

TECHNICAL MEMORANDUM

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Project No. 1786658 WO#30

TO Mr. Richard Hassall, P. Eng.,
Morrison Hershfield

CC

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**FOUNDATION ENGINEERING SERVICES TO ASSESS PERFORMANCE OF HIGH FILL EMBANKMENT
HIGHWAY 405 EASTBOUND BETWEEN STA 10+820 AND STA 10+880
FORT ERIE, NIAGARA REGION, ONTARIO
ASSIGNMENT NO. 2017-E-0016-30, WO#30, G.W.P. 2112-19-00
MTO Geocres No.: 30M3-321**

Golder Associates Ltd. (Golder) has been retained by Morrison Hershfield (MH) on behalf of the Ministry of Transportation, Ontario (MTO) to provide foundation engineering services to investigate the subsurface conditions and assess the potential cause(s) of past pavement cracking and a shallow slope failure/sloughing along the north facing (median) embankment slope of the Highway 405 Eastbound lanes (EBL), approximately between STA 10+820 and STA 10+880.

This technical memorandum presents the results of our site visit and geotechnical investigation and provides a summary of our interpretation of the available information to assess the potential cause(s) of the previous distress (i.e. pavement cracking and shallow slope failures/sloughing) observed at the site. The investigation and discussion with the interpretations and recommendations are intended for the use of the MTO and their designers and shall not be used or relied upon for any other purpose or by any other parties. Where comments are made on construction, they are provided only to highlight those aspects which could affect design and execution of the project. The Contractor must make their own interpretation of the factual information provided as it may affect equipment selection, proposed construction methods and scheduling.

1.0 GENERAL SITE DESCRIPTION

The section of the Highway 405 EBL embankment between STA 10+820 and STA 10+880 is located about 150 m east of The Queen Elizabeth Way (QEW) in Fort Erie, Ontario as shown on Drawing 1. The highway at this location was built within a localized creek valley with an approximately 11 m high fill embankment. Two streams run from South to North below the Highway 405 embankment through two precast concrete box culverts (about 1.8 m and 3.0 m in span) in this area. A Corrugated Steel Pipe (CSP) (about 0.9 m diameter) culvert passes below the Highway 405 WBL in the vicinity of the site which drains water from the North side of the WBL embankment to the median ditch (between Highway 405 EBL and WBL embankments). The road surface along the Highway 405 EBL ranges from approximately Elevation El. 130 m to El. 132 m at the site. The upper portion of the existing embankment side slopes are shown on the design drawings to be at about 2H:1V, however, localized steepened sections were observed during our site visit as discussed in this memorandum.

2.0 BACKGROUND INFORMATION

Highway 405 (from QEW to Hwy 8) was originally constructed in the 1960's. The original design drawings (titled "Hwy 405, District 4 Hamilton, Q.E.W. to Just West of Hwy 8 including structures at Q.E.W", W.P. 281-59-1, 282-59, 283-59, Contract No. 1961-0123) were prepared by McCormick & Rankin and were provided to Golder by MH for reference. Since original construction of Hwy 405, there have been several rehabilitation contracts as listed below and contract drawings (if available) were provided to Golder:

- Contract 1986-0081 – No Drawings Available – Sketches of Joint Repairs & Subdrains
- Contract 1990-0049 – Resurfacing (Drawing Sheets 1 to 83)
- Contract 1999-0133 – FTMS Installation on QEW (Drawing Sheets 1 – 122)
- Contract 2007-2029 – Pavement Rehabilitation (full Contract Package)
- Contract 2009-2022 – Pavement Rehabilitation (full Contract Package)

Based on a search of the MTO GEOCRE database, there have been several geotechnical investigations performed along this stretch of Hwy 405 due to poor performance of the embankments since original construction. Poor performance has included excessive settlements of the highway surface, formation of voids, and slope failures / instabilities of the embankment side-slopes.

At the area of concern (Highway 405 EBL, Station 10+820 to 10+880), the first recorded incidence of poor performance was pavement cracking and a shallow slope failure (surficial sloughing) that was reported by MTO in 2006. A limited geotechnical investigation (consisting of a single hand dug test pit) was performed by Golder (Golder Project No. 06-1181121, dated Feb. 2007) and preliminary remedial options were recommended to restore the slope and improve surface water drainage near the upper portion of the embankment. It is noted that a foundation (borehole) investigation was not performed at that time and the existing slope was not analysed for global / deep-seated stability. The selected remediation option consisted of excavating a longitudinal trench along the toe of the failure and backfilling with filter sand and capped with rip-rap and topsoil as shown in the Contract 2009-2029 design drawings. Although we are unaware of any slope failures that have occurred in this area since the remedial measures were implemented more than 10 years ago, it is understood that significant pavement cracks reappeared in 2016 and the area of concern was resurfaced with asphalt at that time. During the most recent pavement investigation for the current assignment carried out in 2019, excessive or abnormal pavement cracking at the area of concern was not observed.

Considering the history of the site and relatively frequent maintenance required at the area of concern, and following discussions / meetings between MTO and the designer, it was considered prudent to perform a foundation investigation at the area of concern prior to issuing the tender documents for the next stage of rehabilitation on Hwy 405 under the current agreement (2017-E-0016).

3.0 FOUNDATION INVESTIGATION

Three boreholes (designated as Boreholes BH-1 to BH-3) were advanced on March 17 and 18, 2020 as part of the foundation investigation and as shown on Drawing 1. The field investigation was carried out using a GT8 track-mounted drilling rig supplied and operated by Landshark Drilling of Brantford, Ontario. Boreholes BH-1 and BH-2 were advanced using nominal 150 mm inner diameter hollow stem augers followed by tricone advancement using drilling mud. Borehole BH-3 was advanced using nominal 60 mm inner diameter hollow stem augers. Soil samples were generally obtained at 0.75 m and 1.5 m intervals of depth, using nominal 50 mm outside diameter and 35 mm inside diameter split-spoon samplers driven by an automatic hammer

mounted on the drill rig, performed in general accordance with the Standard Penetration Test (SPT) procedure (ASTM D1586¹). Considering the inside diameter of the split-spoon sampler, any soil particles larger than 35 mm are not retrievable.

Fieldwork was observed on a full-time basis by a member of Golder's engineering staff who arranged for the clearance of underground utilities through public and private agencies, supervised the sampling and in situ testing operations, logged the boreholes and cared for soil samples.

The borehole locations and ground surface elevations were obtained using a mobile GPS unit (Trimble XH 3.5G), having a horizontal accuracy of 0.05 m and a vertical accuracy of 0.02 m. The locations provided on the borehole records and shown on Drawing 1 are relative to the MTM NAD83 Zone 10 coordinate system and the ground surface elevations are referenced to CGVD28 Geodetic datum benchmark. The borehole locations (including geographic latitude and longitude co-ordinates), ground surface elevations and drilled depths are summarized in Table 1 below.

Table 1: Summary of Borehole Locations, Elevations, and Depths

Borehole I.D.	MTM NAD 83 Zone 10		Ground Surface Elevation (m)	Borehole Depth (m)
	Northing (m) (Latitude)	Easting (m) (Longitude)		
BH-1	4,779,182.2 (43.151951)	333,481.9 (-79.147349)	132.1	15.6
BH-2	4,779,187.2 (43.151995)	333,518.9 (-79.146894)	131.1	18.9
BH-3	4,779,192.3 (43.152039)	333,555.1 (-79.146449)	130.4	11.3

Boreholes BH-1 and BH-2 were advanced on the highway within the area of concern and Borehole BH-3 was advanced on the highway east (and just outside) the area of concern.

All boreholes were backfilled in general accordance with Ontario Regulation 903 (as amended) and the highway surface re-instated using cold patch asphalt.

The stratigraphic boundaries shown on the borehole records and on the stratigraphic profile on Drawing 1 are inferred from non-continuous sampling, observations of drilling progress and the results of SPTs, and therefore, represent transitions between soil types rather than exact planes of geological change. Furthermore, subsurface conditions will vary between and beyond the borehole locations, however, the factual data presented on the borehole records governs any interpretation of the site conditions.

¹ American Society of Testing and Materials (ASTM) D1586-11, Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils.

3.1 Regional Geology

The site is located within the physiographic region known as the Iroquois Plain, as delineated in *The Physiography of Southern Ontario* (Chapman and Putnam, 1984)² and *Urban Geology of Canadian Cities* (Menzies and Taylor, 1998)³.

The Iroquois Plain extends around the western shores of Lake Ontario and on the south side of the lake, in the St. Catharines area, the Plain is located between the present Lake Ontario shorebluffs and the foot of the Niagara Escarpment. 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 the Iroquois Plain are typically comprised of glaciolacustrine clays and silts. The surficial sands, silts and clays are underlain by an extensive till deposit; portions of the till are considered to be “water-lain” (that is, formed by sediment rain-out either from a floating ice margin or from iceberg dumping), resulting in a predominantly massive, matrix-supported structure, as well as relatively thin sand to silt stringers or interlayers. This extensive till deposit may be underlain by or interlayered with a lower glaciolacustrine clay deposit, although this glaciolacustrine layer is absent in some portions of the Iroquois Plain in the St. Catharines area. Finally, the till and/or glaciolacustrine layer may be underlain by a lower till unit, that typically has increasing gravel content with proximity to the underlying bedrock (Menzies and Taylor, 1998).

3.2 Subsurface Conditions

The following summarizes the subsurface conditions encountered in the boreholes:

- **Asphalt:** An approximately 180 mm to 240 mm thick layer of asphalt was encountered immediately at ground surface in all boreholes, which were advanced through the Highway 405 roadway.
- **Sand and Gravel (Fill):** An approximately 0.6 m to 0.7 m thick layer of sand and gravel fill was encountered below the asphalt in all boreholes, and is considered part of the pavement structure. The base of this fill layer extended to between Elevations (El.) 131.3 m and El. 129.6 m. The SPT “N” values measured within the sand and gravel fill generally range between 22 blows and 28 blows per 0.3 m of penetration, indicating this fill layer generally has a compact level of compactness.
- **Silty Sand (Fill):** An approximately 0.1 m to 0.7 m thick layer of silty sand fill was encountered below the sand and gravel fill in all boreholes. The base of this fill layer extended to between El. 131.0 m and El. 129.6 m. The SPT “N” values measured within the silty sand fill generally range between 6 blows and 10 blows per 0.3 m of penetration, indicating this fill layer generally has a loose level of compactness.

A grain size distribution test was carried out on one selected sample of the sandy silt fill and the results are shown on Figure B1 in Appendix B. A laboratory water content test was carried out on a selected sample of the silty sand fill and measured about 17 per cent.

- **Silty Clay to Clayey Silt (Fill):** An approximately 6.4 m to 10.2 m thick deposit of silty clay to clayey silt (fill) was encountered below the silty sand fill in all boreholes. The base of this fill layer extended to El. 123.4 m to El. 119.4 m. The clayey fill was observed to contain wood and asphalt fragments and organics / rootlets throughout in Boreholes BH-2 and BH-3. The SPT “N” values measured within the silty

²Chapman, L.J. and Putnam, D.F. 1984. *The Physiography of Southern Ontario*, Ontario Geological Survey, Special Volume 2, Third Edition. Accompanied by Map P. 2715, Scale 1:600,000.

³Menzies, J., and Taylor, E.M., 1998. *Urban Geology of St. Catharines-Niagara Falls, Region Niagara*. In *Urban Geology of Canadian Cities*, Geological Association of Canada Special Paper 42, Ed. P.F. Karrow and O.L. White.

clay to clayey silt (fill) layer range between 5 blows and 25 blows per 0.3 m of penetration, suggesting a firm to very stiff consistency.

Grain size distribution testing was carried out on five selected samples of the silty clay to clayey silt (fill) and the results are shown on Figure B2 in Appendix B. An Atterberg limit tests were carried out on five selected samples of the silty clay to clayey silt (fill). These results, which are plotted on Figure B3 in Appendix B, measured liquid limits between about 34 per cent and 46 per cent, plastic limits between about 18 per cent and 20 per cent, and plasticity indices between about 16 per cent and 26 per cent indicating the clayey silt to silty clay (fill) has a predominantly intermediate plasticity. Water content tests were carried out on selected samples of the silty clay to clayey silt (fill) and measured water contents between about 16 per cent and 30 per cent.

- **Silty Clay to Sandy Clayey Silt:** A layer of silty clay to sandy clayey silt, typically containing variable amounts of organics (rootlets and wood fragments) was encountered underlying the fill layers in all boreholes. The cohesive deposit ranged from about 1.5 m to 1.6 m thick. The SPT “N” values measured in the clayey silt range between 17 blows and 25 blows per 0.3 m of penetration, suggesting the layer has a very stiff consistency.

Grain size distribution testing was carried out on two selected samples of the silty clay to sandy clayey silt and the results are shown on Figure B4 in Appendix B. Atterberg limits tests were carried out on two selected samples of the silty clay to sandy clayey silt. These results, which are plotted on Figure B5 in Appendix B, measured liquid limits of about 33 per cent and 35 per cent, plastic limits of about 18 per cent and 20 per cent, and plasticity indices of about 12 per cent and 18 per cent indicating the cohesive deposit is of low to intermediate plasticity. Water content tests carried out on selected samples of the silty clay to clayey silt measured water contents between about 17 per cent and 30 per cent.

- **Clayey Silt to Sandy Silt (Till):** A deposit of clayey silt to sandy silt till was typically encountered underlying the silty clay to sandy clayey silt layer in the boreholes. All boreholes were terminated within this deposit after penetrating it for depths ranging from 2.6 m to 5.4 m. The SPT “N” values measured within the till deposit range between 24 blows per 0.3 m of penetration to 100 blows per 0.2 m of penetration, suggesting the deposit has a very stiff to hard consistency / dense to very dense level of compactness.

Grain size distribution testing was carried out on three selected samples of the clayey silt to sandy silt (till) and the results are shown on Figure B6 in Appendix B. Atterberg limits tests were carried out on three selected samples of the clayey silt to sandy silt (till). These results, which are plotted on Figure B7 in Appendix B, measured liquid limits between about 18 per cent and 25 per cent, plastic limits between about 15 per cent and 17 per cent, and plasticity indices of about 1 per cent to 10 per cent, indicating the silt till is slightly plastic to having a low plasticity. Water content tests were carried out on selected samples of the silt till and measured a water content ranging between about 16 per cent and 18 per cent.

- **Groundwater Conditions:** The groundwater level was not able to be observed in Boreholes BH-1 and BH-2 due to the method of advancement that required drilling mud to be introduced into the borehole during drilling operations below a depth of about 3.7 m; however, no groundwater or water seepage was encountered up to a depth of 3.7 m in both boreholes. Borehole BH-3 was observed to be dry in the open borehole following the completion of drilling operations.

4.0 VISUAL INSPECTION

While on site for the drilling investigation, Golder personnel visually inspected the south and north sides of the Highway 405 EBL embankment near the previously distressed area and also surveyed the north (median side) slope at four locations using a mobile GPS unit (Trimble XH 3.5G), having a horizontal accuracy of 0.05 m and a vertical accuracy of 0.02 m. The slope inspection record and corresponding photographs (Photograph C1 to C4) are provided in Appendix C, and the results are summarized below:

- Upper portion of the north (median) side of the embankment slope consisted of sand and gravel and was unvegetated compared to bottom portion of the slope that was vegetated with grass / shrubs;
- Upper portion of the north (median) side of the embankment slope appeared to be locally steeper in some areas and was measured to be inclined at 1.5 Horizontal: 1 Vertical (1.5H:1V) at about Station 10+890, while the lower portion of the slope was measured to be inclined at about 2H:1V;
- Active erosion / water seepage was not observed on the north or south sides of the Highway 405 EBL embankment;
- Some surficial surface water rills were evident in the granular fills on the south side of the Highway 405 EBL slope;
- No signs of slope instability or cracking / bulging were observed on the north or south side of the Highway 405 EBL embankment;
- The inlet for the box culvert located directly below the area of concern (at about Station 10+880) of the Highway 405 EBL embankment was observed to be free of obstructions and water was flowing freely into the structure (i.e. no ponding). A grate / catch basin was observed to be present at the midpoint of the culvert (to facilitate drainage of surface water from the median ditch between Highway 405 EBL and WBL) and was observed to be free of obstructions. Water was observed to be flowing through the culvert when looking through the grate and there was no sign of sediment build-up or obstructions.
- The box culvert located west of the area of concern (Station 10+780 at the Hwy 405 EBL centreline) connects to another culvert and extends south below the QEW; thus, the inlet was not inspected. As shown in the design drawings for Contract 2009-2029, a grate / catch basin was observed to be present at the midpoint of the culvert (to facilitate drainage of surface water from the median ditch between Highway 405 EBL and WBL) and was observed to be free of obstructions. Water was observed to be flowing through the culvert when looking through the grate and there was no sign of sediment build-up or obstructions.
- In addition, the CSP culvert located below the Highway 405 WBL (Station 10+780) was observed to be free of obstructions and water was draining from the north side into the median ditch, running east along the ditchline, and entering the grate into the box culvert.

5.0 DISCUSSION

5.1 Stability Analysis

A stability analysis was conducted to check the global stability of the existing Highway 405 EBL embankment at the area of concern. The critical section where the steepest slope was measured (1.5H:1V near the crest) on the north (median) side of the Hwy 405 EBL embankment was selected for the analysis. The long-term (effective stress) condition was analyzed only as the short term (undrained) condition was not considered to be

applicable given that any excess porewater pressure caused from the initial construction of the embankment would have dissipated over the past 50+ years since construction.

Two-dimensional limit equilibrium slope stability analysis was conducted using the commercially available program Slide 2018 (Version 8.014), developed by Rocscience Inc., employing the Morgenstern-Price method of analysis. Morgenstern-Price is a general method of slices which is based on equilibrium of forces and moments acting on each slice of soil mass above the potential failure surface.

5.1.1 Soil Parameters

The slope profile identified as the steepest slope was measured near the location of Borehole BH-2; thus, the stratigraphy from Borehole BH-2 has primarily been used for the slope stability model.

For the soils present at the site, the effective stress parameters employed in the analyses were estimated using correlations based on the in-situ Standard Penetration Tests (SPT) and the plasticity indices obtained from the Atterberg limits test results as proposed by Peck et al (1974)⁴, Meyerhof (1956)⁵, Holtz et al. (2011)⁶ and U.S. Navy (1986)⁷. The parameters as estimated from the lab tests and from the correlations were adjusted, if necessary, using engineering judgment based on precedent experience in similar soil conditions, where appropriate. A groundwater level representative of the creek level (water level observed in the culverts) was used in the analyses.

Table 2 below summarizes the simplified stratigraphy and the selected soil parameters employed for the analyses.

Table 2: Soil Parameters for Global Stability Analyses

Idealized Stratigraphy	Soil Parameters (Effective Stress or Drained Analysis)		
	Bulk Unit Weight, γ (kN/m ³)	Effective Cohesion, c' (kPa)	Angle of Internal Friction, ϕ' (°)
Sand and gravel Fill (pavement structure)	21	0	38
Silty Sand (Fill)	19	0	32
Silty Clay to Clayey Silt (Fill)	20	0	28
Silty Clay to Sandy Clayey Silt, containing organics	20	0	26
Clayey Silt to Sandy Silt (Till)	21	0	35

5.1.2 Stability Analyses Results

The global slope stability analyses for the localized steep section (measured to be at 1.5H:1V near the crest of the north slope near the area of concern) calculated a factor of safety against global stability of 1.4 as shown in Figure 1.

⁴ Peck, R.B., Hanson, W.E., and Thornburn, T.H., 1974. Foundation Engineering, 2nd ed., John Wiley and Sons, New York, NY.

⁵ Meyerhof, G.G. 1956. "Penetration tests and bearing capacity of cohesionless soils," J. of Soil Mech. and Foundations Div., ASCE, Vol.82, No.SM1, pp.1-19.

⁶ Holtz, R.D., Kovacs, W.D., Sheahan, T.C. 2011. An Introduction to Geotechnical Engineering, 2nd Edition. Pearson Education Inc.

⁷ U.S. Navy. 1971. Soil Mechanics, Foundations, and Earth Structures. NAVFAC Design Manual DM-7. Washington, D.C.

Shallow surficial failure surfaces (with a Factor of Safety below 1) were calculated in the upper steepest portion of the embankment slope. Figure 1 also shows a failure surface where a factor of safety equal to 1.2 was calculated where the toe of the failure surface daylighted at about the mid-slope of the embankment, consistent with the pictures of the observed failure that occurred back in 2006 (refer to Golder 2007 report). If a perched groundwater surface is modeled near the ground surface of the slope (i.e. assuming near surface soils become saturated from surface water due to inadequate drainage and/or localized surface water accumulation), the factor of safety reduces to less than 1.

Target minimum factors of safety of 1.5 for long-term global stability are normally adopted in the design of slopes under static conditions, per the *Canadian Highway Bridge Design Code* (CHBDC 2014)⁸; This target value is based on a typical consequence factor, ψ , for Highway 405, and a typical degree of understanding, ϕ_{gu} , based on the borehole investigation at the site. Similarly, the *Canadian Foundation Engineering Manual* suggests a minimum factor of safety ranging from 1.3 to 1.5 be adopted for global stability for earthworks (CFEM, 2006 - Table 8.3)⁹.

5.2 Potential Cause(s) of Poor Performance of Hwy 405 EBL Embankment

Based on the site visit, drilling investigation and a review of the available information in GEOCRESS and the previous contracts provided by MH, the following facts can be made regarding the area of concern (i.e. north side of Hwy 405 EBL embankment, Station 10+800 to 10+900):

- Based on the original design drawings, the area of concern is located directly above a previous watercourse / creek alignment within a localized valley where the embankment fill is up to about 11 m thick. The watercourse was re-routed through the existing concrete culvert (at the east limit of the area of concern) that passes below the Highway 405 EBL and WBL embankments and conveys surface water from the south to the north;
- According to the original Contract design drawings (Sheets 11, 12 and Drawing DM5022-E), there is a storm sewer (labelled as "conc/clay, 12-inch (300 mm) diameter) that runs below the north shoulder / crest and parallel to Hwy 405 EBL directly within and beyond the area of concern. The design drawings also show a curb and gutter, and several grates / catch basins leading into the storm sewer at this location; however, these features were not observed / confirmed during our site visit. The presence of these features is again shown in the 1999 Contract drawings (Contract 99-133, Sheet 41) but are not shown on the more recent 2007/2009 Contract drawings. Based on our review of the available information, it is not known whether the storm sewer and associated grates / catch basins were removed or decommissioned, or still exist below ground surface at the site.
- According to the 2007/2009 Contract drawings (Sheets 58 and 85), the Hwy 405 EBL north (median) side slope was remediated by excavating a trench along the toe of the observed 2006 failure (parallel to the highway) and backfilling with filter sand and topped with rip-rap and topsoil.
- The borehole investigation at the site indicates the embankment fill consists predominantly of cohesive fill with variable amounts of organics (including wood fragments, rootlets) and deleterious materials throughout. The native clayey foundation soil directly below the embankment fill also contained variable organics. A summary of the organic / deleterious materials encountered within the boreholes is provided in **Table 3**.

⁸ CSA International. 2014. Canadian Highway Bridge Design Code. CSA International, Toronto

⁹ CFEM 2006. Canadian Foundation Engineering Manual 4th Edition, Canadian Geotechnical Society 2006

Table 3: Summary of Organic materials in boreholes

Borehole I.D.	Materials Encountered	Elevation Range (m)
BH-2	Wood and Asphalt Fragments	128.1 – 127.4
	Wood Fragments and Organic Pockets	119.4 – 117.8
BH-3	Wood Fragments	127.4 – 126.8, 125.8 – 125.2
	Rootlets	124.3 – 121.7

Native soils below the embankment fills and clayey layer containing organics were generally competent and not considered to be a contributing factor (in terms of settlement) related to the poor performance of the highway. The investigation did not indicate the presence of any weak or compressible clayey layers below the highway fill embankment.

- The cohesive fill was generally thicker and less stiff (i.e. weaker) within the area of concern where previous distress was observed (Boreholes BH-1 and BH-2) compared to the stiffer cohesive fill encountered within the borehole located outside of the previously reported distressed area (Borehole BH-3).
- The results of grain size distribution testing on the cohesive embankment fills indicate the fill generally has a low susceptibility to frost heaving.
- Global stability analysis calculated a factor of safety of 1.4 against global instability. Shallow (surficial sloughing) failure surfaces along the upper portion of the embankment slope calculated factors of safety slightly above 1. When a temporary “saturated” condition within the upper portion of the fill is modelled, the factor of safety for shallow instability was calculated below 1.
- MH compared the original design highway profile against the most recent highway profile and indicates settlements may have occurred along this section of highway where the embankment fill thickness is the greatest. Asphalt pavement core samples collected at areas where the embankment fill thickness is the greatest were generally measured to be much thicker compared to other areas of the embankment. The thicker pavement measured at these areas (valleys where previous watercourse ran below the highway embankment) suggests that localized settlement has occurred over time and these areas have been padded / raised to maintain adequate rideability.

In summary, the factual information collected in 2020 indicates that the existing cohesive embankment fill is highly variable (both in composition and consistency), suggesting that the high fill embankment may not have been composed of consistent suitable material and may not have been adequately compacted in some areas. The lower strength / relative compaction of the fill materials (Boreholes BH-1 and BH-2) in addition to the presence of decaying organic materials and compressible nature of the clayey fill itself could be contributing to ongoing pavement cracking as it relates to long-term post-construction settlements that may have occurred and continue to occur along the Highway 405 EBL embankment. This settlement over time is confirmed by the comparison of the original and current highway profiles and the thicker asphalt measured in areas where the embankment thickness is greatest.

While it is acknowledged that there may be been significant contribution to past highway surface settlement and pavement cracking from the “less compacted” cohesive embankment fill (containing organics) and the presence of a thin layer of clayey soil containing organics below the embankment fill, it is expected that the majority of

consolidation settlement of the clayey materials has occurred. Although decomposition of the organic materials within and below the embankment fill may still be ongoing, there is no indication from the available data to suggest that a significant thickness or large pocket of organic material is present. Therefore, the risk of future large settlements of the highway is considered to be low and can likely be accommodated by regular maintenance activities, as evidenced over the past 50+ years.

Based on the results of the stability analyses, the calculated factor of safety against global instability is considered adequate. However, a factor of safety near 1 was calculated for shallow (surficial sloughing) failures in the upper portion of the slope where the geometry was measured to be steeper than 2H:1V. In addition, a factor of safety below 1 was calculated for a temporary saturated upper slope where the failure surface is consistent with the location of the previously observed shallow failure and pavement cracking on site.

Although the groundwater level is estimated to be near the culvert invert based on the borehole information, temporary perched water levels that could cause saturation of the upper portion of the slope (and subsequent instability) were observed during the field study in the previous Golder (2007) investigation. A possible cause of the accumulation of surface water / groundwater near the crest of the slope could be related to the storm sewer / catchbasins that were identified in the original design drawings but could not be verified on site. The presence and condition of the concrete / clay storm sewer pipe, joints and related catchbasins should be confirmed as any mitigation options presented herein may not be effective if the storm sewer is not performing as intended. If the storm sewer was removed or decommissioned, details of the removal and/or decommissioning should be provided, if available. It is possible that uncontrolled soil / water could be collecting and/or entering the pipe(s) or previous bedding soil could be acting as a preferred pathway for surface water / groundwater to collect and temporarily saturate the slope in this area, which could be directly related to the observed surficial slope failures and associated pavement cracking.

The remediation work that was shown to have been carried out in the 2007/2009 contract is considered to have improved drainage of surface water / groundwater in the upper portion of the slope and has lowered the risk for shallow instability. Although we are not aware of any reports of subsequent failures in this area since the remediation took place, there was an observation of cracking and local asphalt patching that took place in 2016. The most recent cracking in 2016 could be related to the factors previously discussed, and/or could be time dependant relaxation of the clayey fills since the initial failure, possibly influenced by the ability of the overlying pavement structure to temporarily “bridge” soil movements for a period of time.

5.2.1 Recommendations

Based on our review of the available information, we recommend that the area of concern be investigated further to confirm the presence, condition and performance of the storm sewer and catchbasins, or whether the storm sewer has been removed and if so, properly backfilled and/or decommissioned to prevent surface water / groundwater accumulation and saturation of the upper portion of the slope.

Assuming the storm sewer system has been completely removed or has been properly decommissioned, the following mitigation options may be considered for implementation into the upcoming contract documents.

Option 1 – Do Nothing: Given there is a low risk of global instability or future large settlements in the area of concern and the fact that the highway has been in operation for over 50 years, consideration could be given to rehabilitating this area as currently planned and repairing any future cracking / surficial sloughing at this localized area as required during regular maintenance activities;

Option 2 – Regrade Slope to 2H:1V: Flatten embankment slope to no steeper than 2H:1V as part of the widening / rehabilitation. Based on our site visit, the upper portion of the north (median side) embankment slope is at about 1.5H:1V and should be flattened as part of the proposed widening / rehabilitation.

MH has also indicated that the current survey drawings indicate another localized area on the south embankment slope near the area of concern is also steeper than 2H:1V and this slope should also be flattened. Any new embankment fill for the widening / re-grading should consist of OPSS.PROV Granular 'A' soil placed and compacted as per OPSS.PROV 206. Benching into the existing embankment should be in accordance with OPSD208.010. In areas where the embankment fill height is in excess of 8 m, consideration should be given to adding a mid-height berm/bench (min. 2 m wide) as per typical MTO practice; however, the space limitations and the presence of the median ditch and culvert may introduce challenges at this site.

Option 3 – Regrade Slope to 2H:1V using reinforced earth slope: Similar to Option 2; however, the near surface embankment slope soils could be reinforced with geogrid (placed along bottom of benched slope) to improve stability and erosion potential and lower the risk of future shallow failures (surficial sloughing) in this area. The surface of the regraded slopes could be covered with vegetation (seed and cover) or gravel sheeting within the upper half to control erosion and reduce the risk for future sloughing and shallow instability.

From a geotechnical / foundations perspective, the presence and performance of the storm sewer within the area of concern should be confirmed as it may influence the mitigation options proposed above. Alternatively, assuming the previous drainage improvements were carried out in this area as part of the 2007/2009 Contract, *Option 3 – Regrade Slope to 2H:1V using reinforced earth slope* is considered to be the preferred alternative.

6.0 CLOSURE

This technical memorandum was prepared by Mr. Carter Comish, E.I.T., geotechnical engineer-in-training and Ms. Manisha Ahuja, P.Eng., P.E., a geotechnical engineer with Golder. Mr. Kevin J. Bentley, P.Eng., an Associate and MTO Foundations Designated Contact with Golder, conducted an independent technical and quality control review of this memorandum.

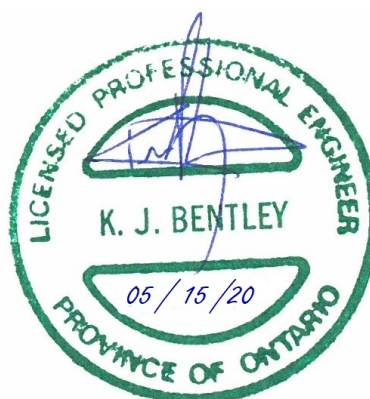
Golder Associates Ltd.



Carter Comish, E.I.T.
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Geotechnical Engineer



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Associate, MTO Foundations Designated Contact

CC/MA/KJB/ml

Attachments:

Drawing 1: Borehole location Plan and Soil Strata

Figure 1: Stability for Hwy 405 EBL North (Median) Embankment – Long term (Effective Stress) Conditions

Appendix A – Borehole Records from 2020 Investigation

List of Symbols and Abbreviations

Records of Boreholes BH-1 to BH-3

Appendix B – Geotechnical Laboratory Test Results

- Figure B-1 Grain Size distribution – Silty Sand (FILL)
- Figure B-2 Grain Size distribution – Silty Clay to Clayey Silt (FILL)
- Figure B-3 Plasticity Chart - Silty Clay to Clayey Silt (FILL)
- Figure B-4 Grain Size distribution – Silty Clay to Sandy Clayey Silt
- Figure B-5 Plasticity Chart - Silty Clay to Sandy Clayey Silt
- Figure B-6 Grain Size distribution – Clayey Silt to Sandy Silt (TILL)
- Figure B-7 Plasticity Chart – Clayey Silt to Sandy Silt (TILL)

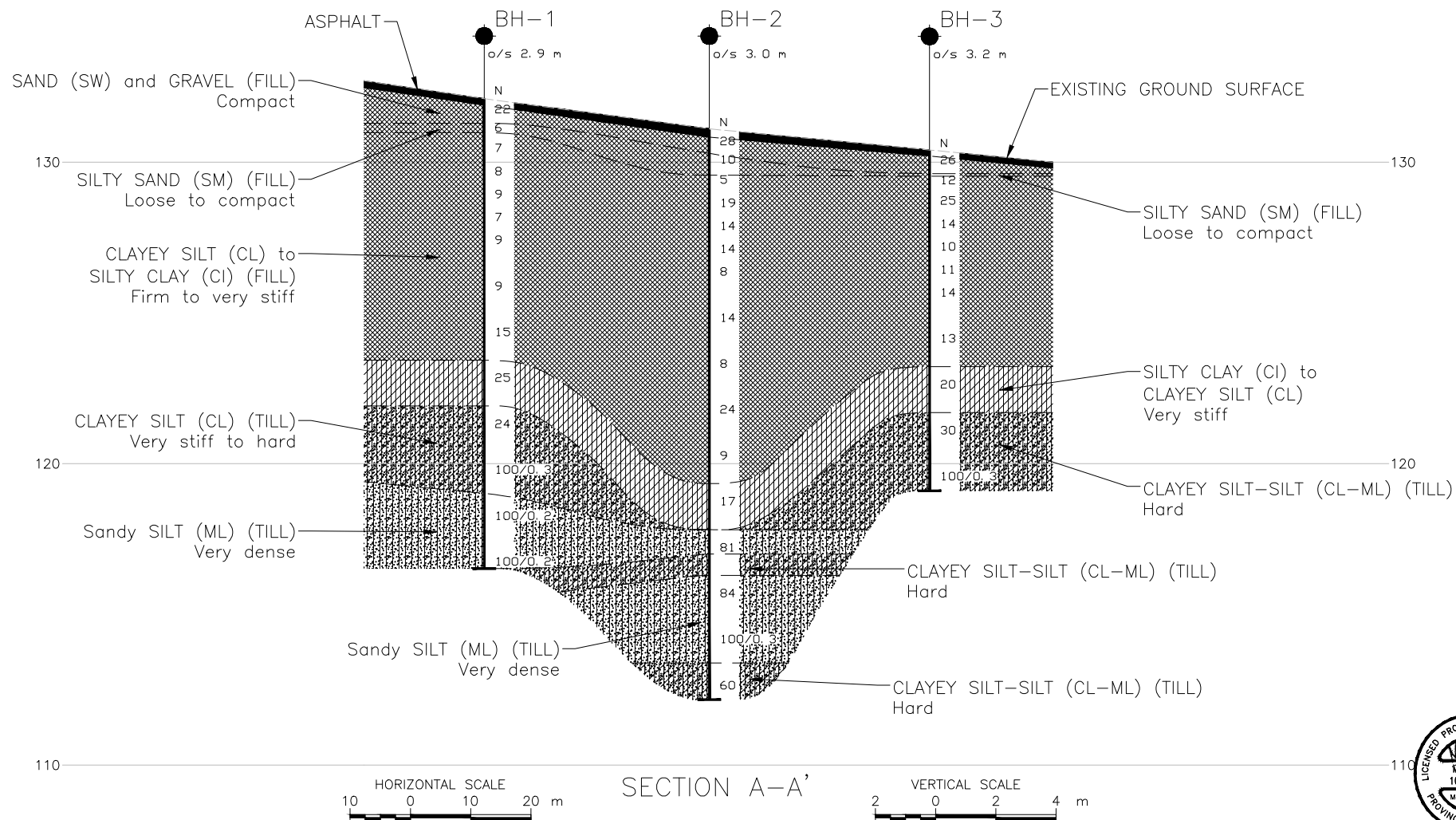
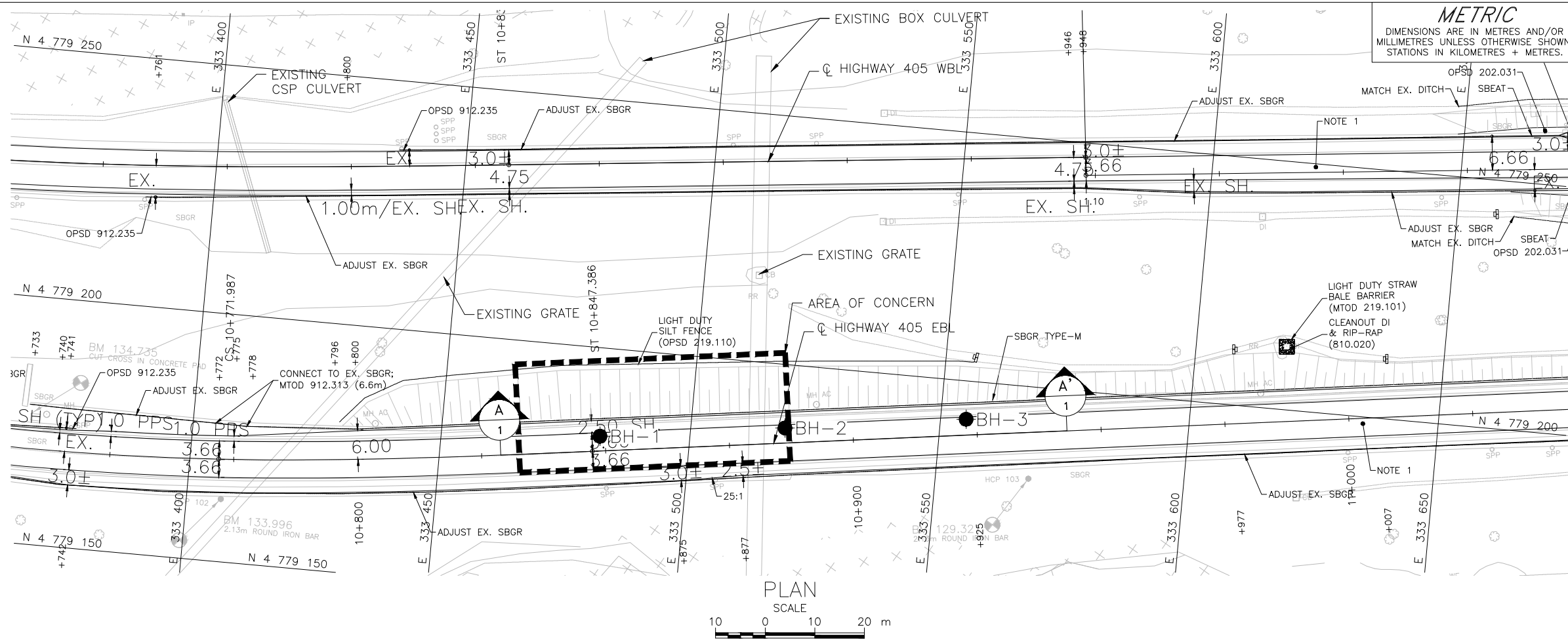
Appendix C – Slope Inspection and Photographs

Figure C1 to C4 Site Photographs

Slope Inspection Record

<https://golderassociates.sharepoint.com/sites/21998g/deliverables/wo30 - additional foundation investigation highway 405/technical memo/final/1786658 wo 30 highway 405 technical summary 2020may15.docx>

Drawing

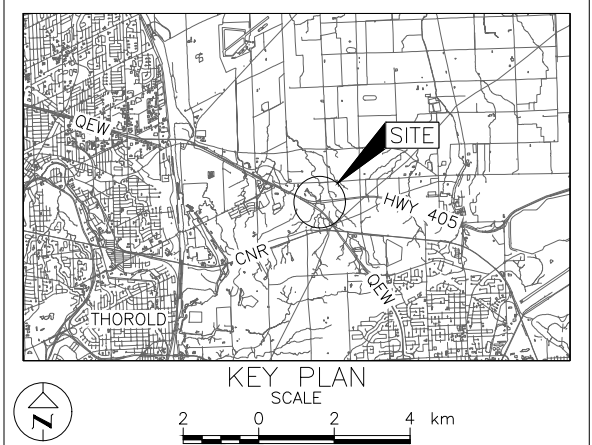


METRIC
DIMENSIONS ARE IN METRES AND/OR
MILLIMETRES UNLESS OTHERWISE SHOWN.
STATIONS IN KILOMETRES + METRES.

CONT No.
WP No.2112-19-00

HIGHWAY 405
EMBANKMENT INVESTIGATION
STA. 10+820 TO STA. 10+880
BOREHOLE LOCATIONS AND SOIL STRATA

SHEET



LEGEND

Borehole - Current Investigation
N Standard Penetration Test Value
16 Blows/0.3m unless otherwise stated
(Std. Pen. Test, 475 j/blow)

BOREHOLE CO-ORDINATES			
No.	ELEVATION	NORTHING	EASTING
BH-1	132.1	4779182.2	333481.9
BH-2	131.1	4779187.2	333518.9
BH-3	130.4	4779192.3	333555.1

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.

REFERENCE

Base plan, design plan and alignment provided in digital format by Morrison Hershfield, drawing file nos. x117116624_Base, X117116624_DESIGN and X117116624_ALIGN, received Mar. 23, 2020.

NO.	DATE	BY	REVISION				
Geocres No. 30M3-321							
HWY. 405			PROJECT NO. 1786658			DIST. CENTRAL	
SUBM'D. CC		CHKD. MA		DATE: 5/15/2020		SITE: .	
DRAWN: JM		CHKD. MA		APPD. KJB		DWG. 1	

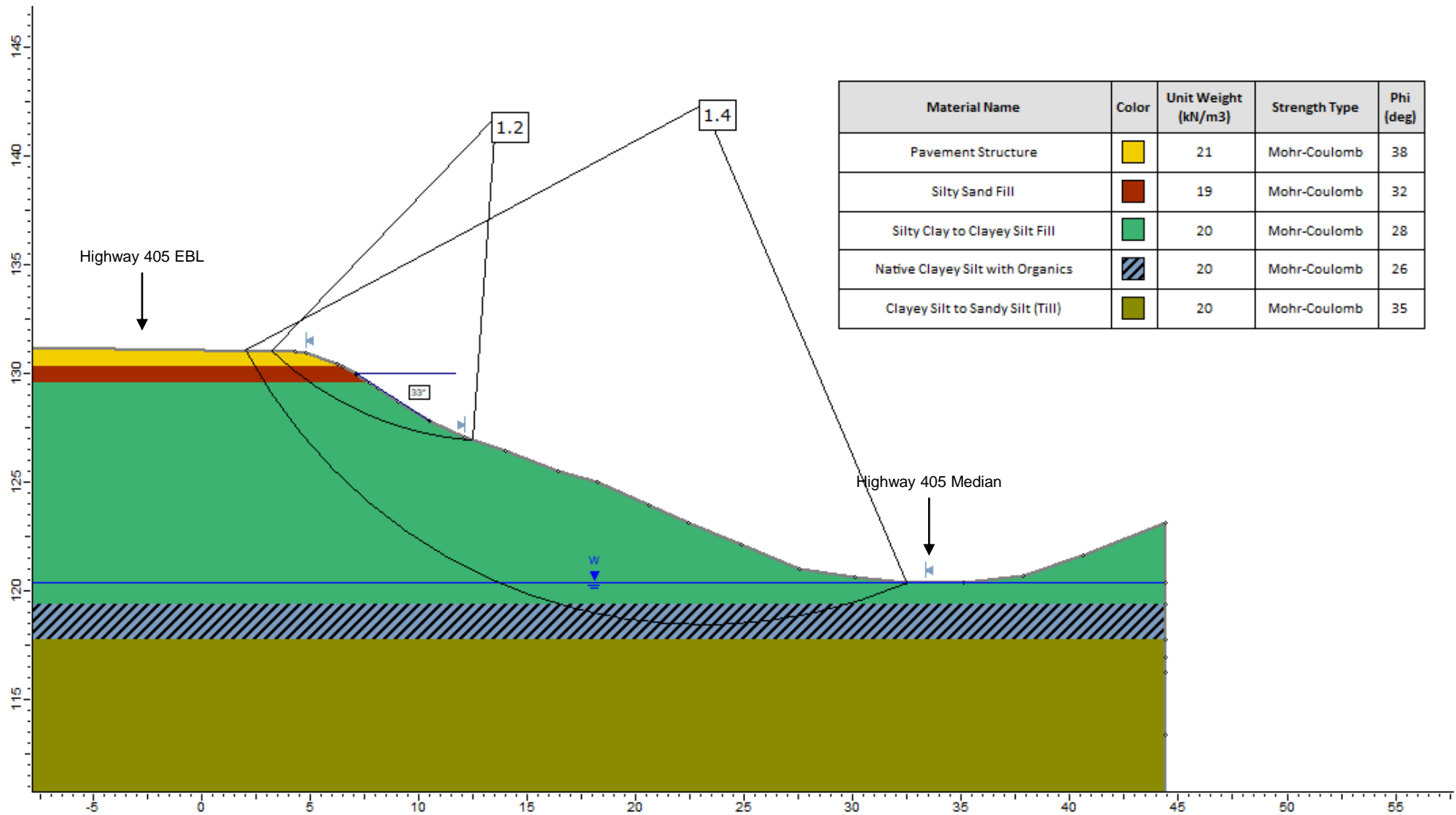


Figure



Highway 405 Embankment (STA. 10+820 to STA. 10+880) Slope Stability Analysis - Long Term (Effective Stress) Case

Figure 1



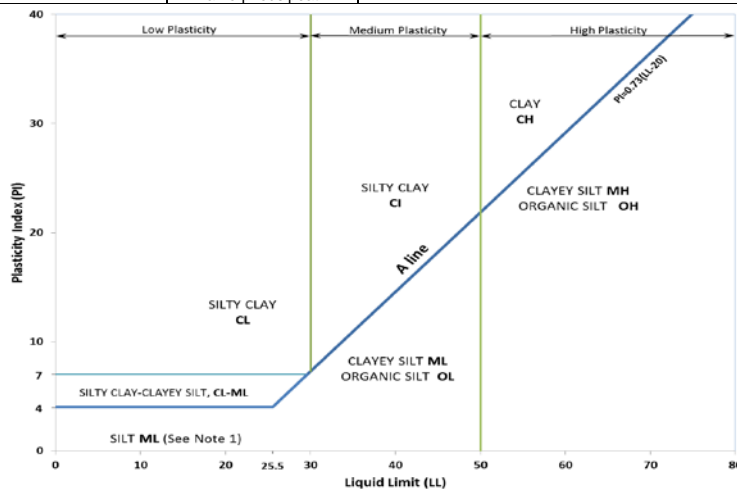
APPENDIX A

**Borehole Records from
2020 Investigation**

METHOD OF SOIL CLASSIFICATION

The Golder Associates Ltd. Soil Classification System is based on the Unified Soil Classification System (USCS)

Organic or Inorganic	Soil Group	Type of Soil		Gradation or Plasticity	$Cu = \frac{D_{60}}{D_{10}}$		$Cc = \frac{(D_{30})^2}{D_{10} \times D_{60}}$			Organic Content	USCS Group Symbol	Group Name		
INORGANIC (Organic Content ≤30% by mass)	COARSE-GRAINED SOILS (>50% by mass is larger than 0.075 mm)	GRAVELS (>50% by mass of coarse fraction is larger than 4.75 mm)	Gravels with ≤12% fines (by mass)	Poorly Graded	<4		≤1 or ≥3			≤30%	GP	GRAVEL		
				Well Graded	≥4		1 to 3				GW	GRAVEL		
			Gravels with >12% fines (by mass)	Below A Line	n/a						GM	SILTY GRAVEL		
				Above A Line	n/a						GC	CLAYEY GRAVEL		
		SANDS (≥50% by mass of coarse fraction is smaller than 4.75 mm)	Sands with ≤12% fines (by mass)	Poorly Graded	<6	≤1 or ≥3			SP		SAND			
				Well Graded	≥6	1 to 3			SW		SAND			
			Sands with >12% fines (by mass)	Below A Line	n/a						SM	SILTY SAND		
				Above A Line	n/a						SC	CLAYEY SAND		
		Organic or Inorganic	Soil Group	Type of Soil	Laboratory Tests	Field Indicators					Organic Content	USCS Group Symbol	Primary Name	
		INORGANIC (Organic Content ≤30% by mass)	FINE-GRAINED SOILS (≥50% by mass is smaller than 0.075 mm)	SILTS (Non-Plastic or Pl and LL plot below A-Line on Plasticity Chart below)	Liquid Limit <50	Rapid	None	None	>6 mm		N/A (can't roll 3 mm thread)	<5%	ML	SILT
Slow	None to Low					Dull	3mm to 6 mm	None to low	<5%	ML	CLAYEY SILT			
Slow to very slow	Low to medium					Dull to slight	3mm to 6 mm	Low	5% to 30%	OL	ORGANIC SILT			
Liquid Limit ≥50	Slow to very slow				Low to medium	Slight	3mm to 6 mm	Low to medium	<5%	MH	CLAYEY SILT			
	None			Medium to high	Dull to slight	1 mm to 3 mm	Medium to high	5% to 30%	OH	ORGANIC SILT				
	CLAYS (Pl and LL plot above A-Line on Plasticity Chart below)			Liquid Limit <30	None	Low to medium	Slight to shiny	~ 3 mm	Low to medium	0% to 30%	CL	SILTY CLAY		
Liquid Limit 30 to 50				None	Medium to high	Slight to shiny	1 mm to 3 mm	Medium	(see Note 2)	CI	SILTY CLAY			
Liquid Limit ≥50				None	High	Shiny	<1 mm	High		CH	CLAY			
HIGHLY ORGANIC SOILS (Organic Content >30% by mass)				Peat and mineral soil mixtures							30% to 75%	PT	SILTY PEAT, SANDY PEAT	
				Predominantly peat, may contain some mineral soil, fibrous or amorphous peat							75% to 100%		PEAT	



Note 1 – Fine grained materials with PI and LL that plot in this area are named (ML) SILT with slight plasticity. Fine-grained materials which are non-plastic (i.e. a PL cannot be measured) are named SILT.

Note 2 – For soils with <5% organic content, include the descriptor “trace organics” for soils with between 5% and 30% organic content include the prefix “organic” before the Primary name.

Dual Symbol — A dual symbol is two symbols separated by a hyphen, for example, GP-GM, SW-SC and CL-ML.

For non-cohesive soils, the dual symbols must be used when the soil has between 5% and 12% fines (i.e. to identify transitional material between “clean” and “dirty” sand or gravel.

For cohesive soils, the dual symbol must be used when the liquid limit and plasticity index values plot in the CL-ML area of the plasticity chart (see Plasticity Chart at left).

Borderline Symbol — A borderline symbol is two symbols separated by a slash, for example, CL/CI, GM/SM, CL/ML.

A borderline symbol should be used to indicate that the soil has been identified as having properties that are on the transition between similar materials. In addition, a borderline symbol may be used to indicate a range of similar soil types within a stratum.

ABBREVIATIONS AND TERMS USED ON RECORDS OF BOREHOLES AND TEST PITS

PARTICLE SIZES OF CONSTITUENTS

Soil Constituent	Particle Size Description	Millimetres	Inches (US Std. Sieve Size)
BOULDERS	Not Applicable	>300	>12
COBBLES	Not Applicable	75 to 300	3 to 12
GRAVEL	Coarse Fine	19 to 75 4.75 to 19	0.75 to 3 (4) to 0.75
SAND	Coarse Medium Fine	2.00 to 4.75 0.425 to 2.00 0.075 to 0.425	(10) to (4) (40) to (10) (200) to (40)
SILT/CLAY	Classified by plasticity	<0.075	< (200)

MODIFIERS FOR SECONDARY AND MINOR CONSTITUENTS

Percentage by Mass	Modifier
>35	Use 'and' to combine major constituents (i.e., SAND and GRAVEL)
> 12 to 35	Primary soil name prefixed with "gravelly, sandy, SILTY, CLAYEY" as applicable
> 5 to 12	some
≤ 5	trace

PENETRATION RESISTANCE

Standard Penetration Resistance (SPT), N:

The number of blows by a 63.5 kg (140 lb) hammer dropped 760 mm (30 in.) required to drive a 50 mm (2 in.) split-spoon sampler for a distance of 300 mm (12 in.). Values reported are as recorded in the field and are uncorrected.

Cone Penetration Test (CPT)

An electronic cone penetrometer with a 60° conical tip and a project end area of 10 cm² pushed through ground at a penetration rate of 2 cm/s. Measurements of tip resistance (q_t), porewater pressure (u) and sleeve frictions are recorded electronically at 25 mm penetration intervals.

Dynamic Cone Penetration Resistance (DCPT); 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

SAMPLES

AS	Auger sample
BS	Block sample
CS	Chunk sample
DD	Diamond Drilling
DO or DP	Seamless open ended, driven or pushed tube sampler – note size
DS	Denison type sample
GS	Grab Sample
MC	Modified California Samples
MS	Modified Shelby (for frozen soil)
RC	Rock core
SC	Soil core
SS	Split spoon sampler – note size
ST	Slotted tube
TO	Thin-walled, open – note size (Shelby tube)
TP	Thin-walled, piston – note size (Shelby tube)
WS	Wash sample

SOIL TESTS

w	water content
PL , w _p	plastic limit
LL , w _L	liquid limit
C	consolidation (oedometer) test
CHEM	chemical analysis (refer to text)
CID	consolidated isotropically drained triaxial test ¹
CIU	consolidated isotropically undrained triaxial test with porewater pressure measurement ¹
D _R	relative density (specific gravity, G _s)
DS	direct shear test
GS	specific gravity
M	sieve analysis for particle size
MH	combined sieve and hydrometer (H) analysis
MPC	Modified Proctor compaction test
SPC	Standard Proctor compaction test
OC	organic content test
SO ₄	concentration of water-soluble sulphates
UC	unconfined compression test
UU	unconsolidated undrained triaxial test
V (FV)	field vane (LV-laboratory vane test)
γ	unit weight

1. Tests anisotropically consolidated prior to shear are shown as CAD, CAU.

NON-COHESIVE (COHESIONLESS) SOILS

Compactness²

Term	SPT 'N' (blows/0.3m) ¹
Very Loose	0 to 4
Loose	4 to 10
Compact	10 to 30
Dense	30 to 50
Very Dense	>50

- SPT 'N' in accordance with ASTM D1586, uncorrected for the effects of overburden pressure.
- Definition of compactness terms are based on SPT 'N' ranges as provided in Terzaghi, Peck and Mesri (1996). Many factors affect the recorded SPT 'N' value, including hammer efficiency (which may be greater than 60% in automatic trip hammers), overburden pressure, groundwater conditions, and grain size. As such, the recorded SPT 'N' value(s) should be considered only an approximate guide to the soil compactness. These factors need to be considered when evaluating the results, and the stated compactness terms should not be relied upon for design or construction.

Field Moisture Condition

Term	Description
Dry	Soil flows freely through fingers.
Moist	Soils are darker than in the dry condition and may feel cool.
Wet	As moist, but with free water forming on hands when handled.

COHESIVE SOILS

Consistency

Term	Undrained Shear Strength (kPa)	SPT 'N' ^{1,2} (blows/0.3m)
Very Soft	<12	0 to 2
Soft	12 to 25	2 to 4
Firm	25 to 50	4 to 8
Stiff	50 to 100	8 to 15
Very Stiff	100 to 200	15 to 30
Hard	>200	>30

- SPT 'N' in accordance with ASTM D1586, uncorrected for overburden pressure effects; approximate only.
- SPT 'N' values should be considered ONLY an approximate guide to consistency; for sensitive clays (e.g., Champlain Sea clays), the N-value approximation for consistency terms does NOT apply. Rely on direct measurement of undrained shear strength or other manual observations.

Water Content

Term	Description
w < PL	Material is estimated to be drier than the Plastic Limit.
w ~ PL	Material is estimated to be close to the Plastic Limit.
w > PL	Material is estimated to be wetter than the Plastic Limit.

LIST OF SYMBOLS

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

I. GENERAL

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

II. STRESS AND STRAIN

γ	shear strain
Δ	change in, e.g. in stress: $\Delta \sigma$
ε	linear strain
ε_v	volumetric strain
η	coefficient of viscosity
ν	Poisson's ratio
σ	total stress
σ'	effective stress ($\sigma' = \sigma - u$)
σ'_{vo}	initial effective overburden stress
$\sigma_1, \sigma_2, \sigma_3$	principal stress (major, intermediate, minor)
σ_{oct}	mean stress or octahedral stress $= (\sigma_1 + \sigma_2 + \sigma_3)/3$
τ	shear stress
u	porewater pressure
E	modulus of deformation
G	shear modulus of deformation
K	bulk modulus of compressibility

III. SOIL PROPERTIES

(a) Index Properties

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

(a) Index Properties (continued)

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

(b) Hydraulic Properties

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

(c) Consolidation (one-dimensional)

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

(d) Shear Strength

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

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

Notes: 1
2

$$\tau = c' + \sigma' \tan \phi'$$

$$\text{shear strength} = (\text{compressive strength})/2$$

PROJECT <u>1786658</u>		RECORD OF BOREHOLE No BH-1		1 OF 2 METRIC	
W.P. <u>2112-19-00</u>		LOCATION <u>N 4779182.2; E 333481.9 NAD83 MTM ZONE 10 (LAT. 43.151951; LONG. -79.147349)</u>		ORIGINATED BY <u>CC</u>	
DIST <u> </u> HWY <u>405</u>		BOREHOLE TYPE <u>Power Auger; 210 mm O.D., 150 mm I.D. Hollow Stem Auger; Tricone</u>		COMPILED BY <u>CC</u>	
DATUM <u>Geodetic</u>		DATE <u>March 17, 18, 2020</u>		CHECKED BY <u>MA</u>	

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT γ kN/m³	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						
132.1	GROUND SURFACE						20 40 60 80 100		10 20 30					
0.0	ASPHALT (230 mm)													
0.2	SAND (SW) and GRAVEL (FILL) Compact Grey Moist		1	SS	22									
131.3														
131.0	Silty SAND (SM), trace to some clay, trace gravel (FILL) Loose Reddish brown Moist		2A 2B	SS	6								5 13 49 33	
1.1														
	CLAYEY SILT (CL), trace to some sand, trace gravel (FILL) Firm to stiff Brown Moist		3	SS	7									
			4	SS	8									
			5	SS	9									
			6	SS	7									
			7	SS	9									
			8	SS	9									
			9	SS	15									
123.4														
8.7	CLAYEY SILT (CL), some sand, trace gravel Very stiff Brown Moist		10	SS	25									
121.9														
10.2	CLAYEY SILT (CL), some sand, trace to some gravel (TILL) Very stiff to hard Reddish brown Moist		11	SS	24								3 11 66 20	
			12	SS	100/0.3									
119.0														
13.1	Sandy SILT (ML), trace to some clay, trace gravel (TILL) Very dense Reddish brown Moist		13	SS	100/0.2								4 15 74 7	

Continued Next Page

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

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PROJECT <u>1786658</u>		RECORD OF BOREHOLE No BH-1				2 OF 2 METRIC	
W.P. <u>2112-19-00</u>		LOCATION <u>N 4779182.2; E 333481.9 NAD83 MTM ZONE 10 (LAT. 43.151951; LONG. -79.147349)</u>				ORIGINATED BY <u>CC</u>	
DIST <u> </u> HWY <u>405</u>		BOREHOLE TYPE <u>Power Auger; 210 mm O.D., 150 mm I.D. Hollow Stem Auger; Tricone</u>				COMPILED BY <u>CC</u>	
DATUM <u>Geodetic</u>		DATE <u>March 17, 18, 2020</u>				CHECKED BY <u>MA</u>	

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa					WATER CONTENT (%)				
								20	40	60	80	100	W _p	W	W _L		
	--- CONTINUED FROM PREVIOUS PAGE ---																
116.5	END OF BOREHOLE		14	SS	100/0.2												
15.6	NOTES: 1. Water level could not be determined due to use of drilling mud. 2. Borehole was dry prior to addition of drilling mud at a depth of 3.66 m.																

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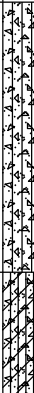
PROJECT 1786658		RECORD OF BOREHOLE No BH-2		1 OF 2 METRIC	
W.P. 2112-19-00		LOCATION N 4779187.2; E 333518.9 NAD83 MTM ZONE 10 (LAT. 43.151995; LONG. -79.146894)		ORIGINATED BY CC	
DIST HWY 405		BOREHOLE TYPE Power Auger; 210 mm O.D., 150 mm I.D. Hollow Stem Auger; Tricone		COMPILED BY CC	
DATUM Geodetic		DATE March 18, 2020		CHECKED BY MA	

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT					PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%)			
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa					WATER CONTENT (%)				GR	SA	SI	CL
								<div><div></div><div></div><div></div><div></div><div></div></div> <div>20 40 60 80 100</div>					<div><div></div><div></div><div></div><div></div><div></div></div> <div>W_P W W_L</div>							
131.1	GROUND SURFACE																			
0.0	ASPHALT (240 mm)																			
0.2	SAND (SW) and GRAVEL (FILL)		1A	SS	28															
130.3	Compact Grey Moist		1B																	
0.8	Silty SAND (SM), trace to some clay, trace gravel (FILL)		2	SS	10													3 60 27 10		
129.6	Compact Reddish brown Moist		3	SS	5															
1.5	SILTY CLAY (CI), trace to some sand, trace gravel (FILL)																			
	Firm to very stiff Brown Moist		4	SS	19													0 6 54 40		
	- Wood and asphalt fragments from 3.05 m to 3.66 m		5	SS	14															
			6	SS	14															
			7	SS	8															
			8	SS	14															
		9	SS	8													0 9 51 40			
		10	SS	24																
		11	SS	9																
119.3	Sandy CLAYEY SILT (CL), trace wood fragments, organic pockets																			
11.7	Very stiff Dark brown Moist		12	SS	17												0 21 65 14			
117.8	Sandy SILT (ML), trace gravel, trace clay (TILL)																			
13.3	Very dense Reddish brown Moist		13A	SS	81															
117.0	CLAYEY SILT-SILT (CL-ML), trace to some sand, trace gravel (TILL)		13B																	
14.1	Hard Reddish brown Moist																0 8 76 12			
116.3																				
14.8																				

Continued Next Page

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

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PROJECT <u>1786658</u>		RECORD OF BOREHOLE No BH-2				2 OF 2 METRIC								
W.P. <u>2112-19-00</u>		LOCATION <u>N 4779187.2; E 333518.9 NAD83 MTM ZONE 10 (LAT. 43.151995; LONG. -79.146894)</u>				ORIGINATED BY <u>CC</u>								
DIST <u> </u> HWY <u>405</u>		BOREHOLE TYPE <u>Power Auger; 210 mm O.D., 150 mm I.D. Hollow Stem Auger; Tricone</u>				COMPILED BY <u>CC</u>								
DATUM <u>Geodetic</u>		DATE <u>March 18, 2020</u>				CHECKED BY <u>MA</u>								
SOIL PROFILE			SAMPLES			DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT NATURAL MOISTURE CONTENT LIQUID LIMIT			UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL		
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	SHEAR STRENGTH kPa		WATER CONTENT (%)				
	--- CONTINUED FROM PREVIOUS PAGE ---							20 40 60 80 100	W _p W W _L	10 20 30				
	Sandy SILT (ML), trace to some gravel, trace to some clay (TILL) Very dense Reddish brown Moist		14	SS	84		115							
								114						
113.4			15	SS	100/0.3									
17.7	CLAYEY SILT-SILT (CL-ML), trace sand (TILL) Hard Reddish brown Moist							113						
112.2			16	SS	60									
18.9	END OF BOREHOLE NOTES: 1. Water level could not be determined due to use of drilling mud. 2. Borehole was dry prior to addition of drilling mud at a depth of 3.66 m.													

PROJECT		1786658		RECORD OF BOREHOLE No BH-3				1 OF 1 METRIC						
W.P.		2112-19-00		LOCATION		N 4779192.3; E 333555.1 NAD83 MTM ZONE 10 (LAT. 43.152039; LONG. -79.146449)		ORIGINATED BY CC						
DIST		HWY 405		BOREHOLE TYPE		Power Auger; 57 mm I.D. Hollow Stem Auger		COMPILED BY CC						
DATUM		Geodetic		DATE		March 18, 2020		CHECKED BY MA						
SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT		PLASTIC LIMIT W _p	NATURAL MOISTURE CONTENT W	LIQUID LIMIT W _L	UNIT WEIGHT γ kN/m ³	REMARKS & GRAIN SIZE DISTRIBUTION (%)
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES			SHEAR STRENGTH kPa						
130.4	GROUND SURFACE													
0.0	ASPHALT (180 mm)													
0.2	SAND (SW) and GRAVEL (FILL)													
129.6	Compact Grey Moist		1A	SS	26									
			1B											
0.9	Silty SAND (SM), trace to some clay, trace gravel (FILL)		2	SS	12									
	Compact Reddish brown Moist		3	SS	25									
	SILTY CLAY (CI), trace to some sand, trace to some gravel (FILL)													
	Stiff to very stiff Reddish brown to brown to grey Moist		4	SS	14									
	- Trace wood fragments from 3.0 m to 3.6 m		5	SS	10									
			6	SS	11									
	- Trace wood fragments from 4.57 m to 5.18 m		7	SS	14									
	- Rootlets from 6.10 m to 8.23 m		8	SS	13									
123.2	SILTY CLAY (CI), trace to some sand, trace gravel, contains trace rootlets													
7.2	Very stiff Brown to reddish brown Moist		9	SS	20									
121.7	CLAYEY SILT (CL), some sand, some gravel (TILL)													
8.7	Hard Reddish brown Moist		10	SS	30									
120.2	CLAYEY SILT-SILT CL-ML, slight plasticity, some sand, some gravel (TILL)													
10.2	Hard Reddish brown Moist		11	SS	100/0.3									
119.1														
113	END OF BOREHOLE													
NOTES:														
1. Open borehole was dry on completion of drilling.														

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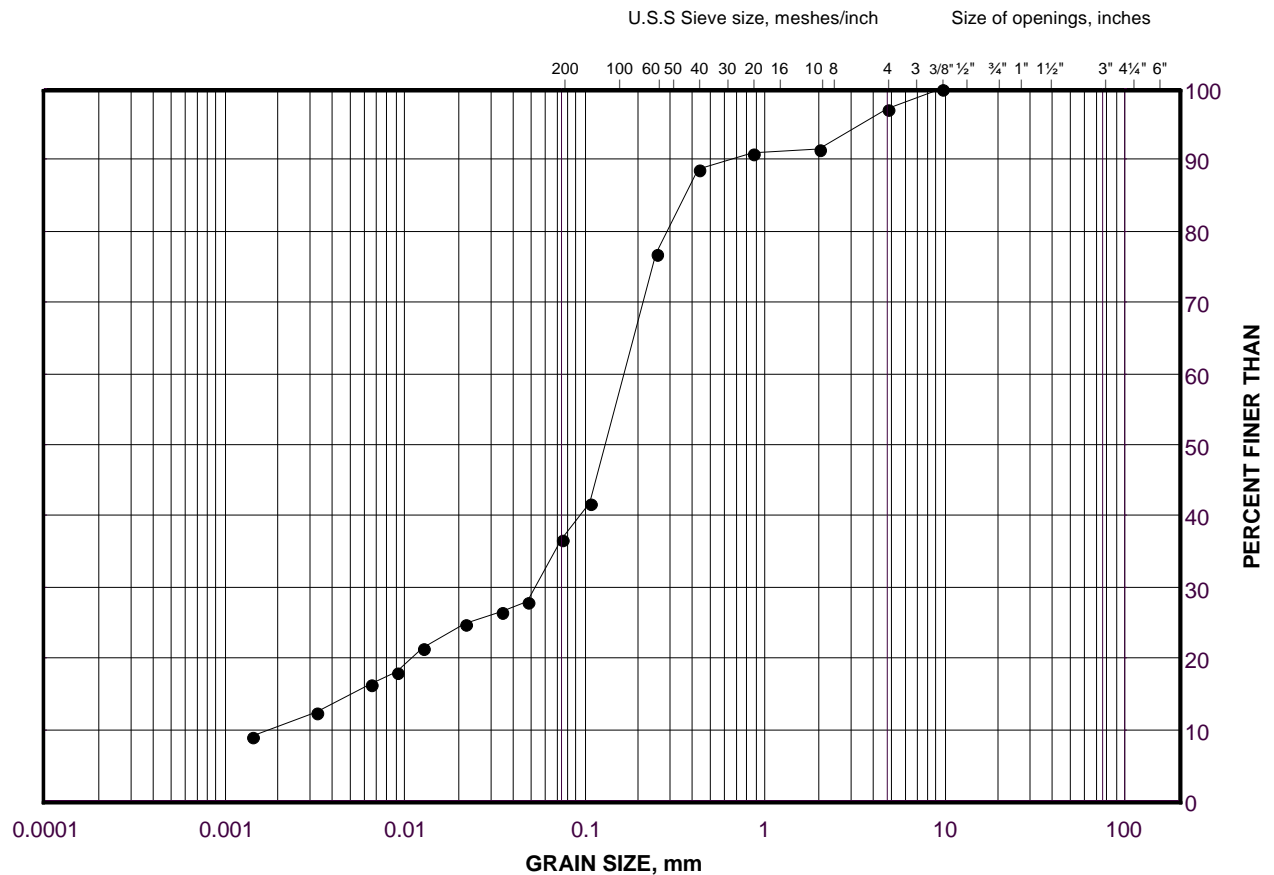
APPENDIX B

Geotechnical Laboratory Test Results

GRAIN SIZE DISTRIBUTION

Silty SAND (SM) (FILL)

FIGURE B1



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

LEGEND

SYMBOL	Borehole	SAMPLE	ELEVATION(m)
•	BH-2	2	129.9

Project Number: 1786658

Checked By: CC/MA

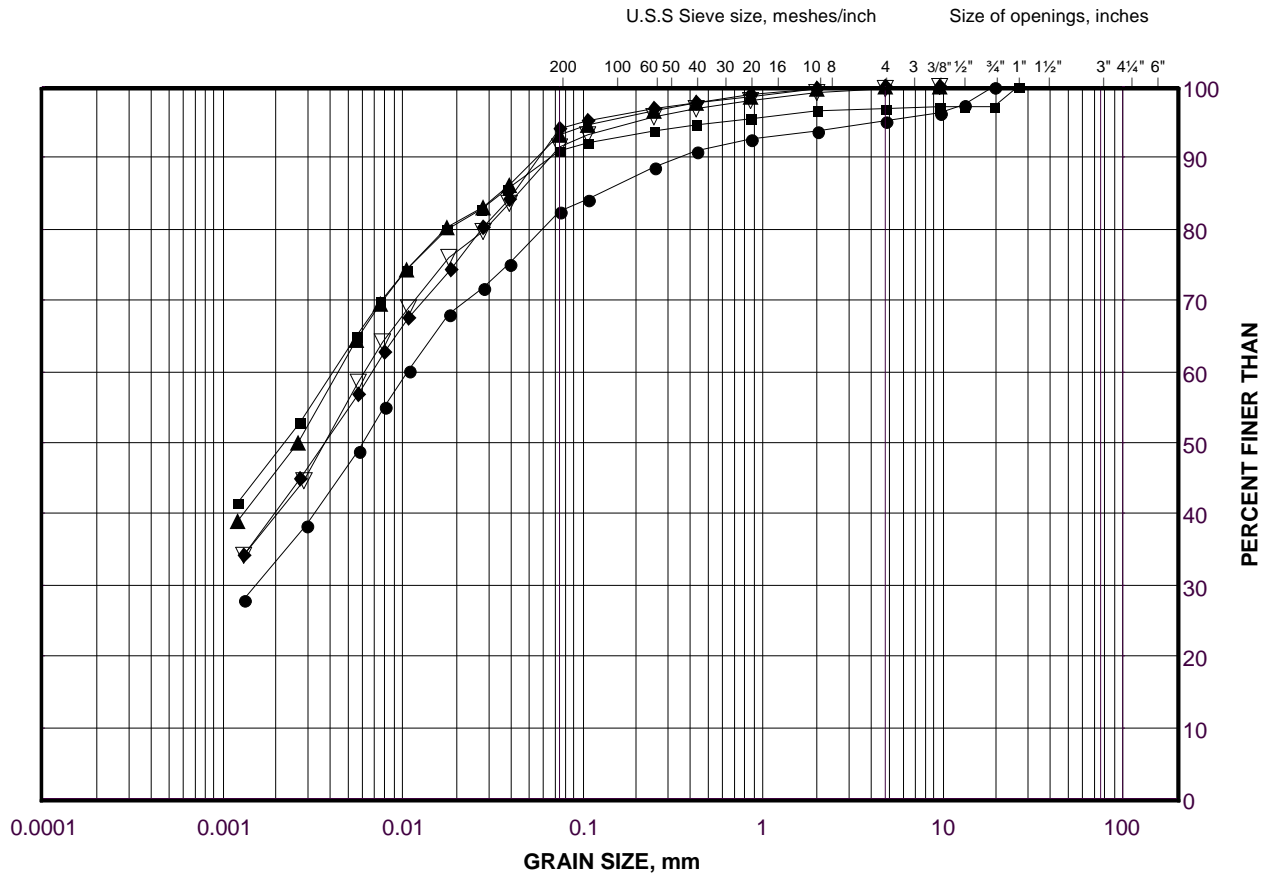
Golder Associates

Date: 15-Apr-20

GRAIN SIZE DISTRIBUTION

SILTY CLAY (CI) to CLAYEY SILT (CL) (FILL)

FIGURE B2



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

LEGEND

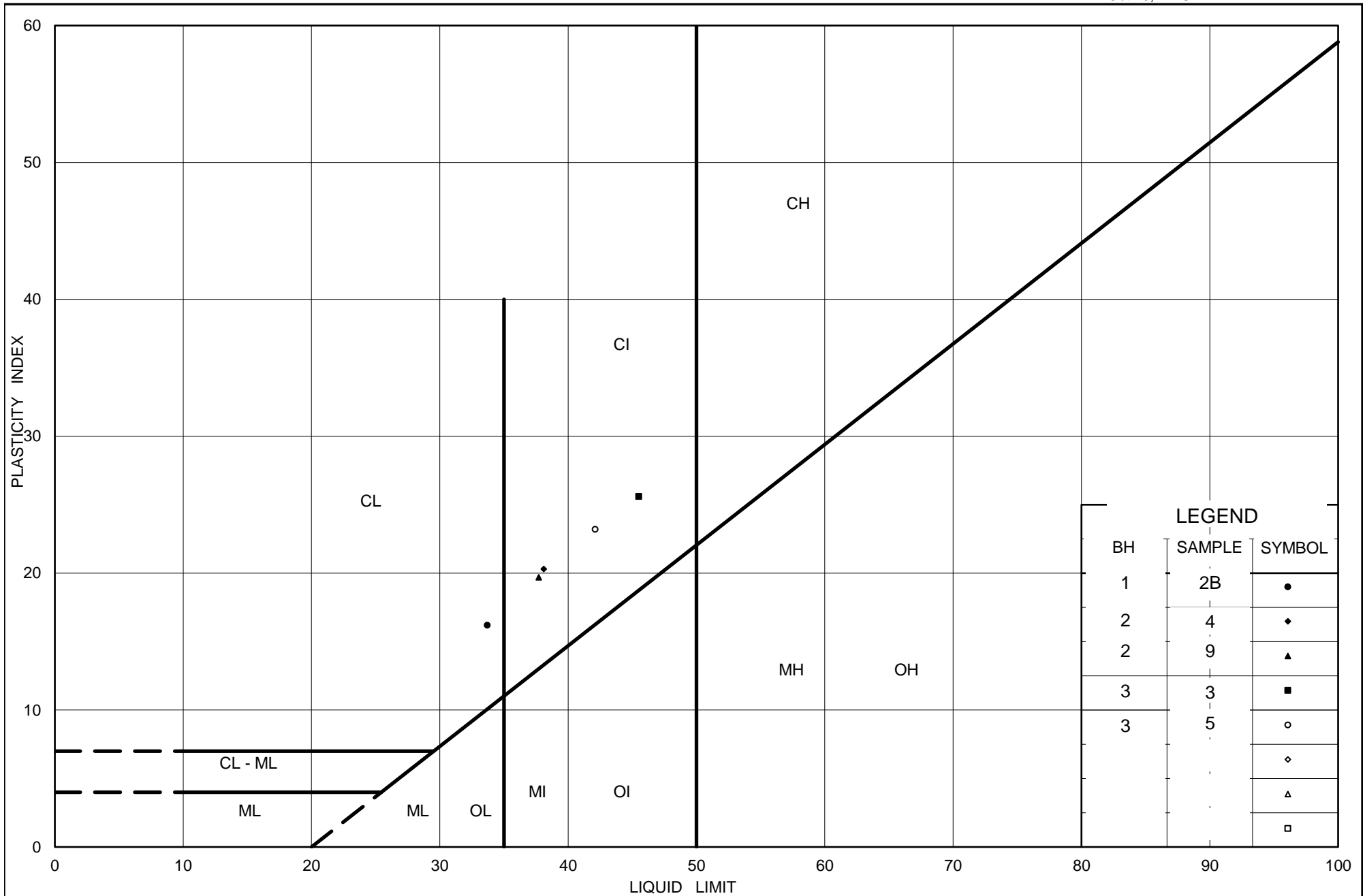
SYMBOL	Borehole	SAMPLE	ELEVATION(m)
●	BH-1	2B	130.8
■	BH-3	3	128.6
◆	BH-2	4	128.5
▲	BH-3	5	127
▽	BH-2	9	123.2

Project Number: 1786658

Checked By: CC/MA

Golder Associates

Date: 15-Apr-20



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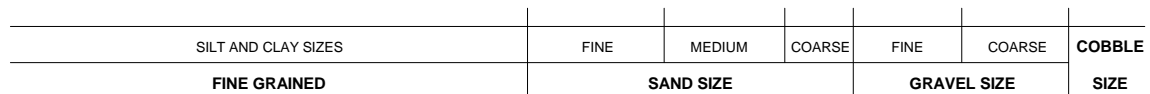
PLASTICITY CHART SILTY CLAY (CI) to CLAYEY SILT (CL) (FILL)

Figure No. B3

Project No. 1786658

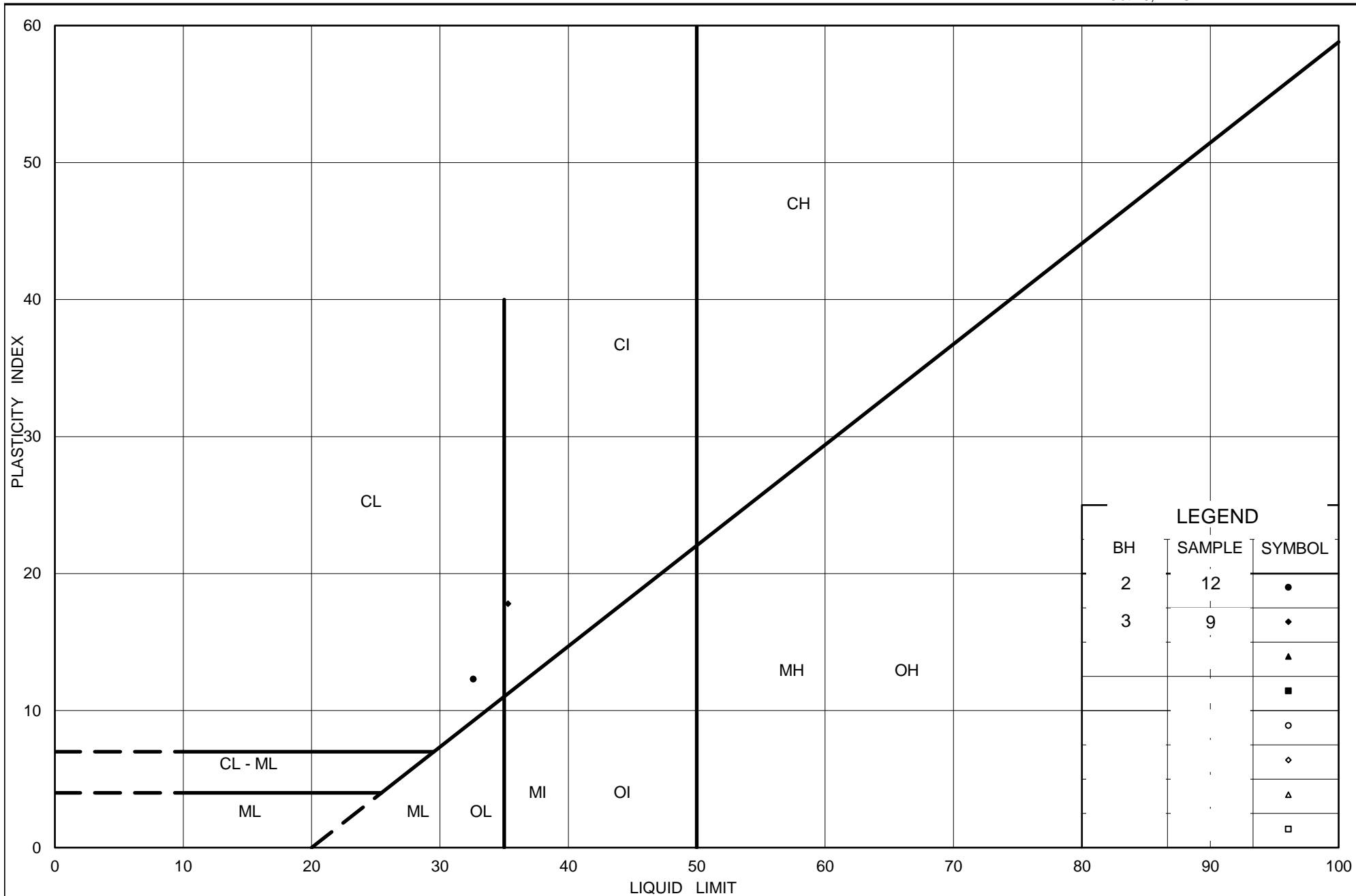
Checked By: CC/MA

FIGURE B4



SYMBOL	Borehole	SAMPLE	ELEVATION(m)
●	BH-2	12	118.6
■	BH-3	9	122.5

Date: 15-Apr-20



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Ontario

PLASTICITY CHART SILTY CLAY (CI) to Sandy CLAYEY SILT (CL)

Figure No. B5

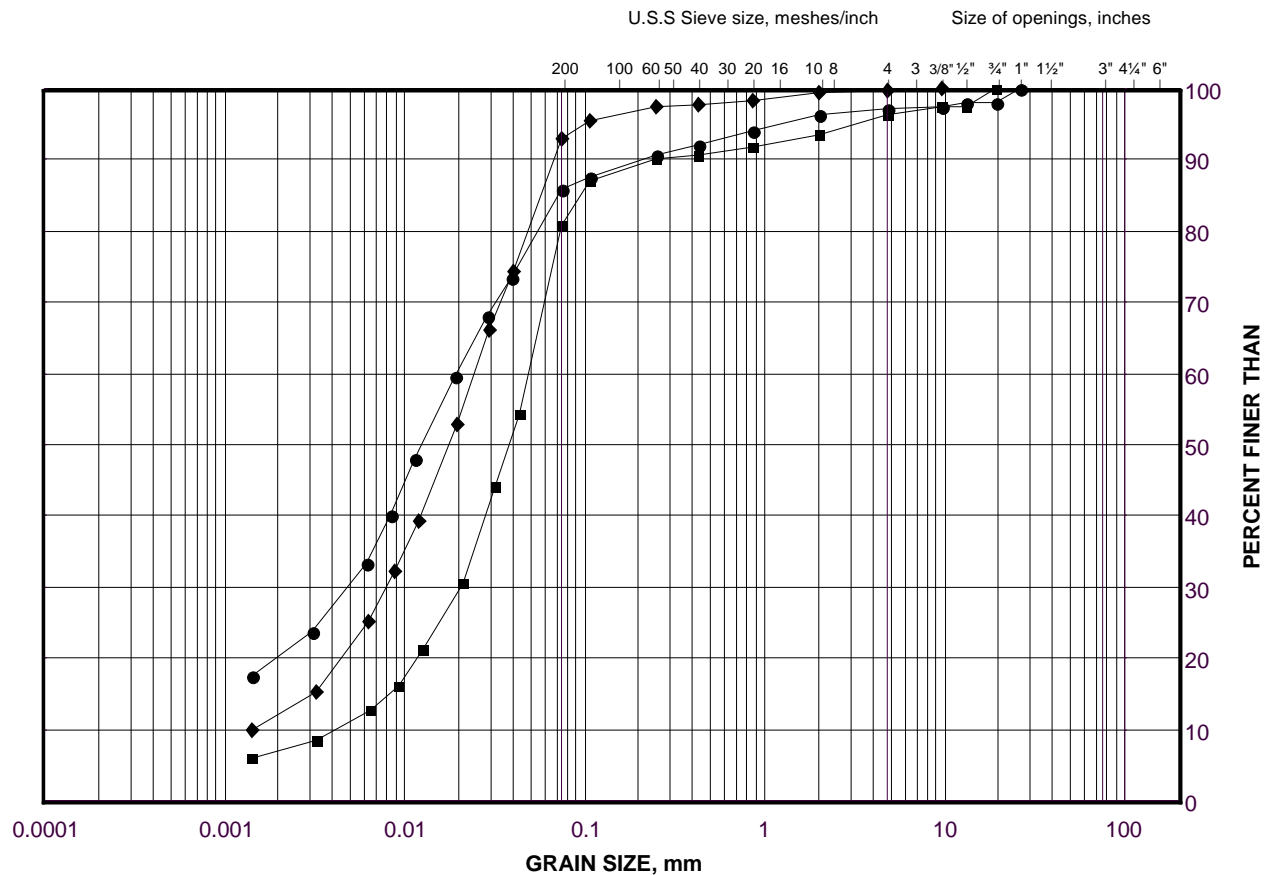
Project No. 1786658

Checked By: CC/MA

GRAIN SIZE DISTRIBUTION

CLAYEY SILT-SILT (CL-ML) to Sandy SILT (ML) (TILL)

FIGURE B6



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

LEGEND

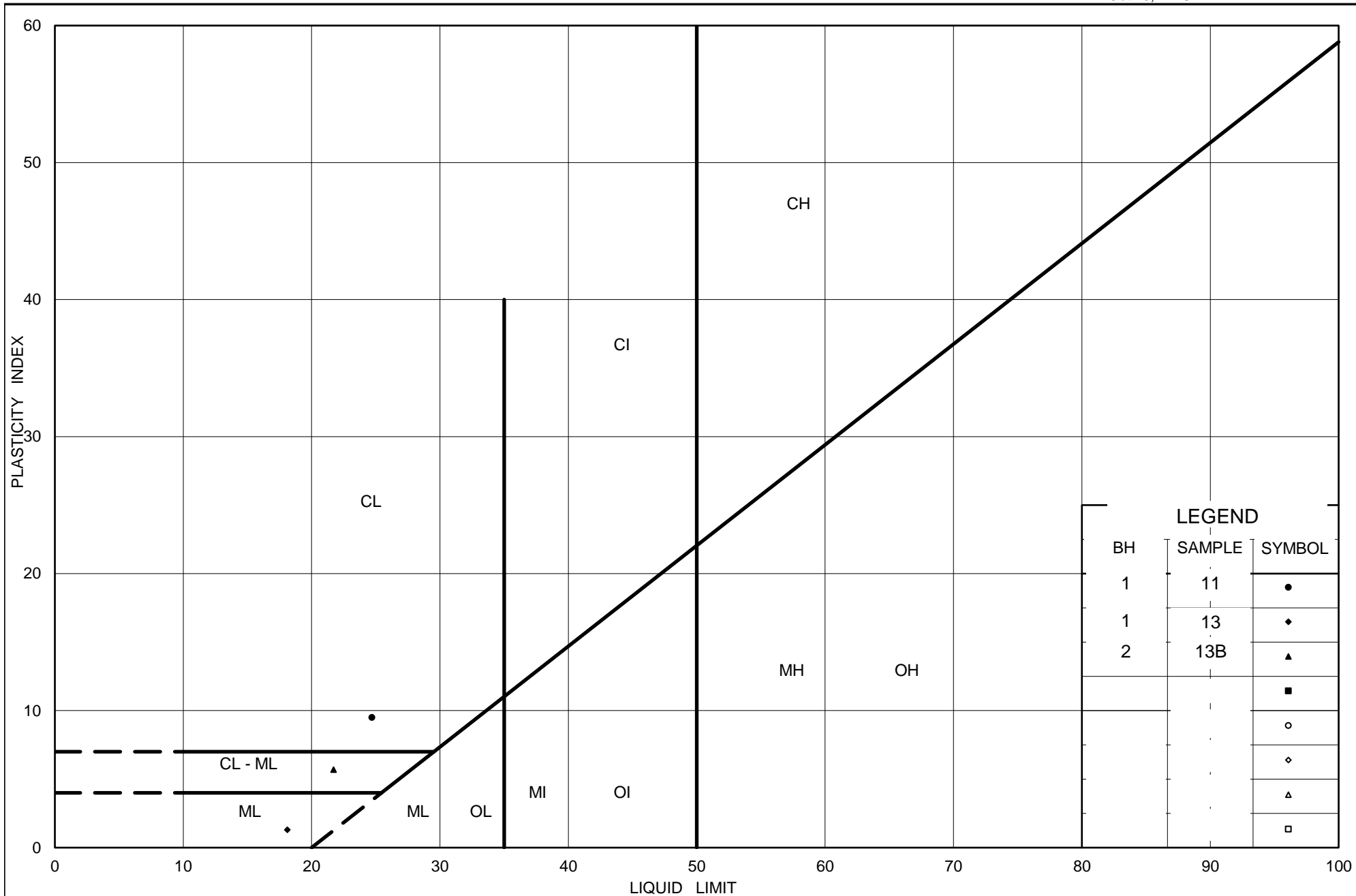
SYMBOL	Borehole	SAMPLE	ELEVATION(m)
●	BH-1	11	121.1
■	BH-1	13	118.2
◆	BH-2	13B	116.9

Project Number: 1786658

Checked By: CC/MA

Golder Associates

Date: 15-Apr-20



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PLASTICITY CHART CLAYEY SILT-SILT (CL-ML) to Sandy SILT (ML) (TILL)

Figure No. B7

Project No. 1786658

Checked By: CC/MA

APPENDIX C

Slope Inspection and Photographs



PROJECT

**Highway 405 Embankment Investigation from
STA 10+820 to STA 10+880**

TITLE

**From Top of Slope on Highway 405
Eastbound Looking Northwards**



GOLDER

PROJECT No. 1786658

FILE No. ----

DESIGN CC 15/04/2020

SCALE NTS

REV. v.1

CADD -- --

CHECK MA

REVIEW

FIGURE C1



PROJECT

**Highway 405 Embankment Investigation from
STA 10+820 to STA 10+880**

TITLE

**From Toe of Slope at Catch Basin Looking
Southwards towards Crest of Highway 405
Eastbound**



GOLDER

PROJECT No. 1786658

FILE No. ----

DESIGN CC 15/04/2020

SCALE NTS

REV. v.1

CADD -- --

CHECK MA

REVIEW

FIGURE C2



PROJECT

**Highway 405 Embankment Investigation from
STA 10+820 to STA 10+880**

TITLE

Median Embankment Slope - Facing West



GOLDER

PROJECT No. 1786658			FILE No. ----		
DESIGN	CC	15/04/2020	SCALE	NTS	REV. v.1
CADD	-- --		FIGURE C3		
CHECK	MA				
REVIEW					



PROJECT

**Highway 405 Embankment Investigation from
STA 10+820 to STA 10+880**

TITLE

Median Embankment Slope - Facing East



GOLDER

PROJECT No. 1786658			FILE No. ----		
DESIGN	CC	15/04/2020	SCALE	NTS	REV. v.1
CADD	-- --		FIGURE C4		
CHECK	MA				
REVIEW					

Highway 405 EBL Station 10+820 to 10+880: Slope Inspection Record	
File Name/No.	1786658 WO 30
Inspection Date:	March 19, 2020
Weather:	Clear, 4°C
Inspected By:	Carter Comish, E.I.T.
Site Location:	North Slope Embankment, Highway 405 Eastbound, STA 10+820 to STA 10+880, Fort Erie, Ontario
Watershed:	Niagara
Property Ownership:	Ministry of Transportation (MTO)
Slope Data:	Slope is approximately 10.5 m tall. The top 4 m (measured vertically) of the slope face is inclined at approximately 1.5H:1V near Station 10+880. The remaining areas west and the lower portion of the slope face is inclined at approximately 2H:1V. Four sections measured using GPS unit.
Slope Drainage:	Drainage ditch located at the slope toe. Two catch basins were observed within the ditch bringing surface water into the culverts running below the embankment to north of the embankment.
Slope Soil Stratigraphy:	Approximately 1.5 m of pavement structure consisting of asphalt, sand and gravel and silty sand. Slope face appears to be covered with Granular 'A' from the slope crest to approximately 4 m below the slope crest (measured vertically). The lower portion of the slope face is covered with topsoil and grass / vegetation.
Water Course Features:	Two streams running from the south side of the Highway 405 embankment to north of the embankment through two concrete box culverts underlying the embankment.
Vegetation Cover:	Top 4 m of the slope face has minimal vegetation, bottom of slope and drainage ditch are well vegetated with tall grasses.

Highway 405 EBL Station 10+820 to 10+880: Slope Inspection Record	
Structures:	Two concrete box culverts allowing two streams to pass underneath Highway 405. One CSP culvert draining a small stream from the north side of the Highway 405 westbound embankment into the drainage ditch between the eastbound and westbound lanes observed
Erosion Features:	N/A
Slope Slide Features:	Minor sluffing of surficial Granular 'A' on upper portion of the slope when conducting inspection.