April 6, 2017

FOUNDATION INVESTIGATION AND DESIGN REPORT

Centreline Culvert Replacement - Highway 112
STA 13+234, Township of Pacaud
Ministry of Transportation, Ontario
G.W.P. 5105-12-00; W.P. 5428-15-01

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PART A

FOUNDATION INVESTIGATION REPORT
CENTRELINE CULVERT REPLACEMENT – HIGHWAY 112
STA 13+234, TOWNSHIP OF PACAUD
MINISTRY OF TRANSPORTATION, ONTARIO
G.W.P. 5105-12-00; W.P. 5428-15-01

1.0 INTRODUCTION

Golder Associates Ltd. (Golder) has been retained by MMM Group Limited (MMM) on behalf of Ministry of Transportation, Ontario (MTO) to provide Foundation Engineering services for the replacement of the centreline culvert at STA 13+234 on Highway 112 in the Township of Pacaud, approximately 16 km south of Kirkland Lake, Ontario.

The Terms of Reference and the Scope of Work for the foundation investigation are outlined in MTO's Work Order / Assignment #2, dated March 2016. Golder's proposal for the foundation engineering services associated with the culverts is contained in Golder's letter addressed to MMM, dated April 13, 2016. The work has been carried out in accordance with Golder's Supplementary Specialty Plan for foundation engineering services for this project, dated May 25, 2016.

This report addresses the investigation carried out for the culvert at STA 13+234 on Highway 112 which has been identified for replacement. The foundation investigation associated with the other culverts for Work Order / Assignment #2 are presented in separate reports.

2.0 SITE DESCRIPTION

The centreline culvert requiring replacement is located at approximately STA 13+234 on Highway 112 in the Township of Pacaud, approximately 16 km south of Kirkland Lake, Ontario. The existing culvert is a 910 mm wide by 610 mm high by 30.5 m long open footing culvert covered with approximately 5.5 m and 3 m of embankment fill on the west side and east side of the highway, respectively. Details of the culvert are also summarized in Table 1 following the text of this report.

In general, the topography in the area of the culvert consists of rolling surface topography with sparsely to densely populated treed areas and numerous bedrock outcrops separated by valleys which generally contain agricultural land or swamps containing slow flowing to standing water, various types of vegetation and organic soils. The developed area directly adjacent to Highway 112 is primarily used for residential purposes and agriculture. The ground surface at the borehole and DCPT locations advanced for the culvert investigation, including through the existing Highway 112 embankment, varies between Elevation 293.3 m and 288.7 m, referenced to Geodetic datum. Figure 1 contains photographs of the culvert location.

3.0 INVESTIGATION PROCEDURES

The fieldwork for the foundation investigation associated with the culvert at STA 13+234 was carried out on May 30 and 31, 2016, during which time a total of three boreholes and one Dynamic Cone Penetration Test (DCPT) were advanced at, or in the immediate vicinity of the culvert alignment, as summarized in Table 1 and as shown on Drawing 1.

The field investigation was carried out using a truck-mounted CME55 drill rig and portable drilling equipment which were supplied and operated by Landcore Drilling of Sudbury, Ontario.

The borehole drilled by the truck-mounted CME55 drill rig was advanced through the overburden using 152 mm diameter solid stem augers and wash boring techniques. The boreholes completed by the portable equipment were advanced through the overburden using NQ and HQ size casing with wash boring techniques. Boreholes that were completed with rock coring were advanced with an NQ sized core barrel. In general, soil samples were obtained at intervals of depth of about 0.75 m and 1.5 m using a 50 mm outside diameter (O.D.) split-spoon sampler operated by an automatic hammer on the drill rig, performed in accordance with Standard Penetration Test (SPT) procedures (ASTM D1586). Boreholes advanced by portable equipment employed a full-weight hammer lifted manually and dropped from the SPT height. In situ field vane testing, using a MTO standard "N''-vane (ASTM D2573), was carried out in the cohesive soils, where appropriate, to measure the undrained shear strength of the deposit.

All open boreholes were backfilled with bentonite upon completion in accordance with R.R.O. 1990, Regulation 903 (Wells) (as amended). The groundwater conditions and water levels in the open boreholes were observed during the drilling operations and are described on the Record of Borehole sheets in Appendix A.

A sample of creek water was obtained at the culvert location on June 12, 2016 and submitted to a specialist analytical laboratory under chain of custody procedures for testing for a suite of parameters including pH, resistivity, conductivity, sulphates and chlorides. The results of the analytical testing are included in Appendix C.

The fieldwork was observed by members of Golder's engineering and technical staff, who located the boreholes, arranged for the clearance of underground services, observed the drilling, sampling and in situ testing operations, logged the boreholes, and examined the soil samples. The soil samples were identified in the field, placed in appropriate containers, labelled and transported to Golder's Mississauga geotechnical laboratory where the samples underwent further visual examination and laboratory testing. All of the laboratory tests were carried out to MTO Laboratory Standards and/or ASTM Standards, as appropriate. Classification testing (water content, Atterberg limits and grain size distribution) was carried out on selected soil samples. Point Load tests and an Unconfined Compressive Strength test were carried out on selected specimen of the rock core samples. The results of the laboratory testing are summarized on the Record of Borehole and Drillhole sheets in Appendix A and presented in the laboratory test figures in Appendix B.

Classification of the rock mass quality of the bedrock with respect to the Rock Quality Designation (RQD) is described based on Table 3.10 of the Canadian Foundation Engineering Manual (CFEM)[1]. Classification of the bedrock core samples with respect to strength from point load tests and unconfined compression test is described based on Table 3.5 of CFEM[1]. The degree of weathering of the bedrock samples (i.e. fresh to slightly weathered – W1 to W2) and the strength classification of the intact rock mass based on field identification (i.e. strong – R4) are described in accordance with the International Society for Rock Mechanics (ISRM)[2] standard classification system.

Borehole locations were surveyed in the field relative to a fixed markers on site. The as-drilled borehole locations, in stations and offsets, were measured in reference to the applicable markers and from existing site features and were subsequently converted into MTM NAD 83 (Zone 12) coordinates in AutoCAD. Borehole elevations were surveyed by a member of our technical staff in reference to the centerline of Highway 112 and the existing culvert and were subsequently converted to Geodetic elevations using topographic information, provided by MTO. The borehole locations, ground surface elevations and drilled depths are summarized below.

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[1] Canadian Geotechnical Society. (2006). Canadian Foundation Engineering Manual, 4th Edition.

[2] International Society for Rock Mechanics Commission on test Methods. (1985). Int. J. Rock Mech. Min. Sci & Geomech. Abstr. Vol 22, No. 2, pp.51-60.

Culvert Location	Borehole / DCPT	Location		Ground Surface Elevation (m)	Depth of Borehole / DCPT (m)
		Northing (m) / Latitude (º)	Easting (m) / Longitude (º)		
STA 13+234 (Township of Pacaud)	C1-1	5,318,327.9 / 47.999704	378,035.1 / -80.018537	288.7	7.2
	C1-2	5,318,321.6 / 47.999645	378,048.7 / -80.018355	293.3	14.9*
	C1-3	5,318,318.3 / 47.999613	378,071.3 / -80.018053	290.2	4.6*
	DCPT 1-1	5,318,325.1 / 47.999678	378,034.1 / -80.018550	288.7	7.7

Note: * Includes between 1.4 m and 3.3 m length of bedrock coring.

4.0 SITE GEOLOGY AND SUBSURFACE CONDITIONS

4.1 Regional Geology

Highway 112 is located in the Abitibi Uplands physiographic region, within the Canadian Shield as delineated by the *Geomorphic Systems of North America*[3]. The Abitibi Uplands generally slopes towards Hudson Bay and is typically characterized by low broad hills with gently sloping, rolling or undulating topography and subdued relief. This region is underlain by massive, mainly crystalline rocks covered by Quaternary glaciolacustrine, glaciofluvial, and till deposits, as well as more recent organic deposits within the depressions between bedrock knobs[4].

Highway 112 crosses four main assemblages, or batholiths associated with the southern Abitibi Greenstone Belt[5]: Round Lake Batholith; Catharine-Pacaud assemblage; Boston assemblage and Temiskaming assemblage. The southern end of the highway, where it meets the TransCanada Highway is located within the granodioritic Round Lake Batholith. The highway trends north passing through the Catharine-Pacaud and Boston assemblages which are characterized by mafic to intermediate grey to green basalt flows with felsic to silicious banding and plagioclase phenocrysts and metavolcanic to metasedimentary basalts, cherts and conglomerates, respectively. The northern end of Highway 112 contains the Temiskaming assemblage, characterized by clastic metasedimentary rocks, primarily cherts (jasper) and sandstones. This area contains multiple faults and deformations associated within the Larder-Cadillac shear zone which generally runs along Highway 11 in the area where it intersects with Highway 112.

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[3] Graf, W. L. (1987). *Geomorphic systems of North America*. Geological Society of America, Inc.: Boulder, Colorado.

[4] Ministry of Northern Development and Mines, Ontario (MNDMO). (2016). *OGSEarth:* Quaternary Geology [Electronic Map]. 1:1,000,000. Retrieved July 28, 2016 from OGSEarth. Queen's Printer for Ontario, 2016.

[5] Jackson, S. L. and Fyon, J. A. (1991). The western Abitibi subprovince in Ontario; in Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.405-482.

4.2 General Overview of Local Subsurface Conditions

The detailed subsurface soil and groundwater conditions as encountered in the boreholes advanced during this investigation, together with the results of the laboratory tests carried out on selected soil and bedrock samples, are presented on the Record of Borehole sheets and the laboratory test sheets in Appendices A and B, respectively. The results of the in situ field testing (i.e. SPT 'N'-values) as presented in the Record of Borehole sheets and in Section 4.3 are uncorrected. The stratigraphic boundaries shown on the Record of Boreholes sheets are inferred from non-continuous sampling, observations of drilling progress and in situ testing and are approximate. These boundaries, therefore, represent transitions between soil types rather than exact planes of geological change. Further, subsurface conditions will vary between and beyond the borehole locations.

The stratigraphy at the borehole locations at the culvert site consists of surficial layers of organic silt and clayey silt trace organics, or embankment fill, underlain by a deposit of firm to very stiff silty clay to clay. The silty clay to clay deposit is underlain by a deposit of compact silt and sand to silty sand, which is in turn underlain by a deposit of very dense sand and gravel in places. The overburden deposits are underlain by porphyritic basalt bedrock. A detailed description of the subsurface conditions at the culvert crossing is provided in the following section of this report. Where relatively significant thicknesses of overburden were encountered, the various soil types are described in detail for each main deposit or stratum.

4.3 Culvert at STA 13+234

The plan and profile along the centreline of the existing culvert at STA 13+234 showing the borehole locations and interpreted stratigraphy are shown on Drawing 1. The height of the embankment at the culvert location is about 5.5 m on the west side of the highway and 3 m on the east side of the highway and the existing culvert is about 30.5 m long. A total of three boreholes and one DCPT were completed to investigate the subsurface conditions at the culvert location: two boreholes (Borehole C1-1 and C1-3) and one DCPT (DCPT C1-DCPT-1) were advanced near the ends of the existing culvert; and one borehole (Borehole C1-2) was advanced through the Highway 112 southbound lane highway embankment, south of the existing culvert alignment.

4.3.1 Asphalt

An approximately 100 mm layer of asphalt was encountered at ground surface in Borehole C1-2.

4.3.2 Embankment Fill

Embankment fill approximately 4.4 m thick was encountered below the asphalt in Borehole C1-2 at Elevation 293.2 m. The embankment fill consists of an upper 1.8 m thick layer of sand and gravel, and a lower 0.3 m thick layer of sand, some gravel, some silt containing cobbles, underlain by a 2.3 m thick deposit of cohesive fill comprised of layers/zones of sandy clayey silt, silt and sand and silty clay, trace gravel.

The SPT 'N'-values measured within the non-cohesive portion of the fill deposit are between 43 blows and 49 blows per 0.3 m of penetration, indicating a dense relative density. The SPT 'N'-values measured within the portion of the cohesive fill deposit range between 4 blows and 20 blows per 0.3 m of penetration, suggesting a firm to very stiff consistency.

The natural water content measured on a sample of the non-cohesive fill is about 1 per cent. The natural water content measured on two samples of the cohesive fill are about 19 per cent.

The result of a grain size distribution test completed on one sample of the silt and sand fill is shown on Figure B1 in Appendix B.

An Atterberg limits test carried out on a sample of the cohesive fill measured a liquid limit of about 37 per cent and a plastic limit of about 16 per cent, corresponding to a plasticity index of about 21 per cent. The result of the Atterberg limits test is shown on the plasticity chart on Figure B2 in Appendix B and indicates that the cohesive fill is classified as a silty clay of intermediate plasticity.

4.3.3 Organic Silt

A 0.3 m thick deposit of organic silt was encountered at ground surface in Borehole C1-1. The organic silt layer contains some sand, trace gravel, trace clay, roots and rootlets.

A SPT ‘N’-value of 8 blows per 0.3 m of penetration was measured within the organic silt deposit, suggesting a firm consistency.

4.3.4 Clayey Silt to Clay

A 2.1 m to 4.7 m thick deposit of clayey silt to silty clay to clay, trace sand, trace organics was encountered between Elevations 290.2 m and 288.4 m, at ground surface in Borehole C1-3, underlying the organic silt in Borehole C1-1 and below the embankment fill in Borehole C1-2.

The measured SPT ‘N’-values within the clayey silt to clay deposit range from 5 blows to 24 blows per 0.3 m of penetration. Field vane tests carried out in a borehole adjacent to Borehole C1-1 and in Borehole C1-2 measured undrained shear strengths ranging from about 65 kPa to greater than 96 kPa and sensitivities between 2 and 5. The SPT ‘N’-values together with the field vane undrained shear strength results indicate that the deposit has a firm to very stiff consistency.

The natural water contents measured on four samples of the clayey silt to clay deposit range from about 26 per cent to 41 per cent.

The result of a grain size distribution test completed on a sample of clay is shown on Figure B3.

Atterberg limits tests were carried out on three samples of the cohesive portion of the deposit and measured liquid limits ranging from 38 per cent to 57 per cent, plastic limits ranging from 19 per cent to 22 per cent and plasticity indices ranging from 19 per cent to 36 per cent. The test results, which are plotted on a plasticity chart on Figure B4 in Appendix B, indicate that portions of the cohesive deposit are classified as a silty clay of intermediate plasticity to clay of high plasticity.

4.3.5 Silt and Sand to Silty Sand

A deposit of silt and sand to silty sand was encountered below the clayey silt to clay deposit at all borehole locations. The surface of the deposit was encountered between Elevations 288.1 m and 283.7 m and the thickness of the deposit ranges from 1.1 m to 2.9 m. Cobbles were inferred at a depth of 9.1 m and 2.7 m

(Elevations 284.2 m and 287.5 m, respectively) by the grinding of the casing as it advanced through the deposit in Boreholes C1-2 and C1-3. Borehole C1-1 was terminated in the silt and sand deposit at a depth of 7.2 m below ground surface (Elevation 281.5 m) after encountering refusal to further split spoon advancement.

The measured SPT 'N'-values within the silt and sand to silty sand deposit range from 18 blows to 38 blows per 0.3 m of penetration, indicating a compact to dense relative density. SPT 'N'-values of 25 blows per 0.15 m of penetration and 40 blows per 0.27 m of penetration were measured within the silt and sand to silty sand deposit but these values are not considered to be representative of the deposits relative density as the split-spoon sampler was bouncing on inferred cobbles, boulders or bedrock.

The natural water contents measured on three samples of the silt and sand to silty sand deposit range from about 17 per cent to about 22 per cent.

The results of grain size distribution testing completed on two samples of the silt and sand portion of the deposit are shown on Figure B5.

4.3.6 Sand and Gravel

A 1.4 m thick deposit of sand and gravel, trace silt was encountered below the silt and sand deposit in Borehole C1-2 at a depth of 10.2 m below ground surface, corresponding to Elevation 283.1 m. Cobbles were inferred within the deposit below a depth of 11.0 m (Elevation 282.3 m) by the grinding of the casing as it advanced through the deposit.

A SPT 'N'-value of 62 blows per 0.3 m of penetration was measured within the sand and gravel deposit, indicating a very dense relative density.

The natural water content measured on one sample of the sand and gravel was about 7 per cent.

4.3.7 Bedrock / Refusal

Bedrock was encountered in Boreholes C1-2 and C1-3 at depths of 11.6 m and 3.2 m below ground surface, respectively, corresponding to Elevations 281.7 m and 287.0 m. Refusal to DCPT advancement was encountered in the borehole adjacent to Borehole C1-1 and in C1-DCPT-1 at a depth of 7.2 m and 7.7 m, respectively corresponding to Elevations 281.5 m and 281.0 m.

Based on review of the bedrock core samples, the bedrock consists of fine grained porphyritic basalt with coarse grained quartz and feldspar clasts. The bedrock is fresh and very strong. The bedrock descriptions are shown on the Record of Drillhole sheets in Appendix A and the rock core samples are shown on the photographs on Figure B6.

The Total Core Recovery (TCR) and Solid Core Recovery (SCR) of samples recovered are between 93 per cent and 100 per cent and between 62 per cent and 100 per cent, respectively. The Rock Quality Designation (RQD) based on the borehole data ranges from 62 per cent to 100 per cent, indicating a rock mass of fair to excellent quality.

Point load strength index tests were carried out on selected samples of the bedrock core. The corrected point load strength index values (Is_{50}) presented in Table B1 and on the Drillhole sheet in Appendix B are 15 MPa and 12 MPa for the axial and diametral tests, respectively.

An Unconfined Compression (UC) test performed on a core sample of the bedrock from Borehole C1-3 measured a uniaxial compressive strength (UCS) of 120 MPa as presented in Figure B7. Based on the laboratory Point Load strength index and the UC test, the bedrock is classified as very strong (R5, 100 MPa < UCS < 250 MPa) to extremely strong (R6 > 250 MPa).

4.3.8 Groundwater Conditions

The water level was measured in Boreholes C1-1 to C1-3 upon completion of drilling operations at depths of 0.8 m and 8.0 m below ground surface, ranging from Elevations 289.4 m to 285.3 m. The water level at the site is expected to fluctuate seasonally in response to changes in precipitation and snow melt, and is expected to be higher during the spring and periods of precipitation.

4.3.9 Analytical Testing of Creek Water

Analytical testing was carried out on a sample of creek water taken from the culvert site to assess the corrosivity and concrete degradation potential from the creek water/groundwater for the new culvert structure. The results from the specialist analytical laboratory are presented in Appendix C and are summarised below:

Parameter	Test Result
Water Resistivity	21,000 ohm-cm
Water Conductivity	48 μmho/cm
Sulphate Concentration	Less than 1.0 mg/L
Chloride Concentration	2.0 mg/L
Water pH	6.72

5.0 CLOSURE

Messrs. Shane Albert and Dave Marmor, EIT, supervised the borehole investigation program. This report was prepared by Ms. Madison C. Kennedy, B.A.Sc., and was reviewed by Mr. Christopher Ng, P.Eng., a senior geotechnical engineer and an Associate of Golder. Mr. Jorge M. A. Costa, P.Eng., a Senior Consultant with Golder and Designated MTO Foundations Contact, conducted an independent quality control review of this report.

Report Signature Page

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PART B

FOUNDATION DESIGN REPORT
CENTRELINE CULVERT REPLACEMENT – HIGHWAY 112
STA 13+234, TOWNSHIP OF PACAUD
MINISTRY OF TRANSPORTATION, ONTARIO
G.W.P. 5105-12-00; W.P. 5428-15-01

6.0 DISCUSSION AND ENGINEERING RECOMMENDATIONS

This section of the report provides foundation design recommendations for the proposed replacement of the open footing culvert at STA 13+234 on Highway 112. These recommendations are based on interpretation of the factual data obtained from the boreholes advanced during the investigation. The discussion and recommendations presented are intended to provide the designer with sufficient information to assess the feasible foundation alternatives and carry out the design of the culvert foundations. The foundation investigation report, discussion and recommendations are intended for the use of the Ministry of Transportation, Ontario (MTO) and shall not be used or relied upon for any other purpose or by any other parties, including the construction or design-build contractor. The contractor must make their own interpretation based on the factual data in Part A of the report. Where comments are made on construction, they are provided to highlight those aspects that could affect the design of the project and for which special provisions may be required in the Contract Documents. Those requiring information on the aspects of construction must make their own interpretation of the factual information provided as such interpretation may affect equipment selection, proposed construction methods, scheduling and the like.

6.1 General

Golder Associates Ltd. (Golder) was retained by MMM Group Limited (MMM) on behalf of the MTO to provide recommendations on the foundation aspects of the detail design for the replacement of the existing open footing culvert at STA 13+234 on Highway 112 in the Township of Pacaud.

This report presents geotechnical resistances for design of the replacement culvert as well as the results of stability and settlement analyses associated with the temporary embankments required for staged construction, and provides recommendations for stable embankment geometry and embankment fill materials that may be required as a means to reduce culvert settlements and to improve embankment stability (if necessary). The report also addresses potential construction concerns and geotechnical issues associated with the culvert replacement and temporary embankments associated with staged construction, sub-excavating soft/organic materials and placement of new fill materials.

It is understood that the replacement culvert will be a 525 mm diameter Corrugated Steel Pipe (CSP) constructed at the same invert elevations as the existing culvert, with the upstream (east end) and downstream (west end) inverts at about Elevations 289.9 m and 287.9 m, respectively. In addition, it is understood that the replacement of the existing culvert by staged construction will require either an embankment widening of up to 5 m on the east side of the existing embankment or an approximately 1 m grade lowering and staged construction to facilitate the culvert replacement. There are no permanent embankment widening or grade raise as part of the culvert replacement.

6.2 Consequence and Site Understanding Classification

In accordance with Section 6.5 of the 2014 Canadian Highway Bridge Design Code and its Commentary (CHBDC, S6-14, 2014), the proposed culvert and its foundation system is considered to be classified as having a “typical consequence level” associated with exceeding limits states design. In addition, given the level of foundation investigation completed to date in comparison to the degree of site understanding in Section 6.5 of CHBDC (2014), the level of confidence for design is considered to be a “typical degree of site and prediction model understanding.” Accordingly, the appropriate corresponding ULS and SLS consequence factor, Ψ, from Table 6.1 and geotechnical resistance factors, ϕ_{gu} and ϕ_{gs}, from Table 6.2 of the CHBDC (2014) have been used for design, as indicated in Sections 6.3 and 6.4 below.

6.3 Culvert/Foundation Types for Culvert Replacement

6.3.1 Culvert/Foundation Options

A CSP culvert, concrete pipe culvert, precast box culvert, and cast-in-place open footing culvert are all feasible alternatives for the replacement of the existing culvert. Foundation recommendations have been provided for the various culvert alternatives although it is understood that the proposed replacement culvert will be a 525 mm diameter CSP.

The advantages and disadvantages associated with replacing the existing culvert with the various culvert alternatives are summarized in Table 2, following the text of this report. Recommendations for replacement of the existing culvert with a CSP, concrete pipe, precast box as well as cast-in-place open footing structure are provided in the following sections. From a foundation perspective a CSP culvert is considered to be the preferred replacement alternative, given the relatively small size of the replacement structure.

6.3.2 Founding Elevations and Frost Protection Requirements

6.3.2.1 Corrugated Steel Pipe Culvert Replacement

It is not necessary to found the CSP culvert replacement at or below the standard depth of frost penetration for frost protection purposes, as CSP culverts are tolerant of small magnitudes of movement related to freeze-thaw cycles, should these occur. Table 3, following the text of this report, provides recommended founding elevations and founding conditions for a CSP replacement culvert, assuming a 0.3 m thick combined bedding layer and culvert bottom thickness.

6.3.2.2 Concrete Pipe Culvert Replacement

It is not necessary to found the concrete pipe culvert replacement at or below the standard depth of frost penetration for frost protection purposes, as concrete pipes are tolerant of small magnitudes of movement related to freeze-thaw cycles, should these occur. Table 3, following the text of this report, provides recommended founding elevations and founding conditions for a concrete pipe replacement culvert, assuming a 0.3 m thick combined bedding layer and culvert bottom thickness.

6.3.2.3 Precast Box Culvert Replacement

It is not necessary to found the precast box culvert replacement at or below the standard depth of frost penetration for frost protection purposes, as precast box structures are tolerant of small magnitudes of movement related to freeze-thaw cycles, should these occur. Table 3, following the text of this report, provides recommended founding elevations and founding conditions for a precast box replacement culvert, assuming a 0.3 m thick combined bedding layer, levelling layer and culvert bottom thickness.

6.3.2.4 Open Footing Culvert Replacement

The strip footings for an open footing culvert replacement should be founded at a minimum depth of 2.4 m below the lowest surrounding grade to provide adequate protection against frost penetration, as per OPSD 3090.100 (Foundation, Frost Penetration Depths for Northern Ontario). Table 3, following the text of this report, provides recommended founding elevations and founding conditions for an open footing replacement culvert.

6.3.3 Factored Geotechnical Resistances

6.3.3.1 Corrugated Steel Pipe (CSP) Culvert Replacement

A CSP culvert placed on the properly prepared subgrade (compacted granular fill on the native firm to very stiff silty clay to clay deposit), at the founding elevation recommended in Table 4, should be designed based on the recommended factored ultimate geotechnical resistance at Ultimate Limit State (ULS) and the factored serviceability geotechnical resistance at Serviceability Limit State (SLS) for 25 mm of settlement, as given in Table 3.

The factored ultimate geotechnical resistance at ULS and the factored serviceability geotechnical resistance at SLS for 25 mm of settlement are dependent on the culvert diameter and founding elevation and as such, the geotechnical resistances should be reviewed if the culvert diameter or founding elevation differs from those given in Table 3.

The factored ultimate geotechnical resistance provided in Table 3 is based on loading applied perpendicular to the top surface of the culvert. Where the load is not applied perpendicular to the top surface of the culvert, inclination of the load should be taken into account in accordance with Section 6.10.4 and Section C6.10.4 of the CHBDC (2014) and its *Commentary*.

6.3.3.2 Concrete Pipe Culvert Replacement

A concrete pipe culvert placed on the properly prepared subgrade (compacted granular fill on the native firm to very stiff silty clay to clay deposit), at the founding elevation recommended in Table 3, should be designed based on the recommended factored ultimate geotechnical resistance at ULS and the factored serviceability geotechnical resistance at SLS for 25 mm of settlement, as given in Table 3.

The factored ultimate geotechnical resistance at ULS and the factored serviceability geotechnical resistance at SLS for 25 mm of settlement are dependent on the culvert diameter and founding elevation and as such, the geotechnical resistances should be reviewed if the culvert diameter or founding elevation differs from those given in Table 3.

The factored ultimate geotechnical resistance provided in Table 3 is based on loading applied perpendicular to the top surface of the culvert. Where the load is not applied perpendicular to the top surface of the culvert, inclination of the load should be taken into account in accordance with Section 6.10.4 and Section C6.10.4 of the CHBDC (2014) and its *Commentary*.

6.3.3.3 Precast Box Culvert Replacement

A precast box culvert placed on the properly prepared subgrade (compacted granular fill on firm to very stiff silty clay to clay deposit), at the founding elevation recommended in Table 3, should be designed based on the recommended factored ultimate geotechnical resistance at ULS and the factored serviceability geotechnical resistance at SLS for 25 mm of settlement, as given in Table 3.

The factored ultimate geotechnical resistance at ULS and the factored serviceability geotechnical resistance at SLS for 25 mm of settlement are dependent on the culvert width and founding elevation and as such, the geotechnical resistances should be reviewed if the culvert width or founding elevation differs from those given in Table 3.

The factored ultimate geotechnical resistance provided in Table 3 is based on loading applied perpendicular to the top surface slab of the culvert. Where the load is not applied perpendicular to the top surface slab of the culvert, inclination of the load should be taken into account in accordance with Section 6.10.4 and Section C6.10.4 of the CHBDC (2014) and its *Commentary*.

6.3.3.4 Open Footing Culvert Replacement

Strip footings placed on the properly prepared subgrade (firm to very stiff silt clay to clay/compact to dense silt and sand to silty sand), at the founding elevation recommended in Table 3, should be designed based on the factored ultimate geotechnical resistance at ULS and the factored serviceability geotechnical resistance at SLS for 25 mm of settlement, as given in Table 3.

The factored ultimate geotechnical resistance at ULS and factored serviceability geotechnical resistance at SLS for 25 mm of settlement are dependent on the culvert footing and founding elevation and as such, the geotechnical resistances should be reviewed if the culvert strip footing width differs from 0.6 m or the founding elevation differs from that given in Table 3.

The factored ultimate geotechnical resistance provided in Table 3 is based on loading applied perpendicular to the surface of the footings. Where the load is not applied perpendicular to the surface of the footings, inclination of the load should be taken into account in accordance with Section 6.10.4 and Section C6.10.4 of the CHBDC (2014) and its *Commentary*.

6.3.4 Resistance to Lateral Loads / Sliding Resistance

Resistance to lateral forces / sliding resistance between the base of the CSP, concrete pipe or box culvert, or strip footings for the open footing culverts, and the subgrade should be calculated in accordance with Section 6.10.5 of the CHBDC(2014). Table 4, following the text of this report, provides the coefficients of friction (tan δ) between the base of the culvert/footing and potential interface materials.

6.4 Embankment Stability and Settlement

It is understood that there are no changes to the final grade and embankment geometry of Highway 112 associated with this culvert replacement, and that either a temporary embankment widening of up to about 5 m wide and 3 m high on the east side of Highway 112, or an approximately 1 m grade lowering of the existing 3 m high embankment are being evaluated for staged construction. The purpose of the temporary embankment widening and grade lowering is to maintain traffic on the existing roadway during the replacement works without the need for temporary roadway protection systems.

The results of stability and settlement analysis for the temporary and final embankment geometry are presented in the following sections.

6.4.1 Stability

6.4.1.1 Methods

Limit equilibrium slope stability analyses for the temporary and permanent embankments were carried out using the commercially available program Slide (version 6.0), developed by Rocscience Inc., employing the Morgenstern-Price method of analysis. For all analyses, the Factors of Safety (FoS) of numerous potential failure surfaces were computed for the critical embankment cross-section in order to establish the minimum FoS. The FoS is defined as the ratio of the forces tending to resist failure to the driving forces tending to cause failure. For the purpose of the stability analysis, the FoS is equal to the inverse of the product of the consequence factor, Ψ, and the geotechnical resistance factor, ϕ_{gu}. (i.e. $FoS = 1/(\Psi \cdot \phi_{gu})$). Accordingly, target minimum factors of safety of 1.3 and 1.5 have been used for the design of the embankment slopes for temporary and permanent conditions against deep-seated global failures, respectively, as per Table 6.2 of CHBDC (2014). The stability analyses assume that all organics and other deleterious materials are removed prior to constructing the approach embankments.

6.4.1.2 Parameter Selection

For the non-cohesive soils present at this site, the effective stress parameters employed in the analysis were estimated from empirical correlations based on the results of the in situ Standard Penetration Tests (SPT). The correlations proposed by Peck et al. (1974) and U.S. Navy (1986) were employed and the results were adjusted by engineering judgment based on precedent experience in similar soils. The parameters used in the analysis are summarized in Table 5, following the text of this report.

For the purpose of the stability analysis, the groundwater level at each site was assumed to be at ground surface at the toes of the embankment, consistent with the level at which it was encountered in boreholes advanced during the site investigation and observations of surface water on site.

Table 5 presents the simplified stratigraphy and the associated strengths and unit weights employed for the existing and new fill material as well as the native overburden deposits encountered.

6.4.1.3 Results of Analysis

The results of the stability analysis for the temporary and final embankment geometry are summarized in Table 6 and shown on Figure D1 to D5 in Appendix D. At this site, the minimum FoS for deep-seated global failure of the temporary embankment widening and for the grade lowering geometry of the temporary stage embankment, as well as for the final embankment geometry, is equal to or greater than 1.3 in short-term conditions, and 1.5 in long-term conditions.

6.4.2 Settlement

6.4.2.1 Methods

To estimate the magnitude of expected settlement of the temporary embankment widening and final embankment, analysis was carried out at the critical section at STA 13+234. Settlement analyses were carried out using the commercially available program Settle^{3D} (Version 4.0), developed by Rocscience Inc. The settlement analyses assume that all organics and other deleterious materials (i.e. organic silt, and rootlets) are removed prior to constructing the temporary embankment widening.

6.4.2.2 Parameter Selection

The simplified stratigraphy and the associated unit weights and strengths employed for the estimation of settlement of the foundation soils of the temporary widening and final embankment are presented in Table 5. The immediate compression of the non-cohesive overburden soils were modelled by estimating an elastic modulus of deformation based on the SPT ‘N’-values and using correlations proposed by Bowles (1984) and Kulhawy and Mayne (1990). These estimated values were compared with the typical range of expected values for similar soil types, as outlined in *CHBDC* (2014) and adjusted, as appropriate. The consolidation settlement parameters of the cohesive deposits was assessed using empirical correlations proposed in literature by Koppula (1986), Terzaghi and Peck (1967), Kulhawy and Mayne (1990) and Azzouz et al. (1976).

For the purpose of the settlement analysis, the groundwater level was assumed to be at ground surface at the toe of the embankment, which is consistent with the level at which it was encountered in boreholes advanced during the site investigation and observations of surface water on site.

6.4.2.3 Results of Analysis

Based on the settlement analysis, the total factored settlement of the foundation soils due to the 3 m high and 5 m wide temporary embankment widening on the east side of the existing embankment is estimated to be about 20 mm. This settlement is estimated to be comprised of about 5 mm of factored immediate settlement due to the compression of the non-cohesive deposits and about 15 mm of factored primary settlement within the cohesive deposit. Based on the average coefficient of consolidation (c_v) of about 1.4×10^{-2} cm^2/s estimated for the cohesive deposit and the imposed loading conditions, and assuming a two way drainage of approximately 4.7 m thick cohesive deposit, it is estimated that about 90 per cent of the factored primary consolidation settlement will be completed in about 40 days.

Given that there is no grade raise or permanent platform widening of the final embankment, the existing fill below the existing culvert invert level as well as native overburden is not expected to experience additional load as a result of the culvert replacement and as such, the settlement of the foundation soils below the culvert is estimated to be less than 25 mm.

The results of the foundation soil settlement analysis for the temporary widening, grade lowering and final embankment at the critical section are summarized in Table 7.

6.5 Lateral Earth Pressures for Design

The lateral earth pressures acting on the walls of the culvert will depend on the type and method of placement of the backfill material, the nature of the soils/embankment fill behind the backfill, the magnitude of surcharge including construction loadings, the freedom of lateral movement of the structure, and the drainage conditions behind the walls.

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

- Select, free draining granular fill meeting the specifications of OPSS.PROV 1010 (Aggregates) Granular ‘A’ or Granular ‘B’ Type II should be used as backfill behind the culvert walls, and on top of the culvert for a thickness of not less than 300 mm. Backfill should be placed in a maximum of 200 mm loose lift thickness and nominally compacted. Compaction (including type of equipment, target densities, etc.) should be carried out in accordance with OPSS.PROV 501 (Compacting).
- For restrained walls in box culvert design, granular fill should be placed in a zone with the width equal to at least 2.4 m behind the back of the wall (in accordance with Figure C6.20(a) of the *Commentary* to the *CHBDC (2014*). For unrestrained walls in open footing culvert design, fill should be placed within the wedge-shaped zone defined by a line drawn at 1.5 horizontal to 1 vertical (1.5H:1V) extending up and back from the rear face of the footing (in accordance with Figure C6.20(b) of the *Commentary* to the *CHBDC (2014*). The pressures are based on the proposed embankment fill material and the following parameters (unfactored) may be used:

Fill Type	Soil Unit Weight	Coefficients of Static Lateral Earth Pressure	
		At-Rest, K_o	Active, K_a
Granular ‘A’	22 kN/m^3	0.43	0.27
Granular ‘B’ Type II	21 kN/m^3	0.43	0.27

If the culvert structure does not allow lateral yielding, at-rest earth pressures should be assumed for the foundation design. If the culvert structure allows for lateral yielding, active earth pressures should be used in the foundation design. The movement required to allow active pressures to develop within the backfill, and thereby assume an unrestrained structure for design, should be calculated in accordance with Section C6.12.1 and Table C6.6 of the *Commentary* to the *CHBDC (2014)*.

6.6 Construction Considerations

6.6.1 Temporary Roadway Protection

The temporary excavations for the culvert replacement will be made through the existing embankment fill and into native overburden soils, which typically are comprised of firm to very stiff clayey silt to silty clay to clay and compact to dense silt and sand to silty sand. Excavation works must be carried out in accordance with the guidelines outlined in the Occupational Health and Safety Act (OHSA) and Regulations for Construction Projects. According to OHSA, the existing fill and native overburden soils would be classified as Type 3 and Type 2 soils, respectively. Provided that proper groundwater control is in place, temporary open-cut excavations through the embankment fill and native overburden soils should be made with side slopes inclined no steeper than 1H:1V.

Where required, temporary protection systems should be designed and constructed in accordance with OPSS.PROV 539 (Temporary Protection Systems). The lateral movement of the temporary shoring should meet Performance Level 2 as specified in OPSS.PROV 539.

The selection and design of the protection system is the responsibility of the Contractor. The support systems may be designed using the parameters provided in Table 5.

The temporary protection system should be assessed for both the drained (ϕ) and undrained cases (s_u), based on the more conservative earth pressure conditions. The earth pressure coefficients noted in Section 6.5 and Table 5 are based on a horizontal surface adjacent to the excavation. If sloped surfaces are present, the coefficient of earth pressure should be adjusted accordingly.

Design of the temporary support system should include an evaluation of base stability, soil squeezing stability and the hydraulic uplift stability as defined in the Canadian Foundation Engineering Manual (CFEM 2006). Further, the native soil (i.e. silty clay to clay) at this site is sensitive to disturbance from driving operations for pile installation which should be considered in the design, installation and removal of the temporary protection system.

Consideration could be given to either partial or full removal of the temporary protection system upon completion of construction or each stage of construction (as required). Where possible, full removal of the temporary protection system should be considered to mitigate potential impediments to future rehabilitation/reconstruction work at the culvert site. However, where the temporary protection system penetrates into cohesive soils, there is a potential risk that full removal will result in a void within the soil column due to adhesion along the sheet pile (or H-pile soldier piles) walls (CFEM, 2006, p. 428). Given the founding depth of the proposed culvert replacement at this site, it is anticipated that the temporary protection system will be installed within or through the cohesive clayey silt to clay deposit. There is little to no risk of pile adhesion within the granular embankment fill, however if the temporary protection system, as designed and installed by the Contractor, extends into the cohesive deposit, there is a potential risk of adhesion which should be re-evaluated after pile installation depending on the depth of penetration. For piles installed to a toe Elevation 289.2 m or lower, penetrating greater than 1 m into the clayey silt to clay deposit consideration will need to be given to only partial depth removal.

6.6.2 Sloughing of Temporary Side Slopes

Given that the embankment fill is heterogeneous in composition and the angle of internal friction of the material(s) is variable, sloughing of the temporary 1 horizontal to 1 vertical (1H:1V) embankment slopes may occur during construction. If sloughing of the surficial/near surface slope material(s) should occur, consideration could be given to the placement of a surficial layer of granular fill on the temporary embankment slope to prevent further sloughing. Alternatively, consideration could also be given to flattening the temporary side slopes to 1.5 horizontal to 1 vertical (1.5H:1V) to reduce the potential for sloughing of the temporary slopes during construction. Barriers along the temporary 1H:1V embankment slopes should be positioned to provide as much separation distance as practical from the edge of the embankment crest. Further, visual monitoring of the embankment side slopes for signs of sloughing/instability should be carried out on a regular basis.

6.6.3 Sub-Excavation and Replacement below Culvert Bedding

Prior to the placement of any bedding material or granular fill, all organic soils should be stripped from the plan limits of the proposed works. Given the proposed culvert founding elevations of the replacement culverts summarized in Table 3, excavation of the embankment fill, organic material and native overburden soils up to about 5.5 m below existing ground surface will be required. Where excavation below the proposed culvert foundation level is required to remove disturbed/unsuitable material or the existing culvert footings, replacement backfill should consist of OPSS.PROV 1010 Granular ‘B’ Type II material.

The culvert subgrade, if comprised of native material, or the excavation base following sub-excavation, should be inspected to ensure that all organic soils or other unsuitable materials have been removed, in accordance with OPSS.PROV 421 (Pipe Culvert Installation in Open Cut) for a concrete pipe or CSP culvert, OPSS 422 (Precast Reinforced Concrete Box Culverts) for a precast box culvert and OPSS 902 (Excavating and Backfilling Structures) for a cast-in-place open footing culvert. Following inspection, the sub-excavated area should be backfilled with granular material meeting OPSS.PROV 1010 (Aggregates) Granular ‘A’ or Granular ‘B’ Type II and placed and compacted in accordance with OPSS.PROV 501 (Compacting) to at least 98 per cent of the Standard Proctor maximum dry density of the material.

Taking into consideration that backfill/bedding will be placed on the native clayey silt to clay deposit, it is recommended that a non-woven geotextile be placed between the subgrade soils and the bottom of the backfill/bedding. The geotextile should meet the specification for OPSS 1860 (Geotextiles) Class II and have a Filtration Opening Size (FOS) not greater than 150 μm.

All excavations should be carried out in accordance with OPSS 902 (Excavating and Backfilling – Structures) and must be carried out in accordance with Ontario Regulation 213 Ontario Occupational Health and Safety Act for Construction Projects (as amended).

6.6.4 Embankment Fill Placement

Prior to the placement of any granular fill for the embankment widening, all organic soils should be stripped from the plan limits of the proposed works. Placement of granular fill for the construction of embankment widening and final embankment should be carried out in accordance with OPSS.PROV 206 (Grading) and compaction of the granular fill should be in accordance with OPSS.PROV 501 (Compacting), with inspection during construction to confirm that appropriate materials are used and that adequate levels of compaction are achieved. The granular fill used in embankment construction should be compacted to not less than 95 per cent of the materials standard proctor maximum dry density (SPDMDD).

The up to 4 m high staged embankment, which will be incorporated into the final construction of permanent embankment, may be constructed at a 1 horizontal to 1 vertical (1H:1V) median/internal side slope. The final embankment could be constructed with permanent side slopes no steeper than 2 horizontal to 1 vertical (2H:1V).

Where granular fill is placed on an embankment side slope, benching of the embankment side slopes should be should be carried out in accordance with OPSD 208.010 (Benching of Earth Slopes) to integrate the new fill into the existing embankment fill.

6.6.5 Culvert Bedding and Backfill

Culvert construction, including placement of bedding, cover and backfill should be placed in accordance with the following standards associated with each culvert type:

Culvert Type	Bedding, Cover Material and Backfill	Culvert Construction
Corrugated Steel Pipe	OPSD 802.010 – Flexible Pipe Embedment and Backfill, Earth Excavation	OPSS.PROV 421 – Pipe Culvert Installation in Open Cut
Concrete Pipe	OPSD 802.031 – Rigid Pipe Bedding, Cover, And Backfill, Type 3 Soil - Earth Excavation	OPSS.PROV 421 – Pipe Culvert Installation in Open Cut
Precast Box	OPSD 803.010 – Backfill and Cover for Concrete Culverts	OPSS 422 – Precast Reinforced Concrete Box Culverts
Open Footing	OPSD 803.010 – Backfill and Cover for Concrete Culverts	OPSS 902 – Excavating And Backfilling – Structures

Culvert bedding should be placed on a properly prepared subgrade, whether comprised of native material or sub-excavation backfill. The bedding, cover and backfill should be placed in lifts not exceeding 200 mm in loose thickness, and compacted to at least 95 per cent of the Standard Proctor maximum dry density of the material.

The backfill behind the culvert walls should consist of granular fill meeting the specifications for OPSS.PROV 1010 Granular ‘A’ or Granular ‘B’ Type II. The granular backfill should be placed and compacted in accordance with OPSS.PROV 501 (Compacting). Backfill placement for reconstruction of the highway embankments along and over the culvert should be carried out as per OPSD 208.010 (Benching of Earth Slopes) to integrate the new fill into the existing embankment fill along the cut faces.

Inspection and field density testing should be carried out during all engineered fill placement operations to ensure that appropriate materials are used, and that adequate levels of compaction have been achieved.

Additional requirements/recommendations for culvert construction are provided below for each culvert option.

6.6.5.1 Corrugated Steel Pipe Culvert

It is important that the backfill at the haunches be well compacted. The circular culvert should be constructed on a minimum 300 mm thick layer of OPSS.PROV 1010 (Aggregates) Granular ‘A’ or Granular ‘B’ Type II material for bedding and be covered with a minimum 300 mm above the pipe for cover purposes, while Granular ‘B’ Type I may be used as backfill above the cover.

Backfill should be placed concurrently on both sides of the culvert walls, ensuring that the backfill depth on one side does not exceed the other side by more than 200 mm as per OPSS.PROV 401 (Trenching, Backfilling and Compacting).

6.6.5.2 Concrete Pipe Culvert

It is important that the backfill at the haunches be well compacted. The circular culvert should be constructed on a 300 mm thick layer of OPSS.PROV 1010 (Aggregates) Granular ‘A’ or Granular ‘B’ Type II material for bedding and be covered with a minimum 300 mm above the pipe for cover purposes, while Granular ‘B’ Type I may be used as backfill above the cover.

Backfill should be placed concurrently on both sides of the culvert walls, ensuring that the backfill depth on one side does not exceed the other side by more than 200 mm as per OPSS.PROV 401 (Trenching, Backfilling and Compacting).

6.6.5.3 Precast Box Culvert

It is recommended that at least 300 mm of OPSS.PROV 1010 (Aggregates) Granular 'A' or Granular 'B' Type II material be used for bedding purposes. In addition, a minimum 75 mm thick uncompacted levelling layer consisting of OPSS.PROV 1010 Granular 'A' or concrete fine aggregate meeting the gradation requirements specified in OPSS.PROV 1002 (Aggregates – Concrete) should be provided as shown on OPSD 803.010 (Backfill and Cover for Concrete Culverts) for culvert construction.

Backfill should be placed concurrently on both sides of the culvert walls, ensuring that the backfill depth on one side does not exceed the other side by more than 400 mm as per OPSS 422 (Precast Reinforced Concrete Box Culverts).

6.6.5.4 Open Footing Culvert

Backfill should be placed concurrently on both sides of the culvert walls, ensuring that the backfill depth on one side does not exceed the other side by more than 500 mm as per OPSS 902 (Excavating and Backfilling – Structures).

6.6.6 Subgrade Protection

The cohesive overburden soils exposed at the founding level will be susceptible to disturbance from construction traffic and/or ponded water. To limit the effect of this disturbance a concrete working slab could be placed on the subgrade if the concrete for the footings, or the box culvert, is not placed within four hours after preparation, inspection and approval of the subgrade. The minimum thickness of the concrete working slab should be 100 mm and the concrete should have a 28-day compressive strength of not less than 20 MPa. A Non-Standard Special Provision (NSSP) to address this requirement is included in Appendix E.

6.6.7 Erosion Protection

Provision should be made for scour and erosion protection at the culvert location. In order to prevent surface water from flowing either beneath the culvert (potentially causing undermining and scouring), or around the culvert (creating seepage through the embankment fill, and potentially causing erosion and loss of fine soil particles), a clay seal or concrete cut-off wall should be provided at the upstream and downstream ends of the CSP, concrete pipe and precast box culvert. If a clay seal is adopted, the clay material should meet the requirements of OPSS.PROV 1205 (Clay Seal), and the seal should be a minimum 1 m thick if constructed of natural clay or soil-bentonite mix, and extend from a depth of 1 m below the scour level for a CSP, concrete pipe or precast box culvert, and from the ground surface immediately adjacent to an open footing culvert, to a minimum horizontal distance of 2 m on either side of the culvert inlet opening and to a minimum vertical height equivalent to the high water level, including along the embankment slopes.

The requirements for and design of erosion protection measures for the inlet and outlet of the culvert should be assessed by the hydraulics design engineer. As a minimum, rip-rap treatment for the outlet of the culvert should be consistent with the standard presented in OPSD 810.010 (Rip-Rap Treatment for Sewer and Culvert Outlets). Erosion protection for the inlet of the culverts should generally follow the standard presented in OPSD 810.010, with the rip-rap placed up to the toe of slope level, in combination with the cut-off measures noted above, including over the full extent of the clay seal on the embankment slope.

6.6.8 Temporary Culvert Extension

A temporary culvert extension may be required to provide surface water passage/drainage below the temporary embankment widening. The temporary culvert extension may consist of a precast concrete culvert (box or pipe) or corrugated steel pipe (CPS) culvert. Bedding recommendations for the temporary culvert extension should be in accordance with the corresponding OPSS and/or OPSD, as outlined in Section 6.6.5, depending on the type of temporary culvert extension chosen.

Settlement of the temporary culvert extension below the temporary embankment will occur concurrently with and be of the same magnitude as the settlement of the temporary embankment. The anticipated magnitude of settlement of the temporary embankment, and therefore the temporary culvert extension, is provided in Table 7. The selection of the temporary culvert extension should take into account the anticipated settlement and should be sized such that it may still perform its intended function for the duration that the temporary embankment widening will be in place.

6.6.9 Surface Water and Groundwater Control

Groundwater control may be required as the foundation excavation will extend below the existing ground surface for the removal of organic and overburden soils prior to placement of the culvert, and below the groundwater level for the culvert footing level. As this is a seasonal water course and excavations will be advanced through the native clayey silt to silty clay to clay deposits it is anticipated that seepage into the excavation should be adequately controlled by pumping from properly filtered sumps. Surface water flow should be directed away from the excavation. Dewatering of all excavations should be carried out in accordance with OPSS 517 (Dewatering).

6.6.10 Recommendations for Construction Materials Based on Analytical Testing

The results of an analytical test on one sample of creek water are summarized in Section 4.3.9 and presented in Appendix C. The potential for deterioration of concrete due to sulphate attack and corrosion of steel elements are discussed in the following sections. It is the responsibility of the designer to determine the appropriate construction materials, including the exposure class and ensuring that all aspects of CSA A23.1-14 Section 4.1.1 “Durability Requirements” are followed when designing concrete components and protection of steel elements.

6.6.10.1 Potential for Sulphate Attack

The analytical test results were compared to CSA A23.1-14 Table 3 *("Additional requirements for concrete subjected to sulphate attack”)* for the potential sulphate attack on concrete. The sulphate concentration measured in the creek water sample is less than 0.0001 per cent (<1 mg/L), which is below the exposure class of S-3 (Moderate). Therefore, based on the single sample of creek water tested, when the designer is selecting the exposure class for the structure, the effects of sulphates from within the creek water around the culvert may not need to be considered.

6.6.10.2 Potential for Corrosion

The water sample tested exhibited a pH of 6.72 and a resistivity of 21,000 ohm-cm. According to the MTO Gravity Pipe Design Guidelines (2014), the pH is not considered detrimental to culvert durability as it is less than a pH of 8.5. The resistivity is greater than 10,000 ohm-cm, which indicates that the soil corrosiveness is very low (10,000 > R > 6,000 ohm-cm), as per Table 3.2 of the MTO Gravity Pipe Design Guidelines (2014). However, the culvert will be located under the roadway shoulder and will be exposed to de-icing salt. Therefore, concrete should be designed for a “C” type exposure class as defined by CSA A23.1-14 Table 1 and consideration should be given to providing corrosion protection to reinforcing elements. All culverts should be designed with consideration given to Table 7.1 of the MTO Gravity Pipe Design Guidelines (2014).

7.0 CLOSURE

This Foundation Design Report was prepared by Ms. Madison Kennedy, B.A.Sc., a member of the geotechnical engineering group. The technical aspects were reviewed by Mr. Christopher Ng, P.Eng., a geotechnical engineer and an Associate of Golder. Mr. Jorge M. A. Costa, P.Eng., a Senior Consultant with Golder and Designated MTO Foundations Contact conducted an independent quality control review of this report.

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ASTM International:

ASTM D1586	Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils

Ontario Water Resources Act:

Ontario Regulation 331/13	Amendment to Revised Regulations of Ontario 1990, Regulation 903

Ontario Occupational Health and Safety Act:

Ontario Regulation 213/91 Construction Projects as amended by O. Reg. 443/09

Ontario Provincial Standard Drawing:

OPSD 208.010	Benching of Earth Slopes
OPSD 802.010	Flexible Pipe Embedment and Backfill
OPSD 802.031	Rigid Pipe Bedding, Cover and Backfill, Type 3 Soil – Earth Excavation
OPSD 803.010	Backfill and Cover for Concrete Culverts with Spans Less Than or Equal to 3.0 m
OPSD 810.010	Rip-Rap Treatment for Sewer and Culvert Outlets
OPSD 3090.100	Foundation, Frost Penetration Depths for Northern Ontario

Ontario Provincial Standard Specification:

OPSS.PROV 206	Construction Specification for Grading
OPSS.PROV 401	Construction Specification for Trenching, Backfilling and Compacting
OPSS.PROV 421	Construction Specification for Pipe Culvert Installation in Open Cut
OPSS 422	Construction Specifications for Precast Reinforced Concrete Box Culverts and Box Sewers in Open Cut
OPSS.PROV 501	Construction Specifications for Compacting
OPSS 517	Construction Specifications for Dewatering of Pipeline, Utility, and Associated Structure Excavation
OPSS.PROV 539	Construction Specifications for Temporary Protection Systems
OPSS 902	Construction Specifications for Excavating and Backfilling – Structures
OPSS.PROV 1002	Construction Specification for Material Specifications for Aggregates - Concrete
OPSS.PROV 1010	Construction Specification for Material Specifications for Aggregates – Base, Subbase, Select Subgrade, Backfill Material
OPSS.PROV 1205	Construction Specification for Material Specification for Clay Seal
OPSS 1860	Construction Specification for Material Specification for Geotextiles

Commercial Software:

Slide (Version 6.0) by Rocscience Inc

Settle^{3D} (Version 4.0) by Rocscience Inc

TABLES

Table 1: Summary of Existing Culvert Details

Culvert Location (Township)	Culvert ID	Approximate Height of Embankment [1]	Existing Culvert			Approximate Invert Elevation [2]		Boreholes	Dynamic Cone Penetration Tests
			Type	Approximate Dimension	Approximate Length	Upstream	Downstream		
STA 13+234 (Pacaud)	C1	Up to about 5.5 m	Open Footing	910 mm span by 610 mm high	30.5 m	289.9 m (East End)	287.9 m (West End)	3 Boreholes (C1-1 to C1-3)	1 DCPT (C1-DCPT-1)

Notes:
1. Embankment height is relative to existing ground surface level at the toe of embankment adjacent to the culvert.
2. Culvert invert elevations are based on the Drainage and Hydrology Report for the Replacement of Four Centreline Culverts on Highway 112 and Highway 650, W.P. 5427 15-01, prepared by MMM, dated November 2016.

Prepared By: MCK
Checked By: CN
Reviewed By: JMAC

Table 2: Comparison of Culvert Replacement Options

Replacement Alternatives	Advantages	Disadvantages	Risks/Consequences
Corrugated Steel Pipe (CSP) Culvert	■ Minimizes the depth of excavation, excavation support and dewatering requirements compared to cast-in-place open footing culvert. ■ Culvert construction using CSP pipes is expected to be the fastest, resulting in the shortest duration for traffic control, dewatering and surface water pumping, where required. ■ More tolerant of total and differential settlement resulting from embankment widening (or if a grade raise is required) at the culvert site than precast and cast-in-place open footing culverts.	■ Dewatering/unwatering would be required if excavation extends below the groundwater level and construction is to be carried out in-the-dry to allow for placement and compaction of backfill around the culvert. ■ Cut-off wall or clay blanket may be required at inlet/outlet ends to mitigate potential for scour around/under the culvert. ■ Proper compaction of backfill material under the haunches and to the springline is difficult. ■ CSP construction is not expected to have as long a service life as a concrete structure. ■ Reduced hydraulic capacity compared to a similar size precast box or open footing culvert.	■ Some risk of disturbance of the firm to very stiff clayey silt to silty clay to clay deposit under the culvert during construction.
Concrete Pipe Culvert	■ Minimizes the depth of excavation, excavation support and dewatering requirements compared to cast-in-place open footing culvert. ■ Compared to cast-in-place open footings, the use of precast concrete pipe segments is expected to allow for faster construction, resulting in shorter duration for traffic control, dewatering and surface water pumping, where required. ■ More tolerant of total and differential settlement resulting from embankment widening (or if a grade raise is required) at the culvert site than a cast-in-place open footing culvert.	■ A concrete pipe culvert will require slightly longer duration for construction as compared to the construction of a CSP culvert. ■ Dewatering/unwatering would be required if the excavation extends below the groundwater level and construction is to be carried out in-the-dry to allow for placement and compaction of backfill around the culvert. ■ Cut-off wall or clay blanket may be required at inlet/outlet ends to mitigate potential for scour around/under the culvert. ■ Proper compaction of backfill material under the haunches and to the springline is difficult. ■ Reduced hydraulic capacity compared to a similar width precast box or open footing culvert.	■ Some risk of disturbance of the firm to very stiff clayey silt to silty clay to clay deposit under the culvert during construction.

Table 2: Comparison of Culvert Replacement Options

Replacement Alternatives	Advantages	Disadvantages	Risks/Consequences
Precast Box Culvert	■ Minimizes the depth of excavation, excavation support and dewatering requirements compared to cast-in-place open footing culvert. ■ Compared to cast-in-place open footings, the use of precast box segments is expected to allow for faster construction, resulting in shorter duration for traffic control, dewatering and surface water pumping. ■ More tolerant of total and differential settlement resulting from embankment widening (or if a grade raise is required) at the culvert site than a cast-in-place open footing culvert. ■ Box culvert of similar span width and height as a CSP or concrete pipe culvert can accommodate higher flows.	■ A precast box culvert will require longer duration for construction than a CSP and a concrete pipe culvert. ■ Cut-off wall required at inlet/outlet ends to mitigate potential for scour around/under the culvert.	■ Some risk of disturbance of the firm to very stiff clayey silt to silty clay to clay deposit under the culvert during construction.
Cast-In-Place Open Footing Culvert	■ Provides a relatively higher bearing capacity due to the depth of embedment of footings. ■ Open footing culvert of similar span width and height as a CSP or concrete pipe culvert can accommodate higher flows. ■ Excavation of the existing culvert footings may be reused to accommodate the new footings, provided such excavation extends to below the depth of frost penetration or bedrock, as applicable.	■ Deeper excavations, excavation support and dewatering requirements compared to other culvert types; ■ Additional time will be required to implement a dewatering system for the construction of footings in-the-dry; also resulting in a longer duration for traffic control. ■ A cast-in-place open footing culvert is less tolerant of total and differential settlement.	■ High risk of disturbance of the firm to very stiff clayey silt to silty clay to clay deposit under the culvert during construction. ■ Culvert joints may be required to accommodate total and differential settlement (if applicable)

Prepared By: MCK
Checked By: CN
Reviewed By: JMAC

Table 3: Factored Ultimate and Serviceability Geotechnical Resistances for Culvert Replacement Options

Culvert Location (Township)	Proposed Invert Elevation [1] (Upstream / Downstream)	Culvert Type	Culvert Dimensions	Approximate Founding Elevation (Upstream / Downstream) [1]	Founding Condition	Factored Ultimate Geotechnical Resistance at ULS [2]	Factored Serviceability Geotechnical Resistance at SLS for 25 mm of Settlement [2]
STA 13+234 (Pacaud)	289.9 m / 287.9 m (East End / West End)	Corrugated Steel Pipe (CSP)	525 mm diameter / 30.9 m long	289.6 m / 287.6 m (East / West)	Compacted Granular Fill over Silty Clay to Clay	175 kPa	NA[3]
		Concrete Pipe Culvert	525 mm diameter / 30.9 m long	289.6 m / 287.6 m (East / West)	Compacted Granular Fill over Silty Clay to Clay	175 kPa	NA[3]
		Precast Box	525 mm wide x 525 mm high / 30.9 m long	289.6 m / 287.6 m (East / West)	Compacted Granular Fill over Silty Clay to Clay	175 kPa	NA[3]
		Cast-In-Place Open Footing	0.6 m wide footings / 525 mm wide x 525 mm high 30.9 m long	287.5 m / 285.5 m (East / West)	Firm to Very Stiff Silty Clay to Clay / Compact Silty Sand	200 kPa	NA[3]
			1.2 m wide footings / 525 mm wide x 525 mm high 30.9 m long	287.5 m / 285.5 m (East / West)	Firm to Very Stiff Silty Clay to Clay / Compact Silty Sand	200 kPa	NA[3]

Notes:
1. Culvert invert elevations are based on the Drainage and Hydrology Report for the Replacement of Four Centreline Culverts on Highway 112 and Highway 650, W.P. 5427-15-01, prepared by MMM, dated November 2016.
2. The factored ultimate geotechnical resistance at ULS and factored serviceability geotechnical resistance at SLS for 25 mm of settlement are estimated based on the assumed culvert dimensions. The geotechnical resistances should be reviewed if the founding elevation and/or the footing/base width differ from those given above. The estimated settlement for the culverts designed on the basis of the factored ultimate geotechnical resistance at ULS would be less than 25 mm.
3. The factored serviceability geotechnical resistance at SLS for 25 mm of settlement will be greater than the factored ultimate geotechnical resistance at ULS and as a result, the SLS condition does not apply.

Prepared By: MCK
Checked By: CN
Reviewed By: JMAC

Table 4: Resistance to Lateral Loads/Sliding Resistance for Culvert Replacement Options

Culvert Type	Interface Material	Coefficient of Friction (tan δ)
Corrugated Steel Pipe Culvert (CSP)	Compacted Granular Fill (Bedding)	0.35
Concrete Pipe Culvert	Compacted Granular Fill (Bedding)	0.40
Precast Box Culvert	Compacted Granular Fill (Bedding)	0.40
Cast-In-Place Open Footing Culvert	Firm to Very Stiff Silty Clay to Clay / Compact Silty Sand	0.30

Prepared By:	MCK
Checked By:	CN
Reviewed By:	JMAC

Table 5: Summary of Foundation Engineering Parameters

Culvert Designation	***Culvert Location (Township)***	***Stratigraphic Unit***	***Top Elevation Encountered (m)***	***Thickness Encountered (m)***	γ' ***(kN/m^3)***	ϕ' **(°)**	***c' (kPa)***	***S_u (kPa)***	***σ_p' (kPa)***	***e_o***	***C_c***	***C_r***	***m_v (kPa^{-1})***	***E' (MPa)***	***c_v (cm^2/s)***	**Coefficient of Earth Pressure**		
																Active, K_a	**At Rest, K_o**	**Passive, K_p**
C1	Highway 112 STA 13+234 (Pacaud)	New Granular Embankment Fill	-	-	21	35	-	-	-	-	-	-	-	150	-	0.27	0.43	3.69
		Existing Dense Sand to Sand and Gravel Fill	293.2	~ 2.2	20	33	-	-	-	-	-	-	-	50	-	0.29	0.46	3.39
		Existing Firm to Very Stiff Sandy Clayey Silt to Silty Clay with Sand Fill	291.1	~ 2.3	18	30	-	50 – 100	-	-	-	-	1×10^{-4}	-	1.4×10^{-2}	0.33	0.50	3.00
		Firm to Very Stiff Clayey Silt to Clay	290.2 - 288.4	2.1 - 4.7	18	30	-	50 - 100	-	-	-	-	1×10^{-4}	-	1.4×10^{-2}	0.33	0.50	3.00
		Compact to Dense Silt and Sand to Silty Sand	288.1 - 283.7	1.1 - 2.9	19	32	-	-	-	-	-	-	-	35	-	0.31	0.47	3.25
		Very Dense Sand and Gravel	283.1	~ 1.4	21	34	-	-	-	-	-	-	-	100	-	0.28	0.44	3.54

Prepared By:	MCK
Checked By:	CN
Reviewed By:	JMAC

Table 6: Summary of Stability Analysis

Culvert ID Culvert Location (Township)	Stability Analysis [1]					Figure Number
	Condition	Embankment	Slope Profile	Embankment Height at Culvert Location	Minimum Factor of Safety [2]	
C1 STA 13+234 (Pacaud)	5 m Embankment Widening – East Side (Temporary) [3]	West Slope	1.5H:1V	3 m	≥ 1.3	D1
	Median/Internal Side Slopes with 5 m Embankment Widening – East Side (Temporary)	East Slope	1H:1V [4]	Up to 4 m	≥ 1.3	D1
		West Slope	1H:1V [4]	Up to 4 m	≥ 1.3	D2
	Median/Internal Side Slopes with Grade Lowering (Temporary)	East Slope	1H:1V [4]	Up to 3 m	≥ 1.3	D3
		West Slope	1H:1V [4]	Up to 3 m	≥ 1.3	D4
	Final Embankment	East Slope	2H:1V	3 m	≥ 1.5	D5
		West Slope	2H:1V	5 m	≥ 1.5	D5

Note:
1. Stability analysis was carried out using total stress (undrained) parameters for cohesive deposits and Mohr-Coulomb (drained) parameters for non-cohesive deposits.
2. The minimum FoS is based on a deep seated, global trial failure surface that would impact the operation of the highway.
3. Where embankment widening is required, benching of the existing embankment side slope should be carried out in accordance with OPSD 208.010 (Benching of Earth Slopes).
4. For temporary 1H:1V side slopes, surficial sloughing may occur which may require maintenance. If sloughing occurs during construction, consideration could be given to the placement of a surficial layer of granular fill on the temporary embankment slope or flattening slopes to 1.5H:1V inclination to mitigate against further sloughing.

Prepared By:	MCK
Checked By:	CN
Reviewed By:	JMAC

Table 7: Summary of Settlement Analysis

Culvert ID Culvert Location (Township)	Construction Stage	Estimated Factored Immediate Settlement of Foundation Soils	Estimated Factored Consolidation Settlement of Foundation Soils [1]	Estimated Total Factored Settlement
C1 STA 13+234 (Pacaud)	5 m Embankment Widening – West Side (Temporary)	5 mm	15 mm	20 mm
	Final Embankment	< 5 mm	< 5 mm	< 10 mm

Notes: 1. About 90 per cent of the factored primary consolidation settlement is estimated to be completed in about 40 days.

Prepared By:	MCK
Checked By:	CN
Reviewed By:	JMAC

FIGURES

East side of Highway 112 at STA 13+234 (Township of Pacaud) Culvert Inlet, looking west. May 31, 2016.

PROJECT	**Detail Design for Replacement of 3 Centreline Culverts – Highway 112 GWP 5105-12-00; WP 5428-15-01**
TITLE	**Site Photographs Culvert STA 13+234 (Township of Pacaud) Highway 112**

PROJECT No. 1530157			FILE No. ----		
DESIGN	MCK	Aug16	SCALE	NTS	REV.
CADD	-- --		**FIGURE 1A**		
CHECK	CN	Aug 16			
REVIEW	JMAC	Aug 16			

Golder Associates

REVISION DATE: February 3, 2017 BY: MCK Project: 1531057

West side of Highway 112 at STA 13+234 (Township of Pacaud) Culvert Outlet, looking east. June 1, 2016.

PROJECT

Detail Design for Replacement of 3 Centreline Culverts – Highway 112
GWP 5105-12-00; WP 5428-15-01

TITLE

Site Photographs
Culvert STA 13+234 (Township of Pacaud)
Highway 112

Golder Associates

PROJECT No. 1530157		
DESIGN	MCK	Aug16
CADD	-- --	
CHECK	CN	Aug 16
REVIEW	JMAC	Aug 16

FILE No. ----

SCALE NTS REV.

FIGURE 1B

REVISION DATE: February 3, 2017 BY: MCK Project: 1531057

DRAWINGS

MINISTRY OF TRANSPORTATION, ONTARIO

METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN.
STATIONS IN KILOMETRES + METRES.

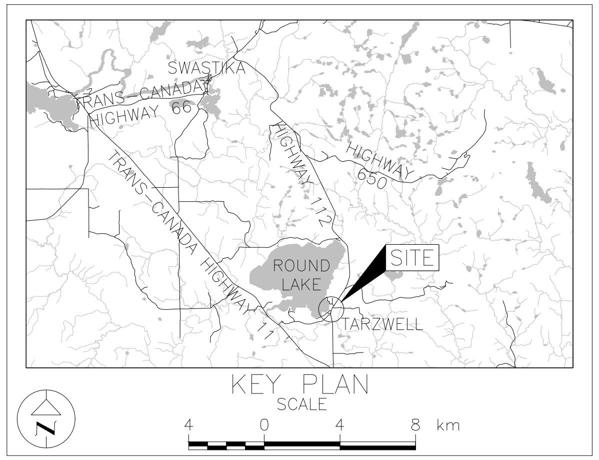
CONT No.
WP No. 5428-15-01

SHEET

HIGHWAY 112
CULVERT STA. 13+234
BORHOLE LOCATIONS AND SOIL STRATA

Golder Associates

PLAN
SCALE



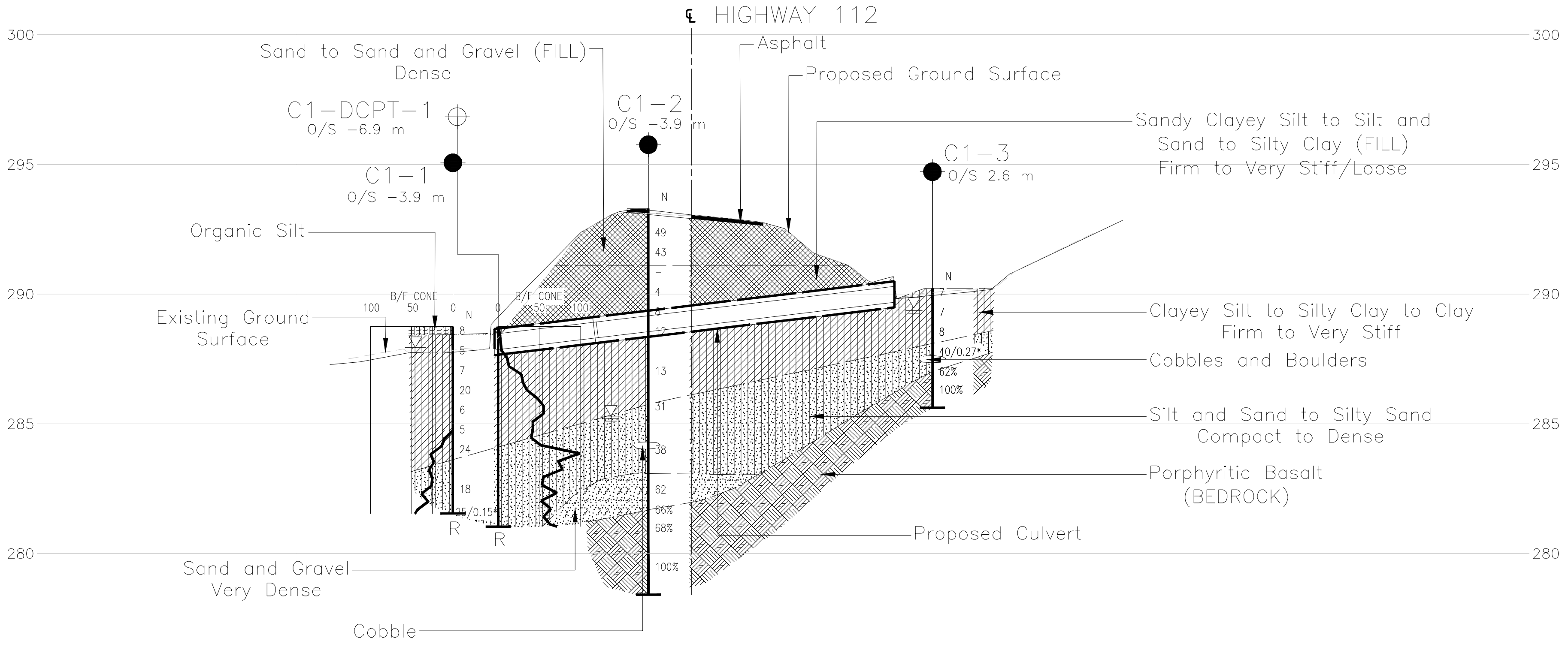
KEY PLAN
SCALE

LEGEND

●	Borehole – Current Investigation
⊕	Dynamic Cone Penetration Test
N	Standard Penetration Test Value
16	Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
100%	Rock Quality Designation (RQD)
≚	WL upon completion of drilling

BOREHOLE CO-ORDINATES

No.	ELEVATION	NORTHING	EASTING
C1-1	288.7	5318327.9	378035.1
C1-2	293.3	5318321.6	378048.7
C1-3	290.2	5318318.3	378071.3
C1-DCPT-1	288.7	5318325.1	378034.1



A-A′ 1 CULVERT C1
STA. 13+234

HORIZONTAL SCALE
5 0 5 10 m

VERTICAL SCALE
2.5 0 2.5 5 m

NOTES
This drawing is for subsurface information only. The proposed structure details/works are shown for illustration purposes only and may not be consistent with the final design configuration as shown elsewhere in the Contracts Documents.

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

REFERENCE
Base plan, culvert section and surface data provided in digital format by MTO, drawing file no. "b07590112001.dwg", dated May, 2016, received June 29, 2016. Key plan data obtained from MNRF 2016.

J. M. A. COSTA
Apr. 04, 2017

C.C. NG
100086170
Apr. 04, 2017

NO.	DATE	BY	REVISION
.	.	.	.

Geocres No. 42A-113

HWY. 112	PROJECT NO. 1531057		DIST. .
SUBM'D. MCK	CHKD. MCK	DATE: 4/4/2017	SITE: .
DRAWN: MR	CHKD. CN	APPD. JMAC	DWG. 1

PLOT DATE: April 4, 2017
FILENAME: S:\Clients\MTO\Hwy_112\99_PROJ\1531057_MMMGroup_CulvReplac\40_PROD\0001_C1_FoundatInv\1531057-0001-BG-0001.dwg

APPENDIX A

Record of Boreholes

LIST OF SYMBOLS

Unless otherwise stated, the symbols employed in the report are as follows:

I. GENERAL

π	3.1416
ln x,	natural logarithm of x
$\log_{10}$	x or log x, logarithm of x to base 10
g	acceleration due to gravity
t	time
FoS	factor of safety

II. STRESS AND STRAIN

γ	shear strain
Δ	change in, e.g. in stress: $\Delta \sigma$
ε	linear strain
ε_v	volumetric strain
η	coefficient of viscosity
υ	Poisson's ratio
σ	total stress
σ'	effective stress ($\sigma' = \sigma - u$)
σ'_{vo}	initial effective overburden stress
$\sigma_1, \sigma_2, \sigma_3$	principal stress (major, intermediate, minor)
σ_{oct}	mean stress or octahedral stress $= (\sigma_1 + \sigma_2 + \sigma_3)/3$
τ	shear stress
u	porewater pressure
E	modulus of deformation
G	shear modulus of deformation
K	bulk modulus of compressibility

III. SOIL PROPERTIES

(a) Index Properties

$\rho(\gamma)$	bulk density (bulk unit weight)*
$\rho_d(\gamma_d)$	dry density (dry unit weight)
$\rho_w(\gamma_w)$	density (unit weight) of water
$\rho_s(\gamma_s)$	density (unit weight) of solid particles
γ'	unit weight of submerged soil ($\gamma' = \gamma - \gamma_w$)
D_R	relative density (specific gravity) of solid particles ($D_R = \rho_s / \rho_w$) (formerly G_s)
e	void ratio
n	porosity
S	degree of saturation

(a) Index Properties (continued)

w	water content
w_l or LL	liquid limit
w_p or PL	plastic limit
I_p or PI	plasticity index = $(w_l - w_p)$
w_s	shrinkage limit
I_L	liquidity index = $(w - w_p) / I_p$
I_C	consistency index = $(w_l - w) / I_p$
e_{max}	void ratio in loosest state
e_{min}	void ratio in densest state
I_D	density index = $(e_{max} - e) / (e_{max} - e_{min})$ (formerly relative density)

(b) Hydraulic Properties

h	hydraulic head or potential
q	rate of flow
v	velocity of flow
i	hydraulic gradient
k	hydraulic conductivity (coefficient of permeability)
j	seepage force per unit volume

(c) Consolidation (one-dimensional)

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

(d) Shear Strength

τ_p, τ_r	peak and residual shear strength
ϕ'	effective angle of internal friction
δ	angle of interface friction
μ	coefficient of friction = $\tan \delta$
c'	effective cohesion
c_u, s_u	undrained shear strength ($\phi = 0$ analysis)
p	mean total stress $(\sigma_1 + \sigma_3)/2$
p'	mean effective stress $(\sigma'_1 + \sigma'_3)/2$
q	$(\sigma_1 - \sigma_3)/2$ or $(\sigma'_1 - \sigma'_3)/2$
q_u	compressive strength $(\sigma_1 - \sigma_3)$
S_t	sensitivity

Notes: 1 $\tau = c' + \sigma' \tan \phi'$

2 shear strength = (compressive strength)/2

---

* Density symbol is ρ. Unit weight symbol is γ where $\gamma = \rho g$ (i.e. mass density multiplied by acceleration due to gravity)

LIST OF ABBREVIATIONS

The abbreviations commonly employed on Records of Boreholes, on figures and in the text of the report are as follows:

I. SAMPLE TYPE

AS	Auger sample
BS	Block sample
CS	Chunk sample
DS	Denison type sample
FS	Foil sample
RC	Rock core
SC	Soil core
SS	Split-spoon
ST	Slotted tube
TO	Thin-walled, open
TP	Thin-walled, piston
WS	Wash sample

II. PENETRATION RESISTANCE

Standard Penetration Resistance (SPT), N:

The number of blows by a 63.5 kg. (140 lb.) hammer dropped 760 mm (30 in.) required to drive a 50 mm (2 in.) drive open sampler for a distance of 300 mm (12 in.)

Dynamic Cone Penetration Resistance; N_d:

The number of blows by a 63.5 kg (140 lb.) hammer dropped 760 mm (30 in.) to drive uncased a 50 mm (2 in.) diameter, 60° cone attached to “A” size drill rods for a distance of 300 mm (12 in.).

PH: Sampler advanced by hydraulic pressure
PM: Sampler advanced by manual pressure
WH: Sampler advanced by static weight of hammer
WR: Sampler advanced by weight of sampler and rod

Piezo-Cone Penetration Test (CPT)

A electronic cone penetrometer with a 60° conical tip and a project end area of 10 cm^2 pushed through ground at a penetration rate of 2 cm/s. Measurements of tip resistance (Q_t), porewater pressure (PWP) and friction along a sleeve are recorded electronically at 25 mm penetration intervals.

III. SOIL DESCRIPTION

(a) Non-Cohesive Soils

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

(b) Cohesive Soils

Consistency

	c_u, s_u kPa	c_u, s_u psf
Very soft	0 to 12	0 to 250
Soft	12 to 25	250 to 500
Firm	25 to 50	500 to 1,000
Stiff	50 to 100	1,000 to 2,000
Very stiff	100 to 200	2,000 to 4,000
Hard	over 200	over 4,000

IV. SOIL TESTS

w	water content
w_p	plastic limit
w_l	liquid limit
C	consolidation (oedometer) test
CHEM	chemical analysis (refer to text)
CID	consolidated isotropically drained triaxial test[1]
CIU	consolidated isotropically undrained triaxial test with porewater pressure measurement[1]
D_R	relative density (specific gravity, G_s)
DS	direct shear test
M	sieve analysis for particle size
MH	combined sieve and hydrometer (H) analysis
MPC	Modified Proctor compaction test
SPC	Standard Proctor compaction test
OC	organic content test
SO_4	concentration of water-soluble sulphates
UC	unconfined compression test
UU	unconsolidated undrained triaxial test
V	field vane (LV-laboratory vane test)
γ	unit weight

Note: 1 Tests which are anisotropically consolidated prior to shear are shown as CAD, CAU.

V. MINOR SOIL CONSTITUENTS

Per cent by Weight	Modifier	Example
0 to 5	Trace	Trace sand
5 to 12	Trace to Some (or Little)	Trace to some sand
12 to 20	Some	Some sand
20 to 30	(ey) or (y)	Sandy
over 30	And (non-cohesive (cohesionless)) or With (cohesive)	Sand and Gravel Silty Clay with sand / Clayey Silt with sand

LITHOLOGICAL AND GEOTECHNICAL ROCK DESCRIPTION TERMINOLOGY

WEATHERING STATE

Fresh: no visible sign of weathering

Faintly weathered: weathering limited to the surface of major discontinuities.

Slightly weathered: penetrative weathering developed on open discontinuity surfaces but only slight weathering of rock material.

Moderately weathered: weathering extends throughout the rock mass but the rock material is not friable.

Highly weathered: weathering extends throughout rock mass and the rock material is partly friable.

Completely weathered: rock is wholly decomposed and in a friable condition but the rock and structure are preserved.

BEDDING THICKNESS

Description	Bedding Plane Spacing
Very thickly bedded	Greater than 2 m
Thickly bedded	0.6 m to 2 m
Medium bedded	0.2 m to 0.6 m
Thinly bedded	60 mm to 0.2 m
Very thinly bedded	20 mm to 60 mm
Laminated	6 mm to 20 mm
Thinly laminated	Less than 6 mm

JOINT OR FOLIATION SPACING

Description	Spacing
Very wide	Greater than 3 m
Wide	1 m to 3 m
Moderately close	0.3 m to 1 m
Close	50 mm to 300 mm
Very close	Less than 50 mm

GRAIN SIZE

Term	Size*
Very Coarse Grained	Greater than 60 mm
Coarse Grained	2 mm to 60 mm
Medium Grained	60 microns to 2 mm
Fine Grained	2 microns to 60 microns
Very Fine Grained	Less than 2 microns

Note: * Grains greater than 60 microns diameter are visible to the naked eye.

CORE CONDITION

Total Core Recovery (TCR)

The percentage of solid drill core recovered regardless of quality or length, measured relative to the length of the total core run.

Solid Core Recovery (SCR)

The percentage of solid drill core, regardless of length, recovered at full diameter, measured relative to the length of the total core run.

Rock Quality Designation (RQD)

The percentage of solid drill core, greater than 100 mm length, recovered at full diameter, measured relative to the length of the total core run. RQD varied from 0% for completely broken core to 100% for core in solid sticks.

DISCONTINUITY DATA

Fracture Index

A count of the number of discontinuities (physical separations) in the rock core, including both naturally occurring fractures and mechanically induced breaks caused by drilling.

Dip with Respect to Core Axis

The angle of the discontinuity relative to the axis (length) of the core. In a vertical borehole a discontinuity with a 90º angle is horizontal.

Description and Notes

An abbreviation description of the discontinuities, whether naturally occurring separations such as fractures, bedding planes and foliation planes, or mechanically induced features caused by drilling such as ground or shattered core and mechanically separated bedding or foliation surfaces. Additional information concerning the nature of fracture surfaces and infillings are also noted.

Abbreviations

JN	Joint	PL	Planar
FLT	Fault	CU	Curved
SH	Shear	UN	Undulating
VN	Vein	IR	Irregular
FR	Fracture	K	Slickensided
SY	Stylolite	PO	Polished
BD	Bedding	SM	Smooth
FO	Foliation	SR	Slightly Rough
CO	Contact	RO	Rough
AXJ	Axial Joint	VR	Very Rough
KV	Karstic Void		
MB	Mechanical Break		

Golder Associates

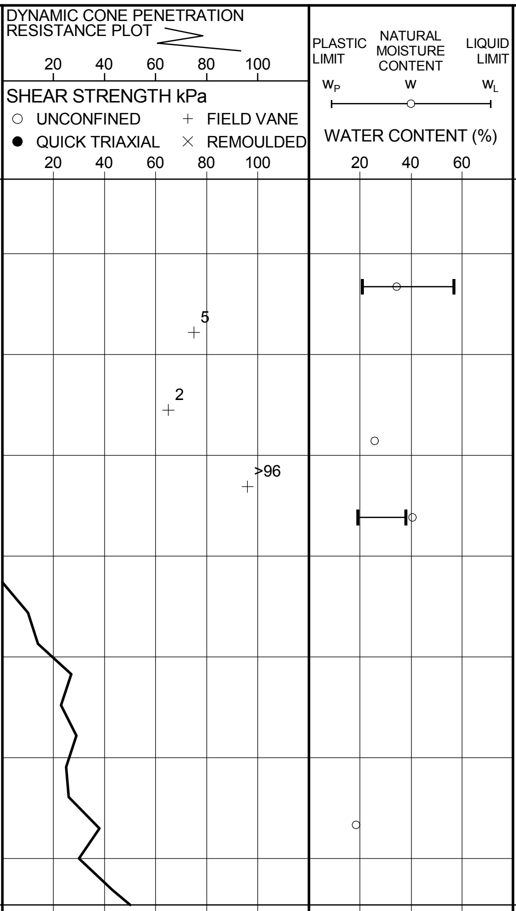
RECORD OF BOREHOLE No C1-1

SHEET 1 OF 1

METRIC

PROJECT 1531057
W.P. 5428-15-01
DIST
HWY 112
DATUM Geodetic
LOCATION N 5318327.9; E 378035.1 MTM ZONE
BOREHOLE TYPE Portable Equipment, HQ Casing, DCPT (Manual Hammer)
DATE May 30, 2016
ORIGINATED BY SA
COMPILED BY MR
CHECKED BY TWB

SOIL PROFILE		SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	REMARKS & GRAIN SIZE DISTRIBUTION (%)			
ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES			GR	SA	SI	CL
288.7	GROUND SURFACE									
0.0	Organic SILT, some sand, trace gravel, trace clay, trace roots and rootlets Firm Dark brown Moist	1A 1B	SS	8						
288.4 0.3	SILTY CLAY to CLAY, trace sand, silt laminations throughout Firm to very stiff Brown Moist				∇	288				
		2	SS	5			0	2	25	73
		3	SS	7		287				
		4	SS	20		286				
		5	SS	6		285				
		6	SS	5		284				
		7	SS	24						
283.7 5.0	SILT and SAND, trace clay Compact Grey Wet					283				
		8	SS	18		282	0	61	38	1
281.5		9	SS	25/0.15*						
7.2	END OF BOREHOLE SPLIT-SPOON REFUSAL									



NOTE:

1. Water level in open borehole at a depth of 0.8 m below ground surface (Elev. 287.9 m) upon completion of drilling.

2. An additional borehole was advanced about 1.0 m South of Borehole C1-1 to obtain a Shelby Sample, carry out vanes and a DCPT to confirm depth of refusal. DCPT refusal at a depth of 7.2 m, 50 blows for less than 0.01 m of penetration.

* Split-Spoon Bouncing

3. Geographic Coordinates:

Latitiude: 47.999704
Longitude: -80.018537

$+^3$, $\times^3$: Numbers refer to Sensitivity ○$^{3\%}$ STRAIN AT FAILURE

RECORD OF BOREHOLE No C1-2

SHEET 1 OF 2

METRIC

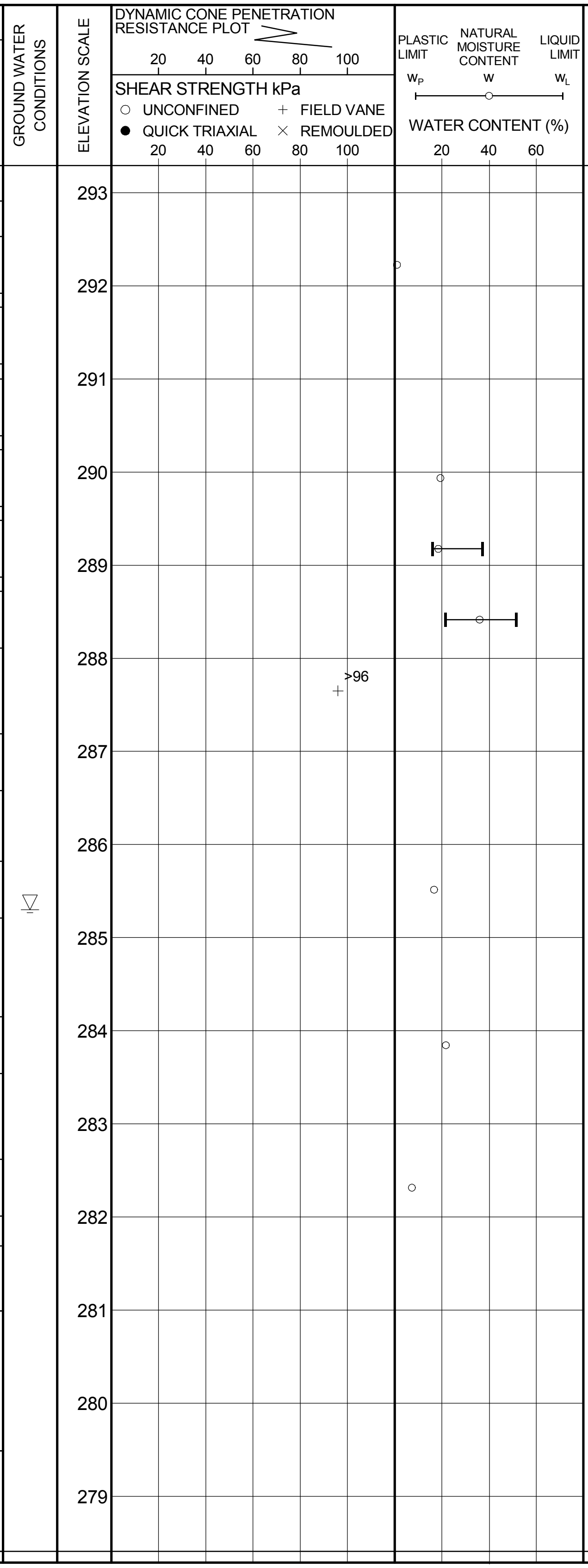
PROJECT	1531057		
W.P.	5428-15-01	LOCATION	N 5318321.6; E 378048.7 MTM ZONE
DIST		HWY	112
BOREHOLE TYPE	CME 55, 152 mm Diameter Solid Stem Augers, NW Casing, Wash bore		
DATUM	Geodetic	DATE	May 30, 2016
ORIGINATED BY	DM	COMPILED BY	MR
CHECKED BY	TWB		

SOIL PROFILE

ELEV DEPTH	DESCRIPTION
293.3	GROUND SURFACE
0.0	ASPHALT (100 mm)
0.1	Sand and gravel, some cobbles (FILL) Dense Brown Moist
291.4	Sand, some gravel, some silt, some cobbles (FILL)
291.1 2.2	Dense Brown Moist
290.3 3.0	Sandy clayey silt (FILL) Very stiff Brown Moist
289.6 3.7	Silt and sand, trace gravel (FILL) Loose Brown Moist
288.8 4.5	Silty clay with sand, trace gravel, trace organics (FILL) Firm Grey Moist
	CLAY, trace sand, trace organics Stiff Grey Moist
286.0 7.3	SILT and SAND, trace to some gravel Dense Grey Wet - Casing grinding at a depth of 9.1 m on inferred cobble
283.1 10.2	SAND and GRAVEL, trace silt Very dense Grey Wet - Casing grinding between depths of 11.4 m and 11.6 m
281.7 11.6	PORPHYRITIC BASALT (BEDROCK) Bedrock cored from depths of 11.6 m to 14.9 m. For bedrock coring details refer to Record of Drillhole C1-2.
278.4	

SAMPLES

NUMBER	TYPE	"N" VALUES	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR	SA	SI	CL
1	AS	-				
2	SS	49				
3A 3B	SS	43				
4	SS	20				
5	SS	4	9	40	47	4
6	SS	8				
7	SS	12				
8	SS	13				
9	SS	31				
10	SS	38	0	47	45	8
11	SS	62				
1	RC	REC 100%	RQD = 66%			
2	RC	REC 100%	RQD = 68%			
3	RC	REC 100%	RQD = 100%			



UNIT WEIGHT γ kN/m³

Continued Next Page

+³, ×³: Numbers refer to Sensitivity

○³% STRAIN AT FAILURE

RECORD OF BOREHOLE No C1-2

SHEET 2 OF 2

METRIC

PROJECT 1531057

W.P. 5428-15-01

LOCATION N 5318321.6; E 378048.7 MTM ZONE

ORIGINATED BY DM

DIST HWY 112

BOREHOLE TYPE CME 55, 152 mm Diameter Solid Stem Augers, NW Casing, Wash bore

COMPILED BY MR

DATUM Geodetic

DATE May 30, 2016

CHECKED BY TWB

SOIL PROFILE			SAMPLES					DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100 SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × REMOULDED 20 40 60 80 100	PLASTIC LIMIT W_P — NATURAL MOISTURE CONTENT W — LIQUID LIMIT W_L WATER CONTENT (%) 20 40 60	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV / DEPTH	DESCRIPTION *--- CONTINUED FROM PREVIOUS PAGE ---*	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE				
14.9	END OF BOREHOLE NOTE: 1. Water level in open borehole at 8.0 m below ground surface (Elev. 285.3 m) upon completion of drilling. 2. Geographic Coordinates: Latitiude: 47.999645 Longitude: -80.018355										

$+^3, \times^3$: Numbers refer to Sensitivity

$\bigcirc^{3\%}$ STRAIN AT FAILURE

PROJECT: 1531057

RECORD OF DRILLHOLE: C1-2

SHEET 1 OF 1

LOCATION: N 5318321.6 ;E 378048.7

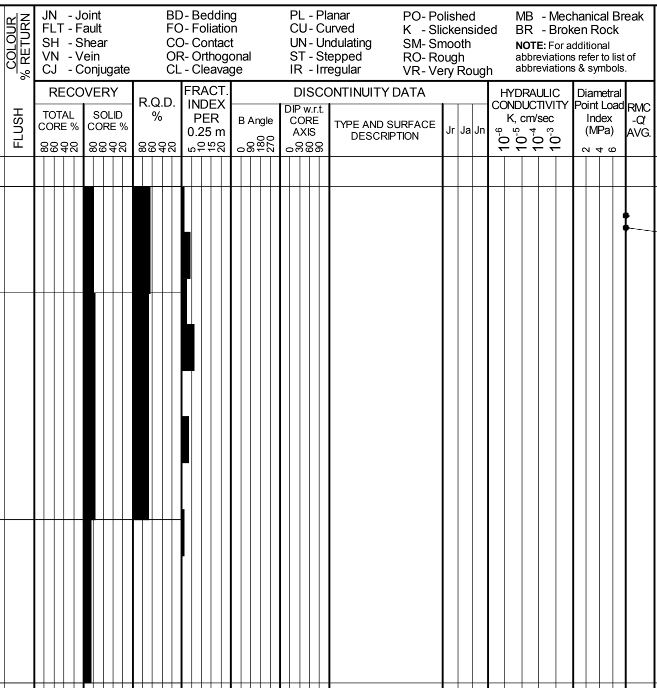
INCLINATION: -90° AZIMUTH: ---

DRILLING DATE: May 30, 2016
DRILL RIG: CME 55, NQ Coring
DRILLING CONTRACTOR: Landcore Drilling Inc.

DATUM: Geodetic

JN - Joint	BD - Bedding	PL - Planar	PO - Polished	MB - Mechanical Break
FLT - Fault	FO - Foliation	CU - Curved	K - Slickensided	BR - Broken Rock
SH - Shear	CO - Contact	UN - Undulating	SM - Smooth	NOTE: For additional abbreviations refer to list of abbreviations & symbols.
VN - Vein	OR - Orthogonal	ST - Stepped	RO - Rough	
CJ - Conjugate	CL - Cleavage	IR - Irregular	VR - Very Rough	

DEPTH SCALE METRES	DRILLING RECORD	DESCRIPTION	ELEV. DEPTH (m)	RUN No.	NOTES
		GROUND SURFACE	281.69		
	NW Casing	Fresh, massive, grey, fined grained matrix with medium to coarse grained white quartz and feldspar porphyries, non-porous, very strong PORPHYRITIC BASALT	11.60	1	15.0 MPa (Axial) 11.7 MPa
12					
13	NQ RC May 30, 2016			2	
14				3	
			278.41		
15		END OF DRILLHOLE	14.88		
16					
17					
18					
19					
20					
21					



DEPTH SCALE
1 : 50

Golder Associates

LOGGED: DM
CHECKED: TWB

RECORD OF BOREHOLE No C1-3

SHEET 1 OF 1

METRIC

PROJECT 1531057

W.P. 5428-15-01

LOCATION N 5318318.3; E 378071.3 MTM ZONE

ORIGINATED BY SA

DIST ______ HWY 112

BOREHOLE TYPE Portable Equipment, HQ Casing (Manual Hammer)

COMPILED BY MR

DATUM Geodetic

DATE May 31, 2016

CHECKED BY TWB

SOIL PROFILE			SAMPLES					DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100 SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × REMOULDED 20 40 60 80 100	PLASTIC LIMIT W_P NATURAL MOISTURE CONTENT W LIQUID LIMIT W_L WATER CONTENT (%) 20 40 60	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE				
290.2	GROUND SURFACE										
0.0	CLAYEY SILT, trace to some peat, trace gravel, trace organics Firm Grey/brown Moist		1	SS	7		290				
289.6 0.6	SILTY CLAY with silt laminations Firm Grey/brown Moist		2	SS	7	∇	289				
			3	SS	8						
288.1 2.1	Silty SAND, trace to some gravel Compact Grey Wet - Cobbles and boulders below 2.7 m		4	SS	40/0.27*		288				
287.0 3.2	PORPHYRITIC BASALT (BEDROCK) Bedrock cored from depths of 3.2 m to 4.6 m. For bedrock coring details refer to Record of Drillhole C1-3.		1	RC	REC 100%		287				RQD = 62%
			2	RC	REC 93%		286				RQD = 100%
285.6 4.6	END OF BOREHOLE										

NOTE:

1. Water level in open borehole at a depth of 0.8 m below ground surface (Elev. 289.4 m) upon completion of drilling.

* Split-Spoon Bouncing

2. Geographic Coordinates:

Latitiude: 47.999613
Longitude: -80.018053

$+^3, \times^3$: Numbers refer to Sensitivity $\bigcirc^{3\%}$ STRAIN AT FAILURE

PROJECT: 1531057

RECORD OF DRILLHOLE: C1-3

SHEET 1 OF 1

LOCATION: N 5318318.3 ;E 378071.3

INCLINATION: -90° AZIMUTH: ---

DRILLING DATE: May 31, 2016

DRILL RIG: Portable Equipment, NQ Coring

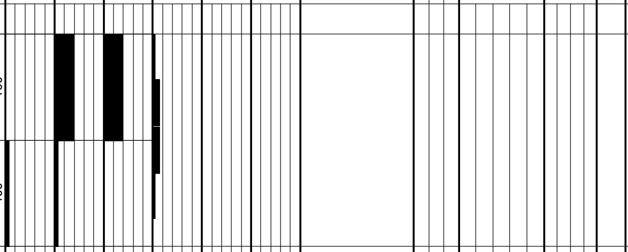
DRILLING CONTRACTOR: Landcore Drilling Inc.

DATUM: Geodetic

JN - Joint
FLT - Fault
SH - Shear
VN - Vein
CJ - Conjugate
BD - Bedding
FO - Foliation
CO - Contact
OR - Orthogonal
CL - Cleavage
PL - Planar
CU - Curved
UN - Undulating
ST - Stepped
IR - Irregular
PO - Polished
K - Slickensided
SM - Smooth
RO - Rough
VR - Very Rough
MB - Mechanical Break
BR - Broken Rock

NOTE: For additional abbreviations refer to list of abbreviations & symbols.

DEPTH SCALE METRES	DRILLING RECORD	DESCRIPTION	SYMBOLIC LOG	ELEV. DEPTH (m)	RUN No.	COLOUR % RETURN FLUSH	NOTES
		GROUND SURFACE		287.02			
4	NW Casing NQ RC May 31, 2016	Fresh, massive, grey, fined grained matrix with medium to coarse grained white quartz and feldspar porphyries, non-porous, very strong PORPHYRITIC BASALT	▨	3.20	1 2	100 100	UC = 120 MPa
		END OF DRILLHOLE		285.62 4.60			



5

6

7

8

9

10

11

12

13

GTA-RCK 018 S:\CLIENTS\MTO\HWY_112\02_DATA\GINT\HWY_112.GPJ GAL-MISS.GDT 24/03/17

DEPTH SCALE

1 : 50

Golder Associates

LOGGED: SA

CHECKED: TWB

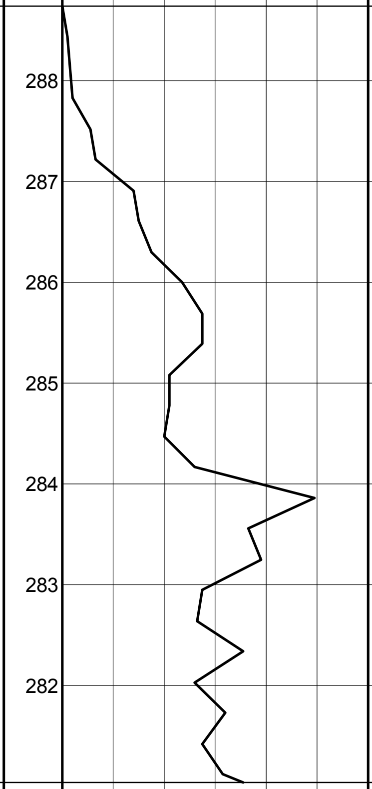
RECORD OF DCPT No C1-DCPT-1

SHEET 1 OF 1

METRIC

PROJECT 1531057
W.P. 5428-15-01
LOCATION N 5318325.1; E 378034.1 MTM ZONE
ORIGINATED BY SA
DIST
HWY 112
BOREHOLE TYPE Portable Equipment, Dynamic Cone Penetration Test (Manual Hammer)
COMPILED BY MR
DATUM Geodetic
DATE May 30, 2016
CHECKED BY MCK

SOIL PROFILE ELEV DEPTH	SOIL PROFILE DESCRIPTION	STRAT PLOT	SAMPLES NUMBER	SAMPLES TYPE	SAMPLES "N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100 SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × REMOULDED 20 40 60 80 100	PLASTIC LIMIT W_P NATURAL MOISTURE CONTENT W LIQUID LIMIT W_L WATER CONTENT (%) 20 40 60	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
288.7	GROUND SURFACE										
0.0	Dynamic Cone Penetration Test (DCPT)										
281.0 7.7	END OF DCPT REFUSAL TO FURTHER PENETRATION (71 Blows / 0.08 m) (HAMMER BOUNCING) NOTE: 1. Geographic Coordinates: Latitiude: 47.999678 Longitude: -80.018550										



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

APPENDIX B

Geotechnical Laboratory Test Results

TABLE B1

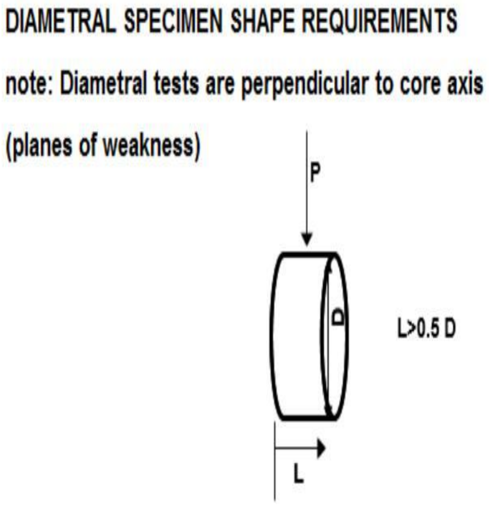
SUMMARY OF POINT LOAD TESTS ON ROCK SAMPLES

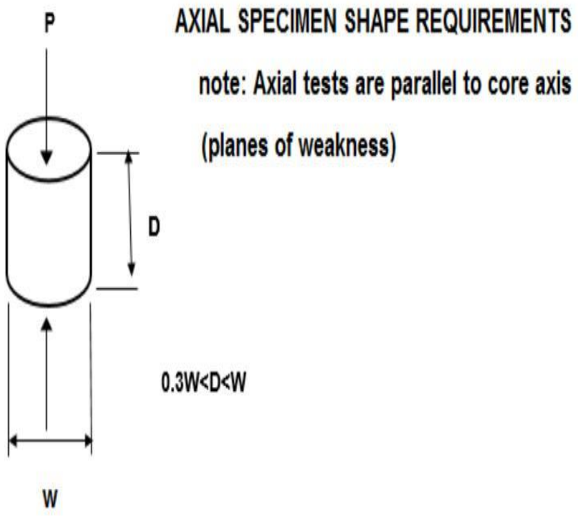
PROJECT NO. 1531057
DATE July, 2016

Borehole Number	Run Number	Sample Depth (m)	Sample Elevation (m)	Bedrock Description	Test Type	**Is (50mm)** (MPa)
C1-2	1	11.8	281.5	Porphyritic Basalt	Axial	15.0
C1-2	1	11.9	281.4	Porphyritic Basalt	Diametral	11.7

(1) Is_{50} x C (actual value will have to be confirmed by UCS testing), from ISRM ("Suggested Methods for Determining Point Load Strength", International Society for Rock Mechanics Commission on Testing Methods, Int. J. Rock. Mech. Min. Sci. and Geomechanical Abstr., Vol 22, No. 2 1985, pp. 51-60.

(2) Actual distance between point load cones at time of failure.

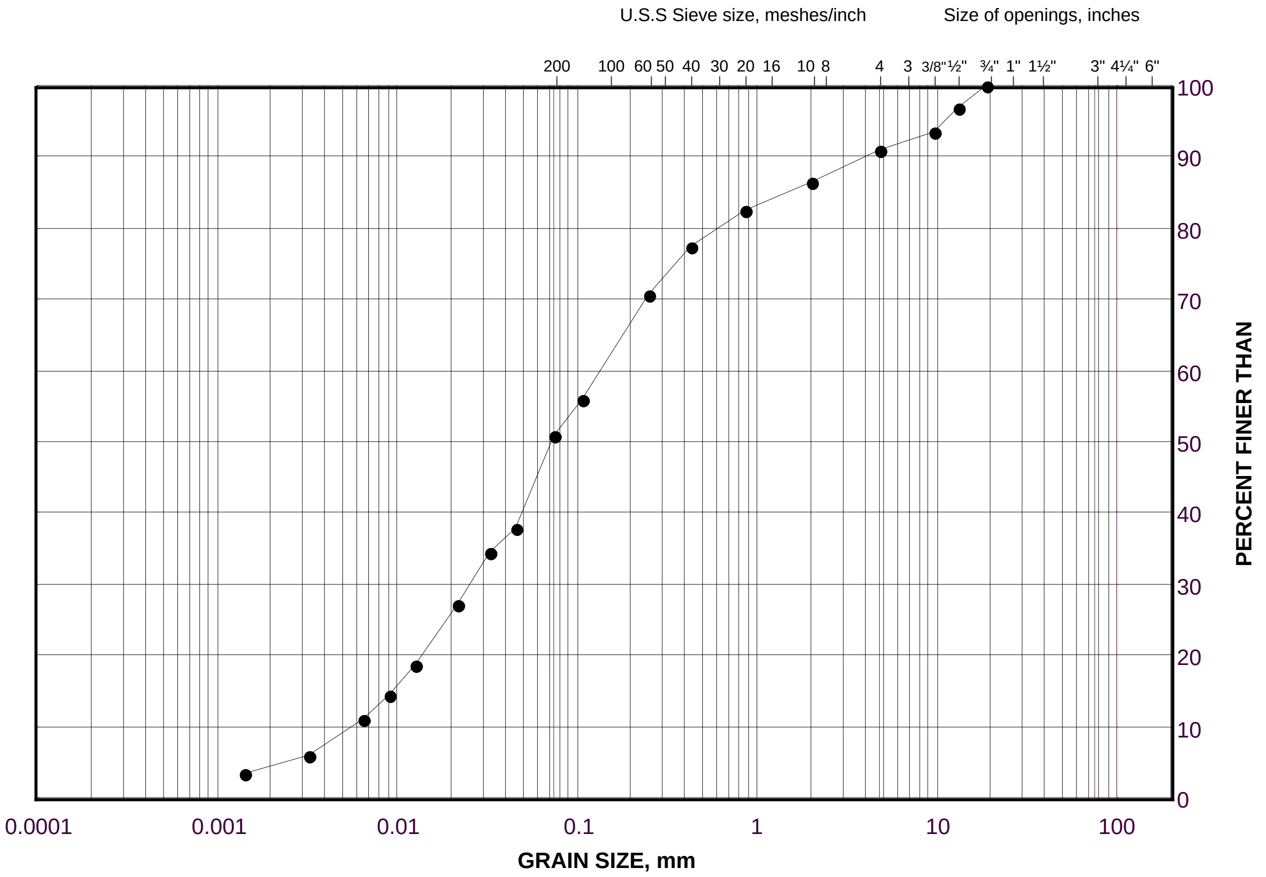




GRAIN SIZE DISTRIBUTION

Silt and Sand (FILL)

FIGURE B1



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

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	C1-2	5	289.9

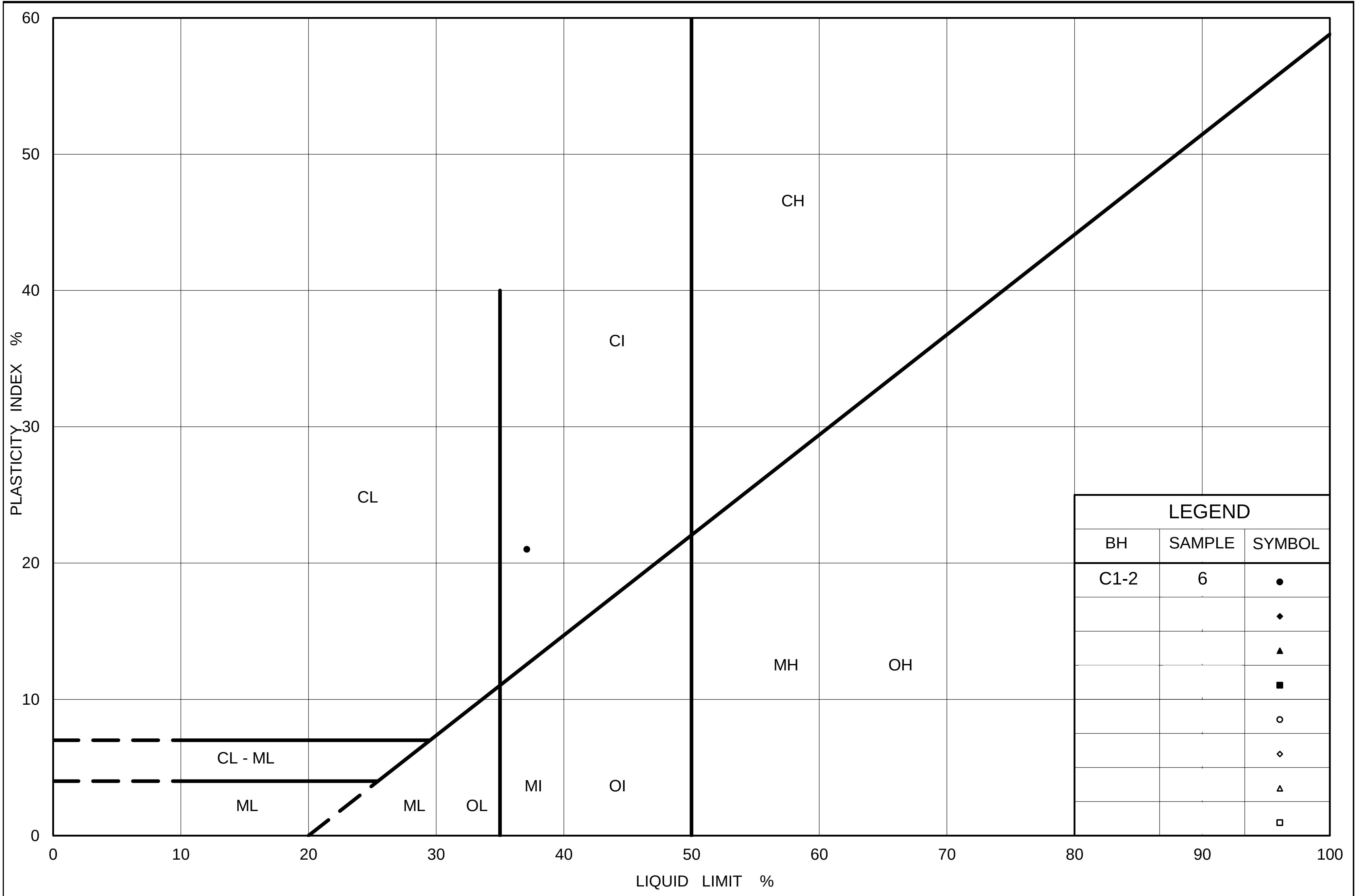
Project Number: 1531057

Checked By: CN

Golder Associates

Date: 11-Aug-16

Oct 75, FF-S-21



Ministry of Transportation

Ontario

PLASTICITY CHART
Silty Clay (FILL)

Figure No. B2

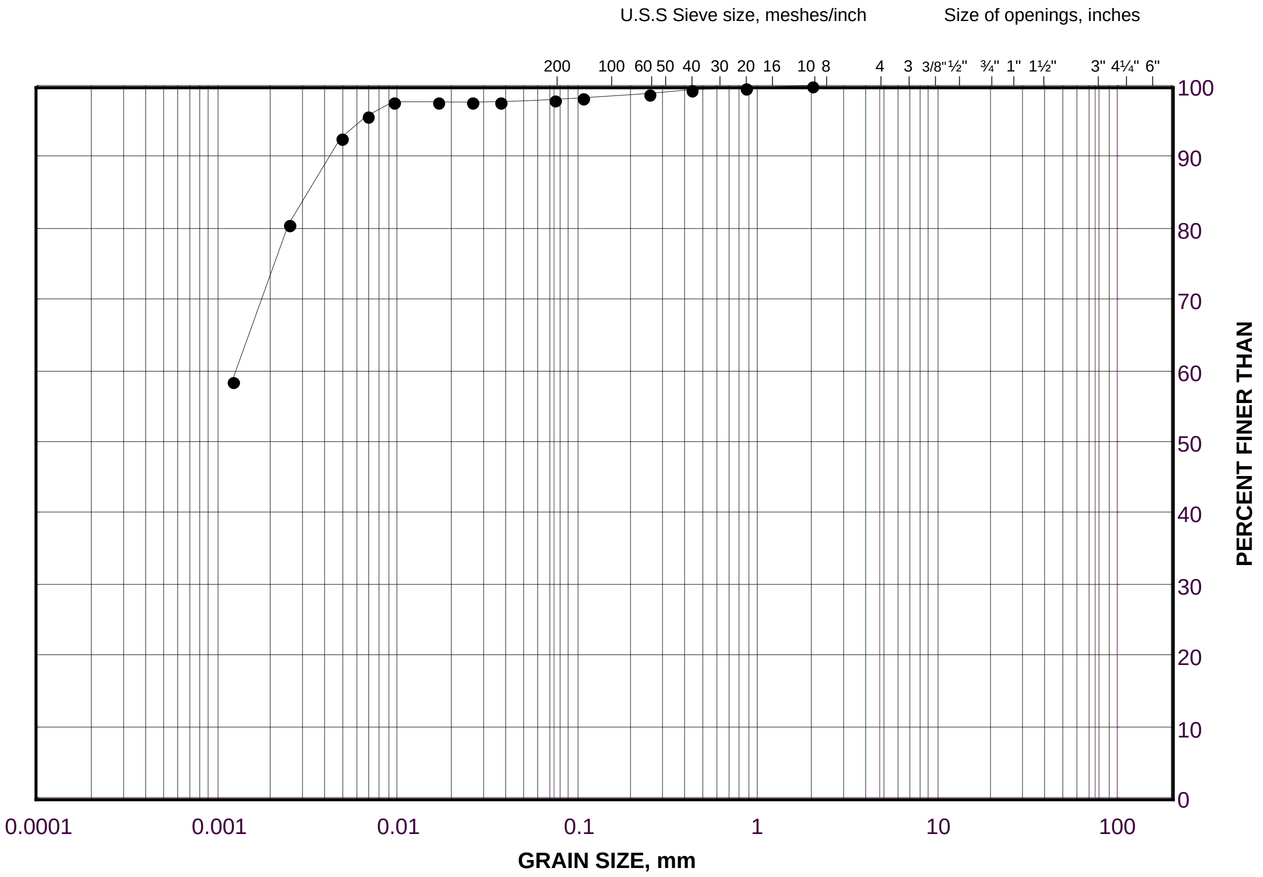
Project No. 1531057

Checked By: CN

GRAIN SIZE DISTRIBUTION

Clay

FIGURE B3



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

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	C1-1	2	287.6

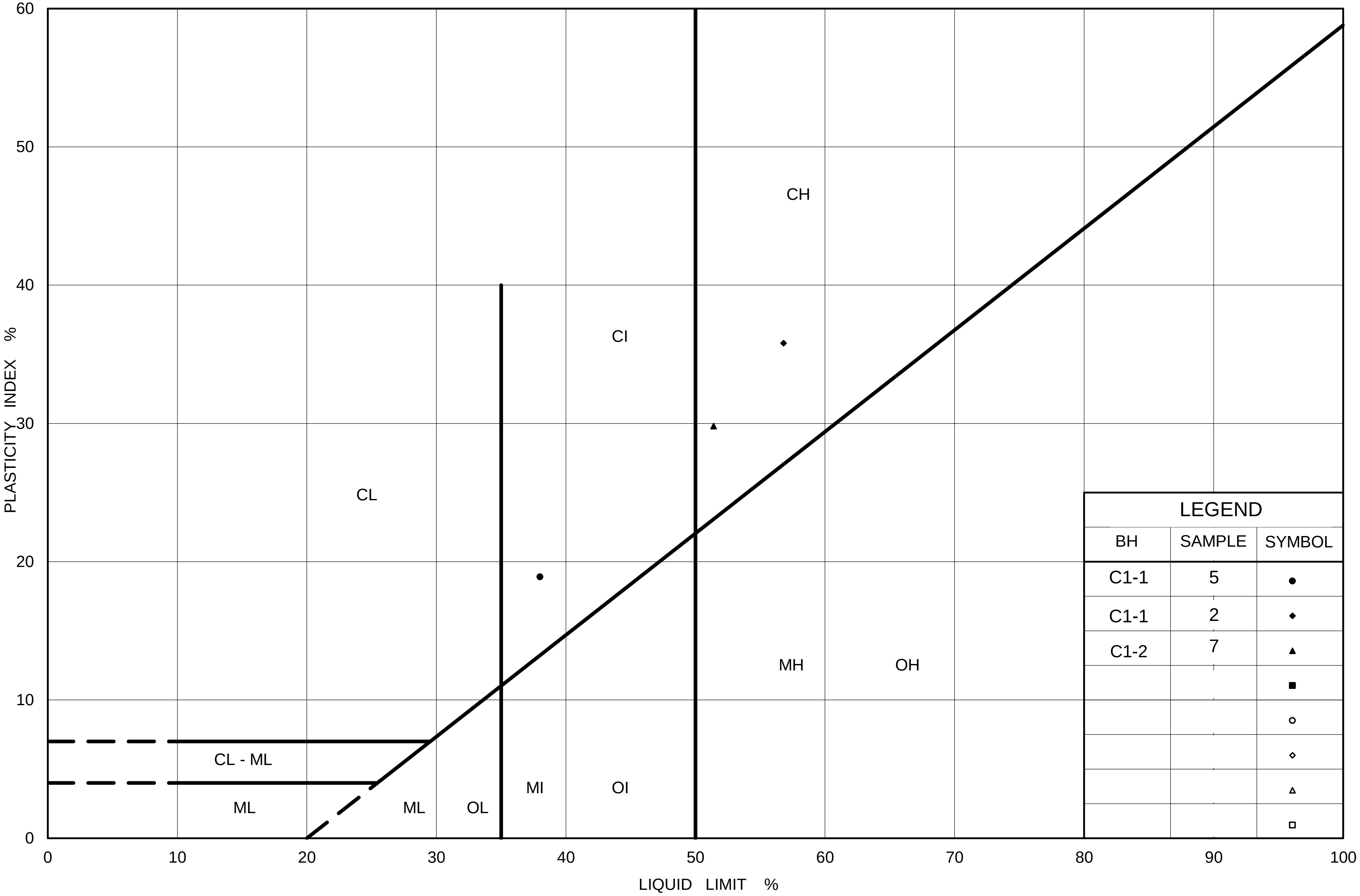
Project Number: 1531057

Checked By: CN

Golder Associates

Date: 11-Aug-16

Oct 75, FF-S-21



Ministry of Transportation

Ontario

PLASTICITY CHART
Silty Clay to Clay

Figure No. B4

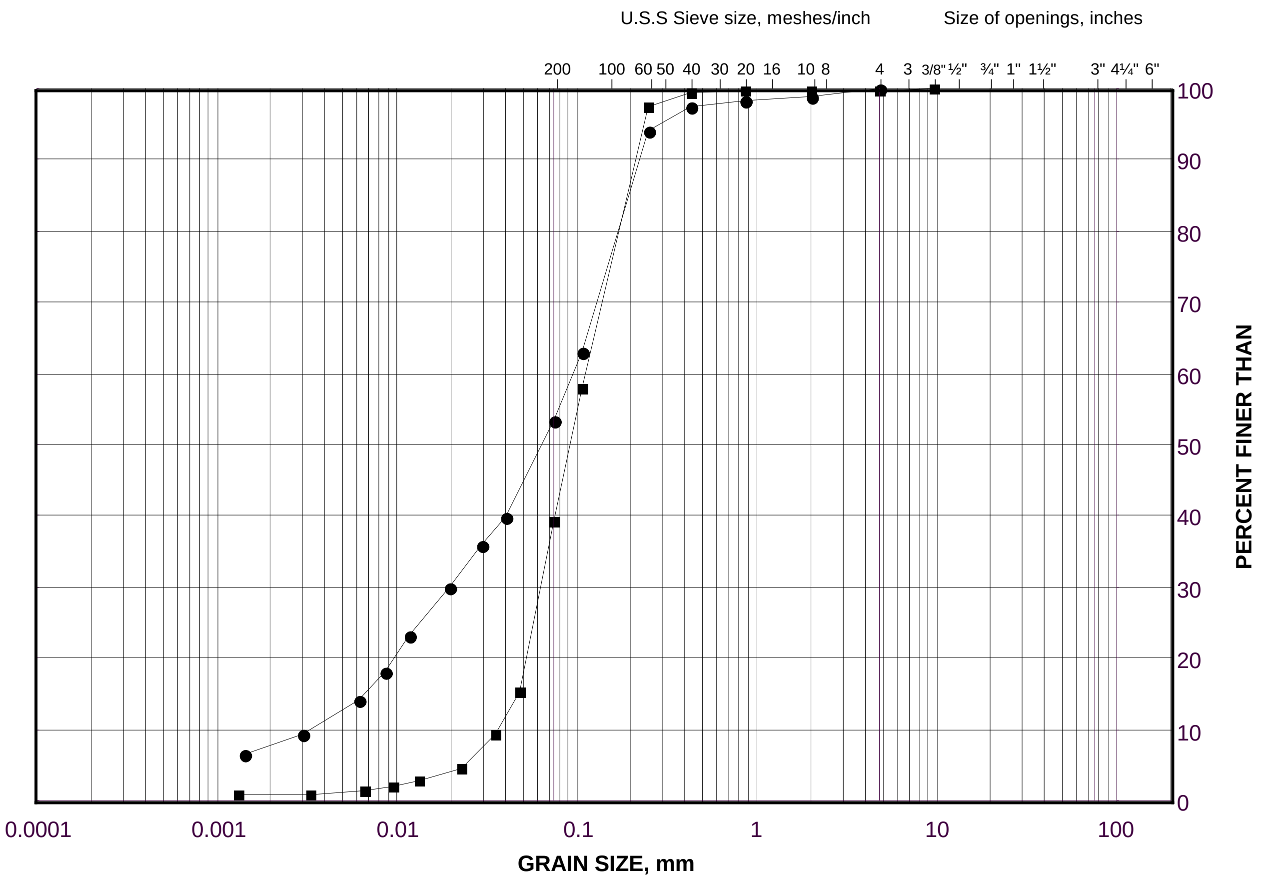
Project No. 1531057

Checked By: CN

GRAIN SIZE DISTRIBUTION

Silt and Sand

FIGURE B5



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

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	C1-2	10	283.8
■	C1-1	8	282.3

Project Number: 1531057

Checked By: CN

Golder Associates

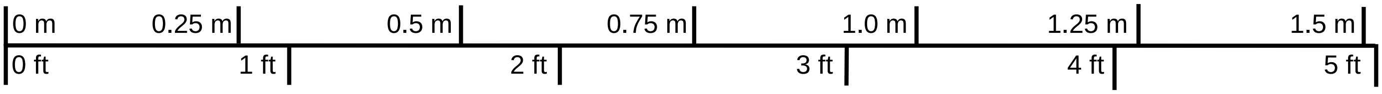
Date: 29-Jul-16

Borehole C1-2

Box 1: 11.60 m – 14.88 m

Borehole C1-3

Box 1: 3.20 m – 4.60 m



Scale

PROJECT

Detail Design for Replacement of Centreline
Culvert– Highway 112
WP 5427-15-01

TITLE

Bedrock Core Photographs – Highway 112
Borehole C1-2 and C1-3

Golder Associates

PROJECT No.	1531057		FILE No.	----
DESIGN	MCK	AUG 16	SCALE NTS	REV.
CADD	-- --			
CHECK	CN	AUG 16	**FIGURE B6**	
REVIEW	JMAC	AUG 16		

REVISION DATE: August 9, 2016 BY: MCK Project: 1531057

UNCONFINED COMPRESSION TEST (UC)

Figure B7

ASTM D7012

SAMPLE IDENTIFICATION

PROJECT NUMBER	1531057	SAMPLE NUMBER	Run 1
PROJECT NAME	MMM/5015-E-0003/LV Retainer NE	SAMPLE DEPTH, m	3.53-3.68
BOREHOLE NUMBER	C1-3	DATE:	2016-07-19

TEST CONDITIONS

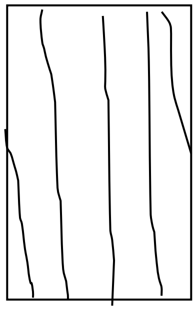
MACHINE SPEED, mm/min	N/A	TYPE OF SPECIMEN	Rock Core
DURATION OF TEST,min	>2 <15	L/D	2.21

SPECIMEN INFORMATION

SAMPLE HEIGHT, cm	9.39	WATER CONTENT, (specimen) %	0.04
SAMPLE DIAMETER, cm	4.26	UNIT WEIGHT, kN/m^3	26.76
SAMPLE AREA, cm^2	14.24	DRY UNIT WT., kN/m^3	26.75
SAMPLE VOLUME, cm^3	133.73	SPECIFIC GRAVITY	-
WET WEIGHT, g	365.02	VOID RATIO	-
DRY WEIGHT, g	364.87		

VISUAL INSPECTION

FAILURE SKETCH



TEST RESULTS

STRAIN AT FAILURE, %	N/A	COMPRESSIVE STRENGTH, MPa	120.3

REMARKS:

Checked By: CN

Golder Associates

APPENDIX C

Analytical Test Results

Your Project #: 1531057
Site Location: LV RETAINER NER ASSIGN#2, HWY 112
Your C.O.C. #: 565300-01-01

Attention:Chris Ng

Golder Associates Ltd
Mississauga - Standing Offer
6925 Century Ave
Suite 100
Mississauga, ON
CANADA L5N 7K2

Report Date: 2016/06/20
Report #: R4035051
Version: 1 - Final

CERTIFICATE OF ANALYSIS

MAXXAM JOB #: B6C1265
Received: 2016/06/13, 11:35

Sample Matrix: Water
Samples Received: 4

Analyses	Quantity	Date Extracted	Date Analyzed	Laboratory Method	Reference
Chloride by Automated Colourimetry	4	N/A	2016/06/16	CAM SOP-00463	EPA 325.2 m
Conductivity	4	N/A	2016/06/16	CAM SOP-00414	SM 22 2510 m
pH	4	N/A	2016/06/16	CAM SOP-00413	SM 4500H+ B m
Resistivity of Water	4	2016/06/14	2016/06/17	CAM SOP-00414	SM 22 2510 m
Sulphate by Automated Colourimetry	4	N/A	2016/06/16	CAM SOP-00464	EPA 375.4 m

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.

Maxxam Analytics is accredited 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.

Reference Method suffix “m” indicates test methods incorporate validated modifications from specific reference methods to improve performance.

Encryption Key

Please direct all questions regarding this Certificate of Analysis to your Project Manager.
Ema Gitej, Senior Project Manager
Email: EGitej@maxxam.ca
Phone# (905)817-5829
==
Maxxam has procedures in place to guard against improper use of the electronic signature and have the required "signatories", as per section 5.10.2 of ISO/IEC 17025:2005(E), signing the reports. For Service Group specific validation please refer to the Validation Signature Page.

Total Cover Pages : 1

RESULTS OF ANALYSES OF WATER

Maxxam ID		CNJ774	CNJ775	CNJ776	CNJ777			
Sampling Date		2016/06/12 11:00	2016/06/12 10:45	2016/06/12 07:45	2016/06/12 07:40			
COC Number		565300-01-01	565300-01-01	565300-01-01	565300-01-01			
	UNITS	**C1**	**C2**	**C3**	**C4**	**RDL**	**QC Batch**	**MDL**
Calculated Parameters								
Resistivity	ohm-cm	21000	7900	28000	7000		4538726	
Inorganics								
Conductivity	umho/cm	48	130	36	140	1.0	4541542	0.20
pH	pH	6.72	7.11	7.16	7.46		4541543	
Dissolved Sulphate (SO4)	mg/L	<1.0	<1.0	<1.0	<1.0	1.0	4541170	0.10
Dissolved Chloride (Cl)	mg/L	2.0	24	1.3	15	1.0	4541163	0.30

RDL = Reportable Detection Limit
QC Batch = Quality Control Batch

TEST SUMMARY

Maxxam ID: CNJ774
Sample ID: C1
Matrix: Water

Collected: 2016/06/12
Shipped:
Received: 2016/06/13

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride by Automated Colourimetry	KONE	4541163	N/A	2016/06/16	Alina Dobreanu
Conductivity	AT	4541542	N/A	2016/06/16	Yogesh Patel
pH	AT	4541543	N/A	2016/06/16	Yogesh Patel
Resistivity of Water		4538726	2016/06/17	2016/06/17	Automated Statchk
Sulphate by Automated Colourimetry	KONE	4541170	N/A	2016/06/16	Deonarine Ramnarine

Maxxam ID: CNJ775
Sample ID: C2
Matrix: Water

Collected: 2016/06/12
Shipped:
Received: 2016/06/13

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride by Automated Colourimetry	KONE	4541163	N/A	2016/06/16	Alina Dobreanu
Conductivity	AT	4541542	N/A	2016/06/16	Yogesh Patel
pH	AT	4541543	N/A	2016/06/16	Yogesh Patel
Resistivity of Water		4538726	2016/06/17	2016/06/17	Automated Statchk
Sulphate by Automated Colourimetry	KONE	4541170	N/A	2016/06/16	Deonarine Ramnarine

Maxxam ID: CNJ776
Sample ID: C3
Matrix: Water

Collected: 2016/06/12
Shipped:
Received: 2016/06/13

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride by Automated Colourimetry	KONE	4541163	N/A	2016/06/16	Alina Dobreanu
Conductivity	AT	4541542	N/A	2016/06/16	Yogesh Patel
pH	AT	4541543	N/A	2016/06/16	Yogesh Patel
Resistivity of Water		4538726	2016/06/17	2016/06/17	Automated Statchk
Sulphate by Automated Colourimetry	KONE	4541170	N/A	2016/06/16	Deonarine Ramnarine

Maxxam ID: CNJ777
Sample ID: C4
Matrix: Water

Collected: 2016/06/12
Shipped:
Received: 2016/06/13

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride by Automated Colourimetry	KONE	4541163	N/A	2016/06/16	Alina Dobreanu
Conductivity	AT	4541542	N/A	2016/06/16	Yogesh Patel
pH	AT	4541543	N/A	2016/06/16	Yogesh Patel
Resistivity of Water		4538726	2016/06/17	2016/06/17	Automated Statchk
Sulphate by Automated Colourimetry	KONE	4541170	N/A	2016/06/16	Deonarine Ramnarine

GENERAL COMMENTS

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

Package 1	9.3°C

Results relate only to the items tested.

QUALITY ASSURANCE REPORT

			Matrix Spike		SPIKED BLANK		Method Blank		RPD	
QC Batch	**Parameter**	**Date**	**% Recovery**	**QC Limits**	**% Recovery**	**QC Limits**	**Value**	**UNITS**	**Value (%)**	**QC Limits**
4541163	Dissolved Chloride (Cl)	2016/06/16	NC	80 - 120	101	80 - 120	<1.0	mg/L	0.024	20
4541170	Dissolved Sulphate (SO4)	2016/06/16	NC	75 - 125	104	80 - 120	<1.0	mg/L	4.3	20
4541542	Conductivity	2016/06/16			102	85 - 115	<1.0	umho/cm	1.9	25
4541543	pH	2016/06/16			101	98 - 103			1.2	N/A

N/A = Not Applicable

Matrix Spike: A sample to which a known amount of the analyte of interest has been added. Used to evaluate sample matrix interference.

Spiked Blank: A blank matrix sample to which a known amount of the analyte, usually from a second source, has been added. Used to evaluate method accuracy.

Method Blank: A blank matrix containing all reagents used in the analytical procedure. Used to identify laboratory contamination.

NC (Matrix Spike): The recovery in the matrix spike was not calculated. The relative difference between the concentration in the parent sample and the spiked amount was too small to permit a reliable recovery calculation (matrix spike concentration was less than 2x that of the native sample concentration).

Maxxam Job #: B6C1265
Report Date: 2016/06/20

Golder Associates Ltd
Client Project #: 1531057
Site Location: LV RETAINER NER ASSIGN#2, HWY 112
Sampler Initials: SA

VALIDATION SIGNATURE PAGE

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
A Bureau Veritas Group Company

IMMEDIATE TEST

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

CHAIN OF CUSTODY RECORD

Page 1 of 1

INVOICE TO:

Company Name: #1326 Golder Associates Ltd
Attention: Central Acct:1112, 1113, 1118
Address: 6925 Century Ave Suite 100
Mississauga ON L5N 7K2
Tel: (905) 567-4444 Fax: (905) 567-6561
Email: Catherine_Guiao@golder.com, Rachel_Benjamin@gol

REPORT TO:

Company Name:
Attention:
Address:
Tel: Fax:
Email:

PROJECT INFORMATION:

Quotation #: B52596
P.O. #:
Project: 1531057
Project Name: LV Retainer NER Assign#2
Site #: HWY112
Sampled By: S.A + D.M

Laboratory Use Only:

Maxxam Job #:	Bottle Order #:
	565300
COC #:	**Project Manager:**
C#565300-01-01	Ema Gitej

MOE REGULATED DRINKING WATER OR WATER INTENDED FOR HUMAN CONSUMPTION MUST BE SUBMITTED ON THE MAXXAM DRINKING WATER CHAIN OF CUSTODY

Regulation 153 (2011)
☐ Table 1 ☐ Res/Park ☐ Medium/Fine
☐ Table 2 ☐ Ind/Comm ☐ Coarse
☐ Table 3 ☐ Agri/Other ☐ **For RSC**
☐ Table ___

Other Regulations
☐ CCME ☐ Sanitary Sewer Bylaw
☐ Reg 558 ☐ Storm Sewer Bylaw
☐ MISA Municipality ______
☐ PWQO
☐ Other ______

Special Instructions

Include Criteria on Certificate of Analysis (Y/N)? ______

ANALYSIS REQUESTED (PLEASE BE SPECIFIC)

Turnaround Time (TAT) Required:
Please provide advance notice for rush projects

Regular (Standard) TAT: ☒
(will be applied if Rush TAT is not specified)
Standard TAT = 5-7 Working days for most tests.
Please note: Standard TAT for certain tests such as BOD and Dioxins/Furans are > 5 days - contact your Project Manager for details.

Job Specific Rush TAT (if applies to entire submission) ☐
Date Required: ______ Time Required: ______
Rush Confirmation Number: ______ *(call lab for #)*

	Sample Barcode Label	Sample (Location) Identification	Date Sampled	Time Sampled	Matrix	Field Filtered (please circle): Metals / Hg / Cr VI	Chloride & Sulphate	Conductivity, Resistivity and pH	# of Bottles	Comments
1		C1	June 12/16	11:00AM	Surface water		X	X	1	*Small puddle (~3" deep) NOT Flowing
2		C2	June 12/16	10:45AM	"		X	X	1	
3		C3	June 13/16	7:50AM	"		X	X	1	
4		C4	June 13/16	7:40AM	"		X	X	1	
5										
6										
7										
8										
9										
10										

Received in Sudbury

13-Jun-16 11:35
Ema Gitej
B6C1265
GK1 ENV-1107

* RELINQUISHED BY: (Signature/Print)	Date: (YY/MM/DD)	Time	RECEIVED BY: (Signature/Print)	Date: (YY/MM/DD)	Time	# jars used and not submitted
Shane Albert	16/06/13	11:35am	Bradley Frappier	2016/06/13	11:35	
			NUSRAT NAZ	2016/06/14	11:00	

Laboratory Use Only

Time Sensitive	Temperature (°C) on Receipt	Custody Seal	Yes	No
	9, 10, 9°C	Present		✓
		Intact		

* IT IS THE RESPONSIBILITY OF THE RELINQUISHER TO ENSURE THE ACCURACY OF THE CHAIN OF CUSTODY RECORD. AN INCOMPLETE CHAIN OF CUSTODY MAY RESULT IN ANALYTICAL TAT DELAYS.

SAMPLES MUST BE KEPT COOL (< 10° C) FROM TIME OF SAMPLING UNTIL DELIVERY TO MAXXAM

White: Maxxam Yellow: Client

2/5/4

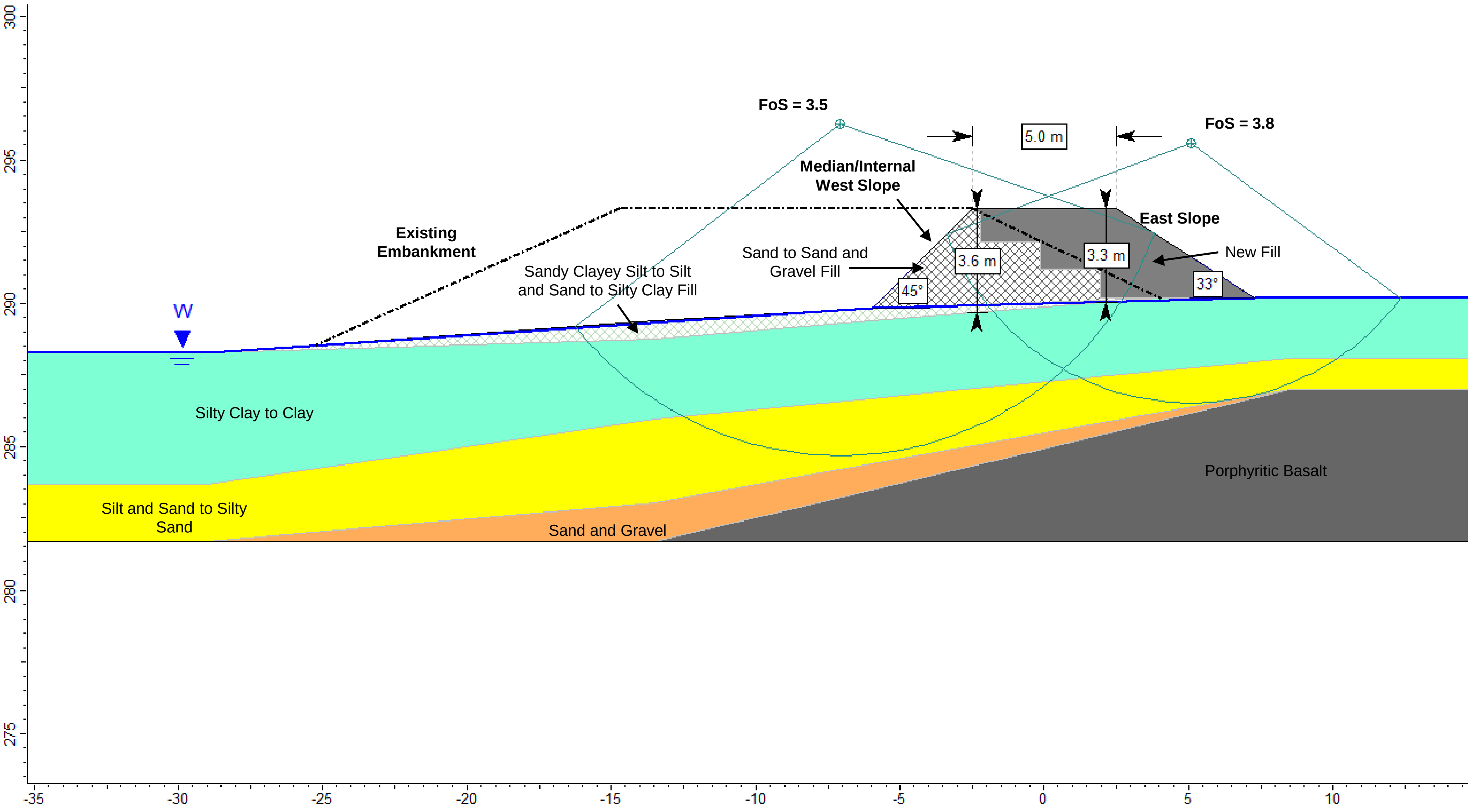
Maxxam Analytics International Corporation o/a Maxxam Analytics

APPENDIX D

Stability Analysis Figures

Stability Analysis: Median/Internal Side Slopes with 5 m Embankment Widening (East Slope)

Figure D1



Date: April 2017

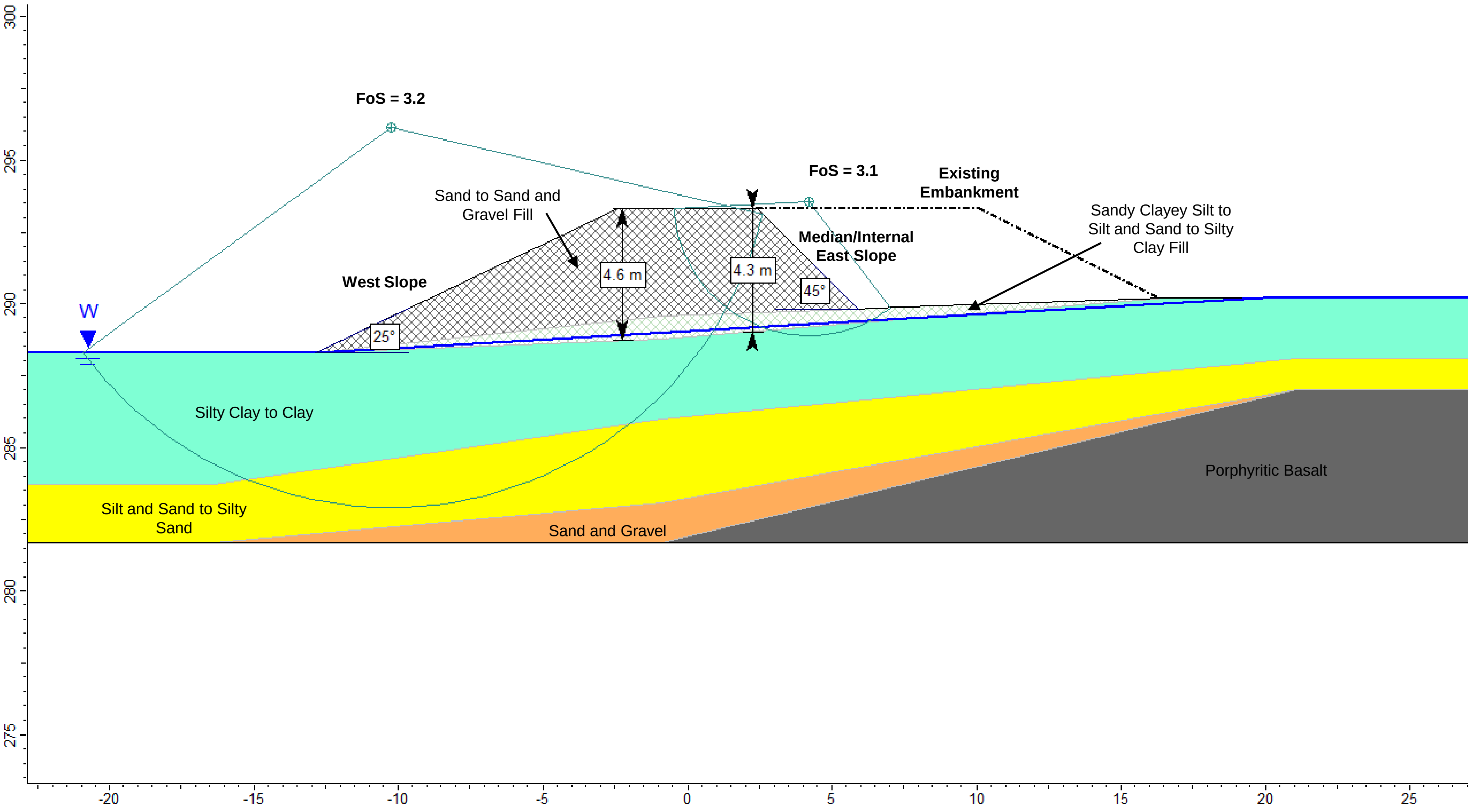
Project No: 1531057-1

Analysis By: MCK **Reviewed By:** CN

Golder Associates

Stability Analysis: Median/Internal Side Slopes with 5 m Embankment Widening (West Slope)

Figure D2

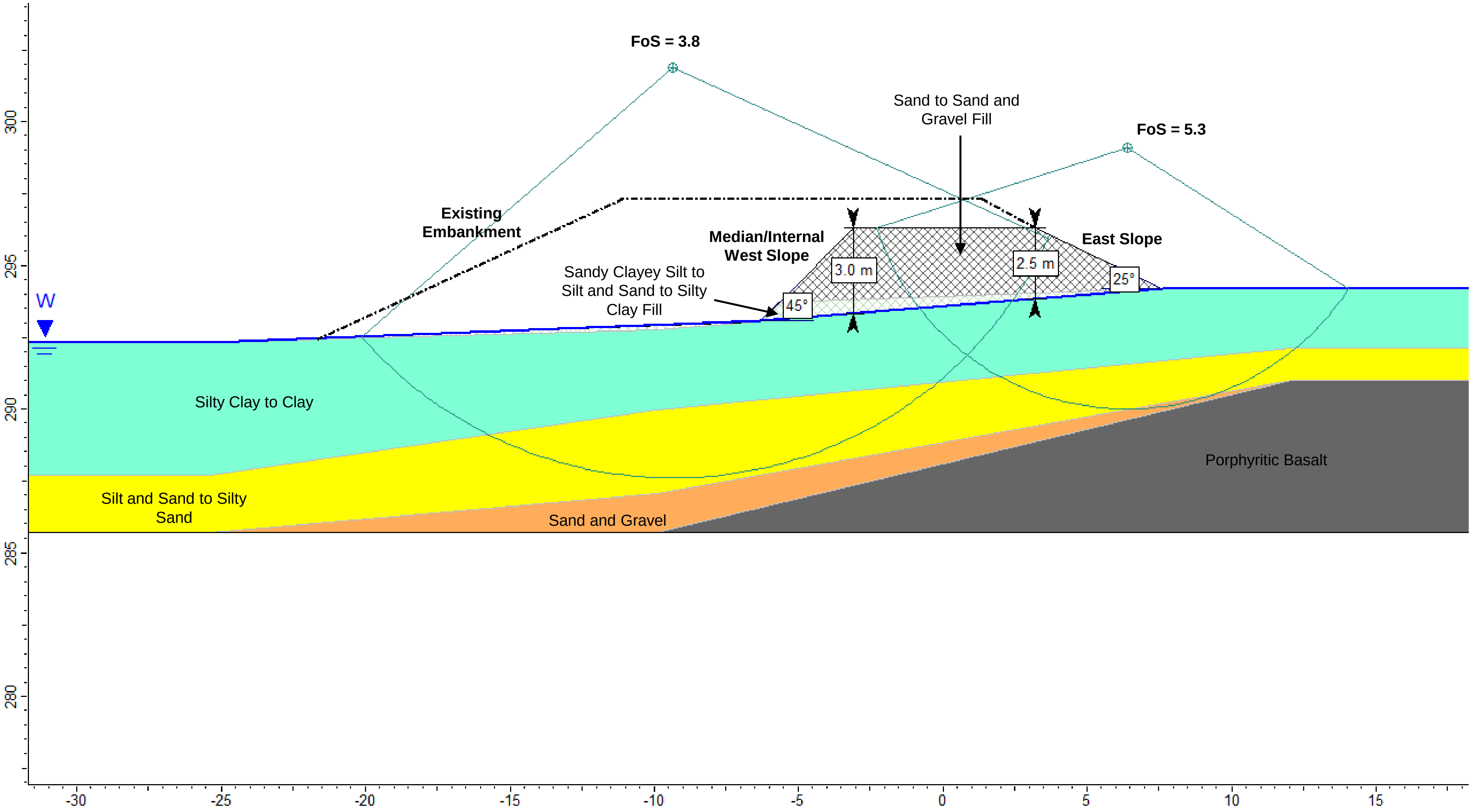


Date: April 2017

Project No: 1531057-1

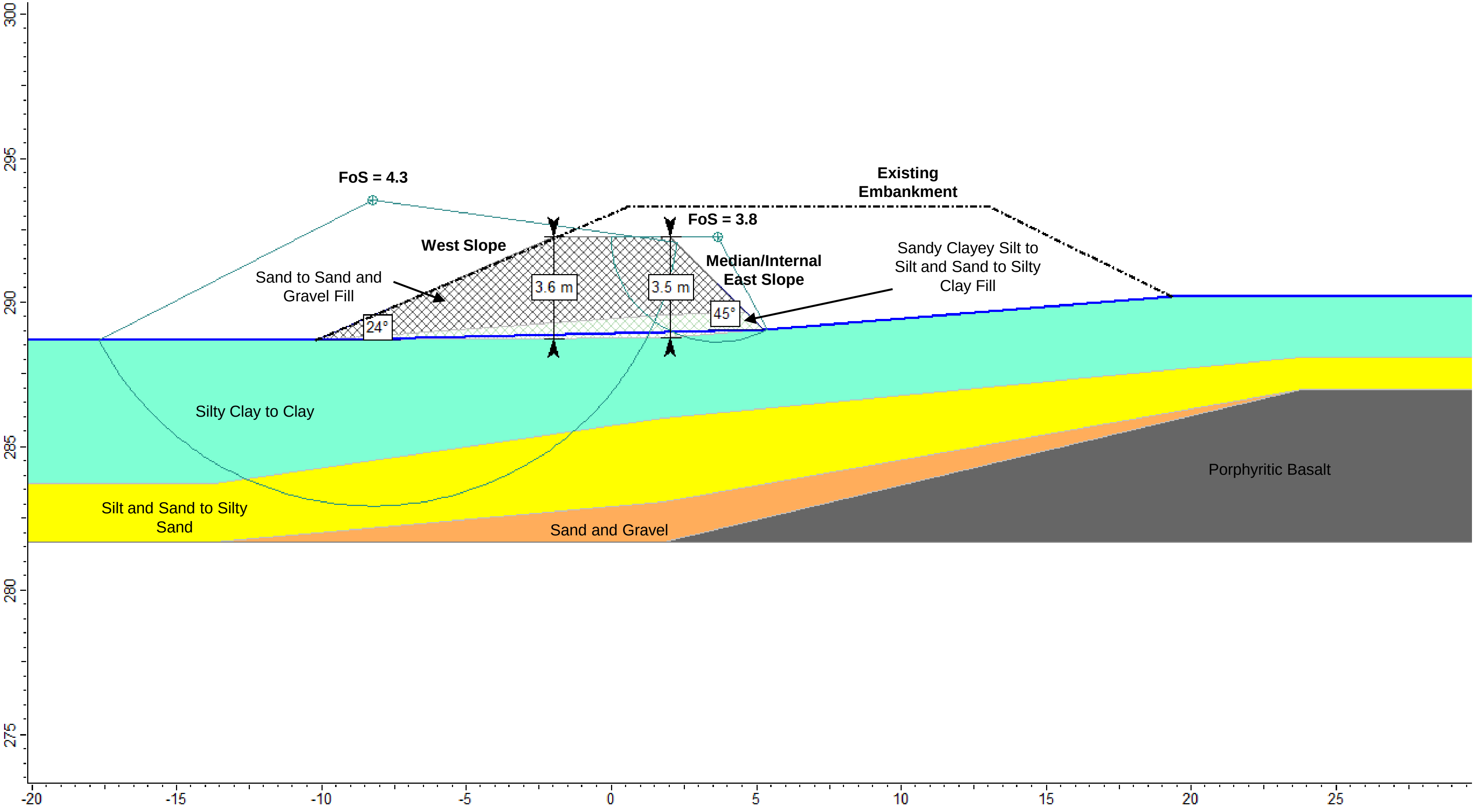
Analysis By: MCK **Reviewed By:** CN

Golder Associates


FoS = 3.8
Sand to Sand and Gravel Fill
FoS = 5.3
Existing Embankment
Median/Internal West Slope
East Slope
Sandy Clayey Silt to Silt and Sand to Silty Clay Fill
3.0 m
2.5 m
45°
25°
W
Silty Clay to Clay
Silt and Sand to Silty Sand
Sand and Gravel
Porphyritic Basalt
300
295
290
285
280
-30
-25
-20
-15
-10
-5
0
5
10
15

Stability Analysis: Median/Internal Side Slopes with Grade Lowering (West Slope)

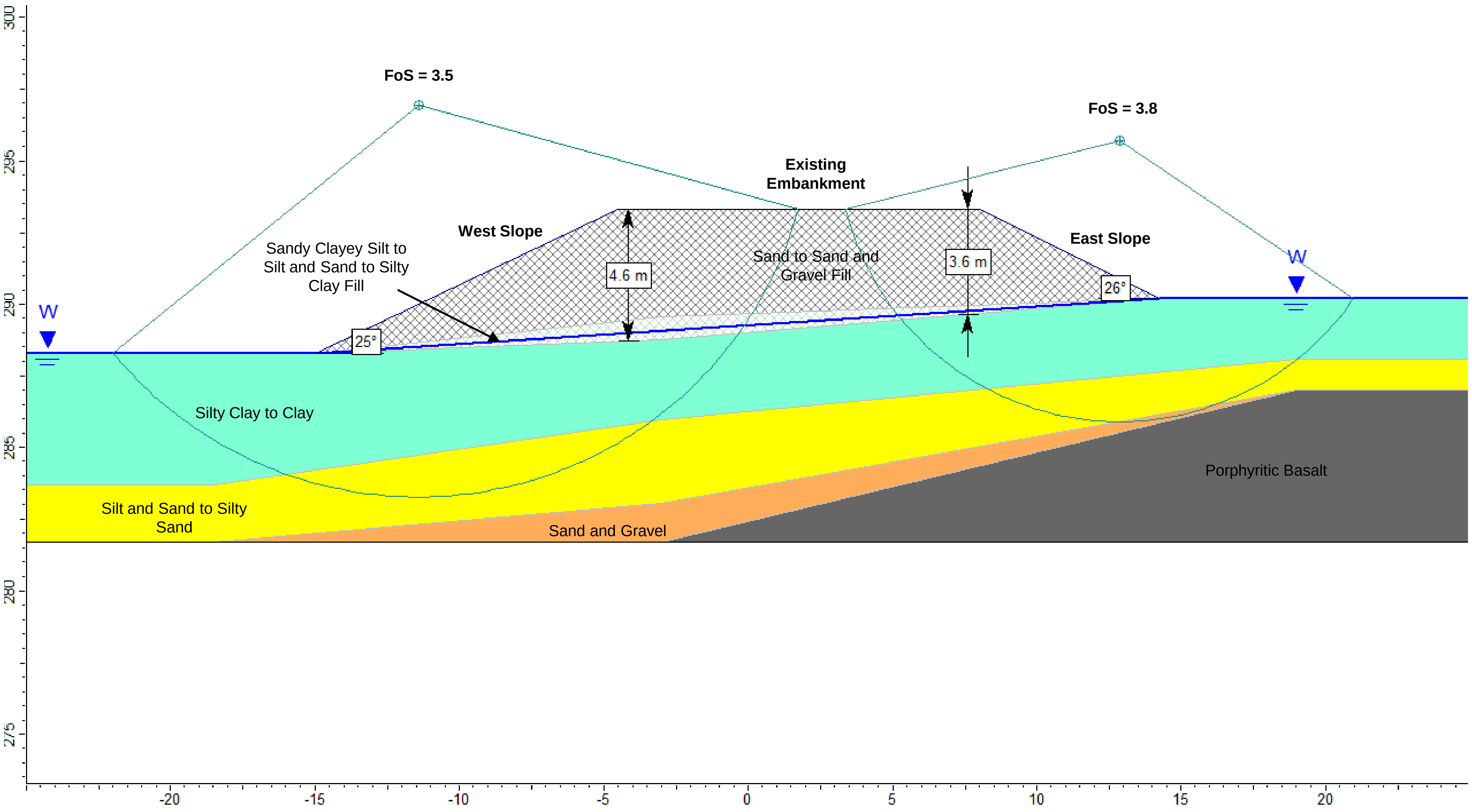
Figure D4



Date: April 2017

Project No: 1531057-1

Analysis By: MCK **Reviewed By:** CN


FoS = 3.5
FoS = 3.8
Existing Embankment
West Slope
East Slope
Sandy Clayey Silt to Silt and Sand to Silty Clay Fill
Sand to Sand and Gravel Fill
4.6 m
3.6 m
25°
26°
W
W
Silty Clay to Clay
Silt and Sand to Silty Sand
Sand and Gravel
Porphyritic Basalt
300
295
290
285
280
275
-20
-15
-10
-5
0
5
10
15
20

APPENDIX E

Non-Standard Special Provisions

WORKING SLAB – Item No.

Non-Standard Special Provision

At Culvert C1 (Highway 112 STA 13+234, Township of Pacaud), the subgrade soils may be susceptible to disturbance and loosening from construction traffic and ponded water.

Where precast box culverts or open footing culverts are used, if the culvert is not placed on the prepared subgrade within four hours of its inspection and approval, a concrete working slab of 20 MPa compressive strength at 28-days with minimum thickness of 100 mm, shall be placed on the foundation subgrade. A minimum 75 mm thick uncompacted levelling pad consisting of Granular 'A' material (OPPS.PROV 1010) or concrete fine aggregate (meeting the grading requirements specified in OPSS.PROV 1002) shall be provided on top of the concrete working slab.

BASIS OF PAYMENT

Payment at the lump sum contract price for this tender item shall be full compensation for all labour, equipment and materials for completion of the work.

END OF SECTION

As a global, employee-owned organisation with over 50 years of experience, Golder Associates is driven by our purpose to engineer earth's development while preserving earth's integrity. We deliver solutions that help our clients achieve their sustainable development goals by providing a wide range of independent consulting, design and construction services in our specialist areas of earth, environment and energy.

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