



June 12, 2017

## FOUNDATION INVESTIGATION AND DESIGN REPORT

**Highway 401 Structural Culvert, Site No. 21-487/C**  
**Structural Culvert Rehabilitation/Replacement**  
**Highway 35/115 and Highway 401**  
**Ministry of Transportation, Ontario**  
**G.W.P. 2242-14-00**

**Submitted to:**

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REPORT





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# **PART A**

**FOUNDATION INVESTIGATION REPORT  
HIGHWAY 401 STRUCTURAL CULVERT - SITE NO. 21-487/C  
STRUCTURAL CULVERT REHABILITATION/REPLACEMENT  
HIGHWAY 35/115 AND HIGHWAY 401  
MINISTRY OF TRANSPORTATION, ONTARIO  
G.W.P. 2242-14-00**



## **1.0 INTRODUCTION**

Golder Associates Ltd. (Golder) has been retained by D.M. Wills Associates Ltd. (D.M. Wills) on behalf of Ministry of Transportation, Ontario (MTO) to provide Foundation Engineering services for the replacement / rehabilitation of various culverts on Highway 35/115 and Highway 401 in the Regional Municipality of Durham, Ontario.

The Terms of Reference and the Scope of Work for the foundation investigation are outlined in MTO's Request for Quotation, dated August 2015. Golder's proposal for the Foundation Engineering services associated with the culvert replacement is contained in Section 3.5 of D.M. Wills' Technical Proposal for this assignment. The work has been carried out in accordance with Golder's Supplementary Specialty Plan for foundation engineering services for this project, dated December 1, 2016.

This report addresses the investigation carried out for the Structural Culvert C9 at about STA 11+817 on Highway 401 (MTO Structure Site No. 21-487/C) which has been identified for rehabilitation or potential replacement. The foundation investigation associated with the other culverts, which forms part of the Foundation assignment are presented in separate reports.

## **2.0 SITE DESCRIPTION**

The structural culvert Site No. 21-487/C (Culvert C9) requiring rehabilitation or replacement is located at approximately STA 11+817 on Highway 401, in the City of Oshawa, Regional Municipality of Durham, Ontario, as shown on the Key Plan on Drawing 1. The existing structural culvert is an open footing cast-in-place concrete structure and is 112.6 m long and 4.6 m wide by 3.6 m high. The structure is located across an embankment which provides approximately 7.9 m of soil cover. Details of the culvert are also summarized in Table 1 following the text of this report.

The overall surface topography in the vicinity of the site is generally flat-lying to gently sloping, with the natural ground surface at approximately Elevation 84 m. The Highway 401 grade in the vicinity of the culvert is at about Elevation 95 m. The existing Highway 401 embankment is comprised of earth fill, up to about 11 m high with side slopes inclined at approximately 2 horizontal to 1 vertical (2H:1V).

## **3.0 INVESTIGATION PROCEDURES**

The fieldwork for the current investigation associated with structural culvert Site No. 21-487/C was carried out between July 24 and 26, 2016, between September 7 and 14, 2016 and December 7 and 8, 2016, during which time a total of six boreholes were advanced at, or in the immediate vicinity of the culvert alignment as shown in plan on Drawing 1.

The field investigation was carried out using portable and truck-mounted drilling equipment supplied and operated by specialist drilling contractors, Kodiak Drilling Inc. of Toronto, Ontario and Atcost Drilling Inc. of Gormley, Ontario, respectively. The boreholes that were advanced by portable equipment used 102 mm outer diameter (O.D.) hollow stem augers; the boreholes advanced by the truck-mounted drill used 208 mm outer diameter (O.D.) hollow stem augers. Soil samples were obtained at intervals of depth of about 0.75 m and 1.5 m using a 50 mm O.D.



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split-spoon sampler operated by an automatic hammer on the truck-mounted drill and by a manual hammer on the portable drill, performed in accordance with Standard Penetration Test (SPT) procedures (ASTM D1586)<sup>1</sup>.

A piezometer was installed in Borehole C9-6 to allow monitoring of the groundwater level at this site. The piezometer consists of a 50 mm diameter PVC pipe, with a slotted screen sealed positioned within the zone of silty clay fill / silty clay till / silty sand deposits. The borehole and annulus surrounding the piezometer pipe above the screen and sand pack were backfilled with bentonite pellets to ground surface. The piezometer installation details and water level readings are noted on the Record of Borehole C9-6 in Appendix A. All of the remaining boreholes were backfilled with bentonite upon completion of drilling in accordance with Ontario Regulation 903 (Wells) (as amended). The groundwater conditions and water levels in the open boreholes were observed during and immediately following the drilling operations and are described on the Record of Borehole sheets in Appendix A.

The fieldwork was observed by members of Golder's engineering and technical staff, who located the boreholes, arranged for the clearance of underground services, observed the drilling, sampling and in situ testing operations, logged the boreholes, and examined the soil samples. The soil samples were identified in the field, placed in appropriate containers, labelled and transported to our Mississauga geotechnical laboratory where the samples underwent further visual examination and laboratory testing. All of the laboratory tests were carried out to MTO Laboratory and/or ASTM Standards, as appropriate. Classification testing (water content, Atterberg limits and grain size distribution) was carried out on selected soil samples. The results of the laboratory testing are summarized on the Record of Borehole sheets in Appendix A and provided on Figures B1 to B10 in Appendix B.

A soil sample obtained during the field investigation at about the culvert invert elevation in Borehole C9-4, using appropriate sampling protocols, was submitted to a specialist analytical laboratory under chain of custody procedures for chemical analysis of conductivity / resistivity, pH, sulphate and chloride content and redox potential to assess the potential for the soil to cause deterioration of buried concrete and corrosion of steel. The results of the Analytical testing are presented in Appendix C and are discussed in Section 4.3.

The as-drilled borehole locations were measured relative to existing site features and were subsequently converted into MTM NAD 83 coordinates in AutoCAD. The elevation of the boreholes was obtained by plotting the borehole locations on the topographic mapping provided by D.M. Wills on January 20, 2016. The borehole locations given on the Record of Borehole sheets and shown on Drawing 1 are positioned relative to MTM NAD 83 (Zone 10) northing and easting coordinates and the ground surface elevations are referenced to Geodetic datum. The borehole locations (including geographic coordinates), ground surface elevations and drilled depths are as follows:

<sup>1</sup> ASTM D1586-11 Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils, ASTM International, West Conshohocken, PA, 2011



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Borehole	Location (m)		Ground Surface Elevation (m)	Depth of Borehole (m)
	Northing (Latitude)	Easting (Longitude)		
C9-1	4859886.2 (43.876705)	362457.6 (-78.782548)	88.6	15.9
C9-2	4859865.2 (43.876516)	362456.0 (-78.782571)	95.1	26.0
C9-3	4859867.9 (43.876540)	362473.2 (-78.782356)	95.0	26.1
C9-4	4859836.3 (43.876245)	362486.6 (-78.782190)	95.0	26.1
C9-5	4859839.8 (43.876275)	362505.2 (-78.781959)	95.0	25.9
C9-6	4859818.6 (43.876091)	362533.8 (-78.781608)	85.8	12.8

## 4.0 SITE GEOLOGY AND SUBSURFACE CONDITIONS

### 4.1 Regional Geology

This section of Highway 401 is located within the Iroquois Plain physiographic region, as delineated in *The Physiography of Southern Ontario* (Chapman and Putnam, 1984)<sup>2</sup> and *Urban Geology of Canadian Cities* (Karrow and White, 1998)<sup>3</sup>. The Iroquois Plain extends around the western shores of Lake Ontario. The Plain is comprised of the flat to undulating lakebed and beaches of the former glacial Lake Iroquois, which occupied this area during the last glacial recession. The surficial soils in this area of the Iroquois Plain are typically comprised of glaciolacustrine clays, silts and sands to gravelly sands.

### 4.2 General Overview of Local Subsurface Conditions

The detailed subsurface soil and groundwater conditions as encountered in the boreholes advanced during this investigation, together with the results of the laboratory tests carried out on selected soil samples, are presented on the Record of Borehole sheets and the laboratory test sheets in Appendices A and B, respectively. The stratigraphic boundaries shown on the Record of Borehole sheets and on the stratigraphic profile on Drawing 1 are inferred from non-continuous sampling, observations of drilling progress and in situ testing and are approximate. These boundaries, therefore, represent transitions between soil types rather than exact planes of geological change. Further, subsurface conditions will vary between and beyond the borehole locations.

The stratigraphy at the borehole locations at the culvert location generally consists of a layer of asphalt at the boreholes drilled on the highway embankment, underlain by or an upper layer of non-cohesive embankment fill and a lower layer of cohesive embankment fill, underlain by a very stiff to hard clayey silt to silty clay till or silty clay to clay deposits in places. An interlayer of silty sand is present at one borehole location underlying the fill deposit. The embankment fill deposit, the silty sand interlayer and the clayey silt to silty clay till deposit are in turn underlain by a deposit of clayey silt to silty clay, in turn underlain by interlayers of silty sand, silty clay till and/or

<sup>2</sup> Chapman, L.J., and Putnam, D.F., 1984. *The Physiography of Southern Ontario*, 3rd Edition. Ontario Geological Survey, Special Volume 2. Ontario Ministry of Natural Resources.

<sup>3</sup> Karrow, P. F., and White, O. L., 1998. *Urban Geology of Canadian Cities*. Geological Association of Canada Special Paper No. 42. St. John's, Nfld.





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silty clay. A detailed description of the subsurface conditions at the culvert crossing is provided in the following section of this report. Where relatively significant thicknesses of overburden were encountered, the various soil types are described in detail for each main deposit or stratum.

### 4.2.1 Asphalt

Boreholes C9-2, C9-3, C9-4 and C9-5, advanced through the existing Highway 401 roadway, penetrated an asphalt layer between approximately 100 mm and 200 mm thick.

### 4.2.2 Embankment Fill

Embankment fill, approximately 2.3 m to 10.6 m thick was encountered in all boreholes immediately below existing ground surface, or underlying the asphalt (where present). The embankment fill consists of: an upper non-cohesive layer of silty sand to gravelly silty sand to gravelly silt and sand to sand and gravel, approximately 0.6 m to 4.1 m thick in all six boreholes; and a lower layer of cohesive fill approximately 1.5 m to 9.4 m thick comprised of clayey silt to silty clay, trace sand to with sand, trace to some gravel. Trace organics were encountered within the fill deposit at some borehole locations. Cobbles and /or boulders were inferred to be present within the layer of non-cohesive fill based on grinding of the augers as noted on the Record of Borehole C9-2, C9-3 and C9-5. It is noted that in addition to the potential presence of cobbles and/or boulders within the fill deposit, our recent experience with trenchless crossings of major MTO highways suggests that there may also be debris present within the fill and at the interface with the underlying native materials consisting of abandoned temporary works associated with the original culvert construction. This debris buried in the fill may consist of logs, stumps, and brush from the clearing and grubbing operations.

The SPT 'N'-values measured within the non-cohesive embankment fill layer range from 5 blows to 40 blows per 0.3 m of penetration, indicating a generally loose to dense relative density. The SPT 'N'-values measured in the cohesive layers of the embankment fill deposit range from 4 blows to 28 blows per 0.3 m of penetration, suggesting a soft to very stiff consistency.

The natural water content measured on seven samples of the non-cohesive embankment fill ranges between about 4 per cent and 17 per cent. The natural water content measured on seven samples of the cohesive embankment fill ranges between about 6 per cent and 25 per cent.

The results of grain size distribution tests completed on three samples of the non-cohesive embankment fill are shown on Figure B1 in Appendix B. The results of grain size distribution tests completed on nine samples of the cohesive embankment fill are shown on Figures B2A and B2B in Appendix B.

Atterberg limits tests were carried out on eleven samples of the cohesive embankment fill deposit and measured liquid limits ranging between about 14 per cent and 41 per cent, plastic limits ranging between about 10 per cent and 17 per cent and plasticity indices ranging between about 4 and 25 per cent. These test results, which are plotted on a plasticity chart on Figure B3 in Appendix B, indicate that the cohesive fill material is a clayey silt of low plasticity to silty clay of intermediate plasticity.

Atterberg limits tests were carried out on the fines portion of two samples of the non-cohesive embankment fill deposit and measured liquid limits of about 14 per cent and 15 per cent, plastic limits of about 11 per cent and 12 per cent and plasticity indices of about 3 per cent. These test results, which are plotted on a plasticity chart on Figure B4 in Appendix B, indicate that the fines portion of the silt and sand to silty sand embankment fill is comprised of silt of slight plasticity.





### **4.2.3 Clayey Silt to Silty Clay Till**

A 1.6 m and 9.3 m thick deposit of clayey silt to silty clay till, trace to some sand, trace gravel was encountered in Boreholes C9-1 and C9-6, underlying the embankment fill at Elevation 86.3 m and 80.2 m, respectively.

The SPT 'N'-values measured within clayey silt till to silty clay deposit range between 19 blows and 101 blows per 0.3 m of penetration, suggesting a very stiff to hard consistency.

The natural water content measured on four samples of the silty clay to clayey silt till deposit range between about 11 per cent and 21 per cent.

The results of grain size distribution tests completed on two samples of the clayey silt till to silty clay from Borehole C9-1 are shown on Figure B5 in Appendix B.

Atterberg limits testing was carried out on three samples of the cohesive till deposit and measured liquid limits between about 26 and 34 per cent, plastic limits between about 12 and 14 per cent and plasticity indices between about 13 and 20 per cent. These test results, which are plotted on a plasticity chart on Figure B6 in Appendix B, indicate that the material tested is a clayey silt of low to silty clay of intermediate plasticity.

### **4.2.4 Silty Clay to Clay**

A cohesive deposit consisting of silty clay to clay, trace to some sand, trace gravel, containing silty sand seams/pockets, was encountered in all of the boreholes advanced at this site underlying the till, fill or interlayer of silty sand (described below), at depths ranging between about 10.2 m and 11.7 m below ground surface (Elevation 84.8 m and 74.1 m) and the thickness of the deposit ranges between 1.1 m and 14.4 m to the sampled depth, but is 13.2 m and 13.7 m thick in the boreholes where it was fully penetrated. Boreholes C9-1, C9-2 and C9-6 were terminated within this deposit at between Elevations 69.1 m and 73.0 m.

The SPT 'N'-values measured within the clayey silt to silty clay deposit range from 18 blows to 62 blows per 0.3 m of penetration, with three 'N'-values of 79 blows for 0.13 m of penetration to 50 blows for 0.08 m of penetration, suggesting a very stiff to hard consistency.

The natural water content measured on samples of the silty clay to clay deposit range between about 14 per cent and 31 per cent.

The results of grain size distribution tests completed on eight samples of the silty clay to clay deposit are shown on Figures B7A and B7B in Appendix B.

Atterberg limits testing was carried out on eight samples of the cohesive deposit and measured liquid limits between about 33 per cent and 58 per cent, plastic limits between about 15 per cent and 23 per cent and plasticity indices between about 18 per cent and 35 per cent. These test results, which are plotted on a plasticity chart on Figure B8 in Appendix B, indicate that the material tested is a silty clay of intermediate plasticity to clay of high plasticity.

### **4.2.5 Silty Sand**

A deposit comprised of silty sand, trace to some clay, trace gravel was encountered as interlayers between the embankment fill and silty clay deposit at Elevation 85.0 m in Borehole C9-2, between the silty clay till and silty clay deposit at Elevation 78.6 m in Borehole C9-6 and underlying the silty clay to clay deposit at about Elevation 71.1 m in Boreholes C9-3, C9-4 and C9-5. Shale fragments were encountered within this deposit in Borehole C9-5. The thickness of the deposit ranges between about 0.8 m and 4.5 m in the boreholes where it was fully penetrated.



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The SPT 'N'-values measured within the silty sand deposit range between 32 blows to 84 blows per 0.3 m of penetration, with two 'N'-values of 50 blows per 0.02 m of penetration and 50 blows per 0.1 m of penetration, indicating a dense to very dense relative density.

The natural water content measured on samples of the silty sand ranged between about 14 per cent and 24 per cent.

The results of the grain size distribution tests completed on three samples of the silty sand deposit are shown on Figure B9 in Appendix B.

An Atterberg limits test was carried out on the fines portion of one sample of the silty sand deposit from Borehole C5-9 and measured a liquid limit of about 17 per cent, a plastic limit of about 13 per cent and a plasticity index of about 4 per cent. This test result, which is plotted on a plasticity chart on Figure B10 in Appendix B, indicate that the fines portion of the silty sand sample tested is a silt of low plasticity.

### 4.2.6 Sandy Silty Clay Till

A till deposit consisting of sandy silty clay, some gravel, was encountered in Boreholes C9-3 and C9-4 at depths of about 25.5 m and 24.7 m below ground surface (Elevation 69.5 m and 70.3 m, respectively). The thickness of the deposit is 0.6 m and 1.4 m in the respective borehole but the deposit was not fully penetrated in either of the boreholes to a depth of 26.1 m below ground surface (Elevation 68.9 m).

The SPT 'N'-values measured in the sandy silty clay till deposit are 50 blows per 0.05 m of penetration and 50 blows per 0.02 m of penetration, suggesting a hard consistency.

### 4.2.7 Groundwater Conditions

The water levels were measured in Borehole C9-1, C9-3, C9-4 and C9-5 upon completion of drilling operations and noted on the Record of Borehole sheets in Appendix A and summarised below. The water level was not recorded in Borehole C9-2 prior to backfilling.

A standpipe piezometer was installed in Borehole C9-6 to allow for future monitoring of the groundwater level. The water level observed in the open boreholes upon completion of drilling and the groundwater level measured in the piezometer is shown on the Record of Borehole sheets and summarized below:



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Borehole	Depth to Water Level (m)	Groundwater Elevation (m)	Date of Measurement
C9-1	Dry	--	July 26, 2016 – open borehole
C9-3	9.1	85.9	September 14, 2016 – open borehole
C9-4	9.5	85.5	September 9, 2016 – open borehole
C9-5	10.7	84.3	September 13, 2016 – open borehole
C9-6	7.6	78.2	July 24, 2016 – Piezometer
	7.4	78.4	March 28, 2017 – Piezometer

The water level observed in the boreholes during and/or upon completion of drilling may not represent the longer-term, stabilized groundwater level at the site. The water level at the site is expected to fluctuate seasonally in response to changes in precipitation and snow melt, and is expected to be higher during the spring and periods of precipitation.

### 4.3 Analytical Testing of Soil Sample

Analytical testing was carried out on a composite soil sample constituted from the SPT samples recovered from near the culvert invert elevation in Borehole C9-4. The analytical parameters include conductivity / resistivity, pH sulphate and chloride to allow for the assessment of the potential for the soil to cause deterioration of concrete and corrosion of steel. The laboratory test results are included in Appendix C and are summarized below.

Parameter	Test Result
Soil Resistivity	880 ohm-cm
Soil Conductivity	1130 umho/cm
Sulphate Concentration	<20 ug/g
Chloride Concentration	570 ug/g
Soil pH	7.42

## 5.0 CLOSURE

Messrs. Pat Speirs and Michael Bentley, supervised the borehole investigation program. This report was prepared by Mr. Matthew Kelly, P.Eng., a geotechnical engineer with Golder. Mr. Jorge Costa, P.Eng., a Senior Consultant and Designated MTO Foundations Contact with Golder conducted an independent quality control review of this report.



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### Report Signature Page

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# **PART B**

**FOUNDATION DESIGN REPORT  
HIGHWAY 401 STRUCTURAL CULVERT - SITE NO. 21-487/C  
STRUCTURAL CULVERT REHABILITATION/REPLACEMENT  
HIGHWAY 35/115 AND HIGHWAY 401  
MINISTRY OF TRANSPORTATION, ONTARIO  
G.W.P. 2242-14-00**



## **6.0 DISCUSSION AND ENGINEERING RECOMMENDATIONS**

This section of the report provides foundation design recommendations for Structural Culvert C-9 at Site No. 21-487/C located at about STA 11+817 on Highway 401, at Robinson Creek in the City of Oshawa, Regional Municipality of Durham, Ontario. The existing structural culvert is an open footing cast-in-place concrete structure about 112.6 m long and 4.6 m wide by 3.6 m high. The current design based on direction provided at the 90% Executive Review meeting requires only rehabilitation of the existing culvert (i.e. there is no new replacement culvert, headwalls/wing walls or culvert extensions planned). Although foundation design recommendations are not required for the proposed rehabilitation, MTO's Foundation Section requested preliminary recommendations for feasible trenchless installation methods for this site for a new or replacement culvert in the future.

These recommendations are based on interpretation of the factual data obtained from the boreholes advanced during the investigation. The discussion and recommendations presented for the design of trenchless crossings are preliminary and are intended to provide the designer with sufficient information to assess the feasible design alternatives only. The foundation investigation report, discussion and recommendations are intended for the use of the Ministry of Transportation, Ontario (MTO) and shall not be used or relied upon for any other purpose or by any other parties, including the Construction or design-build contractor. The Contractor must make their own interpretation based on the factual data in Part A (Foundation Investigation) of the Report. Additional recommendations will be required to carry out the detailed design of any new culvert(s), if required, once invert elevations, alignments and culvert sizes are known. Where comments are made on construction, they are provided in order to highlight those aspects that could affect the design of the project and for which special provisions may be required in the Contract Documents. Those requiring information on the aspects of construction should make their own interpretation of the factual information provided as such interpretation may affect equipment selection, proposed construction methods, scheduling and the like.

### **6.1 Consequence and Site Understanding Classification**

In accordance with Section 6.5 of the Canadian Highway Bridge Design Code (CHBDC 2014) and its Commentary, a classification of 'typical' consequence has been assumed for a replacement culvert section and foundation system. This consequence classification should be confirmed by the MTO.

The degree of understanding based on the scope of the foundation investigation and proximity of the boreholes to the culvert is considered 'typical' as described in Clause 6.5.3.2 of the 2014 CHBDC. The appropriate Ultimate Limit States (ULS) and Serviceability Limits (SLS) consequence factor  $\Psi$ , geotechnical resistance factors at ULS ( $\phi_{gu}$ ) and SLS ( $\phi_{gs}$ ), respectively from Tables 6.1 and 6.2 of the CHBDC have been used for design.

### **6.2 Design Assumptions – Trenchless Replacement**

It is anticipated that a new or replacement culvert at Site No. 21-487/C would likely be installed adjacent to and at a vertical profile near the existing culvert approximate invert Elevations of 84.5 m and 82.4 m at the invert and outlet, respectively, or lower. Assuming that the existing open footing culvert is representative of the minimum size required to convey the design flows and satisfy hydraulic requirements, a single replacement culvert is expected to have an equivalent diameter of about 4.5 m. Based on this diameter, the depth of cover to the existing Highway 401 pavement surface is expected to be about 8 m over the culvert obvert.

It has been assumed that the alignment of any replacement or relief culvert will be close to the existing culvert. If space and hydraulic requirements permit, it is recommended that any new or relief culvert be installed no closer than 1 m from the edge of the closest existing culvert however a separation distance of 2 tunnel diameters is preferred/recommended.



### 6.3 Anticipated Ground Conditions

Progressing from north to south, the subsurface conditions encountered along the proposed alignment generally consist of mixed face conditions primarily consisting of firm to very stiff clayey silt to silty clay fill underlain by deposits of very stiff to hard clayey silt to silty clay or clayey silt to silty clay till. A layer of dense silty sand was encountered at Elevation 85.0 m in Borehole C9-2. Cohesive embankment fill and native deposits are anticipated to occupy a majority of the face of the tunnel along the alignment. The presence of cobbles and boulders within the embankment fill deposits has been inferred from auger resistance/grinding encountered in Boreholes C9-2, C9-3 and C9-5. Our recent experience with trenchless crossings of major MTO highways suggests that there may be debris consisting of abandoned temporary works associated with the original culvert construction. This debris may be buried in the fill, or present at the interface between the embankment fill and native soil. It may consist of logs, stumps, and brush from the clearing and grubbing operations. Generally, the groundwater level along the tunnel profile is anticipated to be near or slightly above the culvert invert, between about Elevations 84.5 m and 82.4 m. During construction, groundwater may be encountered perched within the granular fill layers overlying the lower permeability cohesive fill deposits.

The behavior of the anticipated subsurface materials along the tunnel profile can be classified using Terzaghi's Tunnelman's Ground Classification system as modified by Heuer (1974), and is summarized as follows.

Material	Tunnelman's Ground Classification	
	Above Groundwater Level	Below Groundwater Level
Cohesive Fill	Firm	Firm
Silty Sand	Cohesive running	Flowing
Clayey Silt to Silty Clay or Clayey Silt to Silty Clay Till	Firm to slow raveling	Firm to fast raveling

The cohesive fill, native cohesive deposits and the properly dewatered silty sand deposit would have a stand-up time ranging from a few minutes to several hours depending on the degree of seepage, disturbance and localized gradation of the deposits. In the absence of proper groundwater control and ground support, the silty sand would flow into the excavation within minutes.

Trenchless installations will be primarily affected by five factors associated with the subsurface and groundwater conditions, namely:

- The nature of the embankment fill: the embankment fill is anticipated to be cohesive and favourable for most types of trenchless technologies.
- Buried obstructions: Cobbles and/or boulders are inferred to be present within the fill based on auger resistance and grinding encountered when advancing the boreholes. Our recent experience with trenchless crossings of major MTO highways suggests that there may be debris consisting of abandoned temporary works associated with the original construction; such as logs, stumps and brush from the clearing and grubbing operations; and cobbles and boulders buried in the fill. Such obstructions have the potential to damage/clog/obstruct machinery and halt trenchless operations, particularly if there is no person-access to the excavation face to clear the obstruction.





- **Mixed Face Tunnelling:** Generally the vertical alignment will encounter a face of generally firm to very stiff cohesive fill above the springline with very stiff to hard or dense native deposits below the springline. In addition to the potential for encountering obstructions buried in the fill, the selected trenchless methodology must be adaptable to varying subsurface conditions which can change from firm in the cohesive fills to fast ravelling in the native deposits. The native materials near the invert, particularly the glacial till, are harder than the overlying fill. There is the potential for the casing/pipe to ride-up on the more resistant materials near the invert and into the softer (firm to stiff) overlying fills.
- **Presence of cobbles and boulders:** Cobbles and boulders should be anticipated in the fill materials and glacial till deposits as inferred present by auger grinding in some boreholes or by the depositional history of the glacially derived deposits. The advance of microtunneling and conventional tunnel boring machines (TBM)s can be hindered, if not fully obstructed, by cobble nests or boulders. The assumed diameter of the new/replacement culvert at this site is such that person entry for removal of obstructions is possible depending on the selected means and methods.
- **Groundwater between the invert and springline:** Groundwater is not a concern due to the cohesive nature of the fills and native soils expected within the face. Special precautions will be required to control groundwater in the silty sand deposit. Due to the limited extent and depth/thickness of this deposit, it will be difficult to dewater it from the Highway 401 level. Depending on the selected invert elevation and trenchless method, it would be beneficial and may be necessary to move the pit/heading closer to the road edge to permit installation of horizontal drainage lances and pipes to effectively dewater this deposit. Machinery and methods that do not provide effective face support for the silty sand deposit should be prohibited.

## 6.4 Review of Trenchless Construction Methods

Several methodologies can be considered for execution of this crossing: horizontal auger boring (jacking-and-boring), pipe ramming, microtunnelling, hand mining or mechanically-assisted excavation within a shield with jacked pipe or steel liner plate or steel ribs and lagging, and conventional tunneling with a TBM, and utility tunnelling.

### 6.4.1 Jack-and-Bore

Jack-and-bore involves forming a horizontal borehole through the ground from a drive shaft to an exit shaft by means of a rotating cutting head. The cutting head is attached to continuous-flight helical augers within a casing which transports spoils from the face to the drive shaft. Jack-and-bore installations in mixed face conditions with looser fill soils overlying denser native soils containing cobbles and /or boulders are risky since the casing is highly susceptible to being deflected or impeded by the obstructions. The availability of contractors with the equipment and experience to complete a jack-and-bore installation with a diameter greater than 1.8 m is quite limited. Considering the subsurface conditions and diameter ranges that may be selected for a replacement culvert, jack-and-bore is not considered a feasible option.

### 6.4.2 Pipe Ramming

Pipe ramming involves the use of a steel casing, inserted from a launch pit, and driven by a pneumatic percussion hammer or a hydraulic jacking system. The leading edge or head of the initial steel casing is fitted with a cutting shoe/band to reinforce the pipe for open-face pipe ramming and reduce friction by creating a slight overcut. As the casing advances towards the exit pit, additional lengths of steel casing are welded on to the preceding piece. Bentonite or polymer lubricants may be used to facilitate advancement of the casing where the soil conditions



dictate. The material within the casing is removed by augering after the casing is installed. The accuracy of the line and grade are comparable to the jack-and-bore method.

Compared to hand mining, conventional tunnelling with a TBM and microtunnelling, pipe ramming is more susceptible to deflection if the pipe is being driven along an interface with materials of differing densities. There are very few pipe ramming contractors in Ontario capable of completing a large-scale ramming installation (for pipes greater than 2.0 m in diameter) or that can overcome the frictional forces for pipe alignments longer than about 75 m. Given the subsurface conditions and the assumed length and diameter of the culvert, use of pipe ramming is considered not feasible for this site.

### 6.4.3 Microtunnelling

Microtunnelling is a guided pipejacking process which uses a remotely controlled tunnelling machine to provide continuous support to the excavation face. It relies on a horizontal jacking force applied to the pipe to propel the remotely controlled microtunnel boring machine (MTBM) along with the pipe string through the ground. The pipe is typically installed while the bore is being advanced and serves both as temporary ground support and the final culvert. Specially designed jacking pipe made from steel, glass fibre reinforced plastic (GFRP) or reinforced concrete, and capable of transferring the jacking forces from the jacking reaction frame in the shaft to the MTBM, will be required. Entry and receiving shafts are required for microtunnelling operations. Dewatering will be required only at the shafts since most MTBMs can operate in saturated soils below the groundwater level. Microtunnelling is typically able to maintain high accuracy ( $\pm 25\text{mm}$ ) with line and grade control.

A slurry MTBM has a full-face rotating cutting head with openings through which the spoil enters a pressurized slurry chamber behind the head. The slurry is used to balance the hydrostatic pressure and convey suspended cuttings away from the face. Typically, MTBMs are ill-equipped for crushing or cutting boulders once they enter the machine even though some models have a crusher chamber which breaks down obstructions to a size which can be pumped with the cuttings. However, the volume, diameter or numbers of the cobbles and boulders may be such that the capacity of the crusher could be exceeded resulting in either abandonment of the bore or advancement of a rescue shaft to remove the obstructions and permit resumption of tunnelling. If woody debris is encountered in the fill, it will likely clog the machine, also necessitating a rescue shaft and possibly repairs.

The soft ground MTBM should be equipped for mixed face conditions. The selected cutting tools and methods should be compatible with variable ground conditions, including cobbles and boulders. Properly selected rock disc cutter should be used to cut the glacial tills and break cobbles and boulders at the face into smaller enough fragments to pass through the apertures in the face. Only closed-face machines equipped with rock disc cutters in combination with soft ground excavation tools on the MTBM face, relatively small face openings and an internal crusher chamber should be used at this site. In addition to cobbles and boulders, the Contractor's work plan should include a method of dealing with debris in the fill materials.

An overcut will be required to reduce frictional forces along the pipe string, reduce jacking forces, and facilitate steering. The annulus between the outside of the pipe and ground should be immediately filled with bentonite slurry of an appropriate viscosity from flow from the MTBM face and around the MTBM ports in the tail of the MTBM and/or lubrication ports in the pipes installed at regular intervals.

The fill deposits along the tunnel alignment are generally softer than the native deposits at or below the invert. Noting that the embankment fill contains cobbles and boulders, as well as the glacial till, the contractor should be prepared for steering difficulties, deflection of the machine and increased wear or damage to the cutters or cutter



housings due to high impact forces. Steering difficulties may be most acute where the tunnel invert is particularly close to the interface between the fill and native deposits.

Person-entry to remove obstructions is generally not feasible for most MTBMs. Even if equipped with a crusher chamber and rock cutting tools, the MTBM will likely be stopped by boulders greater than one third of the diameter. Given the potential for encountering obstructions in the embankment fill there is a high to very high risk of these obstructions either impeding or halting the machine. The practical range of pipe sizes that can be installed using microtunnelling ranges from 1.2 to 4.2 m although most Ontario contractors have equipment capable of installing pipes with a maximum internal diameter of 2.5 m. Unless installation of a smaller diameter relief culvert or replacement of the existing culvert with two culverts with an internal diameter in the range of 1.8 m to 2.5 m is planned, microtunnelling is considered to be impractical at this site.

#### **6.4.4 Hand Mining or Mechanically-Assisted Mining**

Hand mining or mechanically assisted excavation within a shield with jacked pipe, steel liner plate, or steel ribs and lagging is considered a feasible method for the culvert installation at this site provided groundwater pressures and seepage are adequately controlled. The applicable range of pipe diameters is limited only by cost and availability of labour. However a minimum diameter of 1.2 m is required for person-entry, which is the case for the assumed culvert(s) for this site. In this method, the tunnelling process is carried out by removing excavated soil from the front cutting face and installing a liner to form a continuous ground support structure. The liner may be installed using a two-pass system or a single pass where the culvert pipe is jacked in during excavation and provides both temporary and permanent support. With a two-pass system, a conduit is installed between the entry and exit shaft by first installing a segmental temporary or primary liner. Once the full length of the primary liner has been constructed, a permanent or secondary liner is installed. The primary liner may consist of steel ribs and wooden lagging or steel liner plates. The secondary liner is typically of cast-in-place concrete construction but may be a smaller primary conduit (carrier) pipe of any suitable material. If the carrier pipe option is used, the annulus between the primary and secondary liners is grouted. The soil may be excavated using hand mining techniques and shields that include the capability of closing the face with breasting boards, plates or mechanical systems. The most economical option would be to install the culvert in a single pass using a steel pipe. Higher costs would be incurred for concrete pipes and two-pass systems.

In hand mining, excavation is conducted at the face using picks, shovels, or pneumatic hand held tools. Using conventional tunnelling or pipe jacking techniques, a protective shield, which may have a forward hood projection to provide additional face stability during soil excavation is usually required. If an articulated shield is used, line and grade corrections can be accomplished by activating the hydraulic propulsion cylinders. In a fixed shield, minor line and grade changes are accomplished by differential excavation in the desired direction.

Mechanically-assisted excavation is accomplished by using special shields equipped with power excavation devices. Such soil cutting devices can be rotary cutter booms mounted on the front of the shield, modified hydraulic backhoes, or rotary boom cutters. The soil excavation rate of open-face mechanical excavation is much faster than that of hand mining. Mechanical assistance is normally required for pipe diameters of 2.1 m or greater.

Dewatering of the shaft at the inlet may be required if the silty sand layer is intersected. As noted in Section 6.3, in order to provide enhance control of the face, it may be necessary to extend horizontal vacuum drainage lances/pipes from the shaft face.

The Contractor's selected equipment and methods must provide effective control of the stability of the face soils which are prone to ravelling. Use of a hooded shield where the top of the shield extends beyond the invert by



providing an angled profile to the leading edge of about 60 degrees from the horizontal is recommended. This angle must be measured from the top of the shield to the invert. As noted above, the shield should have doors which can close off the entire face and retractable breast plates or horizontal bench plates when additional support of the face is necessary, such as when excavating the water bearing silty sand.

The overcut should be limited to a maximum of 15 mm. It is important that care be taken with the installation of the liner in order to minimize settlements.

The materials along the proposed alignment are variable in texture and consistency/relative density. In addition, the alignment will proceed along the interfaces between the softer embankment fill and stiffer native materials. As such, the jacking forces will be variable and high jacking pressures and difficulty maintaining line and grade may be experienced, particularly if cobbles or boulders are encountered. For each separate jack, it will be necessary to use varying hydraulic pressures and travel movements to improve or correct steering.

Lubricants should be used where high jacking pressures are encountered. The spacing and number of grout ports should be optimized to result in even distribution of lubricant over the entire length of pipe and facilitate post-installation grouting of the annulus, if necessary.

Face access facilitates removal of cobbles, boulders and obstructions if encountered. The appropriate health and safety precautions associated with confined spaces as outlined in the current Ontario Regulation 213 in the Occupational Health and Safety Act (OSHA) must be observed by the contractor. Hand mining is considered to be feasible at this site only if proper dewatering measures are employed. This method offers the most flexibility to adapt methods of face support and excavation to unforeseen ground conditions.

### 6.4.5 Conventional Tunnelling with Tunnel Boring Machine

Depending on the selected equipment, it may be possible to install the culvert using a tunnel boring machine (TBM). This option is suitable for any pipe diameter. Since the ground conditions require continual support of the face only closed-face TBMs that provide support to the face to balance hydrostatic and earth pressures should be employed. Dewatering will likely be required at the shaft for the inlet only.

Depending on the contractor's available equipment and experience, the size of this installation allows for small diameter conventional (person -entry) TBMs to be used. In this case, face control and cuttings transport may be accomplished using "earth pressure balance" (EPB) technologies in which discharge from the chamber is controlled by pressure relieving gates or doors that open at pre-set pressures or loads. Another system uses a screw conveyor to remove materials from the chamber at rates that maintain specified pressures within much of the excavated chamber. Because of the potential for encountering cobbles, boulders and other obstructions, EPB TBMs that use screw conveyors should be avoided. While older relieving gate EPB systems are not as controlled as with screw conveyor systems, the combination of face opening sizes and relieving gate opening size allows for passage of cobbles, boulders and smaller debris without clogging and damaging the machine and, providing flowing ground is controlled, can allow access to the face to remove larger obstructions. Some TBM systems are promoted as being "earth pressure balance" when they do not actually achieve the goals of the EPB technology. Such unacceptable systems rely only on doors that close the face or rely on jacking forces being transmitted to the steel sections of the machine face where this is then interpreted as "face pressure." Such systems should be prohibited for this project since they could result in significant ground losses and the consequential safety risks and claims. Also, older TBMs that do not include a secondary bulkhead and controlled muck discharge system should be prohibited for this project.



The machine should be equipped with hardened disc cutters (as well as soft ground spade, drag bits and picks) to handle the fill containing cobbles and boulders. The contractor should be prepared to deal with obstructions in the embankment fill deposits.

Face stability should be constantly monitored. Overexcavation above or ahead of the TBM and lining should be avoided to maintain face stability. The overcut should be minimized by selection of a lining diameter which is similar to that of the TBM. Face pressure should be selected and maintained at values no less than the active earth pressure at the tunnel vertical centreline. If over excavation or ground losses occur, the annulus between the outside of the pipe and the ground and any voids at the face should be immediately filled with bentonite slurry of an appropriate viscosity and/or low strength grout.

Maintenance of line and grade and advancement of the TBM will be very challenging due to the mixed face condition presents the greatest risk to successful completion of a TBM installation.

### 6.5 Comparison of Tunneling Methods

Trenchless construction methods described in Section 6.4 include various advantages and disadvantages depending on soil conditions, depth of cover, vertical and horizontal alignment, length of pipe installation, cost and availability of equipment, and carry varying levels of risk of successfully completing the installation. The advantages, disadvantages and relative costs and risks are compared in Table 2, following the text of this report.

Should trenchless replacement of the existing culvert be considered in the future, a cost-benefit analysis should be carried out comparing open cut installation to the trenchless options discussed in this report. To aid in decision making, the feasible options (microtunnelling, hand or mechanically-assisted mining and conventional tunnelling with a TBM) have been ranked in order of decreasing suitability. Methods which were highly adaptable to changing subsurface conditions, at the invert and had the potential to provide effective face support were ranked higher. The recommended ranking is as follows:

1. Hand Mining or Mechanically-Assisted Mining
2. Conventional Tunnelling with a TBM

### 6.6 Detailed Design of Future Trenchless Replacements

If future trenchless replacement of the existing structural culvert at this site is to be considered, the preliminary recommendations provided in this report should be reviewed. The foundation investigation carried out for this report is considered adequate for detailed design of a trenchless crossing, however it may be necessary to advance test pits or shallow boreholes at the shaft locations for design of the temporary shoring and reaction wall/frames required for pipejacking and microtunnelling operations particularly if multiple culverts are proposed or the new alignments will be offset some distance from the existing boreholes. Additional boreholes may also be warranted if new permanent retaining walls are to be constructed at the site. The detailed design report for trenchless replacement should include discussions and recommendations on:

- Dewatering and groundwater control;
- Suitable trenchless alternatives;
- Face stability and tunnel support;
- Alignment control;
- Estimated settlement/heave and settlement mitigation;





- Settlement monitoring program; and
- Exit/entry shaft and roadway protection.

As has been carried out for other components of this assignment, the Foundations Engineer, design consultant and MTO (including the Foundations Section) should discuss requirements for either a Geotechnical Baseline Report (GBR) or Subsurface Condition Baseline Report (SCBR) in order to provide a contractual baseline for allocation of risks. The GBR should be prepared in accordance with the guidelines prepared by the American Society of Civil Engineers (Essex, 2007).<sup>4</sup> If a SCBR is prepared, it will only present baseline soil and groundwater conditions and a description of the anticipated behaviour of the subsurface soils during installation of the trenchless culvert(s). Unlike a GBR, discussion of the anticipated ground response to the specific construction means and methods will not be included in a SCBR.

### 6.7 Groundwater Control

It is understood that retrofit wall drains are proposed to be installed along the existing culvert walls as part of the culvert rehabilitation. Measured groundwater levels at this culvert site were typically below the elevation of the proposed retrofit wall drains with the exception of some water levels recorded at the completion of drilling near the Highway median. The existing embankment fill consists of clayey silt to silty clay which will be slow draining. Thus, it is anticipated that any continuous seepage / flow through the wall drains would be relatively low volumes. However, it is recommended that the wall drains be adequately filtered to limit the potential for migration of fine soil particles if surrounding groundwater or surface water levels inside the culvert rise to the wall drain level.

### 6.8 Corrosion Assessment and Protection

Soil corrosivity may affect the concrete pipes and headwalls, steel pipes and reinforced steel and other concrete elements buried in the soil. The long-term performance and durability of the structures are directly related to their respective corrosion resistance. Generally, the corrosivity of a structure depends on the soil resistivity, hydrogen ion concentration, salts (chloride and sulphate) concentrations and redox potential. The analytical results for a single composite sample are presented in Section 4.3 and included in Appendix C.

The analytical test results were compared to CSA Standard, CAN/CSA-A23.1-14 Table 3 ("*Additional requirements for concrete subjected to sulphate attack*") for potential sulphate attack on concrete. The sulphate concentration measured in the composite soil sample constituted from SPT samples recovered near the existing culvert invert is less than 0.1 per cent, which is below the exposure class of S-3 (Moderate). Therefore, based on the test results of the single composite sample of existing fill and native soils, when the designer is selecting the exposure class for the structure, the effects of sulphates from within the existing fill and native deposits around the culvert may not need to be considered.

The composite soil sample has a pH of 7.4 and a resistivity of 1,130 ohm-cm. According to the MTO Gravity Pipe Design Guidelines (2014), the pH is not considered detrimental to culvert durability. However, the resistivity is less than 2,000 ohm-cm, which indicates that the soil corrosiveness is severe ( $R < 2,000$  ohm-cm), as per Table 3.2 of the MTO Gravity Pipe Design Guidelines (2014). Based on these results some level of pipe protection will be required depending on pipe material may be used.

<sup>4</sup> Essex, R.J. (ed) (2007). Geotechnical Baseline Reports For Construction, Suggested Guidelines. ASCE, Reston, VA.



## FOUNDATION REPORT - STRUCTURAL CULVERT REPLACEMENT - HIGHWAY 401, SITE NO. 21-487/C

Based on the results of the sample tested, and given that the culvert is located under a roadway and will be exposed to de-icing salt particularly below the shoulders, consideration should be given by the designer to designing for a “C” type exposure class as defined by CSA A23.1 Table 1.

It is ultimately up to the designer to determine the appropriate exposure class and to ensure that all aspects of CSA A23.1 Section 4.1.1 “Durability Requirements” are followed.

### 7.0 CLOSURE

This Foundation Design Report was prepared by Mr. Matthew Kelly, P.Eng., a member of the geotechnical engineering group. The technical aspects were reviewed by Ms. Dirka U. Prout, P.Eng., a senior geotechnical engineer with tunnelling experience. Mr. Jorge M. A. Costa, P.Eng., a Senior Consultant of Golder and Designated MTO Foundations Contact conducted an independent quality control review of this report.

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MWK/DUP/JMAC/mck

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Ontario Occupational Health and Safety Act:

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

Ontario Water Resources Act:

Ontario Regulation 372/9 Amendment to Ontario Regulation 903

## ASTM

ASTM D1586-11	Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils
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# TABLES



## FOUNDATION REPORT - STRUCTURAL CULVERT REPLACEMENT - HIGHWAY 401, SITE NO. 21-487/C

Table 1: Summary of Existing Culvert Details

Culvert Location (City)	Culvert ID	Approximate Height of Embankment <sup>1</sup>	Existing Culvert			Approximate Invert Elevation <sup>2</sup>		Boreholes
			Type	Approximate Dimension	Approximate Length	North End of Culvert	South End of Culvert	
STA 11+817 (Oshawa)	C9	Up to about 11 m	Open Footing	4.6 m x 3.6 m	112.6 m	84.4 m	82.4 m	6 Boreholes (C9-1 to C9-6)

Notes:

1. Embankment height is relative to existing ground surface level at the toe of embankment adjacent to the culvert.
2. Culvert invert elevations are estimated based on the top of culvert surveys and culvert dimensions provided by MTO.



Table 2: Comparison of Trenchless Techniques for Culvert Replacement

Method	Feasibility	Advantages	Disadvantages	Estimated Relative Cost Factor <sup>2, 3</sup>	Risk/Consequence
Jack-and-Bore	Not Feasible	Length and diameter preclude the use of Jack-and-Bore <sup>1</sup>			
Pipe Ramming	Not Feasible	Length and diameter preclude the use of pipe ramming <sup>1</sup>			
Microtunnelling	Not Practical	Large diameter precludes the use of Microtunneling <sup>1</sup>			
Hand Mining or Mechanically-Assisted Excavation within shield with jacked pipe, steel liner plate or steel ribs and lagging	Feasible and preferred option	<ul style="list-style-type: none"><li>■ Highly adaptable to variable conditions along alignment</li><li>■ Face access facilitates removal of cobbles, boulders and obstructions</li><li>■ Good accuracy for line and grade</li><li>■ Most economical solution with line and grade accuracy comparable to microtunnelling</li><li>■ Smallest footprint required for entry shaft</li><li>■ Potentially the most economical method of installing the culvert at low end of cost range.</li></ul>	<ul style="list-style-type: none"><li>■ Labour intensive: Due to the presence of sandy soils at invert level which may be saturated, the contractor's selected equipment and methods must provide effective control of the stability of the face (e.g., use of hooded shield, stiffeners, forepoling, retractable breast plates with doors etc.)</li><li>■ Extensive delays may occur removing and breaking up oversized boulders with high strength, if encountered</li><li>■ Unlike microtunnelling and conventional tunneling, dewatering by horizontal drainage lances/pipes from start/ end shaft(s) may be required to control flow in saturated sandy soils</li><li>■ Slowest rate of advance</li><li>■ Cost may approach conventional tunneling with TBM option due to dewatering requirements.</li></ul>	1.0	<ul style="list-style-type: none"><li>■ Encountering woody debris and oversized cobble nests or boulders - low to moderate risk of not completing installation</li><li>■ Groundwater level between springline and tunnel invert - moderate risk to high of ground loss due to flowing of sands; risk can be minimized with proper horizontal drainage within tunnel and effective dewatering at shafts</li></ul>
Conventional Tunnelling with Tunnel Boring Machine (TBM)	Feasible	<ul style="list-style-type: none"><li>■ Face access possibility can facilitate removal of cobbles, boulders and obstructions in the fill, sand and gravel and glacial till</li><li>■ Closed-face machine must be used to provide effective control of face stability</li><li>■ High accuracy with line and grade</li><li>■ Dewatering required at shafts only if EPB TBM used and can be enhanced with localized use of horizontal drainage lances from entry and exit shafts/pits</li><li>■ Compared to hand mining methods, conventional tunnelling may achieve more consistent and effective support of the face</li></ul>	<ul style="list-style-type: none"><li>■ Older TBMs that do not include a secondary bulkhead and controlled muck discharge system (e.g., discharge gates controlled by load or pressure sensors) should be prohibited</li><li>■ Machines can become jammed or clogged with wood and/or cobbles and boulders; particularly machines that rely on screw conveyors for pressure control and muck transport.</li><li>■ Requires a work area at the entry shaft somewhat smaller than that needed for microtunnelling</li></ul>	1.0 – 1.5	<ul style="list-style-type: none"><li>■ Encountering woody debris and oversized cobble nests or boulders - moderate to high risk of not completing installation</li><li>■ Tunnel invert along interface between embankment fill and native materials - low to moderate risk of not achieving line and grade if machine deflected by hard soils</li><li>■ Groundwater between springline and tunnel invert – low to moderate risk of ground loss due to flowing of sands if closed-face machine selected</li><li>■ Moderate to high risk of ground losses in saturated granular soils when removing or mining through boulders or other obstructions if groundwater is not controlled by other means</li></ul>

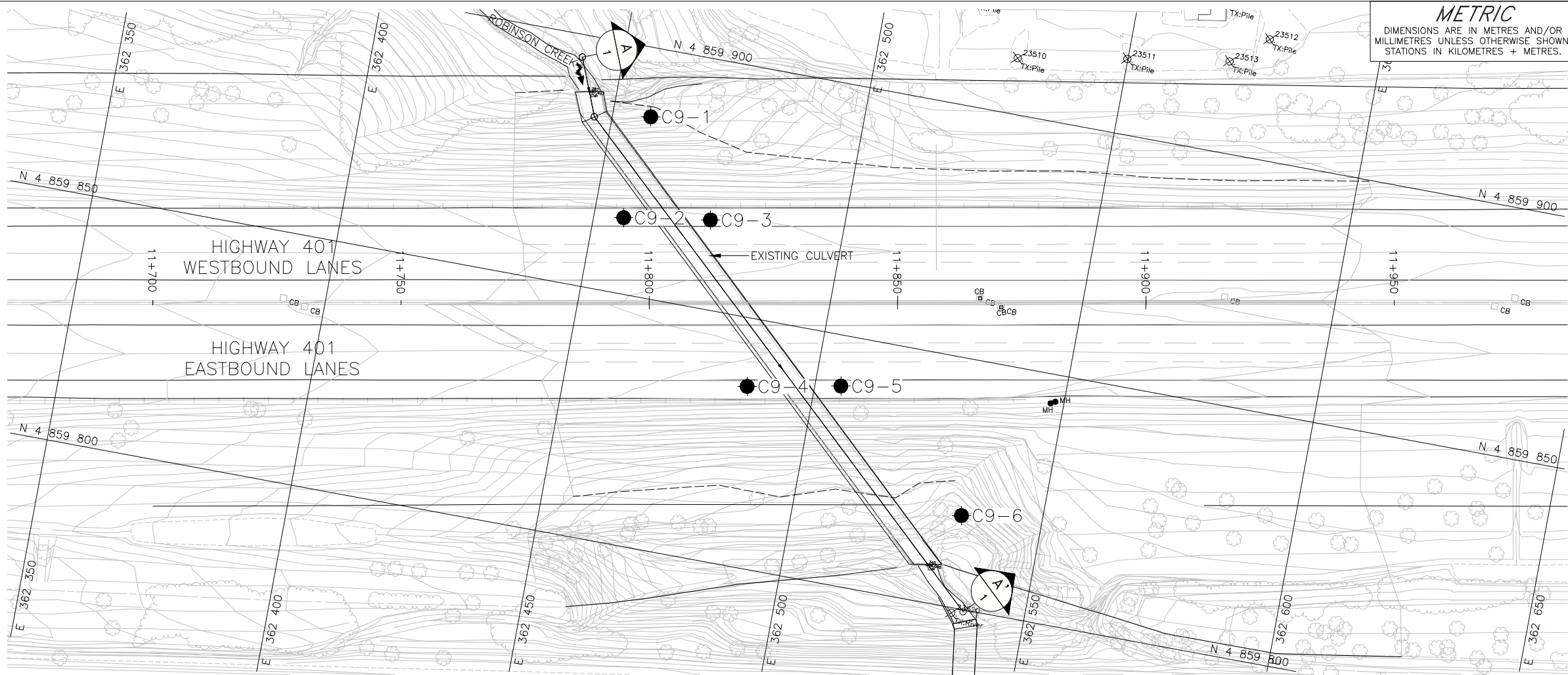


Table 2: Comparison of Trenchless Techniques for Culvert Replacement

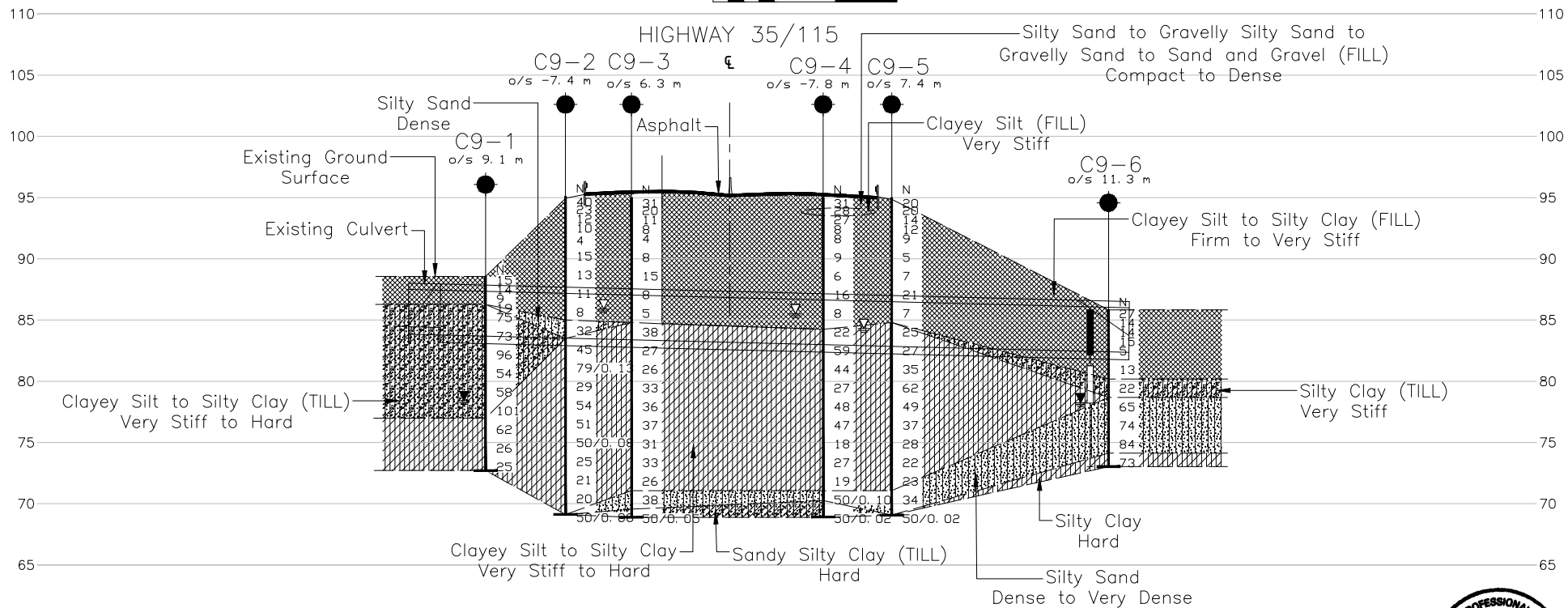
1. The availability of contractors in Ontario with large-scale jack-and-bore, pipe ramming or microtunneling equipment and experience installing pipes with diameters of 2.0 m to 3.5 m or greater is rare or non-existent. The typical maximum casing sizes are 1.8 m for jack-and-bore and 2.5 m for pipe ramming. Considering MTBMs currently manufactured, the maximum pipe size that can be installed is 4.2 m (outer diameter); however most Ontario microtunnelling contractors can typically install casing having a maximum internal diameter of 2.5 m.
2. Costs are based on order of magnitude estimates in 2017 dollars derived from projects of generally similar scope and technologies. They are intended to provide a comparison between alternatives rather than actual construction costs, and exclude additional costs such as traffic control, staging and shoring that may influence the total cost. Therefore, the costs should be considered only for comparative purposes.
3. The estimated relative cost factor represents an approximately simplified cost estimate for each option divided by the estimated cost for the least expensive option (e.g., a relative cost factor of 2 indicates that the trenchless technology option is twice as costly as the least expensive option).
4. Table to be read in conjunction with accompanying report.



# DRAWINGS



PLAN  
SCALE  
10 0 10 20 m



HORIZONTAL SCALE  
10 0 10 20 m

VERTICAL SCALE  
5 0 5 10 m

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

CONT No. 2017-2016  
WP No. 2242-14-00

HIGHWAY 401  
SITE 21-487/C  
BOREHOLE LOCATIONS AND  
SOIL STRATA



SHEET  
22



KEY PLAN  
SCALE  
6 0 6 12 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)
- ▽ WL in piezometer, measured on Mar. 28, 2017
- ▽ WL upon completion of drilling

BOREHOLE CO-ORDINATES			
No.	ELEVATION	NORTHING	EASTING
C9-1	88.6	4859886.2	362457.6
C9-2	95.1	4859865.2	362456.0
C9-3	95.0	4859867.9	362473.2
C9-4	95.0	4859836.3	362486.6
C9-5	95.0	4859839.8	362505.2
C9-6	85.8	4859818.6	362533.8

NOTES

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

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

Geographic Coordinates of Culvert: Latitude 43.875983; Longitude -78.781664.

REFERENCE

Base Plan and Contours provided in digital format by DM Wills, drawing file nos. 124208.dwg, received Jan. 20, 2016. Design Plan and Section provided in digital format by DM Wills, drawing file no. 4561-C9 GA.dwg, received Jan. 3, 2017.



NO.	DATE	BY	REVISION
Geocres No. 30M15-311			
HWY. 401	PROJECT NO. 1540419	DIST. .	
SUBM'D. MCK	CHKD. MCK	DATE: 6/12/2017	SITE: 21-487/C
DRAWN: SMD	CHKD. MWK	APPD. JMAC	DWG. 1





# **APPENDIX A**

## **Record of Boreholes**



## LIST OF SYMBOLS

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

### I. GENERAL

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

### II. STRESS AND STRAIN

$\gamma$	shear strain
$\Delta$	change in, e.g. in stress: $\Delta \sigma$
$\varepsilon$	linear strain
$\varepsilon_v$	volumetric strain
$\eta$	coefficient of viscosity
$\nu$	Poisson's ratio
$\sigma$	total stress
$\sigma'$	effective stress ( $\sigma' = \sigma - u$ )
$\sigma'_{vo}$	initial effective overburden stress
$\sigma_1, \sigma_2, \sigma_3$	principal stress (major, intermediate, minor)
$\sigma_{oct}$	mean stress or octahedral stress $= (\sigma_1 + \sigma_2 + \sigma_3)/3$
$\tau$	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
$\gamma'$	unit weight of submerged soil ( $\gamma' = \gamma - \gamma_w$ )
$D_R$	relative density (specific gravity) of solid particles ( $D_R = \rho_s / \rho_w$ ) (formerly $G_s$ )
e	void ratio
n	porosity
S	degree of saturation

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

#### (a) Index Properties (continued)

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

#### (b) Hydraulic Properties

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

#### (c) Consolidation (one-dimensional)

$C_c$	compression index (normally consolidated range)
$C_r$	recompression index (over-consolidated range)
$C_s$	swelling index
$C_{\alpha}$	secondary compression index
$m_v$	coefficient of volume change
$C_v$	coefficient of consolidation (vertical direction)
$C_h$	coefficient of consolidation (horizontal direction)
$T_v$	time factor (vertical direction)
U	degree of consolidation
$\sigma'_p$	pre-consolidation stress
OCR	over-consolidation ratio = $\sigma'_p / \sigma'_{vo}$

#### (d) Shear Strength

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

Notes: 1  
2

$\tau = c' + \sigma' \tan \phi'$   
shear strength = (compressive strength)/2



## LIST OF ABBREVIATIONS

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

### I. SAMPLE TYPE

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

### II. PENETRATION RESISTANCE

#### Standard Penetration Resistance (SPT), N:

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

#### Dynamic Cone Penetration Resistance; $N_d$ :

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

**PH:** Sampler advanced by hydraulic pressure

**PM:** Sampler advanced by manual pressure

**WH:** Sampler advanced by static weight of hammer

**WR:** Sampler advanced by weight of sampler and rod

#### Piezo-Cone Penetration Test (CPT)

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

### III. SOIL DESCRIPTION

#### (a) Non-Cohesive Soils

Density Index	N
Relative Density	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

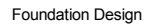
### IV. SOIL TESTS

w	water content
w <sub>p</sub>	plastic limit
w <sub>l</sub>	liquid limit
C	consolidation (oedometer) test
CHEM	chemical analysis (refer to text)
CID	consolidated isotropically drained triaxial test <sup>1</sup>
CIU	consolidated isotropically undrained triaxial test with porewater pressure measurement <sup>1</sup>
D <sub>R</sub>	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 <sub>4</sub>	concentration of water-soluble sulphates
UC	unconfined compression test
UU	unconsolidated undrained triaxial test
V	field vane (LV-laboratory vane test)
$\gamma$	unit weight

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

### V. MINOR SOIL CONSTITUENTS

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

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

PROJECT 1540419		<b>RECORD OF BOREHOLE No C9-1</b>				SHEET 2 OF 2		<b>METRIC</b>									
G.W.P. 2242-14-00		LOCATION N 4859886.2; E 362457.6 MTM ZONE 10 (LAT. 43.876705; LONG. -78.782548)				ORIGINATED BY PKS											
DIST _____ HWY 401		BOREHOLE TYPE Mini-Mole 102 mm O.D. Solid Stem Augers (Manual Hammer)				COMPILED BY ZMR/MR											
DATUM Geodetic		DATE July 25 and 26, 2016				CHECKED BY MCK											
SOIL PROFILE		SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT W <sub>p</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL	
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE			"N" VALUES	SHEAR STRENGTH kPa									
	--- CONTINUED FROM PREVIOUS PAGE ---						20 40 60 80 100 ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × REMOULDED					10 20 30 WATER CONTENT (%)					
72.7	SILTY CLAY, trace sand, containing silty sand seams Very stiff to hard Grey Moist to wet		13	SS	25	73											
15.9	END OF BOREHOLE  NOTE:  1. Borehole dry upon completion of drilling.																

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<b>PROJECT</b> 1540419		<b>RECORD OF BOREHOLE No C9-2</b>		SHEET 1 OF 2		<b>METRIC</b>	
G.W.P. 2242-14-00		LOCATION N 4859865.2; E 362456.0 MTM ZONE 10 (LAT. 43.87652; LONG. -78.7826)		ORIGINATED BY AJ			
DIST _____ HWY 401		BOREHOLE TYPE CME 75, 208 mm O.D., 108 mm I.D. Hollow Stem Augers		COMPILED BY MR			
DATUM Geodetic		DATE December 7 and 8, 2016		CHECKED BY MWK			

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC NATURAL LIQUID LIMIT MOISTURE LIMIT CONTENT			UNIT WEIGHT $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL			
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa							WATER CONTENT (%)		
								○ UNCONFINED ● QUICK TRIAXIAL	+ FIELD VANE × REMOULDED								
95.1	GROUND SURFACE							20	40	60	80	100	10	20	30		
0.0	ASPHALT																
0.2	Sand and gravel (FILL)		1	SS	40												
94.3	Dense Brown Moist																
0.8	Clayey silt to silty clay, trace sand to with sand, trace to some gravel, trace organics (FILL) Firm to very stiff Mottled brown to mottled grey/black Moist		2	SS	23												
			3	SS	12												
			4	SS	10												
			5A	SS	4												
			5B														
			6	SS	15												
	- Auger grinding at a depth of 5.5 m (Elev. 89.6 m)																
			7	SS	13												
			8	SS	11												
	- Auger grinding at a depth of 8.2 m (Elev. 86.9 m)																
			9	SS	8												
85.0	Silty SAND																
10.1	Dense Mottled grey/dark grey Wet		10	SS	32												
83.5	SILTY CLAY, trace sand, trace gravel																
11.6	Very stiff to hard Grey Moist to wet		11	SS	45												
			12	SS	79/0.13												

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+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity      ○ 3% STRAIN AT FAILURE

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PROJECT 1540419		<b>RECORD OF BOREHOLE No C9-2</b>				SHEET 2 OF 2		<b>METRIC</b>											
G.W.P. 2242-14-00		LOCATION N 4859865.2; E 362456.0 MTM ZONE 10 (LAT. 43.87652; LONG. -78.7826)				ORIGINATED BY AJ													
DIST _____ HWY 401		BOREHOLE TYPE CME 75, 208 mm O.D., 108 mm I.D. Hollow Stem Augers				COMPILED BY MR													
DATUM Geodetic		DATE December 7 and 8, 2016				CHECKED BY MWK													
SOIL PROFILE		SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT W <sub>p</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT $\gamma$ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL			
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE			"N" VALUES	SHEAR STRENGTH kPa											
--- CONTINUED FROM PREVIOUS PAGE ---							<div style="display: flex; justify-content: space-between;"> <span>20 40 60 80 100</span> <span>20 40 60 80 100</span> </div> <div style="display: flex; justify-content: space-between;"> <span>○ UNCONFINED + FIELD VANE</span> <span>● QUICK TRIAXIAL × REMOULDED</span> </div>												
	SILTY CLAY, trace sand, trace gravel Very stiff to hard Grey Moist to wet		13	SS	29		80										0 2 40 58		
			14	SS	54		79												
			15	SS	51		78												
			16	SS	50/0.08		77												
			17	SS	25		76												
			18	SS	21		75												
			19	SS	20		74												
			20	SS	50/0.08		73												
			21	SS	25		72												
			22	SS	21		71												
			23	SS	20		70												
			24	SS	20		69.1												
			25	SS	20		26.0												
	END OF BOREHOLE																		



PROJECT <u>1540419</u>		<b>RECORD OF BOREHOLE No C9-3</b>		SHEET 2 OF 2		<b>METRIC</b>	
G.W.P. <u>2242-14-00</u>		LOCATION <u>N 4859867.9; E 362473.2 MTM ZONE 10 (LAT. 43.87654; LONG. -78.7824)</u>		ORIGINATED BY <u>MB</u>			
DIST <u>          </u> HWY <u>401</u>		BOREHOLE TYPE <u>208 mm O.D., 102 mm I.D. Hollow Stem Augers (Automatic Hammer)</u>		COMPILED BY <u>SD</u>			
DATUM <u>Geodetic</u>		DATE <u>September 13 and 14, 2016</u>		CHECKED BY <u>MCK</u>			

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT w <sub>p</sub>	NATURAL MOISTURE CONTENT w	LIQUID LIMIT w <sub>L</sub>	UNIT WEIGHT γ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL					
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa							WATER CONTENT (%)				
								○ UNCONFINED	+ FIELD VANE						● QUICK TRIAXIAL	× REMOULDED			
	--- CONTINUED FROM PREVIOUS PAGE ---																		
	SILTY CLAY, trace to some sand, trace gravel Very stiff to hard Grey Moist to wet		13	SS	33								49						
			14	SS	36														
			15	SS	37														
			16	SS	31														
			17	SS	33														
			18	SS	26														
71.1																			
23.9	Silty SAND, trace to some clay, trace gravel Dense Grey Wet		19	SS	38														
69.6																			
25.5	Sandy SILTY CLAY, some gravel (TILL) Hard Grey Moist		20	SS	50/0.05														
68.9																			
26.1																			
	- Auger grinding at a depth of 25.6 m (Elev. 69.4 m) END OF BOREHOLE																		
	NOTES:  1. Groundwater encountered during drilling at a depth of 9.1 m below ground surface. (Elev. 85.9 m)																		


PROJECT 1540419		<b>RECORD OF BOREHOLE No C9-4</b>		SHEET 1 OF 2		<b>METRIC</b>	
G.W.P. 2242-14-00		LOCATION N 4859836.3; E 362486.6 MTM ZONE 10 (LAT. 43.876245; LONG. -78.78219)		ORIGINATED BY MK			
DIST _____ HWY 401		BOREHOLE TYPE CME 75, 208 mm O.D., 102 mm I.D. Hollow Stem Augers (Automatic Hammer)		COMPILED BY SZ/MR			
DATUM Geodetic		DATE September 7 and 9, 2016		CHECKED BY MCK			

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT  $\gamma$  kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)  GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa		WATER CONTENT (%)				
								○ UNCONFINED      + FIELD VANE ● QUICK TRIAXIAL    × REMOULDED	w <sub>p</sub> w      w <sub>L</sub>					
95.0	GROUND SURFACE						20 40 60 80 100							
0.0	ASPHALT (130 mm)													
0.1	Sand and gravel (FILL)		1	SS	31									
94.1	Dense Brown Dry													
0.9	Clayey silt, trace sand, some gravel (FILL)		2	SS	28									
93.5	Very stiff Brown Moist													
1.5	Sand and gravel, trace to some silt, trace clay (FILL)		3	SS	27									
92.6	Compact Brown Dry													
2.4	Clayey silt, trace to some sand, trace to some gravel (FILL)		4	SS	8									
	Stiff Brown Moist to wet													
			5	SS	8									
			6	SS	9									
89.4														
5.6	Clayey silt, sandy to with sand, trace gravel, trace organics to a depth of 8.7 m (FILL)													
	Firm to very stiff Brown Moist to wet		7	SS	6									
			8	SS	16									
			9	SS	8									
84.3														
10.7	SILTY CLAY, trace sand, trace gravel		10	SS	22									
	Very stiff to hard Grey Moist													
			11	SS	59									
			12	SS	44									

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+ <sup>3</sup>, × <sup>3</sup>: Numbers refer to Sensitivity      ○ 3% STRAIN AT FAILURE

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PROJECT 1540419		<b>RECORD OF BOREHOLE No C9-4</b>				SHEET 2 OF 2		<b>METRIC</b>									
G.W.P. 2242-14-00		LOCATION N 4859836.3; E 362486.6 MTM ZONE 10 (LAT. 43.876245; LONG. -78.78219)				ORIGINATED BY MK											
DIST _____ HWY 401		BOREHOLE TYPE CME 75, 208 mm O.D., 102 mm I.D. Hollow Stem Augers (Automatic Hammer)				COMPILED BY SZ/MR											
DATUM Geodetic		DATE September 7 and 9, 2016				CHECKED BY MCK											
SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT				PLASTIC LIMIT W <sub>p</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT γ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)	
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa									WATER CONTENT (%)
--- CONTINUED FROM PREVIOUS PAGE ---								20	40	60	80	100					
	SILTY CLAY, trace sand, trace gravel Very stiff to hard Grey Moist		13	SS	27												0 1 33 66
71.1																	
23.9	Silty SAND Very dense Grey Moist																
70.3																	
24.7	Sandy SILTY CLAY, some gravel (TILL) Hard Grey Moist to wet																
68.9	- Auger grinding at a depth of 25.3 m (Elev. 69.7 m)																
26.1	END OF BOREHOLE																
	NOTE:  1. Water level in open borehole at a depth of 9.5 m below ground surface (Elev. 85.5 m) upon completion of drilling.																

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+<sup>3</sup>, ×<sup>3</sup>: Numbers refer to Sensitivity      ○<sup>3%</sup> STRAIN AT FAILURE



PROJECT 1540419		<b>RECORD OF BOREHOLE No C9-5</b>				SHEET 2 OF 2		<b>METRIC</b>							
G.W.P. 2242-14-00		LOCATION N 4859839.8; E 362505.2 MTM ZONE 10 (LAT. 43.876275; LONG. -78.781959)				ORIGINATED BY MB									
DIST _____ HWY 401		BOREHOLE TYPE CME 75, 208 mm O.D., 102 mm I.D. Hollow Stem Augers (Automatic Hammer)				COMPILED BY SD									
DATUM Geodetic		DATE September 13 and 14, 2016				CHECKED BY MCK									
SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT			PLASTIC LIMIT W <sub>p</sub>	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W <sub>L</sub>	UNIT WEIGHT γ kN/m <sup>3</sup>	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa							
--- CONTINUED FROM PREVIOUS PAGE ---								20 40 60 80 100							
	SILTY CLAY to CLAY, trace to some sand Very stiff to hard Grey Moist to wet		13	SS	62		79								
			14	SS	49		78								
			15	SS	37		77								
			16	SS	28		75								
			17	SS	22		74								
			18	SS	23		73								
71.1							72								
23.9	Silty SAND, trace to some clay, trace gravel Dense Grey Wet		19	SS	34		71								
69.1							70								
25.9	- Containing shale fragments at a depth of 25.9 m below ground surface (Elev. 69.1 m) END OF BOREHOLE		20	SS	50/0.02										
NOTES: 1. Groundwater encountered during drilling at a depth of 10.7 m below ground surface (Elev. 84.3 m)															

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



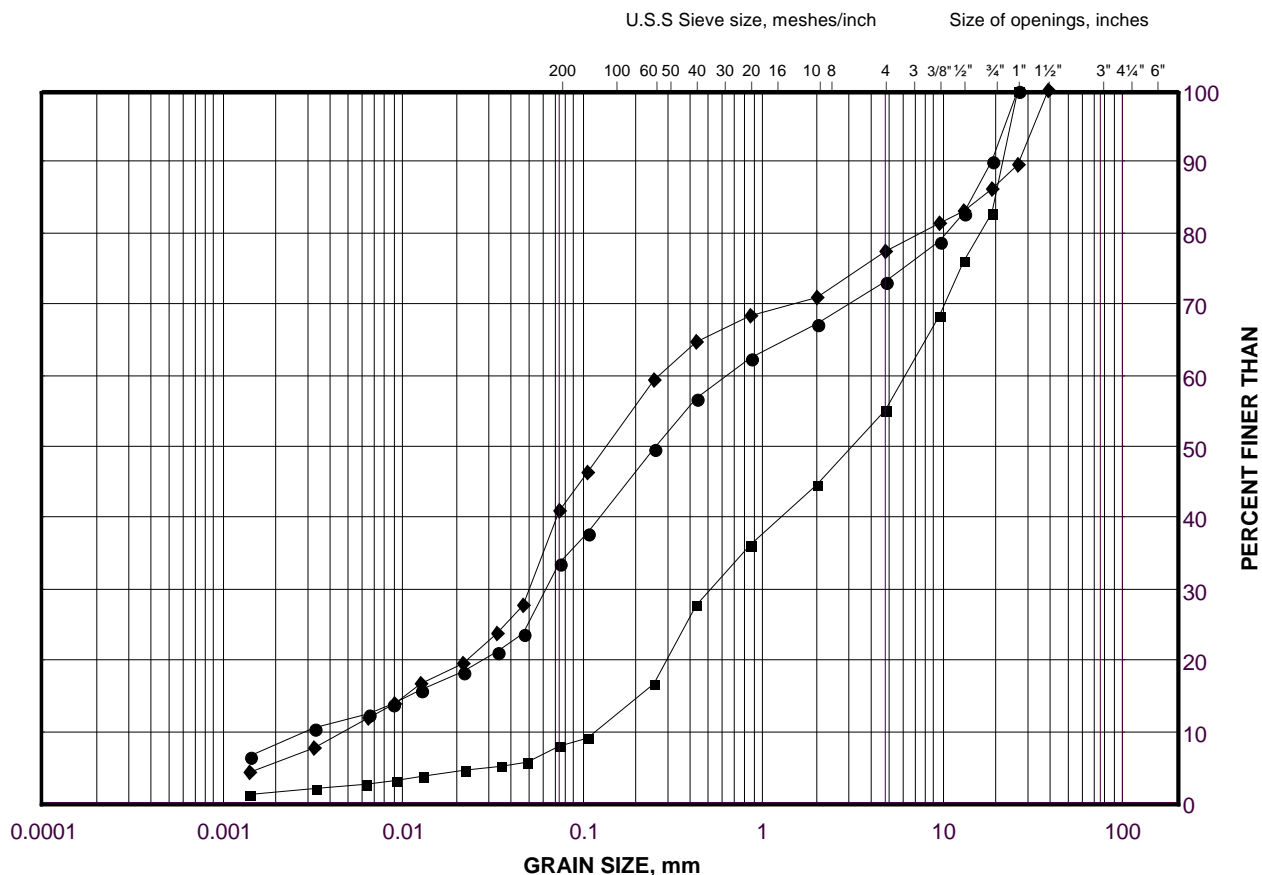
# **APPENDIX B**

## **Laboratory Results**

# GRAIN SIZE DISTRIBUTION

Gravelly Silt and Sand to Sand and Gravel (Fill)

FIGURE B1



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

## LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	C9-5	3	93.2
■	C9-4	3	93.2
◆	C9-6	4	83.2

Project Number: 1540419

Checked By: MWK

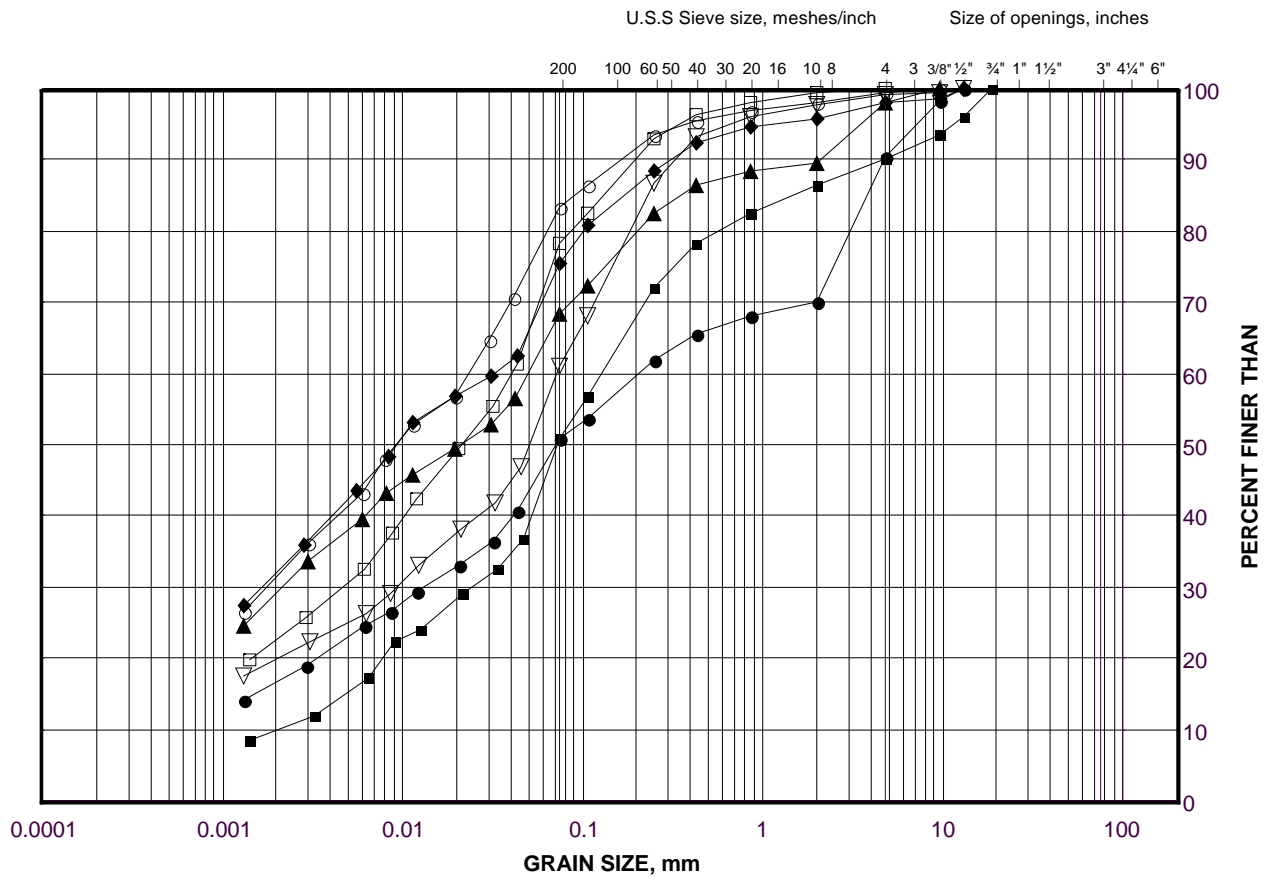
**Golder Associates**

Date: 31-Jan-17

# GRAIN SIZE DISTRIBUTION

Clayey Silt to Silty Clay with Sand (Fill)

FIGURE B2A



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

## LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	C9-1	2	87.5
■	C9-2	4	92.5
◆	C9-2	6	90.2
▲	C9-3	6	90.1
▽	C9-4	7	88.6
○	C9-3	8	87.1
□	C9-2	9	85.6

Project Number: 1540419

Checked By: MWK

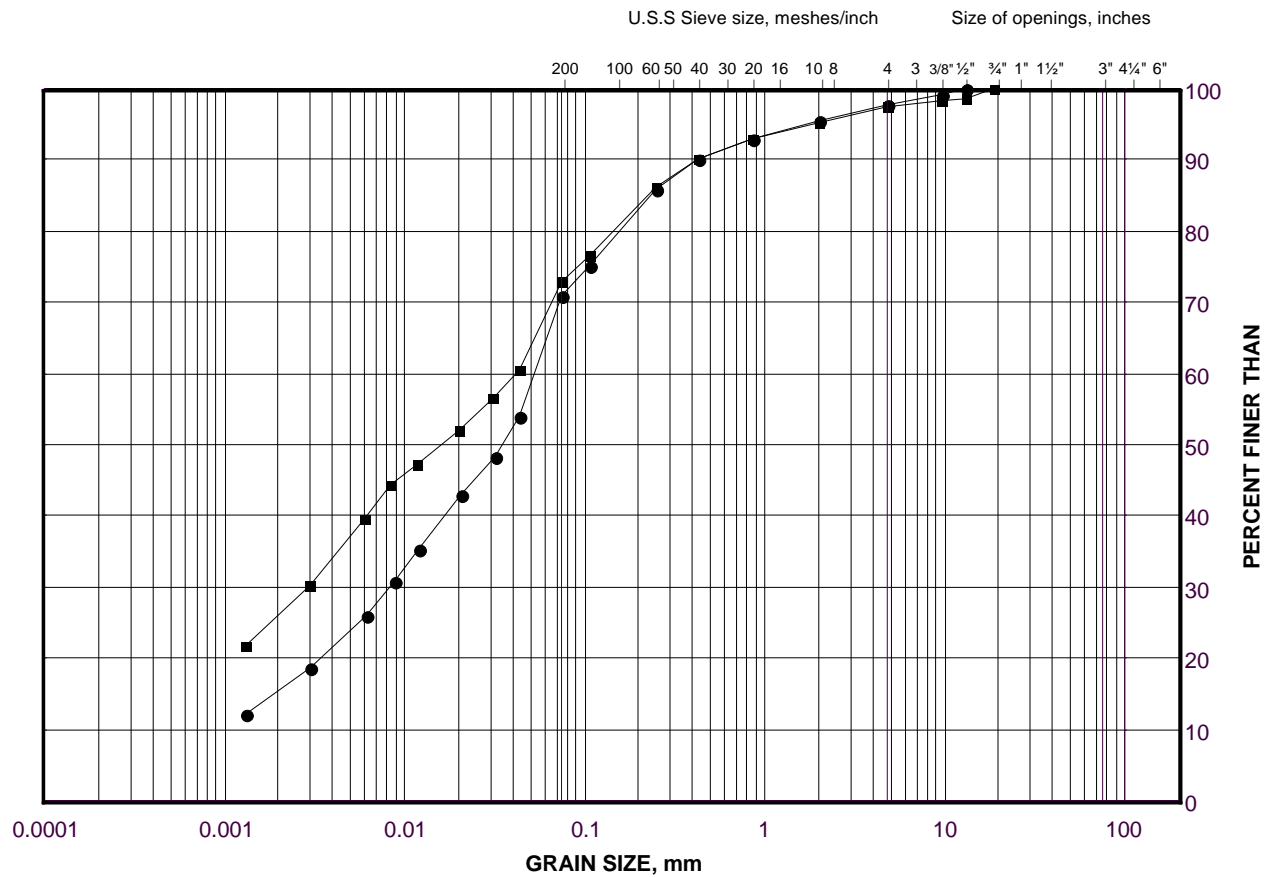
**Golder Associates**

Date: 31-Jan-17

# GRAIN SIZE DISTRIBUTION

Clayey Silt (Fill)

FIGURE B2B



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

## LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	C9-5	7	88.6
■	C9-4	9	85.5

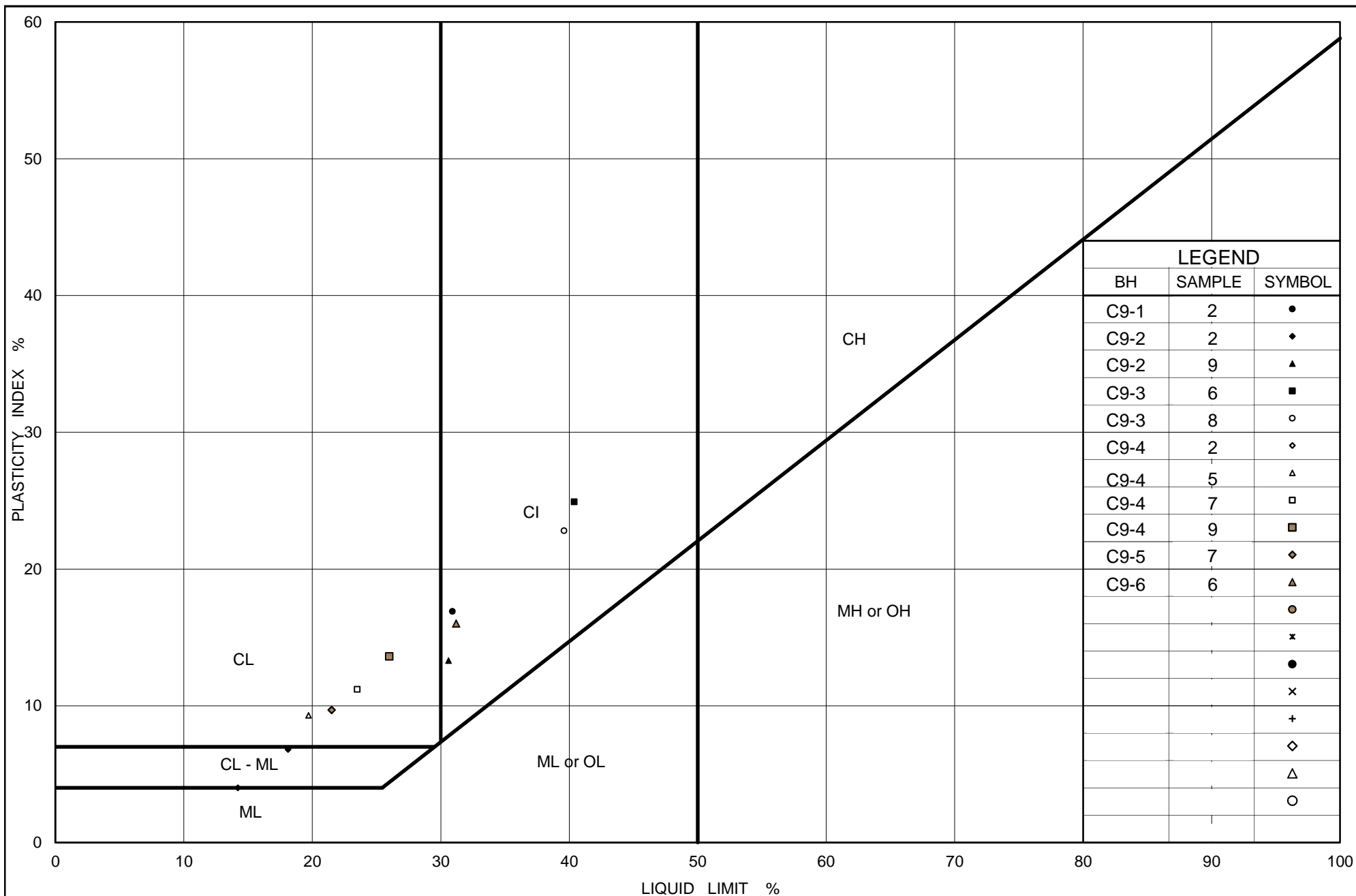
Project Number: 1540419

Checked By: MWK

**Golder Associates**

Date: 31-Jan-17



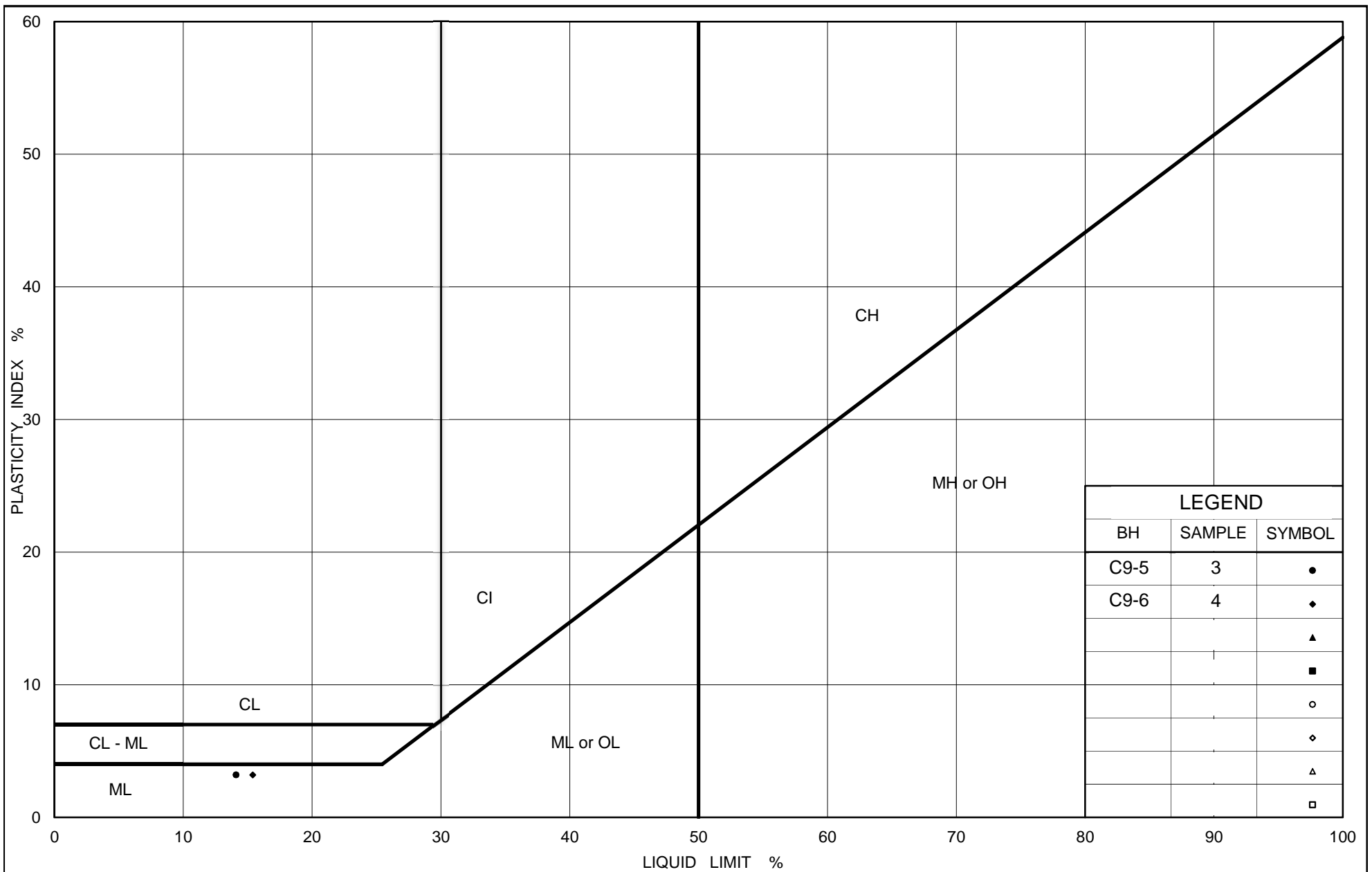


# **PLASTICITY CHART** Clayey silt to silty clay (Fill)

Figure No. B3

Project No. 1540419

Checked By: MWK



# PLASTICITY CHART Silt and Sand to Silty Sand (Fill)

Figure No. B4

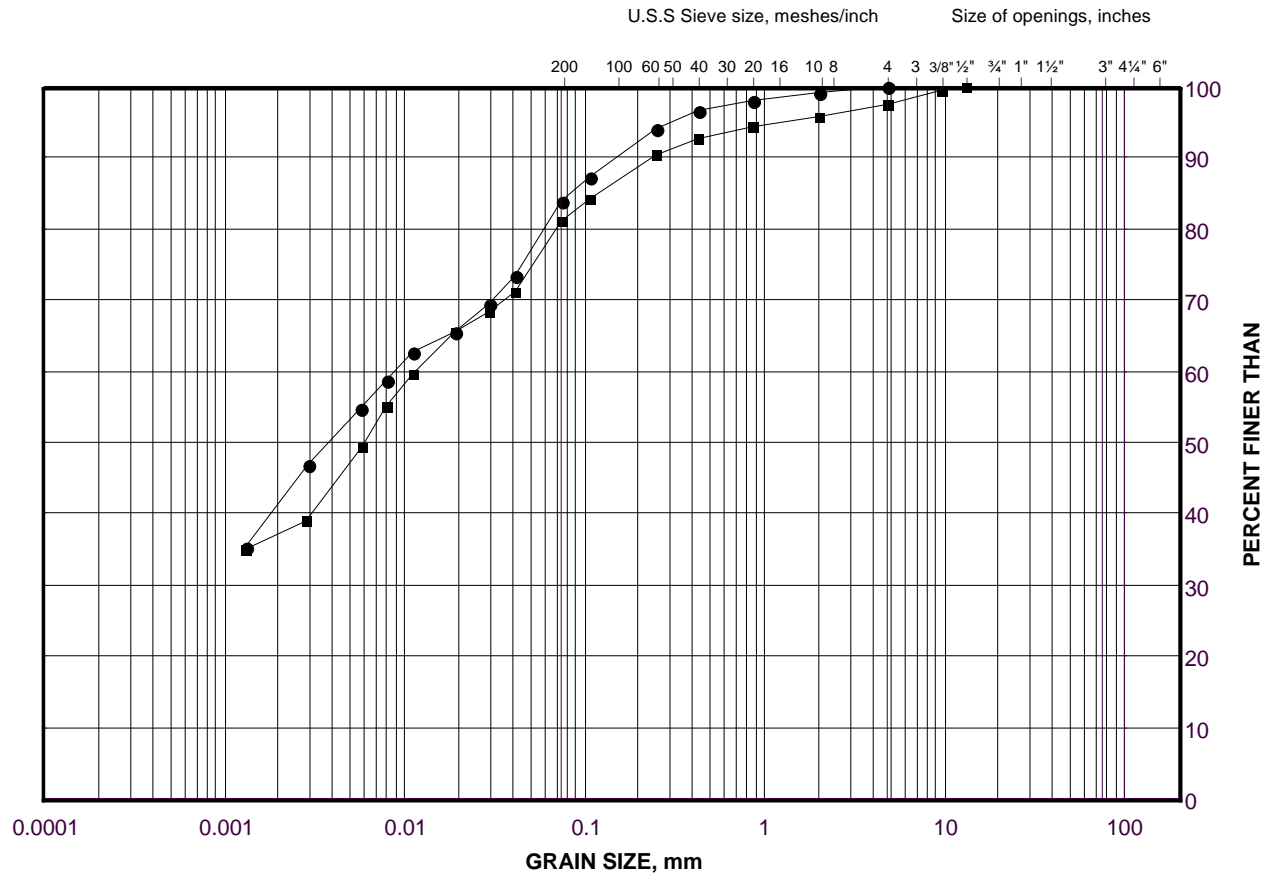
Project No. 1540419

Checked By: MWK

# GRAIN SIZE DISTRIBUTION

Clayey Silt to Silty Clay (Till)

FIGURE B5



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

## LEGEND

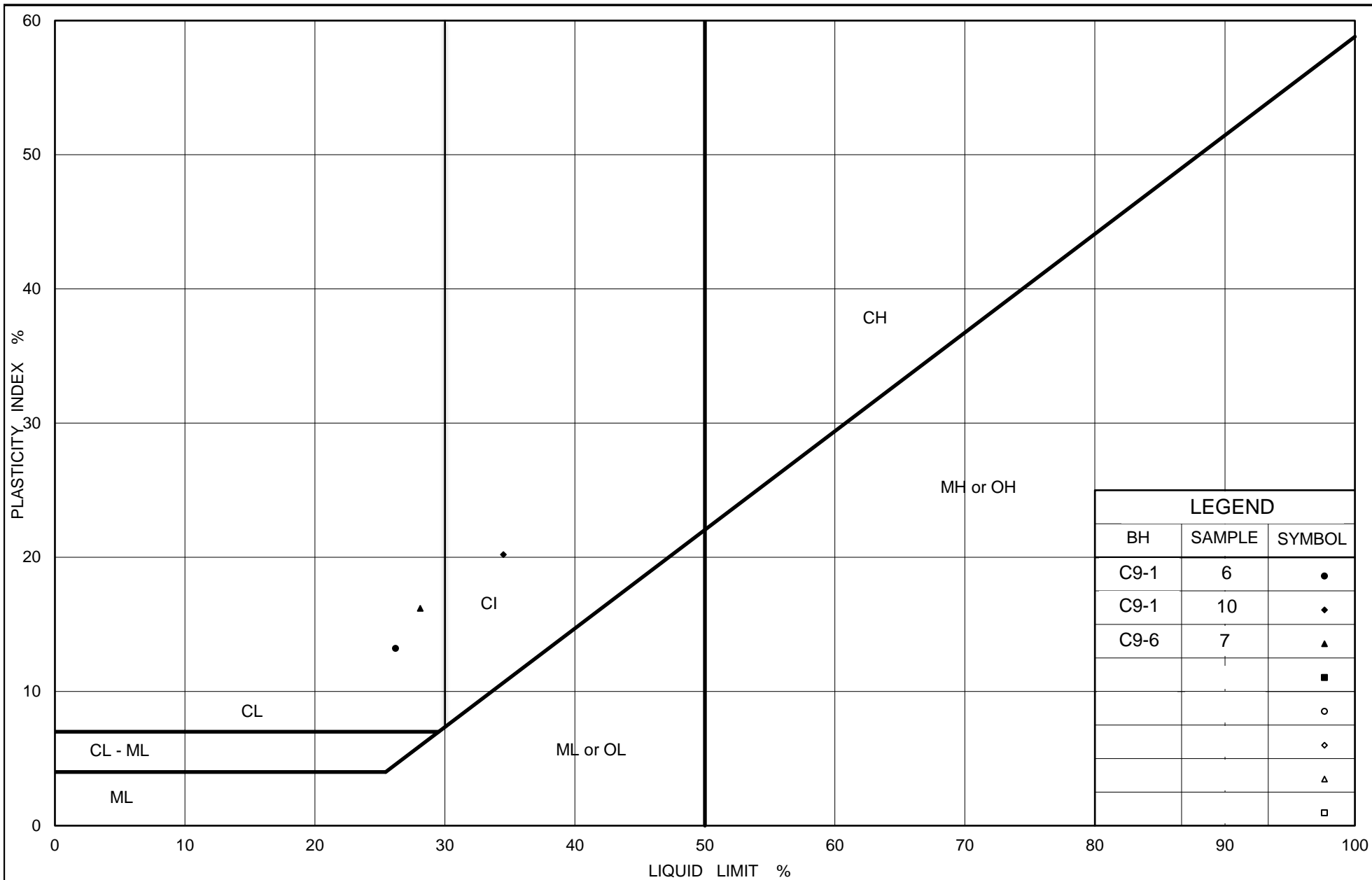
SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	C9-1	10	77.5
■	C9-1	6	83.7

Project Number: 1540419

Checked By: MWK

**Golder Associates**

Date: 31-Jan-17



## PLASTICITY CHART

Clayey Silt to Silty Clay (Till)

Figure No. B6

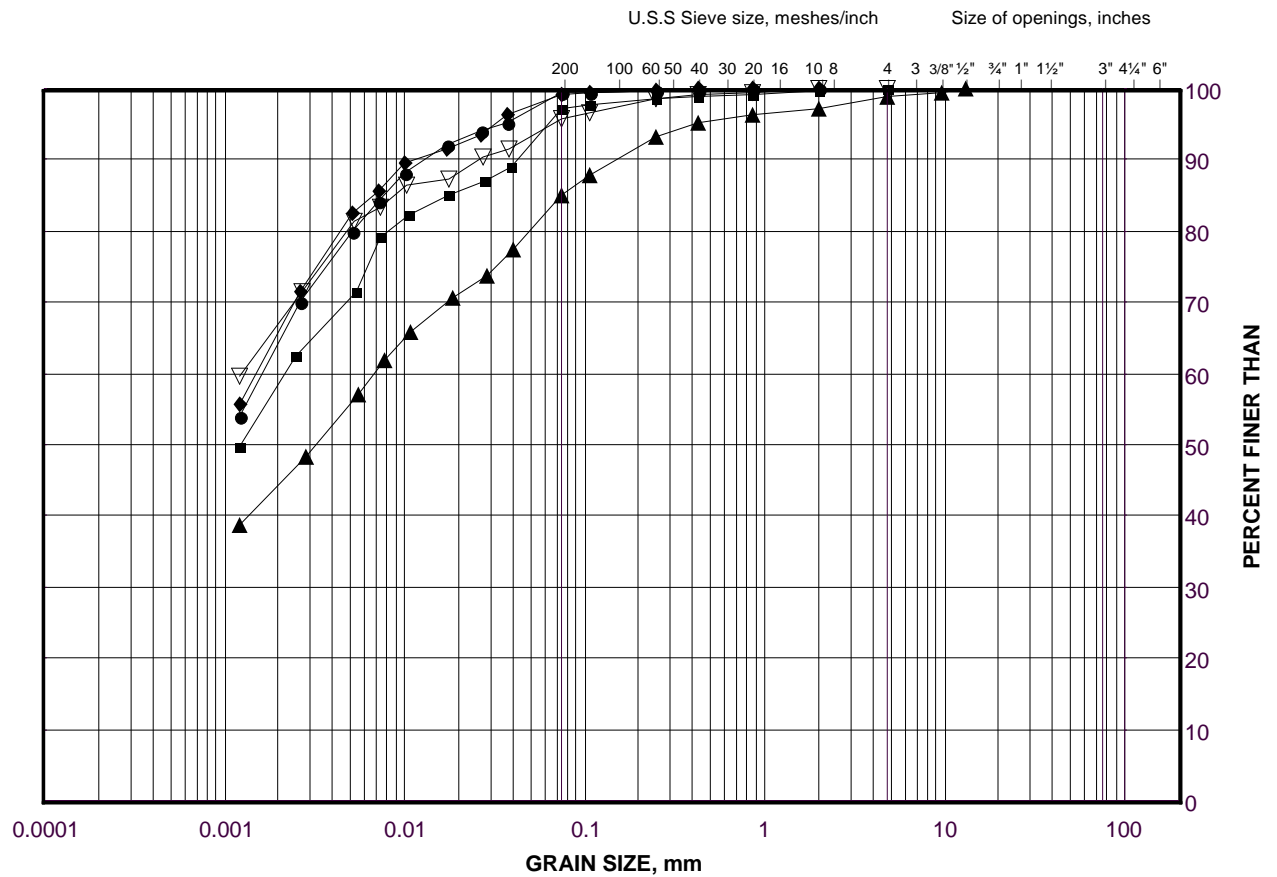
Project No. 1540419

Checked By: MWK

# GRAIN SIZE DISTRIBUTION

Silty Clay

FIGURE B7A



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

## LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	C9-3	11	82.5
■	C9-2	13	79.5
◆	C9-4	13	79.5
▲	C9-3	15	76.4
▽	C9-2	17	73.5

Project Number: 1540419

Checked By: MWK

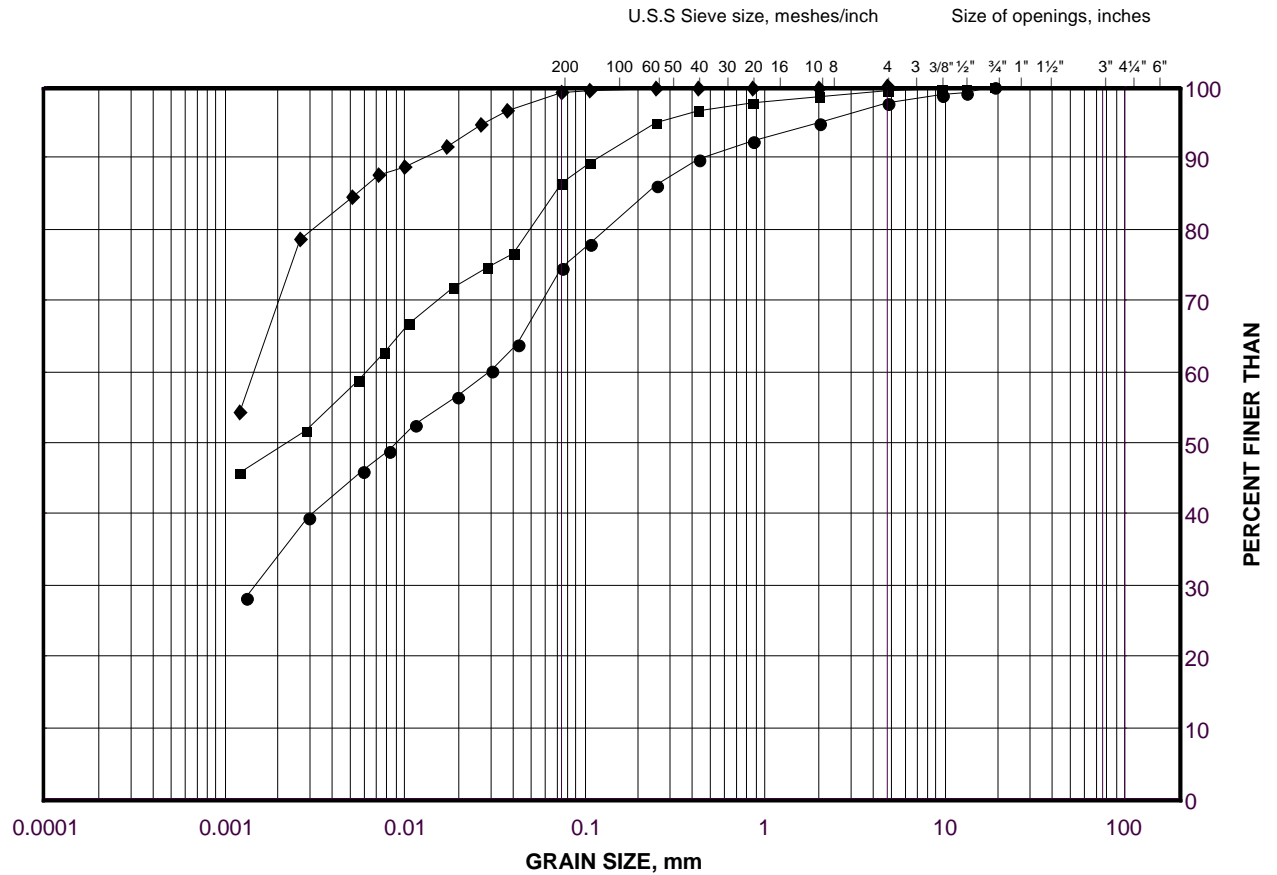
Golder Associates

Date: 31-Jan-17

# GRAIN SIZE DISTRIBUTION

Silty Clay to Clay

FIGURE B7B



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

## LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	C9-5	10	84.0
■	C9-4	15	76.4
◆	C9-5	16	74.9

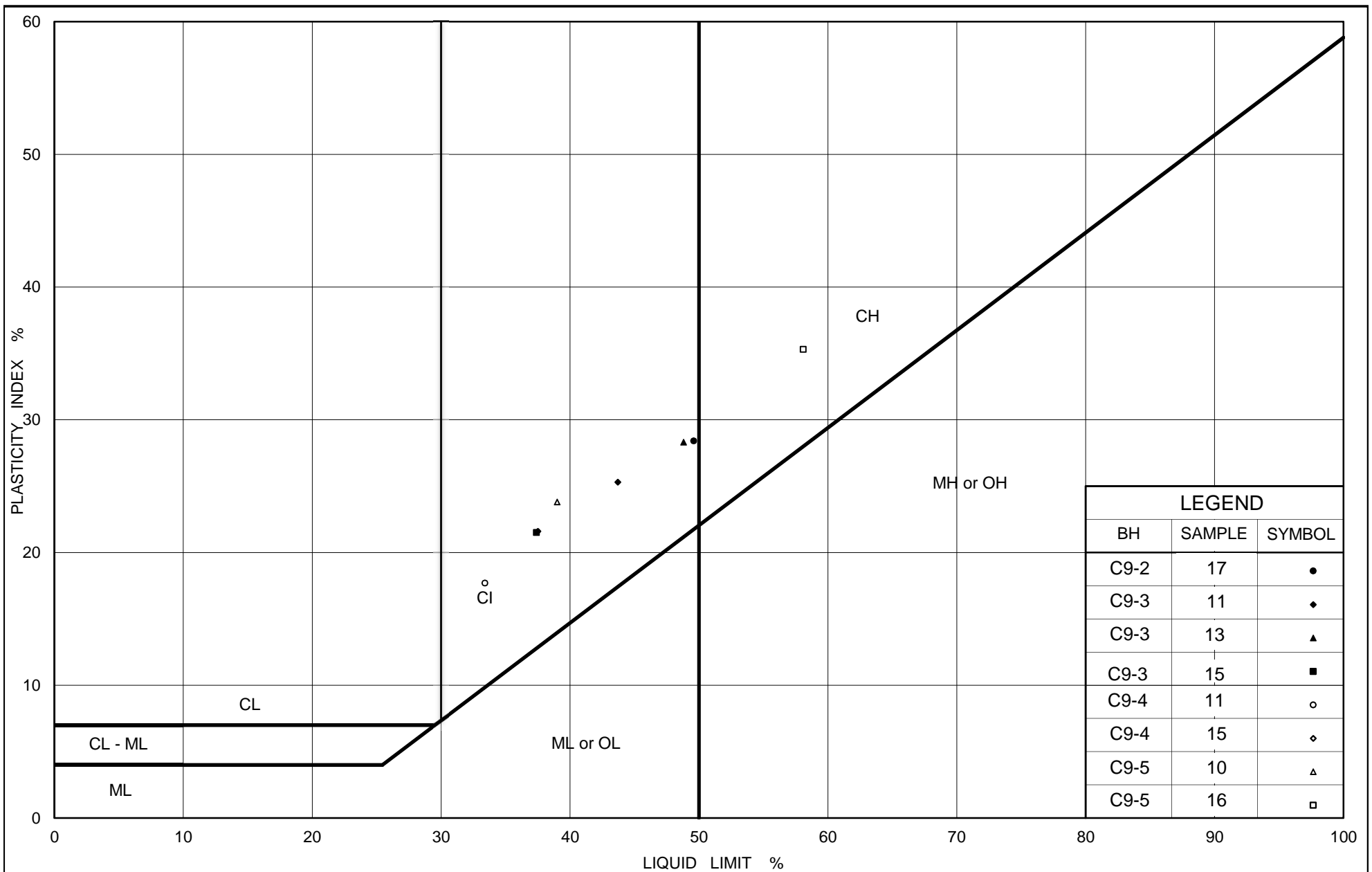
Project Number: 1540419

Checked By: MWK

**Golder Associates**

Date: 31-Jan-17





## PLASTICITY CHART Silty Clay to Clay

Figure No. B8

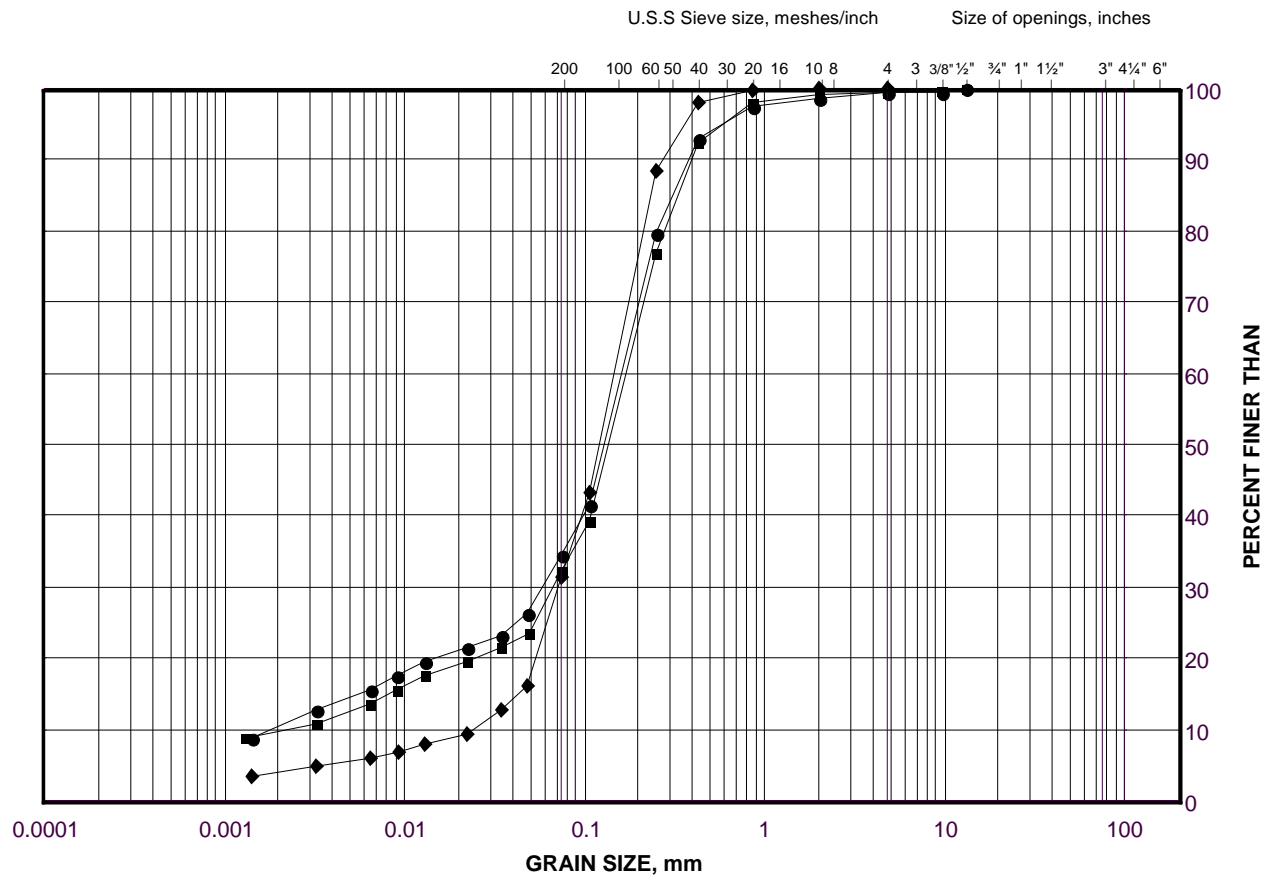
Project No. 1540419

Checked By: MWK

# GRAIN SIZE DISTRIBUTION

Silty Sand

FIGURE B9



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

## LEGEND

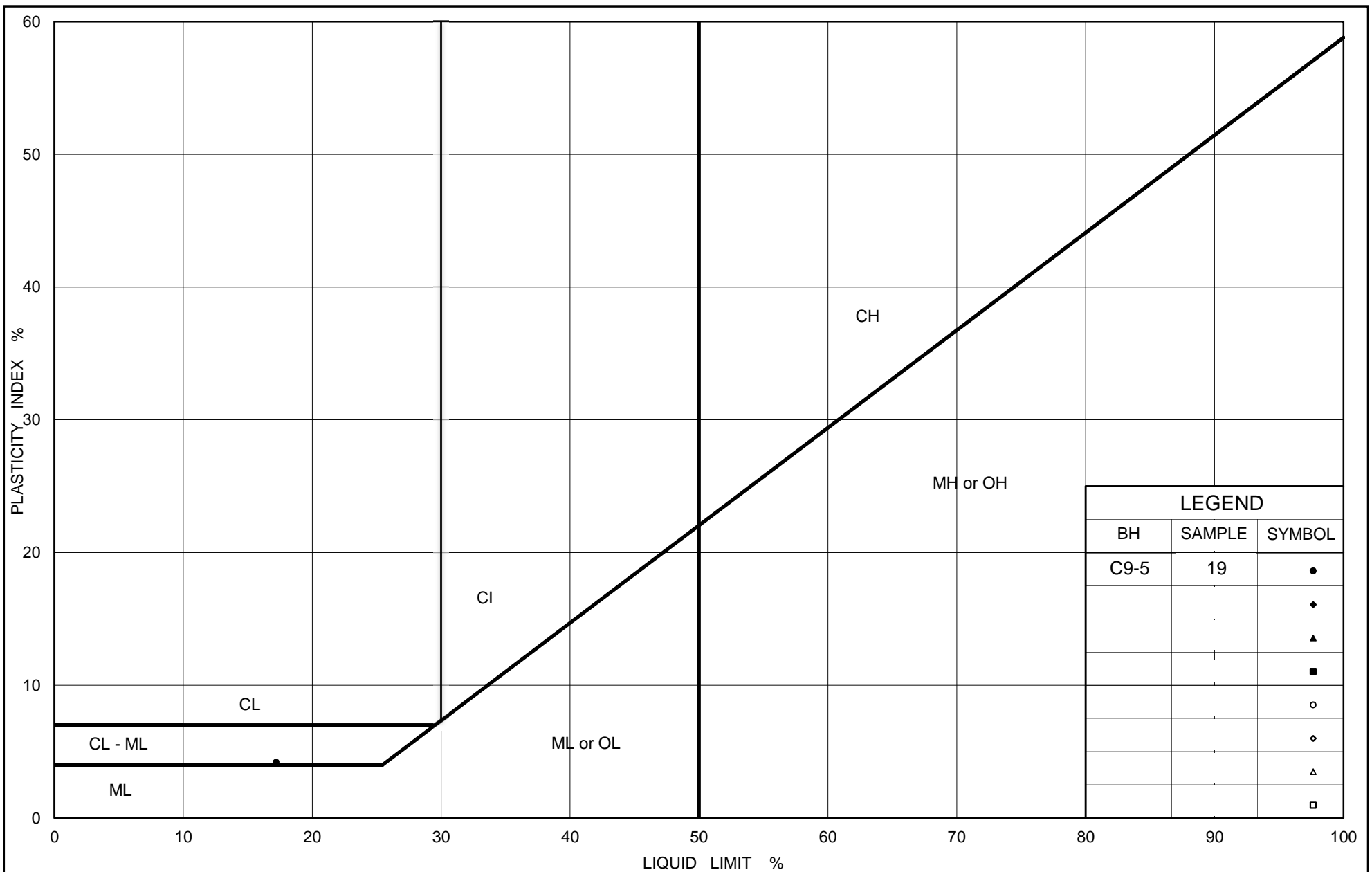
SYMBOL	BOREHOLE	SAMPLE	ELEVATION(m)
●	C9-5	19	70.3
■	C9-3	19	70.3
◆	C9-6	8	77.9

Project Number: 1540419

Checked By: MWK

**Golder Associates**

Date: 31-Jan-17



## PLASTICITY CHART Silty Sand

Figure No. B10

Project No. 1540419

Checked By: MWK



# **APPENDIX C**

## **Analytical Test Results**

Your Project #: 1540419  
Your C.O.C. #: 573330-01-01

**Attention: Matt Kelly**

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

**Report Date: 2016/09/29**  
Report #: R4184963  
Version: 1 - Final

**CERTIFICATE OF ANALYSIS**

**MAXXAM JOB #: B6K5174**

**Received: 2016/09/23, 12:57**

Sample Matrix: Soil  
# Samples Received: 5

Analyses	Date		Date Analyzed	Laboratory Method	Reference
	Quantity	Extracted			
Chloride (20:1 extract)	5	N/A	2016/09/29	CAM SOP-00463	EPA 325.2 m
Conductivity	5	N/A	2016/09/29	CAM SOP-00414	OMOE E3530 v1 m
pH CaCl2 EXTRACT	5	2016/09/28	2016/09/28	CAM SOP-00413	EPA 9045 D m
Resistivity of Soil	5	2016/09/23	2016/09/29	CAM SOP-00414	SM 22 2510 m
Sulphate (20:1 Extract)	5	N/A	2016/09/29	CAM SOP-00464	EPA 375.4 m

**Remarks:**

Maxxam Analytics has performed all analytical testing herein in accordance with ISO 17025 and the Protocol for Analytical Methods Used in the Assessment of Properties under Part XV.1 of the Environmental Protection Act. All methodologies comply with this document and are validated for use in the laboratory. The methods and techniques employed in this analysis conform to the performance criteria (detection limits, accuracy and precision) as outlined in the Protocol for Analytical Methods Used in the Assessment of Properties under Part XV.1 of the Environmental Protection Act.

Maxxam Analytics is accredited for all specific parameters as required by Ontario Regulation 153/04. Maxxam Analytics is limited in liability to the actual cost of analysis unless otherwise agreed in writing. There is no other warranty expressed or implied. Samples will be retained at Maxxam Analytics for three weeks from receipt of data or as per contract.

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

\* RPDs calculated using raw data. The rounding of final results may result in the apparent difference.

**Encryption Key**

Please direct all questions regarding this Certificate of Analysis to your Project Manager.

Ema Gitej, Senior Project Manager

Email: EGitej@maxxam.ca

Phone# (905)817-5829

=====

Maxxam has procedures in place to guard against improper use of the electronic signature and have the required "signatories", as per section 5.10.2 of ISO/IEC 17025:2005(E), signing the reports. For Service Group specific validation please refer to the Validation Signature Page.

### RESULTS OF ANALYSES OF SOIL

Maxxam ID		DCX431	DCX432	DCX433	DCX434	DCX435		
Sampling Date		2016/08/23 10:00	2016/08/27 13:00	2016/08/28 13:00	2016/08/31 11:00	2016/09/08 02:00		
COC Number		573330-01-01	573330-01-01	573330-01-01	573330-01-01	573330-01-01		
	UNITS	C1	C2	C3	C4	C9	RDL	QC Batch
<b>Calculated Parameters</b>								
Resistivity	ohm-cm	1800	1900	1300	1500	880		4673817
<b>Inorganics</b>								
Soluble (20:1) Chloride (Cl)	ug/g	190	280	410	360	570	20	4681464
Conductivity	umho/cm	557	540	798	687	1130	2	4681504
Available (CaCl2) pH	pH	7.57	7.77	7.63	7.61	7.42		4679490
Soluble (20:1) Sulphate (SO4)	ug/g	200	26	<20	<20	<20	20	4681465
RDL = Reportable Detection Limit								
QC Batch = Quality Control Batch								

## TEST SUMMARY

**Maxxam ID:** DCX431  
**Sample ID:** C1  
**Matrix:** Soil

**Collected:** 2016/08/23  
**Shipped:**  
**Received:** 2016/09/23

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride (20:1 extract)	KONE/EC	4681464	N/A	2016/09/29	Alina Dobreanu
Conductivity	AT	4681504	N/A	2016/09/29	Neil Dassanayake
pH CaCl2 EXTRACT	AT	4679490	2016/09/28	2016/09/28	Neil Dassanayake
Resistivity of Soil		4673817	2016/09/29	2016/09/29	Automated Statchk
Sulphate (20:1 Extract)	KONE/EC	4681465	N/A	2016/09/29	Alina Dobreanu

**Maxxam ID:** DCX432  
**Sample ID:** C2  
**Matrix:** Soil

**Collected:** 2016/08/27  
**Shipped:**  
**Received:** 2016/09/23

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride (20:1 extract)	KONE/EC	4681464	N/A	2016/09/29	Alina Dobreanu
Conductivity	AT	4681504	N/A	2016/09/29	Neil Dassanayake
pH CaCl2 EXTRACT	AT	4679490	2016/09/28	2016/09/28	Neil Dassanayake
Resistivity of Soil		4673817	2016/09/29	2016/09/29	Automated Statchk
Sulphate (20:1 Extract)	KONE/EC	4681465	N/A	2016/09/29	Alina Dobreanu

**Maxxam ID:** DCX433  
**Sample ID:** C3  
**Matrix:** Soil

**Collected:** 2016/08/28  
**Shipped:**  
**Received:** 2016/09/23

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride (20:1 extract)	KONE/EC	4681464	N/A	2016/09/29	Alina Dobreanu
Conductivity	AT	4681504	N/A	2016/09/29	Neil Dassanayake
pH CaCl2 EXTRACT	AT	4679490	2016/09/28	2016/09/28	Neil Dassanayake
Resistivity of Soil		4673817	2016/09/29	2016/09/29	Automated Statchk
Sulphate (20:1 Extract)	KONE/EC	4681465	N/A	2016/09/29	Alina Dobreanu

**Maxxam ID:** DCX434  
**Sample ID:** C4  
**Matrix:** Soil

**Collected:** 2016/08/31  
**Shipped:**  
**Received:** 2016/09/23

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride (20:1 extract)	KONE/EC	4681464	N/A	2016/09/29	Alina Dobreanu
Conductivity	AT	4681504	N/A	2016/09/29	Neil Dassanayake
pH CaCl2 EXTRACT	AT	4679490	2016/09/28	2016/09/28	Neil Dassanayake
Resistivity of Soil		4673817	2016/09/29	2016/09/29	Automated Statchk
Sulphate (20:1 Extract)	KONE/EC	4681465	N/A	2016/09/29	Alina Dobreanu

**Maxxam ID:** DCX435  
**Sample ID:** C9  
**Matrix:** Soil

**Collected:** 2016/09/08  
**Shipped:**  
**Received:** 2016/09/23

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
Chloride (20:1 extract)	KONE/EC	4681464	N/A	2016/09/29	Alina Dobreanu
Conductivity	AT	4681504	N/A	2016/09/29	Neil Dassanayake

Maxxam Job #: B6K5174  
Report Date: 2016/09/29

Golder Associates Ltd  
Client Project #: 1540419  
Sampler Initials: MK

## TEST SUMMARY

**Maxxam ID:** DCX435  
**Sample ID:** C9  
**Matrix:** Soil

**Collected:** 2016/09/08  
**Shipped:**  
**Received:** 2016/09/23

Test Description	Instrumentation	Batch	Extracted	Date Analyzed	Analyst
pH CaCl2 EXTRACT	AT	4679490	2016/09/28	2016/09/28	Neil Dassanayake
Resistivity of Soil		4673817	2016/09/29	2016/09/29	Automated Statchk
Sulphate (20:1 Extract)	KONE/EC	4681465	N/A	2016/09/29	Alina Dobreanu



### GENERAL COMMENTS

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

Package 1	6.7°C
-----------	-------

**Results relate only to the items tested.**

## QUALITY ASSURANCE REPORT

QC Batch	Parameter	Date	Matrix Spike		SPIKED BLANK		Method Blank		RPD	
			% Recovery	QC Limits	% Recovery	QC Limits	Value	UNITS	Value (%)	QC Limits
4679490	Available (CaCl <sub>2</sub> ) pH	2016/09/28			99	97 - 103			0.48	N/A
4681464	Soluble (20:1) Chloride (Cl)	2016/09/29	NC	70 - 130	109	70 - 130	<20	ug/g	NC	35
4681465	Soluble (20:1) Sulphate (SO <sub>4</sub> )	2016/09/29	NC	70 - 130	107	70 - 130	<20	ug/g	NC	35
4681504	Conductivity	2016/09/29			99	90 - 110	<2	umho/cm	2.9	10

N/A = Not Applicable

Duplicate: Paired analysis of a separate portion of the same sample. Used to evaluate the variance in the measurement.

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

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

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

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

NC (Duplicate RPD): The duplicate RPD was not calculated. The concentration in the sample and/or duplicate was too low to permit a reliable RPD calculation (one or both samples < 5x RDL).

### VALIDATION SIGNATURE PAGE

The analytical data and all QC contained in this report were reviewed and validated by the following individual(s).

*Cristina Carriere*

---

Cristina Carriere, Scientific Services

---

Maxxam has procedures in place to guard against improper use of the electronic signature and have the required "signatories", as per section 5.10.2 of ISO/IEC 17025:2005(E), signing the reports. For Service Group specific validation please refer to the Validation Signature Page.



Maxxam Analytics International Corporation o/a Maxxam Analytics  
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23-Sep-16 12:57

Ema Gitej  
B6K5174

Page of

Only:

Bottle Order #:

579330

Project Manager:

Ema Gitej

INVOICE TO:		REPORT TO:		PROJECT INFORMATION:	
Company Name:	#1326 Golder Associates Ltd	Company Name:	Golder Associates Ltd	Quotation #:	B63104
Attention:	Central Acct:1112, 1113, 1118	Attention:	Matt Kelly / Madison Kennedy	P.O. #:	
Address:	6925 Century Ave Suite 100	Address:		Project:	1540419
	Mississauga ON L5N 7K2			Project Name:	
Tel:	(905) 567-4444	Tel:		Site #:	
Fax:	(905) 567-6561	Fax:		Sampled By:	
Email:	Catherine_Guiao@golder.com, Rachel_Benjamin@gol	Email:	Matthew_Kelly@golder.com, MadKennedy@golder.com		

JFU

ENV-107  
COC #:



C#573330-01-01

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

Regulation 153 (2011)		Other Regulations		Special Instructions
<input type="checkbox"/> Table 1	<input type="checkbox"/> Res/Park	<input type="checkbox"/> CCME	<input type="checkbox"/> Sanitary Sewer Bylaw	
<input type="checkbox"/> Table 2	<input type="checkbox"/> Ind/Comm	<input type="checkbox"/> Reg 558	<input type="checkbox"/> Storm Sewer Bylaw	
<input type="checkbox"/> Table 3	<input type="checkbox"/> Agri/Other	<input type="checkbox"/> MISA	Municipality	
<input type="checkbox"/> Table	<input type="checkbox"/> For RSC	<input type="checkbox"/> PWQO		
		<input type="checkbox"/> Other		

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

	Sample Barcode Label	Sample (Location) Identification	Date Sampled	Time Sampled	Matrix
1		C1	2016/08/23	10:00am	Soil
2		C2	2016/08/27	1:00pm	Soil
3		C3	2016/08/28	1:00pm	Soil
4		C4	2016/08/31	11:00am	Soil
5		C9	2016/09/06	2:00am	Soil
6					
7					
8					
9					
10					

Field Filtered (please circle):

Metals / Hg / Cr VI

Corrosivity pkg (C) SO4, EC, Resistivity (pH)

ANALYSIS REQUESTED (PLEASE BE SPECIFIC)

Turnaround Time (TAT) Required:

Please provide advance notice for rush projects

Regular (Standard) TAT:

(will be applied if Rush TAT is not specified)

Standard TAT = 5-7 Working days for most tests

Please note: Standard TAT for certain tests such as BOD and Dioxin/Furans are > 5 days - contact your Project Manager for details

Job Specific Rush TAT (if applies to entire submission)

Date Required:

Time Required:

Rush Confirmation Number:

(call lab for it)

# of Bottles

Comments

RELINQUISHED BY: (Signature/Print)		Date: (YY/MM/DD)	Time	RECEIVED BY: (Signature/Print)		Date: (YY/MM/DD)	Time	# Jars used and not submitted	Laboratory Use Only				
Madison Kennedy		26/09/23	12:57	Tanvir Bhatt Tanvir Bhatt		2016/09/23	12:57		Time Sensitive	Temperature (°C) on Receipt	Custody Seal	Yes	No
										7/6/7	Present		
											Intact		

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

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

White: Maxxam Yellow: Client

Maxxam Analytics International Corporation o/a Maxxam Analytics

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

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