October 30, 2015

PRELIMINARY FOUNDATION INVESTIGATION AND DESIGN REPORT

LYON CREEK CULVERT No. 2 - SITE NO. 45-264/C
HIGHWAY 602, DISTRICT OF RAINY RIVER
TOWNSHIP OF LASH
MINISTRY OF TRANSPORTATION, ONTARIO
G.W.P 6342-14-00

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REPORT

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PART A

PRELIMINARY FOUNDATION INVESTIGATION REPORT
LYON CREEK CULVERT NO. 2 – SITE NO. 45-264/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 Lyon Creek culvert no. 2 (Site No. 45-264/C). The Lyon Creek culvert is located in the District of Rainy River in the Township of Lash on Highway 602 at STA 10+035, approximately 2.6 km south of the junction of Highway 602 and Highway 11. The key plan showing the general location of this section of Highway 602 and the location of the investigated area are shown on Drawing 1.

2.0 SITE DESCRIPTION

The Lyon Creek culvert consists of a concrete, open footing structure, 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 the area of the culvert is relatively flat with agricultural land use beyond the highway right-of-way. It should be noted that the orientation (i.e., north, south, east, west) stated in the text of the report is typically referenced to project north and therefore may differ from magnetic north shown on the drawing. For the purposes of this report Highway 602 runs in a north-south direction with the culvert in an east-west orientation on a slight skew from perpendicular with the roadway. At the culvert location, Lyon Creek flows westerly. The highway grade is at Elevation 343.1 m and the culvert invert, as provided by MTO, is at approximately Elevation 339.4 m and 339.3 m, at the inlet and outlet, respectively. The creek water level was at Elevation 339.8 m as measured by others on June 17, 2014. The creek ice level of the culvert was at Elevation 340.1 m as measured by Golder on February 13, 2015. Surface conditions at the culvert inlet and outlet areas are shown on Photographs 1 to 4, attached.

3.0 INVESTIGATION PROCEDURES

The field work for this subsurface investigation was carried out on February 13 and March 15, 2015, during which time four boreholes (Boreholes LY-1 to LY-4) were advanced at approximately the locations shown on Drawing 1. Boreholes LY-1 and LY-4 were advanced at the toe of slope near the culvert inlet/outlet and Boreholes LY-2 and LY-3 were advanced from the existing highway platform. The boreholes were advanced using a track-mounted CME 55 drill rig supplied and operated by George Downing Estate Drilling Ltd. of Grenville-Sur-La-Rouge, Quebec.

The boreholes were advanced using 108 mm inside diameter hollow stem augers. 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 level in the open boreholes was 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 members 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 and organic content determinations, grain size distributions, and Atterberg limits were carried out on selected soil samples. The geotechnical laboratory testing was completed according to MTO LS standards.

A sample of the creek water was obtained during the field investigation (on February 24, 2015) 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 members 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 (Drawing E7256022.dwg). The MTM NAD83 northing and easting coordinates, ground surface elevations referenced to Geodetic datum and borehole depths at each borehole location 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)
LY-1	5386728.3	245177.1	340.9	7.5
LY-2	5386715.7	245177.2	343.1	11.6
LY-3	5386718.5	245167.0	343.1	11.6
LY-4	5386712.5	245161.3	340.5	7.5

4.0 SITE GEOLOGY AND SUBSURFACE CONDITIONS

4.1 Regional Geology

Based on Northern Ontario Engineering Geology Terrain (NOEGTS)[1] mapping, the subsoils in the vicinity of the Lyon Creek culvert no. 2 site generally consist of glaciolacustrine plain deposits of clays and silts bordering with areas of organic terrain deposits comprised mainly of peat/muck.

Based on geological mapping by the Ministry of Northern Development and Mines (MNDM)[2], the site is underlain by bedrock of the Archean Era, comprised of mafic and ultramafic suites consisting of metasedimentary, and massive granodiorite to granite.

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 detailed 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

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

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

Section 4 are uncorrected. The stratigraphic boundaries shown on the Record of Borehole sheets and on the interpreted stratigraphic profile 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 embankment fill comprised of sand and gravel, sandy silt and clay (for boreholes advanced through the embankment), underlain by organics consisting of topsoil and organic clay, underlain by a deposit of clay. A more detailed description of the soil deposits and groundwater conditions encountered in the boreholes is provided below.

Deposit/Layer Description	Boreholes	Deposit Thickness (m)	Deposit Surface Elevation (m)	N Values (blows) / Shear Strength (kPa) / Consistency or Relative Density	Laboratory Testing
Asphalt	LY-2, LY-3	0.040	343.1	N/A	N/A
(FILL) [1] Sand and Gravel, trace silt; Sandy Silt, trace clay, wood fragments; and Clay, trace to some sand, trace gravel, wood fragments; brown to black to grey; frozen	LY-2, LY-3	2.3	343.1	N/A [2]	w = 24% 1 – MH (Fig. B1)
Topsoil/Organic Clay/ Organic Silt, trace to some sand, trace gravel; black to brown; frozen to moist	LY-1 to LY-4	0.1 – 1.5	340.8 – 340.5	N = 7 – 9 [3] **Firm to Stiff**	w = 32% - 38% w_l = 53% w_p = 29% I_p = 24% OC = 8% 1 – MH (Fig. B2) 1 – AL (Fig. B3)
Clay, trace to some sand, trace gravel, trace organics; brown to grey; frozen to wet	LY-1 to LY-4	6.9 – 7.9 (boreholes terminated in this deposit)	340.8 – 339.3	N = 4 – 8 [4] s_u = 86 – >100 S = 1 **Stiff to Very Stiff**	w = 28% - 34% w_l = 56% - 61% w_p = 20% - 25% I_p = 33% - 40% 5 – MH (Fig. B4) 7 – AL (Fig. B5)

Where:
N = SPT 'N'-value; number of blows for 0.3 m of penetration
w = Natural Moisture Content (%)
MH = Combined Sieve and Hydrometer analysis
AL = Atterberg Limits Test
OC = Organic Content (%)
s_u = Undrained Shear Strength (kPa)
S = Sensitivity
w_p = Plastic Limit (%)
w_l = Liquid Limit (%)
I_p = Plasticity Index (%)

Notes:

[1] Wood fragments were encountered within the fill in Boreholes LY-2 and LY-3.

[2] In the fill, SPT 'N'-values ranging from 19 blows to 95 blows per 0.3 m of penetration were measured, however, these are likely indicative of the frozen state of the material and not representative of the relative density of the fill.

[3] In the organic silt deposit, an SPT 'N'-value of 12 blows per 0.3 m was measured near the ground surface in Borehole LY-4, however, this is likely indicative of the frozen state of the material and not representative of the relative density of the deposit.

[4] In the clay deposit, an SPT 'N'-value of 23 blows per 0.3 m was measured near the ground surface in Borehole LY-1, however, this is likely indicative of the frozen state of the material and not representative of the consistency of the clay deposit.

Groundwater Conditions

All boreholes were dry upon completion of drilling. The creek ice level was measured at Elevation 340.1 m on February 13, 2015. Groundwater and creek 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. Mathew Riopelle and Mr. Daryl Miller under the overall direction of Mr. David Muldowney, P.Eng. This Preliminary Foundation Investigation Report was prepared by Mr. Tibor Berecz, and Mr. David Muldowney, P.Eng., provided a technical review of the report. Mr. Jorge M. A. Costa, P.Eng., the Designated MTO Foundations Contact and Principal of Golder, conducted an independent quality control review of this report.

Report Signature Page

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PART B

PRELIMINARY FOUNDATION DESIGN REPORT
LYON CREEK CULVERT NO. 2 – SITE NO. 45-264/C
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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 Lyon Creek Culvert No. 2. 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 culvert will be replaced with a culvert of similar dimensions, along the same alignment as well as at similar invert elevations to those of the existing open footing culvert. In addition, it is assumed that there will be no embankment grade raise or widening in the area of the culvert as part of the Hwy 602 reinstatement. As indicated in the structural inspection report dated February 10, 2014, settlement at the center of the culvert was noted, inferred to be likely due to the embankment loading on the clay deposit.

6.2 Foundations

6.2.1 Foundation Options

The Lyon Creek culvert is located in the District of Rainy River in the Township of Lash on Highway 602 at STA 10+035, approximately 2.6 km south of the junction of Highway 602 and 11. The highway embankment is approximately 3.8 m high relative to the culvert invert with approximately 1.6 m of soil cover over the existing culvert. The existing culvert consists of a concrete open footing structure, the details of which (i.e., width, height, length, etc.) are summarized in Table 1.

Based on discussions with HMM and as indicated on the preliminary General Arrangement (GA) drawings, we understand that the following culvert types are being considered at this location:

- A pre-cast open footing culvert with either a pre-cast concrete box or arch or a metal box; and
- A pre-cast concrete cap on sheet-pile abutments.

In this report we have considered the following options:

- A pre-cast concrete box;
- An open footing box or arch culvert supported on either cast-in-place or pre-cast footings;

- A pre-cast concrete cap on sheet-pile abutments; and
- A pipe culvert(s).

A pipe culvert, including an elliptical culvert and/or flexible arch culvert is considered feasible at this site but would provide less flow-through capacity compared to a box culvert or open footing culvert with a similar span and would likely require multiple, parallel pipes. If a pipe culvert is selected, a concrete pipe would be preferred as a structural plate or corrugated steel pipe typically has a shorter design life. A pre-cast concrete slab supported on sheet-pile abutments is also considered feasible at this site but the sheet-piles may need to be advanced to a significant depth to develop sufficient frictional forces or to penetrate into a competent stratum to develop sufficient toe resistance to meet the geotechnical axial design requirements. Open footing arch culverts could be considered but the flow through capacity could be limited or restricted due to the need to provide adequate soil cover, including the roadway pavement structure and the overall performance of such structures over the longer term is not known. From a foundation perspective, a box culvert sufficiently wide to handle the creek flow is preferred. A pre-cast concrete box culvert is recommended over an open footing culvert at this site as the subsurface conditions at the foundation level are suitable for the support of such a box foundation, it can accommodate an accelerated construction schedule, and there are reduced excavation, dewatering and shoring requirements. Other culvert types may be preferred due to construction staging or other considerations such as fisheries requirements related to natural channel substrate. A comparison of culvert types based on advantages, disadvantages and risks/consequences is presented in Table 2.

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 a box structure is tolerant of small magnitudes of movement related to freeze-thaw cycles, should these occur. We recommend that the replacement box culvert be founded on the stiff to very stiff clay deposit as encountered in the boreholes. In this regard, the central and southern portion of the culvert may have to be constructed on a granular mat/pad replacing the organic clay deposit present along this section of the culvert footprint, as detailed in Section 6.4.2.1. Recommended foundation elevation and foundation conditions for a replacement box culvert are provided in Table 3.

6.2.2.2 Open Footing Culvert

Strip footings for an open footing culvert should be founded at a minimum depth of 2.3 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). We recommend that the replacement box culvert be founded on the stiff to very stiff clay deposit as encountered in the boreholes. In addition, the footings should extend below any existing fill and/or any organics (including the organic clay deposit), where present. Recommended founding elevations and foundation conditions for the replacement open footing culvert are provided in Table 3.

6.2.2.3 Pre-Cast Concrete Slab on Sheet-Pile Abutments

Sheet-pile abutments supporting a concrete slab, if utilized at this site as the culvert construction option, will penetrate well below the frost depth to bear within the stiff to very stiff clay deposit, as noted in Table 3. Therefore, such a foundation should not be subject to frost induced heave per se but adhesion of the subsoils to the sheet-pile walls along 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.

6.2.2.4 Pipe Culvert(s)

It is not necessary to found a pipe culvert at the standard depth for frost protection purposes, as such a culvert is tolerant to small magnitudes of movement related to freeze-thaw cycles, should these occur. We recommend that the replacement pipe culvert(s), if adopted, be founded on the stiff to very stiff clay stratum. Similar to the box culvert option, the central and southern portion of the culvert may have to be constructed on a granular mat/pad replacing the organic clay deposit present along this section of the culvert footprint, as detailed in Section 6.4.2.1. Recommended founding elevations and foundation conditions for a pipe culvert are provided in Table 3.

6.2.3 Geotechnical Resistances

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. These recommendations are based on a box culvert width of 5.5 m as noted 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 those 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 or embankment widening is planned. It is recommended that the structural engineer exercise caution when utilizing the values of the geotechnical resistance at SLS (as provided in Table 3) in the design of the culvert and that consideration be given to the sequence and staging of construction, particularly if a grade raise or widening is to take place as the magnitude of settlement that will occur under the culvert will be governed by the resulting soil loading (not culvert loading).

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 axial resistance at ULS and geotechnical reaction at SLS, for 25 mm of settlement, as provided in Table 3. These recommendations are based on an assumed footing width of 0.6 m or 1.2 m as noted 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 axial resistance/reaction should, therefore, be reviewed if the culvert footing width or founding elevation differs from those 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 its 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 or embankment widening is planned. It is recommended that the structural engineer exercise caution when utilizing the values of the geotechnical resistance at SLS (as provided in Table 3) in the design of the culvert and that consideration be given to the sequence and staging of construction, particularly if a grade raise or widening is to take place as the magnitude of settlement that will occur under the culvert will be governed by the resulting soil loading (not culvert loading).

6.2.3.3 Pre-Cast Slab and Sheet-Pile Abutments

The sheet-piles should be driven to/into the stiff to very stiff clay stratum 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. These values do not include downdrag forces, which will need to be considered if the grade is raised or the embankments are widened, nor do the estimated depths of sheet-pile embedment account for the uplift stresses due to adhesion to frozen ground.

The unit factored geotechnical axial resistance/reaction provided in Table 3 are primarily based on frictional forces between the sheet-pile and the subgrade soil interface material. If a higher geotechnical resistance/reaction is required for design, the sheet-piles would need to be driven to a greater depth to increase the frictional resistance and/or to penetrate into a competent soils stratum to develop higher toe resistances; however, additional drilling would be required to confirm the soil conditions at greater depth.

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 between the 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 Stability and Settlement

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

For the subsurface conditions and the proposed embankments height up to about 2.9 m above the existing ground surface adjacent to the culvert (i.e., about 3.8 m high relative to the existing culvert invert), granular fill embankments at this site will be stable at side slopes inclined at 2 Horizontal to 1 Vertical (2H:1V) or flatter.

Given the presence of the stiff to very stiff clay deposit at this site, additional long term settlement and stability analysis will be required if a grade raise and/or widening is proposed. Further, depending on the magnitude of the grade raise and/or widening, additional field work and/or specialized laboratory testing may be required. Given that the existing culvert appears to have settled over time, it is important that there be no additional loading on the subsoils. Even small grade raises/widening could result in time-dependent settlement as well as differential settlement.

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 allow for 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 2.3 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 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:

Fill Type	Internal Angle of Friction (ϕ)	Unit Weight	Coefficients of Static Lateral Earth Pressure	
			At-Rest, K_o	Active, K_a
Granular 'A'	35°	22 kN/m^3	0.43	0.27
Granular 'B' Type II	35°	21 kN/m^3	0.43	0.27
Granular 'B' Type I or III	32°	21 kN/m^3	0.47	0.30
Clay	27°	17 kN/m^3	0.55	0.38

If the structure allows for lateral yielding, active earth pressures may be used in the design of the structure(s). If the structure does not allow for 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 replacement will be made through the existing embankment fill, comprised of sand and gravel, sandy silt and clay and into the native soils, which are comprised of organic clay and stiff to very stiff 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 embankment fill and native soils are considered to be Type 3 soil above the groundwater table and Type 4 soil below the groundwater table. Temporary open-cut excavations in Type 3 soils should remain stable if side slopes are formed no steeper than 1H:1V. In Type 4 soils, the side slopes 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 extended to suitable depth, or soldier piles and lagging where H-piles are driven to a suitable depth and horizontal lagging is installed as the excavation proceeds. Support to the temporary protection 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 wood, as encountered within the sandy silt fill and clay fill materials in Boreholes LY-2 and LY-3, respectively, and the potential presence of corduroy road material, which may have been used locally based on anecdotal information. It may be necessary to excavate and replace the existing fill materials in the areas of sheet-pile installation in a series of narrow trenches of limited length. In general, the narrowest suitable excavator bucket should be used. The replacement fill could consist of excavated fill material or imported granular material such as OPSS.PROV 1010 Granular 'A' or Granular 'B' Type I, II or III provided that 100 per cent of the material passes the 75 mm size and less than 5 per cent passes the 75 μm size. The excavated fill materials may be re-used to backfill the excavation after removing the wood (and any cobbles and boulders, if encountered) that would otherwise impede the sheet-pile installation. Excavation and replacement should be carried out on the same day to avoid leaving any trench open overnight. Consideration should be given to including 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, engineered fill or concrete, the existing embankment fill, topsoil, and organic clay/silt and any softened or disturbed soils, should be sub-excavated from below the plan limits of the proposed works to the founding levels provided in Table 3.

The culvert subgrade should be inspected by a Quality Verification Engineer following sub-excavation to ensure that all existing fill and other unsuitable materials have been removed as noted above, in accordance with OPSS 422 (Precast 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 OPSS.PROV 1010 (Aggregates) Granular ‘A’ or Granular ‘B’ Type 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 and levelling pad 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 groundwater seepage through the embankment fill during excavation to the invert and bedding level, it is recommended that a minimum 300 mm thick layer of OPSS.PROV 1010 (Aggregates) Granular ‘B’ Type II material be used for bedding purposes. As the native soil below the bedding is generally 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 meet 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 (SPMDD) 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 provided with a geometry similar to that provided on OPSD 803.010 (Backfill and Cover for Concrete Culverts) for culvert construction in dry conditions.

A frost taper should be constructed in a similar configuration as that shown in OPSD 803.010 (Backfill and Cover for Concrete Culverts). Although OPSD 803.010 relates to box culverts with spans less than or equal to 3.0 m, a similar frost taper at 10H:1V is considered acceptable for the assumed 5.5 m wide box culvert replacement option.

6.4.3.2 Open Footing Culvert

The excavation and backfilling 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 2.3 m of soil cover for frost protection.

Should a pre-cast open footing culvert be the selected replacement option, a bedding layer and levelling pad will be required above the native soil. The bedding layer and levelling pad for the pre-cast open footings should follow the recommendations as discussed above in Section 6.4.3.1 for the box culvert replacement option.

A frost taper should be constructed in a similar configuration as that shown in OPSD 803.010 (Backfill and Cover for Concrete Culverts). Although OPSD 803.010 also relates to an open footing culvert with spans less than or equal to 3.0 m, a similar frost taper at 10H:1V is considered acceptable for the assumed 12 m wide open footing culvert replacement option shown on the preliminary GA drawings.

6.4.3.3 Pipe Culvert(s)

The bedding, levelling and backfill for a concrete pipe, CSP culvert or SP CSP arch should be in accordance with OPSD 802.034 (Rigid Pipe Bedding and Cover in Embankment), OPSD 802.014 (Flexible Pipe, Embedment in Embankment) or OPSD 802.024 (Flexible Pipe Arch, Embedment in Embankment), 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 pipe 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, however this layer thickness should be confirmed at the detail design stage for the actual culvert type and size selected.

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 backfill should be placed in maximum 200 mm thick loose lifts and be compacted to at least 98 per cent of the SPMDD of the materials 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 native clay subgrade 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 concrete working slab should 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. An NSSP should 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 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 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. 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. 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 culvert 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 creek side slopes and fill slope over the culvert if a clay blanket is adopted.

6.4.6 Control of Groundwater and Surface Water

Excavation along the culvert alignment will be required to remove the existing fill, organic soils where present and some of the native clay stratum to achieve the required invert / bedding level prior to placement of bedding, the actual culvert, backfill and the roadway pavement structure. Groundwater flow into the excavation can be expected due to the depth of the excavations and the presence of relatively permeable embankment fill. 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 creek flow, local 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, the existing culvert or diverted by pumping from behind temporary cofferdams.

For the box culvert, open footing culvert(s) and pipe culvert options, excavations will extend below the creek water level, and potentially the groundwater level, and will therefore require temporary shoring with dewatering to allow for construction/placement of the footings and/or placement of engineered fill pad in dry conditions, where required. Although the open boreholes were noted to be dry upon completion of drilling, it is likely that the groundwater level is near ground surface, but discharge of groundwater into open excavations will be slow and of limited volume, and the need for dewatering will be limited. Temporary shoring and groundwater control could be in the form of a cut off wall or cofferdam advanced to an appropriate depth to control groundwater inflow from the creek and to prevent base heaving. As discussed in Section 6.4.2, engineered fill or sub-excavation replacement backfill can be placed subaqueously, however, dewatering may still be required for footing/box culvert placement as the culvert invert is at or below the creek water 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. An 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

Based on anecdotal information, we understand that corduroy roads were commonly used during culvert construction in the Northwest Region. The Contractor should be alerted to the presence of wood fragments and the potential for buried wood within the fill material, as encountered in Boreholes LY-2 and LY-3. An NSSP should be developed at the detail design stage for inclusion into the Contract Documents to alert the contractor to the potential presence of such obstructions.

6.4.8 Analytical Testing for Construction Materials

The results of an analytical test on a sample of creek water taken at the culvert site are presented in 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 and/or alignment of the culvert and the replacement strategy (i.e., staging). In particular, consideration should be given to drilling additional boreholes advanced to a suitable penetration depth within the clay deposit if the pre-cast slab supported on sheet-pile abutments option is selected or for design of temporary works if the culvert is to be constructed in stages while maintaining one open lane of traffic. The scope and results of this investigation must be reviewed at the time of the detail design 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 assessment of and 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, P.Eng. and the technical aspects were reviewed by Mr. David Muldowney, P.Eng. Mr. Jorge M. A. Costa, P.Eng., Designated MTO Foundations Contact and Principal of Golder, conducted an independent quality control review of this report.

Report Signature Page

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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(as amended).

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

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

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 Sewer 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 206	Construction Specification for Grading
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 of 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 with Spans Less Than or Equal to 3.0 m

OPSD 803.031	Frost Treatment – Pipe Culverts, Frost Penetration Line between Top of Pipe and Bedding Grade
OPSD 810.010	General Rip-Rap Layout for Sewer and Culvert Outlets
OPSD 3090.100	Foundation, Frost Penetration 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]	
			Type	Approximate Dimension[2]	Approximate Length (m)	East End of Culvert (m)	West End of Culvert (m)
Hwy 602 STA 10+035 (Township of Lash)	45-264/C	3.8	Concrete open footing	5.5 m wide x 2.1 m high	16.6	339.4	339.3

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 field review performed by HMM and the culvert invert elevations are based on the plan and profile drawings provided by MTO (Drawing E7256022.dwg).

Prepared by: AC
Checked by: DAM
Reviewed by: JMAC

Table 2: Comparison of Foundation Alternatives

Option	Advantages	Disadvantages	Risks/Consequences
Pre-Cast Box Culvert	■ Minimizes depth of excavation (required at the east side where there is a organic thin layer), protection system (if required) and dewatering requirements compared to open footing option. ■ Allows for faster construction resulting in shorter duration for dewatering and surface water pumping. ■ More tolerant of total and differential settlement due to frost penetration into the subgrade soils and if the highway embankment is raised or widened at the culvert site, or remnants of the organic deposit are not fully removed. ■ Backfill/bedding 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 seal) typically required at inlet to mitigate potential scour under the culvert. ■ Transportation to and on-site lifting of large pre-cast sections is required. ■ May require water diversion of the creek channel to accommodate construction using a full width culvert section, unless the culvert is comprised of multiple parallel box sections.	■ Some risk of disturbance of the native clay deposit during construction; can be mitigated with use of a tremie concrete working slab or Granular B Type II working pad. ■ Lower risk related to settlement performance as box segments are more tolerant of differential settlement.
Open Footing Culvert	■ May be feasible to construct the culvert on pre-cast footing sections, to accelerate construction schedule and reduce time for dewatering/unwatering (pumping) of surface water. ■ Would likely satisfy fisheries requirements related to natural channel substrate, if applicable. ■ Existing culvert can be used for water diversion while new footings are being constructed adjacent to the culvert. ■ Readily suitable for construction using concrete or metal sections.	■ Excavation depths to found the footings below the depth of frost penetration are greater than for a concrete box culvert option, resulting in increased excavation support and dewatering/unwatering requirements and additional spoil material to be disposed 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. ■ Concrete or metal arch sections supported on concrete open (strip) footings must provide for adequate flow-through capacity and allow for adequate soil cover to be placed including the roadway pavement structure.	■ High risk of disturbance of the native clay deposit during construction; can be somewhat mitigated with use of a concrete working slab or granular working pad but would require greater depth of dewatering for footing construction. ■ Higher risk of additional settlement for footings due to the smaller foundation footprint. ■ Culvert joints may be required to accommodate total and differential settlement (if applicable).

Option	Advantages	Disadvantages	Risks/Consequences
Pre-Cast Slab on Sheet-Pile Abutments	■ May not require temporary diversion of the creek depending on the required width of the culvert in comparison to the existing culvert as the sheet-piles can be installed around the existing culvert, which acts as the channel diversion and the new culvert can be constructed in sections. ■ Minimizes excavation depths and does not require dewatering. ■ Would satisfy fisheries requirements related to natural channel substrate, if applicable.	■ Likely will require additional deeper boreholes to assess adequacy of subsurface soils for potentially higher bearing capacities. ■ Potential difficulties in driving/vibrating sheet-piles due to the sensitivity of the subgrade soils. ■ Less tolerant of total and differential settlement if the highway embankment is raised or widened at the culvert site (i.e. potential for downdrag and/or heave due to adhesion, during frozen ground conditions, on the sheet-piles). ■ Steel sheet-piles may not have as long of a design life compared to concrete options. ■ Other issues such as guide rail installation and pavement structure thickness should be considered in low cover situations.	■ High risk that additional sheet-pile lengths will be required to achieve sufficient geotechnical axial resistance/reaction. ■ Some risk that additional sheet-pile lengths may be required due to disturbance of the subsurface soils during sheet-pile installation. ■ Joints may need to be incorporated into the slab to accommodate total and differential settlement.
Circular Pipe	■ Allows for 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. ■ Backfill under the culvert may be placed underwater (i.e. Granular 'B' Type II) minimizing or eliminating water pumping requirements.	■ Reduced flow-through capacity; additional flow capacity would have to be provided by multiple pipes. ■ Cut-off wall (or clay seal) may be required at inlet to mitigate potential scour under culvert. ■ Difficult to compact backfill materials to springline level of the culvert. ■ CSP does not have as long a design life compared to concrete options.	■ Some risk of disturbance of the native clay deposit during construction; can be mitigated with use of a tremie concrete working slab or Granular B Type II working pad. ■ Limited risk related to settlement performance.

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

Culvert Location (Township)	Approximate Invert Elevation [1] (East End / West End)	Culvert Type	Approximate Backfill/Bedding/Footing Founding Elevation (East End / West End)	Founding Condition	Factored Geotechnical Axial Resistance at ULS [2]	Geotechnical Reaction at SLS for 25 mm of Settlement [2]
Hwy 602 STA 10+035 (Township of Lash)	339.4 m / 339.3 m	Pre-Cast Box [2]	339.0 m / 338.9 m	Bedding over Stiff to Very Stiff Clay Stratum	200 kPa	100 kPa
		Open Footing [2] (0.6 m wide)	337.1 m / 337.0 m	Stiff to Very Stiff Clay or Replacement Fill over Stiff to Very Stiff Clay Stratum	200 kPa	150 kPa
		Open Footing [2] (1.2 m wide)				
		Pipe Culvert [3]	339.1 m / 339.0 m	Stiff to Very Stiff Clay Stratum	N/A	N/A
		Pre-Cast Slab on Sheet-Pile Abutments [4]	~ 332.0 m	Stiff to Very Stiff Clay Stratum	45 kN/m	40 kN/m

Notes:
1. Culvert invert elevations are based on the profile drawings provided by MTO (Drawing E7256022.dwg).
2. The factored geotechnical axial resistance at ULS and geotechnical reaction at SLS for 25 mm of settlement are estimated based on an assumed 5.5 m wide box culvert and a 0.6 m or 1.2 m wide open 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 foundation elevation may need to be adjusted based on the type and size of the pipe culvert and required bedding thickness.
4. The factored geotechnical resistance at ULS and geotechnical reaction at SLS (for 25 mm of settlement) are provided per horizontal metre of EZ88 series sheet-piling. 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: DAM
Reviewed by: JMAC

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 Open Footing		Cast-in-place Open Footing	
	Interface Material	Coefficient of Friction[1] (tan δ)	Interface Material	Coefficient of Friction[1] (tan δ)
Hwy 602 STA 10+035 (Township of Lash)	Compacted Granular Fill (Bedding/Levelling Pad)	0.45	Stiff to Very Stiff Clay	0.30

Notes: 1. These values are unfactored.

Prepared by: AC
Checked by: DAM
Reviewed by: JMAC

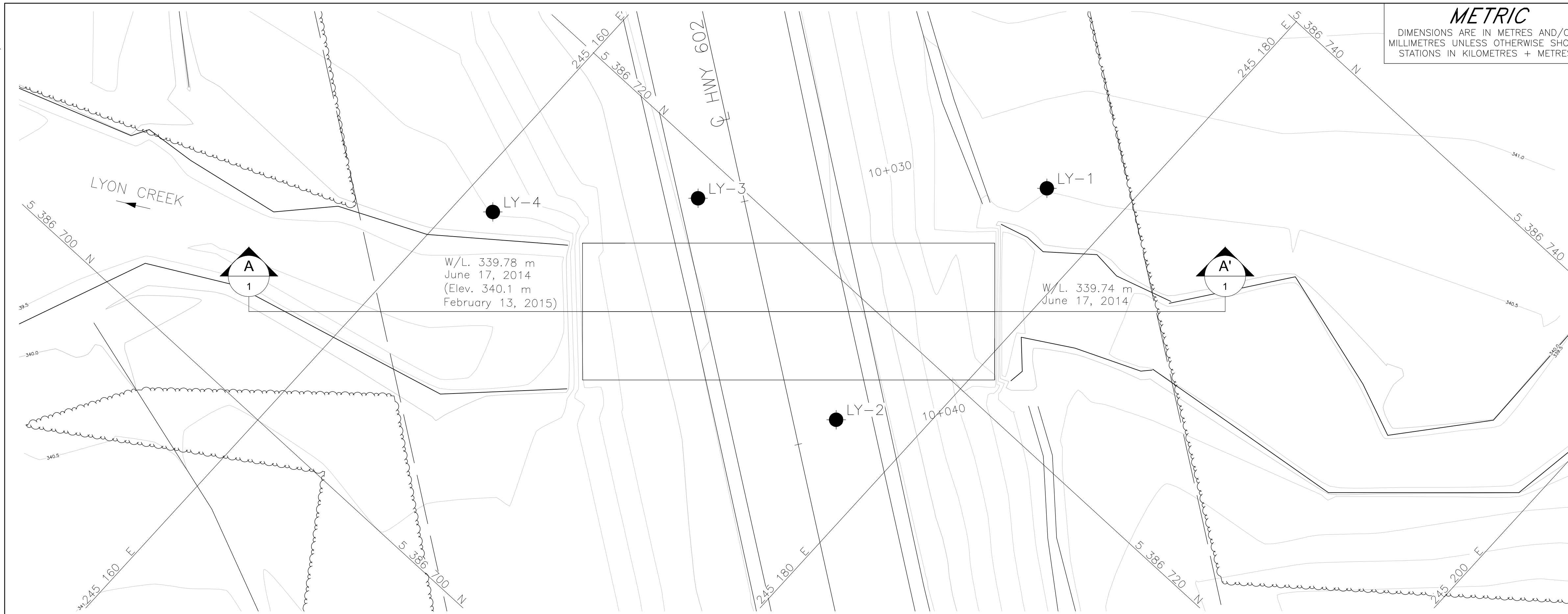
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS IN KILOMETRES + METRES.

CONT No.
GWP No. 6342-14-00

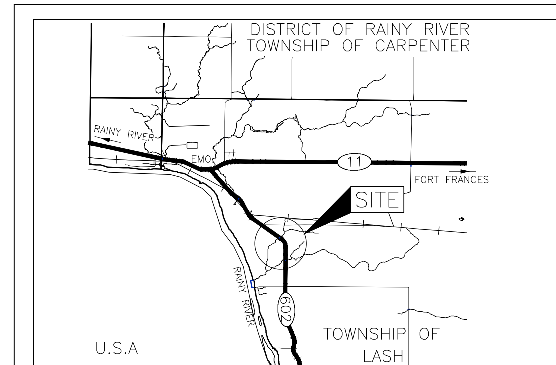
SHEET

HIGHWAY 602
LYON CREEK CULVERT NO. 2 STA 10+035
BOREHOLE LOCATION PLAN AND SOIL STRATA

Golder Associates



PLAN
SCALE
2 0 2 4 m



KEY PLAN
1 0 1 2 km
1:50,000 m

LEGEND

●	Borehole
N	Standard Penetration Test Value
16	Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
▽	WL upon completion of drilling

BOREHOLE CO-ORDINATES

No.	ELEVATION	NORTHING	EASTING
LY-1	340.9	5386728.3	245177.1
LY-2	343.1	5386715.7	245177.2
LY-3	343.1	5386718.5	245167.0
LY-4	340.5	5386712.5	245161.3

NOTES

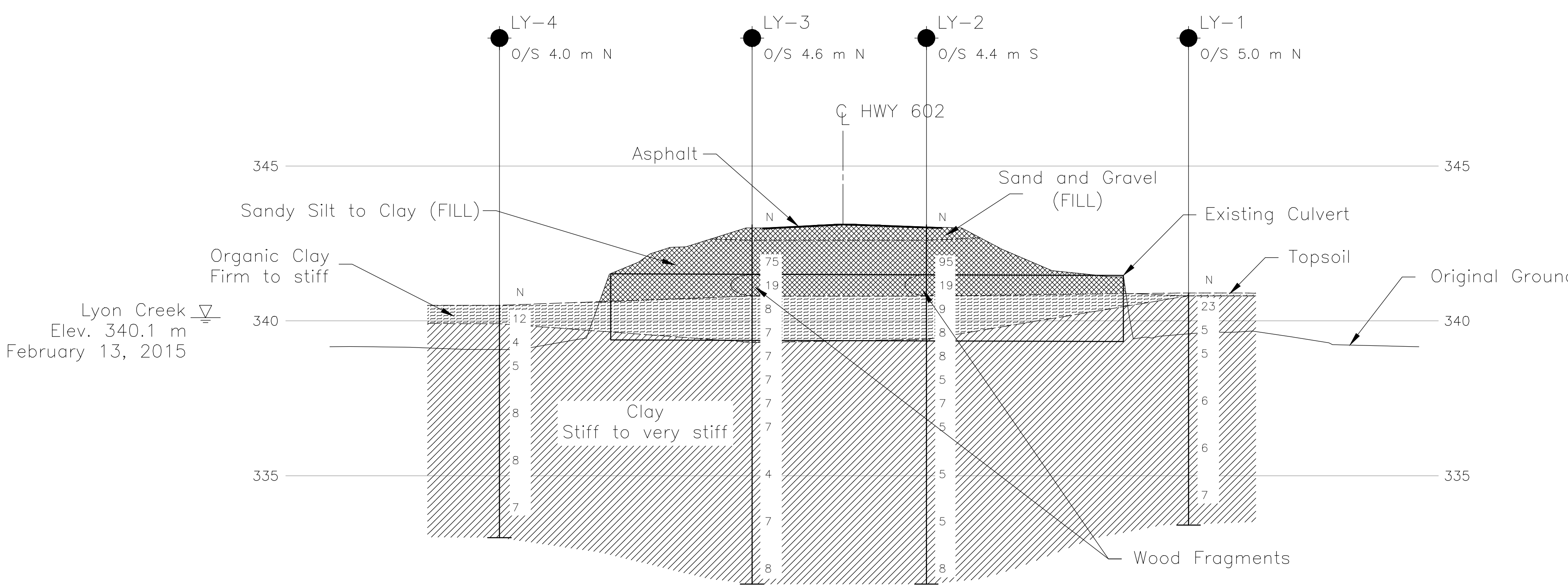
This drawing is for subsurface information only. The proposed structure details/works are shown for illustration purposes only and may not be consistent with the final design configuration as shown elsewhere in the Contracts Documents.

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 MTO, drawing file no. E7256022, dated JUN 2014, received JAN 27, 2015.



PROFILE
A-A' 1
HORIZONTAL SCALE
2 0 2 4 m
2 0 2 4 m
VERTICAL SCALE

LICENSED PROFESSIONAL ENGINEER D.A. MULDOWNEY 100164716 OCT 28 2015 PROVINCE OF ONTARIO

LICENSED PROFESSIONAL ENGINEER J.M.A. COSTA OCT 28 2015 PROVINCE OF ONTARIO

NO.	DATE	BY	REVISION

Geocres No. 52C-44

HWY. 602	PROJECT NO. 1411523		DIST.
SUBM'D. AC	CHKD.	DATE: 10/26/2015	SITE: 45-264/C
DRAWN: TB	CHKD. DAM	APPD. JMAC	DWG. 1

Photograph 1: Lyon Creek No. 2 Culvert
East Side - Inlet (Taken from MTO, OSIM_11-29-2013)

Photograph 2: Lyon Creek Culvert
West Side - Outlet (Taken from MTO, OSIM_11-29-2013)

Photograph 3: Lyon Creek Culvert
East Side – Inlet (Golder – February 24, 2015)

Photograph 4: Lyon Creek Culvert
West Side – Outlet (Golder – March 12, 2015)

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

* 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, 60º 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	Sand and Gravel
	With (cohesive)	Silty Clay with sand / Clayey Silt with sand

RECORD OF BOREHOLE No LY-1

 METRIC

PROJECT 1411523
G.W.P. 6342-14-00
LOCATION N 5386728.3; E 245177.1
ORIGINATED BY MR
DIST ___ HWY 602
BOREHOLE TYPE 108 mm I. D. Hollow Stem Augers
COMPILED BY TB
DATUM GEODETIC
DATE March 15, 2015
CHECKED BY DAM

ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	DYNAMIC CONE PENETRATION / SHEAR STRENGTH kPa	WATER CONTENT (%)	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
340.9	GROUND SURFACE								
0.0 / 0.1	TOPSOIL (75 mm)								
	CLAY, trace to some sand, trace gravel Stiff to very stiff Brown to grey Frozen* to wet Trace organics in the upper 1.5 m.	1	SS	23*					
		2	SS	5	340				
		3	SS	5	339				
						>100			
					338				
		4	SS	6			wP–w–wL		
					337	Field vane + (sensitivity 1)			
						>100			
		5	SS	6	336				
						Field vane + (sensitivity 1)			
					335	Field vane + (sensitivity 1)			
		6	SS	7			w ○		
					334	Field vane + (sensitivity 1)			
333.4						>100			
7.5	END OF BOREHOLE Note: 1. Borehole dry upon completion of drilling.								

Legend: ○ UNCONFINED; + FIELD VANE; ● QUICK TRIAXIAL; × REMOULDED. Plastic Limit w_P, Natural Moisture Content w, Liquid Limit w_L.

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

RECORD OF BOREHOLE No LY-2

 METRIC

PROJECT 1411523 | G.W.P. 6342-14-00 | DIST | HWY 602 | DATUM GEODETIC

LOCATION N 5386715.7; E 245177.2

BOREHOLE TYPE 108 mm I. D. Hollow Stem Augers

DATE February 13, 2015

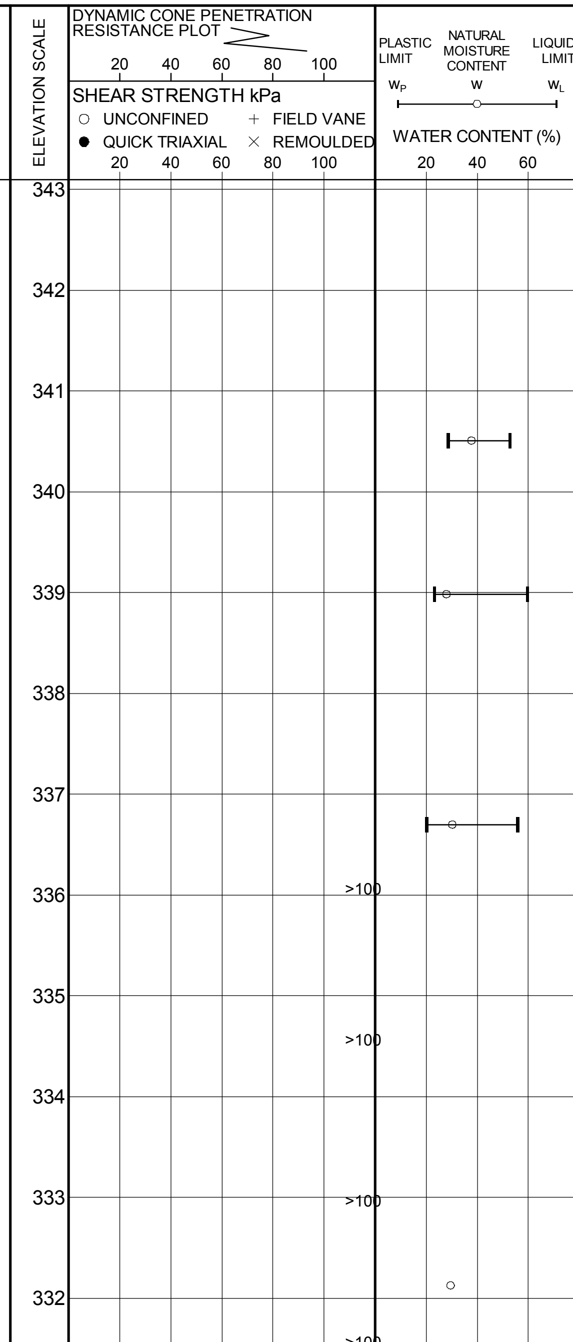
ORIGINATED BY DM | COMPILED BY TB | CHECKED BY DAM

ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
343.1	GROUND SURFACE				
0.0	ASPHALT (40 mm)				
342.6 0.5	Sand and gravel, trace silt (FILL) Brown Frozen				
	Sandy silt, trace clay, wood fragments (FILL) Grey Frozen	1	SS	95	
		2	SS	19	
340.8 2.3	ORGANIC CLAY, some sand Stiff Black Moist	3	SS	9	OC=8.1%; 0 19 44 37
		4	SS	8	
339.4 3.7	CLAY, some sand, trace gravel Very stiff Grey Moist	5	SS	8	4 12 38 46
		6	SS	5	
		7	SS	7	
		8	SS	5	2 13 37 48
		9	SS	5	
		10	SS	5	
		11	SS	8	
331.5 11.6	END OF BOREHOLE				

Note:

1. Borehole dry upon completion of drilling.

Dynamic cone penetration: >100 at approx. elev. 336.1, 334.6, 333.0, 331.6



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

Golder Associates

RECORD OF BOREHOLE No LY-3

 METRIC

PROJECT 1411523
G.W.P. 6342-14-00
LOCATION N 5386718.5; E 245167.0
ORIGINATED BY DM
DIST HWY 602
BOREHOLE TYPE 108 mm I. D. Hollow Stem Augers
COMPILED BY TB
DATUM GEODETIC
DATE February 13, 2015
CHECKED BY DAM

ELEV DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION	Water content (%)	GR	SA	SI	CL
343.1	GROUND SURFACE				343					
0.0	ASPHALT (40 mm)									
0.0	Sand and gravel, trace silt (FILL) Brown Frozen									
342.6 0.5	Clay, trace to some sand, trace gravel, wood fragments (FILL) Black to grey Frozen	1	SS	75	342	○	1	7	56	36
		2	SS	19						
340.8 2.3	ORGANIC CLAY, some sand Firm to stiff Black to brown Moist	3	SS	8	341	○				
		4	SS	7	340					
339.3 3.8	CLAY, some sand, trace gravel Very stiff Brown to grey Wet	5	SS	7	339					
		6	SS	7	338	wP–w–wL	1	12	41	46
		7	SS	7						
		8	SS	7	337					
					336	>100 (shear strength)				
		9	SS	4	335	wP–w–wL	0	13	38	49
						>100 (shear strength)				
		10	SS	7	334					
					333	>100 (shear strength)				
		11	SS	8	332					
331.5 11.6	END OF BOREHOLE					>100 (shear strength)				

Note:

1. Borehole dry upon completion of drilling.

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

SUD-MTO 001 1411523.GPJ GAL-MISS.GDT 28/10/15 DATA INPUT:

RECORD OF BOREHOLE No LY-4

 METRIC

PROJECT 1411523
G.W.P. 6342-14-00
LOCATION N 5386712.5; E 245161.3
ORIGINATED BY MR
DIST HWY 602
BOREHOLE TYPE 108 mm I. D. Hollow Stem Augers
COMPILED BY TB
DATUM GEODETIC
DATE March 15, 2015
CHECKED BY DAM

ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT / SHEAR STRENGTH kPa	WATER CONTENT (%)	UNIT WEIGHT γ kN/m³	GR	SA	SI	CL
340.5	GROUND SURFACE													
0.0	ORGANIC SILT, trace sand, trace gravel Brown Frozen		1	SS	12		340							
339.9 0.6	CLAY, trace to some sand, trace gravel Stiff to very stiff Brown to grey Wet		2	SS	4		339							
			3	SS	5		338	>100						
			4	SS	8		337	>100						
			5	SS	8		336				0	12	31	57
			6	SS	7		335	>100						
							334	+1						
333.0 7.5	END OF BOREHOLE Note: 1. Borehole dry upon completion of drilling.						333	>100						

Legend: ○ UNCONFINED; + FIELD VANE; ● QUICK TRIAXIAL; × REMOULDED. PLASTIC LIMIT W_P, NATURAL MOISTURE CONTENT W, LIQUID LIMIT W_L.

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

APPENDIX B

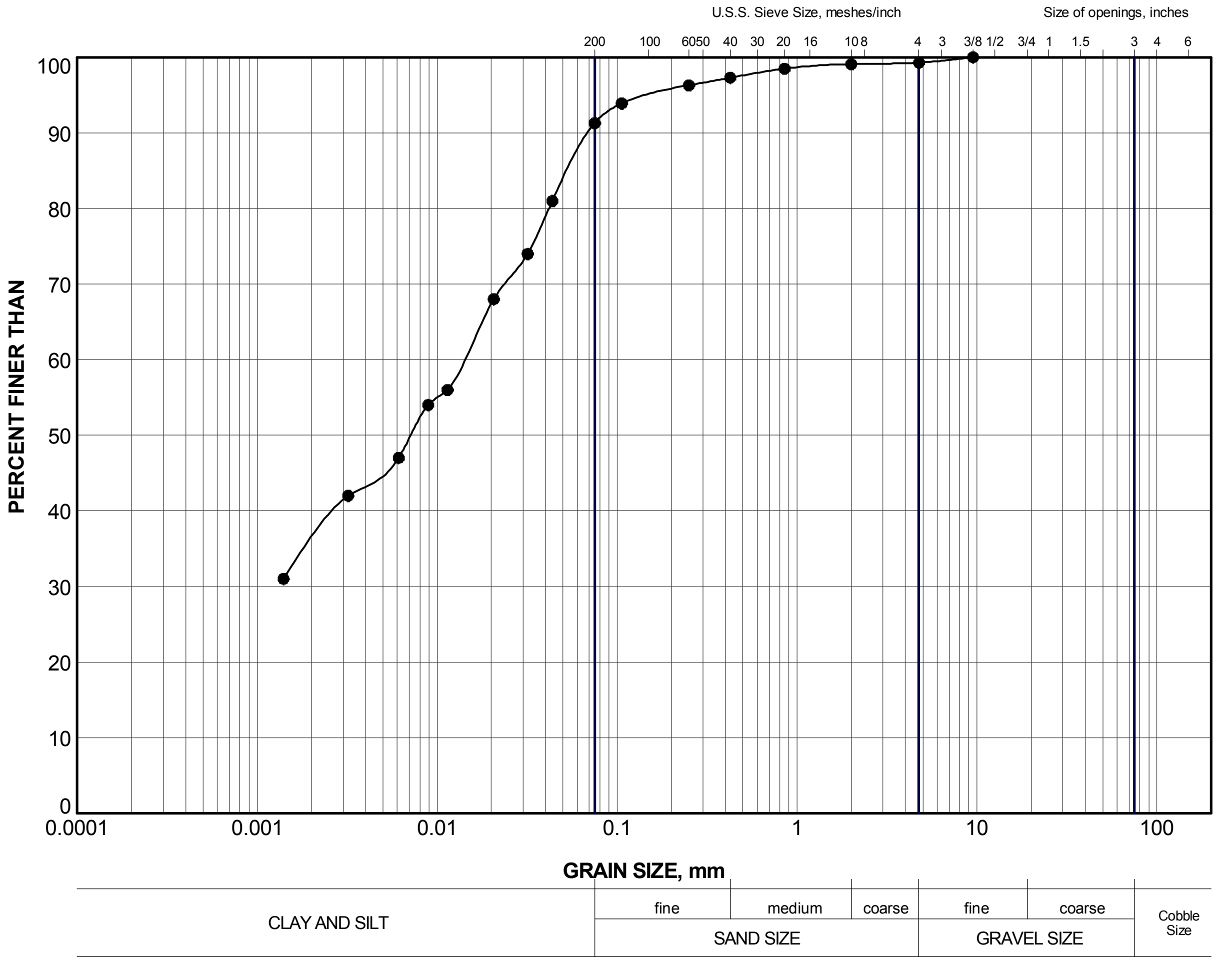
Laboratory Test Results

Table B1: Summary of Analytical Testing of Lyon Creek Water Sample

Parameter	Units	Result
Chloride (CL)	mg/L	31.3
Sulphate (SO4)	mg/L	6.44
Conductivity (EC)	µS/cm	459
Resistivity	µohm-cm	<0.33
pH	n/a	7.06

Notes:
1. Sample obtained on February 24, 2015.
2. Analytical testing carried out by ALS Canada Ltd.

Prepared by: TB
Checked by: DAM
Reviewed by: JMAC



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	LY-3	1	342.0

PROJECT

HIGHWAY 602
LYON CREEK CULVERT NO. 2 STA 10+035

TITLE

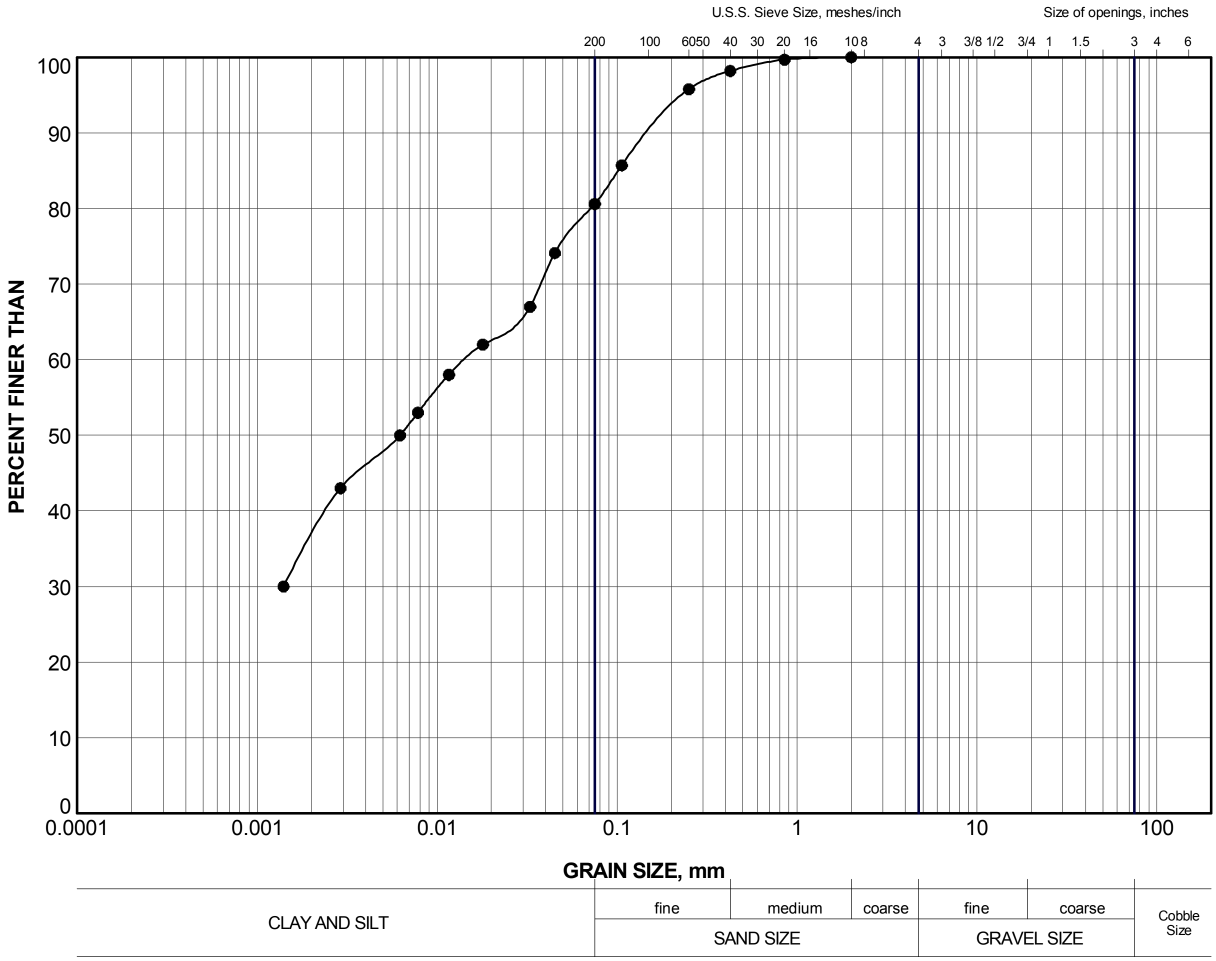
GRAIN SIZE DISTRIBUTION

CLAY (FILL)

Golder Associates
SUDBURY, ONTARIO

PROJECT No.		1411523	FILE No.	1411523.GPJ
DRAWN	TB	May 2015	SCALE N/A	REV.
CHECK	DAM	May 2015	**FIGURE B1**	
APPR	JMAC	May 2015		

SUD-MTO GSD (NEW) GLDR_LDN.GDT



LEGEND

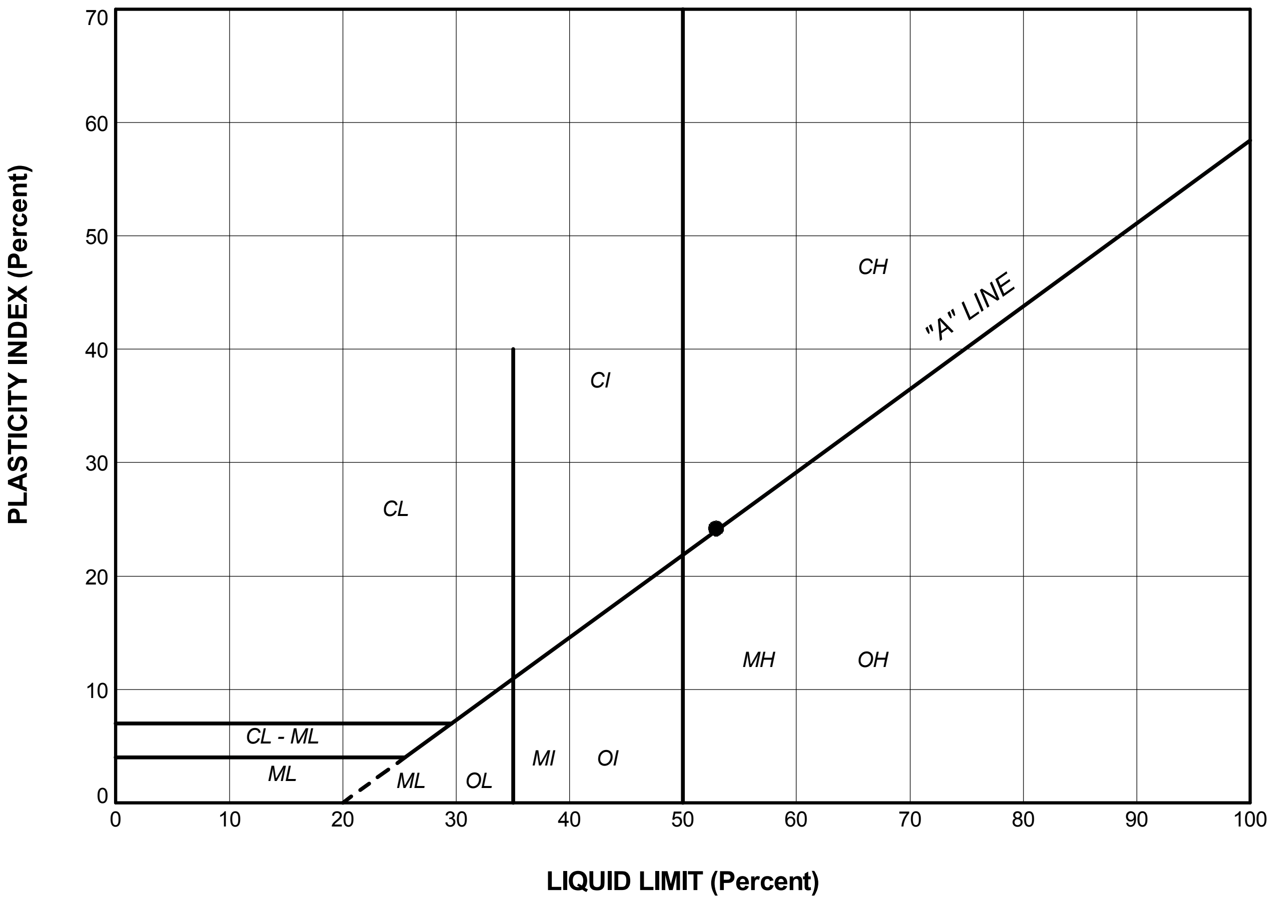
SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	LY-2	3	340.5

PROJECT	HIGHWAY 602 LYON CREEK CULVERT NO. 2 STA 10+035
TITLE	**GRAIN SIZE DISTRIBUTION** ORGANIC CLAY

Golder Associates
SUDBURY, ONTARIO

PROJECT No.		1411523	FILE No.	1411523.GPJ
DRAWN	TB	May 2015	SCALE N/A	REV.
CHECK	DAM	May 2015	**FIGURE B2**	
APPR	JMAC	May 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
●	LY-2	3	52.9	28.7	24.2

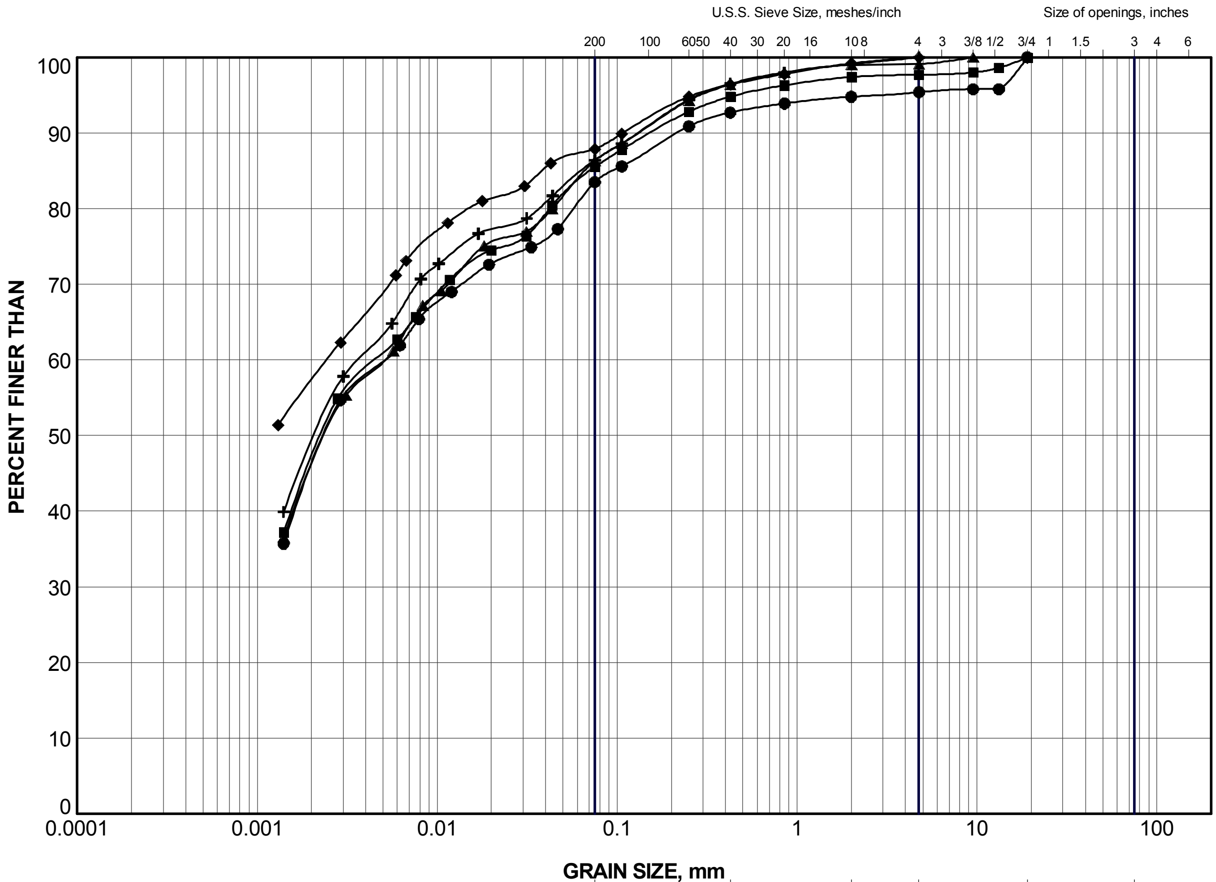
PROJECT
HIGHWAY 602
LYON CREEK CULVERT NO. 2 STA 10+035

TITLE
PLASTICITY CHART
ORGANIC CLAY

Golder Associates
SUDBURY, ONTARIO

PROJECT No.		1411523	FILE No.	1411523.GPJ
DRAWN	TB	May 2015	SCALE N/A	REV.
CHECK	DAM	May 2015		
APPR	JMAC	May 2015	**FIGURE B3**	

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)
●	LY-2	5	339.0
■	LY-2	8	336.7
▲	LY-3	6	338.2
✚	LY-3	9	335.2
◆	LY-4	5	335.6

PROJECT

HIGHWAY 602
LYON CREEK CULVERT NO. 2 STA 10+035

TITLE

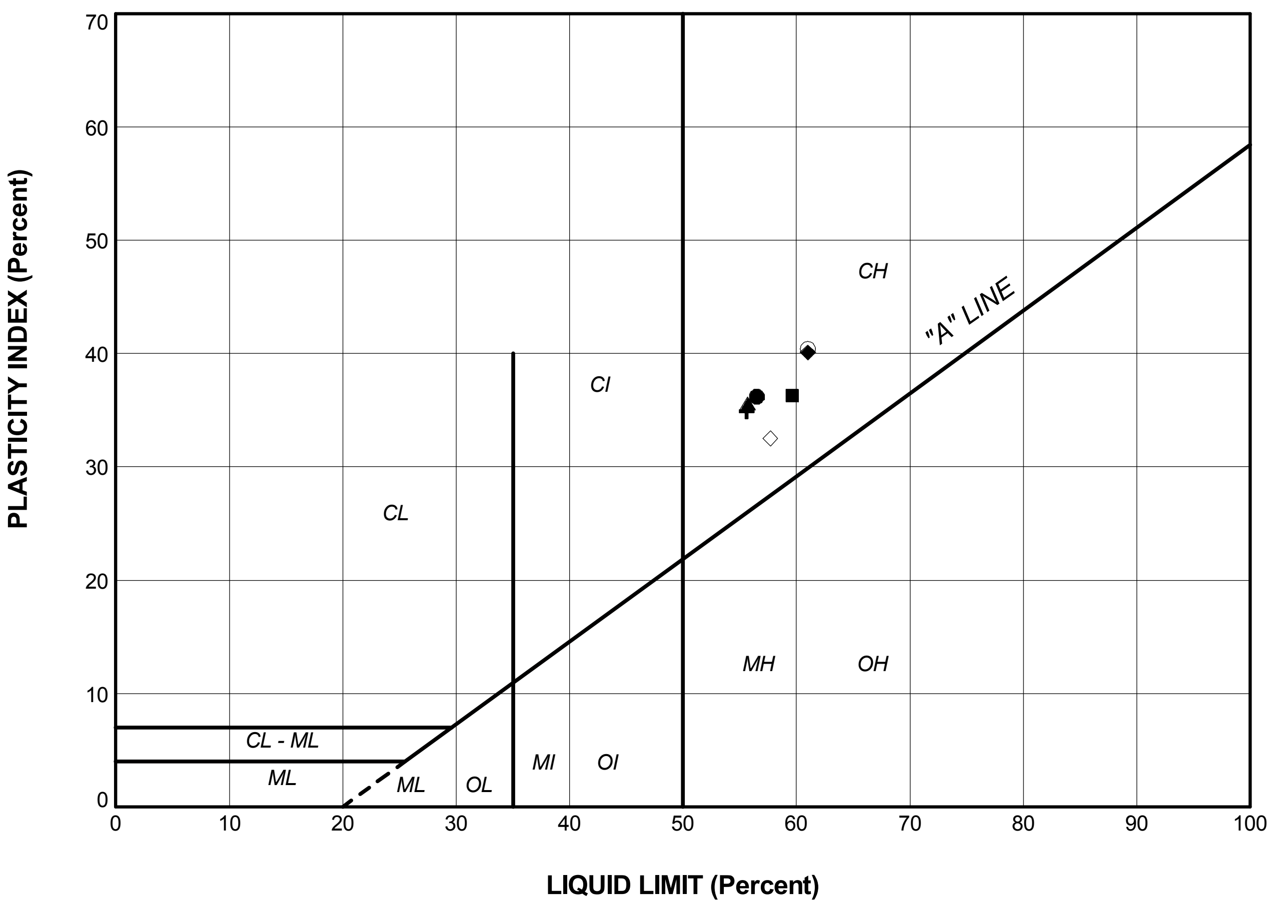
GRAIN SIZE DISTRIBUTION

CLAY

Golder Associates
SUDBURY, ONTARIO

PROJECT No.		1411523	FILE No.	1411523.GPJ
DRAWN	TB	May 2015	SCALE N/A	REV.
CHECK	DAM	May 2015		
APPR	JMAC	May 2015	**FIGURE B4**	

SUD-MTO GSD (NEW) GLDR_LDN.GDT



SOIL TYPE	PLASTICITY
C = Clay	L = Low
M = Silt	I = Intermediate
O = Organic	H = High

LEGEND

SYMBOL	BOREHOLE	SAMPLE	LL(%)	PL(%)	PI
●	LY-1	4	56.5	20.3	36.2
■	LY-2	5	59.6	23.3	36.3
▲	LY-2	8	55.7	20.1	35.6
✚	LY-3	6	55.6	20.7	34.9
◆	LY-3	9	61.0	20.9	40.1
◇	LY-4	2	57.7	25.2	32.5
○	LY-4	5	61.0	20.6	40.4

PROJECT

HIGHWAY 602
LYON CREEK CULVERT NO. 2 STA 10+035

TITLE

PLASTICITY CHART

CLAY

Golder Associates
SUDBURY, ONTARIO

PROJECT No.		1411523	FILE No. 1411523.GPJ	
DRAWN	TB	May 2015	SCALE N/A	REV.
CHECK	DAM	May 2015	FIGURE B5	
APPR	JMAC	May 2015		

SUD-MTO PL (NEW) GLDR_LDN.GDT

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