June 2015

PRELIMINARY FOUNDATION INVESTIGATION AND DESIGN REPORT

Structural Culvert Replacement
Tributary to Murray Drain, Site Number 19-650/C
Highway 401 Interchange Improvements/
Structural Replacements
GWP 3054-11-00, Assignment No. 1 (3011-E-0046)
Ministry of Transportation, Ontario - West Region

Submitted to:
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REPORT

Report Number: 12-1132-0076-1001-R05A

Geocres No. 40I14-158

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PRELIMINARY FOUNDATION INVESTIGATION REPORT

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MINISTRY OF TRANSPORTATION, ONTARIO - WEST REGION

1.0 INTRODUCTION

Golder Associates Ltd. (Golder Associates) has been retained by Dillon Consulting Limited (Dillon) on behalf of the Ministry of Transportation, Ontario (MTO) to carry out foundation investigations as part of the preliminary design and 30% detailed design work for GWP 3030-11-00, 3054-11-00, 3053-11-00, 3070-11-00, 3059-11-00, and 3055-11-00. The project involves the preliminary design and 30% detailed design for ten (10) bridges, including improvements at five (5) interchanges, and two structural culverts on Highway 401. The work for GWP 3054-11-00 includes replacement of the Pond Mills Road Overpass and C.N.R. Overhead, as well as culverts for the Tributary to Murray Drain and Elliot-Laidlaw Drain.

This report addresses the replacement and/or rehabilitation of the Tributary to Murray Drain structural culvert, Station 24+954, located approximately 1.7 kilometres west of Highbury Avenue South, in the City of London, Ontario (Site 19-650/C).

The purpose of the foundation investigation is to explore the subsurface conditions at the location of the proposed structure upgrades by drilling boreholes and carrying out in situ testing and laboratory testing on selected samples. The terms of reference for the scope of work are outlined in the MTO's Request for Proposal and in Golder Associates' proposal P2-1132-0076-P01 dated September 10, 2012. The work was carried out in accordance with our Quality Control Plan for Foundations Engineering dated November 2012.

2.0 SITE DESCRIPTION

2.1 General

The subject structural culvert is located in the City of London, Ontario. The location of the site is shown on the Key Plan, Figure 1. For the purposes of this report, Highway 401 and the culvert are assumed to be oriented in an east-west direction and a north-south direction, respectively. This section of Highway 401 is currently a six lane divided highway oriented generally northeast-southwest. The areas adjacent to the culvert site consist of relatively flat-lying commercial lands. Site photographs are presented in Appendix B.

The existing Tributary to Murray Drain culvert was constructed in 1953 and is a concrete, non-rigid frame, open footing culvert. The original 51.8 metre long structure was subsequently extended with open footing rigid frame extensions added to each end, for a total length of about 74 metres. The composite structure has a span of about 3.1 metres, height of 1.8 metres, and approximately 2.1 metres of soil cover. It is understood that various rehabilitation/replacement options are being considered for the culvert site.

2.2 Site Geology

This project lies within the physiographic region known as the Westminster Moraine. The physiographic mapping indicates that the culvert site is situated on an undrumlinized till plane.[1] Geology mapping indicates that the surficial material consists of Port Stanley silty clay till and clayey silt till, in places covered by thin patches of lacustrine silt.[2]

The rock formation in the area of the culvert site is described as medium brown, microcrystalline limestone of the Dundee Formation which belongs to the Hamilton Group of Middle Devonian Age.[3] The bedrock surface is estimated to be at about elevation 210 metres, some 65 metres below ground surface.

[1] Chapman, L.J. and Putnam, D.F., 1984: The Physiography of Southern Ontario, Third Edition. Ontario Geological Survey, Special Volume 2.

[2] Dreimanis, A., 1963: Pleistocene Geology of the St. Thomas Area (East Half), Southern Ontario. Ontario Department of Mines, Preliminary Geological Map 238, scale 1:50,000.

[3] Sanford, B.V., 1969: Geology, Toronto-Windsor Area, Ontario. Geological Survey of Canada, Map 1263A, scale 1:250,000.

3.0 INVESTIGATION PROCEDURES

The field work for the investigation was carried out on May 15 and 16, 2013, during which time 3 boreholes were drilled at the locations shown on the Borehole Location Plan, Drawing 1. The table below summarizes the borehole locations, ground surface elevations at the borehole locations, and borehole depths.

Borehole	Location (m)		Ground Surface Elevation (m)	Borehole Depth (m)
	Northing	Easting		
601	4 755 462	410 935	266.0	9.4
602	4 755 406	410 955	263.8	7.5
603	4 755 414	410 945	265.8	8.7

The investigation was carried out using all-terrain drilling equipment supplied and operated by a specialist drilling contractor. Samples of the overburden were obtained at generally 0.75 metre intervals of depth in the boreholes using 50 millimetre outside diameter split spoon sampling equipment in accordance with the standard penetration test (SPT) procedures of ASTM D1586. According to ASTM D1586, the SPT resistance, or N value, is defined as the number of blows required by a 63.5 kilogram hammer dropped from a height of 760 millimetres to drive a split-spoon sampler a distance of 300 millimetres, after an initial 150 millimetres of penetration. The spilt spoon samplers used in the investigation limit the maximum particle size that can be sampled and tested to about 38 millimetres. Therefore, particles or objects that may exist within the soils that are larger than this dimension will not be sampled or represented in the grain size distributions. The results of the SPT testing as presented on the Record of Borehole sheets and in Section 4 are unmodified (not standardized for hammer efficiency, borehole diameter, rod length, etc.).

The boreholes were terminated between 7.5 and 9.4 metres below the existing ground surface at the borehole locations. Groundwater conditions in the boreholes were observed throughout the drilling operations and a standpipe was installed in borehole 601 as indicated on the corresponding Record of Borehole sheet. The boreholes were backfilled in accordance with current MTO procedures and Ontario Regulation 903 (as amended).

The field work was monitored on a full-time basis by experienced Golder Associates staff members who also located the boreholes in the field, obtained utility locates, monitored the drilling, sampling, and in situ testing operations, and logged the boreholes. The samples were identified in the field, placed in labelled containers, and transported to our London laboratory for further examination and testing. Index and classification tests, consisting of water content determinations, grain size distribution analyses, and Atterberg Limits determinations were carried out on selected samples. The results of the testing are shown on the Record of Borehole sheets and in Appendix A.

The locations of the boreholes are shown on the Record of Borehole sheets and on Drawing 1, attached.

4.0 SUBSURFACE CONDITIONS

4.1 Site Stratigraphy

The detailed subsurface soil and groundwater conditions encountered in the boreholes, together with the results of the in situ testing and the laboratory testing carried out on selected samples, are provided on the attached Record of Borehole sheets following the text of this report and in Appendix A. The stratigraphic boundaries shown on the Record of Borehole sheets are inferred from non-continuous samples and observations of drilling resistance and, therefore, may represent transitions between soil types rather than exact planes of geological change. Further, the subsurface conditions will vary between and beyond the borehole locations.

The boreholes drilled at the site generally encountered topsoil or pavement structure overlying fill materials, overlying layers of silt and clayey silt.

The locations and elevations of the boreholes, together with the interpreted stratigraphic profiles, are shown on Drawing 1. Detailed descriptions of the subsurface conditions encountered in the boreholes are provided on the Record of Borehole sheets and are summarized in the following sections.

4.1.1 Topsoil

Approximately 75 and 275 millimetres of topsoil was encountered at the ground surface in boreholes 601 and 602. Materials designated as topsoil in this report were classified solely based on visual and textural evidence. Testing of organic content or for other nutrients was not carried out. Therefore, the use of materials classified as topsoil cannot be relied upon for support and growth of landscaping vegetation.

4.1.2 Pavement Structure

Approximately 180 millimetres of asphalt was encountered at the ground surface in borehole 603. The asphalt was underlain by about 180 millimetres of granular base material which was underlain by about 850 millimetres of granular sub-base material. The granular sub-base materials were noted to contain cobbles. A single measured N value from standard penetration testing carried out in the granular sub-base material was 24 blows per 0.3 metres.

4.1.3 Fill

Fill materials were encountered in boreholes 601 and 602 beneath the topsoil and in borehole 603 beneath the pavement structure. Approximately 1.9 to 4.2 metres of fill materials were encountered. The fill materials were clayey silt or silty clay with some sand and gravel. Measured N values in the fill materials ranged from 6 to 13 blows per 0.3 metres. Water contents of two samples of the fill materials were about 15 and 24 per cent. Two samples of the cohesive fill materials had plastic limits of 18 and 25 per cent and liquid limits of 33 and 47 per cent, based on Atterberg limits determinations the results of which are shown on Figure A-6. The results of grain size determinations carried out on samples of the fill materials are shown on Figure A-1.

4.1.4 Silt

Layers of compact to very dense silt were encountered in boreholes 601 and 602 underlying the fill materials and in borehole 602 beneath an upper layer of clayey silt. The silt layer in borehole 601 was encountered at about elevation 261.7 metres and was about 3.1 metres thick. The silt layers in borehole 602 were encountered at elevations 261.7 and 259.4 and were 0.8 and 1.8 metres thick.

Measured N values in the silt ranged from 12 to 54 blows per 0.3 metres. Water contents of samples of the silt ranged from about 17 to 18 per cent. The silt in borehole 602 was noted to contain clayey silt seams and layers, which is reflected in the grain size distribution by a higher clay content than is representative of the silt layer. The results of grain size determinations carried out on samples of the silt and silt with clayey layers are shown on Figure A-2.

4.1.5 Clayey Silt

Stiff to hard clayey silt was encountered in boreholes 601 and 602 beneath each of the silt layers and in borehole 603 beneath the fill. The clayey silt layers were encountered between elevations 257.5 and 263.0 metres. The upper layer of clayey silt in borehole 602 was about 1.5 metres thick. Boreholes 601, 602, and 603 were terminated in the clayey silt after exploring for between about 1.2 and 5.9 metres.

Measured N values in the clayey silt ranged from 12 to 35 blows per 0.3 metres. Water contents of samples of the clayey silt ranged from about 15 to 20 per cent. The clayey silt had plastic limits of between 13 and 16 per cent and liquid limits of between 19 and 25 per cent, based on five Atterberg limits determinations, the results of which are shown on Figure A-4. The results of grain size determinations carried out on samples of the clayey silt material are shown on Figure A-3.

4.2 Groundwater Conditions

Groundwater conditions were observed during and on completion of drilling and sampling. Also, a standpipe was installed in borehole 601. A summary of the encountered and measured groundwater levels and the water levels in the drain is provided in the table below.

Borehole	Ground Surface Elevation (m)	Encountered Groundwater Elevation (m)	Installation	Measured Groundwater Elevation (m)		Elevation of Water Level in Drain (m)	
				June 5, 2013	June 20, 2013	May 15, 2013	May 16, 2013
601	266.0	*	Standpipe	263.9	263.9	263.5	263.5
602	263.8	*	-	-	-		
603	265.8	263.0	-	-	-		

* Groundwater level not established.

Based on the observed groundwater levels, the surrounding topography, and water levels in the drain, the groundwater level is inferred to be about elevation 263.5 metres. Groundwater levels are expected to fluctuate seasonally and are expected to be higher during periods of sustained precipitation or during spring snow melt conditions and will be influenced by the water levels in the municipal drain.

5.0 MISCELLANEOUS

This investigation was carried out using equipment supplied and operated by Lantech Drilling Services Inc., an Ontario Ministry of Environment licensed well contractor. The field operations were supervised by Mr. Michael Arthur under the direction of Mr. David J. Mitchell.

The laboratory testing was carried out at Golder Associates' London laboratory under the direction of Mr. Chris M. Sewell. The laboratory is an accredited participant in the MTO Soil and Aggregate Proficiency Program and is certified by the Canadian Council of Independent Laboratories for testing Types C and D aggregates. This report was prepared by Ms. Nicole A. Gould, P.Eng. under the direction of the Project Engineer, Ms. Dirka U. Prout, P.Eng. and the Team Leader, Dr. Storer J. Boone, P.Eng. This report was reviewed by Mr. Azmi M. Hammoud, P.Eng. An independent audit of this report was carried out by Mr. Fintan J. Heffernan, P.Eng., the Designated MTO Contact and Quality Control Auditor for this assignment.

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PART B

PRELIMINARY FOUNDATION DESIGN REPORT

STRUCTURAL CULVERT REPLACEMENT
TRIBUTARY TO MURRAY DRAIN, SITE NUMBER 19-650/C
HIGHWAY 401 INTERCHANGE IMPROVEMENTS/STRUCTURAL REPLACEMENTS
GWP 3054-11-00, ASSIGNMENT No. 1 (3011-E-0046)
MINISTRY OF TRANSPORTATION, ONTARIO - WEST REGION

6.0 ENGINEERING RECOMMENDATIONS

6.1 General

This section of the report provides our recommendations on the foundation aspects of the design of the replacement and/or rehabilitation of the Tributary to Murray Drain culvert at Station 24+954, located approximately 1.7 kilometres west of Highbury Avenue South, in the City of London, Ontario (Site 19-650/C). The recommendations are based on our interpretation of the factual information obtained during the investigation. It should be noted that the interpretation and recommendations are intended for use only by the design engineer. Where comments are made on construction, they are provided only in order to highlight those aspects which could affect the design of the project. Those requiring information on aspects of construction should make their own interpretation of the factual information provided as it may affect equipment selection, proposed construction methods, and scheduling.

It is understood that rehabilitation and full replacement options are being considered for the Tributary to Murray Drain culvert. The options include lining the culvert with 1500 millimetre diameter pipes grouted in place, structural rehabilitation with a 1710 by 2680 millimetre elliptical pipe, and full replacement with a 1830 by 1830 millimetre box culvert. MTO has indicated that full replacement is preferred. Also, the grade at the site is to be raised by 0.5 metres. Consideration may also be given to replacing the culvert with an open footing structure founded on shallow strip footings.

It has been indicated by Dillon that the design catchment area of the Tributary to Murray Drain culvert has been reduced from 70 hectares to about 10 hectares; therefore, the culvert size will be reduced. It should be noted that a culvert with a span of less than 3 metres is not considered by the MTO to be a structural culvert. It is anticipated that the replacement culvert invert elevations will be similar to those of the existing structure.

6.2 Existing Structure

The existing culvert was constructed in 1953 and is a concrete, non-rigid frame, open footing culvert. The original 51.8 metre long structure was subsequently extended with open footing rigid frame extensions added to each end, extending the total length to approximately 74 metres. The composite structure has a span of about 3.1 metres, height of 1.8 metres, approximately 2.1 metres of soil cover, and an invert elevation of about 263.0 metres.

6.3 Foundations

The subsurface conditions encountered during the investigation generally consisted of topsoil or pavement structure overlying fill materials, overlying layers of silt and clayey silt. The groundwater level is inferred to be about elevation 263.5 metres.

The culvert replacement should be designed to withstand the appropriate weight of fill and traffic loading. If an open footing culvert design is selected, adequate cover for frost protection is required. Alternatively, if a box or pipe culvert design is selected, it is not necessary to found the culvert replacement at the standard depth for frost penetration protection purposes as pipe and pre-cast box culvert structures are tolerant of small magnitude movements related to freeze-thaw cycles should these occur. A pipe or box culvert replacement should, however, be founded below any existing fill and organic materials.

Based on the existing invert elevation, a pipe or box culvert may be founded at or below elevation 262.6 metres and shallow foundations for an open bottom culvert may be founded at or below 261.8 metres.

It is anticipated that excavations to the elevations noted above may not fully penetrate the existing fill materials. If fill materials, organics, or loose or soft soils are observed in the base of culvert excavations, the excavations should be extended to the native silt or clayey silt. The native soils were encountered between elevations 261.7 and 263.0 metres. It is anticipated that subexcavation to reach the native soils will likely not exceed about 0.3 metres for shallow foundations and 0.9 metres for a pipe or box culvert.

For pipe or box culvert construction, areas of sub-excavation should be brought to design grade with engineered fill placed on the native silt to clayey silt. The engineered fill should consist of OPSS Granular A or Granular B, Type II placed in maximum 300 millimetre loose lifts and compacted to at least 98 per cent of the standard Proctor maximum dry density. Shallow footings for an open bottom culvert should be founded on the native soils.

Geotechnical Resistances

The compact to very dense silt and stiff to very stiff clayey silt at the site are suitable for support of the proposed culvert replacement. A pipe or box culvert and shallow footings for an open bottom culvert founded on the native soils may be designed using a factored geotechnical resistance at Ultimate Limit States (ULS) of 270 kilopascals (kPa) and a geotechnical resistance at Serviceability Limit States (SLS) of 180 kPa. A pipe or box culvert founded on engineered fill as described above may also be designed using a factored geotechnical resistance at ULS of 270 kPa and a geotechnical reaction at SLS of 180 kPa. The SLS values correspond to a maximum of 25 millimetres total settlement.

Resistance to Lateral Forces

The resistance to lateral forces/sliding resistance between the culvert base or footings and the bedding or native soils should be calculated in accordance with Section 6.7.5 of the Canadian Highway Bridge Design Code (CHBDC). Assuming that the founding soils are not loosened/disturbed during excavation and footing construction, and the bedding and leveling pad are adequately constructed, the following angles of friction between the culvert concrete foundation and founding stratum, and corresponding unfactored coefficient of friction, tan δ, may be used.

Culvert Type	Interaction	Angle of Friction, δ (degrees)	Coefficient of Friction, Tan δ
Open footing culvert	Cast-in-place concrete footing on:		
	native silt	26	0.49
	native clayey silt	24	0.45
Pre-cast box culvert	Pre-cast concrete on Granular A levelling pad	30	0.58

Frost Protection

Frost treatment in the form of a frost taper symmetrical about the culvert centreline must be provided in accordance with Ontario Provincial Standard Drawing (OPSD) 803.010 or 803.031, as appropriate. Shallow footings should be provided with a minimum of 1.2 metres of earth cover or thermal equivalent for frost protection purposes.

6.3.1 Bedding

For a pipe or pre-cast box culvert, bedding should be placed on a properly prepared subgrade from which all frozen, soft, uncompacted fill, organic materials, or other deleterious materials have been removed. Subexcavated material below the design subgrade elevation should be replaced with compacted OPSS Granular A or Granular B, Type II fill material. It is recommended that the box culvert units be placed on a minimum thickness of 300 millimetres of compacted OPSS Granular A bedding material. A minimum 75 millimetre thick levelling course consisting of uncompacted Granular A or fine aggregates as specified in MTO Special Provision (SP) 422S01 may be placed on the bedding material.

6.3.2 Backfill and Cover

Backfill, cover, and construction of the frost tapers (backfill transition) should be completed in accordance with OPSD 803.010 or 803.031, as appropriate. The excavations for the culvert replacement should exceed the culvert dimensions by at least one metre on each side to promote good workmanship and effective compaction of the fill.

The backfill should consist of free-draining, non-frost susceptible granular materials such as OPSS Granular A or Granular B, Type II but with less than 5 per cent passing the number 200 sieve placed and compacted in accordance with SP105S21. All bedding, backfill, and cover materials should be placed in accordance with OPSS 422, 501, and 902.

Heavy compaction equipment should not be used immediately adjacent to the walls of the culvert. The height of backfill adjacent to the culvert walls should be maintained as equal as possible on both sides of the walls during all stages of backfill placement with one side not exceeding the other by more than 500 millimetres.

6.4 Lateral Earth Pressures

The lateral pressures acting on the proposed culvert will depend on the type and method of placement of the backfill materials, on the nature of the soil behind the backfill, on the magnitude of surcharge including construction loadings, on the freedom of lateral movement of the structure, and on the drainage conditions behind the walls.

The following recommendations are made concerning the design of the walls in accordance with the current CHBDC. It should be noted that these design recommendations and parameters assume level backfill and ground surface behind the walls. Where there is sloping ground behind the walls, the coefficient of lateral earth pressure must be adjusted to account for the slope.

- Select, free-draining granular fill meeting the specifications of OPSS Granular A or Granular B, Type II but with less than 5 per cent passing the No. 200 sieve should be used as backfill behind the walls. The fill should be compacted in loose lifts not greater than 200 millimetres in thickness. Longitudinal drains and weep holes should be installed to provide positive drainage of the granular backfill.
- A compaction surcharge equal to 12 kPa should be included in the lateral earth pressures for the structural design in accordance with CHBDC Figure 6.6.
- If the wall support does not allow lateral yielding (such is typically the case for a rigid concrete box culvert), at-rest earth pressures should be assumed for geotechnical design. The granular fill should be placed in a zone with a width equal to at least 1.2 metres behind the culvert walls (case (a) from commentary on CHBDC Figure C6.6).
- For Case (a), the restrained case, which is typical for box culvert walls, the pressures are based on the existing embankment fill materials, assuming a Select Subgrade Material (SSM) is used. The following parameters (unfactored) may be used:

  Soil unit weight: 19 kN/m³

  Coefficients of lateral earth pressure:

  'at rest' or restrained, K_o 0.50

- If the wall support allows lateral yielding (unrestrained structure, such as typically the case for wingwalls), active earth pressures may be used in the geotechnical design of the structure. The granular fill should be placed in a wedged shaped zone with a width equal to at least 1.2 metres at the footing level against a cut slope which begins at the footing level and extends upwards at a maximum inclination of 1 horizontal to 1 vertical (case (b) from commentary on CHBDC Figure C6.20).

- For walls backfilled using granular materials in accordance with case (b), the following parameters (unfactored) may be assumed:

	GRANULAR A	GRANULAR B, TYPE II
Fill unit weight:	22 kN/m^3	21 kN/m^3
Coefficients of lateral earth pressure:		
'active' or unrestrained, K_a	0.27	0.27
'passive', K_p	3.7	3.7

6.5 Construction Considerations

6.5.1 General

Care should be taken during construction to avoid disturbance of the subgrades prior to constructing foundations for the replacement culvert. All existing fill and any topsoil, organics, and soft or loose soils should be stripped from the proposed founding areas prior to placement of base materials. Subgrade preparation should be performed and monitored in accordance with OPSS 902.

It is recommended that the footing excavations be carried out such that the final 0.5 metres of excavation is completed with a geotechnical Quality Verification Engineer (QVE) on site. The prepared excavation bases should be inspected by the QVE. If shallow spread/strip footings are to be constructed, a working slab should be placed immediately after inspection to protect the founding materials.

6.5.2 Erosion and Scour Protection

Water flowing beneath a culvert could potentially cause undermining and scouring. Seepage flowing around the culvert walls has the potential to remove fines from the embankment fill and lead to piping and erosion. Therefore the replacement culvert must be designed with the appropriate end treatment to prevent undermining, scouring and piping. The native silts encountered at the site are considered to be susceptible to piping. As required by the CHDBC, a pre-cast concrete box culvert should be designed with cutoff walls, at least at the upstream end, to prevent undermining or possible collapse of the ends.

Erosion and scour protection for the culvert backfill and stream banks should be provided to protect the roadway, approach embankments, and culvert, as appropriate. In addition, sediment control such as silt fences and erosion control blankets may be required during construction and diversion/piping of the watercourse to minimize migration of fine particles should be carried out. Consideration could be given to using suitable non-woven geotextile and rip rap, as required, to provide erosion protection based on hydraulic requirements. Rip-rap treatment at the culvert outlet should be provided in accordance with OPSD 810.010.

6.5.3 Camber

Considering the relatively low cover for the proposed replacement culvert and the presence of stiff to hard cohesive soils and compact to very dense granular soils below the founding elevation, the provision of camber for replacement culvert is not required.

6.6 Excavations and Temporary Cut Slopes

Excavations for the replacement/rehabilitation of the culvert will encounter topsoil and fill materials, silt, and clayey silt. Temporary open cut slopes within these materials should be maintained no steeper than 1 horizontal to 1 vertical and localized sloughing and ground movements should be expected. All debris, cobbles, and boulders should be removed from slope surfaces. Where excavations extend below the groundwater level in granular soils, it may be necessary to use flatter slopes. All excavations should be carried out in accordance with the latest edition of the Ontario Occupational Health and Safety Act and Regulations for Construction Projects. Any existing embankment fill materials that may be encountered and the saturated native granular soils at the site would be classified as Type 3 soils. The clayey silt and effectively dewatered native granular soils would be classified as Type 2 soils.

Excavations for open bottom culvert strip footings or for a pipe or box culvert will extend below the inferred groundwater elevation of 263.5 metres. Dewatering of excavations made into the saturated silt may be required in order to construct the footings in the dry. Gravity methods such as wells are not considered to be effective in the silt encountered at the site. Dewatering of these soils should be carried out using an eductors or vacuum well point systems. Groundwater at the site may be controlled by using properly filtered sumps at the base of the excavation. Sumps should be maintained outside the actual footing limits. The volume of seepage from the native soils is expected to be low due to the low hydraulic conductivity. The estimated hydraulic conductivity of the silt and clayey silt is expected to be less than 10^{-6} centimetres per second.

The existing culvert flows will need to be diverted/piped during construction. Surficial water seepage into the excavations should be expected and will be heavier during periods of sustained precipitation. Surface water should be directed away from the excavations at all times. The appropriate NSSP should be included in the contract documents to alert the contractor about the need for adequate control of surface and groundwater flows.

The exposed silt and clayey silt will be sensitive to disturbance from construction activities once exposed to moisture. Therefore, it will be essential to redirect surface water flow away from the excavations and construct all granular levelling pads or cast-in-place concrete footings during the same day the excavation is completed to the planned subgrade elevation.

6.6.1 Temporary Roadway Protection

Temporary roadway protection systems may be required where space is restricted and will not permit open cuts, to support the sides of the excavation and permit the use of vertical cuts. If protection systems are to be used during construction they are to be designed by the contractor and the limits of the systems are to be determined by the contractor.

Temporary support systems could consist of soldier piles and lagging where the H-piles would be driven to a suitable depth and horizontal lagging installed as the excavation proceeds or driven steel sheet piling. Support of the systems could be in the form of struts and walers in the case of footing excavations or rakers and anchors in the case of roadway protection. The raker/anchor support must be designed to accommodate the loads applied from pressures and surcharge pressures from area line or point loads as well as the impact of sloping ground behind the system.

7.0 COMMENTS FOR DETAIL DESIGN

Design options for the culvert upgrades include the installation of grouted in place pipe liners, structural rehabilitation with an elliptical pipe, and full culvert replacement with an open footing or a pre-cast box culvert. A Foundation Design Report will need to be prepared during a future assignment to provide appropriate information for future Detail Design. Provided that the vertical and horizontal alignment of the proposed culvert do not vary significantly from the assumptions made within this report, the current investigation meets the MTO requirements for detail design of culverts, therefore, additional boreholes may not be required. However, an additional borehole in the northern section of the culvert area at detail design would be beneficial to provide additional information of the depths of subexcavation.

The preliminary recommendations given in this Preliminary Foundation Design report should be expanded upon and updated in the Foundation Design Report for detail design in accordance with MTO's standard requirements for foundation engineering assignments. Emphasis should be placed on provision of detailed recommendations for foundations for the culvert. If the approach embankments are to be modified, the stability of the altered embankments should be confirmed and the resulting settlement evaluated. If the culvert is to be replaced using staged construction and temporary roadway protection, the discussion on conceptual shoring alternatives must be expanded to include lateral earth pressures and detailed impact of ground conditions on shoring construction and design.

8.0 MISCELLANEOUS

This report was prepared by Ms. Nicole A. Gould, P.Eng. under the direction of the Project Engineer, Ms. Dirka U. Prout, P.Eng. and the Team Leader, Dr. Storer J. Boone, P.Eng. This report was reviewed by Mr. Azmi M. Hammoud, P.Eng. An independent audit of this report was carried out by Mr. Fintan J. Heffernan, P. Eng., the Designated MTO Contact and Quality Control Auditor for this assignment.

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MTO Designated Contact

NG/DUP/AMH/MEB/FJH/cr

n:\active\2012\1132 - geo\1132-0000\12-1132-0076 dillon-11 structures-3011-e-0046\ph 1000 gwp 3011-e-0046\ph 1001 fdns\rpts\r05a structural culvert site 19-650c\1211320076-1001-r05a jun 17 15 (final) fdns parta&b site 19-650c.docx

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
SS	Split-spoon
DS	Denison type sample
FS	Foil sample
RC	Rock core
SC	Soil core
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.) split spoon 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) 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.

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
F	factor of safety
V	volume
W	weight

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
v	poisson's ratio
σ	total stress
σ'	effective stress ($\sigma' = \sigma$-u)
σ'_{vo}	initial effective overburden stress
$\sigma_1, \sigma_2, \sigma_3$	principal stress (major, intermediate, minor)
σ_{oct}	mean stress or octahedral stress $= (\sigma_1+\sigma_2+\sigma_3)/3$
τ	shear stress
u	porewater pressure
E	modulus of deformation
G	shear modulus of deformation
K	bulk modulus of compressibility

III. SOIL PROPERTIES

(a) Index Properties

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

(a) Index Properties (continued)

w	water content
w_l	liquid limit
w_p	plastic limit
l_p	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_a	coefficient of secondary consolidation
m_v	coefficient of volume change
c_v	coefficient of consolidation
T_v	time factor (vertical direction)
U	degree of consolidation
σ'_p	pre-consolidation pressure
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 δ
c'	effective cohesion
c_u, s_u	undrained shear strength (ϕ = 0 analysis)
p	mean total stress $(\sigma_1 + \sigma_3)/2$
p'	mean effective stress $(\sigma'_1 + \sigma'_3)/2$
q	$(\sigma_1 + \sigma_3)/2$ or $(\sigma'_1 + \sigma'_3)/2$
q_u	compressive strength $(\sigma_1 + \sigma_3)$
S_t	sensitivity

Notes:
1 $\tau = c' + \sigma' \tan \phi'$
2 shear strength = (compressive strength)/2
* density symbol is ρ. Unit weight symbol is γ where $\gamma = \rho g$ (i.e. mass density x acceleration due to gravity)

Golder Associates
London, Ontario

RECORD OF BOREHOLE No 601

METRIC

PROJECT 12-1132-0076
W.P. 3054-11-00
LOCATION N 4755461.9 , E 410934.9
ORIGINATED BY MA
DIST HWY 401
BOREHOLE TYPE POWER AUGER, HOLLOW STEM
COMPILED BY LMK
DATUM GEODETIC
DATE May 16, 2013
CHECKED BY

ELEV / DEPTH (m)	SOIL PROFILE – DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	WATER CONTENT (%)	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
265.95	GROUND SURFACE						
0.08	TOPSOIL, sandy, trace gravel Brown				Cuttings		
0.21	FILL, sand and gravel, some silt Brown						
	FILL, clayey silt, some sand to sandy, some gravel, some topsoil, with asphalt pieces Stiff Brown	1	SS	8	Granular bentonite		
264.73 / 1.22	FILL, clayey silt, some sand, trace gravel, with silt layers Stiff to firm Brown	2	SS	13			
		3	SS	12	Water level (▼ approx. elev. 263.9)		
		4	SS	7	Cuttings	plotted (Wp, w, WL)	0 8 62 30
		5	SS	6			
261.68 / 4.27	SILT, trace to some clay Compact to very dense Brown turning grey at about elev. 260.7m	6	SS	28	Granular bentonite	plotted (w)	
		7	SS	53		plotted (w)	0 1 90 9
		8	SS	54			
		9	SS	52	Cuttings		
258.63 / 7.32	CLAYEY SILT Very stiff to hard	10	SS	26		plotted (Wp, w)	0 0 71 29
					Standpipe		
		11	SS	35	Caved material		
256.50 / 9.45	END OF BOREHOLE						

Elevation scale: 265, 264, 263, 262, 261, 260, 259, 258, 257

DYNAMIC CONE PENETRATION RESISTANCE PLOT: 20 40 60 80 100
SHEAR STRENGTH kPa: ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE — 20 40 60 80 100
PLASTIC LIMIT W_P — NATURAL MOISTURE CONTENT W — LIQUID LIMIT W_L
WATER CONTENT (%) 10 20 30
UNIT WEIGHT γ kN/m³

Borehole dry during drilling on May 16, 2013.

Water level measured in standpipe at elev. 263.85m on June 5, 2013.

Water level measured in standpipe at elev. 263.88m on June 20, 2013.

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

Golder Associates
London, Ontario

RECORD OF BOREHOLE No 602

METRIC

PROJECT 12-1132-0076

W.P. 3054-11-00 LOCATION N 4755405.9 , E 410955.1 ORIGINATED BY MA

DIST ____ HWY 401 BOREHOLE TYPE POWER AUGER, HOLLOW STEM COMPILED BY LMK

DATUM GEODETIC DATE May 15, 2013 CHECKED BY ____

ELEV / DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	WATER CONTENT (%)	GR	SA	SI	CL
263.79	GROUND SURFACE								
0.00	TOPSOIL, silty, trace sand, trace gravel								
263.52 / 0.27	FILL, clayey silt, some sand, some gravel, trace topsoil, Brown								
263.18 / 0.61	FILL, silty clay, some sand, trace topsoil, Firm, Mottled brown and grey	1	SS	8					
		2	SS	4					
261.66 / 2.13	SILT, trace clay, with clayey silt layers, Compact, Brown	3	SS	12					
260.89 / 2.90	CLAYEY SILT, with silt seams and layers, Very stiff, Grey	4	SS	20		0	0	72	28
		5	SS	21					
259.37 / 4.42	SILT, trace sand, trace gravel, with clayey silt layers, Dense, Grey	6	SS	34		4	1	75	20
		7	SS	38					
257.54 / 6.25	CLAYEY SILT, trace sand, with silt seams and layers, Stiff to very stiff, Grey	8	SS	22		0	0	70	30
		9	SS	13					
256.32 / 7.47	END OF BOREHOLE. Borehole dry during drilling on May 15, 2013.								

Column headings: SOIL PROFILE (ELEV DEPTH, DESCRIPTION, STRAT PLOT); SAMPLES (NUMBER, TYPE, "N" VALUES); GROUND WATER CONDITIONS; ELEVATION SCALE (263, 262, 261, 260, 259, 258, 257); DYNAMIC CONE PENETRATION RESISTANCE PLOT (20, 40, 60, 80, 100); SHEAR STRENGTH kPa (○ UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × LAB VANE; 20, 40, 60, 80, 100); PLASTIC LIMIT W_P, NATURAL MOISTURE CONTENT W, LIQUID LIMIT W_L; WATER CONTENT (%) (10, 20, 30); UNIT WEIGHT γ kN/m³; REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL

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

Golder Associates
London, Ontario

RECORD OF BOREHOLE No 603

METRIC

PROJECT 12-1132-0076
W.P. 3054-11-00
LOCATION N 4755413.6 , E 410945.1
ORIGINATED BY MA
DIST
HWY 401
BOREHOLE TYPE POWER AUGER, HOLLOW STEM
COMPILED BY LMK
DATUM GEODETIC
DATE May 15, 2013
CHECKED BY

ELEV / DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	WATER CONTENT (%)	GR	SA	SI	CL
265.76	PAVEMENT SURFACE									
0.00	ASPHALT									
0.18	FILL, sand and gravel, trace silt, crushed, Brown									
0.37	FILL, sand and gravel, with cobbles, Compact, Brown	1	SS	24						
264.54 / 1.22	FILL, silty clay, trace sand, trace gravel, with topsoil layers, Stiff, Brown	2	SS	11						
		3	SS	8		LL 47	0	6	56	38
263.02 / 2.74	CLAYEY SILT, trace sand, trace gravel, Firm, Mottled brown and grey	4	SS	6	∇ (elev. 263.0)					
262.25 / 3.51	CLAYEY SILT, trace sand, with silt seams and partings, Stiff to very stiff, Brown turning grey at about elev. 260.4m	5	SS	12			0	2	68	30
		6	SS	12						
		7	SS	15						
		8	SS	17						
		9	SS	17			0	0	76	24
		10	SS	22						
257.07 / 8.69	END OF BOREHOLE									

Groundwater encountered at about elev. 263.0m during drilling on May 15, 2013.

Elevation scale: 265, 264, 263, 262, 261, 260, 259, 258

DYNAMIC CONE PENETRATION RESISTANCE PLOT: 20 40 60 80 100
SHEAR STRENGTH kPa: ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × LAB VANE: 20 40 60 80 100
PLASTIC LIMIT W_P, NATURAL MOISTURE CONTENT W, LIQUID LIMIT W_L; WATER CONTENT (%) 10 20 30
UNIT WEIGHT γ kN/m³
REMARKS & GRAIN SIZE DISTRIBUTION (%)

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

LDN_MTO_06 12-1132-0076-1001.GPJ LDN_MTO.GDT 05/11/13

REFERENCE

PLAN BASED ON CANMAP STREETFILES V.2008.5.

NOTE

THIS DRAWING IS TO BE READ IN CONJUNCTION WITH ACCOMPANYING TEXT.

PROJECT

STRUCTURAL CULVERT REPLACEMENT 19-650/C
HIGHWAY 401 INTERCHANGE IMPROVEMENTS
GWP 3054-11-00

TITLE

KEY PLAN

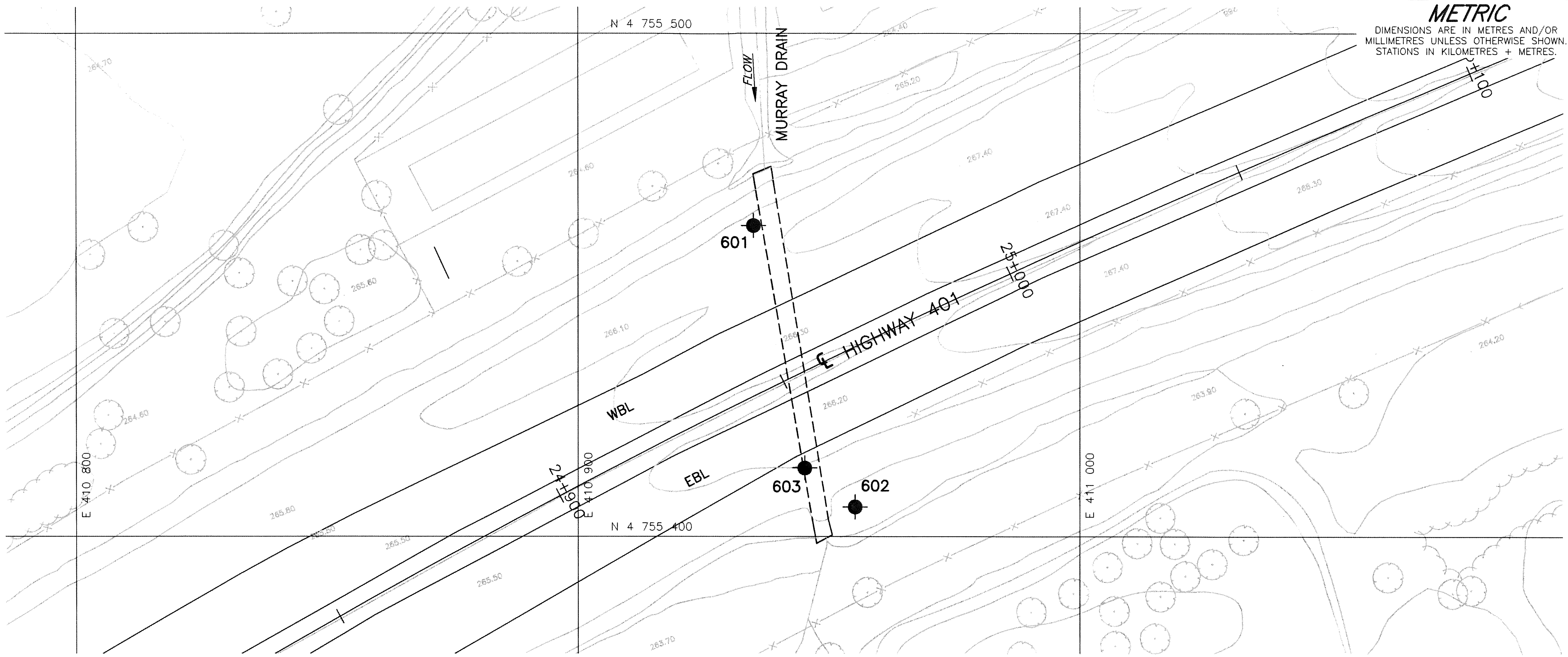
Golder Associates
LONDON, ONTARIO

PROJECT No.		12-1132-0076	FILE No.	1211320076-1001-F05A01
			SCALE AS SHOWN	REV. 0
CADD	LMK/WDF	Nov. 01/13	**FIGURE 1**	
CHECK				

Drawing file: 1211320076-1001-F05A01.dwg Nov 05, 2013 - 10:45am

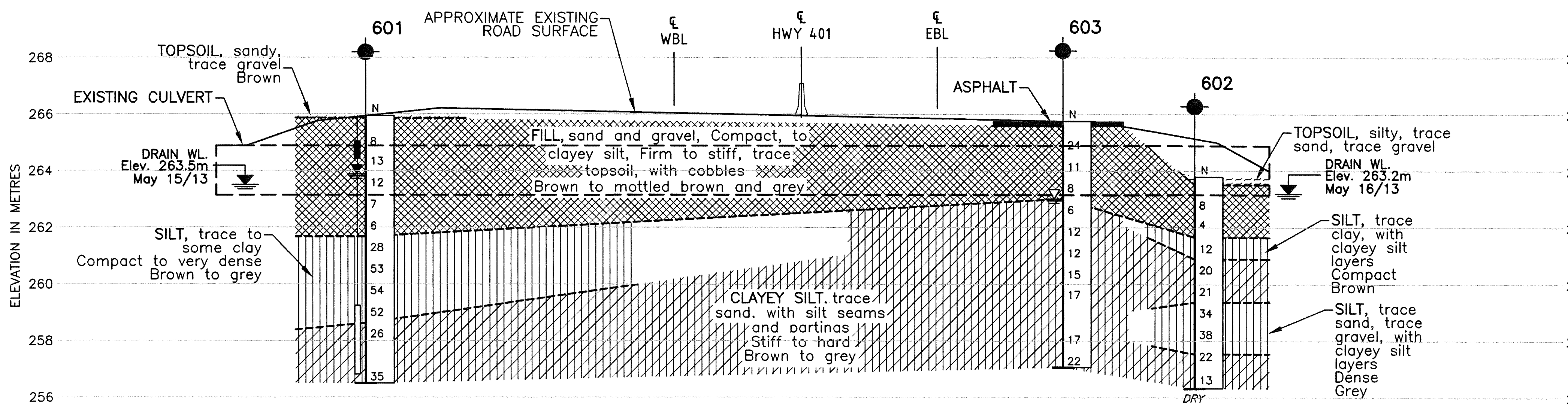
METRIC

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



PLAN

SCALE 10 0 10m



PROFILE ALONG ℄ CULVERT

HORIZONTAL SCALE 4 0 4m VERTICAL SCALE 2 0 2m

CONT No.
WP No. 3054-11-00

SHEET

STRUCTURAL CULVERT REPLACEMENT
STATION 24+954
HIGHWAY 401 INTERCHANGE IMPROVEMENTS
BOREHOLE LOCATIONS AND SOIL STRATA

Golder Associates

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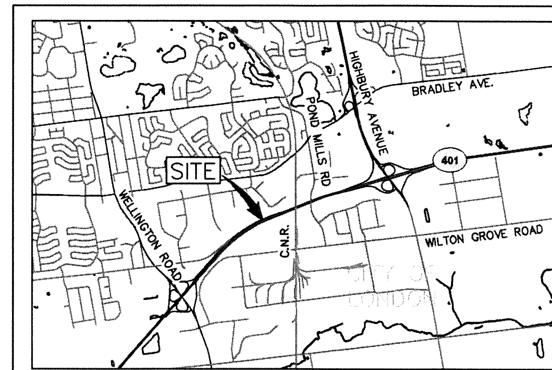
LONDON, ONTARIO, CANADA



KEY PLAN

SCALE IN KILOMETRES 0 1 2

LEGEND

- Borehole – Current Investigation
- Seal
- Standpipe
- N Standard Penetration Test Value
- 16 Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
- WL measured on June 20, 2013.
- WL encountered during drilling
- DRY Water level not established

No.	ELEVATION	CO-ORDINATES (MTM ZONE 10) NORTHING	EASTING
601	265.95	4 755 461.9	410 934.9
602	263.79	4 755 405.9	410 955.1
603	265.76	4 755 413.6	410 945.1

NOTES

This drawing is for subsurface information only. Surface details and features are for conceptual illustration.

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

REFERENCE

Base plans based on City of London Digital Mapping Disc 2011 (converted to MTM ZONE 11)

D. U. PROUT 06/18/15 LICENSED PROFESSIONAL ENGINEER PROVINCE OF ONTARIO

F.J. HEFFERNAN 06/18/15 REGISTERED PROFESSIONAL ENGINEER PROVINCE OF ONTARIO

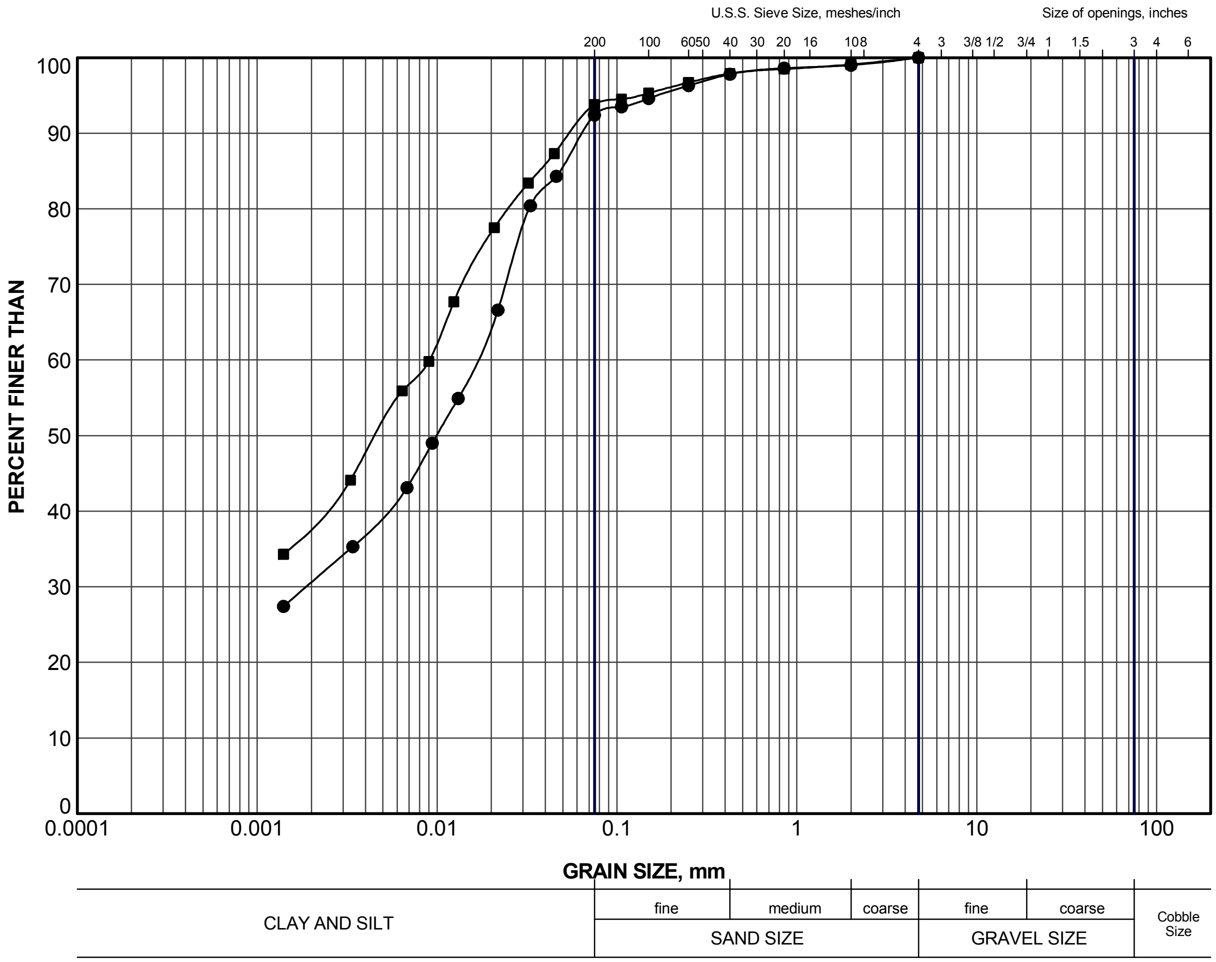
NO.	DATE	BY	REVISION

Geocres No. 40I14-158

HWY. 401		PROJECT NO. 12-1132-0076	DIST.
SUBM'D. NG	CHKD. NAG	DATE: Aug. 07/13	SITE: 19-650/C
DRAWN: WDF/LMK	CHKD. DUP	APPD. FJH	DWG. 1

APPENDIX A

Laboratory Test Data



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	601	4	263.4
■	603	3	263.4

PROJECT
STRUCTURAL CULVERT REPLACEMENT 19-650/C
HIGHWAY 401 INTERCHANGE IMPROVEMENTS
GWP 3054-11-00

TITLE

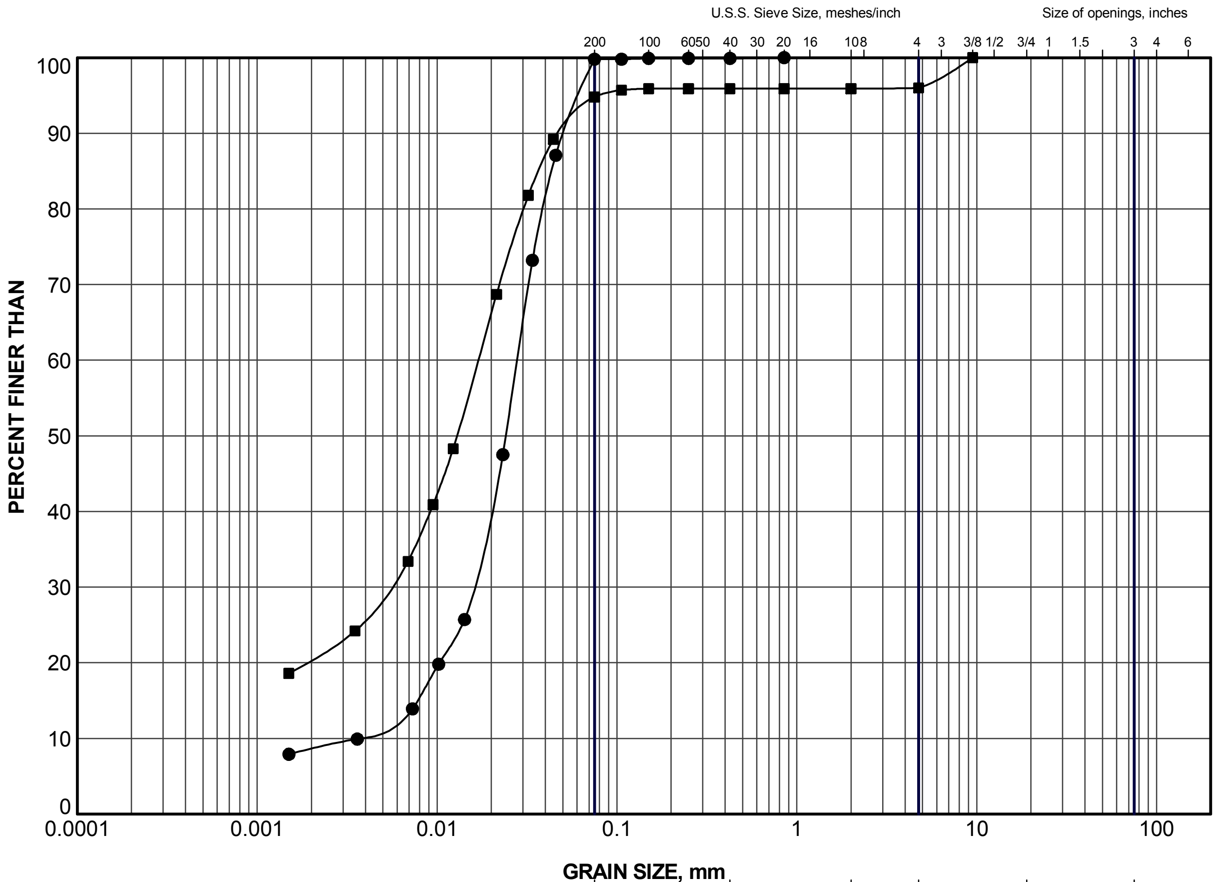
GRAIN SIZE DISTRIBUTION

FILL

Golder Associates
LONDON, ONTARIO

PROJECT No.		12-1132-0076	FILE No. 1211320076-1001-F05AA1	
			SCALE N/A	REV.
DRAWN	LMK\WDF	Aug. 07/13	FIGURE A-1	
CHECK				

LDN_MTO_GSD GLDR_LDN.GDT



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

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	601	7	260.5
■	602	6	259.0

PROJECT STRUCTURAL CULVERT REPLACEMENT 19-650/C
HIGHWAY 401 INTERCHANGE IMPROVEMENTS
GWP 3054-11-00

TITLE

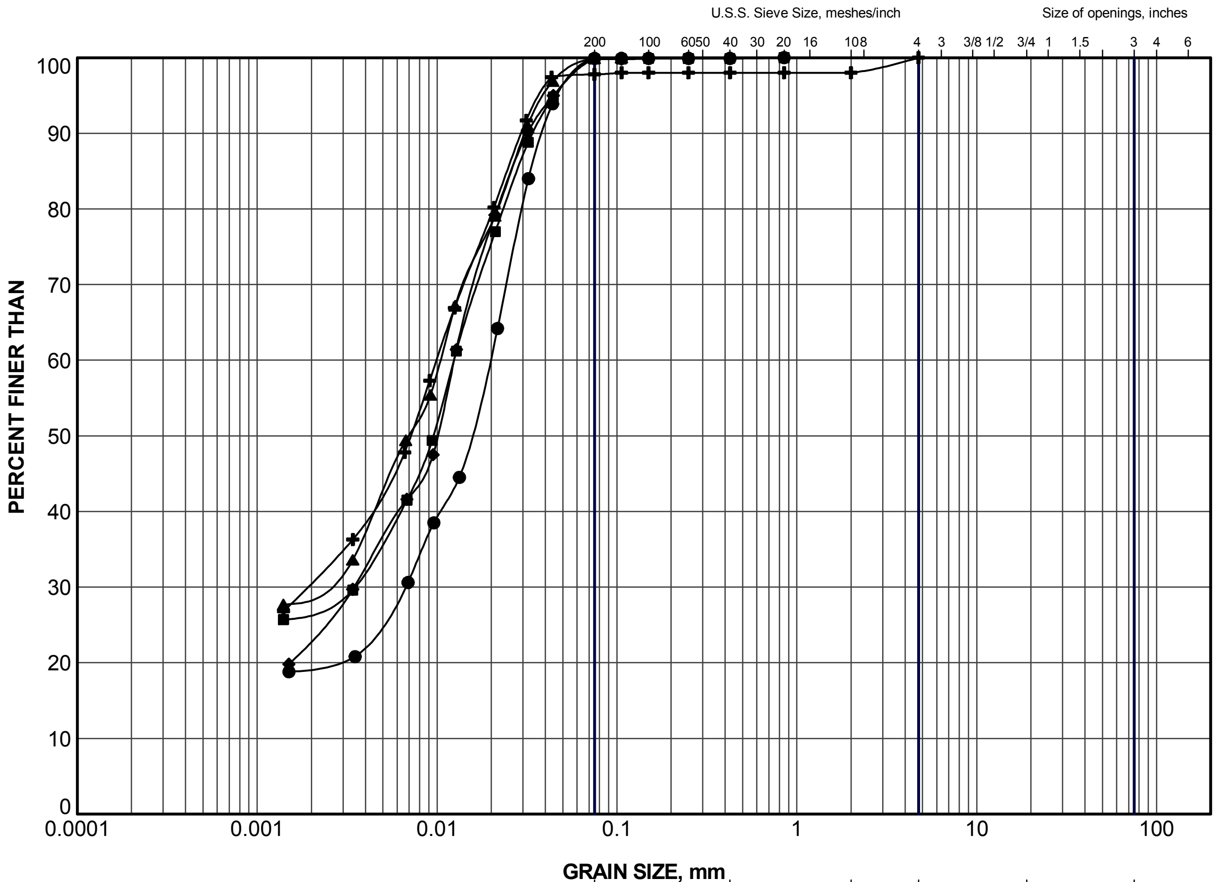
GRAIN SIZE DISTRIBUTION

SILT

Golder Associates
LONDON, ONTARIO

PROJECT No.	12-1132-0076	FILE No. 1211320076-1001-F05AA2
		SCALE N/A REV.
DRAWN LMK\WDF	Aug. 07/13	FIGURE A-2
CHECK		

LDN_MTO_GSD GLDR_LDN.GDT



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

LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	601	10	258.0
■	602	4	260.5
▲	602	8	257.4
✚	603	5	261.9
◆	603	9	258.1

PROJECT STRUCTURAL CULVERT REPLACEMENT 19-650/C
HIGHWAY 401 INTERCHANGE IMPROVEMENTS
GWP 3054-11-00

TITLE

GRAIN SIZE DISTRIBUTION

CLAYEY SILT

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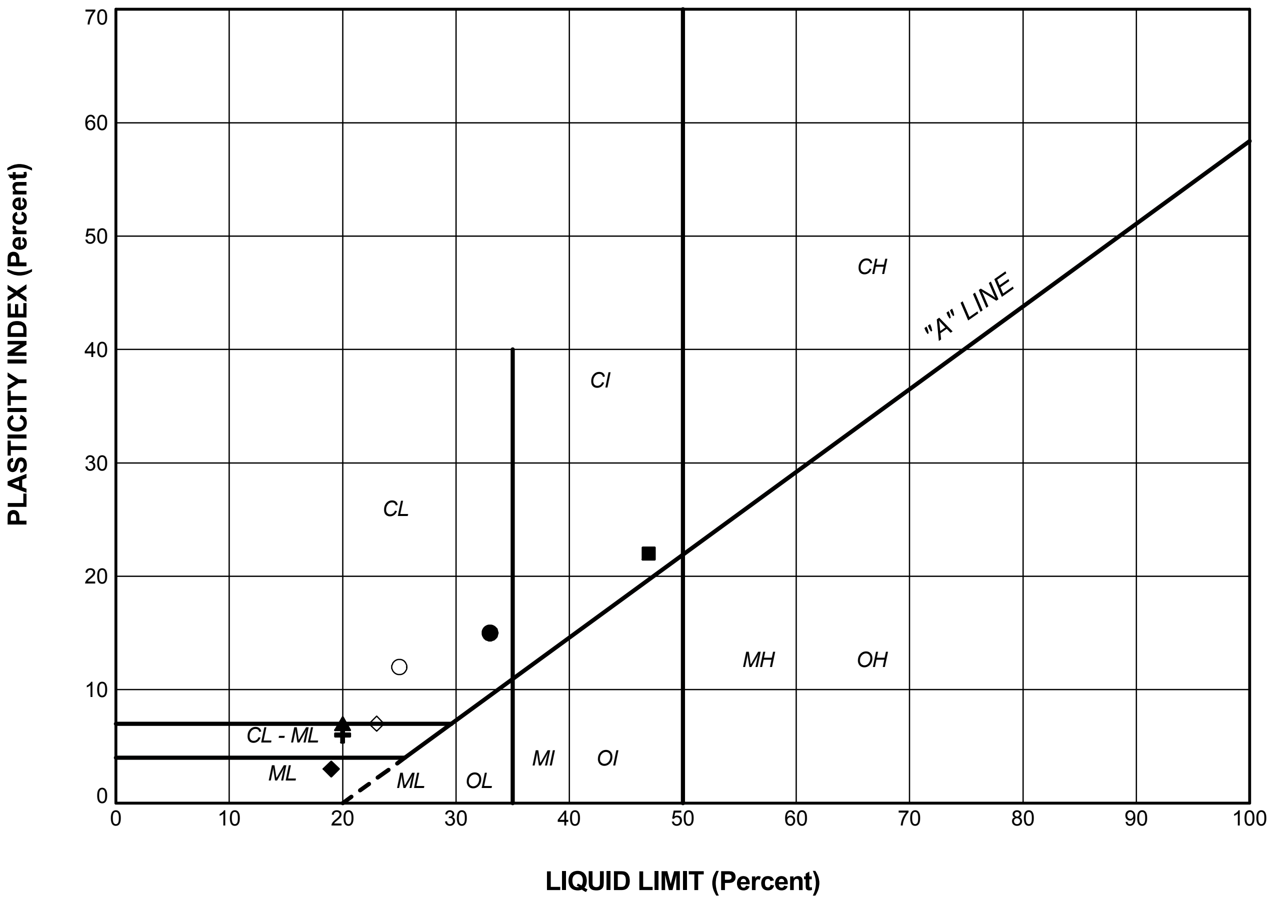
LONDON, ONTARIO

PROJECT No. 12-1132-0076-1001			FILE No. 1211320076-1001-F05AA3	
			SCALE N/A	REV.
DRAWN	LMK	Jun 28/13	FIGURE A-3	
CHECK				

LDN_MTO_GSD 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
FILL					
●	601	4	32.9	18.0	14.9
■	603	3	46.8	24.7	22.1
CLAYEY SILT					
▲	601	10	19.5	13.3	6.2
✚	602	4	20.2	14.5	5.7
◆	602	8	19.3	15.6	2.7
◇	603	5	23.0	15.5	7.5
○	603	9	24.8	13.1	11.7

PROJECT STRUCTURAL CULVERT REPLACEMENT 19-650/C
HIGHWAY 401 INTERCHANGE IMPROVEMENTS
GWP 3054-11-00

TITLE

PLASTICITY CHART

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PROJECT No.	12-1132-0076	FILE No. 1211320076-1001-F05AA4	
		SCALE N/A	REV.
DRAWN LMK\WDF	Aug. 07/13	FIGURE A-4	
CHECK			

LDN_MTO_PI GLDR_LDN.GDT

APPENDIX B

Photographs

Photograph 1: Tributary to Murray Drain, inlet, north end.

Photograph 2: Highway 401 Eastbound Lanes riding surface.

n:\active\2012\1132 - geo\1132-0000\12-1132-0076 dillon-11 structures-3011-e-0046\ph 1000 gwp 3011-e-0046\ph 1001 fdns\rpts\r05a structural culvert site 19-650c\1211320076-1001-r05a jun 15 15 (final) app b-site photos.docx

At Golder Associates we strive to be the most respected global group of companies specializing in ground engineering and environmental services. Employee owned since our formation in 1960, we have created a unique culture with pride in ownership, resulting in long-term organizational stability. Golder professionals take the time to build an understanding of client needs and of the specific environments in which they operate. We continue to expand our technical capabilities and have experienced steady growth with employees now operating from offices located throughout Africa, Asia, Australasia, Europe, North America and South America.

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