June 5, 2015

PRELIMINARY FOUNDATION INVESTIGATION AND DESIGN REPORT

MCINTYRE RIVER CULVERT
SITE NO. 48C-36/C
HIGHWAY 589, DISTRICT OF THUNDER BAY
UNSURVEYED TERRITORY
MINISTRY OF TRANSPORTATION, ONTARIO
G.W.P 6301-14-00

Submitted to:
Hatch Mott MacDonald
200 S. Syndicate Ave., Suite 301
Thunder Bay, ON
P7E 1C9

GEOCRES No. 52A-198

REPORT

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Golder Associates

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PRELIMINARY FOUNDATION INVESTIGATION REPORT
MCINTYRE RIVER CULVERT – SITE NO. 48C-36/C
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1.0 INTRODUCTION

Golder Associates Ltd. (Golder) has been retained by Hatch Mott MacDonald (HMM), on behalf of the Ministry of Transportation, Ontario (MTO) to provide preliminary foundation engineering services for the replacement of the McIntyre River culvert (Site No. 48C-36/C). The McIntyre River culvert is located in the Thunder Bay district on Highway 589 at STA 17+459 in the Township of Gorham approximately 11.4 km north of Highway 102. The key plan showing the general location of this section of Highway 589 and the location of the investigated area are shown on Drawing 1.

2.0 SITE DESCRIPTION

The existing culvert consists of a Steel Plate Corrugated Steel Pipe Arch Culvert (SPCSPA), the details of which (i.e., width, height, length, etc.) are summarized in Table 1 following the text of the report.

In general, the topography in this area is relatively flat with moderate to dense tree cover bordering the Highway right-of-way and the McIntyre River. At the culvert location, the highway grade is at Elevation 418.6 m, the invert is at about Elevation 413.3 m and the river flows in an easterly direction.

Surface conditions in the culvert area from the inspection report dated February 2014 and from the field investigation in December 2014 are shown on Photographs 1 to 4, attached.

3.0 INVESTIGATION PROCEDURES

The field work for this subsurface investigation was carried out on December 5 and 6, 2014, during which time a total of five boreholes (Boreholes MR-1 to MR-5) were advanced. Boreholes MR-1, MR-4 and MR-5 were advanced using track-mounted CME-55 drill rig and Boreholes MR-2 and MR-3 were advanced using a truck-mounted CME 55 drill rig. Both drill rigs were supplied by and operated by George Downing Estate Drilling Ltd. of Grenville-Sur-La-Rouge, Quebec.

Boreholes MR-1, MR-4 and MR-5 were advanced at the toe of slope near the culvert inlet/outlet using 108 mm inside diameter hollow stem augers. Boreholes MR-2 and MR-3 were advanced from the existing highway platform using 108 mm inside diameter hollow stem augers and/or NW casing and wash boring techniques. Soil samples were obtained in the boreholes at 0.75 m and 1.5 m intervals of depth using 50 mm outer diameter split-spoon samplers driven by an automatic hammer, in accordance with the Standard Penetration Test (SPT) procedures (ASTM D1586). Field vane shear tests were conducted in cohesive soils for determination of undrained shear strengths (ASTM D2573) using MTO Standard 'N' size vanes. The groundwater levels in the open boreholes were observed during the drilling operations as described on the Record of Borehole sheets in Appendix A. The boreholes were backfilled upon completion in accordance with Ontario Regulation 903 Wells (as amended).

The field work was supervised on a full-time basis by a member of Golder's technical staff who located the boreholes in the field, arranged for the clearance of underground services; supervised the drilling and sampling operations, logged the boreholes; and examined and cared for the soil samples. The soil samples were identified in the field, placed in labelled containers and transported to Golder's geotechnical laboratory in Sudbury for further examination and laboratory testing. Index and classification testing consisting of water content determinations, grain size distributions, and Atterberg limits tests were carried out on selected soil samples. The geotechnical laboratory testing was completed according to MTO LS standards.

A sample of the river water was obtained during the field investigation, using appropriate sampling protocols 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 as-drilled borehole locations and ground surface elevations were measured and surveyed by member of our technical staff, referenced to the highway centerline and existing culvert and converted into Northing/Easting on the plan drawing. The ground surface elevation of the highway centerline was obtained from the profile drawing provided by MTO (BC7355895.dwg). The MTM NAD83 northing and easting coordinates, ground surface elevations referenced to geodetic datum and borehole depths at each borehole locations are presented on the Record of Borehole sheets in Appendix A and summarized below.

Borehole Number	MTM NAD83 Northing (m)	MTM NAD83 Easting (m)	Ground Surface Elevation (m)	Borehole Depth (m)
MR-1	5382090.6	352310.3	416.1	9.0
MR-2	5382088.0	352323.5	418.6	11.6
MR-3	5382099.5	352329.0	418.5	14.4
MR-4	5382094.6	352337.1	417.3	1.5
MR-5	5382107.7	352339.8	415.3	10.2

4.0 SITE GEOLOGY AND SUBSURFACE CONDITIONS

4.1 Regional Geology

Based on the Northern Ontario Engineering Geology Terrain (NOEGTS)[1] mapping, the subsoils in the vicinity of the McIntyre River culvert site generally consist of glaciolacustrine plain deposits, comprised primarily of clayey subsoils.

Based on geological mapping by the Ministry of Northern Development and Mines (Map 2542)[2], the site is underlain by bedrock of the Archean Era, comprised of mafic to intermediate metavolcanic rocks, consisting of basaltic and andesitic flows, tuffs and breccia's, chert, iron formation, minor metasedimentary and intrusive rocks, related migmatites.

4.2 Subsurface Conditions

The detailed subsurface soil and groundwater conditions encountered in the boreholes and the results of in situ and laboratory testing are given on the Record of Borehole sheets contained in Appendix A. The results of geotechnical laboratory testing are contained in Appendix B. The results of the in situ field tests (i.e., SPT 'N' values and undrained shear strengths from field vanes) as presented on the Record of Borehole sheets and in Section 4 are uncorrected. The stratigraphic boundaries shown on the boreholes records and on the interpreted

[1] Northern Ontario Engineering Geology Terrain Study. Ontario Geological Society Electronic Mapping. Map 52ANW

[2] Ministry of Northern Development of Mines. Bedrock Geology of Ontario – West Central Sheet, Ontario Geological Survey – Map 2542.

stratigraphic section on Drawing 1 are inferred from non-continuous sampling and, therefore, represent transitions between soil types rather than exact planes of geological change. The subsoil conditions will vary between and beyond the borehole locations.

Subsoil Conditions

In summary, the subsoil conditions encountered at the site consist of asphalt and granular fill (for boreholes through the embankment) or cohesive silty clay fill overlying an organic silt to organic silty clay deposit (for the boreholes advanced at the toe of the embankment). The fill or organic deposits overly a cohesive deposit of clayey silt to clay, which is underlain in one instance by a deposit of sand and gravel. A more detailed description of the soil deposits and groundwater conditions encountered in the boreholes is provided in the following table and sections.

Deposit/Layer Description	Boreholes	Thickness (m)	Elevation (m)	N Values (blows) / Shear Strength (kPa) Consistency or Relative Density	Laboratory Testing
Asphalt	MR-2, MR-3	0.065 – 0.075	418.6 – 418.5	n/a	n/a
(FILL)[1] sand to sand and gravel, some cobbles, trace to some silt, trace clay, brown, frozen to wet	MR-2, MR-3	5.5	418.5 – 418.4	N = 9 – 25 [2] **Loose to Compact**	w = 9% – 33 % 1 – MH and 2 – M (Fig. B1)
(FILL) silty clay, with organics, some gravel, some sand, reddish brown to dark brown, frozen	MR-1, MR-5	0.8	416.1 – 415.3	N = 17 – 24 **Frozen**	w = 20 %
Organic Silt to Organic Silty Clay, trace to some sand, dark brown, wet	MR-1, MR-5	1.6 – 2.6	415.3 – 414.5	N = 2 – 6 s_u = 40 **Soft to Firm**	w = 33% – 39% 2 – MH (Fig. B2) 2 – AL (Fig. B3) w_p = 26% – 31% w_l = 47% – 54% I_p = 21% – 23% OC = 5% - 7%
Clayey Silt to Clay[3], trace sand, trace organics, reddish brown, wet	MR-1, MR-2, MR-3 and MR-5	MR-3 = 8.0, All other boreholes terminated in this deposit	413.0 – 412.7	N = 2 – 11 s_u = 38 – >100[4] **Firm to Very Stiff**	w = 30% – 67% 7 – MH (Fig. B4) 7 – AL (Fig. B5) w_p = 16% – 29% w_l = 32% – 79% I_p = 16% – 50% OC = 1%
Sand and Gravel, trace to some silt, grey, wet	MR-3	0.8	404.9	N = 37 **Dense**	w = 10% 1 – M (Fig. B6)

Where:

N = SPT 'N'-value; number of blows for 0.3 m of penetration

s_u = Undrained Shear Strength from in situ field 'N'-vane (kPa)

w = Natural Moisture Content (%)

MH = Combined Sieve and Hydrometer analysis

M = Sieve analysis

AL = Atterberg Limits Test

w_p = Plastic Limit (%)

w_l = Liquid Limit (%)

I_p = Plasticity Index (%)

OC = Organic Content (%)

Notes:

[1] Cobbles were encountered throughout the fill deposit in Boreholes MR-2 and MR-3 ranging from 120 mm to 225 mm diameter, requiring NW casing and NQ coring techniques to advance the boreholes through this deposit.

Borehole MR-4 was terminated at Elevation 415.8 m within the fill deposit likely due to the presence of cobbles and/or boulders, and an additional Borehole, MR-5, was advanced on the adjacent side of the river.

[2] In the granular fill, two SPT 'N'-values of 41 blows to 87 blows per 0.3 m of penetration were noted, however these are likely indicative of the frozen state of the material and are not representative. Further, one SPT 'N'-value of 20 blows for 0.05 m of penetration was noted, likely indicative of the presence of a cobble and/or boulder.

[3] A clayey silt to silt seam was encountered in Borehole MR-2 within the clayey silt to clay deposit at approximately 9.1 m depth. The natural moisture content measured on a sample of the clayey silt to silt seam is about 31 per cent. The result of a grain size distribution test completed on the clayey silt to silt seam within the clayey silt to clay deposit is shown on Figure B4. One Atterberg limit test was carried out on a sample of the clayey silt to silt seam within the clayey silt to clay deposit yielded a liquid limit of about 22 per cent, a plastic limit of about 16 per cent and a corresponding plasticity index of about 5 as shown on Figure B5. Based on the results of the Atterberg limit test the material is classified as clayey silt to silt of slight plasticity.

[4]Typically, the deposit is stiffer in the boreholes drilled through the existing embankment.

Refusal

Refusal to further casing and split spoon penetration was encountered in Borehole MR-3, corresponding to Elevation 404.1 m.

Groundwater Conditions

All boreholes were noted to be dry upon completion of drilling. The river ice level was measured at Elevation 414.6 m on December 4, 2014. Groundwater and river water levels in the area are subject to seasonal fluctuations and variations due to precipitation events.

5.0 CLOSURE

The field drilling program was carried out under the supervision of Mr. Cody Walter and Mr. Mathew Riopelle, under the overall direction of Mr. David Muldowney, P.Eng. This Preliminary Foundation Investigation Report was prepared by Mr. Adam Core, E.I.T., and Ms. Sarah E.M. Poot, P.Eng. and Associate, provided a technical review of the report. Mr. Fintan J. Heffernan, P.Eng., the Designated MTO Foundations Contact of Golder conducted an independent quality control review and technical audit of this report.

Report Signature Page

GOLDER ASSOCIATES LTD.

Adam Core, E.I.T.
Geotechnical Engineering Intern

LICENSED PROFESSIONAL ENGINEER
S. E. M. POOT
90471921
6/5/15
PROVINCE OF ONTARIO

Sarah E.M. Poot, P.Eng.
Geotechnical Engineer, Associate

REGISTERED PROFESSIONAL ENGINEER
F. J. HEFFERNAN
06/05/15
PROVINCE OF ONTARIO

Fintan J. Heffernan, P.Eng
Designated MTO Foundations Contact

AC/SEMP/FJH/kp

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PART B

PRELIMINARY FOUNDATION DESIGN REPORT
MCINTYRE RIVER CULVERT – SITE NO. 48C-36/C
HIGHWAY 589, DISTRICT OF THUNDER BAY
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6.0 DISCUSSION AND ENGINEERING RECOMMENDATIONS

6.1 General

This section of the report provides preliminary foundation design recommendations for the proposed replacement of the McIntyre River culvert. The recommendations are based on interpretation of the factual data obtained from the boreholes advanced during this subsurface investigation.

The discussion and recommendations presented are intended to provide the designers with sufficient information to assess the feasible foundation alternatives and to carry out the preliminary design of the culvert replacement. Further investigation and analysis may be required during detail design, once the configuration of the proposed culvert and replacement strategy is finalized, to confirm and expand on the preliminary foundation recommendations provided in this report.

Where comments are made on construction, they are provided to highlight those aspects that could affect the future detail design of the project, and for which special provisions may be required in the Contract Documents. Those requiring information on the aspects of construction should make their own interpretation of the factual information provided as such interpretation may affect equipment selection, proposed construction methods, scheduling and the like.

It is assumed that the replacement culvert is to be of similar dimensions, alignment and invert elevation to that of the existing culvert. In addition, it is assumed that there will be no embankment grade raises or widening as part of the overall rehabilitation of Hwy 589.

6.2 Foundation

6.2.1 Foundation Options

The existing McIntyre River culvert is located on Highway 589 at STA 17+459 located approximately 11.4 km north of the Highway 102 junction in the Township of Gorham. The highway embankment is constructed of granular fill material and is approximately 5.3 m high. The existing culvert consists of a Steel Plate Corrugated Steel Pipe Arch (SPCSPA) culvert the details of which (i.e., width, height, length, etc.) are summarized in Table 1 following the text of the report.

Based on discussions with HMM and preliminary General Arrangement (GA) drawings provided, we understand that a pre-cast concrete box and pre-cast slab supported on sheet-pile abutments replacement culverts are being considered at this site. Open-footing concrete culverts (cast-in-placed or pre-cast footings) should also be considered a feasible alternative for the replacement culvert. Given that the existing culvert is a SPCSPA culvert, circular or arch culverts consisting of concrete or corrugated steel could be considered a feasible option at this culvert site. The advantages and disadvantages associated with pre-cast box culvert, open footing culvert and circular or arch pipe culvert options as well as the pre-cast slab on sheet-pile abutment option are summarized in Table 2. From a foundation perspective, an open footing concrete culvert sufficiently wide to handle the flow is preferred at this site. Other culvert types may be preferred due to construction staging or other considerations such as ease of construction associated with the pre-cast sections.

6.2.2 Foundation Elevations and Frost Protection

6.2.2.1 Box Culvert

It is not necessary to found a box culvert at the standard depth for frost protection purposes, as box structures are tolerant of small magnitudes of movement related to freeze-thaw cycles, should these occur. Recommended foundation elevation and foundation conditions for a replacement box culvert are provided in Table 3. We recommend that the replacement culvert be founded on the native deposit of firm to very stiff clayey silt to clay.

6.2.2.2 Open Footing Culvert

Strip footings for open footing culvert extensions 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 Depths for Northern Ontario). In addition, the footings should extend below any existing fill and below the organic silt to organic silty clay deposit.

6.2.2.3 Pipe Culvert

It is not necessary to found a circular pipe culvert at the standard depth for frost protection purposes, as these structures are tolerant of small magnitudes of movement related to freeze-thaw cycles, should these occur. Recommended foundation elevation and foundation conditions for a replacement circular pipe culvert are provided in Table 3. We recommend that the replacement culvert be founded on the native deposit of firm to very stiff clayey silt to clay.

6.2.2.4 Pre-Cast Concrete Slab on Sheet-Pile Abutments

It is expected that the sheet-pile abutments will penetrate well below the frost depth to bear within the dense sand and gravel deposit. Therefore, the foundations should not be subject to frost induced heave. However, adhesion of the subsoils to the sheet-pile walls through the depth of the frost penetration zone would have to be considered in the overall assessment of the sheet-pile depths in order to resist uplift (heave). An estimate of the additional depth required to resist uplift can be provided at the detail design stage if this is culvert replacement option is selected. The installation of the sheet-piles for culvert construction may be impeded by the presence of cobbles (up to 225 mm in size) within the fill material. It may be necessary to excavate and replace the existing fill material in the areas of sheet-pile installation in a series of limited length and narrow trenches as discussed further in Section 6.4.1.

6.2.3 Geotechnical Resistance

6.2.3.1 Box Culvert

A box culvert, placed on the properly prepared subgrade and/or properly placed granular pad/backfill at or below the founding elevation identified in Table 3, should be based on the recommended factored geotechnical axial resistance at Ultimate Limit States (ULS) and geotechnical reaction at Serviceability Limit States (SLS), for 25 mm of settlement, as provided in Table 3.

The factored geotechnical axial resistance at ULS and geotechnical reaction at SLS are dependent on the foundation size, configuration and applied loads; the geotechnical resistance/reaction should, therefore, be reviewed if the culvert width or founding elevation differs from that given in Table 3.

The geotechnical resistance/reaction provided in Table 3 are based on loading applied perpendicular to the base of the culvert; where applicable, inclination of the load should be taken into account in accordance with Section 6.7.4 and Section C6.7.4 of the Canadian Highway Bridge Design Code (CHBDC 2006) and it's Commentary.

The loading on the foundation soils below the culvert and the associated settlements at the culvert location will be governed by the design height of the overlying and adjacent embankment fill, however it is assumed that no grade raise is planned. It is recommended that the structural engineer exercise caution when utilizing the values of the geotechnical axial resistance at SLS (as provided in Table 3) in the design of the culverts and that consideration be given to the sequence and staging of construction, particularly if a grade raise or widening is applicable as the settlement under the culvert as a result of soil loading (not culvert loading) may govern.

6.2.3.2 Open Footing Culvert

Strip footings placed on the properly prepared subgrade, at or below the founding elevation recommended in Table 3, should be designed based on the factored geotechnical resistance at ULS and geotechnical reaction at SLS (for 25 mm of settlement), provided in Table 3. These recommendations are based on the assumed footing width of 0.6 m.

The factored geotechnical axial resistance at ULS and geotechnical reaction at SLS are dependent on the foundation size, configuration and applied loads; the geotechnical resistance/reaction should, therefore, be reviewed if the culvert strip footing width or founding elevation differs from that given in Table 3.

The geotechnical resistance/reaction provided in Table 3 are based on loading applied perpendicular to the base of the footings; where applicable, inclination of the load should be taken into account in accordance with Section 6.7.4 and Section 6.7.4 of the CHBDC and it's Commentary.

The loading on the foundation soils below the culvert and the associated settlements at the culvert location will be governed by the design height of the overlying and adjacent embankment fill, however it is assumed that no grade raise is planned. It is recommended that the structural engineer exercise caution when utilizing the values of the geotechnical axial resistance at SLS (as provided in Table 3) in the design of the culverts and that consideration be given to the sequence and staging of construction, particularly if a grade raise or widening is applicable as the settlement under the culvert as a result of soil loading (not culvert loading) may govern.

6.2.3.3 Pre-Cast Slab and Sheet-Pile Abutments

The sheet-piles should be driven to the dense sand and gravel at or below the founding elevation recommended in Table 3, and should be designed based on the factored geotechnical resistances at ULS and unit geotechnical reaction at SLS (for 25 mm of settlement), provided in Table 3. The unit factored geotechnical axial resistance and reaction provided in Table 3 are primarily a function of the toe resistance developed within the dense sand and gravel deposit. These values do not included downdrag forces, which may need to be considered if the grade is raised or the embankments are widened.

At detail design, additional boreholes should be advanced to a suitable penetration depth within the sand and gravel deposit if the pre-cast slab and sheet-pile abutment culvert option is selected. The recommended geotechnical resistance/reaction should be reviewed once more information becomes available in terms of the final sheet-piling configuration.

6.2.4 Resistance to Lateral Loads / Sliding Resistance

Resistance to lateral forces / sliding resistance between the base of the box culvert and granular bedding material or base of the strip footing and subgrade soil should be calculated in accordance with Section 6.7.5 of the CHBDC. Table 4 provides the coefficients of friction between the base of the culvert/footing and potential interface materials.

6.2.5 Settlement

Given that the embankment grade raise or widening is not required as part of the culvert replacement, and therefore the existing native soils will not experience additional load, settlement of the culvert will be less than 25 mm.

For the subsurface conditions and the proposed embankments height up to about 5.3 m above the existing ground surface, granular fill embankments at this site will be stable at side slopes of 2 Horizontal to 1 Vertical (2H:1V) or flatter. This assumes that there is no grade raise or platform widening at the culvert site.

6.3 Lateral Earth Pressures

The lateral earth pressures acting on the side walls (or head/wing walls if required) of the culvert will depend on the type and method of placement of backfill materials, the nature of 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 culverts and any wing or head walls. It should be noted that these design recommendations and parameters are applicable to 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 requirements of OPSS.PROV 1010 (Aggregates) Granular 'A' or Granular 'B' Type I, II or III but with less than 5 per cent passing the 200 sieve (0.075 mm) should be used as backfill behind the culvert walls, and on top of the culvert for a thickness of up to 300 mm. Backfill should be placed in a maximum of 200 mm loose lift thickness. Weep holes should be installed to provide positive drainage of the granular backfill. Compaction (including type of equipment, target densities, etc.) should be carried out in accordance with OPSS.PROV 501 (Compacting).

- The granular fill may be placed either in a zone with the width equal to at least 2.4 m behind the back of the walls for a restrained wall (see Figure C6.20(a) of the Commentary to the CHBDC), or within the wedge shaped zone defined by a line drawn at 1.5 horizontal to 1 vertical (1.5 H:1V) extending up and back from the rear face of the base of the walls for an unrestrained wall (see Figure C6.20(b) of the Commentary to the CHBDC).

- The following parameters (unfactored) may be used to calculate the lateral earth pressures acting on the culvert or sheet-piles:

Material Type	Internal Angle of Friction (ϕ)	Unit Weight	Coefficients of Static Lateral Earth Pressure	
			At-Rest, K_o	Active, K_a
Granular 'A' Fill	35°	22 kN/m^3	0.43	0.27
Granular 'B' Type II Fill	35°	21 kN/m^3	0.43	0.27
Granular 'B' Type I or III Fill	32°	21 kN/m^3	0.47	0.30
Native Clayey Silt to Clay	27°	17 kN/m^3	0.55	0.37
Native Sand and Gravel	30°	20 kN/m^3	0.50	0.33

If the structure(s) allow for lateral yielding, active earth pressures may be used in the design of the structure(s). If the structure(s) do not allow lateral yielding, at-rest earth pressures should be assumed for design. The movement to allow active pressures to develop within the backfill, and thereby assume an unrestrained structure, may be taken as presented in Table C6.6 of the Commentary to the CHBDC.

6.4 Construction Considerations

6.4.1 Temporary Roadway Protection

The temporary excavation for the culvert will be made through the existing embankment granular fill and into native soils, which are comprised of soft to firm organic silt and organic silty clay (in some instances) and firm to very stiff clayey silt to clay. All excavations must be carried out in accordance with Ontario Regulation 213, Ontario Occupational Health and Safety Act for Construction Projects (as amended). The granular fills and native soils are considered to be Type 3 soil above the groundwater table and Type 4 soil below. Temporary open-cut excavations in Type 3 soils should remain stable if side slopes are formed no stepper than 1 Horizontal to 1 Vertical (1H:1V). In Type 4 soils, the side sloes should be formed no steeper than 3H:1V.

Temporary protection support systems may be required along the highway to facilitate construction staging and maintain traffic during culvert replacement work. The temporary support systems could consist of either driven sheet-piling or soldier piles and lagging where H-piles would be driven to a suitable depth and horizontal lagging installed as the excavation proceeds. Support to the system could be in the form of struts and walers and rakers or anchors. Where required, temporary protection systems should be designed and constructed in accordance with OPSS.PROV 539 (Temporary Protection Systems). Temporary excavation support systems should be designed to Performance Level 2 for any excavation adjacent to existing roadways.

The installation of the sheet-piles for culvert construction and/or temporary shoring may be impeded by the presence of cobbles (up to 225 mm in size) within the fill material. It may be necessary to excavate and replace the existing fill material in the areas of sheet-pile installation in a series of limited length and narrow trenches. In general, the narrowest suitable excavator bucket should be used. The replacement fill could consist of excavated fill material or imported granular material provided that 100 per cent of the material passes the 75 mm size and less than 5 per cent passes the 75 µm size. Sieving, sorting or picking of large particles from the excavated spoil pile may be required if the excavated material is re-used. Alternatively, imported Granular 'A' or Granular 'B' Type I, II or III may be used as backfill for the excavated trench. Excavation and replacement should be carried out on the same day to avoid leaving any trench open overnight. Consideration should be given to include an NSSP in the contract to address obstructions. A sample NSSP should be provided at the detail design stage, if required depending on final culvert design and construction staging.

6.4.2 Excavation and Replacement Below Culvert

Prior to placement of any bedding material, granular fill or concrete, all organics (including peat, topsoil and mixed organic soil materials such as organic silt and organic silty clay) and any softened soils, should be sub-excavated from below the plan limits of the proposed works. Based on the depth to the base of the fill and base of the organic silt to organic silty clay deposits, the excavation for box and pipe culverts would have to extend to the same elevation as for the open footing culvert. However, in the case of the box, pre-cast open footings and pipe culvert option, backfill to the founding level could be placed below water whereas the cast-in-place open footing culvert has to be constructed in dry conditions.

The culvert subgrade should be inspected by a Quality Verification Engineer following sub-excavation to ensure that all organics and other unsuitable materials have been removed, in accordance with OPSS 422 (Pre-cast Reinforced Concrete Box Culverts) for a pre-cast box culvert and OPSS 902 (Excavating and Backfilling Structures) for an open footing culvert. Following inspection, the sub-excavated area should be backfilled with granular material meeting the requirements of an OPSS.PROV 1010 (Aggregates) Granular 'A' or Granular 'B' Type I, II or III that is placed and compacted in accordance with OPSS.PROV 501 (Compacting). The use of Granular 'B' Type II is recommended in wet ground conditions or below water and placement should be in accordance with OPSS.PROV 209 (Embankments over Swamps).

6.4.3 Culvert Bedding and Backfill

6.4.3.1 Box Culvert

The bedding, levelling pad and granular backfill requirements for a pre-cast box culvert should be accordance with OPSS 422 (Pre-cast Reinforced Concrete Box Culverts). Given the potential for surface water flow and some groundwater seepage through the native soils during excavating to invert and bedding level, it is recommended that a minimum 300 mm thick layer of OPSS.PROV 1010 (Aggregates) Granular 'B' Type II material for bedding purposes. As the native soil below the bedding is fine grained, it is recommended that a non-woven geotextile be placed between the native soil and the bottom of the bedding. The geotextile should be the specifications for OPSS 1860 (Geotextiles) Class II, and have a fabric opening size (FOS) not greater than 212 µm. The bedding should be placed in maximum 200 mm thick loose lifts and compacted to at least 98 per cent of the Standard Proctor maximum dry density of the materials as specified in OPSS.PROV 501 (Compacting). In addition a 75 mm thick uncompacted levelling pad consisting of OPSS.PROV 1010 (Aggregates) Granular 'A' or fine concrete aggregate meeting the grading requirements specified in OPSS.PROV 1002 (Aggregates – Concrete) should be with similar geometry to that presented on OPSD 803.010 (Backfill and Cover for Concrete Culverts) for culvert construction in dry conditions.

A frost taper should be constructed with geometry similar to that presented on OPSD 803.010 (Backfill and Cover for Concrete Culverts).

6.4.3.2 Open Footing Culvert

The backfill requirements for the open footing culvert replacement should be in accordance with OPSS 902 (Excavating and Backfilling – Structures). The open footing culvert should be provided with at least 2.4 m soil cover for frost protection. The backfill should be placed in maximum 200 mm thick loose lifts, and compacted to at least 98 per cent of the Standard Proctor maximum dry density of the materials as specified in OPSS.PROV 501 (Compacting).

A frost taper should be constructed with geometry similar to that presented on OPSD 803.010 (Backfill and Cover for Concrete Culverts).

6.4.3.3 Pipe Culvert

The bedding, levelling and backfill for a circular concrete pipe, CSP culvert or arch pipe culvert should be in accordance with OPSD 802.034 (Rigid Pipe Bedding and Cover in Embankment), OPSD 802.014 (Flexible Pipe Embedment and Backfill – Earth Excavation) or OPSD 802.024 (Flexible Pipe Arch, Embedment in Embankment Original Ground Earth or Rock), respectively, and culvert construction should be in accordance with OPSS 421 (Pipe Culvert Installation in Open Cut). 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 Granular 'A' or Granular 'B' Type II material for bedding purposes.

A frost taper should be constructed in accordance with OPSD 803.031 (Frost Treatment).

6.4.3.4 Backfill

Backfill behind the culvert walls (including the sheet-pile abutments, if selected as the preferred culvert option) should consist of granular fill meeting the specifications for OPSS.PROV 1010 (Aggregates) Granular ‘A’ or Granular ‘B’ Type I, II or III, but with less than 5 per cent passing the No. 200 (0.075 mm) sieve. The granular backfill should be placed and compacted in accordance with OPSS.PROV 501 (Compacting). The fill should also be placed concurrently on both sides of the culvert, ensuring that the backfill depth on one side does not exceed the other side by more than 400 mm.

Backfill placement for reconstruction of the roadway embankments over and along the culvert should be carried out as per OPSD 208.010 (Benching of Earth Slopes) to integrate the existing embankment fill and new fill along the cut faces.

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

6.4.4 Subgrade Protection

The cohesive native soils will be susceptible to disturbance from construction traffic and/or ponded water. To limit the effect of this disturbance and as an alternative to the 300 mm compacted bedding layer, a mass concrete working slab could be placed on the subgrade if the concrete footings, or the box culvert, is not placed within four hours after preparation, inspection, and approval of the foundation subgrade. The minimum thickness of the concrete working slab should be 100 mm and the concrete should have a minimum 28 day compressive strength of 20 MPa. Consideration should be given to include an NSSP in the contract to address subgrade protection at this site. A sample NSSP can be provided at the detail design stage, if required depending on final culvert design and construction staging.

6.4.5 Erosion Protection

Provision should be made for scour and erosion protection at all culvert locations. 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 end of the culvert. If a clay seal is adopted, the clay material should meet the requirements of OPSS 1205 (Clay Seal), and the seal should be a minimum thickness of 1 m, if constructed of natural clay or soil bentonite mix. The clay seal should extend from a depth of 1 m below the scour level to a minimum vertical height equivalent to the high water level. The seal should also extend a minimum horizontal distance of 2 m on either side of the culvert inlet opening. Alternatively, a 0.6 m thick clay blanket may be constructed, extending upstream three times the culvert height and along the adjacent slopes to a height of two times the culvert height or the high water level, whichever is greater.

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). Erosion protection for the inlet of the culverts should also follow the standard presented in OPSD 810.010 (Rip Rap Treatment) similar to the outlet but with the rip rap placed up to the toe of slope level, in combination with the cut off measures noted above. Similarly, rip rap should be provided over the full extent of the clay blanket, including the river side slopes and fill slope over the culvert if this clay seal is adopted.

6.4.6 Control of Groundwater and Surface Water

Excavation at the culvert alignment will be required to remove organic and overburden soils prior to placement of backfill, bedding material and the actual culvert structure. As a result of the excavation, groundwater flow into the excavation can be expected due to the relatively permeable nature of the fill materials. Therefore, control of groundwater will be necessary to allow for construction to be carried out in dry conditions, where required. Surface water should be directed away from the excavation areas to prevent ponding of water that could result in disturbance and weakening of the foundation subgrade.

Depending on the river flow, surface water flow conditions and groundwater level at the time of construction, water flow could be passed through the area by means of a temporary culvert, or diverted by pumping from behind a temporary sheet-pile cofferdam(s).

Groundwater control may be required, for the box culvert as the foundation excavation to the culvert invert or footing level is expected to extend below the groundwater level. Excavations will be advanced through the native soils, however, seepage into the excavation should be adequately controlled by pumping from properly filtered sumps. Excavations for the open footing option will extend well below the groundwater level. Based on the gradation of the clayey silt to clay, this material should be relatively impermeable. Alternatively the foundation area could be excavated within a cofferdam using closed steel sheet-piles driven below founding level. Dewatering of all excavations should be carried out in accordance with OPSS 517 (Dewatering). Consideration should be given to include an NSSP in the contract to address unwatering at this site. A sample NSSP should be provided at the detail design stage, if required depending on final culvert design and construction staging.

At this preliminary stage, an accurate prediction of the groundwater pumping volumes cannot be made, as the flow rate would be dependent on construction methods adopted by the contractor. However, it is considered that groundwater pumping volumes could exceed 50 m^3/day during initial drawdown stages and/or during periods of heavy precipitation. For this pumping volume, a Permit to Take Water (PTTW) would be required.

6.4.7 Obstructions

The Contractor should be alerted to the presence of cobble size materials and potential boulders within the granular fill at this site. An NSSP should be developed at the detail design stage for inclusion into the Contract Documents.

6.4.8 Analytical Testing for Construction Materials

The results of an analytical test on a sample of river water taken at the culvert site are shown on Table B1 in Appendix B. The suite of parameters tested is intended to allow the design engineer to assess the requirements for the appropriate type of cement to be used in construction and the need for corrosion protection of steel reinforcing elements.

6.5 Recommendations for Further Work During Detail Design

During the detail design phase, additional field investigation and testing may be required, based on the final configuration of the culvert and the replacement strategy (i.e., staging). In particular, additional boreholes advanced to a suitable penetration depth within the sand and gravel deposit will be required if the pre-cast slab and sheet-pile abutment culvert option is selected. The scope and results of this investigation must be reviewed at that time to determine if they meet the then-current MTO requirements for the culvert type or staging strategy under consideration, and if additional investigation and analysis is necessary. If a grade raise or widening of the roadway is required at this site, additional settlement and stability analysis will be required. Further, the need for an application for a PTTW should be defined early in the detail design phase of the project as not to delay the start of construction.

7.0 CLOSURE

This Preliminary Foundation Design Report was prepared by Mr. Adam Core, E.I.T. and the technical aspects were reviewed by Ms. Sarah E.M. Poot P.Eng., Associate. Mr. Fintan J. Heffernan, P.Eng., the Designated MTO Foundations Contact of Golder conducted an independent review of this report.

Report Signature Page

GOLDER ASSOCIATES LTD.

Adam Core, E.I.T.
Geotechnical Engineering Intern

LICENSED PROFESSIONAL ENGINEER
S. E. M. POOT
90471921
6/5/15
PROVINCE OF ONTARIO

Sarah E.M. Poot, P.Eng.
Geotechnical Engineer, Associate

REGISTERED PROFESSIONAL ENGINEER
F. J. HEFFERNAN
06/05/15
PROVINCE OF ONTARIO

Fintan J. Heffernan, P.Eng
Designated MTO Foundations Contact

AC/SEMP/FJH/kp

n:\active\2014\1190 sudbury\1191\1411523 - hmm 26 culverts thunder bay\reporting\preliminary design\r11 - mcintyre river\final\1411523 rpt r11 15june5 mcintyre river.docx

REFERENCES

Canadian Standards Association (CSA), 2006. *Canadian Highway Bridge Design Code* and *Commentary on CAN/CSA S6 06*. CSA Special Publication, S6.1 06.

Occupational Health and Safety Act and Regulation for Construction Projects, January 2006.

Northern Ontario Engineering Geology Terrain Study. Ontario Geological Society Electronic Mapping. Map 52ANW

Ministry of Northern Development of Mines. Bedrock Geology of Ontario – West Central Sheet, Ontario Geological Survey – Map 2542.

ASTM International:

ASTM D1586	Standard Test Method for Standard Penetration Test and Split-Barrel Sampling of Soils
ASTM D2573	Standard Test Method for Field Vane Shear Test in Cohesive Soil

Ontario Provincial Standard Specifications (OPSS)

OPSS 421	Construction Specification for Pipe Culvert Installation in Open Cut
OPSS 422	Construction Specification for Pre-cast Reinforced Concrete Box Culverts and Box Sewers in Open Cut
OPSS 517	Construction Specification for Dewatering of Pipeline, Utility, and Associated Structure Excavation
OPSS 902	Construction Specification for Excavating and Backfilling – Structures
OPSS 1205	Material Specification for Clay Seal
OPSS 1860	Material Specification for Geotextiles

Ontario Provincial Standard Specifications (OPSS) – Provincial Oriented

OPSS.PROV 209	Construction Specification for Embankments over Swamps and Compressible Soils
OPSS.PROV 501	Construction Specification for Compacting
OPSS.PROV 539	Construction Specification for Temporary Protection Systems
OPSS.PROV 1002	Material Specification for Aggregates - Concrete
OPSS.PROV 1010	Material Specification for Aggregates – Base, Subbase, Select Subgrade and Backfill Material

Ontario Provincial Standard Drawings (OPSD)

OPSD 208.010	Benching of Earth Slopes
OPSD 802.014	Flexible Pipe, Embedment in Embankment, Original Ground: Earth or Rock
OPSD 802.024	Flexible Pipe Arch, Embedment in Embankment Original Ground: Earth or Rock
OPSD 802.034	Rigid Pipe Bedding and Cover in Embankment Original Ground: Earth or Rock
OPSD 803.010	Backfill and Cover for Concrete Culverts

OPSD 810.010	Rip-Rap Treatment for Sewer and Culvert Outlets
OPSD 3090.100	Foundation, Frost Depths for Northern Ontario

Ontario Water Resource Act:

Regulation 903	Wells (as amended)

Table 1: Summary of Culvert Details

Culvert Location (Township)	Site #	Approximate Height of Embankment[1] (m)	Existing Culvert			Approximate Invert Elevation[2] (m)
			Type	Approximate Dimension[2] (m)	Approximate Length (m)	
Hwy 589 STA 17+459 (Township of Gorham)	48C-36/C	5.3	Steel Plate Corrugated Steel Pipe Arch (SPCSPA)	4.3 m x 2.7 m	21	413.3

Notes: 1. Embankment height is relative to existing ground surface at the centreline of the roadway and the invert elevation of the culvert.

2. Culvert dimensions are based on the RFP and invert elevations are based on the plan and profile drawing provided by MTO on drawing BC7355895.dwg.

Table 2: Comparison of Foundation Alternatives

Option	Advantages	Disadvantages	Risks/Consequences
Open Footing Culvert	■ May be feasible to build culvert on pre-cast footing sections, to accelerate construction schedule and reduce time for dewatering and surface water pumping. ■ Would satisfy fisheries requirements related to natural channel substrate, if applicable.	■ Excavation depths are greater than for box culvert option, resulting in increased excavation support and dewatering requirements and generating additional spoil material to be disposed of off-site. ■ Constructing footings in the dry will take longer due to requirements for groundwater control system, dewatering and surface water pumping. ■ Less tolerant of total and differential settlement if the highway embankment is raised or widened at the culvert site.	■ High risk of disturbance of the firm to stiff clayey silt to clay deposit during construction; can be mitigated with use of a concrete working slab but would require dewatering. ■ Culvert joints may be required to accommodate total and differential settlement (if applicable).
Pre-Cast Box Culvert	■ Allows faster construction resulting in shorter duration for dewatering and surface water pumping. ■ More tolerant of total and differential settlement if the highway embankment is raised or widened at the culvert site. ■ Backfill under the culvert may be placed underwater (i.e. Granular 'B' Type II) minimizing or eliminating water pumping requirements.	■ May not satisfy fisheries requirements related to natural channel substrate, if applicable. ■ Cut-off wall or clay blanket may be required at inlet to mitigation potential scour under the culvert.	■ Some risk of disturbance of the firm to stiff clayey silt to clay deposit during construction; can be mitigated with use of a concrete working slab but would require dewatering. ■ Limited risk related to settlement performance

Table 2: Comparison of Foundation Alternatives

Option	Advantages	Disadvantages	Risks/Consequences
Circular Pipe Culvert	■ Allows faster construction resulting in shorter duration for dewatering and surface water pumping. ■ More tolerant of total and differential settlement if the highway embankment is raised or widened at the culvert site. ■ Backfill under the culvert may be placed underwater (i.e. Granular 'B' Type II) minimizing or eliminating water pumping requirements.	■ Cut-off wall or clay blanket may be required at inlet to mitigation potential scour under culvert. ■ CSP may not have as long of design life compared to concrete options.	■ Some risk of disturbance of the firm to stiff clayey silt to clay deposit during construction; can be mitigated with use of a concrete working slab but would require dewatering. ■ Limited risk related to settlement performance
Pre-Cast Slab and Sheet-Pile Abutment	■ Does not require temporary diversion of the river as it can be installed around the existing culvert, which acts as the channel diversion. ■ Minimizes excavation depths and does not require dewatering. ■ Would satisfy fisheries requirements related to natural channel substrate, if applicable.	■ Less tolerant of total and differential settlement if the highway embankment is raised or widened at the culvert site (i.e. potential for downdrag on the sheet-piles). ■ Steel sheet-piles may not have as long of a design life compared to concrete options. ■ Will require additional deeper boreholes to assess adequacy of subsurface soils. ■ Obstructions (i.e. cobbles) within the fill may require excavation and replacement along the sheet pile alignment prior to installation.	■ Some risk related to obstructions within the fill; can be mitigated by sub-excavation and replacing material prior to installation of the sheet-piles. ■ Joints may need to be incorporated into the slab to accommodate total and differential settlement.

Prepared by: AC
Checked by: SEMP
Reviewed by: FJH

Table 3: Geotechnical Axial Resistance and Reaction for Pre-Cast Box, Open Footing Culvert and Pre-cast Concrete Slab on Sheet-pile Abutment Replacement Culverts

Culvert Location (Township)	Approximate Invert Elevation [1]	Culvert Type	Approximate Founding Elevation	Founding Condition	Factored Geotechnical Axial Resistance at ULS -	Geotechnical Reaction at SLS for 25 mm of Settlement -
Hwy 589 STA 17+459 (Township of Gorham)	413.3 m	Pre-Cast Box [2]	412.7 m	Compacted Bedding material overlying Firm to Very Stiff, Clayey Silt to Clay	150 kPa	100 kPa
		Open Footing [2]	410.9 m	Firm to Very Stiff, Clayey Silt to Clay	150 kPa	100 kPa
	N/A	Pre-Cast Slab on Sheet-Pile Abutments [3]	~ 404.0 m	Dense Sand and Gravel	485 kN/m	325 kN/m

Notes: 1. Culvert invert elevations for conventional culvert replacements are based on the profile drawings provided by MTO.

2. The factored geotechnical resistance at ULS and geotechnical reaction at SLS (for 25 mm of settlement) for conventional culvert replacements are estimated based on an assumed 6.0 m wide box culvert and a 0.6 m wide footing. The recommended geotechnical resistance/reaction should be reviewed if the founding elevation and/or the foundation widths differ from those given above.

3. The factored geotechnical resistance at ULS and geotechnical reaction at SLS (for 25 mm of settlement) are provided per horizontal meter of sheet piling. These values assume the sheeting is driven into the dense sand and gravel layer encountered in Borehole MR-3. The recommended geotechnical resistance/reaction should be reviewed once more information becomes available in terms of the final sheet-piling configuration.

Prepared by: AC
Checked by: SEMP
Reviewed by: FJH

Table 4: Resistance to Lateral Loads/Sliding Resistance for Pre-Cast Box and Open Footing Culvert Replacements

Culvert Location (Township)	Pre-Cast Box Culvert or Pre-Cast Open Footing		Open Footing Culvert	
	Interface Material	Coefficient of Friction (tan δ)	Interface Material	Coefficient of Friction (tan δ)
Hwy 589 STA 17+459 (Township of Gorham)	Compacted Granular Fill (Bedding)	0.45	Firm to Stiff Clayey Silt to Clay	0.35

Notes: 1. These values are unfactored. In accordance with CHBDC, a factor of 0.8 is to be applied in calculating the horizontal resistance

Prepared by: AC
Checked by: SEMP
Reviewed by: FJH

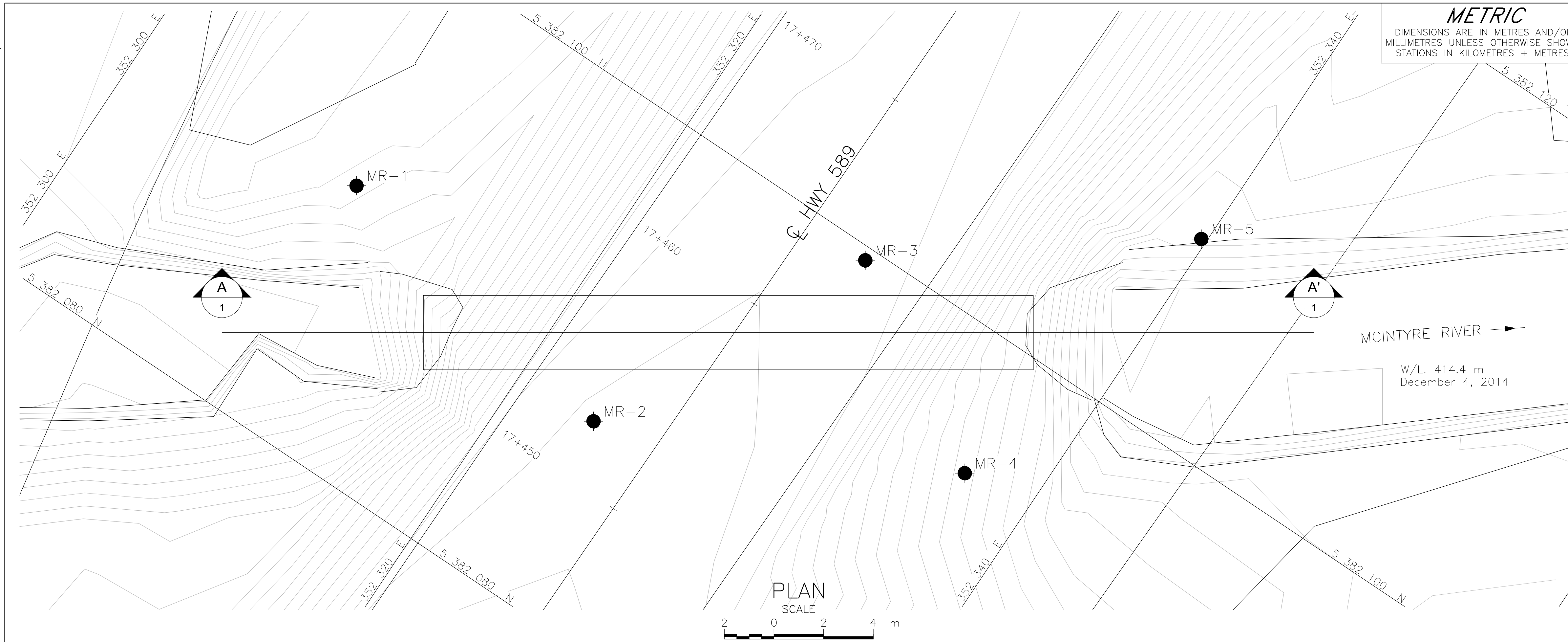
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS IN KILOMETRES + METRES.

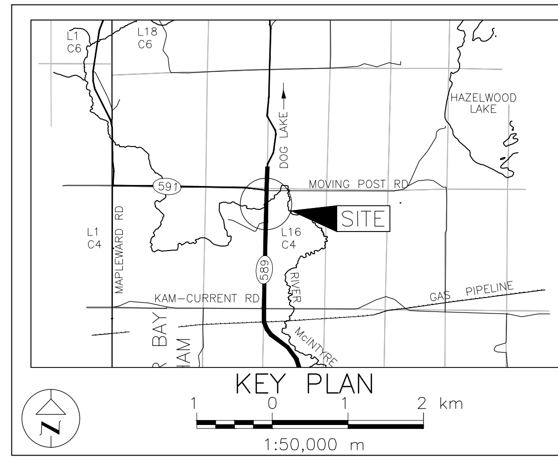
CONT No.
GWP No. 6301-14-00

HIGHWAY 589
MCINTYRE RIVER CULVERT STA 17+459
BOREHOLE LOCATIONS AND SOIL STRATA

SHEET

Golder Associates





LEGEND

●	Borehole
N	Standard Penetration Test Value
16	Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
R	Refusal

BOREHOLE CO-ORDINATES			
No.	ELEVATION	NORTHING	EASTING
MR-1	416.1	5382090.6	352310.3
MR-2	418.6	5382088.0	352323.5
MR-3	418.5	5382099.5	352329.0
MR-4	417.3	5382094.6	352337.1
MR-5	415.3	5382107.7	352339.8

NOTES

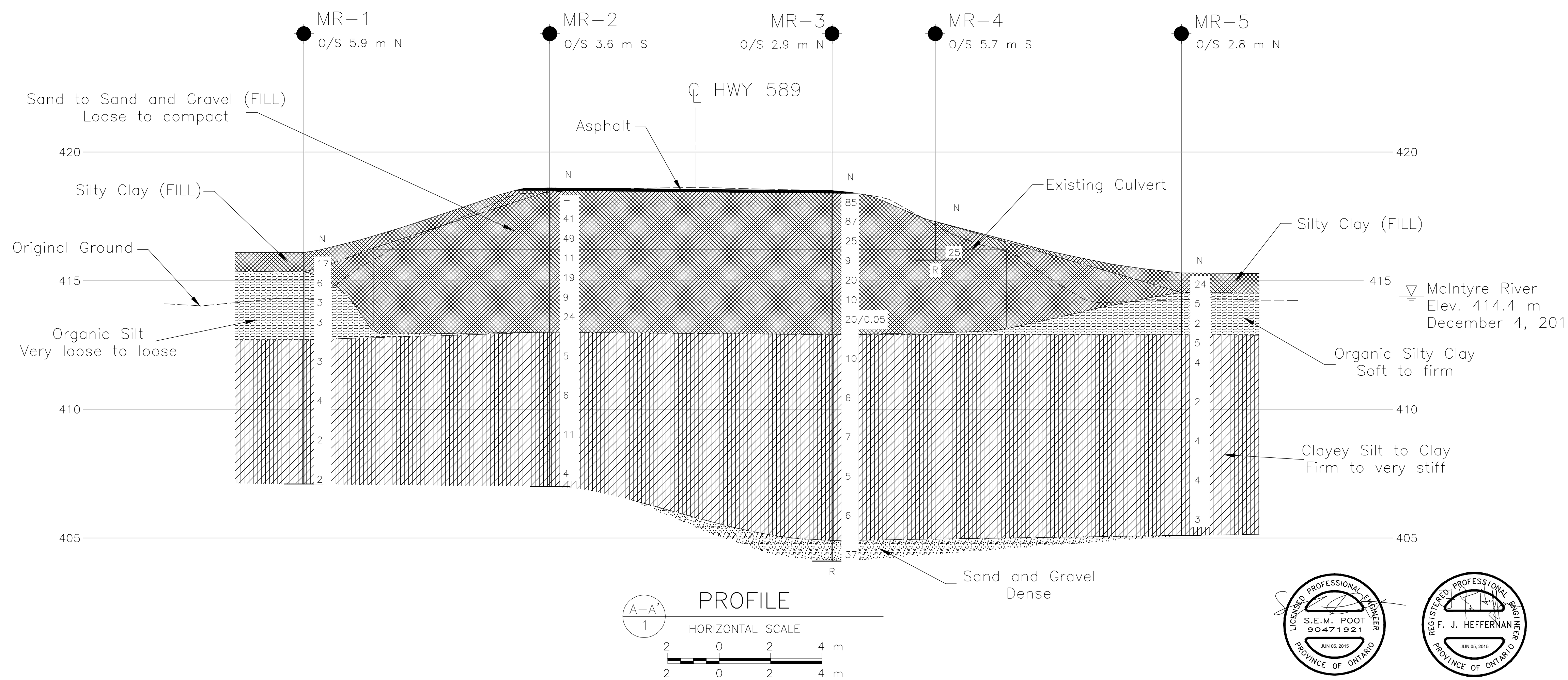
This drawing is for subsurface information only. The proposed structure details/works are shown for illustration purposes only and may not be consistent with the final design configuration as shown elsewhere in the Contracts Documents.

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

The complete Foundation Investigation and Design Report for this project and other related documents may be examined at the Materials Engineering and Research Office, Downsview. Information contained in this report and related documents is specifically excluded in accordance with Section GC 2.01 of OPS General Conditions.

REFERENCE

Base plans provided in digital format by Hatch Mott MacDonald, drawing file nos. BC7355895, dated APR 2014, received FEB 15 2015.



LICENSED PROFESSIONAL ENGINEER S.E.M. POOT 90471921 PROVINCE OF ONTARIO

REGISTERED PROFESSIONAL ENGINEER F. J. HEFFERNAN PROVINCE OF ONTARIO

NO.	DATE	BY	REVISION

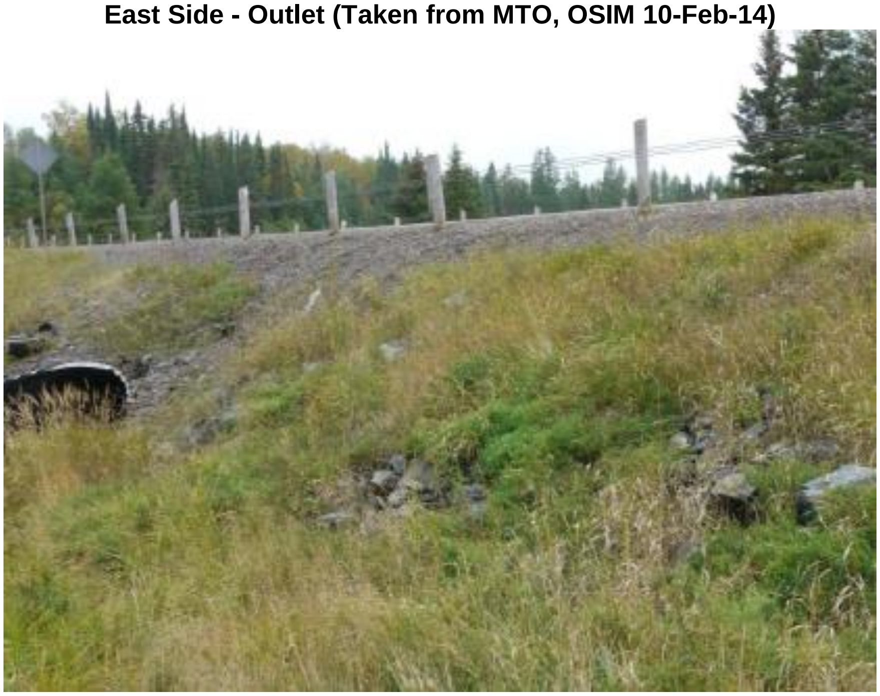
Geocres No. 52A-198

HWY. 589	PROJECT NO. 1411523		DIST.
SUBM'D. AC	CHKD. DAM	DATE: 6/3/2015	SITE: 48C-36/C
DRAWN: JJL	CHKD. SEMP	APPD. FJH	DWG. 1

PLOT DATE: June 3, 2015
FILENAME: \\golder.gds\gal\Sudbury\CAD-GIS\CAD\Projects\2014\1411523_HMM 26 Culverts Thunder Bay\CIVIL 3D\1411523_McIntyre River.dwg

Photograph 1: McIntyre River Culvert
West Side - Inlet (Taken from MTO, OSIM 10-Feb-14)

Photograph 2: McIntyre River Culvert
East Side - Outlet (Taken from MTO, OSIM 10-Feb-14)



Photograph 3: McIntyre River Culvert
Looking West at Culvert (Golder – 3-Dec-14)

Photograph 4: McIntyre River Culvert
Looking West at Culvert (Golder – 3-Dec-14)

APPENDIX A
RECORD OF BOREHOLES

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
σ_1, σ_2, σ_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

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

(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 $= \sigma'_p / \sigma'_{vo}$

(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

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 (Cohesionless) Soils

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

(b) Cohesive Soils

Consistency

	c_u, s_u **kPa**	**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

Golder Associates

RECORD OF BOREHOLE No MR-1

 METRIC

PROJECT 1411523			
G.W.P. 6301-14-00	LOCATION N 5382090.6; E 352310.3		ORIGINATED BY CW
DIST	HWY 589	BOREHOLE TYPE 108 mm I. D. Hollow Stem Augers	COMPILED BY SEMP
DATUM GEODETIC		DATE December 3, 2014	CHECKED BY DAM

ELEV DEPTH	SOIL PROFILE DESCRIPTION	STRAT PLOT	SAMPLES NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	UNIT WEIGHT γ kN/m³	GR	SA	SI	CL
416.1	GROUND SURFACE										
0.0	Silty clay with organics (FILL) Reddish-brown Frozen		1	SS	17						
415.3 0.8	ORGANIC SILT, trace to some sand Soft to firm Reddish-brown Wet		2	SS	6						
			3	SS	3		OC=7.0%	0	7	73	20
			4	SS	3						
412.7 3.4	SILTY CLAY to CLAY, trace sand, trace organics Firm to stiff Reddish-brown Wet		5	SS	3		OC=1.4%	0	5	45	50
			6	SS	4						
			7	SS	2						
			8	SS	2			0	0	15	85
407.1 9.0	END OF BOREHOLE Note: 1. Borehole dry upon completion of drilling.										

ELEVATION SCALE

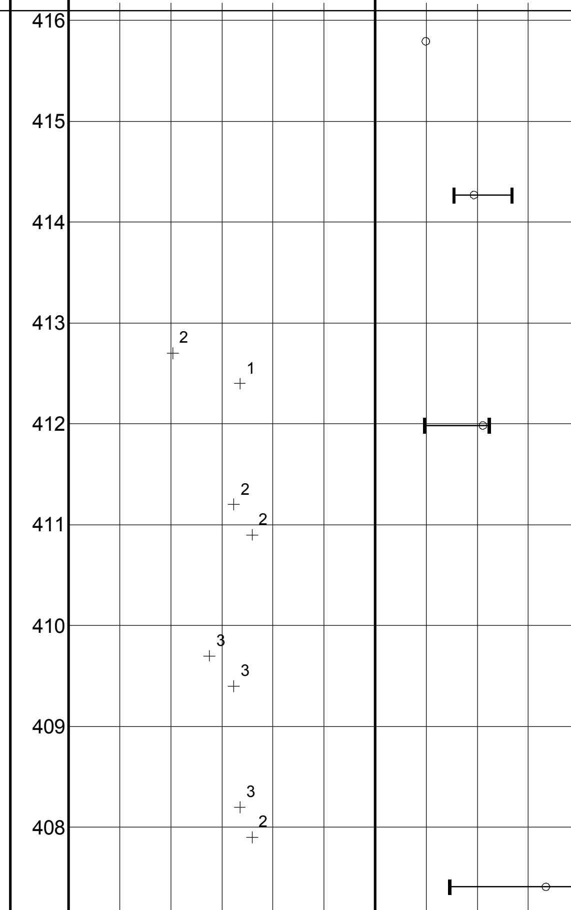
DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100

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

REMARKS & GRAIN SIZE DISTRIBUTION (%)



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

RECORD OF BOREHOLE No MR-2

 METRIC

PROJECT 1411523
G.W.P. 6301-14-00
LOCATION N 5382088.0; E 352323.5
ORIGINATED BY MR
DIST HWY 589
BOREHOLE TYPE 108 mm I. D. Hollow Stem Augers, NW Casing, Wash Boring
COMPILED BY SEMP
DATUM GEODETIC
DATE December 3, 2014
CHECKED BY DAM

ELEV DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
418.6	GROUND SURFACE				
0.0	ASPHALT (75 mm)				
0.1	Sand, some gravel, trace to some silt, trace clay (FILL) Loose to compact Brown Frozen / wet Upper 1.4 m frozen. 225 mm cobble at 1.7 m depth. 150 mm cobble at 2.1 m depth. 175 mm cobble at 2.9 m depth.	1	AS	-	14 74 10 2
		2	SS	41	
		3	SS	49	
		4	SS	11	
		5	SS	19	
		6	SS	9	18 74 (8)
		7	SS	24	
413.0 5.6	SILTY CLAY, trace sand Stiff to very stiff Reddish-brown Wet				
		8	SS	5	
		9	SS	6	0 2 53 45
	Clayey silt to silt seam encountered at 9.1 m depth.	10	SS	11	0 0 74 26
		11	SS	4	
407.0 11.6	END OF BOREHOLE				

Shear strength (field vane) plot annotations: >100, >100 (approx. elev. 411.5); sensitivity 2, 2 (approx. elev. 410); 2 (approx. elev. 407).

Note:

1. Refusal on cobble at 1.7 m depth. Samples 4 through 11 obtained from additional borehole advanced 1.2 m north of MR-2.

2. Borehole caved at 3.8 m depth upon completion of drilling. Borehole dry to 3.8 m depth upon completion of drilling.

Legend: 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; ELEVATION SCALE 418–407.

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

RECORD OF BOREHOLE No MR-3

 METRIC

PROJECT 1411523			
G.W.P. 6301-14-00	LOCATION N 5382099.5; E 352329.0		ORIGINATED BY MR
DIST	HWY 589	BOREHOLE TYPE NW Casing, Wash Boring	COMPILED BY SEMP
DATUM GEODETIC	DATE December 4 and 5, 2014		CHECKED BY DAM

SOIL PROFILE

ELEV / DEPTH	DESCRIPTION
418.5	GROUND SURFACE
0.0	ASPHALT (65 mm)
0.1	Sand and gravel, some silt (FILL) Loose to compact Brown Frozen / wet Upper 1.4 m frozen. 120 mm cobble at 1.4 m depth. 180 mm cobble at 2.0 m depth. 200 mm cobble at 5.1 m depth.
412.9 / 5.6	CLAYEY SILT, trace to some sand Stiff to very stiff Reddish-brown Wet
404.9 / 13.6	SAND and GRAVEL, trace to some silt Dense Grey Wet
404.1 / 14.4	

SAMPLES

NUMBER	TYPE	"N" VALUES	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
1	SS	85	
2	SS	87	33 54 (13)
3	SS	25	
4	SS	9	
5	SS	20	
6	SS	10	
7	SS	20/0.05	
8	SS	10	
9	SS	6	0 8 59 33
10	SS	7	
11	SS	5	0 6 45 49
12	SS	6	
13	SS	37	34 60 (6)

Elevation scale: 418, 417, 416, 415, 414, 413, 412, 411, 410, 409, 408, 407, 406, 405

DYNAMIC CONE PENETRATION RESISTANCE PLOT: 20 40 60 80 100

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

Field vane results: >100, >100 (approx. elev. 411.5); 2, 2 (approx. elev. 410); 2, 2 (approx. elev. 408.3); 2, 2 (approx. elev. 406.8); >100, >100 (approx. elev. 405.3)

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

WATER CONTENT (%): 20 40 60

UNIT WEIGHT γ kN/m³

GROUND WATER CONDITIONS

Continued Next Page

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

RECORD OF BOREHOLE No MR-3

 METRIC

PROJECT 1411523
G.W.P. 6301-14-00
LOCATION N 5382099.5; E 352329.0
ORIGINATED BY MR
DIST HWY 589
BOREHOLE TYPE NW Casing, Wash Boring
COMPILED BY SEMP
DATUM GEODETIC
DATE December 4 and 5, 2014
CHECKED BY DAM

SOIL PROFILE			SAMPLES			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
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES						
	--- CONTINUED FROM PREVIOUS PAGE ---										
	END OF BOREHOLE CASING AND SPLIT-SPOON REFUSAL (HAMMER BOUNCING) Note: 1. Borehole caved at 3.9 m depth upon completion of drilling. Borehole dry to 3.9 m depth upon completion of drilling.										

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

Golder Associates

RECORD OF BOREHOLE No MR-4

 METRIC

PROJECT 1411523
G.W.P. 6301-14-00
LOCATION N 5382094.6; E 352337.1
ORIGINATED BY CW
DIST ___ HWY 589
BOREHOLE TYPE 108 mm I. D. Hollow Stem Augers
COMPILED BY SEMP
DATUM GEODETIC
DATE December 3 and 4, 2014
CHECKED BY DAM

ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"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
417.3	GROUND SURFACE										
0.0	ROCK FILL						417				
416.5 / 0.8	Sand and gravel, some silt, some rock fragments (FILL) Compact Brown Moist		1	SS	25		416		○		
415.8 / 1.5	END OF BOREHOLE AUGER REFUSAL										

Note:

1. Borehole dry upon completion of drilling.

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

Foundation Design

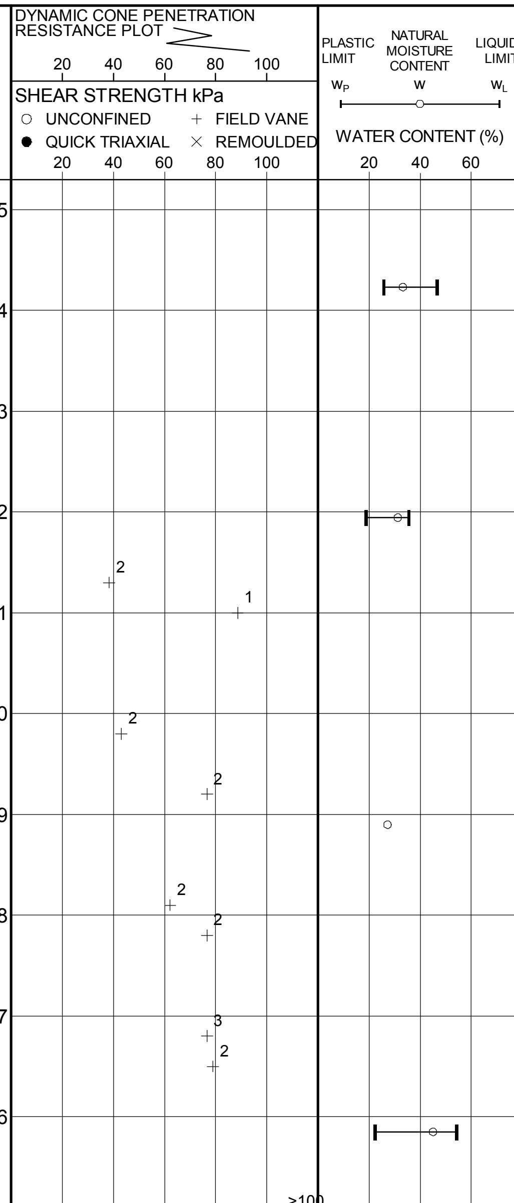
Golder Associates

RECORD OF BOREHOLE No MR-5

 METRIC

PROJECT 1411523			
G.W.P. 6301-14-00	LOCATION N 5382107.7; E 352339.8	ORIGINATED BY CW
DIST ______ HWY 589	BOREHOLE TYPE 108 mm I. D. Hollow Stem Augers	COMPILED BY SEMP
DATUM GEODETIC	DATE December 4, 2014	CHECKED BY DAM

ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	REMARKS (UNIT WEIGHT γ kN/m³)	GR	SA	SI	CL
415.3	GROUND SURFACE											
0.0	Silty clay some organics, some sand (FILL) Dark brown Frozen		1	SS	24		415					
414.5 / 0.8	ORGANIC SILTY CLAY, trace to some sand Soft to firm Dark brown Wet		2	SS	5			OC=5.2%	0	10	67	23
							414					
			3	SS	2							
412.9 / 2.4	SILTY CLAY to CLAY, trace sand, trace organics Firm to very stiff Reddish-brown Wet		4a / 4b	SS	5		413					
			5	SS	4		412	OC=1.0%	0	3	67	30
							411					
			6	SS	2		410					
			7	SS	4		409					
							408					
			8	SS	4		407					
			9	SS	3		406		0	0	37	63
405.1 / 10.2	END OF BOREHOLE Note: 1. Borehole caved at 6.0 m depth upon completion of drilling. Borehole dry upon completion of drilling.											



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

SUD-MTO 001 1411523.GPJ GAL-MISS.GDT 10/03/15 DATA INPUT:

APPENDIX B

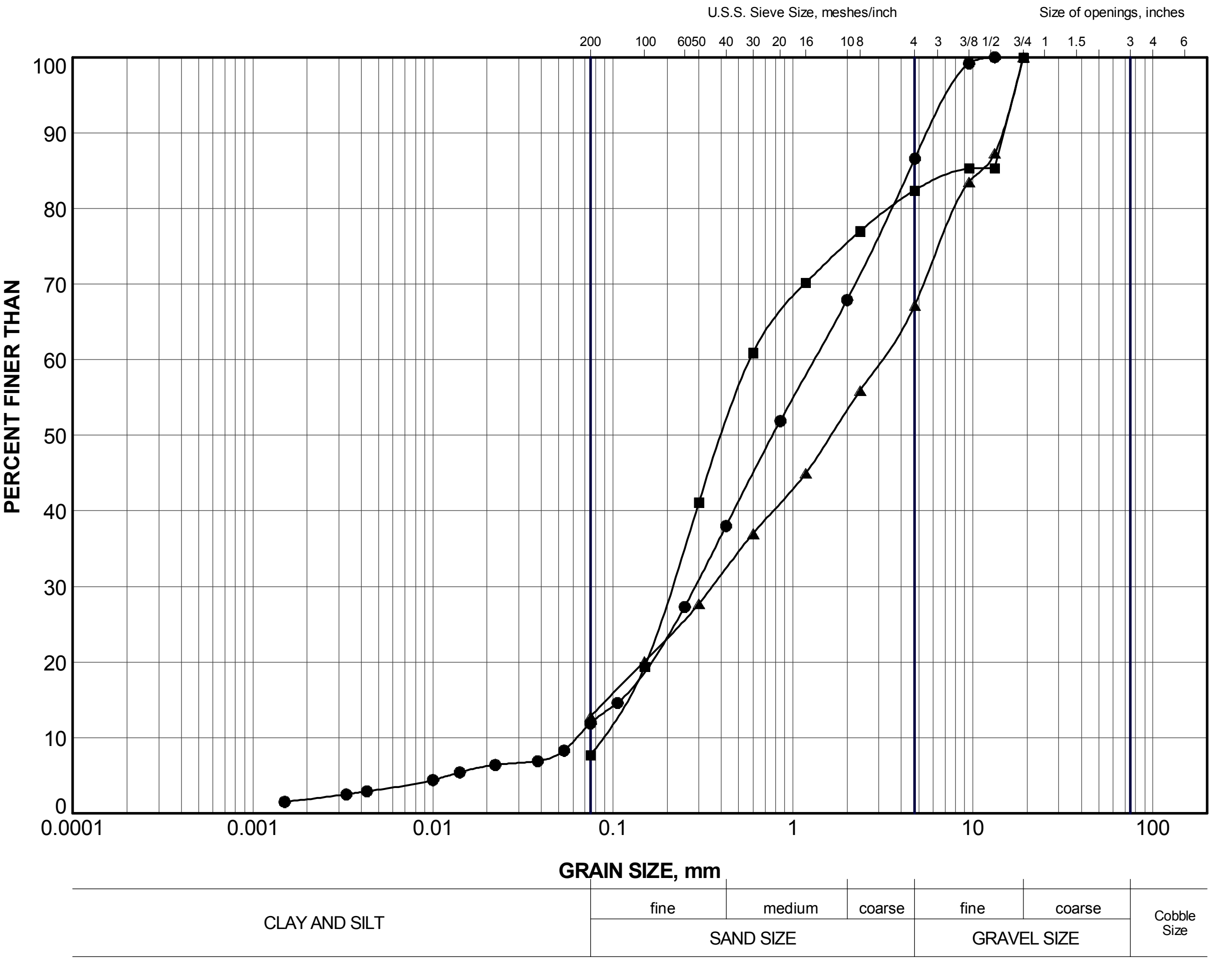
LABORATORY TEST RESULTS

Table B1: Summary of Analytical Testing of McIntyre River Water Sample

Parameter	Units	Result
Chloride (CL)	mg/L	6.41
Sulphate (SO4)	mg/L	6.63
Conductivity (EC)	µS/cm	129
Resistivity	µohm-cm	<0.33
pH	n/a	7.10

Notes:
1. Sample obtained on February 9, 2015.
2. Analytical testing carried out by ALS Canada Ltd.

Prepared by: AC
Checked by: SEMP
Reviewed by: FJH



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	MR-2	1	418.3
■	MR-2	6	414.5
▲	MR-3	2	417.4

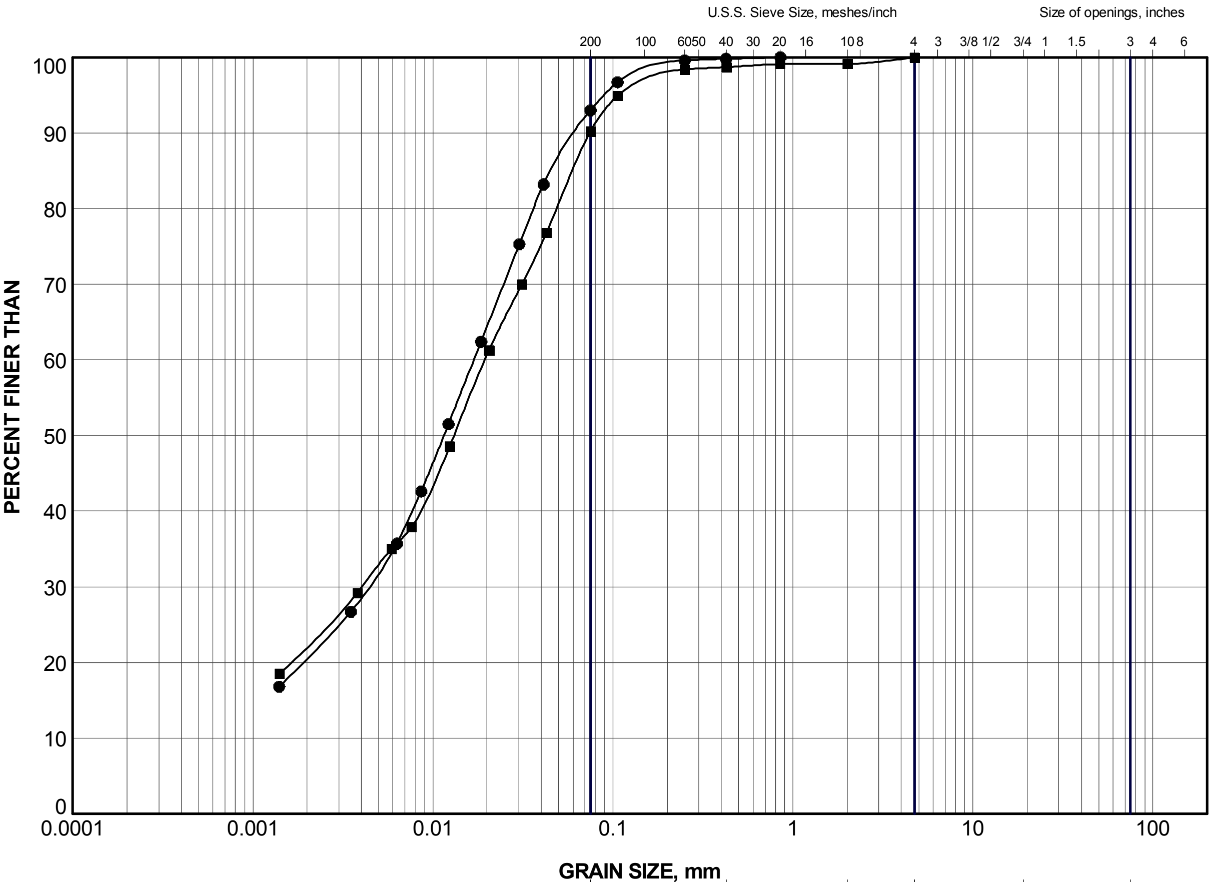
PROJECT
HIGHWAY 589
MCINTYRE RIVER CULVERT STA 17+459

TITLE
GRAIN SIZE DISTRIBUTION
SAND to SAND and GRAVEL (FILL)

Golder Associates
SUDBURY, ONTARIO

PROJECT No.		1411523	FILE No.	1411523.GPJ
DRAWN	JJL	Mar 2015	SCALE N/A	REV.
CHECK	DAM	Mar 2015	**FIGURE B1**	
APPR	FJH	Mar 2015		

SUD-MTO GSD (NEW) GLDR_LDN.GDT



CLAY AND SILT	SAND SIZE: fine	SAND SIZE: medium	SAND SIZE: coarse	GRAVEL SIZE: fine	GRAVEL SIZE: coarse	Cobble Size

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	MR-1	3	414.3
■	MR-5	2	414.2

PROJECT

HIGHWAY 589
MCINTYRE RIVER CULVERT STA 17+459

TITLE

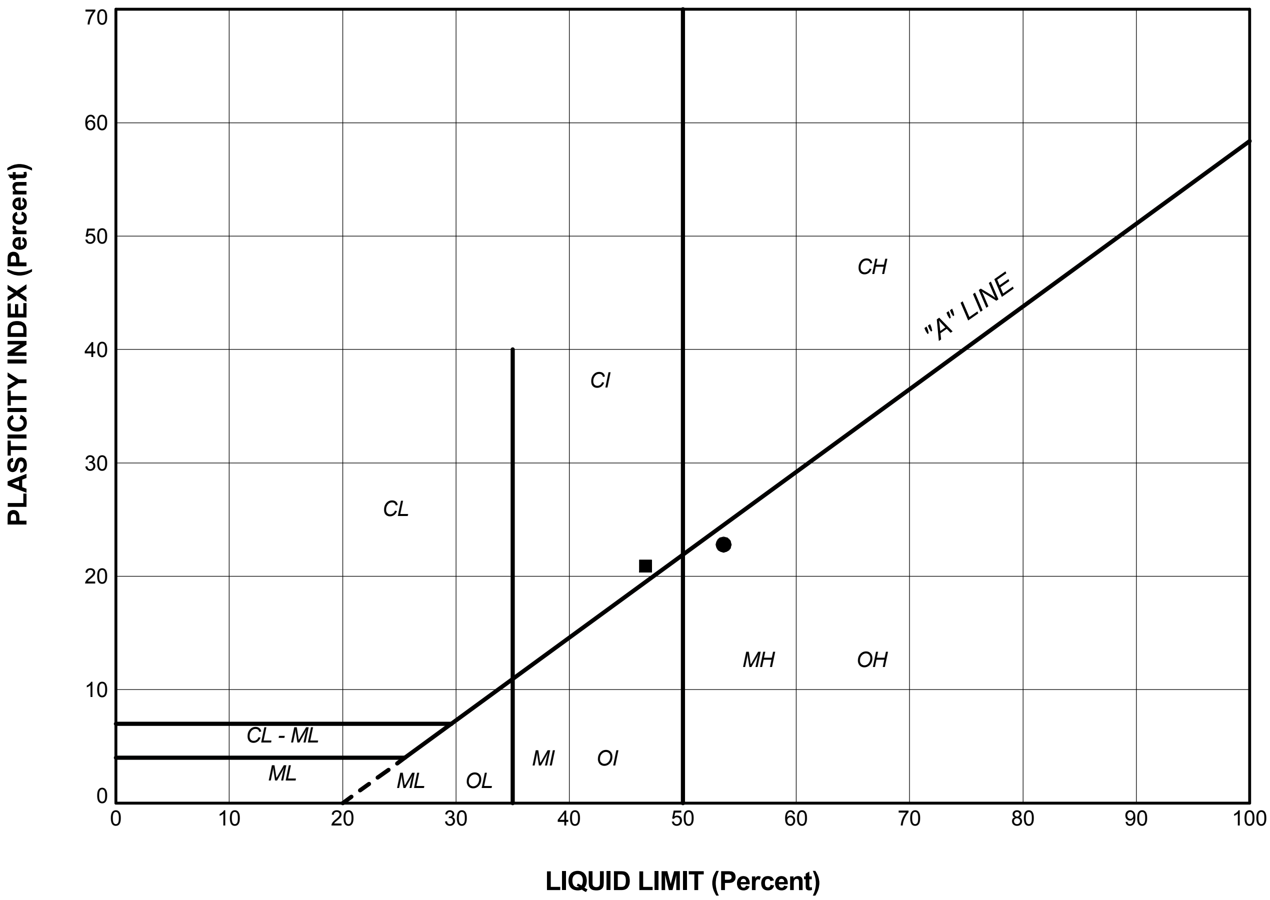
GRAIN SIZE DISTRIBUTION

ORGANIC SILT to ORGANIC SILTY CLAY

Golder Associates
SUDBURY, ONTARIO

PROJECT No.		1411523	FILE No.	1411523.GPJ
DRAWN	JJL	Mar 2015	SCALE N/A	REV.
CHECK	DAM	Mar 2015	FIGURE B2	
APPR	FJH	Mar 2015		

SUD-MTO GSD (NEW) GLDR_LDN.GDT



SOIL TYPE
C = Clay
M = Silt
O = Organic

PLASTICITY
L = Low
I = Intermediate
H = High

LEGEND

SYMBOL	BOREHOLE	SAMPLE	LL(%)	PL(%)	PI
●	MR-1	3	53.6	30.8	22.8
■	MR-5	2	46.7	25.8	20.9

PROJECT

HIGHWAY 589
MCINTYRE RIVER CULVERT STA 17+459

TITLE

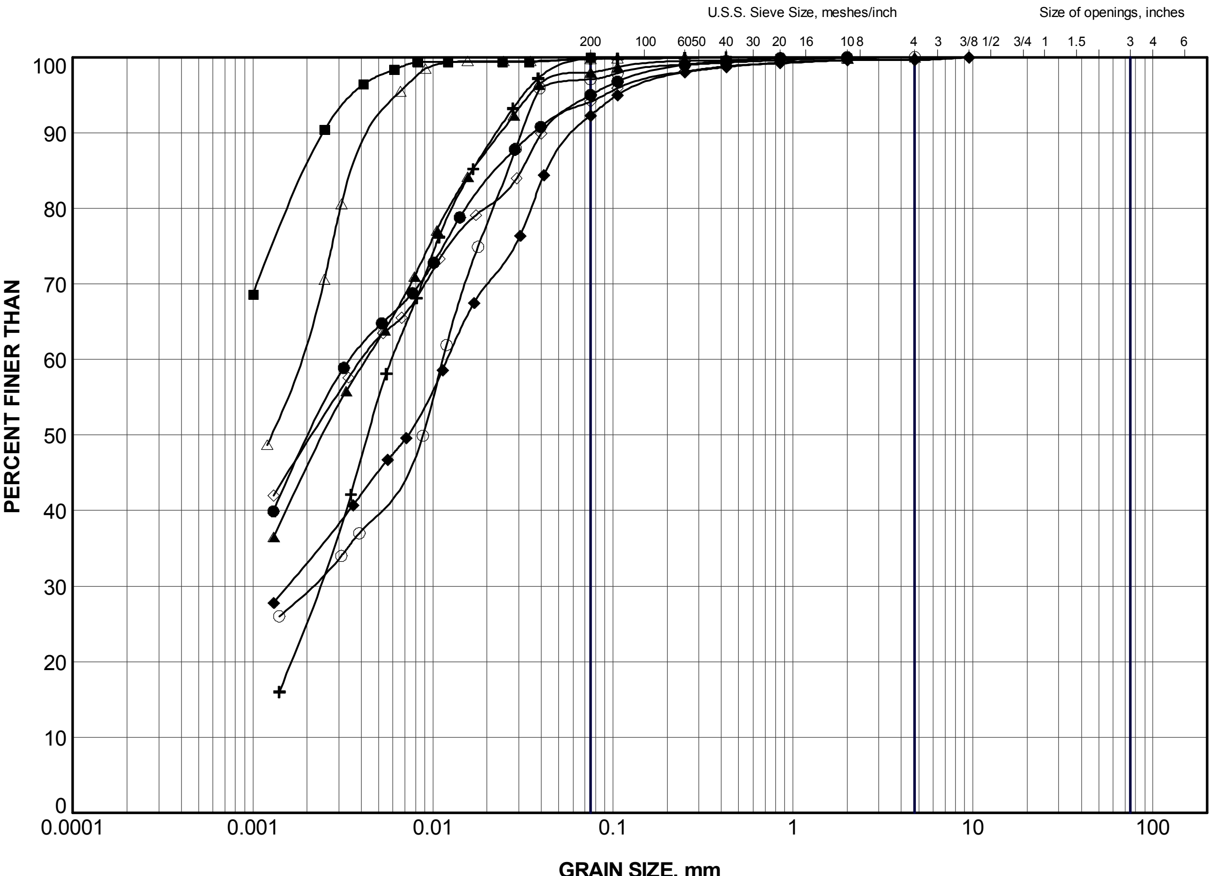
PLASTICITY CHART

ORGANIC SILT to ORGANIC SILTY CLAY

Golder Associates
SUDBURY, ONTARIO

PROJECT No.		1411523	FILE No. 1411523.GPJ
DRAWN	JJL	Mar 2015	SCALE N/A REV.
CHECK	DAM	Mar 2015	**FIGURE B3**
APPR	FJH	Mar 2015	

SUD-MTO PL (NEW) GLDR_LDN.GDT



CLAY AND SILT	SAND SIZE: fine	SAND SIZE: medium	SAND SIZE: coarse	GRAVEL SIZE: fine	GRAVEL SIZE: coarse	Cobble Size

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)	
●	MR-1	5	412.0	
■	MR-1	8	407.4	
▲	MR-2	9	410.7	
+	MR-2	10	409.2	Clayey Silt to Silt seam
◆	MR-3	9	410.6	
◇	MR-3	11	407.5	
○	MR-5	5	411.9	
△	MR-5	9	405.9	

PROJECT

HIGHWAY 589
MCINTYRE RIVER CULVERT STA 17+459

TITLE

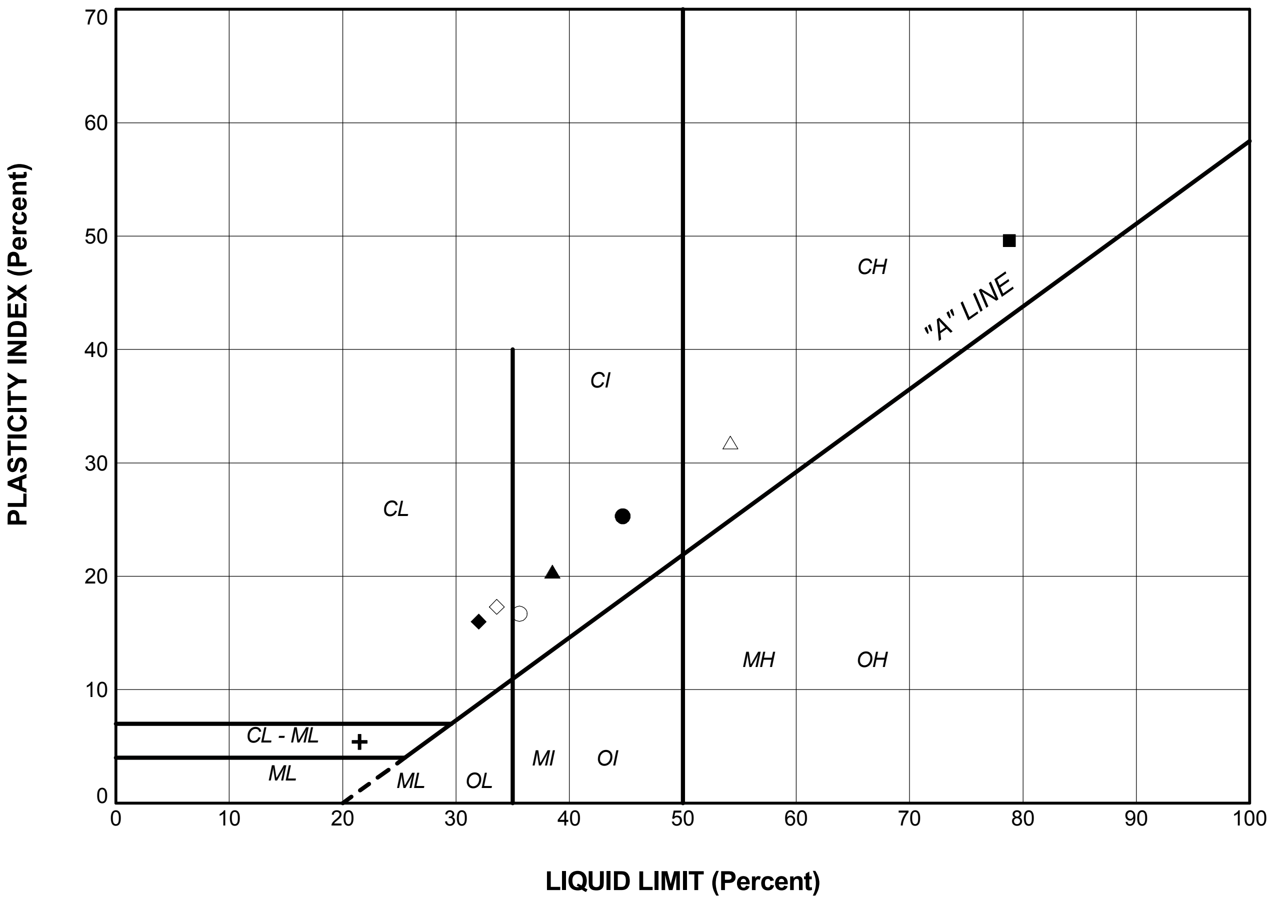
GRAIN SIZE DISTRIBUTION

CLAYEY SILT to CLAY

Golder Associates
SUDBURY, ONTARIO

PROJECT No.		1411523	FILE No. 1411523.GPJ	
DRAWN	JJL	Mar 2015	SCALE N/A	REV.
CHECK	DAM	Mar 2015	**FIGURE B4**	
APPR	FJH	Mar 2015		

SUD-MTO GSD (NEW) GLDR_LDN.GDT



SOIL TYPE
C = Clay
M = Silt
O = Organic

PLASTICITY
L = Low
I = Intermediate
H = High

LEGEND

SYMBOL	BOREHOLE	SAMPLE	LL(%)	PL(%)	PI	
●	MR-1	5	44.7	19.4	25.3	
■	MR-1	8	78.8	29.2	49.6	
▲	MR-2	9	38.5	18.1	20.4	
✚	MR-2	10	21.5	16.1	5.4	Clayey Silt to Silt seam
◆	MR-3	9	32.0	16.0	16.0	
◇	MR-3	11	33.6	16.3	17.3	
○	MR-5	5	35.6	18.9	16.7	
△	MR-5	9	54.2	22.4	31.8	

PROJECT

HIGHWAY 589
MCINTYRE RIVER CULVERT STA 17+459

TITLE

PLASTICITY CHART

CLAYEY SILT to CLAY

PROJECT No.		1411523	FILE No.	1411523.GPJ
DRAWN	JJL	Mar 2015	SCALE N/A	REV.
CHECK	DAM	Mar 2015		
APPR	FJH	Mar 2015	**FIGURE B5**	

Golder Associates
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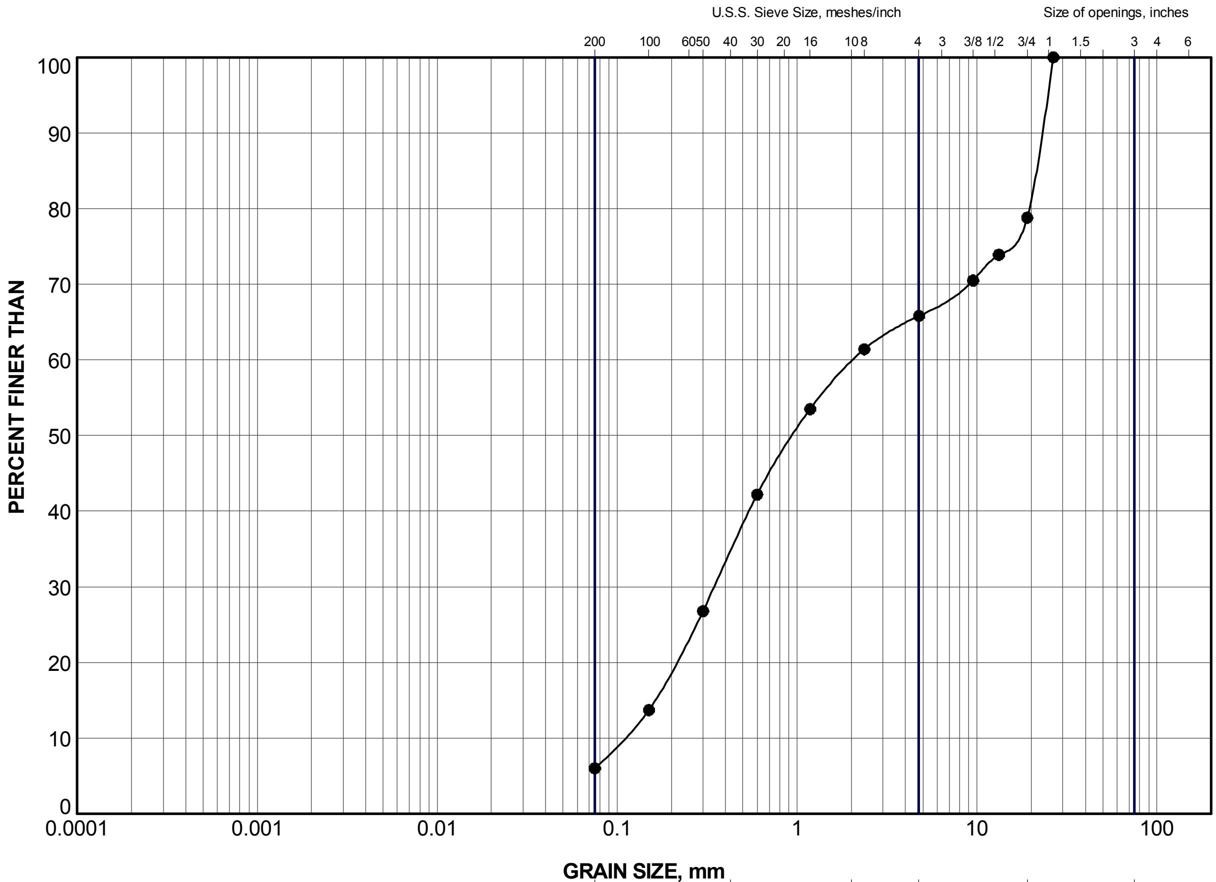
SUD-MTO PL (NEW) GLDR_LDN.GDT



CLAY AND SILT	fine	medium	coarse	fine	coarse	Cobble Size
	SAND SIZE			GRAVEL SIZE		

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	MR-3	13	404.5

PROJECT

HIGHWAY 589
MCINTYRE RIVER CULVERT STA 17+459

TITLE

GRAIN SIZE DISTRIBUTION

SAND and GRAVEL

Golder Associates
SUDBURY, ONTARIO

PROJECT No.		1411523	FILE No. 1411523.GPJ
DRAWN	JJL	Mar 2015	SCALE N/A REV.
CHECK	DAM	Mar 2015	FIGURE B6
APPR	FJH	Mar 2015	

SUD-MTO GSD (NEW) GLDR_LDN.GDT

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solutions@golder.com
www.golder.com

Golder Associates Ltd.
33 Mackenzie Street, Suite 100
Sudbury, Ontario, P3C 4Y1
Canada
T: +1 (705) 524 6861

Golder Associates