March 2012

FOUNDATION INVESTIGATION AND DESIGN REPORT

Turnbull Drain Culvert, Site 12-399/C
Station 12+437, Geographic Township of Stephen
Highway 21 Rehabilitation
From Grand Bend North Limits, Northerly 7.8 km
To 0.1 km North of Hendrick Road
GWP 3952-01-00, Purchase Order No. 3010-E-0026
Ministry of Transportation, Ontario – West Region

Submitted to:
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REPORT

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FOUNDATION INVESTIGATION REPORT

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STATION 12+437, GEOGRAPHIC TOWNSHIP OF STEPHEN
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FROM GRAND BEND NORTH LIMITS, NORTHERLY 7.8 KM
TO 0.1 KM NORTH OF HENDRICK ROAD
GWP 3952-01-00, PURCHASE ORDER NO. 3010-E-0026
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 the foundation investigations as part of the detail design work for GWP 3952-01-00, the rehabilitation of Highway 21, within the project limits.

This report was prepared for the replacement of the structural culvert at the Turnbull Drain at Station 12+437 in the Geographic Township of Stephen, Site Number 12-399/C.

The purpose of the foundation investigation is to determine the subsurface conditions at the location of the proposed structure replacement 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 P0-1132-0014 dated March 28, 2011 and our letter dated July 20, 2011. The work was carried out in accordance with our Quality Control Plan for Foundations Engineering dated May 2011.

Dillon provided Golder Associates with preliminary drawings for this project in digital format.

2.0 SITE DESCRIPTION

2.1 General

Culvert site 12-399/C is situated on Highway 21 approximately 2.4 kilometres north of Highway 81 in the Geographic Township of Stephen, County of Huron, Ontario. The location of the site is shown on the Key Plan, Figure 1.

The culvert at Site 12-399/C is a corrugated steel pipe arch (CSPA) culvert 3.00 metres wide, 2.13 metres high and 30.00 metres long. The culvert has a vertical gated section at the inlet. The culvert was constructed in 1956. The approximate drain invert elevation is 184.25 metres upstream of the culvert with a culvert invert elevation of 182.15 metres at the drop inlet structure and 182.00 at the outlet. The culvert conveys flows from Turnbull Drain east to west under Highway 21. The location of the culvert is shown on the Key Plan, Figure 1, and a site photograph is provided in Appendix B.

Land use in the vicinity of the site is primarily rural agricultural and residential. The adjacent topography is generally flat and ground surface elevations in the vicinity of the culvert range from about 182 to 185 metres.

2.2 Site Geology

This project lies within the physiographic region of southwestern Ontario known as the Huron Slope[1]. The soils generally consist of till formed from a brown calcareous clay containing a minimum of pebbles and boulders.

Based on the Ontario Division of Mines Preliminary Map P.974 entitled “Quaternary Geology, Grand Bend Area, Southern Ontario”, the site lies in an area of primarily St. Joseph clayey silt till.

The Geologic Survey of Canada Map 1263A entitled “Geology, Toronto-Windsor Area, Ontario” indicates that the subcropping bedrock in the area of the site is limestone and shale of the Hamilton group of Middle Devonian age. Based on the Ontario Division of Mines Preliminary Map P.265 entitled “Bedrock Topography Series, Grand Bend Area, Southern Ontario”, the bedrock surface at the site subcrops at about elevation 158 metres or some 30 metres below ground surface.

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

3.0 INVESTIGATION PROCEDURES

The field investigation at this site was carried out on September 26 and 27, 2011 at which time three boreholes, numbered 6 to 8, were drilled at the locations shown on Drawing 1.

The boreholes were drilled using a truck mounted power auger supplied and operated by a specialist drilling contractor. Samples of the overburden were typically obtained at depth intervals of 0.75 metres using 50 millimetre outside diameter split spoon sampling equipment in accordance with the Standard Penetration Test procedures (ASTM D1586). In addition, in situ field vane shear strength testing was carried out, where feasible, in the softer zones of the cohesive strata.

The samplers used in the investigations limit the maximum particle size that can be sampled and tested to about 40 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. Larger particle sizes, including cobbles and boulders, are known to be present in the glacial till deposits as discussed in the text of this report.

Groundwater conditions in the boreholes were observed throughout the drilling operations. A standpipe was installed in borehole 7 as indicated on the corresponding Record of Borehole sheet. The boreholes were backfilled in accordance with current regulations, MTO recommended procedures and Ontario Regulation 903 (as amended).

The field work was supervised on a full-time basis by an experienced member of our engineering staff who arranged for underground utility locates, directed the drilling, sampling and in situ testing operations, logged the boreholes and cared for the samples obtained. The soil samples were identified in the field, placed in labelled containers and transported to Golder's 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 field and laboratory testing are given on the Record of Borehole sheets and in Appendix A.

The as-drilled borehole locations and ground surface elevations are shown on the Record of Borehole sheets and on Drawing 1.

The table below summarizes the coordinates, ground surface elevations and depths of the boreholes.

Borehole	Location (m)		Ground Surface Elevation	Borehole Depth
	Northing	Easting	(m)	(m)
6	4 799 303	366 318	186.37	10.52
7	4 799 288	366 340	186.64	10.52
8	4 799 297	366 336	187.22	10.52

The existing culvert has the following characteristics:

Dimensions (m)	Obvert Elevation (m)		Construction
	Lt	Rt	
3.00 x 2.13 x 30.00	184.13	184.28	CSPA

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 and laboratory testing carried out on selected samples, are given 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 and stratigraphic profiles are inferred from non-continuous sampling and observations of drilling resistance and represent transitions between soil types rather than exact planes of geological change. Subsurface conditions will vary between and beyond the borehole locations.

The boreholes drilled at the site generally encountered variable fill materials overlying clayey silt till.

The locations and elevations of the boreholes, together with the interpreted stratigraphic profile, are shown on Drawing 1. A detailed description of the subsurface conditions encountered in the boreholes is provided on the Record of Borehole sheets and is summarized below.

4.1.1 Topsoil

Layers of topsoil were encountered at the existing ground surface in boreholes 6 and 7. The topsoil layers were 120 and 300 millimetres thick.

4.1.2 Fill

Borehole 8 encountered a 0.3 metre thick layer of crushed sand and gravel fill at the existing ground surface overlying a 0.5 metre thick layer of sand and gravel fill.

Layers of clayey silt fill were encountered below the topsoil in boreholes 6 and 7 and beneath the sand and gravel fill in borehole 8. The clayey silt fill layers were 0.7 to 3.8 metres thick and had N values, as determined in the standard penetration testing, of 5 to 16 blows per 0.3 metres with a water content of 15 per cent.

The clayey silt fill was of low plasticity based on a plastic limit of 15 per cent, a liquid limit 29 per cent and a plasticity index 14 per cent. The Atterberg limits data for the fill are presented on Figure A-3.

A grain size distribution curve for a sample of the clayey silt fill is presented on Figure A-1 in Appendix A.

4.1.3 Clayey Silt Till

A stratum of firm to very stiff clayey silt till was encountered beneath the fill in boreholes 6 to 8 between elevations 182.6 and 185.7 metres. All of the boreholes were terminated in the clayey silt till after exploring it for 6.4 to 9.0 metres.

The clayey silt till had N values of 7 to 24 blows per 0.3 metres and water contents of 14 to 20 per cent with an average water content of about 17 per cent. The clayey silt till is of low plasticity based on seven Atterberg limits determinations carried out on samples obtained during standard penetration testing. The plastic limits ranged from 14 to 16 per cent, the liquid limits ranged from 27 to 30 per cent and the plasticity indices ranged from 13 to 15 per cent. The Atterberg limits data for the clayey silt till are presented on Figure A-3. In situ vane shear testing within the clayey silt till indicated undrained shear strength values of 114 to greater than 144 kilopascals indicating a very stiff consistency.

Grain size distribution curves for samples of the clayey silt till recovered from the standard penetration testing are presented on Figure A-2.

Although not specifically encountered in the boreholes, the presence of cobbles and boulders should be anticipated throughout the clayey silt till deposit.

4.2 Groundwater Conditions

Groundwater conditions were observed during and on completion of drilling and sampling. A standpipe was installed in borehole 7. Installation details are provided on the corresponding Record of Borehole sheets following the text of this report. A summary of the encountered and measured groundwater levels is provided in the following table:

Borehole	Ground Surface Elevation (m)	Encountered Groundwater Elevation (m)	Installation	Measured Groundwater Elevation (m)	
				Sep. 26, 2011	Oct. 21, 2011
6	186.37	Dry	-	-	-
7	186.64	183.6	Standpipe	185.4	184.5
8	187.22	Dry	-	-	-

Groundwater was encountered in borehole 7 at a depth of 3.1 metres or elevation 183.6 metres. Boreholes 6 and 8 remained dry during drilling.

On September 26, 2011, the water level in the Turnbull Drain was at about elevations 184.6 and 183.0 metres at the upstream and downstream ends, respectively.

On October 21, 2011, the water level in the standpipe installed in borehole 7 was about 2.1 metres below ground surface or at about elevation 184.5 metres.

The above-noted water levels are not considered to be representative of the long-term, stabilized groundwater conditions as the readings were taken for a short duration only. Based on the measured and encountered groundwater levels, the inferred groundwater level is at elevation 185 metres. The groundwater levels are expected to fluctuate seasonally and are expected to be higher during periods of sustained precipitation or during spring melt conditions.

5.0 MISCELLANEOUS

This investigation was carried out using equipment supplied and operated by Henderson Drilling Inc., who is 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 Mr. Tyson Pitt, P.Eng. under the direction of the Team Leader, Mr. Philip R. Bedell, P.Eng. This report was reviewed by Mr. Fintan J. Heffernan, P.Eng., the Designated MTO Contact and Quality Control Auditor for this assignment.

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PART B

FOUNDATION DESIGN REPORT

TURNBULL DRAIN CULVERT, SITE 12-399/C
STATION 12+437, GEOGRAPHIC TOWNSHIP OF STEPHEN
HIGHWAY 21 REHABILITATION
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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 of the Turnbull Drain structural culvert at Station 12+437 in the Geographic Township of Stephen on Highway 21 (Site 12-399/C).

The recommendations are based on our interpretation of the factual data obtained from the three boreholes advanced during the investigation at this site. The interpretation and recommendations are intended to provide the designers with sufficient information to assess the feasible foundation alternatives and to design the proposed culvert foundations. As such, 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.

The existing culvert is a CSPA culvert 3.00 metres wide, 2.13 metres high and 30.00 metres long. The existing culvert has invert elevations of 184.25 metres at the inlet and 182.29 metres at the outlet.

The replacement structure could consist of a CSPA culvert, corrugated steel pipe culvert or a pre-cast or cast-in-place (CIP) concrete box culvert. It is understood that the existing drop inlet structure and outlet flume are to remain. A comparison of foundation alternatives is presented in Table I.

It is proposed to replace the existing culvert using open cut installation methods. Traffic staging and temporary roadway protection will be required to facilitate the open trench installation of the replacement culvert to maintain a single lane of traffic during construction.

6.2 Foundations

The subsurface conditions encountered during the investigation generally consisted of surficial topsoil overlying fill materials underlain by layers of clayey silt till. A groundwater elevation of 185 metres has been inferred for the purposes of design.

The replacement culvert should be designed to withstand the appropriate weight of fill and traffic loading. Based on the soil conditions encountered at the borehole locations and the culvert invert elevations of approximately 182.2 and 182.0 metres at the inlet and outlet, respectively, the replacement culvert may be founded at or below elevation 182.0 metres in the stiff to very stiff clayey silt till. Alternatively, the replacement culvert may be founded on an engineered fill consisting of Granular B uniformly compacted to at least 98 per cent of standard Proctor maximum dry density. All topsoil, fill, organics and other deleterious materials should be removed prior to placement of any engineered fill.

6.2.1 Geotechnical Resistances

The stiff to very stiff clayey silt till or properly constructed engineered fill are suitable for support of the proposed culvert replacement. A factored geotechnical resistance at Ultimate Limit States (ULS) of 250 kilopascals and a geotechnical resistance at Serviceability Limit States (SLS) of 175 kilopascals maybe used for design purposes. The SLS value corresponds to 25 millimetres of settlement.

6.2.2 Frost Treatment

Frost treatment in the form of a frost taper symmetrical about the culvert centreline must be provided in accordance with Ontario Provincial Standard Drawings (OPSD) 803.010 and 803.031 for box culverts and CSP culverts, respectively.

6.2.3 Other Design Considerations

An inlet seal and an outlet filter are required for this type of culvert. Inlet and outlet erosion control measures are to be provided based on the results of the hydraulic assessments conducted by others. The provision of camber is not required since the foundation soils are such that excessive post-construction or differential settlements are not anticipated. The new box culvert is to be provided with a cut-off wall at each end in accordance with CHBDC Clause 1.9.5.6.

6.3 Bedding

If a pre-cast culvert is installed, bedding is to be placed on a properly prepared subgrade from which all frozen, soft, uncompacted fill, organic materials or other deleterious materials have been removed. The pre-cast box units should be placed on a minimum 75 millimetre thick levelling course consisting of uncompacted Granular A or fine aggregates as specified in MTO Special Provision (SP) 422S01. Alternatively, if it is necessary to slide the box section(s) into place below the fibre optic ducts, concrete bedding/working slab should be used.

6.4 Backfill

The excavation for the new culvert should exceed the culvert dimensions by at least a metre on each side to allow for good workmanship and effective compaction of the fill.

Based on the results of the boreholes, the existing fill is not suitable for backfill. Thus, the backfill should consist of free-draining, non-frost susceptible granular materials such as Ontario Provincial Standard Specifications (OPSS) Granular A or Granular B, Type III placed and compacted in accordance with OPSS 501. All bedding, backfill and cover materials should be placed in accordance with OPSS 902 and SP 422S01. Prior to placement of bedding and backfill materials, the founding surface should be inspected by a Quality Verification Engineer (QVE) qualified in geotechnical engineering.

Heavy compaction equipment should not be used immediately adjacent to the walls and roof of the culvert. The height of backfill adjacent to the culvert walls should be maintained equal on both sides of the structure during all stages of backfill placement.

6.5 Liquefaction Potential and Seismic Analysis

6.5.1 Seismic Parameters

The site is located near Exeter, Ontario. According to Table A.3.1.1 of the Canadian Highway Bridge Design Code (CHBDC), the zonal acceleration ratio, A, applicable to this site is 0.00. The corresponding acceleration related seismic zone, Z_a, is 0. Based on the site stratigraphy, the soil profile type is categorized as Type I with a seismic site response coefficient, S, of 1.0 based on the CHBDC criteria.

6.5.2 Seismic Hazard Assessment

The soils at the site are not considered to be susceptible to liquefaction and, therefore, a detailed evaluation of the liquefaction potential of the foundation soils is not considered warranted.

6.6 Lateral Earth Pressures for Design

Lateral pressures acting on the proposed culvert will depend on the type and method of placement of the backfill materials, the nature of the soil 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 walls in accordance with the current CHBDC. It should be noted that these design recommendations and parameters assume full removal of the existing poor quality fill and 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 as described in this report.

- Select free-draining granular fill meeting the specifications of OPSS Granular A or Granular B Type III, but with less than 5 per cent passing the No. 200 sieve, should be used as backfill behind the culvert and retaining walls. Longitudinal drains and weep holes should be installed within any concrete walls to provide positive drainage of the granular backfill. Other aspects of the granular backfill requirements with respect to subdrains and frost taper should be in accordance with OPSD 803.010.

- The granular fill may be placed either in a zone with a width equal to at least 1.2 metres behind the back of the stem (Case (a) from Commentary on CHBDC Figure C6.20) or within the wedge-shaped zone defined by a line drawn at a maximum slope of 1 horizontal to 1 vertical extending up and back from the rear face of the foundation (Case (b) from Commentary on CHBDC Figure C6.20).

- A minimum compaction surcharge of 12 kPa should be included in the lateral earth pressures for the structural design of the culvert / wall stem in accordance with CHBDC Figure C6.6. Compaction equipment should be used in accordance with OPSS 501. Other surcharge loadings should be accounted for in the design, as required.

- For walls backfilled using granular materials as noted above, the following parameters (unfactored) may be assumed:

	GRANULAR A	GRANULAR B (Type III)
Fill unit weight:	22 kN/m^3	21kN/m^3
Coefficients of static lateral earth pressure:		
'active' or unrestrained, K_a	0.27	0.31
'at rest' or restrained, K_o	0.43	0.47

- If the wall support allows lateral yielding (unrestrained structure), active earth pressures may be used in the geotechnical design of the structure. The granular fill should be placed in a wedge 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.

- If the wall support does not allow lateral yielding (which 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.

- Resistance to lateral forces (i.e. sliding resistance) for a cast-in-place wall footing with a concrete working slab may be based on the unfactored angle of friction between the clayey silt till and the concrete. The factored horizontal geotechnical resistance, H_{ri}, should be based on CHBDC 6.7.5 as follows:

$$H_{ri} = 0.8A'c' + 0.8V\tan\delta > H_f$$

Where:

A' - effective contact area, square metres

c' = 0 kilopascals

δ = 30 degrees (clayey silt till)

V - unfactored vertical force, kilonewtons

H_f - factored horizontal load, kilonewtons

The unfactored coefficient of passive pressure for the portion of the culvert wall below the ground surface may be taken as 3.0 based on an unfactored effective angle of internal friction, ϕ', of 32 degrees. In general, it is recommended that the frictional resistance of the top 1 metre of soil in front of any wall be ignored due to disturbance caused by frost action.

6.7 Retaining Walls

The wingwalls for the culvert replacement could consist of reinforced concrete walls or reinforced soil system (RSS) walls.

Based on the results of the foundation investigation, the new retaining walls may be founded on the native undisturbed clayey silt till at about elevation 182.5 metres. To provide consistent founding conditions for a CSP or pre-cast culvert, a 0.3 metre thick layer of 19 millimetre crushed stone should be provided below the footing. The crushed stone pad should extend 0.5 metres beyond the edge of the footing.

For design purposes, a factored geotechnical resistance at ULS of 250 kilopascals and a geotechnical resistance at SLS of 175 kilopascals may be used on the 0.3 metre thick base of 19 millimetre crushed stone or on the clayey silt till.

Select, free draining granular fill in accordance with OPSS Granular B, Type III gradation specifications should be used as backfill immediately adjacent to the retaining wall. As a minimum requirement, the granular backfill should be placed in a wedge-shaped zone defined by a 45 degree line extending up and back from the bottom of the rear face of the excavation.

Filtered longitudinal drains should be installed behind the wall(s) to provide positive drainage of the granular backfill. All granular backfill should be placed in maximum 200 millimetre thick loose lifts and uniformly compacted to at least 95 per cent of standard Proctor maximum dry density. Heavy compaction equipment, however, should not be used within the lateral distance behind any structure equal to the current height of the fill above the base of the structure.

A proprietary RSS wall should be designed by the supplier and constructed in accordance with their specifications. The geotechnical aspects of the global stability of the detailed retaining wall design should be reviewed prior to construction.

The recommended geotechnical design parameters for the RSS wall are as follows:

Unit weight of granular backfill	22 kN/m^3
Unit weight of water	9.8 kN/m^3

Active earth pressure coefficient, K_a (based on horizontal ground)	0.3
Coefficient of friction between granular backfill and founding soils	0.28

6.8 Construction Considerations

Care should be taken during construction to avoid disturbance of the subgrade prior to constructing foundations for the culvert. All topsoil, organics and soft or loose soils should be removed from below the proposed founding elevation and wasted or reused as landscaping fill, as required. Subgrade preparation should be performed and monitored in accordance with OPSS 902.

The cleaned excavation base should be inspected by a geotechnical QVE and a working slab placed immediately after inspection to protect the founding materials. It is recommended that the footing excavation be carried out such that the final 0.5 metres of excavation is completed with the QVE on site with construction of the culvert bottom slab commencing immediately after inspection. A Non Standard Special Provision (NSSP) should be added to the Contract Documents specifying protection of the founding soil through use of a working slab for a cast-in-place culvert.

Erosion and scour protection for the culvert aprons should be provided, as appropriate. 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 Ontario Provincial Standard Drawing 810.010. In addition, sediment control such as silt fences and erosion control blankets may be required during construction and diversion/piping of the watercourse to mitigate migration of fine soil particles.

6.9 Excavations and Temporary Cut Slopes

Excavations will extend through the existing Highway 21 pavement structure and embankment fill and into the underlying clayey silt till. Contractors should also be prepared for the presence of cobbles and boulders within the till.

It is anticipated that the excavations will extend below the inferred groundwater level elevation of 185 metres. It is considered that groundwater can be controlled by pumping from properly constructed and filtered sumps located at the base of the excavations. A Permit To Take Water is not considered necessary at this time. Sumps should be maintained outside of the actual foundation limits.

Surficial water seepage into the excavations should be expected and will be heavier during periods of sustained precipitation. Surface water runoff should be directed away from the excavations at all times. The existing culvert flows will need to be diverted/piped during construction. 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.

Temporary open cut slopes within the fill materials should be maintained no steeper than 1 horizontal to 1 vertical and localized sloughing and ground movements should be expected. 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. The fill and any cohesionless materials below the groundwater level would be classified as Type 3 soils. The cohesionless materials above the groundwater level and clayey silt till would be classified as Type 2 soils.

6.9.1 Staging and Temporary Roadway Protection

It is understood that a single lane is to remain open to traffic during construction. Therefore, replacement of the existing Turnbull Drain culvert will need to be conducted in stages using open cut construction and a signalized single lane.

Temporary support systems could consist of soldier piles and lagging or steel sheet piles. A soldier pile and lagging system is preferred for constructability. The temporary shoring will have a maximum height of about 4.5 metres above the excavation base.

Excavation support systems should be designed and constructed in accordance with OPSS 539 and the design should limit the lateral movement of the temporary shoring system to meet Performance Level 2. The contractor is responsible for the complete detailed design of the protection system.

The design of a braced sheet pile wall or a soldier pile and lagging wall should be based on a rectangular earth pressure distribution using the design parameters given below. Where the support to the wall is provided by anchors or rakers, the wall design should be based on a triangular earth pressure distribution using the design parameters given below. 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. Passive toe restraint to the soldier piles may be determined using a triangular pressure distribution acting over an equivalent width equal to three times the pile socket diameter.

The unfactored triangular earth pressure distribution (p in kN/m^2; increasing with depth) can be calculated as follows:

$$p = K_a (\gamma H + q)$$

where H = the height of the excavation at any point in metres

K_a = active coefficient of earth pressure

γ = soil unit weight

q = surcharge for traffic and other loading

For the granular fill, the unfactored rectangular earth pressure distribution (p in kN/m^2; constant with depth), can be calculated as follows:

$$p = 0.65 K_a (\gamma H + q)$$

where H = the total height of the excavation

K_a = active coefficient of earth pressure

γ = soil unit weight

q = surcharge for traffic and other loading

The support systems may be designed using the following parameters:

Soil Type	Coefficient of Earth Pressure			Internal Angle of Friction (degrees)	Unit Weight (kN/m^3)
	Active, K_a	At Rest, K_o	Passive, K_p		
Fill	0.36	0.53	2.8	28	19
Clayey Silt Till	0.31	0.47	3.3	32	19

The earth pressure coefficients identified above may be applied assuming a horizontal ground surface behind the retaining structure. Where the ground surface behind the retaining structure is sloped, the earth pressure coefficients provided in the table above must be increased accordingly. Contractors should be prepared for the presence of cobbles and boulders within the till strata and the appropriate NSSP should be provided.

7.0 MISCELLANEOUS

This report was prepared by Mr. Tyson Pitt, P.Eng. under the direction of the Team Leader, Mr. Philip R. Bedell, P.Eng. This report was reviewed by Mr. Fintan J. Heffernan, P.Eng., the Designated MTO Contact and Quality Control Auditor for this assignment.

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TABLE I

COMPARISON OF FOUNDATION ALTERNATIVES – REPLACEMENT STRUCTURE

Site 12-399/C
Turnbull Drain Culvert
Highway 21 Rehabilitation
GWP 3952-01-00

FOUNDATION OPTION	**FEASIBILITY**	**ADVANTAGES**	**DISADVANTAGES**
Corrugated steel pipe arch or pipe culvert	• Feasible	• Faster construction than pre-cast or cast-in-place concrete box culvert • Ease of construction	• Care required during backfilling, especially around the haunches • Shorter design life than concrete box culverts • More difficult installing the shoring
Pre-cast concrete box culvert	• Feasible	• Faster construction than cast-in-place concrete box culvert • Ease of construction	• Large crane required to move pre-cast box units • Difficult to fit units and install tight to shoring
Cast-in-place concrete box culvert	• Feasible	• Facilitates minor site adjustments at shoring, etc. • Simplifies connection to existing culvert • Smaller equipment	• Longer construction time • Forming, concrete curing and stripping

NOTES: 1. Table to be read in conjunction with accompanying report.

Prepared by: TP
Checked by: PRB

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
σ_1, σ_2, σ_3	principal stress (major, intermediate, minor)
σ_{oct}	mean stress or octahedral stress $= (\sigma_1+\sigma_2+\sigma_3)/3$
τ	shear stress
u	porewater pressure
E	modulus of deformation
G	shear modulus of deformation
K	bulk modulus of compressibility

III. SOIL PROPERTIES

(a) Index Properties

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

(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 ($\phi = 0$ analysis)
p	mean total stress $(\sigma_1 + \sigma_3)/2$
p′	mean effective stress $(\sigma'_1 + \sigma'_3)/2$
q	$(\sigma_1 + \sigma_3)/2$ or $(\sigma'_1 + \sigma'_3)/2$
q_u	compressive strength $(\sigma_1 + \sigma_3)$
S_t	sensitivity

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

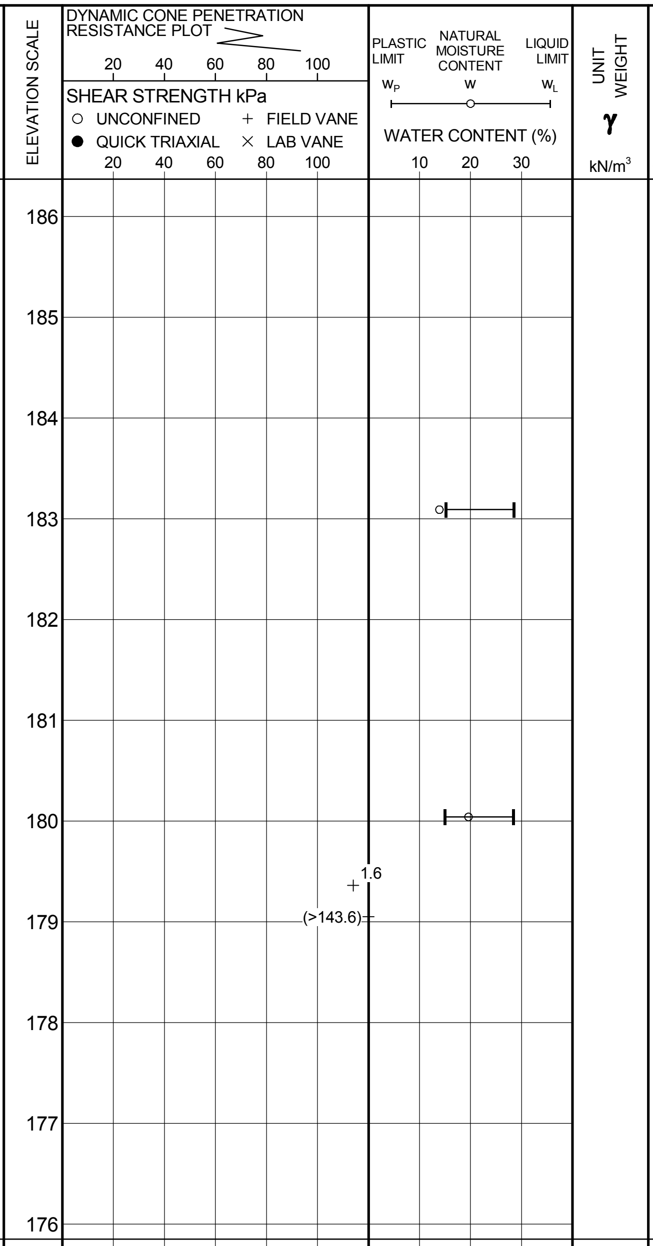
Golder Associates
London, Ontario

RECORD OF BOREHOLE No 6

1 OF 1 **METRIC**

PROJECT 11-1132-0014
W.P. 3952-01-00 LOCATION N 4799302.6 ;E 366317.8 ORIGINATED BY MA
DIST HWY 21 BOREHOLE TYPE POWER AUGER, HOLLOW STEM COMPILED BY WDF
DATUM GEODETIC DATE September 26, 2011 CHECKED BY

ELEV / DEPTH	SOIL PROFILE: DESCRIPTION	SAMPLES: NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	REMARKS & GRAIN SIZE DISTRIBUTION (%): GR	SA	SI	CL
186.37	GROUND SURFACE								
0.00	TOPSOIL, silty Brown								
0.12	FILL, clayey silt, some sand, trace gravel, trace topsoil Stiff to Very Stiff Brown								
		1	SS	16					
		2	SS	10					
184.24 2.13	CLAYEY SILT TILL, trace to some sand, trace gravel Firm to Very Stiff Brown becoming Grey at about elev. 182.7m								
		3	SS	23					
		4	SS	24		3	14	45	38
		5	SS	18					
		6	SS	11					
		7	SS	8					
		8	SS	7		1	13	45	41
		9	SS	11					
		10	SS	7					
		11	SS	8					
175.85 10.52	END OF BOREHOLE Borehole dry during drilling on Sept. 26, 2011.								



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

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London, Ontario

RECORD OF BOREHOLE No 7

1 OF 1

METRIC

PROJECT 11-1132-0014
W.P. 3952-01-00
LOCATION N 4799287.9 ;E 366340.1
ORIGINATED BY MA
DIST
HWY 21
BOREHOLE TYPE POWER AUGER, HOLLOW STEM
COMPILED BY WDF
DATUM GEODETIC
DATE September 26, 2011
CHECKED BY

SOIL PROFILE

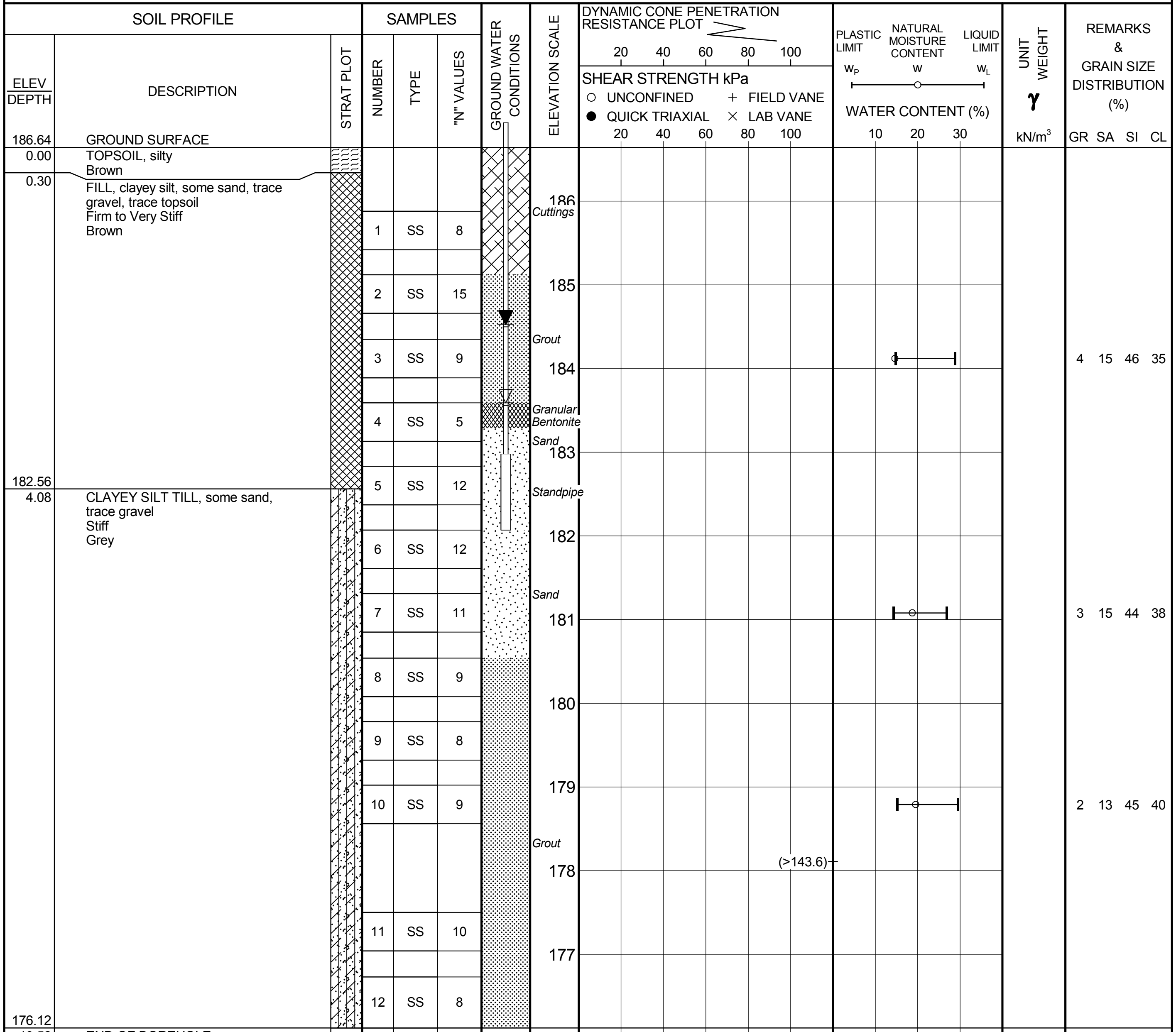
ELEV / DEPTH	DESCRIPTION
186.64	GROUND SURFACE
0.00	TOPSOIL, silty Brown
0.30	FILL, clayey silt, some sand, trace gravel, trace topsoil Firm to Very Stiff Brown
182.56 4.08	CLAYEY SILT TILL, some sand, trace gravel Stiff Grey
176.12 10.52	END OF BOREHOLE

Groundwater encountered at about elev. 183.6m during drilling on Sept. 26, 2011.

Water level in Standpipe at elev. 184.53m on Oct. 21/11.

SAMPLES

NUMBER	TYPE	"N" VALUES	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR	SA	SI	CL
1	SS	8				
2	SS	15				
3	SS	9	4	15	46	35
4	SS	5				
5	SS	12				
6	SS	12				
7	SS	11	3	15	44	38
8	SS	9				
9	SS	8				
10	SS	9	2	13	45	40
11	SS	10				
12	SS	8				



+^{3}, ×^{3}: Numbers refer to Sensitivity

○$^{3\%}$ STRAIN AT FAILURE

LDN_MTO_06 11-1132-0014-2000.GPJ LDN_MTO.GDT 25/10/11

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RECORD OF BOREHOLE No 8

1 OF 1 **METRIC**

PROJECT 11-1132-0014
W.P. 3952-01-00
LOCATION N 4799296.7 ;E 366335.7
ORIGINATED BY MA
DIST
HWY 21
BOREHOLE TYPE POWER AUGER, HOLLOW STEM
COMPILED BY WDF
DATUM GEODETIC
DATE September 27, 2011
CHECKED BY

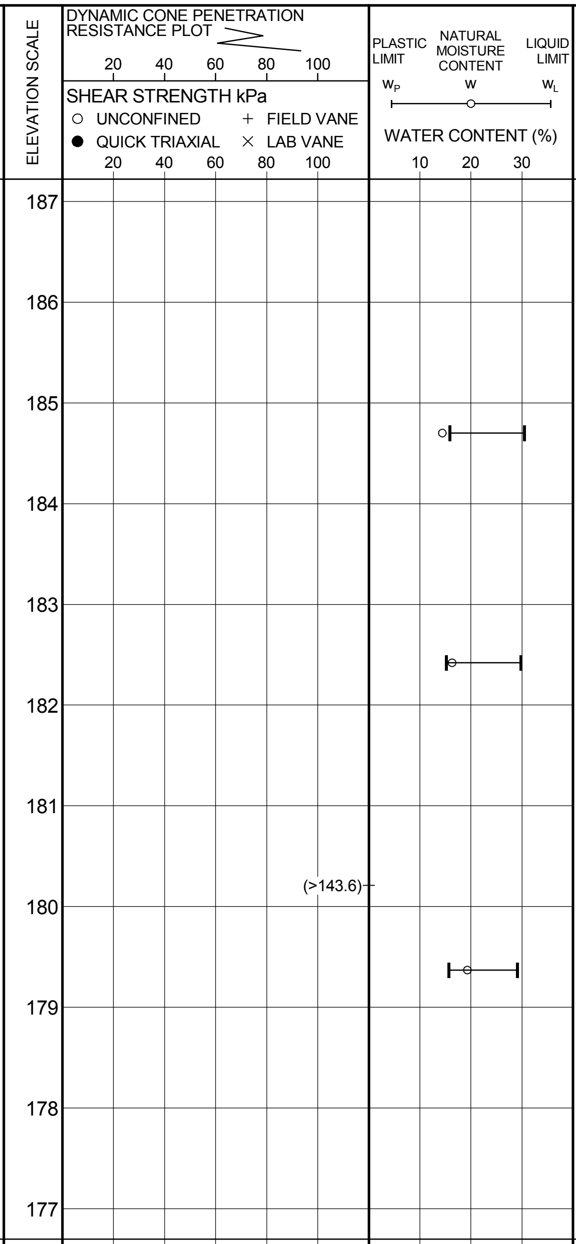
SOIL PROFILE

ELEV DEPTH	DESCRIPTION
187.22	GROUND SURFACE
0.00	FILL, sand and gravel, trace silt, crushed Brown
0.30	FILL, sand and gravel, trace silt Brown
186.40 0.82	FILL, clayey silt, some sand, trace gravel, trace asphalt and topsoil Stiff Brown
185.67 1.55	CLAYEY SILT TILL, some sand, trace gravel Firm to Very Stiff Brown becoming Grey at about elev. 182.8m
176.70 10.52	END OF BOREHOLE Borehole dry during drilling on Sept. 27, 2011.

SAMPLES

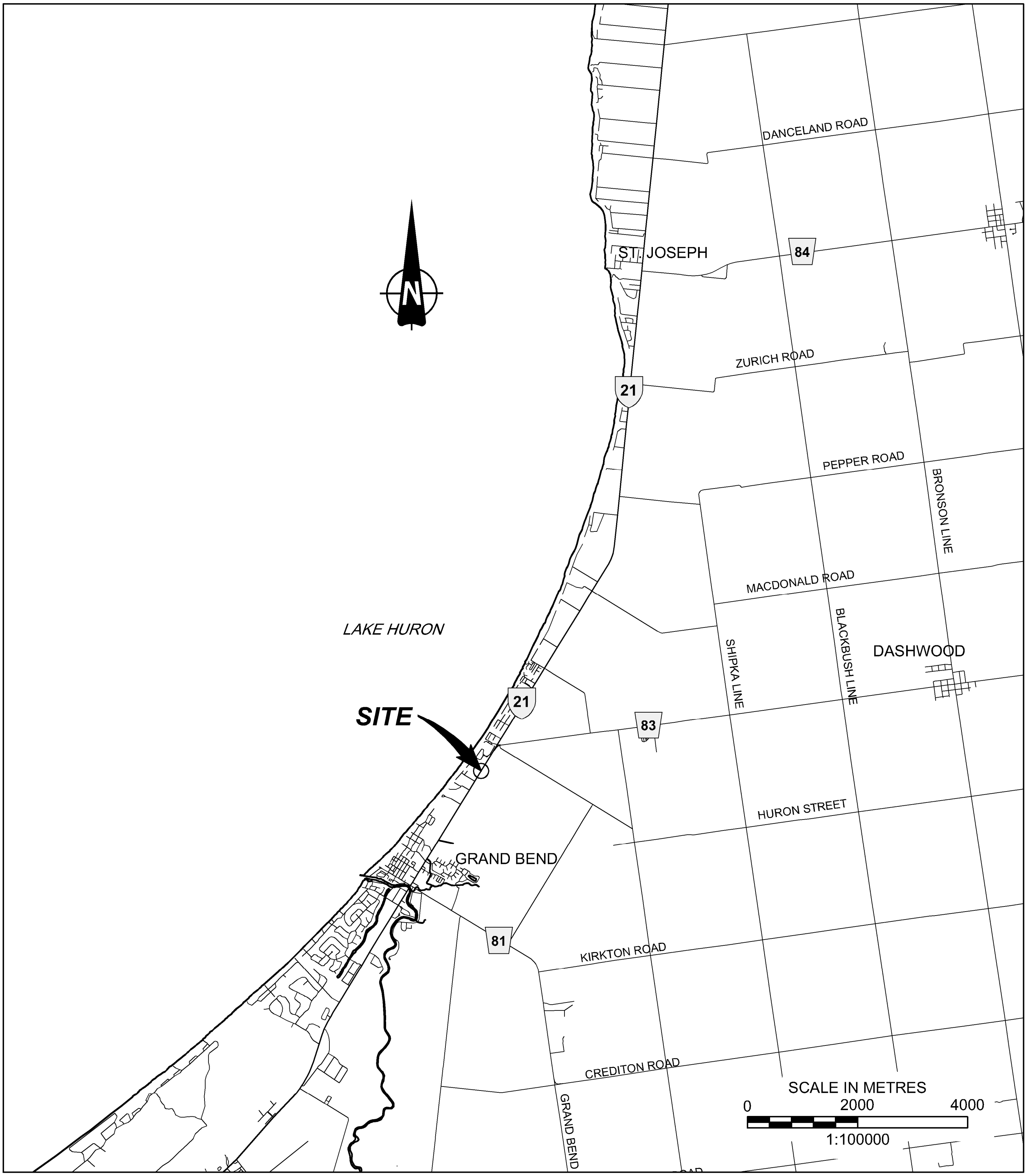
NUMBER	TYPE	"N" VALUES	GR	SA	SI	CL
1	SS	10				
2	SS	13				
3	SS	21	1	14	49	36
4	SS	22				
5	SS	19				
6	SS	12	1	14	47	38
7	SS	8				
8	SS	7				
9	SS	8	1	15	45	39
10	SS	9				
11	SS	8				

STRAT PLOT | GROUND WATER CONDITIONS | ELEVATION SCALE | UNIT WEIGHT γ kN/m³ | REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL



+3, ×3: Numbers refer to Sensitivity

○3% STRAIN AT FAILURE



REFERENCE

DRAWING BASED ON CLIENT SUPPLIED INFORMATION AND CANMAP STREET FILES v2008.4

NOTE

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

PROJECT

TURNBULL DRAIN CULVERT
HIGHWAY 21 REHABILITATION
GWP 3952-01-00, SITE NO. 12-399/C

TITLE

KEY PLAN

Golder Associates
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PROJECT No.		11-1132-0014	FILE No. 1111320014-2000-F02001	
			SCALE AS SHOWN	REV. 0
CADD	WDF	Oct. 19/11	**FIGURE 1**	
CHECK				

Drawing file: 1111320014-2000-F02001.dwg Mar 01, 2012 - 12:02pm

MINISTRY OF TRANSPORTATION, ONTARIO

CONT No. 2012–3009
WP No. 3952–01–00

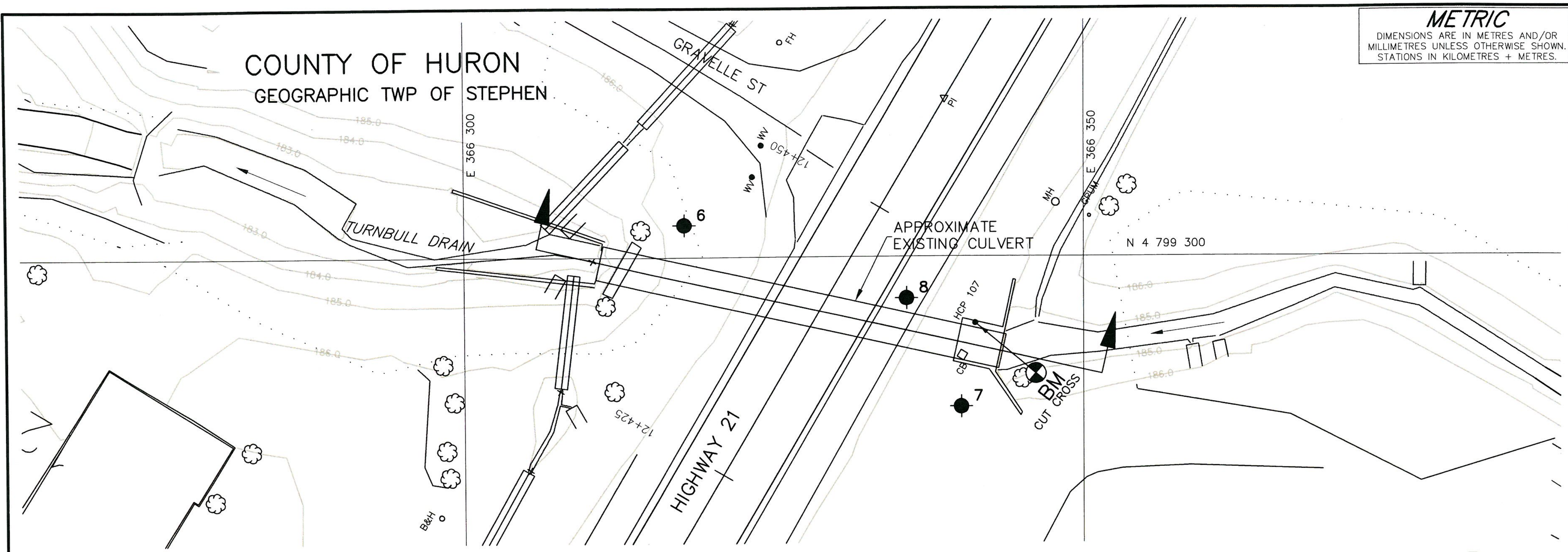
TURNBULL DRAIN CULVERT
HIGHWAY 21 REHABILITATION

BOREHOLE LOCATION & SOIL STRATA

SHEET

Golder Associates Ltd.
LONDON, ONTARIO, CANADA

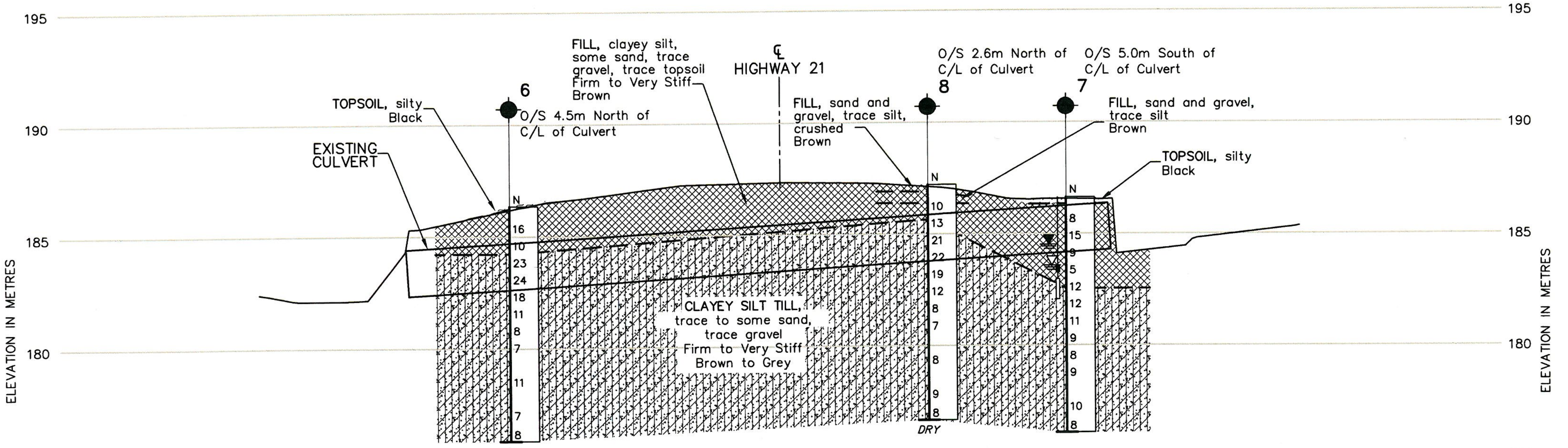
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS IN KILOMETRES + METRES.



PLAN
SCALE
4 0 4 8 m

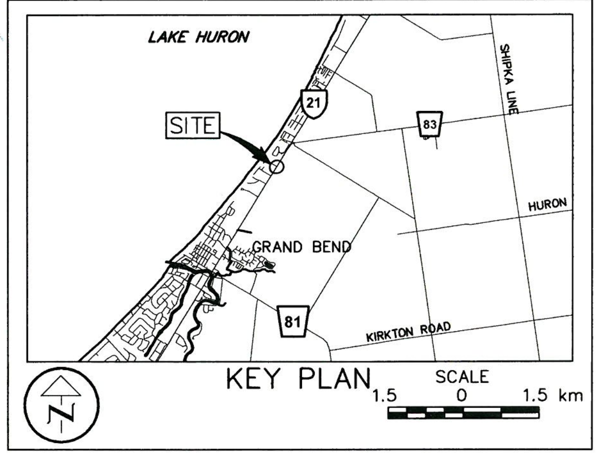
F.J. HEFFERNAN

N.S.PITT
100132967



170
170

PROFILE ALONG CENTRELINE OF CULVERT
SCALE
2.5 0 2.5 5.0 m



KEY PLAN
SCALE
1.5 0 1.5 km

LEGEND

●	Borehole – Current Investigation
▮	Seal
▯	Piezometer
N	Standard Penetration Test Value
16	Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
DRY	Borehole dry during drilling
▽	WL encountered during drilling
▼	WL in Standpipe, measured on Oct. 21, 2011.

No.	ELEVATION	CO–ORDINATES MTM ZONE 11	
		NORTHING	EASTING
6	186.37	4 799 302.6	366 317.8
7	186.64	4 799 287.9	366 340.1
8	187.22	4 799 296.7	366 335.7

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 provided in digital format by Dillon Consulting Limited.

NO.	DATE	BY	REVISION

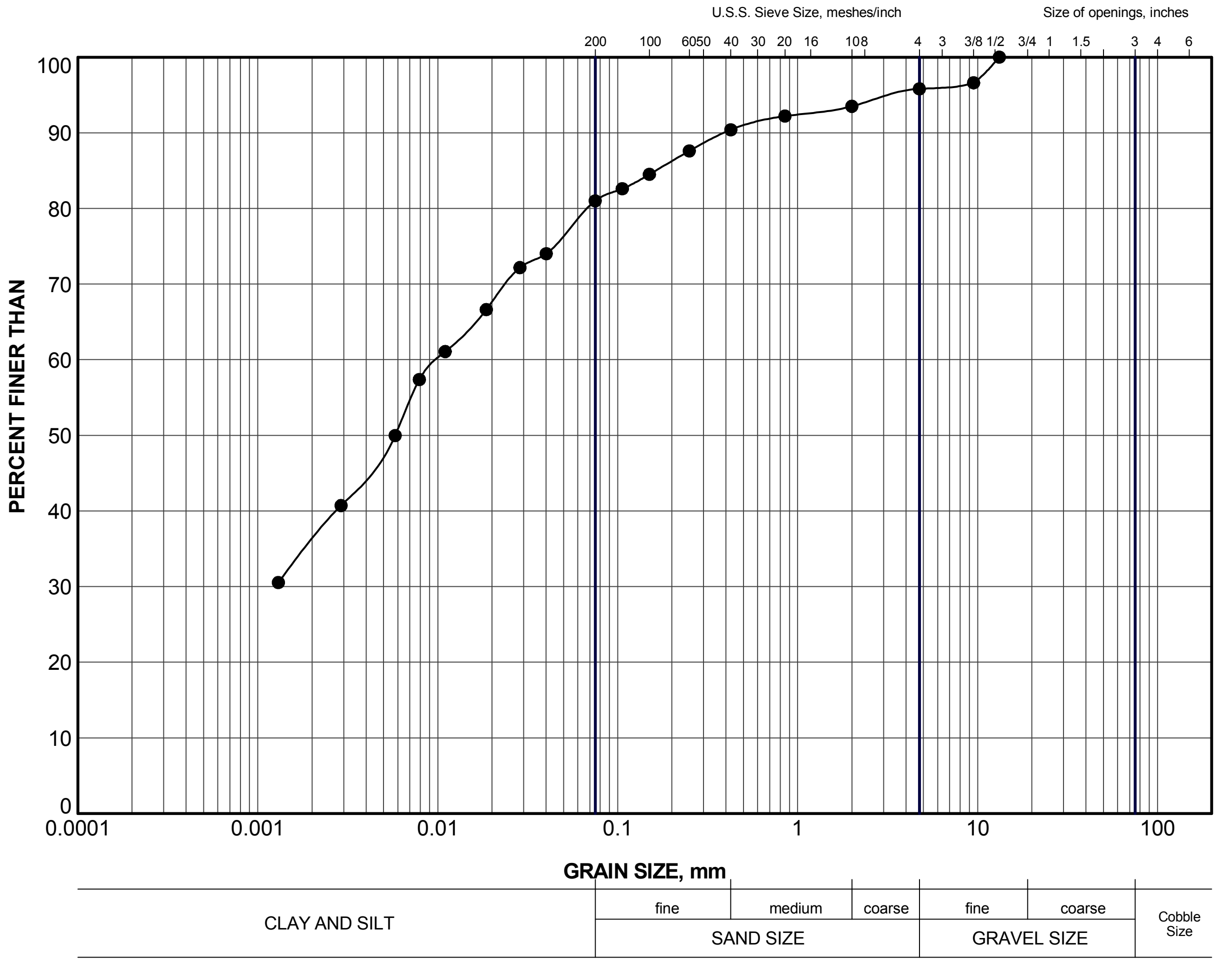
Geocres No. 40P5–17

HWY. 21		PROJECT NO. 11–1132–0014	DIST.
SUBM'D. TP	CHKD. TP	DATE: JAN. 27/12	SITE:12–399/C
DRAWN: WDF	CHKD.	APPD.	DWG. 1

PLOT DATE: March 09, 2012
FILENAME: N:\active\2011\1132-Geo\1132-0000\11-1132-0014 DILLON - GWP 3952-01-00 - HWY 21\Drafting\AutoCAD files\1111320014-2000-D02D01.dwg

APPENDIX A

Laboratory Test Data



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	7	3	184.1

PROJECT

TURNBULL DRAIN CULVERT
HIGHWAY 21 REHABILITATION
GWP 3952-01-00, SITE NO. 12-399/C

TITLE

GRAIN SIZE DISTRIBUTION

FILL, clayey silt

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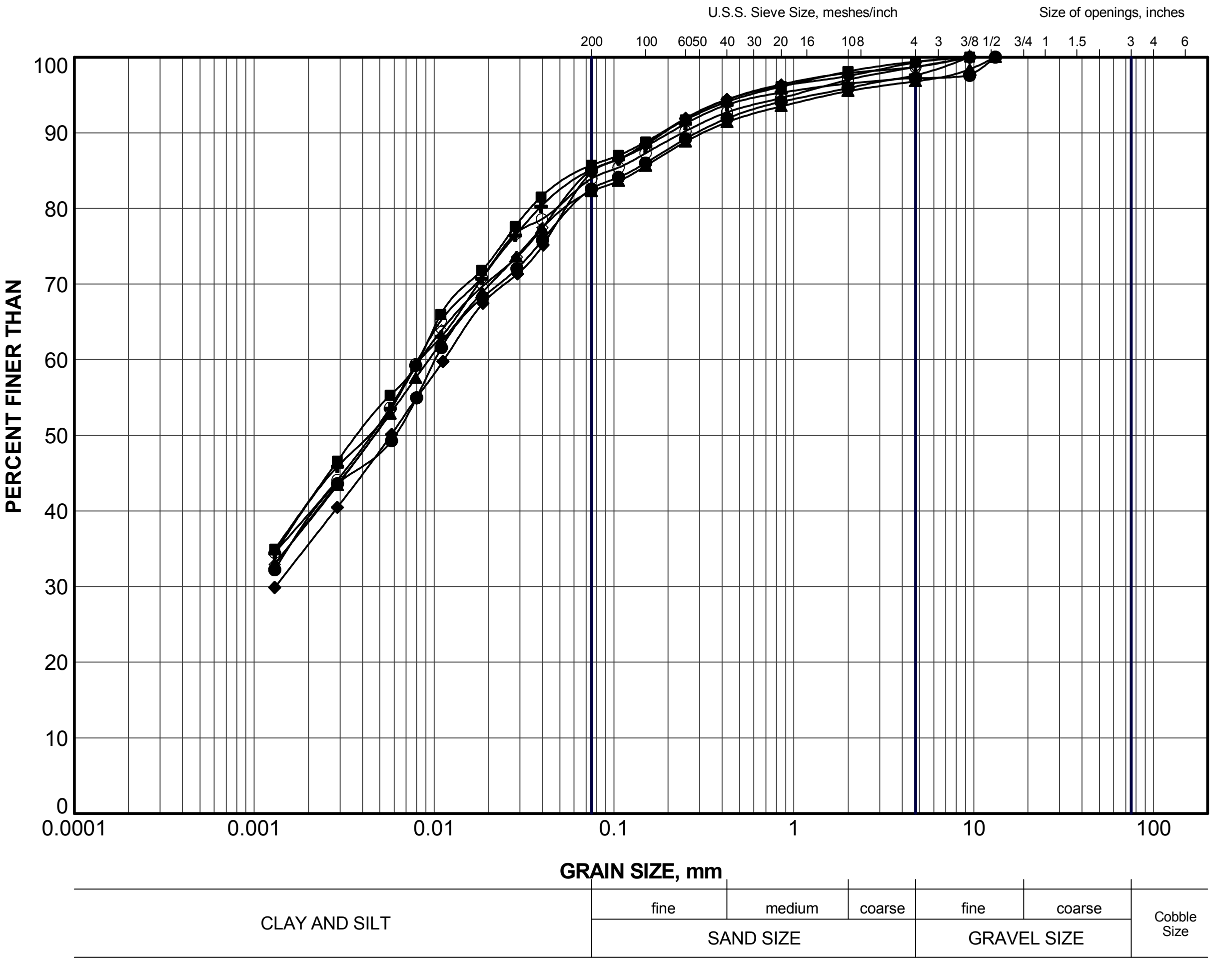
PROJECT No.	11-1132-0014		FILE No. 111320014-2000-F020A1	
			SCALE N/A	REV.
DRAWN	WDF	Oct 20/11	**FIGURE A-1**	
CHECK				

LDN_MTO_GSD GLDR_LDN.GDT



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	6	4	183.1
■	6	8	180.0
▲	7	7	181.1
✚	7	10	177.3
◆	8	3	184.7
◇	8	6	182.4
○	8	9	179.4

PROJECT

TURNBULL DRAIN CULVERT
HIGHWAY 21 REHABILITATION
GWP 3952-01-00, SITE NO. 12-399/C

TITLE

GRAIN SIZE DISTRIBUTION

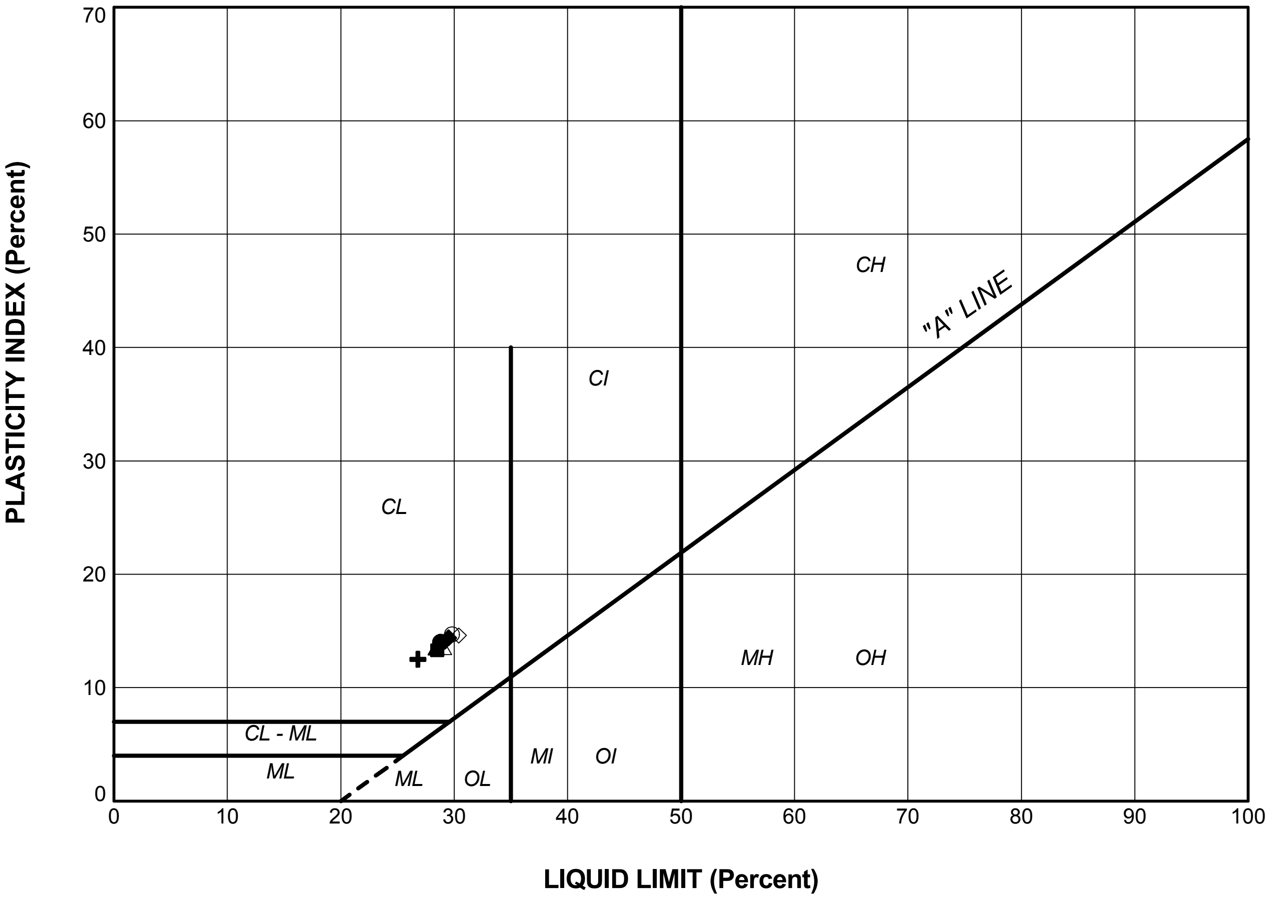
CLAYEY SILT TILL

Golder Associates
LONDON, ONTARIO

PROJECT No.	11-1132-0014	FILE No.	1111320014-2000-F020A2
		SCALE N/A	REV.
DRAWN	WDF	Oct 20/11	
CHECK			

FIGURE A-2

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, clayey silt					
●	7	3	28.8	14.8	14.0
CLAYEY SILT TILL					
■	6	4	28.5	15.2	13.3
▲	6	8	28.4	14.9	13.5
✚	7	7	26.8	14.3	12.5
◆	7	10	29.5	15.1	14.4
◇	8	3	30.4	15.8	14.6
○	8	6	29.8	15.1	14.7
△	8	9	29.1	15.6	13.5

PROJECT
TURNBULL DRAIN CULVERT
HIGHWAY 21 REHABILITATION
GWP 3952-01-00, SITE NO. 12-399/C

TITLE

PLASTICITY CHART

Golder Associates
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PROJECT No.	11-1132-0014		FILE No. 111320014-2000-F020A3	
			SCALE N/A	REV.
DRAWN	WDF	Oct 20/11	**FIGURE A-3**	
CHECK				

LDN_MTO_PI GLDR_LDN.GDT

APPENDIX B

Site Photograph

Photograph 1: Turnbull Drain Culvert, inlet.

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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South America	+ 55 21 3095 9500

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