May 2016

GEOTECHNICAL INVESTIGATION

Proposed Observation Deck
Fort Mississauga Stabilization Phase II
Project#:PRO00808
142 Front Street
Niagara-On-The-Lake, Ontario

Submitted to:
Mr. Jovan Vukotic, P.Eng., Senior Project Manager
PARSONS
625 Cochrane Drive, Suite 500
Markham, Ontario
L3R 9R9

REPORT

Report Number: 1538986-R01

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1.0 INTRODUCTION

This report presents the results of the geotechnical investigation carried out for the design of the proposed observation deck as part of the Fort Mississauga Stabilization Phase II in Niagara-On-The-Lake, Ontario. The location of the site is shown on the Key Plan, Figure 1. The purpose of the work was to explore the subsurface soil and groundwater conditions in the area of the proposed observation deck and provide geotechnical engineering recommendations for the design of the proposed observation deck foundations. Authorization to proceed with the investigation was provided by Mr. Jovan Vukotic, P.Eng., of PARSONS in an email dated September 29, 2015. The scope of work for this assignment did not include examination of or recommendations related to the stability of the natural slopes or fortification embankments. Important information on the limitations of this report is attached.

2.0 SITE DESCRIPTION AND GEOLOGY

The Fort Mississauga site is located at 142 Front Street in Niagara-On-The-Lake, Ontario. Based on the Terms of Reference provided to Golder Associates Ltd. (Golder), the observation deck is proposed to be located within the perimeter fortification berm at the north end of the Fort and would overlook the Niagara River to the north. Based on the photograph provided in the Terms of Reference for Golder's assignment and our observations on site, the earth fortification embankment is some 2 to 3 metres in height. It is understood that the observation deck will be constructed with a steel frame and wooden deck and founded on shallow spread footings or concrete caissons drilled through the fortification embankment. The site is surrounded by a golf course with residential buildings around the perimeter. Based on project correspondence, relatively low height retaining walls, on the order of 2.5 metres or less in total height, may be constructed as part of the site landscaping features.

The site lies in the physiographic region described in "The Physiography of Southern Ontario, Third Edition" by Chapman and Putnam[1] as the Iroquois Plain, which commonly consists of clay derived from the underlying Queenston Formation. Based on the Ontario Geological Survey Map 2496 entitled "Quaternary Geology of the Niagara-Welland Area", the surficial soils in the immediate vicinity of the site consist primarily of glaciolacustrine deeper water clay and silt.

3.0 FIELD PROCEDURES

Field work was carried out on October 5, 2015 during which time two boreholes were drilled through the fortification embankment at the approximate locations shown on the Location Plan, Figure 1. The boreholes were drilled using a track-mounted drill rig supplied and operated by a specialist drilling contractor under the direction of a member of our engineering staff. The subsurface conditions encountered in the boreholes are shown in detail on the attached Record of Borehole sheets.

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

Standard penetration testing and sampling was carried out in the boreholes at suitable intervals of depth using 38 millimetre inside diameter split spoon sampling equipment. All of the samples obtained during the investigation were transported to our laboratory for further examination and testing. The soil stratigraphy encountered in the boreholes and the results of the field and laboratory testing are shown on the Record of Borehole sheets.

Groundwater levels were observed in the boreholes during drilling and the encountered groundwater levels are shown on the Record of Borehole sheets. Upon completion of drilling and sampling, the boreholes were backfilled in accordance with Ontario Regulation (O.Reg.) 903, as amended.

Members of our engineering staff designated the borehole locations in the field, obtained underground utility clearances, monitored the drilling, logged the boreholes and cared for the samples obtained. The ground surface elevations at the borehole locations were referenced to the Drawing provided by PARSONS referenced to geodetic datum.

4.0 SUBSURFACE CONDITIONS

The subsurface conditions encountered in the boreholes drilled at the site are shown in detail on the attached Record of Borehole sheets. The following discussion has been simplified in terms of major soil strata for the purposes of geotechnical design. The soil boundaries discussed in this report and illustrated on the Record of Borehole sheets have been inferred from non-continuous samples and observations of drilling resistance and represent a transition from one soil type to another and should not necessarily be interpreted to represent exact planes of geological change. Further, subsurface conditions may vary between and beyond the borehole locations. The subsurface conditions encountered in the boreholes generally consisted of embankment fill materials, clayey silt, gravelly sand and silty clay.

4.1 Soil Conditions

Boreholes 15-01 and 15-02 encountered cohesive embankment fill materials at the ground surface to depths of about 3.1 metres. The fill generally consisted of silty clay and clayey silt with some organic matter. The fill had measured N values as determined by the standard penetration testing from 5 to 17 blows per 0.3 metres. According to ASTM D1586, the SPT resistance, or N value, is defined as the number of blows required by a 63.5 kilogram hammer dropped from a height of 760 millimetres to drive a split-spoon sampler a distance of 300 millimetres, after an initial 150 millimetres of penetration. The fill exhibited water contents ranging from 10 to 22 per cent.

The silty clay fill had corresponding plastic and liquid limits of 19 and 27 per cent, respectively, based on one Atterberg limits determination, the results of which are shown on Figure 3. A grain size distribution curve for a sample of the silty clay fill is provided on Figure 2.

Clayey silt was encountered beneath the fill in both boreholes. Borehole 15-02 was terminated in the clayey silt after exploring the layer for about 1.4 metres. The clayey silt was 2.4 metres thick in borehole 15-01. The clayey silt had measured N values ranging from 9 to 22 blows per 0.3 metres. The clayey silt samples exhibited water contents ranging from 20 to 32 per cent with an average of about 23 per cent.

A layer of gravelly sand was encountered beneath the clayey silt in borehole 15-01 and was 0.8 metres thick. The gravelly sand layer had N values of 6 and 22 blows per 0.3 metres and water contents of 5 and 12 per cent.

Silty clay was encountered beneath the gravelly sand in borehole 15-01. Borehole 15-01 was terminated in the silty clay after exploring the layer for about 0.4 metres. The silty clay had a measured N value of 6 blows per 0.3 metres with a water content of 27 per cent.

4.2 Groundwater Conditions

Groundwater levels were observed in the boreholes during and upon completion of drilling. Both boreholes contained no free water upon completion of drilling on October 5, 2015. Groundwater conditions at the site should be expected to fluctuate seasonally and in response to significant precipitation events.

5.0 DISCUSSION

This section of the report provides our recommendations related to the geotechnical aspects of design of the proposed observation deck at Fort Mississauga in Niagara-On-The-Lake, Ontario. It should be noted that the interpretation and recommendations provided are intended for use only by the design engineer. Where comments are made on construction, they are provided only to highlight those aspects which could affect the design of the project. Those requiring information on construction should make their own interpretation of the factual information provided as it may affect equipment selection, proposed construction methods and scheduling.

Based on the information provided to Golder, the observation deck is proposed to be primarily located within the historic perimeter fortification berm at the north end of the Fort and would overlook the Niagara River to the north. A small section of the deck may extend over the outside slope of the historic fortification berm in the plan shape of a triangle. The earth fortification embankment is some 6 to 7 metres in height. It is understood that the observation deck would be constructed either with a steel frame and wooden deck and founded on shallow spread footings or concrete caissons drilled through the fortification embankments. An alternative scheme was also under consideration whereby:

- caissons foundations would be constructed to support vertical steel posts, installed at 3 metres centre-to-centre spacing;
- pre-fabricated panels would be installed between each of these posts to retain granular backfill;
- the backfill height for such a scheme would be nominal (approximately 1 to 1.5 metres above the existing grades);
- the steel posts would be fully connected and restrained at the top by a reinforced concrete beam; and
- at least three of the foundation posts along each of the two platform outside edges would be constructed inside of the fortification berm crest.

Information regarding the conceptual foundation loads or designs was not available for preparation of this report and should be reviewed prior to finalizing this report. Further, the scope of work for this report did not include a detailed evaluation of slope stability for the historic fortification berms, slopes below the berms or evaluations of the lateral displacements of retaining structures or foundations subject to lateral loading. If the existing slopes are to be regraded in excess of the nominal amount of fill that might be placed for the observation platform (less than about 3 cubic metres), the stability of the slopes and lateral loading of foundations should be evaluated in detail.

5.1 Foundations

Based on the conditions encountered in the boreholes, the proposed observation deck may be founded on conventional spread and/or strip footings or drilled caissons.

5.1.1 Shallow Foundations

The foundations for the proposed observation deck or associated structures can be founded on spread/strip footings bearing on the native stiff to very stiff clayey silt at least 1.2 metres below the ground surface or below approximate elevation 275.8 metres using a factored geotechnical resistance at Ultimate Limit States (ULS) of 225 kilopascals and a geotechnical resistance at Serviceability Limit States (SLS) of 150 kilopascals. The SLS value corresponds to an estimated total settlement of 25 millimetres. All footings should be provided with a minimum of 1.2 metres of earth cover or thermal equivalent for frost protection purposes. A minimum footing width of 0.6 metres has been assumed. Once final foundation dimensions and loads are defined, estimates of the potential settlement should be reviewed for consistency with the SLS resistance provided above.

Resistance to lateral forces/sliding between the concrete spread/strip footings and the native, undisturbed subsoil should be calculated in accordance with Section 6.7.5 of the Canadian Highway Bridge Design Code (CHBDE). Assuming that the founding soils are not loosened/disturbed during excavation and footing construction, an angle of friction between the mass cast-in-place concrete and the clayey silt founding soils of 27° and corresponding unfactored coefficient of friction, tan δ, of 0.51 may be used for design.

The founding soils are sensitive to disturbance and loosening due to water seepage and/or ponding and construction equipment or foot traffic when damp to wet. Placement of a concrete working slab (on the order of 75 to 100 millimetres thick) will be required at the base of the excavations for the footing areas. Exposure without protection using the working slab may result in loosening or softening of the founding soils. The cleaned excavation base should be inspected by a qualified geotechnical engineer prior to placing the working slab. It is recommended that the footing excavations be carried out such that the final 0.5 metres of excavation is completed with the geotechnical personnel on site and the working slab placed immediately after footing inspection.

5.1.2 Deep Foundations

Given the fortification embankment fill heights, it may not be practical to use spread foundations bearing on native soils for the observation deck. The foundations for the proposed observation deck could be founded on drilled caissons. Drilled, cast-in-place, concrete caissons founded within the stiff to very stiff clayey silt could be considered for support of the observation deck. For design, the table below provides factored axial geotechnical resistances at ULS and unfactored resistance at SLS for 0.8 and 1.2 metre diameter caissons drilled to a minimum depth of two caisson diameters below the frost penetration depth or two diameters into the native clayey silt, whichever is greater. The SLS values correspond to 25 millimetres of settlement.

Caisson Diameter (m)	**Toe Resistance**	
	Factored ULS (kN)	**SLS (kN)**
0.8	900	600
1.2	1650	1100

Temporary liners would be required to support the sides of the caisson holes through the existing fill materials and to permit inspection and cleaning. The recommended spacing between the caissons should be at least three caisson diameters. The contractor’s methods and equipment should be capable of extracting cobbles and boulders.

For the purposes of small-diameter and relatively shallow depth drilled foundations, the ultimate lateral resistance may be based on the passive earth pressure coefficients provided below. In the case of individual caissons, that act much like soldier piles for temporary excavation support, the effective width of the passive earth pressure zone may be taken as three times the drilled foundation diameter provided that the caissons are separated by a distance of more than 3 times the diameter. To limit short and long term lateral displacements of such foundations, an appropriate resistance factor of about 0.3 should be applied to the passive earth resistance calculated as indicated below; however, without completing a detailed assessment, the magnitude of such displacements remains uncertain.

5.2 Lateral Earth Pressures

The lateral pressures acting on the proposed low-height retaining walls will depend on the type and method of placement of the backfill materials, on the nature of the soils behind the backfill, on the freedom of lateral movement of the structure and on the drainage conditions behind the walls. The new retaining walls are considered to be unrestrained and allow lateral yielding and, therefore, active earth pressures may be used in the geotechnical design of the structures. For unrestrained walls, the pressures are based on the granular drainage layer, clayey backfill and native clayey silt behind the walls and the following parameters (unfactored) may be assumed for preliminary evaluation and design:

	GRANULAR DRAINAGE LAYER	MISCELLANEOUS Clay Fill	 Clayey Silt
Soil unit weight:	21 kN/m³	19 kN/m³	20 kN/m³
Internal Angle of Friction, ϕ, degrees	30 degrees	27 degrees	28 degrees
Coefficients of lateral earth pressure:			
Active, K_a	0.33	0.40	0.38
Passive, K_p	3.0	2.6	2.7
At Rest, K_o	0.50	0.54	0.55

It should be noted that the above design parameters assume level backfill and ground surface behind the wall. The lateral earth pressure coefficients should be adjusted if there is sloping ground at the back of the wall. For example, if the slope on the passive resistance side of the wall slopes downward and away from the wall at an angle of about 26 degrees below horizontal (approximately 2 horizontal to 1 vertical slope ratio), the passive earth pressure coefficient provided above will be reduced to approximately 1.0. If the backfill materials are not free-draining and provided with drainage outlets, water pressures should also be included in the design. Under such conditions, Golder should be contacted to provide appropriate recommendations once the retaining wall locations, dimensions and backfill materials are more fully defined.

5.3 Fill Materials and Placement

Any retaining wall backfill materials or new fills placed for raising grades should consist of imported granular soils conforming to Ontario Provincial Standard Specifications (OPSS) Granular A or Granular B gradation requirements. These materials should be placed in loose lifts not exceeding 300 millimetres thickness and be compacted to at least 95 per cent of their maximum dry density as determined through the laboratory water-content density relations test ASTM D698 (“standard Proctor” compaction test). In addition, new fill materials should be placed only after stripping off topsoil and any loose or deleterious soils and after inspection of the subgrade by an appropriately qualified geotechnical technician or engineer. Where new fill must mate with existing slopes, the existing slopes should be prepared by “benching” in accordance with Ontario Provincial Standard Drawing (OPSD) 208.010. If the boundary between new fill materials and existing slopes is not benched, a preferential plane for movement of the new fill materials can be created leading to poor future performance.

6.0 GEOTECHNICAL INSPECTIONS AND TESTING

A regular program of geotechnical inspections and materials testing should be carried out during construction to confirm that the conditions encountered are consistent with the results of the boreholes, to determine that the intent of the design recommendations provided are being met and that the various project and material specifications are consistently achieved.

The factual data, interpretation and recommendations in this report pertain to a specific project as described in the report and are not applicable to any other project or site location. If the project is modified in concept, location or elevation, or if the project is not initiated within twelve months of the date of the report, Golder Associates Ltd. should be given an opportunity to confirm that the recommendations are still valid.

We trust that this report provides sufficient information for your present requirements. Should any point require clarification please contact this office.

GOLDER ASSOCIATES LTD.

LICENSED PROFESSIONAL ENGINEER
Brett
B. R. THORNER
100206922
May 11/16
PROVINCE OF ONTARIO

Brett Thorner, P.Eng.
Geotechnical Engineer

Storer J. Boone, Ph.D., P.Eng.
Principal

BT/DB/SJB/cr

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Standard of Care: Golder Associates Ltd. (Golder) has prepared this report in a manner consistent with that level of care and skill ordinarily exercised by members of the engineering and science professions currently practising under similar conditions in the jurisdiction in which the services are provided, subject to the time limits and physical constraints applicable to this report. No other warranty, expressed or implied is made.

Basis and Use of the Report: This report has been prepared for the specific site, design objective, development and purpose described to Golder by the Client. The factual data, interpretations and recommendations pertain to a specific project as described in this report and are not applicable to any other project or site location. Any change of site conditions, purpose, development plans or if the project is not initiated within eighteen months of the date of the report may alter the validity of the report. Golder can not be responsible for use of this report, or portions thereof, unless Golder is requested to review and, if necessary, revise the report.

The information, recommendations and opinions expressed in this report are for the sole benefit of the Client. No other party may use or rely on this report or any portion thereof without Golder's express written consent. If the report was prepared to be included for a specific permit application process, then upon the reasonable request of the client, Golder may authorize in writing the use of this report by the regulatory agency as an Approved User for the specific and identified purpose of the applicable permit review process. Any other use of this report by others is prohibited and is without responsibility to Golder. The report, all plans, data, drawings and other documents as well as all electronic media prepared by Golder are considered its professional work product and shall remain the copyright property of Golder, who authorizes only the Client and Approved Users to make copies of the report, but only in such quantities as are reasonably necessary for the use of the report by those parties. The Client and Approved Users may not give, lend, sell, or otherwise make available the report or any portion thereof to any other party without the express written permission of Golder. The Client acknowledges that electronic media is susceptible to unauthorized modification, deterioration and incompatibility and therefore the Client can not rely upon the electronic media versions of Golder's report or other work products.

The report is of a summary nature and is not intended to stand alone without reference to the instructions given to Golder by the Client, communications between Golder and the Client, and to any other reports prepared by Golder for the Client relative to the specific site described in the report. In order to properly understand the suggestions, recommendations and opinions expressed in this report, reference must be made to the whole of the report. Golder can not be responsible for use of portions of the report without reference to the entire report.

Unless otherwise stated, the suggestions, recommendations and opinions given in this report are intended only for the guidance of the Client in the design of the specific project. The extent and detail of investigations, including the number of test holes, necessary to determine all of the relevant conditions which may affect construction costs would normally be greater than has been carried out for design purposes. Contractors bidding on, or undertaking the work, should rely on their own investigations, as well as their own interpretations of the factual data presented in the report, as to how subsurface conditions may affect their work, including but not limited to proposed construction techniques, schedule, safety and equipment capabilities.

Soil, Rock and Groundwater Conditions: Classification and identification of soils, rocks, and geologic units have been based on commonly accepted methods employed in the practice of geotechnical engineering and related disciplines. Classification and identification of the type and condition of these materials or units involves judgment, and boundaries between different soil, rock or geologic types or units may be transitional rather than abrupt. Accordingly, Golder does not warrant or guarantee the exactness of the descriptions.

Special risks occur whenever engineering or related disciplines are applied to identify subsurface conditions and even a comprehensive investigation, sampling and testing program may fail to detect all or certain subsurface conditions. The environmental, geologic, geotechnical, geochemical and hydrogeologic conditions that Golder interprets to exist between and beyond sampling points may differ from those that actually exist. In addition to soil variability, fill of variable physical and chemical composition can be present over portions of the site or on adjacent properties. The professional services retained for this project include only the geotechnical aspects of the subsurface conditions at the site, unless otherwise specifically stated and identified in the report. The presence or implication(s) of possible surface and/or subsurface contamination resulting from previous activities or uses of the site and/or resulting from the introduction onto the site of materials from off-site sources are outside the terms of reference for this project and have not been investigated or addressed.

Soil and groundwater conditions shown in the factual data and described in the report are the observed conditions at the time of their determination or measurement. Unless otherwise noted, those conditions form the basis of the recommendations in the report. Groundwater conditions may vary between and beyond reported locations and can be affected by annual, seasonal and meteorological conditions. The condition of the soil, rock and groundwater may be significantly altered by construction activities (traffic, excavation, groundwater level lowering, pile driving, blasting, etc.) on the site or on adjacent sites. Excavation may expose the soils to changes due to wetting, drying or frost. Unless otherwise indicated the soil must be protected from these changes during construction.

Sample Disposal: Golder will dispose of all uncontaminated soil and/or rock samples 90 days following issue of this report or, upon written request of the Client, will store uncontaminated samples and materials at the Client's expense. In the event that actual contaminated soils, fills or groundwater are encountered or are inferred to be present, all contaminated samples shall remain the property and responsibility of the Client for proper disposal.

Follow-Up and Construction Services: All details of the design were not known at the time of submission of Golder's report. Golder should be retained to review the final design, project plans and documents prior to construction, to confirm that they are consistent with the intent of Golder's report.

During construction, Golder should be retained to perform sufficient and timely observations of encountered conditions to confirm and document that the subsurface conditions do not materially differ from those interpreted conditions considered in the preparation of Golder's report and to confirm and document that construction activities do not adversely affect the suggestions, recommendations and opinions contained in Golder's report. Adequate field review, observation and testing during construction are necessary for Golder to be able to provide letters of assurance, in accordance with the requirements of many regulatory authorities. In cases where this recommendation is not followed, Golder's responsibility is limited to interpreting accurately the information encountered at the borehole locations, at the time of their initial determination or measurement during the preparation of the Report.

Changed Conditions and Drainage: Where conditions encountered at the site differ significantly from those anticipated in this report, either due to natural variability of subsurface conditions or construction activities, it is a condition of this report that Golder be notified of any changes and be provided with an opportunity to review or revise the recommendations within this report. Recognition of changed soil and rock conditions requires experience and it is recommended that Golder be employed to visit the site with sufficient frequency to detect if conditions have changed significantly.

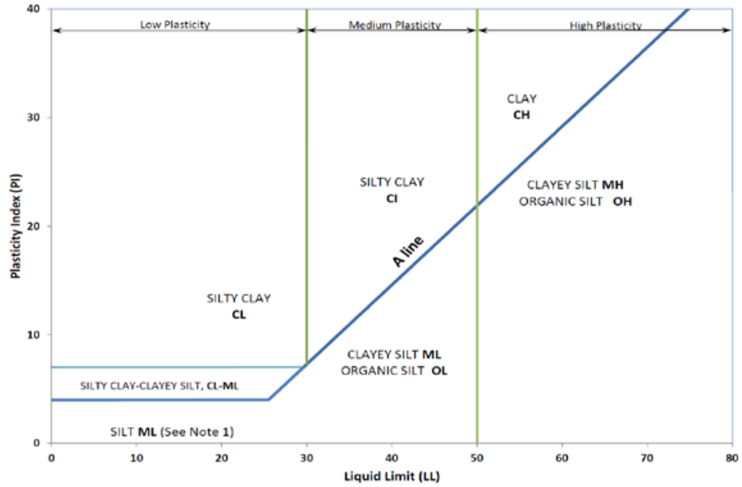
Drainage of subsurface water is commonly required either for temporary or permanent installations for the project. Improper design or construction of drainage or dewatering can have serious consequences. Golder takes no responsibility for the effects of drainage unless specifically involved in the detailed design and construction monitoring of the system.

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	$Cu = \frac{D_{60}}{D_{10}}$	$Cc = \frac{(D_{30})^2}{D_{10} x D_{60}}$	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
				Dilatancy	Dry Strength	Shine Test	Thread Diameter	Toughness (of 3 mm thread)			
INORGANIC (Organic Content ≤30% by mass)	FINE-GRAINED SOILS (≥50% by mass is smaller than 0.075 mm)	SILTS (Non-Plastic or PI 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 (PI 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% **(see Note 2)**	CL	SILTY CLAY
			Liquid Limit 30 to 50	None	Medium to high	Slight to shiny	1 mm to 3 mm	Medium		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 ~~or~~ indicate~~s~~ 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, SAND and CLAY)
> 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.).

Cone Penetration Test (CPT)

An electronic cone penetrometer with a 60° conical tip and a project end area of 10 cm^2 pushed through ground at a penetration rate of 2 cm/s. Measurements of tip resistance (q_t), porewater pressure (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
DO or DP	Seamless open ended, driven or pushed tube sampler – note size
DS	Denison type sample
FS	Foil sample
RC	Rock core
SC	Soil core
SS	Split spoon sampler – note size
ST	Slotted tube
TO	Thin-walled, open – note size
TP	Thin-walled, piston – note size
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, Gs)
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 which are anisotropically consolidated prior to shear are shown as CAD, CAU.

NON-COHESIVE (COHESIONLESS) SOILS

Compactness[2]

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

1. SPT 'N' in accordance with ASTM D1586, uncorrected for overburden pressure effects.
2. Definition of compactness descriptions based on SPT 'N' ranges from Terzaghi and Peck (1967) and correspond to typical average N_{60} values.

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] (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

1. SPT 'N' in accordance with ASTM D1586, uncorrected for overburden pressure effects; approximate only.

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
υ	Poisson's ratio
σ	total stress
σ'	effective stress ($\sigma' = \sigma - u$)
σ'_{vo}	initial effective overburden stress
σ_1, σ_2, σ_3	principal stress (major, intermediate, minor)
σ_{oct}	mean stress or octahedral stress $= (\sigma_1 + \sigma_2 + \sigma_3)/3$
τ	shear stress
u	porewater pressure
E	modulus of deformation
G	shear modulus of deformation
K	bulk modulus of compressibility

III. SOIL PROPERTIES

(a) Index Properties

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

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

(a) Index Properties (continued)

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

(b) Hydraulic Properties

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

(c) Consolidation (one-dimensional)

C_c	compression index (normally consolidated range)
C_r	recompression index (over-consolidated range)
C_s	swelling index
C_α	secondary compression index
m_v	coefficient of volume change
c_v	coefficient of consolidation (vertical direction)
c_h	coefficient of consolidation (horizontal direction)
T_v	time factor (vertical direction)
U	degree of consolidation
σ'_p	pre-consolidation stress
OCR	over-consolidation ratio = 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 δ
c′	effective cohesion
c_u, s_u	undrained shear strength ($\phi = 0$ analysis)
p	mean total stress $(\sigma_1 + \sigma_3)/2$
p′	mean effective stress $(\sigma'_1 + \sigma'_3)/2$
q	$(\sigma_1 - \sigma_3)/2$ or $(\sigma'_1 - \sigma'_3)/2$
q_u	compressive strength $(\sigma_1 - \sigma_3)$
S_t	sensitivity

Notes:
1 $\tau = c' + \sigma' \tan \phi'$
2 shear strength = (compressive strength)/2

PROJECT: 1538986

RECORD OF BOREHOLE 15-01

SHEET 1 OF 1

LOCATION: REFER TO LOCATION PLAN

BORING DATE: October 5, 2015
DRILLING CONTRACTOR: Davis Drilling

DATUM: GEODETIC

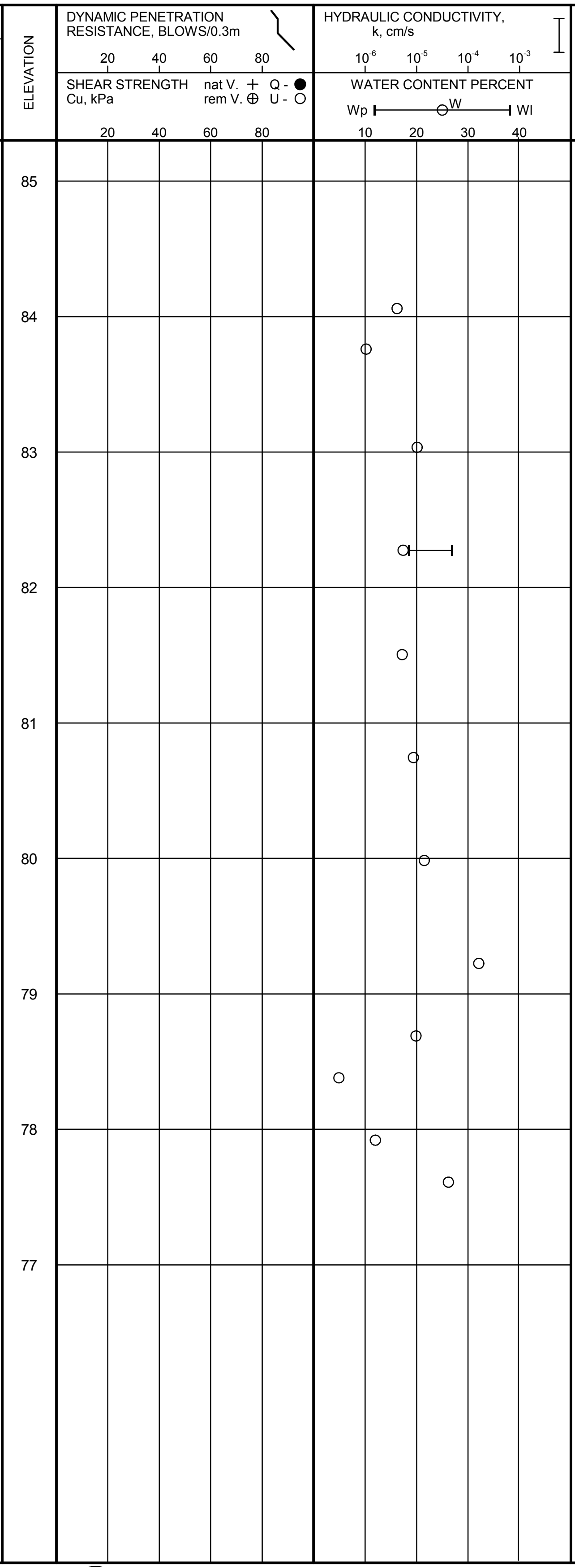
HAMMER TYPE: Auto Hammer

BORING METHOD: POWER AUGER 152mm OD SOLID STEM

DEPTH SCALE METRES: 0 – 9

SOIL PROFILE DESCRIPTION	ELEV. DEPTH (m)
GROUND SURFACE	84.10
FILL - SILTY CLAY, trace sand, trace organic matter; dark brown; firm	0.00
FILL - CLAYEY SILT, trace sand, trace gravel; brown; firm	83.87 0.23
FILL - SILTY CLAY, trace sand; brown; firm to stiff	83.41 0.69
(ML) **CLAYEY SILT**, trace sand; brown, turning grey at about elev. 79.1m; stiff to very stiff	81.05 3.05
(SW) **GRAVELLY SAND**, trace silt; brown; compact to loose	78.61 5.49
(CI) **SILTY CLAY**; brown turning grey; firm	77.83 6.27
END OF BOREHOLE	77.39 6.71

SAMPLES NUMBER	TYPE	BLOWS/0.3m	ADDITIONAL LAB. TESTING
1	SS	7	
2	SS	7	
3	SS	10	MH
4	SS	10	
5	SS	20	
6	SS	16	
7	SS	9	
8	SS	22	
9	SS	6	



INSTALLATION AND GROUNDWATER OBSERVATIONS

Borehole dry during drilling on October 5, 2015.

LDN_BHS_07 1538986.GPJ GLDR_LON.GDT 11/05/16 DATA INPUT: LMK

DEPTH SCALE
1 : 50

Golder Associates

LOGGED: MC
CHECKED:

PROJECT: 1538986

RECORD OF BOREHOLE 15-02

SHEET 1 OF 1

LOCATION: REFER TO LOCATION PLAN

BORING DATE: October 5, 2015
DRILLING CONTRACTOR: Davis Drilling

DATUM: GEODETIC

HAMMER TYPE: Auto Hammer

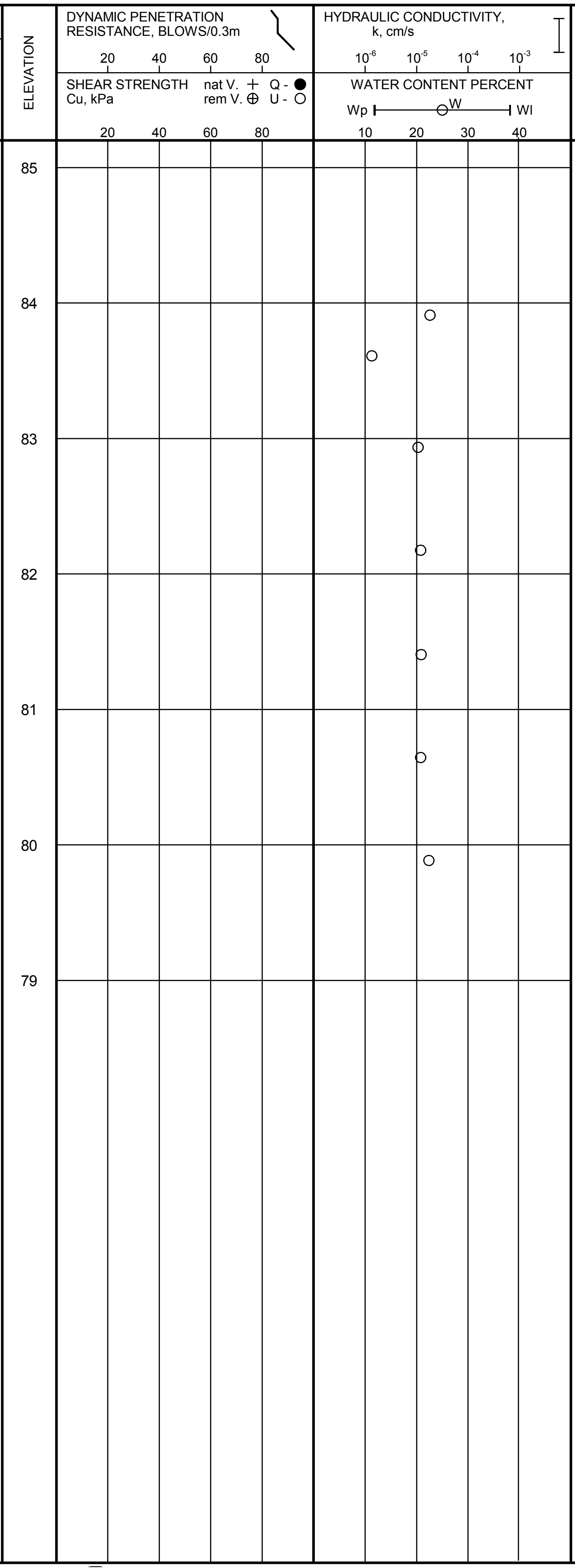
BORING METHOD: POWER AUGER 152mm OD SOLID STEM

SOIL PROFILE

DESCRIPTION	STRATA PLOT	ELEV. DEPTH (m)
GROUND SURFACE		84.00 0.00
FILL - SILTY CLAY. trace sand, trace organic matter; brown; firm	☒	83.82 0.18
FILL - CLAYEY SILT, trace sand; brown; firm	☒	83.31 0.69
FILL - SILTY CLAY, trace sand, trace organic matter; brown; firm to very stiff	☒	80.95 3.05
(ML) **CLAYEY SILT**, trace sand; brown; very stiff	▨	79.58 4.42
END OF BOREHOLE		

SAMPLES

NUMBER	TYPE	BLOWS/0.3m
1	SS	5
2	SS	7
3	SS	17
4	SS	12
5	SS	22
6	SS	15



DEPTH SCALE METRES: 0, 1, 2, 3, 4, 5, 6, 7, 8, 9

ADDITIONAL LAB. TESTING

INSTALLATION AND GROUNDWATER OBSERVATIONS

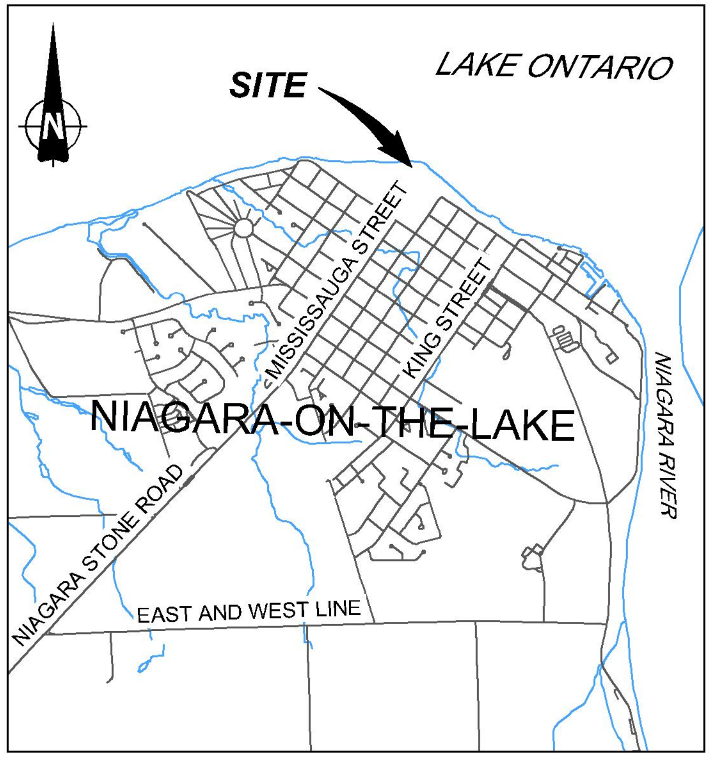
Borehole dry during drilling on October 5, 2015.

LDN_BHS_07 1538986.GPJ GLDR_LON.GDT 11/05/16 DATA INPUT: LMK

DEPTH SCALE
1 : 50

Golder Associates

LOGGED: MC
CHECKED:



KEY PLAN

LEGEND

● BOREHOLE

REFERENCE

PLAN BASED ON BING IMAGERY AS OF DECEMBER 9, 2015 (IMAGE DATE UNKNOWN);
DRAWING PROVIDED BY PARSONS, FORT MISSISSAUGA OBSERVATION DECK, NOVEMBER 2015; AND
CANMAP STREETFILES V.2008.

NOTES

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

ALL LOCATIONS ARE APPROXIMATE ONLY.

PROJECT
GEOTECHNICAL INVESTIGATION, PROPOSED OBSERVATION DECK
FORT MISSISSAUGA STABILIZATION PHASE II, PROJECT #: PRO000808
142 FRONT STREET, NIAGARA-ON-THE-LAKE, ONTARIO

TITLE

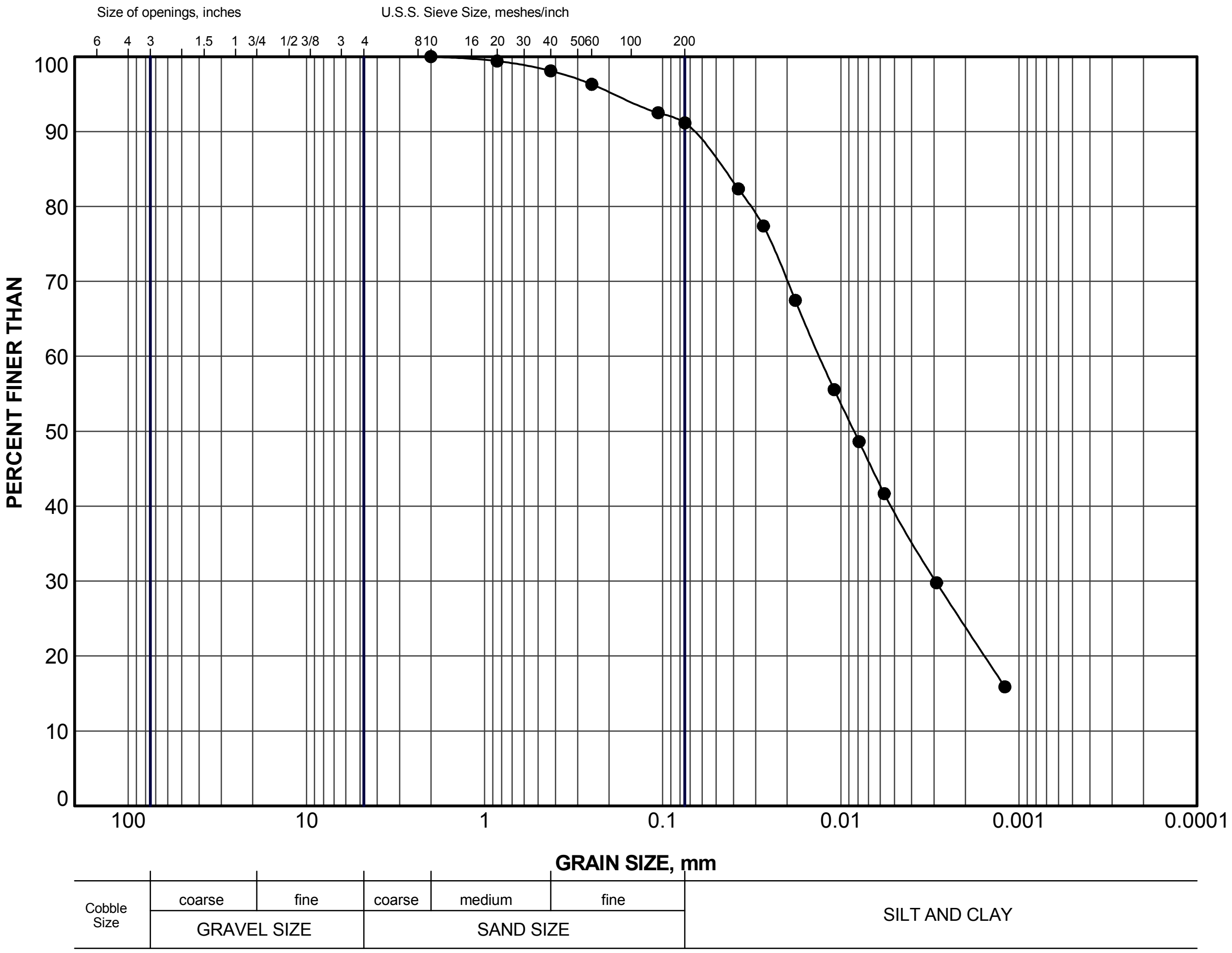
LOCATION PLAN

Golder Associates

PROJECT No.	1538986	FILE No.	1538986-R01001
		SCALE	AS SHOWN REV.
CADD	LMK/DCH	Jan 26/16	
CHECK			

FIGURE 1

Drawing file: 1538986-R01001.dwg Jan 26, 2016 - 11:52am



LEGEND

SYMBOL	BOREHOLE	SAMPLE	ELEV (m)
●	15-01	3	275.2

PROJECT
GEOTECHNICAL INVESTIGATION, PROPOSED OBSERVATION DECK
FORT MISSISSAUGA STABILIZATION PHASE II, PROJECT #: PRO000808
142 FRONT STREET, NIAGARA-ON-THE-LAKE, ONTARIO

TITLE

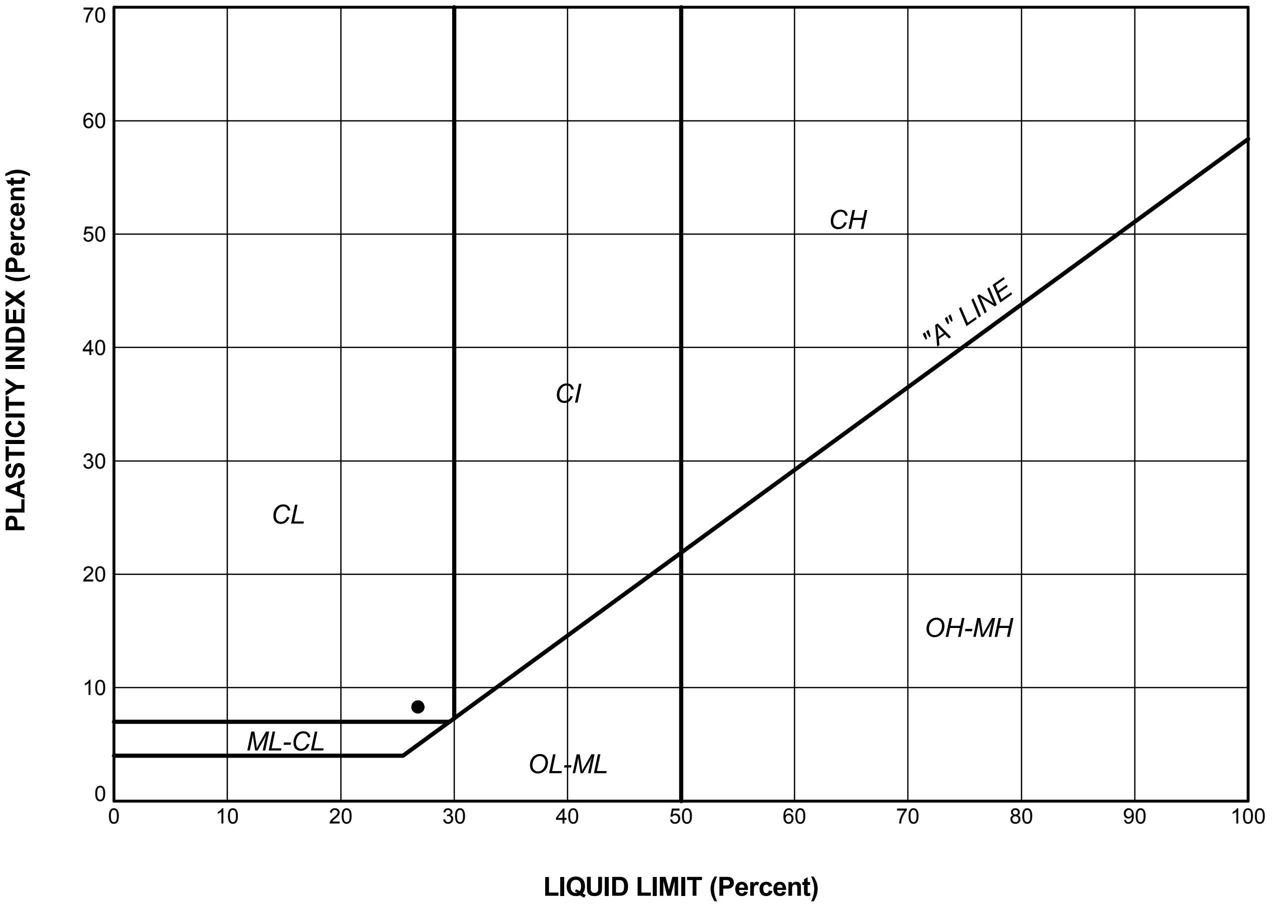
GRAIN SIZE DISTRIBUTION

FILL - SILTY CLAY

Golder Associates

PROJECT No.		1538986	FILE No.	1538986-R01002
			SCALE N/A	REV.
DRAWN	LMK	Jan 26/16	**FIGURE 2**	
CHECK				

LDN_GSD GLDR_LDN.GDT 08/01/16



SOIL TYPE
C = Clay
M = Silt
O = Organic

PLASTICITY
L = Low
I = Intermediate
H = High

LEGEND

SYMBOL	BOREHOLE	SAMPLE	LL(%)	PL(%)	PI
●	15-01	3	26.8	18.5	8.3

PROJECT
GEOTECHNICAL INVESTIGATION, PROPOSED OBSERVATION DECK
FORT MISSISSAUGA STABILIZATION PHASE II, PROJECT #: PRO000808
142 FRONT STREET, NIAGARA-ON-THE-LAKE, ONTARIO

TITLE

PLASTICITY CHART

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PROJECT No.		1538986	FILE No.	1538986-R01003
			SCALE N/A	REV.
DRAWN	LMK	Nov 25/15	**FIGURE 3**	
CHECK				

LDN_PI GLDR_LON.GDT 25/11/15

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For more information, visit golder.com

Africa	+ 27 11 254 4800
Asia	+ 86 21 6258 5522
Australasia	+ 61 3 8862 3500
Europe	+ 44 1628 851851
North America	+ 1 800 275 3281
South America	+ 56 2 2616 2000

solutions@golder.com
www.golder.com

Golder Associates Ltd.
309 Exeter Road, Unit #1
London, Ontario, N6L 1C1
Canada
T: +1 (519) 652 0099

Golder Associates