavations 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:

All fill soil	Type 3
Stiff to hard clayey silt / silty clay	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. 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 6.4.

Cobbles and boulders should be expected within the soils. **The construction contract should include a Nonstandard Special Provision (NSSP) to warn the contractor of the possible presence of cobbles / boulders.**

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.

Groundwater was not encountered in the borehole during the field investigation. However, excavation to replace the existing retaining wall at southwest corner of culvert or new retaining wall at toe areas may encounter groundwater. Groundwater seepage, if any, is expected to be slow through the clayey silt / silty clay, and could be dewatered using a system of sumps and pumps. High rates of seepage may occur from surface water and dewatering effort could require an increased number of sumps and pumps.

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.

6.5 Temporary Shoring

Temporary shoring may be required during the demolition of the existing retaining wall and excavation work of the new retaining wall. The temporary shoring 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. The design of temporary shoring should be carried out in accordance with Canadian Highway Bridge Design Code CAN/CSA-S6-06. Soil parameters given in Table 6.3 may be used for design considerations.

6.6 Soil Corrosivity

One soil sample (BH G30 - 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 are presented in Table 6.9.

Table 6.9 - Results of Corrosivity Testing

Soil Sample No.	pH	Electrical Conductivity μmho/cm	Resistivity (ohms-cm)	Chloride (μg/g)	Sulphate (μg/g)
BH G30 - SS 2	7.82	1250	800	640	<20

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 “severe” 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 15+205 on Highway 21, north of Telephone Road, between Bayfield and Goderich, Ontario.

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

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

Sincerely,

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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 15+205 in Highway 21 about 25 m north of Telephone Road, between Bayfield and Goderich, 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.

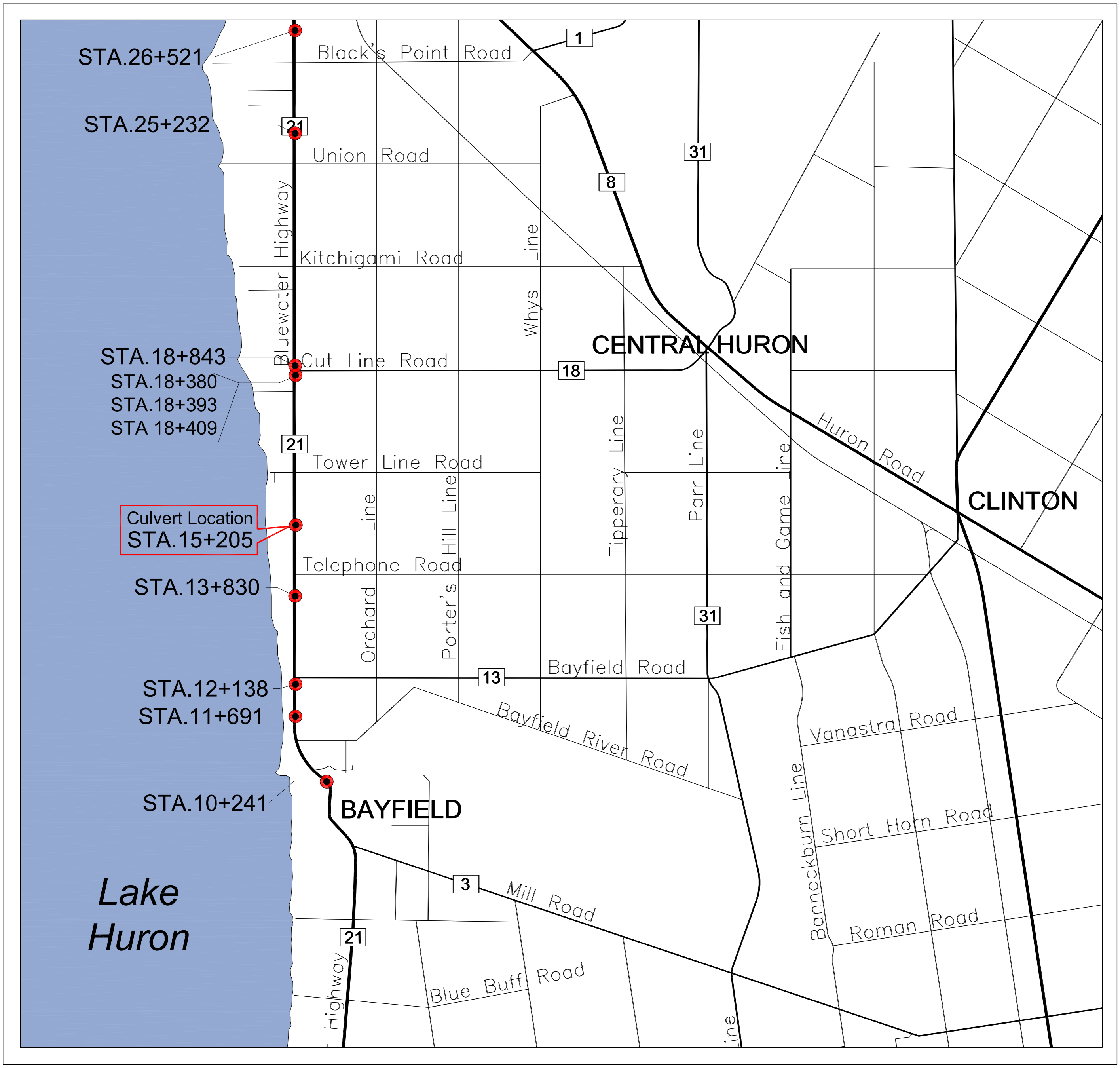
List of Construction Specifications and Drawings

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
SSP 599S23 (Mar/06)	Special Provision for Materials, Quality Control and Quality Assurance Testing and Acceptance Criteria for Precast Concrete Facing Elements including Panels
Drawings	
OPSD 208.010	Benching of Earth Slopes
OPSD 803.010	Backfill, backfill transition and cover for the concrete culvert
OPSD 810.010	Rip-rap treatment for sewer and culvert outlets
OPSD 3121.150	Minimum granular backfill requirements - walls retaining

…/…

DRAWINGS

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



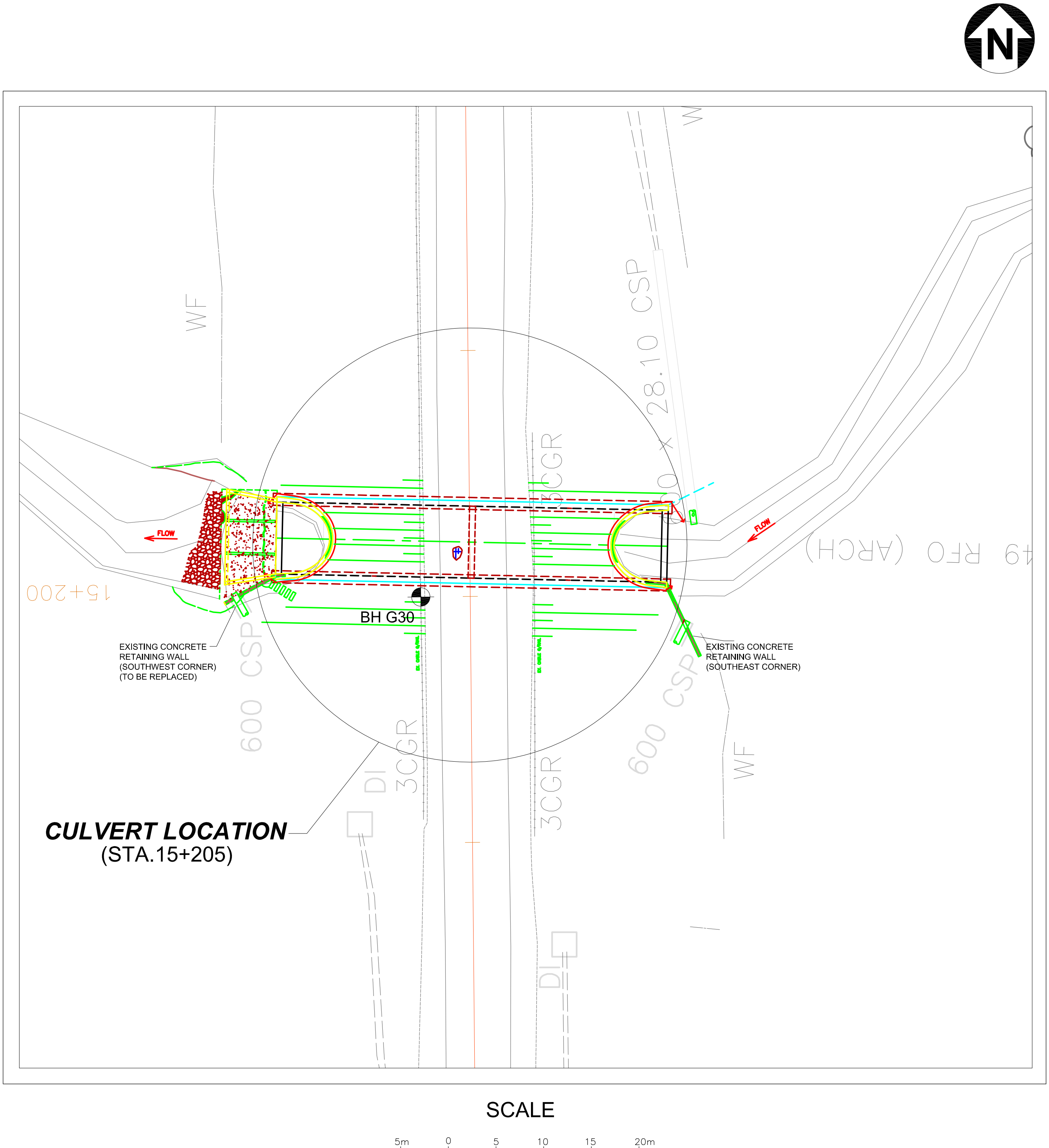
SCALE

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.: 40P12-21		CHK'D BY: PB	REV. NO.: A	PROJECT NO: TP110076
		PROJECTION: -	SCALE: AS SHOWN	DRAWING No. 1



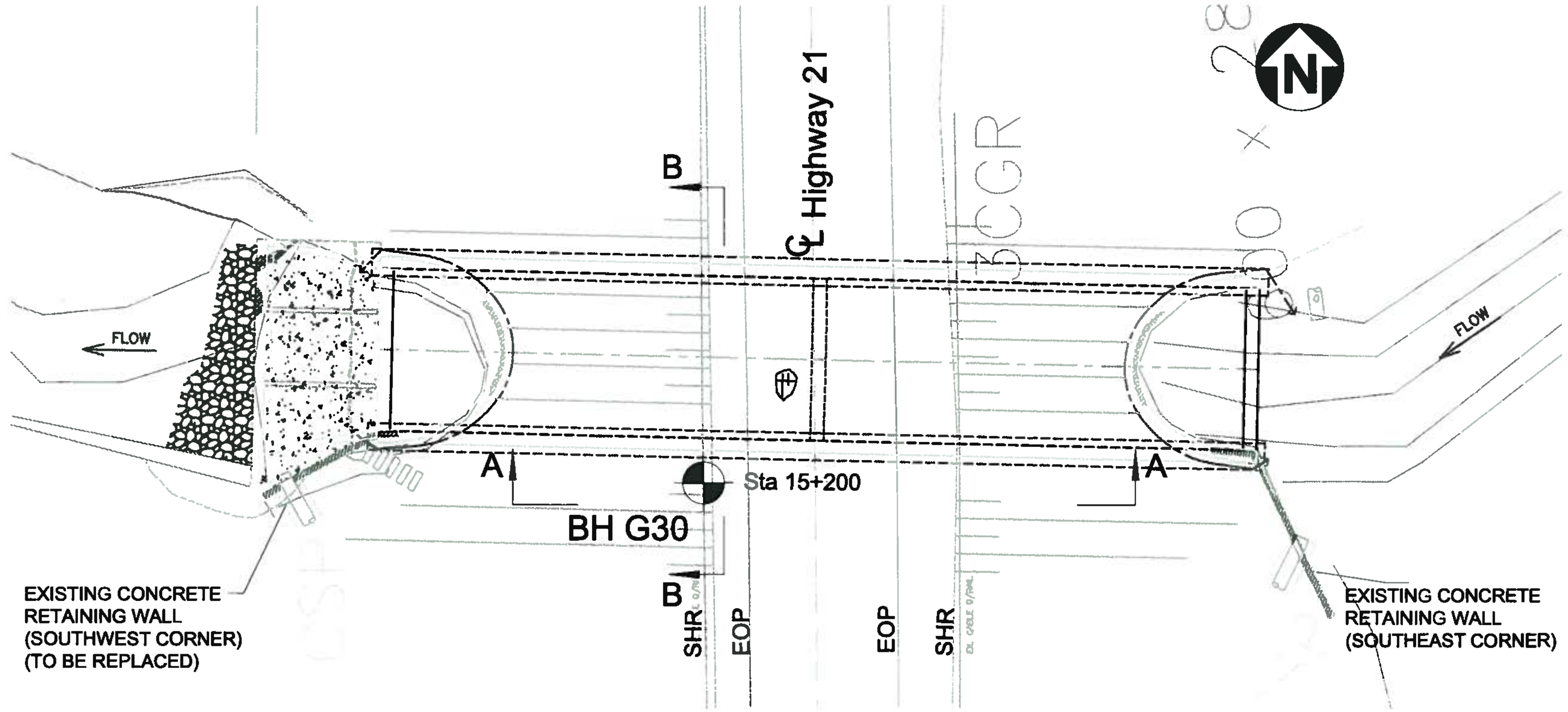
AMEC Environment & Infrastructure, a Division of AMEC Americas Limited

amec

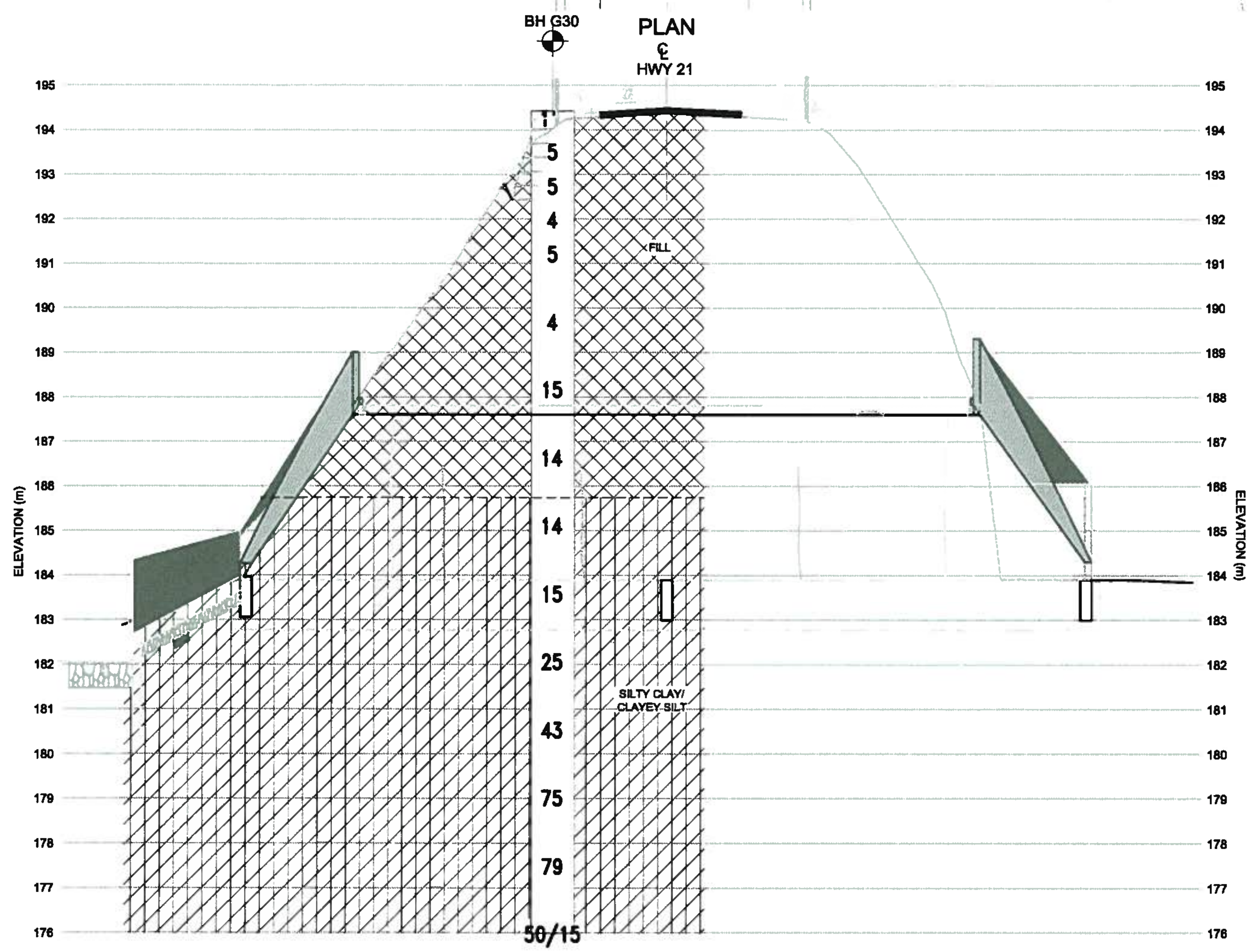
CLIENT LOGO: Ontario	CLIENT: MINISTRY OF TRANSPORTATION ONTARIO WEST REGION		
TITLE: BOREHOLE LOCATION PLAN	DWN BY: KW	DATUM: -	DATE: JANUARY 2013
PROJECT: REHABILITATION OF HIGHWAY 21 - FROM BAYFIELD TO GODERICH PURCHASE ORDER NUMBER: 3009-E-0022, WP 834-93-00, GEOCRES No.: 40P12-21	CHK'D BY: PB	REV.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

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

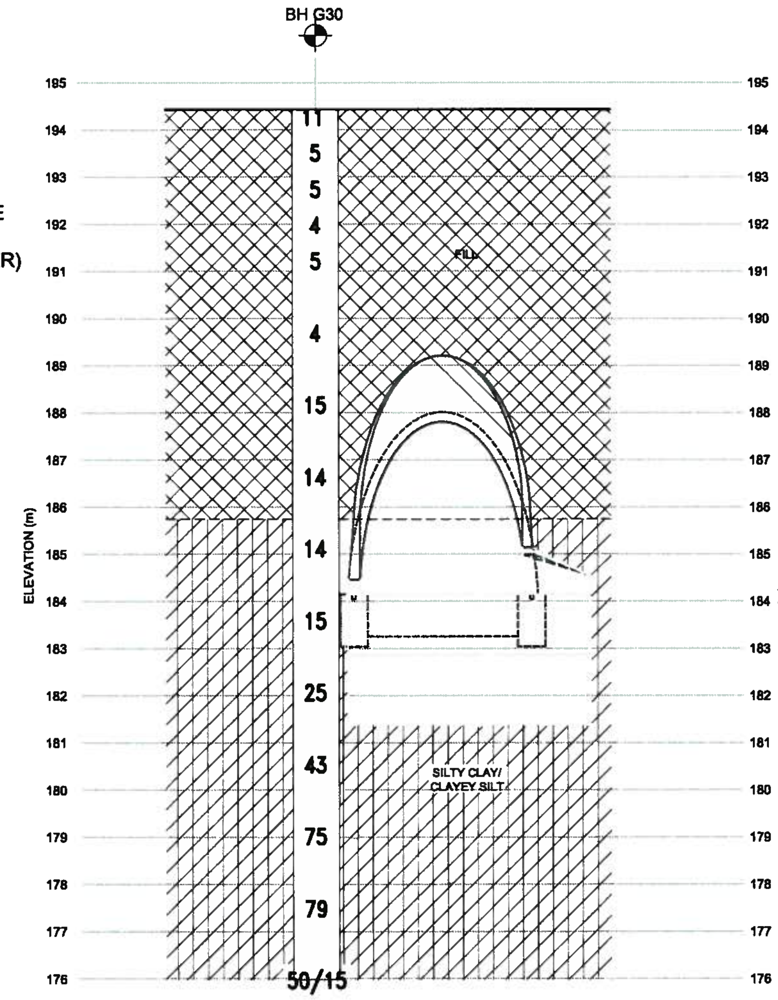
PURCHASE ORDER NUMBER: 3009-E-0022	
G.W.P. No. 834-93-00	
REHABILITATION OF HWY 21 FROM BAYFIELD TO GODERICH GEOCRES No.40P12-21 **CULVERT AT STA 15+205** STRATIGRAPHIC CROSS SECTION	**SHEET 1 OF 1**
amec AMEC Environment & Infrastructure, a Division of AMEC Americas Limited	



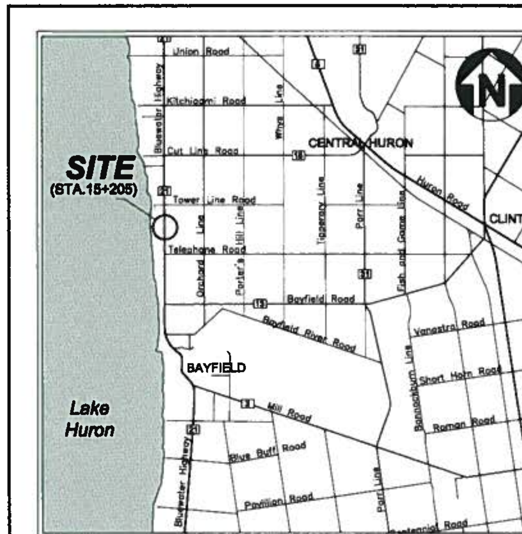
PLAN



SECTION A-A



SECTION B-B



KEY PLAN

2000m 0 2000 4000 6000 8000m
Approximate Scale

LEGEND

- BOREHOLE LOCATION
- GROUND WATER LEVEL AT TIME OF INVESTIGATION
- EOP — EDGE OF PAVEMENT
- SHR — SHOULDER ROUND

DESCRIPTION	UTM COORDINATES NORTHING	UTM COORDINATES EASTING	ELEVATION (m)
BH G30	4829232	443055	194.4

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.

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SOIL STRATIGRAPHY
TOPSOIL
FILL
SILTY CLAY/ CLAYEY SILT

SCALE: 0 2 4 6m HOR; 0 1 2 3m VER

AMEC Reference: TP110076

DESIGN PB	CHK PB	CODE CHBDC-06	CL 625-ONT	DATE JAN. 2013
DRAWN KW	CHK HS	SITE 15+205		DWG 3

REVISIONS

P:\GEO\Projects\2011\TP-Burlington\TP110076-HWY 21\05-Foundation\Drawings...\TB112041 - Washburn Drain.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

MAJOR DIVISION				GROUP SYMBOL	TYPICAL DESCRIPTION	INFORMATION REQUIRED FOR DESCRIBING SOILS
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.
			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
			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	
			PLASTIC FINES (FOR IDENTIFICATION PROCEDURES SEE CL BELOW)	SC	CLAYEY SANDS, POORLY GRADED SAND-CLAY MIXTURES	

FINE-GRAINED SOILS (MORE THAN HALF BY WEIGHT SMALLER THAN 75µm) — SILT AND CLAYS — IDENTIFICATION PROCEDURE ON FRACTION SMALLER THAN 425µm

	DRY STRENGTH (CRUSHING CHARACTERISTICS)	DILATANCY (REACTION TO SHAKING)	TOUGHNESS (CONSISTENCY NEAR PLASTIC LIMIT)	GROUP SYMBOL	TYPICAL DESCRIPTION	INFORMATION REQUIRED FOR DESCRIBING SOILS
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.
	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	
	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	
	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	
HIGH ORGANIC SOILS	READILY IDENTIFIED BY COLOUR, ODOUR, SPONGY FEEL & FREQUENTLY BY FIBROUS TEXTURE			Pt	PEAT AND OTHER HIGHLY ORGANIC SOILS	

LABORATORY CLASSIFICATION CRITERIA

USE GRAIN SIZE CURVE IN IDENTIFYING THE FACTORS AS GIVEN UNDER FIELD IDENTIFICATION

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:

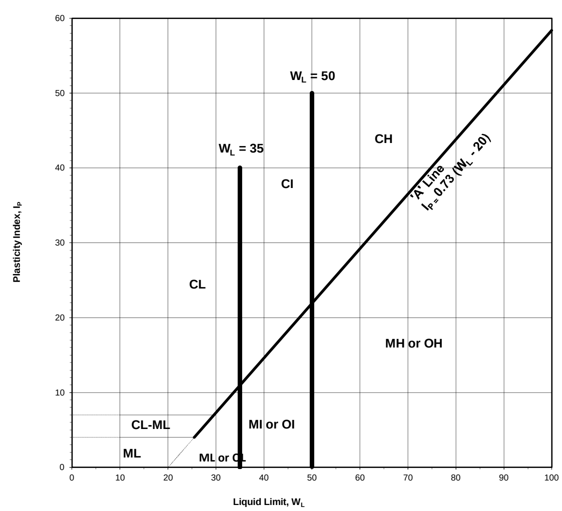
LESS THAN 5%	GW, GP, SW, SP
MORE THAN 12%	GM, GC, SM, SC
5% TO 12%	BORDER LINE CASES REQUIRE USE OF DUAL SYMBOL.

Group	Criteria	
GW	$C_u = \frac{D_{60}}{D_{10}}$ GREATER THAN 4; $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ BETWEEN 1 AND 3	
GP	NOT MEETING ALL GRADATION REQUIREMENTS FOR GW	
GM	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
GC	ATTERBERG LIMITS ABOVE A- LINE WITH Ip GREATER THAN 7	
SW	$C_u = \frac{D_{60}}{D_{10}}$ GREATER THAN 6; $C_C = \frac{(D_{30})^2}{D_{10} \times D_{60}}$ BETWEEN 1 AND 3	
SP	NOT MEETING ALL GRADATION FOR SW	
SM	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
SC	ATTERBERG LIMITS ABOVE A- LINE WITH Ip GREATER THAN 7	

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: 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

AMEC Environment & Infrastructure,
a Division of AMEC American

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MTC SOIL CLASSIFICATION MANUAL

ENGINEERING PROPERTIES OF SOIL

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

amec

RECORD OF BOREHOLE No. BH G30

G.W.P. 834-93-00 | LOCATION Sta.15+205, SBL, 5.0m W of Rd C/L, 2.8m S of Culv C/L, E443055 N4829232 | ORIGINATED BY JF

DIST Goderich HWY 21 | BOREHOLE TYPE 200 mm diameter borehole (Hollow Stem) | COMPILED BY SC

DATUM Geodetic | DATE March 14, 2012 - March 14, 2012 | CHECKED BY SM

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

ELEV DEPTH (m)	DESCRIPTION	NUMBER	TYPE	"N" VALUES	WATER CONTENT (%)	SOIL VAPOUR READING (PPM)	GR	SA	SI	CL
194.4 / 0.0	brown **Sand and Gravel FILL** some silt moist	1	SS	11	5	0				
193.8 / 0.6	brown **Silty Sand FILL** trace gravel moist	2	SS	5	9	0				
	some clay in SS3	3	SS	5	11	5				
	trace organic matter in SS4	4	SS	4	17	10				
191.5 / 2.9	brown **Silty Clay FILL** some sand trace gravel	5	SS	5	14	5				
		6	SS	4	11	0				
	trace organic matter in SS7	7	SS	15	13	15				
	trace organic matter in SS 8	8	SS	14	19	50				
185.7 / 8.7	grey **CLAYEY SILT / SILTY CLAY** some sand trace gravel stiff to hard	9	SS	14	14	40	4	17	45	34

Columns also shown: STRAT PLOT, GROUND WATER CONDITIONS, DEPTH (m) 1–9, ELEVATION SCALE (m) 194–185, 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, REMARKS & GRAIN SIZE DISTRIBUTION (%).

Continued Next Page

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

Ontario

amec

RECORD OF BOREHOLE No. BH G30

G.W.P. 834-93-00 LOCATION Sta.15+205, SBL, 5.0m W of Rd C/L, 2.8m S of Culv C/L, E443055 N4829232 ORIGINATED BY JF

DIST Goderich HWY 21 BOREHOLE TYPE 200 mm diameter borehole (Hollow Stem) COMPILED BY SC

DATUM Geodetic DATE March 14, 2012 - March 14, 2012 CHECKED BY SM

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

ELEV DEPTH (m)	SOIL PROFILE DESCRIPTION	NUMBER	TYPE	"N" VALUES	WATER CONTENT (%)	SOIL VAPOUR READING (PPM)	GR	SA	SI	CL
	grey **CLAYEY SILT / SILTY CLAY** some sand trace gravel stiff to hard									
		10	SS	15	17	0				
		11	SS	25	16	0				
	trace cobbles / boulders in SS12	12	SS	43	14	0				
		13	SS	75	15	0	-	5	52	43
		14	SS	79	12	0				
176.0 18.5	trace cobbles / boulders in SS15	15	SS	50/15	14					
	End of Borehole Groundwater Level on 14 March 2012: dry									

Depth scale (m): 11, 12, 13, 14, 15, 16, 17, 18

Elevation scale (m): 184, 183, 182, 181, 180, 179, 178, 177, 176

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

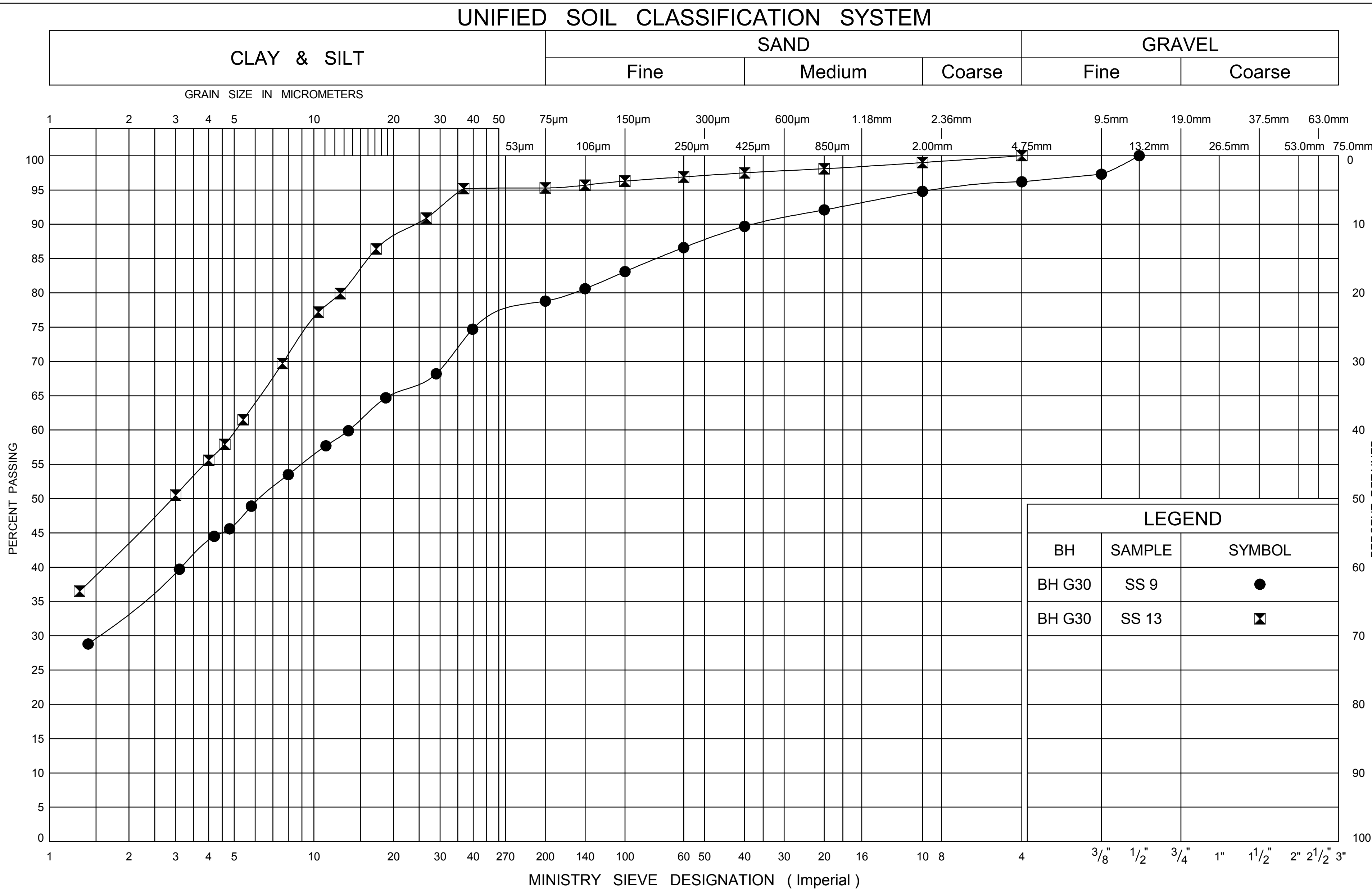
PLASTIC LIMIT W_P — NATURAL MOISTURE CONTENT W — LIQUID LIMIT W_L; WATER CONTENT (%) 20 40 60

REMARKS & GRAIN SIZE DISTRIBUTION (%)

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

APPENDIX B

LABORATORY TEST RESULTS



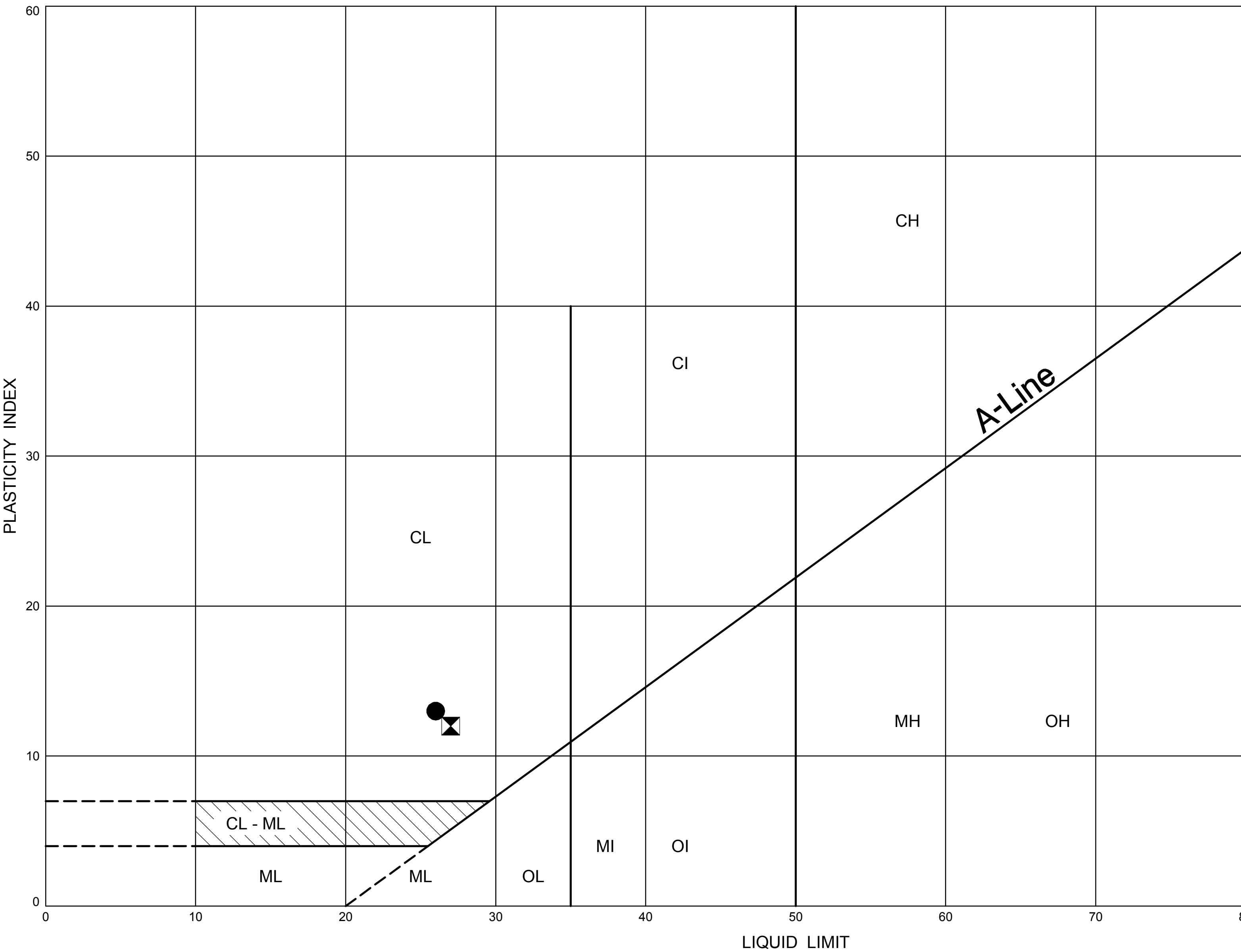
Ministry of Transportation
Ontario

GRAIN SIZE DISTRIBUTION
CLAYEY SILT / SILTY CLAY

Figure No. B 1

G.W.P. 834-93-00

Culvert at Sta. 15+205, Hwy 21, Bayfield to Goderich



LEGEND		
BH	SAMPLE	SYMBOL
BH G30	SS 9	●
BH G30	SS 13	⧗

Ministry of Transportation
Ontario

PLASTICITY CHART
CLAYEY SILT / SILTY CLAY

Figure No. B 2

G.W.P. 834-93-00

Culvert at Sta. 15+205, Hwy 21, Bayfield to Goderich

Your Project #: TP110076.05
Your C.O.C. #: 27188503, 271885-03-01

Attention: Shami Mala
AMEC Environment & Infrastructure
Scarborough
104 Crockford Blvd
Sacroborough, ON
CANADA M1R3C3

Report Date: 2012/03/23

CERTIFICATE OF ANALYSIS

MAXXAM JOB #: B238403
Received: 2012/03/19, 12:10

Sample Matrix: Soil
Samples Received: 9

Analyses	Quantity	Date Extracted	Date Analyzed	Laboratory Method	Method Reference
Chloride (20:1 extract)	9	N/A	2012/03/23	CAM SOP-00463	EPA 325.2
Conductivity	9	N/A	2012/03/23	CAM SOP-00414	APHA 2510
pH CaCl2 EXTRACT	8	2012/03/22	2012/03/22	CAM SOP-00413	SM 4500H+ B
pH CaCl2 EXTRACT	1	2012/03/22	2012/03/23	CAM SOP-00413	SM 4500H+ B
Resistivity of Soil	9	2012/03/19	2012/03/23	CAM SOP-00414	APHA 2510
Sulphate (20:1 Extract)	9	N/A	2012/03/23	CAM SOP-00464	EPA 375.4

Remarks:

Maxxam Analytics has performed all analytical testing herein in accordance with ISO 17025 and the Protocol for Analytical Methods Used in the Assessment of Properties under Part XV.1 of the Environmental Protection Act. All methodologies comply with this document and are validated for use in the laboratory. The methods and techniques employed in this analysis conform to the performance criteria (detection limits, accuracy and precision) as outlined in the Protocol for Analytical Methods Used in the Assessment of Properties under Part XV.1 of the Environmental Protection Act. Reporting results to two significant figures at the RDL is to permit statistical evaluation and is not intended to be an indication of analytical precision.

The CWS PHC methods employed by Maxxam conform to all prescribed elements of the reference method and performance based elements have been validated. All modifications have been validated and proven equivalent following the 'Alberta Environment Draft Addenda to the CWS-PHC, Appendix 6, Validation of Alternate Methods'. Documentation is available upon request. Maxxam has made the following improvements to the CWS-PHC reference benchmark method: (i) Headspace for F1; and, (ii) Mechanical extraction for F2-F4. Note: F4G cannot be added to the C6 to C50 hydrocarbons. The extraction date for samples field preserved with methanol for F1 and Volatile Organic Compounds is considered to be the date sampled.

Maxxam Analytics is accredited by SCC (Lab ID 97) for all specific parameters as required by Ontario Regulation 153/04. Maxxam Analytics is limited in liability to the actual cost of analysis unless otherwise agreed in writing. There is no other warranty expressed or implied. Samples will be retained at Maxxam Analytics for three weeks from receipt of data or as per contract.

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

../2

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

==
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: 2

Maxxam Job #: B238403
Report Date: 2012/03/23

AMEC Environment & Infrastructure
Client Project #: TP110076.05

RESULTS OF ANALYSES OF SOIL

Maxxam ID		MV6494	MV6495	MV6496	MV6497	MV6498		
Sampling Date		2012/03/13 10:00	2012/03/13 10:00	2012/03/13 10:10	2012/03/13 10:10	2012/03/13 09:50		
	Units	**G22-SS6**	**G26-SS4**	**G28-SS2**	**G31-SS2**	**G35-SS1B**	**RDL**	**QC Batch**
Calculated Parameters								
Resistivity	ohm-cm	3400	1400	970	1700	3400		2793995
Inorganics								
Soluble (20:1) Chloride (Cl)	ug/g	90	350	550	290	90	20	2799578
Conductivity	umho/cm	292	734	1030	598	290	2	2799683
Available (CaCl2) pH	pH	7.64	7.41	7.71	7.72	7.71		2798076
Soluble (20:1) Sulphate (SO4)	ug/g	25	54	<20	<20	20	20	2799579

Maxxam ID		MV6499	MV6500		MV6501		MV6502		
Sampling Date		2012/03/16 14:30	2012/03/16 14:40		2012/03/16 15:50		2012/03/16 14:50		
	Units	**G24-SS4**	**G30-SS2**	**QC Batch**	**G37-SS2**	**QC Batch**	**G38-SS2**	**RDL**	**QC Batch**
Calculated Parameters									
Resistivity	ohm-cm	1300	800	2793995	1300	2793995	1100		2793995
Inorganics									
Soluble (20:1) Chloride (Cl)	ug/g	380	640	2799578	350	2799578	450	20	2799578
Conductivity	umho/cm	771	1250	2799683	785	2799683	949	2	2799683
Available (CaCl2) pH	pH	7.47	7.82	2798076	8.05	2799276	7.35		2798048
Soluble (20:1) Sulphate (SO4)	ug/g	<20	<20	2799579	<20	2799579	<20	20	2799579

RDL = Reportable Detection Limit
QC Batch = Quality Control Batch

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

Test Summary

Maxxam ID MV6494
Sample ID G22-SS6
Matrix Soil

Collected 2012/03/13
Shipped
Received 2012/03/19

Test Description	Instrumentation	Batch	Extracted	Analyzed	Analyst
Chloride (20:1 extract)	AC/EC	2799578	N/A	2012/03/23	DEONARINE RAMNARINE
Conductivity	COND	2799683	N/A	2012/03/23	NEIL DASSANAYAKE
pH CaCl2 EXTRACT		2798076	2012/03/22	2012/03/22	XUANHONG QIU
Resistivity of Soil		2793995	2012/03/23	2012/03/23	CRISTINA CARRIERE
Sulphate (20:1 Extract)	AC/EC	2799579	N/A	2012/03/23	DEONARINE RAMNARINE

Maxxam ID MV6495
Sample ID G26-SS4
Matrix Soil

Collected 2012/03/13
Shipped
Received 2012/03/19

Test Description	Instrumentation	Batch	Extracted	Analyzed	Analyst
Chloride (20:1 extract)	AC/EC	2799578	N/A	2012/03/23	DEONARINE RAMNARINE
Conductivity	COND	2799683	N/A	2012/03/23	NEIL DASSANAYAKE
pH CaCl2 EXTRACT		2798076	2012/03/22	2012/03/22	XUANHONG QIU
Resistivity of Soil		2793995	2012/03/23	2012/03/23	CRISTINA CARRIERE
Sulphate (20:1 Extract)	AC/EC	2799579	N/A	2012/03/23	DEONARINE RAMNARINE

Maxxam ID MV6496
Sample ID G28-SS2
Matrix Soil

Collected 2012/03/13
Shipped
Received 2012/03/19

Test Description	Instrumentation	Batch	Extracted	Analyzed	Analyst
Chloride (20:1 extract)	AC/EC	2799578	N/A	2012/03/23	DEONARINE RAMNARINE
Conductivity	COND	2799683	N/A	2012/03/23	NEIL DASSANAYAKE
pH CaCl2 EXTRACT		2798076	2012/03/22	2012/03/22	XUANHONG QIU
Resistivity of Soil		2793995	2012/03/23	2012/03/23	CRISTINA CARRIERE
Sulphate (20:1 Extract)	AC/EC	2799579	N/A	2012/03/23	DEONARINE RAMNARINE

Test Summary

Maxxam ID MV6497
Sample ID G31-SS2
Matrix Soil

Collected 2012/03/13
Shipped
Received 2012/03/19

Test Description	Instrumentation	Batch	Extracted	Analyzed	Analyst
Chloride (20:1 extract)	AC/EC	2799578	N/A	2012/03/23	DEONARINE RAMNARINE
Conductivity	COND	2799683	N/A	2012/03/23	NEIL DASSANAYAKE
pH CaCl2 EXTRACT		2798076	2012/03/22	2012/03/22	XUANHONG QIU
Resistivity of Soil		2793995	2012/03/23	2012/03/23	CRISTINA CARRIERE
Sulphate (20:1 Extract)	AC/EC	2799579	N/A	2012/03/23	DEONARINE RAMNARINE

Maxxam ID MV6498
Sample ID G35-SS1B
Matrix Soil

Collected 2012/03/13
Shipped
Received 2012/03/19

Test Description	Instrumentation	Batch	Extracted	Analyzed	Analyst
Chloride (20:1 extract)	AC/EC	2799578	N/A	2012/03/23	DEONARINE RAMNARINE
Conductivity	COND	2799683	N/A	2012/03/23	NEIL DASSANAYAKE
pH CaCl2 EXTRACT		2798076	2012/03/22	2012/03/22	XUANHONG QIU
Resistivity of Soil		2793995	2012/03/23	2012/03/23	CRISTINA CARRIERE
Sulphate (20:1 Extract)	AC/EC	2799579	N/A	2012/03/23	DEONARINE RAMNARINE

Maxxam ID MV6499
Sample ID G24-SS4
Matrix Soil

Collected 2012/03/16
Shipped
Received 2012/03/19

Test Description	Instrumentation	Batch	Extracted	Analyzed	Analyst
Chloride (20:1 extract)	AC/EC	2799578	N/A	2012/03/23	DEONARINE RAMNARINE
Conductivity	COND	2799683	N/A	2012/03/23	NEIL DASSANAYAKE
pH CaCl2 EXTRACT		2798076	2012/03/22	2012/03/22	XUANHONG QIU
Resistivity of Soil		2793995	2012/03/23	2012/03/23	CRISTINA CARRIERE
Sulphate (20:1 Extract)	AC/EC	2799579	N/A	2012/03/23	DEONARINE RAMNARINE

Test Summary

Maxxam ID MV6500
Sample ID G30-SS2
Matrix Soil

Collected 2012/03/16
Shipped
Received 2012/03/19

Test Description	Instrumentation	Batch	Extracted	Analyzed	Analyst
Chloride (20:1 extract)	AC/EC	2799578	N/A	2012/03/23	DEONARINE RAMNARINE
Conductivity	COND	2799683	N/A	2012/03/23	NEIL DASSANAYAKE
pH CaCl2 EXTRACT		2798076	2012/03/22	2012/03/22	XUANHONG QIU
Resistivity of Soil		2793995	2012/03/23	2012/03/23	CRISTINA CARRIERE
Sulphate (20:1 Extract)	AC/EC	2799579	N/A	2012/03/23	DEONARINE RAMNARINE

Maxxam ID MV6501
Sample ID G37-SS2
Matrix Soil

Collected 2012/03/16
Shipped
Received 2012/03/19

Test Description	Instrumentation	Batch	Extracted	Analyzed	Analyst
Chloride (20:1 extract)	AC/EC	2799578	N/A	2012/03/23	DEONARINE RAMNARINE
Conductivity	COND	2799683	N/A	2012/03/23	NEIL DASSANAYAKE
pH CaCl2 EXTRACT		2799276	2012/03/22	2012/03/23	XUANHONG QIU
Resistivity of Soil		2793995	2012/03/23	2012/03/23	CRISTINA CARRIERE
Sulphate (20:1 Extract)	AC/EC	2799579	N/A	2012/03/23	DEONARINE RAMNARINE

Maxxam ID MV6502
Sample ID G38-SS2
Matrix Soil

Collected 2012/03/16
Shipped
Received 2012/03/19

Test Description	Instrumentation	Batch	Extracted	Analyzed	Analyst
Chloride (20:1 extract)	AC/EC	2799578	N/A	2012/03/23	DEONARINE RAMNARINE
Conductivity	COND	2799683	N/A	2012/03/23	NEIL DASSANAYAKE
pH CaCl2 EXTRACT		2798048	2012/03/22	2012/03/22	XUANHONG QIU
Resistivity of Soil		2793995	2012/03/23	2012/03/23	CRISTINA CARRIERE
Sulphate (20:1 Extract)	AC/EC	2799579	N/A	2012/03/23	DEONARINE RAMNARINE

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Test Summary

Maxxam ID MV6502 Dup
Sample ID G38-SS2
Matrix Soil

Collected 2012/03/16
Shipped
Received 2012/03/19

Test Description	Instrumentation	Batch	Extracted	Analyzed	Analyst
Sulphate (20:1 Extract)	AC/EC	2799579	N/A	2012/03/23	DEONARINE RAMNARINE

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Package 1	10.7°C

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

GENERAL COMMENTS

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Maxxam Job #: B238403
Report Date: 2012/03/23

AMEC Environment & Infrastructure
Client Project #: TP110076.05

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
2799578	Soluble (20:1) Chloride (Cl)	2012/03/23	107	75 - 125	106	75 - 125	<20	ug/g	NC	35		
2799579	Soluble (20:1) Sulphate (SO4)	2012/03/23	114 (1)	75 - 125	104	85 - 115	<20	ug/g	NC (2)	35		
2799683	Conductivity	2012/03/23					<2	umho/cm	0.1	35	99	75 - 125

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.
(1) - Matrix Spike Parent ID [MV6502-01]
(2) - Duplicate Parent ID [MV6502-01]

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Validation Signature Page

Maxxam Job #: B238403

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

==

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.

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APPENDIX C

SITE PHOTOGRAPHS

HIGHWAY 21, GODERICH, ONTARIO
(CULVERT AT Sta. 15 + 205)

PHOTOGRAPH NO. 1

Looking towards the existing culvert at inlet.

PHOTOGRAPH NO. 2

Looking down towards the existing culvert outlet area.

APPENDIX D

SLOPE STABILITY ANALYSIS RESULTS

TP110076 - Rehabilitation of HWY 21 from Bayfield to Goderich, ON
Culvert 20 - Sta. 15+205 (Effective Stress Analysis)
C20-15+205 Existng Slope (At Culvert)) (Apr 13).gsz

Name: Existing non-cohesive Fill Unit Weight: 18 kN/m³ Cohesion: 0 kPa Phi: 30 °
Name: Existing Cohesive Fill Unit Weight: 18 kN/m³ Cohesion: 0 kPa Phi: 28 °
Name: Culvert Unit Weight: 24 kN/m³ Cohesion: 500 kPa Phi: 38 °
Name: Stiff to Hard Clayey Silt / Silty Clay Unit Weight: 20 kN/m³ Cohesion: 0 kPa Phi: 30 °

NOTE: Soil properties used for culvert/RSS wall assumed only for slope stability modelling to disregard slip surface through the culvert/wall.

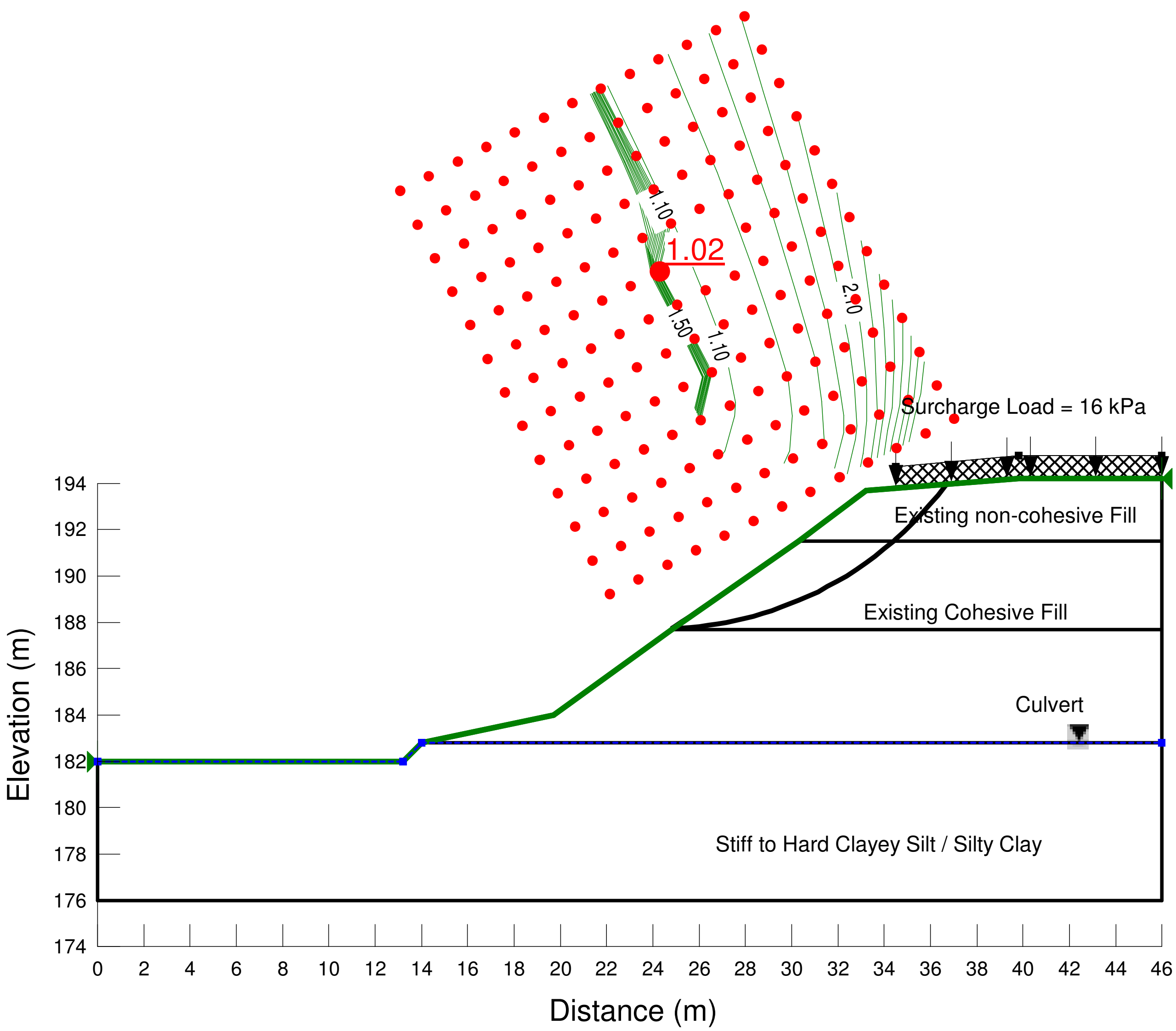

Figure D1 Slope Stability Analysis of Existing Embankment at Culvert Location - Sta. 15+205 (Effective Stress Analysis)

TP110076 - Rehabilitation of HWY 21 from Bayfield to Goderich, ON
Culvert 20 - Sta. 15+205 (Effective Stress Analysis)
C20-15+205 Existng Slope (Beside Culvert)(Apr 13).gsz

Name: Existing Granular Fill   Unit Weight: 18 kN/m³   Cohesion: 0 kPa   Phi: 30 °
Name: Stiff to Hard Clayey Silt / Silty Clay   Unit Weight: 20 kN/m³   Cohesion: 0 kPa   Phi: 30 °
Name: Existing Cohesive Fill   Unit Weight: 18 kN/m³   Cohesion: 0 kPa   Phi: 28 °

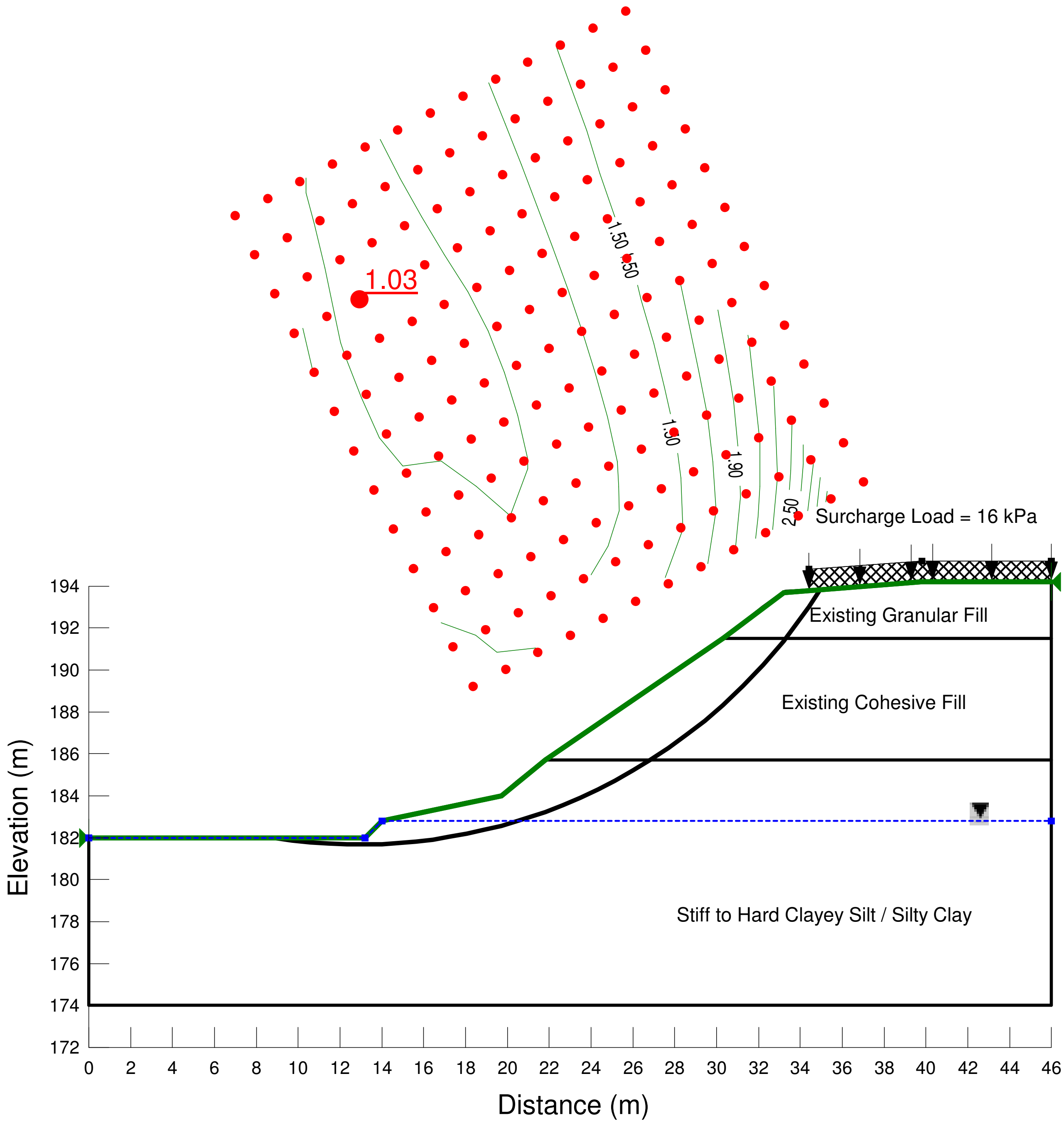

Figure D2 Slope Stability Analysis of Existing Embankment beside Culvert - Sta. 15+205
(Effective Stress Analysis)

TP110076 - Rehabilitation of HWY 21 from Bayfield to Goderich, ON
Culvert 20 - Sta. 15+205 (Total Stress Analysis)
C20-15+205 with Ret Wall (At Culvert)(Apr 13).gsz

Name: Granular Fill   Unit Weight: 21 kN/m³   Cohesion: 0 kPa   Phi: 32 °
Name: Existing Non-cohesive Fill   Unit Weight: 18 kN/m³   Cohesion: 0 kPa   Phi: 30 °
Name: RSS Wall   Unit Weight: 23 kN/m³   Cohesion: 200 kPa   Phi: 36 °
Name: Existing Cohesive Fill (ST)   Unit Weight: 18 kN/m³   Cohesion: 50 kPa
Name: Stiff to Hard Clayey Silt / Silty Clay (ST)   Unit Weight: 20 kN/m³   Cohesion: 75 kPa
Name: Culvert   Unit Weight: 24 kN/m³   Cohesion: 500 kPa   Phi: 38 °

NOTE: Soil properters used for culvert/RSS wall assumed only for slope stability modelling to disregard slip surface through the culvert/wall.

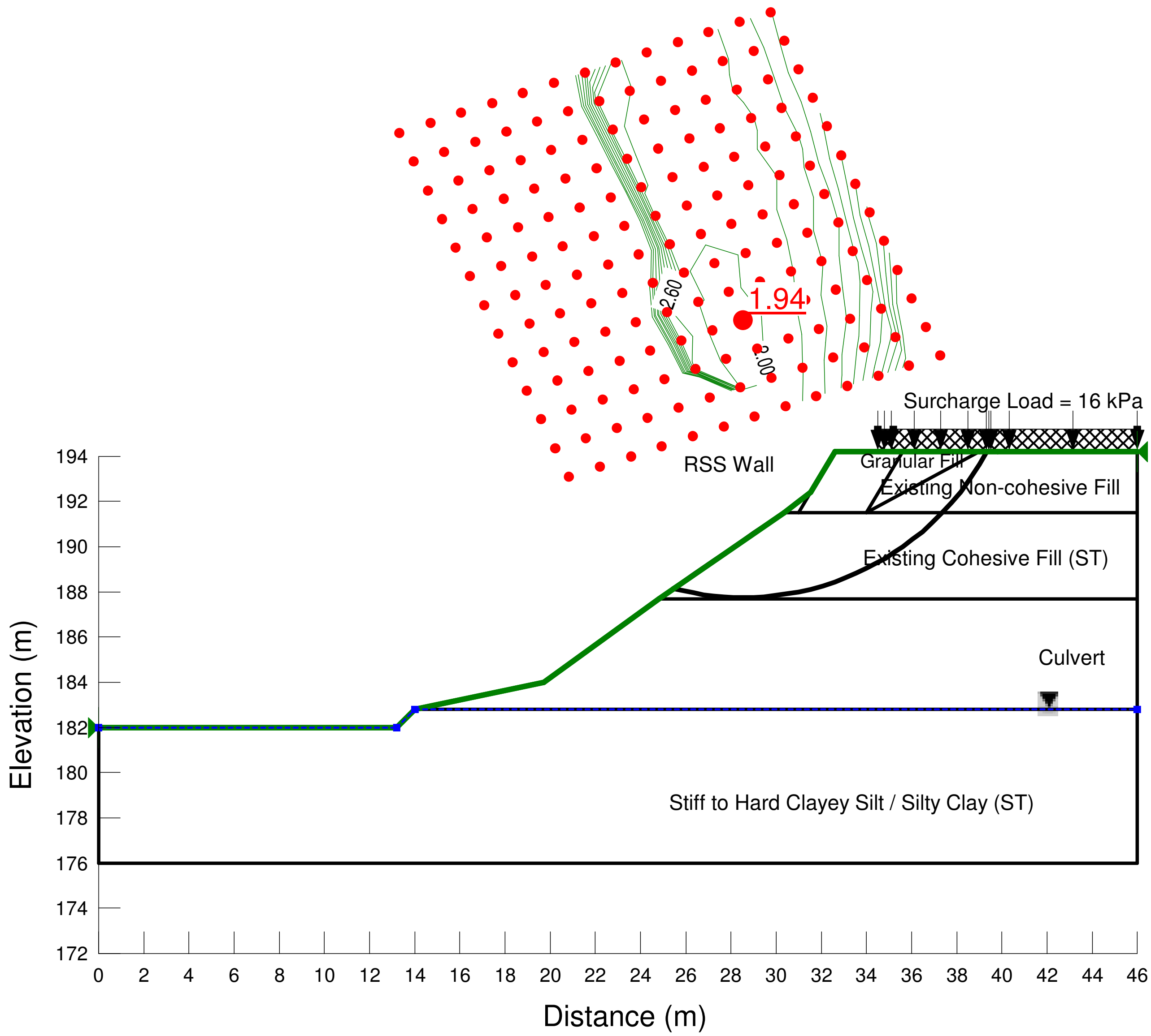

Figure D3 Slope Stability Analysis with Proposed RSS Wall, at culvert - Sta. 15+205
(Total Stress Analysis)

TP110076 - Rehabilitation of HWY 21 from Bayfield to Goderich, ON
Culvert 20 - Sta. 15+205 (Effective Stress Analysis)
C20-15+205 with Ret Wall (At Culvert)(Apr 13).gsz

Name: Granular Fill   Unit Weight: 21 kN/m³   Cohesion: 0 kPa   Phi: 32 °
Name: Existing Non-cohesive Fill   Unit Weight: 18 kN/m³   Cohesion: 0 kPa   Phi: 30 °
Name: Stiff to Hard Clayey Silt / Silty Clay   Unit Weight: 20 kN/m³   Cohesion: 0 kPa   Phi: 30 °
Name: RSS Wall   Unit Weight: 23 kN/m³   Cohesion: 200 kPa   Phi: 36 °
Name: Existing Cohesive Fill   Unit Weight: 18 kN/m³   Cohesion: 0 kPa   Phi: 28 °
Name: Culvert   Unit Weight: 24 kN/m³   Cohesion: 500 kPa   Phi: 38 °

NOTE: Soil properters used for culvert/RSS wall assumed only for slope stability modelling to disregard slip surface through the culvert/wall.

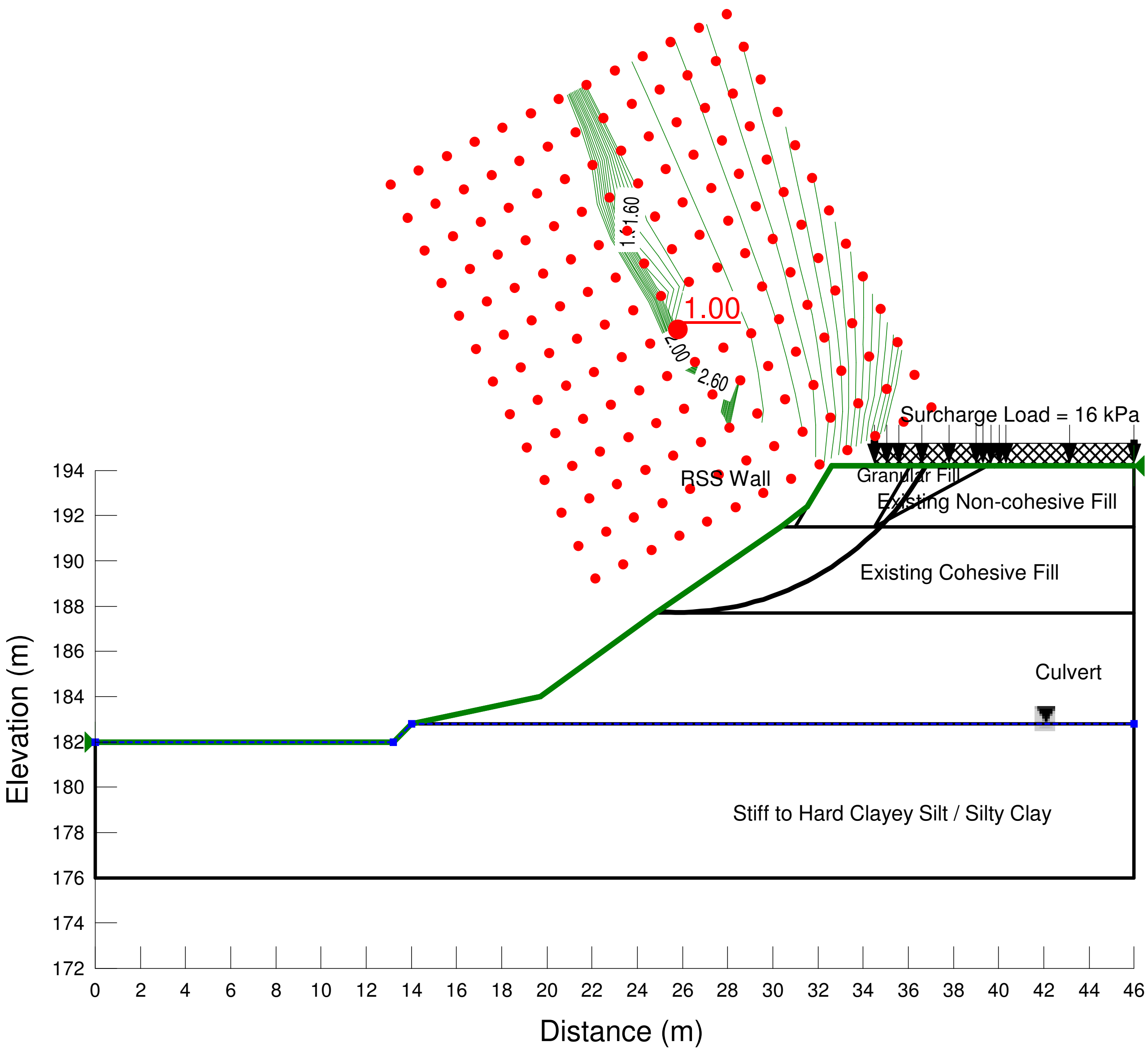

Figure D4 Slope Stability Analysis with Proposed RSS Wall, at culvert - Sta. 15+205 (Effective Stress Analysis)

TP110076 - Rehabilitation of HWY 21 from Bayfield to Goderich, ON
Culvert 20 - Sta. 15+205 (Total Stress Analysis)
C20-15+205 With Ret Wall (Beside Culvert)(Apr 13).gsz

Name: Granular Fill   Unit Weight: 21 kN/m³   Cohesion: 0 kPa   Phi: 32 °
Name: Existing Non-cohesive Fill   Unit Weight: 18 kN/m³   Cohesion: 0 kPa   Phi: 30 °
Name: RSS Wall   Unit Weight: 23 kN/m³   Cohesion: 200 kPa   Phi: 36 °
Name: Existing Cohesive Fill (ST)   Unit Weight: 18 kN/m³   Cohesion: 50 kPa
Name: Stiff to Hard Clayey Silt / Silty Clay (ST)   Unit Weight: 20 kN/m³   Cohesion: 75 kPa

NOTE: Soil properties used for RSS wll assumed only for slope stability modelling to disregard slip surface through the wall.

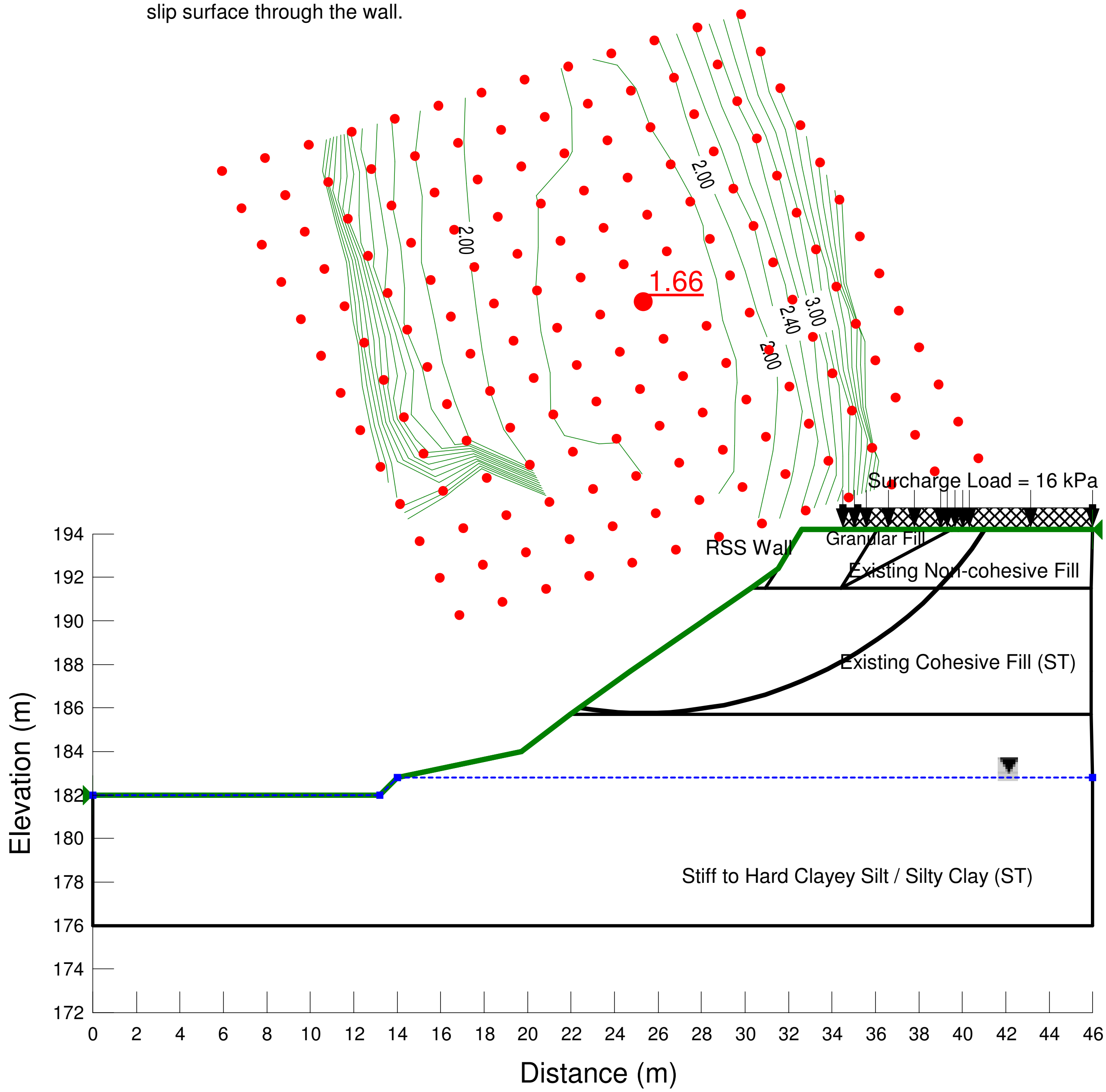

Figure D5 Slope Stability Analysis including Proposed RSS Wall, beside culvert - Sta. 15+205 (Total Stress Analysis)

TP110076 - Rehabilitation of HWY 21 from Bayfield to Goderich, ON
Culvert 20 - Sta. 15+205 (Effective Stress Analysis)
C20-15+205 With Ret Wall (Beside Culvert)(Apr 13).gsz

Name: Granular Fill Unit Weight: 21 kN/m³ Cohesion: 0 kPa Phi: 32 °
Name: Existing Non-cohesive Fill Unit Weight: 18 kN/m³ Cohesion: 0 kPa Phi: 30 °
Name: Stiff to Hard Clayey Silt / Silty Clay Unit Weight: 20 kN/m³ Cohesion: 0 kPa Phi: 30 °
Name: RSS Wall Unit Weight: 23 kN/m³ Cohesion: 200 kPa Phi: 36 °
Name: Existing Cohesive Fill Unit Weight: 18 kN/m³ Cohesion: 0 kPa Phi: 28 °

NOTE: Soil properties used for RSS wll assumed only for slope stability modelling to disregard slip surface through the wall.

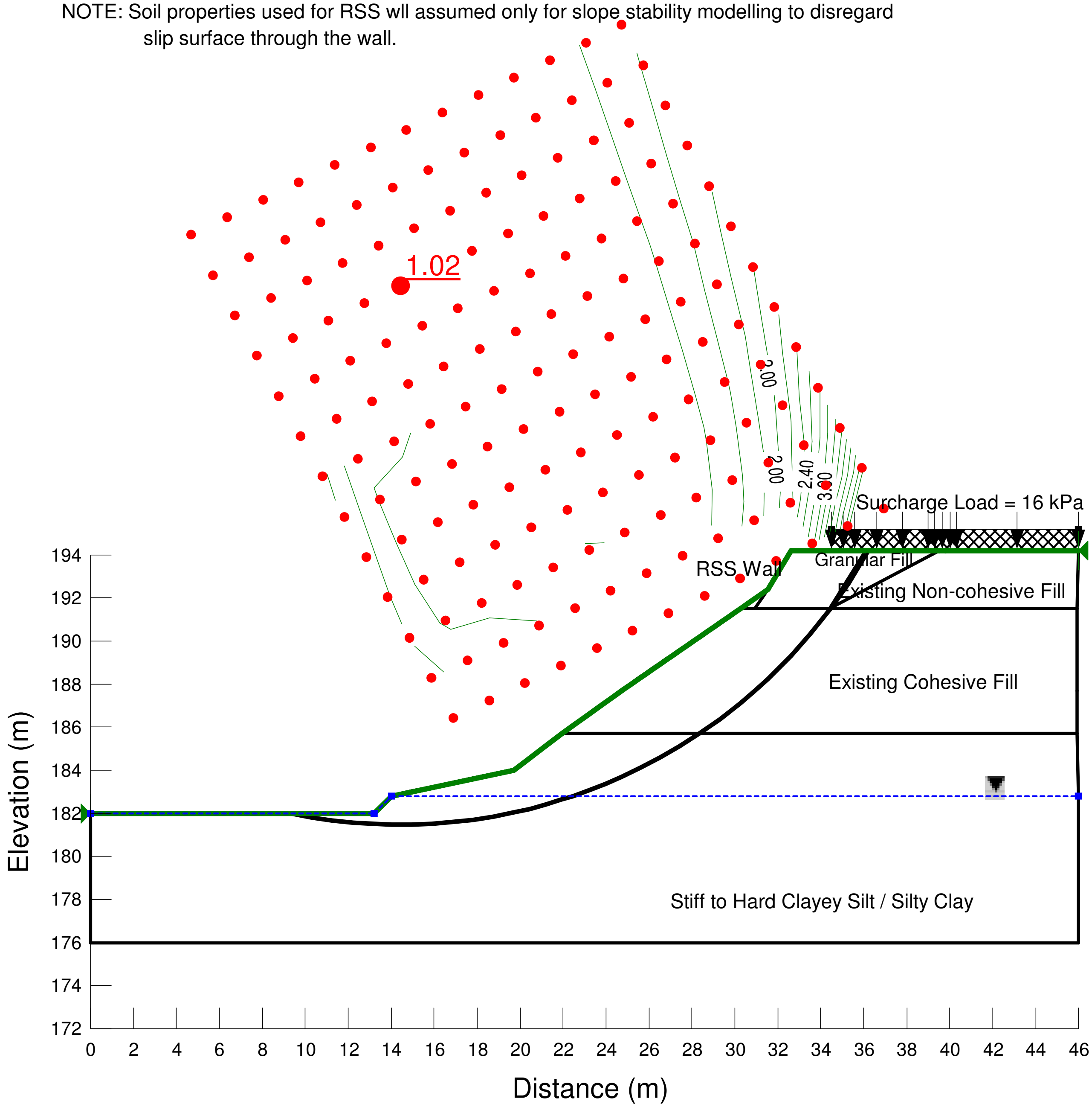

Figure D6 Slope Stability Analysis including Proposed RSS Wall, beside Culvert - Sta. 15+205 (Effective Stress Analysis)

TP110076 - Rehabilitation of HWY 21 from Bayfield to Goderich, ON
Culvert 20 - Sta. 15+205 (Effective Stress Analysis)
C20-15+205 Existng Slope (slip) (Apr 15).gsz

Name: Existing non-cohesive Fill Unit Weight: 18 kN/m³ Cohesion: 0 kPa Phi: 30 °
Name: Existing Cohesive Fill Unit Weight: 18 kN/m³ Cohesion: 0 kPa Phi: 28 °
Name: Culvert Unit Weight: 24 kN/m³ Cohesion: 500 kPa Phi: 38 °
Name: Stiff to Hard Clayey Silt / Silty Clay Unit Weight: 20 kN/m³ Cohesion: 0 kPa Phi: 30 °
Name: Existing Cohesive Fill (reduced) Unit Weight: 18 kN/m³ Cohesion: 0 kPa Phi: 21 °

NOTE: (1) Soil properties used for culvert/RSS wall assumed only for slope stability modelling to disregard slip surface through the culvert/wall.
(2) Reduced friction angle used for fill material in contact with concrete to consider the interface friction between soil and concrete.

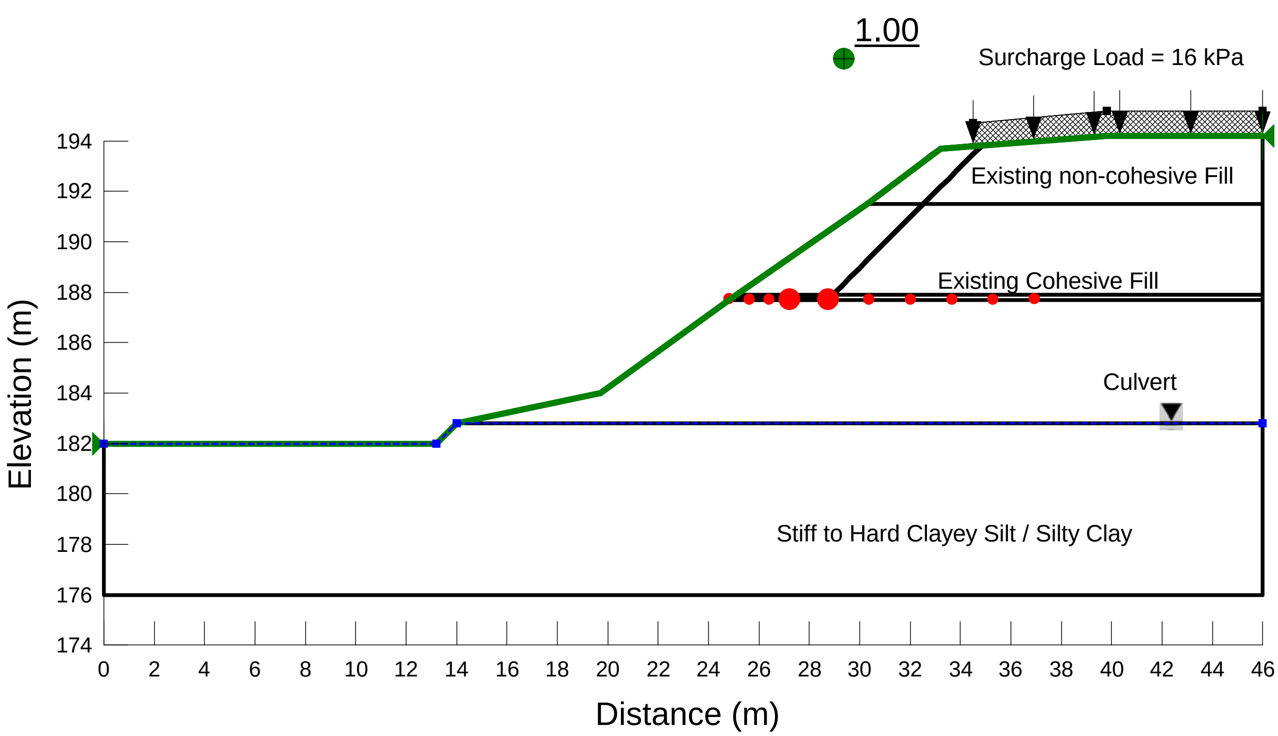

Figure D7 Slope Stability Analysis of Existing Embankment at Culvert Location - Sta. 15+205
(Effective Stress Analysis - non-circular slip)

TP110076 - Rehabilitation of HWY 21 from Bayfield to Goderich, ON
Culvert 20 - Sta. 15+205 (Total Stress Analysis)
C20-15+205 Retaining Wall (culv&Slip)(Apr 13).gsz

Name: Granular Fill   Unit Weight: 21 kN/m³   Cohesion: 0 kPa   Phi: 32 °
Name: Existing Non-cohesive Fill   Unit Weight: 18 kN/m³   Cohesion: 0 kPa   Phi: 30 °
Name: RSS Wall   Unit Weight: 23 kN/m³   Cohesion: 200 kPa   Phi: 36 °
Name: Existing Cohesive Fill (ST)   Unit Weight: 18 kN/m³   Cohesion: 50 kPa
Name: Stiff to Hard Clayey Silt / Silty Clay (ST)   Unit Weight: 20 kN/m³   Cohesion: 75 kPa
Name: Culvert   Unit Weight: 24 kN/m³   Cohesion: 500 kPa   Phi: 38 °

NOTE: Soil properters used for culvert assumed only for slope stability modelling to disregard slip surface through the culvert.

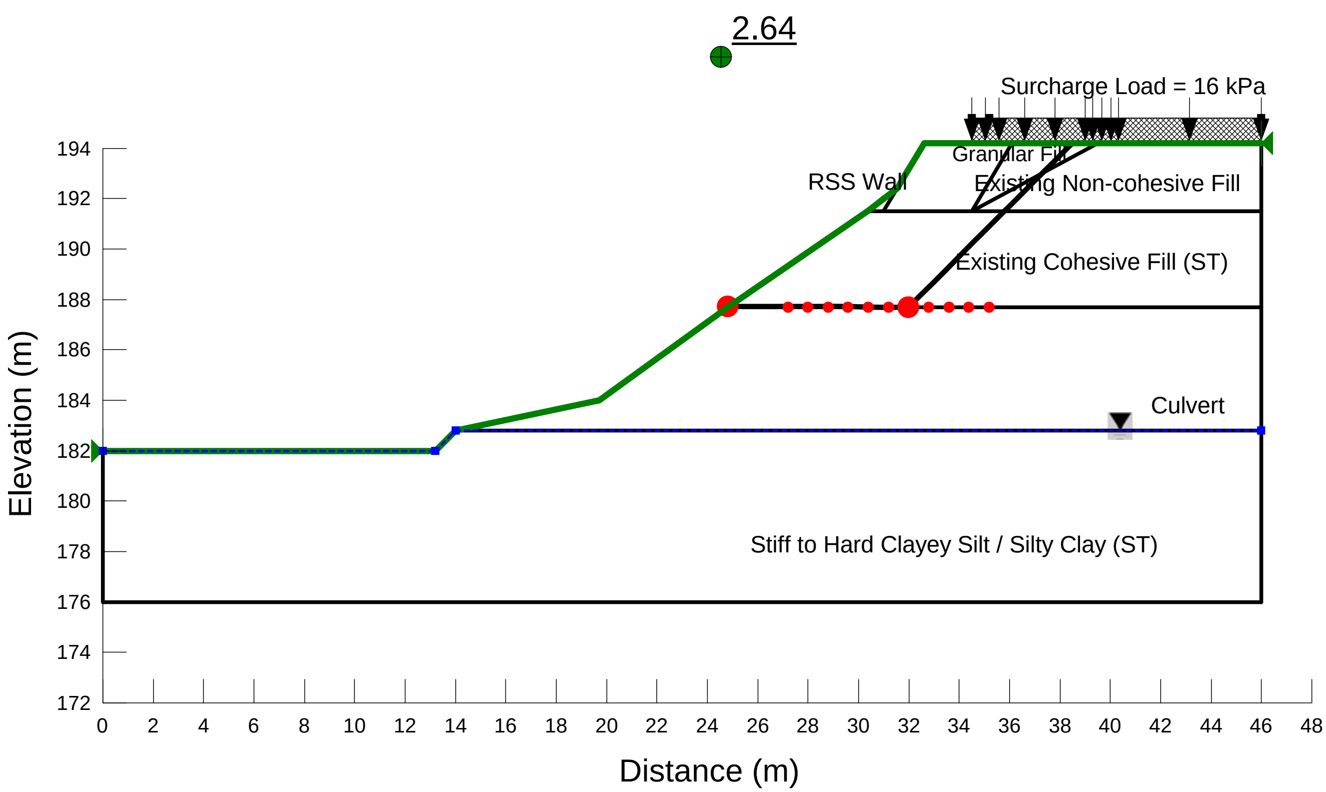

Figure D8 Slope Stability Analysis including Proposed RSS Wall - Sta. 15+205
(Total Stress Analysis - non circular slip)

TP110076 - Rehabilitation of HWY 21 from Bayfield to Goderich, ON
Culvert 20 - Sta. 15+205 (Effective Stress Analysis)
C20-15+205 Retaining Wall (culv&Slip)(Apr 13).gsz

Name: Granular Fill Unit Weight: 21 kN/m³ Cohesion: 0 kPa Phi: 32 °
Name: Existing Non-cohesive Fill Unit Weight: 18 kN/m³ Cohesion: 0 kPa Phi: 30 °
Name: Stiff to Hard Clayey Silt / Silty Clay Unit Weight: 20 kN/m³ Cohesion: 0 kPa Phi: 30 °
Name: RSS Wall Unit Weight: 23 kN/m³ Cohesion: 200 kPa Phi: 36 °
Name: Existing Cohesive Fill Unit Weight: 18 kN/m³ Cohesion: 0 kPa Phi: 28 °
Name: Culvert Unit Weight: 24 kN/m³ Cohesion: 500 kPa Phi: 38 °
Name: Existing Cohesive Fill (reduced) Unit Weight: 18 kN/m³ Cohesion: 0 kPa Phi: 21 °

NOTE: (1) Soil properters used for culvert assumed only for slope stability modelling to disregard slip surface through the culvert.
(2) Reduced friction angle used for fill material to consider the interface friction between soil and concrete.

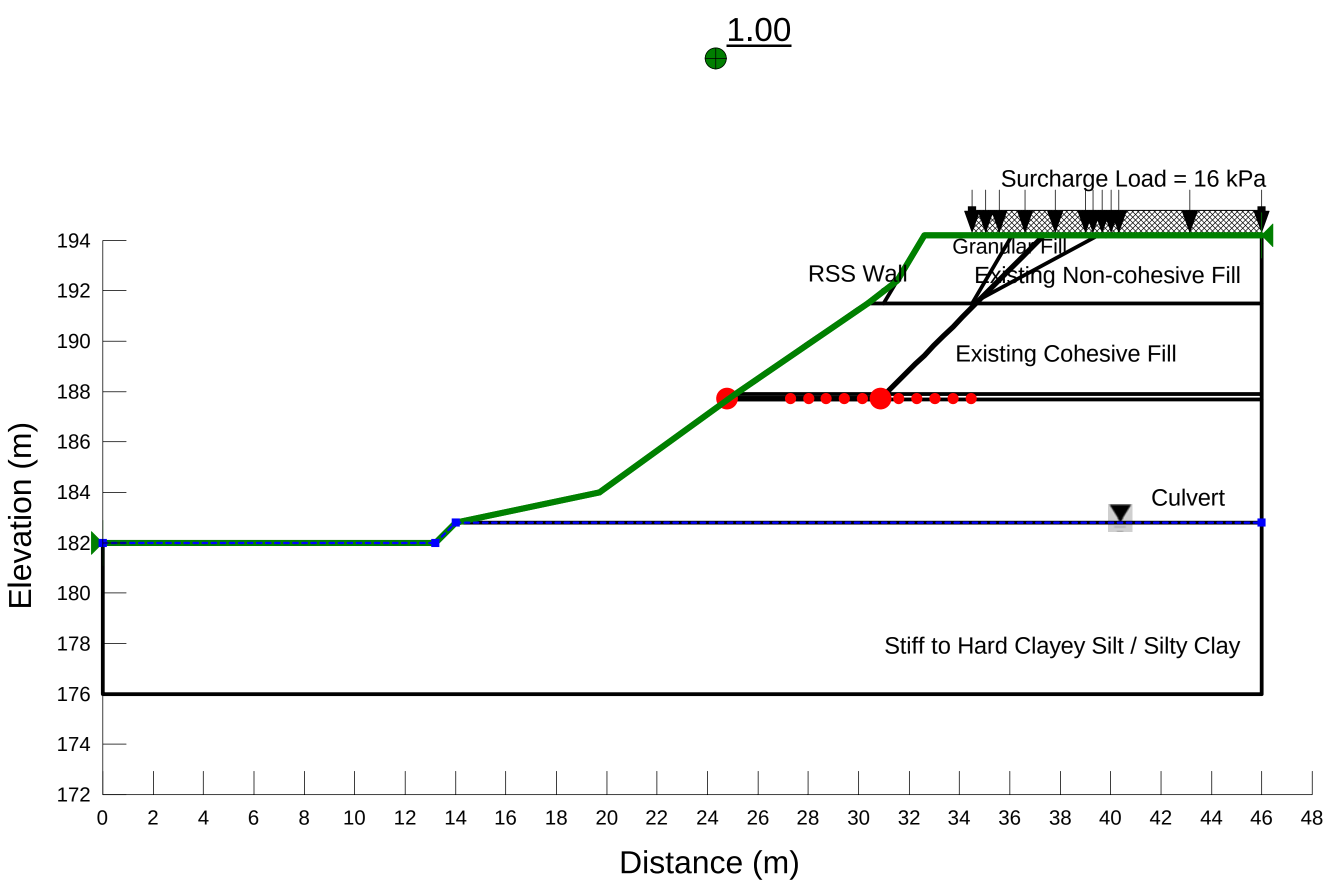

Figure D9 Slope Stability Analysis including Proposed RSS Wall - Sta. 15+205
(Effective Stress Analysis - non circular slip)