April 2017

REPORT ON

FOUNDATION INVESTIGATION
WOODROFFE AVENUE UNDERPASS
SITE NO. 3-041
HIGHWAY 417 WIDENING AND REHABILITATION
FROM WEST OF HIGHWAY 416 TO EAST OF MAITLAND AVENUE
G.W.P. 4124-14-00

Submitted to:
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Ottawa, Ontario
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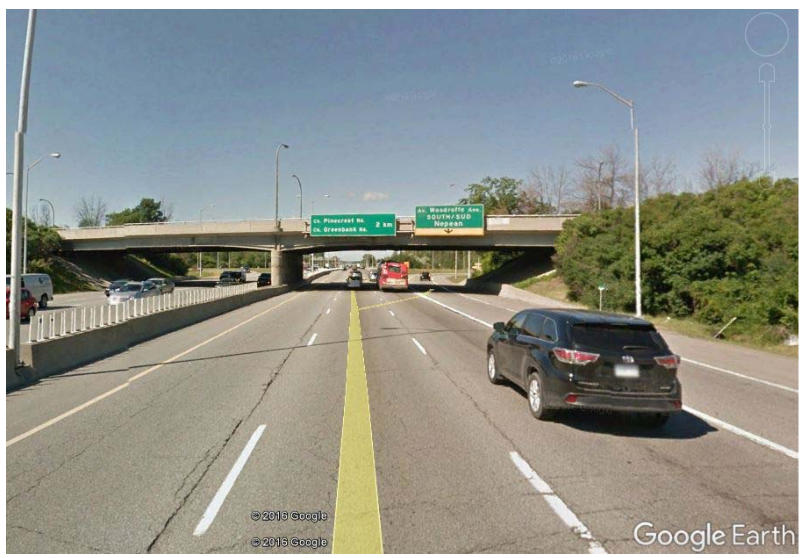

GEOCRES NO: 31G5-278

Report Number: 1546542-1030

Distribution:

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REPORT

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PART A

FOUNDATION INVESTIGATION REPORT
WOODROFFE AVENUE UNDERPASS – SITE NO. 3-041
HIGHWAY 417 WIDENING AND REHABILITATION
FROM WEST OF HIGHWAY 416 TO EAST OF MAITLAND AVENUE
G.W.P. 4124-14-00

1.0 INTRODUCTION

Golder Associates Ltd. (Golder) has been retained by MMM Group Limited (MMM) on behalf of the Ministry of Transportation, Ontario (MTO) to provide foundation engineering services in support of the design for the widening of the Woodroffe Avenue Underpass at Highway 417 in the City of Ottawa. The proposed work is part of the design associated with the Highway 417 widening from west of Highway 416 to east of Maitland Avenue (Assignment Number 4015-E-0017) in Ottawa, Ontario.

This report addresses the proposed widening of, and modifications to, the Woodroffe Avenue Underpass (MTO Structure Site No. 3-041) and the associated retaining walls and underpass approach embankments only. The proposed widening of the existing bridge to the east is required to accommodate a new northbound left turn lane on Woodroffe Avenue. Modifications to the foreslope retaining walls at the north and south abutments are required to accommodate the highway widening. The foreslope paving and approach fills in front of both the north and south bridge abutments will be cut back to form a “truncated toe” with a retaining wall.

The terms of reference and scope of work for the foundation investigation are outlined in the MTO’s Request for Proposal, dated May 2015, and subsequent addenda. Golder’s scope of work for foundation engineering services associated with the Woodroffe Avenue Underpass widening is contained in Table 17.8.3 of MMM’s Technical Proposal for this assignment. The work has been carried out in accordance with Golder’s Quality Control Plan for foundation engineering services for this project, dated May 2, 2016.

2.0 SITE DESCRIPTION AND GEOLOGY

2.1 Site Description

The Woodroffe Avenue Underpass is located within a residential area of the City of Ottawa, and is located approximately 4.5 kilometers east of the junction of Highway 416 and Highway 417. At this location, Highway 417 is a divided highway with three travel lanes in each direction separated by a concrete median. In the westbound direction, there is an off-ramp lane with a wide shoulder. In the eastbound direction, there is an on-ramp lane with a wide shoulder.

The existing Woodroffe Avenue Underpass is a two span continuous steel girder bridge. The spans are each approximately 32 m in length. The central piers are founded on spread footings on rock. The bridge abutments are supported on “perched” foundations on piles end bearing on bedrock. The front row of piles are battered towards Highway 417. The existing approach embankments are about 7 m high relative to the highway profile. The foreslopes of both the north and south abutments are constructed at about 2 Horizontal to 1 Vertical (2H:1V) grade extending down to short toe walls adjacent to the roadway shoulders.

A 200 mm diameter gas main is located about 24 m east of the bridge structure, aligned in a north-south direction.

A previous investigation was conducted for the design of the existing bridge by McRostie & Associates (McRostie) in 1958. The results of that investigation are contained in the report titled “Report on Foundation Investigation at Ottawa Queensway and Woodroffe Avenue, Bridge No. 2, to Deleuw, Cather and Company of Canada Limited” (Geocres 31G5-021). In late 1988 and early 1989, design memorandums were prepared by McCormick Rankin addressing new retaining walls to support the forward fills of the Woodroffe Avenue Underpass as part of W.P. 118-86-01. The sequence of letters and memos between McCormick Rankin and MTO are included in Geocres 31G5-189.

2.2 Regional Geology

As delineated in *The Physiography of Southern Ontario*[1], this section of Highway 417 lies within the minor physiographic region known as the Ottawa Valley Clay Plain, which lies within the major physiographic region of the Ottawa-St. Lawrence Lowland.

The Ottawa Valley Clay Plain region is characterized by relatively thick deposits of sensitive marine clay, silt and silty clay that were deposited within the Champlain Sea basin. These deposits, known as the Champlain Sea clay or Leda clay, overlie relatively thin, commonly reworked glacial till and glaciofluvial deposits, that in turn overlie bedrock[2]. This region is underlain by a series of sedimentary rocks, consisting of sandstones, dolostones, limestones and shales that are, in turn, underlain at depth by igneous and metamorphic bedrock of the Precambrian Shield.

[1] Chapman, 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. Ontario Ministry of Natural Resources.

[2] Belanger, J.R. “Urban Geology of Canada’s National Capital Area”, in *Urban Geology of Canadian Cities*, Geological Association of Canada Special Paper 42, Ed. P.F. Karrow and O.L. White, 1998.

3.0 INVESTIGATION PROCEDURES

The field work for this subsurface investigation was carried out between June 15 and July 28, 2016. During that time, a total of 8 boreholes were advanced at the locations shown on Drawing 1. Borehole 16-301 was advanced adjacent to the east pier location, and Boreholes 16-302 and 16-303 were advanced adjacent to the abutments at the east toe of each of the existing embankments. Boreholes 16-304 and 16-305 were advanced through each of the existing approach embankments, and Boreholes 16-310 to 16-312 were advanced within the currently proposed ‘Construction Staging Area’ within the northwest quadrant of the Woodroffe Avenue interchange. The boreholes were advanced using a combination of truck and track mounted drill rigs supplied and operated by CCC Geotechnical and Environmental Drilling Ltd. of Ottawa, Ontario. The boreholes were advanced to depths of between 2.1 m and 10.2 m below present ground surface. Boreholes 16-306 to 16-309 were not drilled as part of the design.

Samples of the overburden were obtained at 0.6 m to 0.8 m intervals of depth using 50 mm outside diameter split-spoon samplers in accordance with the Standard Penetration Test (SPT) procedure. In the bedrock, rotary diamond drilling techniques were used to retrieve NQ sized core. The bedrock was cored for depths of 3.6 to 5.3 metres, after practical refusal to augering had been reached. One monitoring well was installed (in Boreholes 16-310) to monitor the groundwater level at the site. The monitoring well consists of 30 mm outside diameter PVC pipe with a 1.5 m long slotted tip. The borehole was backfilled with bentonite mixed with soil cuttings. The site conditions were restored following completion of the field work.

The field work was supervised on a full time basis by members of Golder’s staff who located the boreholes in the field, directed the drilling, sampling, and in situ testing operations, and logged the boreholes. The soil and bedrock samples were identified in the field, placed in labelled containers, and transported to Golder’s laboratory in Ottawa for further examination and to Golder’s laboratories in London and Mississauga for testing. Index and classification tests consisting of water content determinations, Atterberg Limit testing, and grain size distribution analyses were carried out on selected soil samples. Unconfined compressive strength testing was carried out on one sample of the bedrock core.

The groundwater level was measured in the monitoring well in Borehole 16-310 on August 2 and September 30, 2016.

In addition to the borehole investigation, shear wave velocity profiling at the site was completed using the Multichannel Analysis of Surface Waves (MASW) technique and was conducted between May 26 and 27, 2016, by personnel from the Golder’s Mississauga and Ottawa offices. A series of 24 low frequency (4.5 Hz) geophones were laid out at 3 m intervals. A 9.9 kg sledge hammer and 45 kg weight drop were used as the seismic source. The source locations were offset at distances of 5, 10, 15, and 20 m off the end and collinear with the geophone array.

The borehole locations were determined by Golder relative to existing site features. The borehole elevations were surveyed by Golder using a Trimble R8 GPS unit. The borehole locations in MTM NAD83 northing and easting coordinates, ground surface elevations referenced to geodetic datum and drilled depths are summarized in the following table and are shown on Drawing 1 in Appendix A.

Borehole Number	Borehole Location	MTM NAD83 Northing (m)	MTM NAD83 Easting (m)	Ground Surface Elevation (m)	Borehole Depth (m)
BH16-301	Pier	5024851.3	362135.6	75.9	7.3
BH16-302	South Embankment Toe	5024821.6	362167.2	76.8	10.2
BH16-303	North Embankment Toe	5024888.8	362143.7	75.7	6.4
BH16-304	South Embankment Crest	5024794.4	362148.3	81.2	8.2
BH16-305	North Embankment Crest	5024885.1	362113.0	81.3	8.2
BH16-310	Staging Area	5024902.8	362037.9	75.1	3.3
BH16-311	Staging Area	5024866.7	362074.2	76.6	3.1
BH16-312	Staging Area	5024850.9	362007.2	75.3	2.1

4.0 DESCRIPTION OF SUBSURFACE CONDITIONS

4.1 General

The Record of Borehole sheets and laboratory testing results from the current investigation are presented in Appendix A. The results of the laboratory testing carried out during the current investigation are presented on the Record of Boreholes sheets and on Figures 1 to 6 in Appendix B. The results of the in situ field tests (i.e. SPT 'N'-values) carried out during the previous investigation as presented on the Record of Borehole sheets.

As part of the current subsurface investigation at this site, five boreholes were advanced within or near the limits of the foundation elements for the proposed widening of the Woodroffe Avenue Bridge. Six boreholes had been previously advanced at the present bridge abutment and pier locations on behalf of the Ministry in 1958, as previously noted (Geocres No. 31G5-021). The borehole records from this previous investigation are provided for reference in Appendix C. The borehole locations from the current and previous investigations are shown on Drawing 1. The interpreted stratigraphic profile projected along the Woodroffe Avenue centreline is also shown on Drawing 1. A stratigraphic profile projected through the proposed staging area is shown on Drawing 2.

The stratigraphic boundaries shown on the Record of Borehole sheets and on the interpreted stratigraphic profile and cross-sections are inferred from observations of drilling progress and non-continuous sampling and, therefore, represent transitions between soil types rather than exact planes of geological change. The subsoil conditions will vary between and beyond the borehole locations.

In general, the subsurface conditions at the site consist of a layer of fill and/or topsoil underlain by silty clay to clayey silt and/or glacial till overlying limestone bedrock with shale interbeds.

A detailed description of the subsurface conditions encountered in the boreholes is provided in the following sections. In the following discussion, emphasis is placed on the subsurface conditions indicated in the boreholes from the present investigation. The boreholes from 1958 were advanced prior to the highway construction and therefore the ground conditions shown on those logs are likely different than currently exist, particularly with respect to the composition and thickness of overburden and fill. The previous Geocres information is referenced only in regard to the bedrock surface elevation, which is in general agreement with the results from the current investigation.

4.2 Topsoil

Topsoil exists at ground surface at Boreholes 16-302, 16-303, and 16-310 to 16-312, with thicknesses of about 50 to 200 mm.

4.3 Fill

Asphaltic concrete exists at ground surface at Boreholes 16-301, 16-304 and 16-305, with a thickness of about 200 to 230 mm.

Fill was encountered beneath the topsoil/asphaltic concrete at all borehole locations. Fill materials are quite variable between locations, consisting of sand, gravel, silty sand, and silty clay.

The layer of fill was fully penetrated in all of the boreholes and varies from about 0.3 to 5.9 m in thickness, with the thicker portions located at the embankments. SPT 'N' values obtained within the fill generally range from about 8 to 29 blows per 0.3 m of penetration indicating a loose to compact state of packing. One higher blow count of 74 was encountered within the pavement structure fill at Borehole 16-301), reflecting a very dense state of packing.

Although not encountered in the boreholes, obstructions (e.g., cobbles and boulders) should be anticipated due to the variability of the fill materials.

Grain size distribution testing was carried out on three samples of the fill, the results of which are provided on Figure 1. The measured water content of five samples of the fill ranges from approximately 8 to 30 percent.

4.4 Silty Clay to Clayey Silt

The fill is underlain by a deposit of sensitive silty clay to clayey silt at Boreholes 16-302 to 16-305, and 16-310. The silty clay to clayey silt was fully penetrated by the all of these boreholes and varies from about 0.5 to 2.2 m in thickness.

The full thickness of the silty clay to clayey silt deposit at Boreholes 16-302, 16-304, 16-305 and the upper 1.7 m at Borehole 16-303 has been weathered to form a grey brown crust. The lowest 0.5 m of the deposit at Borehole 16-303 and the entire 0.5 m thickness encountered at Borehole 16-310 is unweathered and grey. Standard penetration tests carried out within the weathered silty clay to clayey silt gave 'N' values ranging from 2 to 26 blows per 0.3 m of penetration, indicating a generally stiff to very stiff consistency. The results of in situ vane testing at one location in the unweathered portion of the deposit gave an undrained shear strength of 46 kPa, indicating a firm consistency. The calculated sensitivity ratio based on a remoulded shear strength of 8 kPa in this deposit is about 6, indicating a sensitive material in accordance with the CFEM.

The results of Atterberg limit testing carried out on two samples of the weathered silty clay to clayey silt are summarized on Figure 2 and indicate plasticity index values generally ranging from 18 to 37 percent and liquid limit values of 34 and 59 percent, reflecting a soil of low to high plasticity. The measured water content of four samples of this deposit ranges from approximately 30 to 51 percent. Grain size distribution testing was carried out on two samples of this deposit, the results of which are provided on Figure 3.

4.5 Till

A deposit of glacial till was encountered below the fill and silty clay to clayey silt at all the borehole locations, at depths of about 0.6 to 7.6 m below the existing ground surface (or between Elevations 73 and 76 m). The till in this area generally consists a heterogeneous mixture of gravel, cobbles, and boulders in a matrix of sandy silt with trace to some clay.

The till was fully penetrated at Boreholes 16-301 to 16-303 and is about 0.3 to 3.0 m in thickness, extending to about 2.9 to 4.4 m depth below the existing ground surface (i.e., Elevations 72.8 to 72.2 m). The till was not fully penetrated in the other boreholes but was proven to extend to depths of about 2.1 to 8.2 m below the ground surface (i.e., Elevations 73.5 to 71.9 m). Standard penetration test 'N' values of 2 to 'in excess of 50' blows (at Borehole 16-310) per 0.3 m of penetration, but typically less than 15, were measured in the glacial till, indicating a very loose to compact state of packing. The higher 'N' values could reflect the presence of cobbles and boulders or the bedrock surface, rather than the state of packing of the soil matrix.

The measured water contents of ten samples of till ranged from approximately 2 to 33 percent. Grain size distribution testing was carried out on five samples of the till, the results of which are provided on Figure 4. The results confirm that the till matrix generally consists of a silty sand to sandy silt with some clay and trace amounts of gravel. The sample tested from Borehole 16-312 had a higher clay and silt content than is typical for glacial till in the Ottawa area. These samples were retrieved using a 50 mm diameter sampler and the results do not reflect the larger gravel, cobble and boulder content of the deposit.

4.6 Sand and Gravel

A 0.5 m thick layer of sand and gravel was encountered at the bedrock/till interface at Borehole 16-302. One standard penetration test within the sand and gravel deposit gave an SPT ‘N’ value in excess of 50 blows per 0.3 m of penetration. This high blow count may indicate a very dense state of packing of the sand and gravel deposit, or reflect the bedrock surface.

The measured water content of one sample of the sand and gravel was about 14 percent. Grain size distribution testing was carried out on one sample of this deposit, the result of which are provided on Figure 5.

4.7 Bedrock

The bedrock encountered at the bridge foundation elements at Boreholes 16-301 to 16-303, inclusive, consists of limestone with thin shale interbeds, which is consistent with the previous Geocres investigation. Photos of the bedrock core obtained during the current investigation are provided in Appendix A on Figures A1 to A6, inclusive.

The bedrock is slightly weathered to fresh and medium bedded, and was encountered at depths ranging from about 2.9 to 4.9 m below the existing ground surface (i.e., Elevations 72.8 to 71.8 m) during the current investigation. These boreholes were advanced about 3.6 to 5.3 m into the bedrock.

The bedrock was cored in Boreholes 16-301, 16-302 and 16-303 as part of the current investigation, and in Boreholes 1 through 6 as part of the previous investigation in 1958. The following table summarizes the bedrock surface depths and elevations as encountered at the boreholes advanced as part of the current and previous investigations at the site.

Borehole Location	Borehole Number	Ground Surface Elevation (m)	Depth to Bedrock Surface (m)	Bedrock Surface Elevation (m)
South Approach Embankment	16-302	76.8	4.9	71.9
	2	75.7	3.7	72.0
	16-304	81.2	> 8.2[1]	< 73.0[1]
	4	75.6	5.1	70.5
Pier	16-301	75.9	3.7	72.2
	6	75.5	3.4	72.1
	5	75.6	3.2	72.4
North Approach Embankment	16-303	75.7	2.9	72.8
	1	74.9	2.7	72.1
	16-305	81.3	> 8.2[1]	< 73.1[1]
	3	75.3	3.3	72.0
Staging Area (NW)	16-310	75.1	3.3[2]	71.9[2]
	16-311	76.6	3.1[2]	73.5[2]
	16-312	75.3	2.1[2]	73.2[2]

Notes 1: Bedrock was not encountered within the depth of the borehole.
2: Auger refusal on possible bedrock surface.

The limestone bedrock at the site is mapped as the Rockliffe Formation. Thin shale interbeds were also present in the rock core. Rock Quality Designation (RQD) values measured on recovered bedrock core samples ranged from about 17 to 100 percent, but more typically above 75 percent. The RQD values for Borehole 16-301, which was advanced at the pier location, were 89 to 100 percent, indicating good to excellent quality rock. The lowest RQD values were recorded as 17 percent for the run of bedrock from 7.2 to 8.0 m depth in Borehole 16-302 (south abutment). It is however noted that the fracturing observed at this depth could be a result of poor drilling techniques/equipment (i.e., mechanical break) rather than the quality of the bedrock.

The result of one unconfined compressive strength test on a sample of the bedrock from Borehole 16-301 was 55 MPa, as shown on Figure 6, indicating a strong rock. A description of some of the terms used in the description of the bedrock samples from this site is provided on the Lithological and Geotechnical Rock Description Terminology sheet which precedes the Record of Borehole sheets included with this report.

4.8 Groundwater Conditions

A monitoring well was installed in Borehole 16-310. The water levels measured in the well are summarized in the following table:

Borehole Number	Borehole Location	Screened Interval	Date	Depth (m)	Elevation (m)
16-310	Staging Area	Silty Clay/Glacial Till	August 2, 2016	2.4	72.7
			September 30, 2016	1.7	73.4

The water level at the site is expected to fluctuate seasonally in response to changes in precipitation and snow melt, and is expected to be higher during the spring and periods of precipitation.

5.0 CLOSURE

The field operations were supervised by Mr. Doug Grylls and Mr. Jason Derouin. This report was prepared by Ms. Kim Lesage, P.Eng., and was reviewed by Ms. Erin O'Neill, P.Eng., a senior geotechnical engineer and Associate of Golder. Mr. Fintan Heffernan, P.Eng., a Senior Consultant with Golder and the Designated MTO Foundations Contact, conducted an independent quality control review of this report.

GOLDER ASSOCIAT

LICENSED PROFESSIONAL ENGINEER
K. S. LESAGE
100131998
April 3/17
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Kim Lesage, P.Eng.
Geotechnical Enginee

Erin O'Neill, P.Eng.
Senior Geotechnical Engineer, Associate

REGISTERED PROFESSIONAL ENGINEER
F. J. HEFFERNAN
APRIL 3/17
PROVINCE OF ONTARIO

Fintan J. Heffernan, P.Eng.
Designated MTO Foundations Contact

SM/KSL/ESO/FJH/ob

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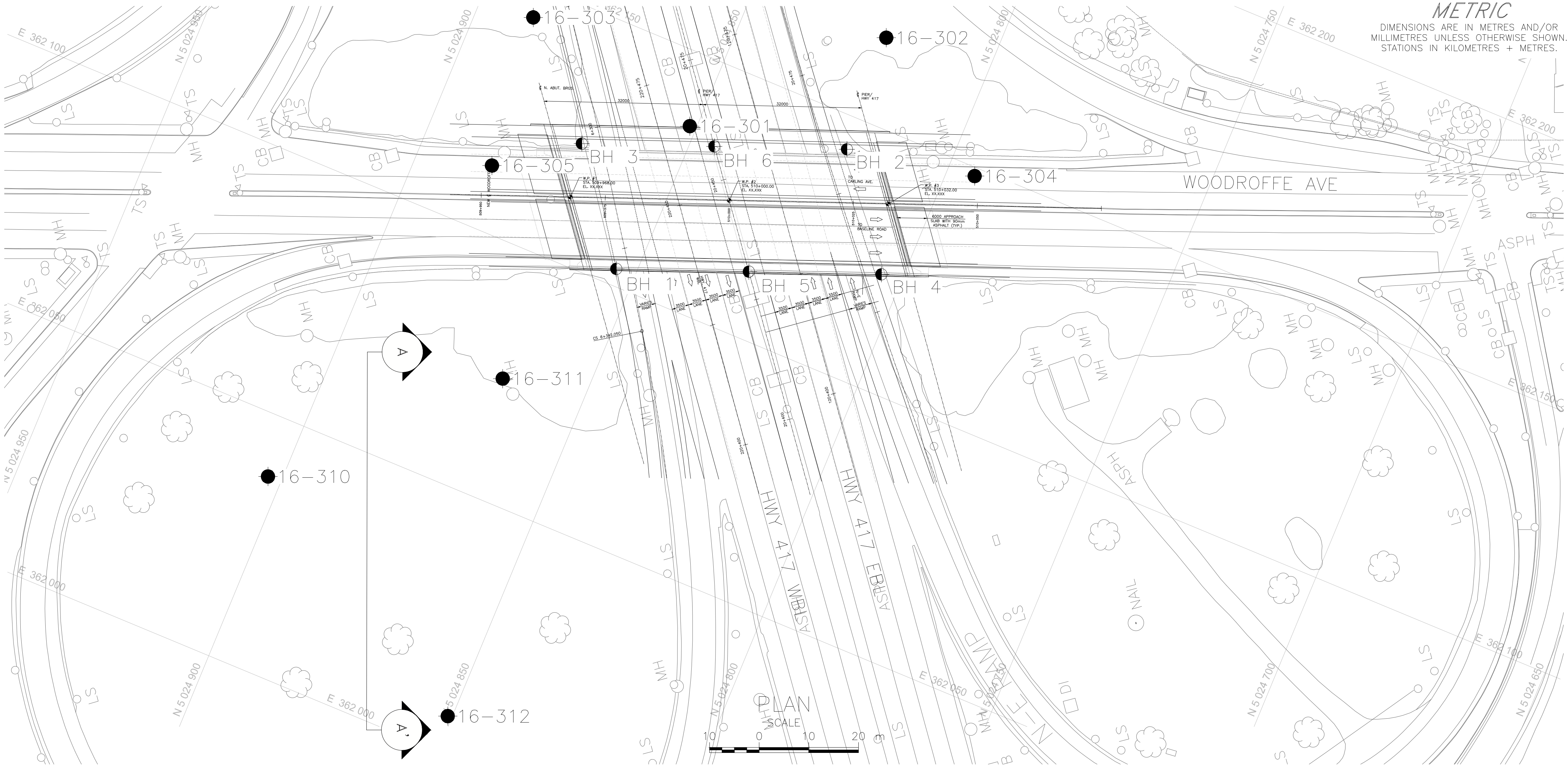
METRIC
DIMENSIONS ARE IN METRES AND/OR MILLIMETRES UNLESS OTHERWISE SHOWN. STATIONS IN KILOMETRES + METRES.

CONT No.
WP No. 4015-E-0017

SHEET

HIGHWAY 417 REHABILITATION AND WIDENING
WOODROFFE AVENUE UNDERPASS
BOREHOLE LOCATIONS AND SOIL STRATA

Golder Associates



PLAN
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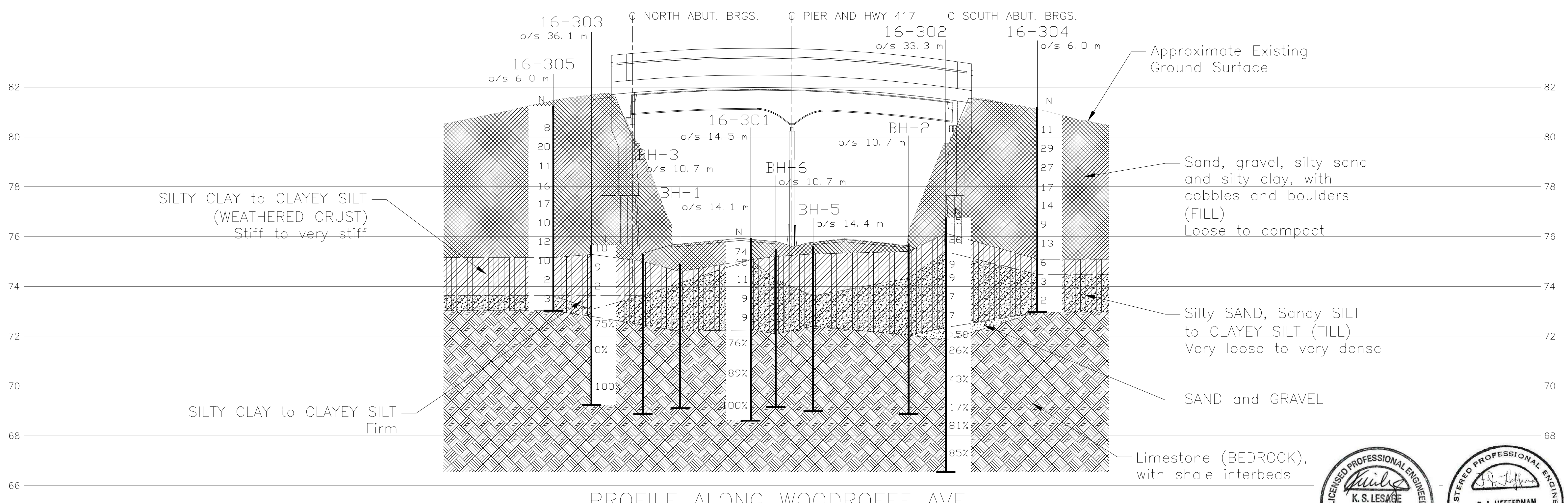

PROFILE ALONG WOODROFFE AVE.
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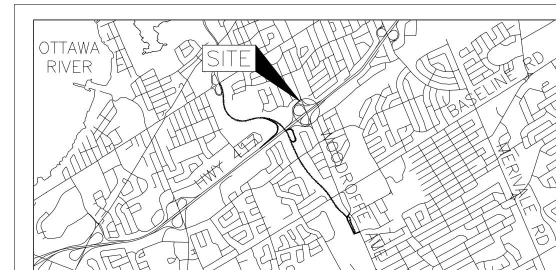
VERT. SCALE



KEY PLAN
SCALE
1 0 1 2 km

LEGEND

●	Borehole – Current Investigation
◐	Borehole – Previous Investigation
N	Standard Penetration Test Value
16	Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
100%	Total Core Recovery (REC)
▮	Seal
▯	Piezometer
▼	WL in piezometer, measured on Sept. 30, 2016

BOREHOLE CO-ORDINATES

No.	ELEVATION	NORTHING	EASTING
16-301	75.9	5024851.3	362135.6
16-302	76.8	5024821.6	362167.2
16-303	75.7	5024888.8	362143.7
16-304	81.2	5024794.4	362148.3
16-305	81.2	5024885.1	362113.0
16-310	75.1	5024902.8	362037.9
16-311	76.6	5024866.7	362074.2
16-312	75.3	5024850.9	362007.2
BH-1	74.9	5024854.0	362103.4
BH-2	75.7	5024820.3	362143.4
BH-3	75.3	5024870.1	362124.0
BH-4	75.6	5024804.2	362122.8
BH-5	75.6	5024829.1	362113.1
BH-6	75.5	5024845.2	362133.7

REFERENCE

Base plans provided in digital format by MMM Group, drawing file no. TN_3416012-304-001_General-Arrangement-I.dwg, received October 26, 2016.

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.

LICENSED PROFESSIONAL ENGINEER K. S. LESAGE 100131993 April 3/17 PROVINCE OF ONTARIO

REGISTERED PROFESSIONAL ENGINEER F. J. HEFFERNAN April 3/17 PROVINCE OF ONTARIO

NO.	DATE	BY	REVISION

Geocres No. 31G5-278

HWY. 417		PROJECT NO. 1546542-1030	DIST. EASTERN
SUBM'D. KSL	CHKD. KSL	DATE: 11/14/2016	SITE: 3-041
DRAWN: JM	CHKD. ESO	APPD. FJH	DWG. 1

PLOT DATE: April 4, 2017
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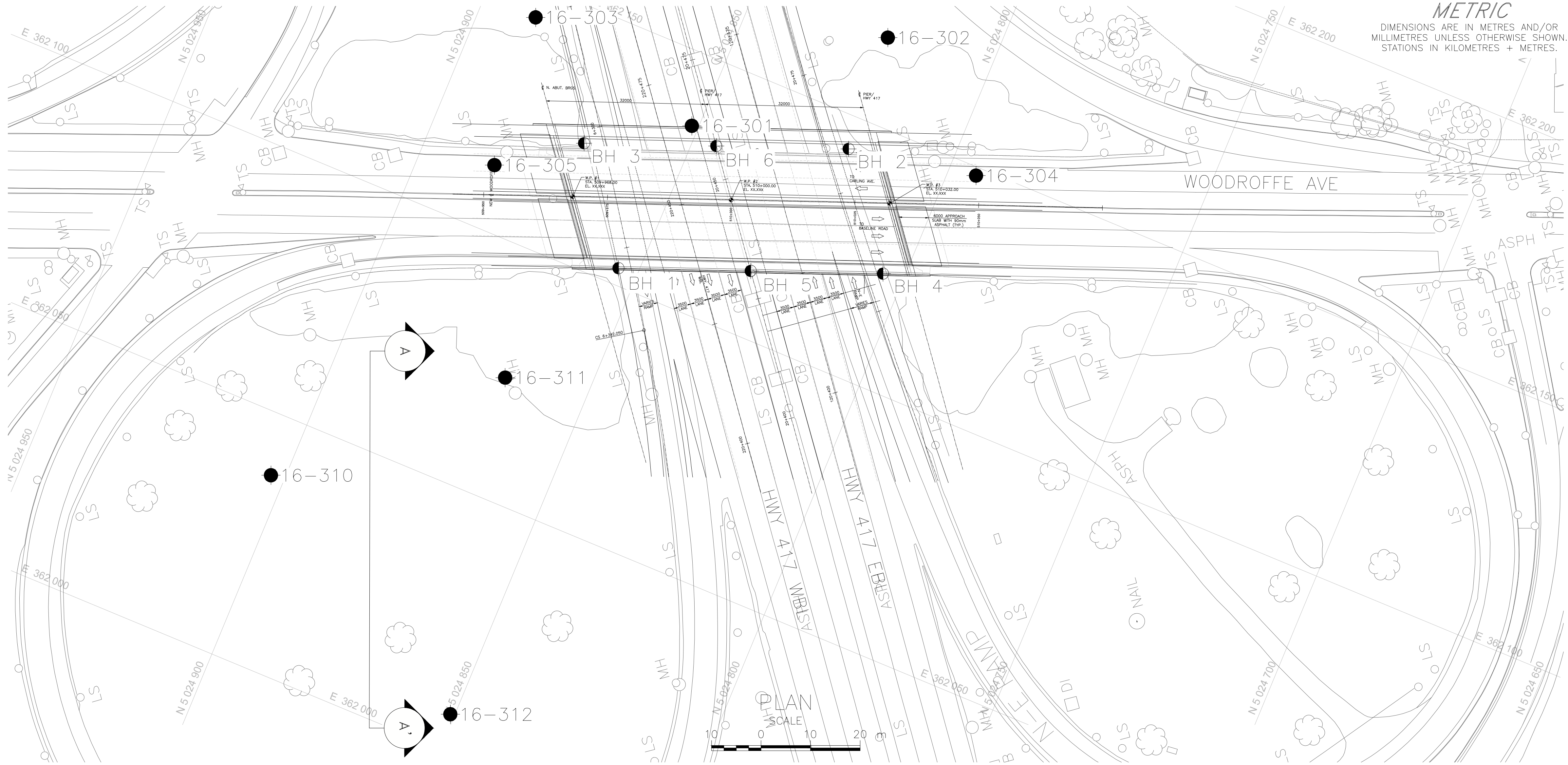
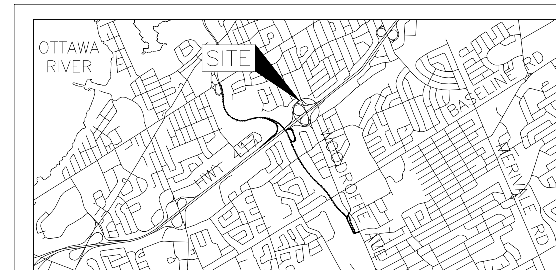


CONT No.
WP No. 4015-E-0017

SHEET

HIGHWAY 417 REHABILITATION
AND WIDENING
WOODROFFE AVENUE UNDERPASS
BOREHOLE LOCATIONS AND SOIL STRATA

Golder Associates



KEY PLAN
SCALE
1 0 1 2 km

LEGEND

●	Borehole – Current Investigation
◐	Borehole – Previous Investigation
N	Standard Penetration Test Value
16	Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
100%	Total Core Recovery (REC)
	Seal
	Piezometer
	WL in piezometer, measured on Sept. 30, 2016

BOREHOLE CO-ORDINATES			
No.	ELEVATION	NORTHING	EASTING
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16-311	76.6	5024866.7	362074.2
16-312	75.3	5024850.9	362007.2
BH-1	74.9	5024854.0	362103.4
BH-2	75.7	5024820.3	362143.4
BH-3	75.3	5024870.1	362124.0
BH-4	75.6	5024804.2	362122.8
BH-5	75.6	5024829.1	362113.1
BH-6	75.5	5024845.2	362133.7

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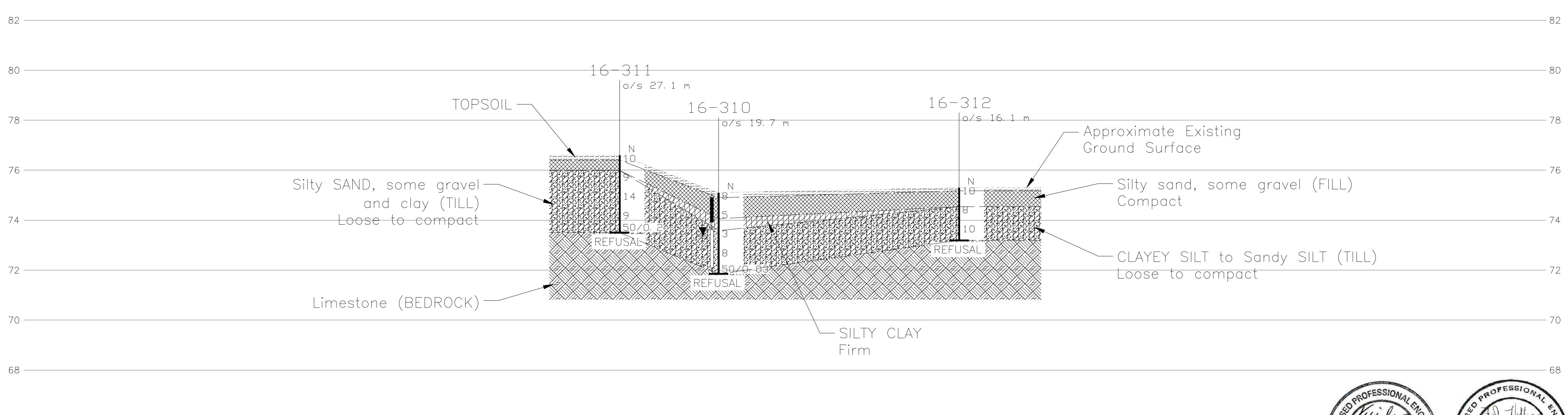

CROSS-SECTION A-A'
HORIZ. SCALE
10 0 10 20 m
2 0 2 4 m
VERT. SCALE

LICENSED PROFESSIONAL ENGINEER K. S. LESAGE 100131993 April 3/17 PROVINCE OF ONTARIO

REGISTERED PROFESSIONAL ENGINEER F. J. HEFFERNAN April 3/17 PROVINCE OF ONTARIO

NO.	DATE	BY	REVISION

Geocres No. 31G5-278

HWY. 417		PROJECT NO. 1546542-1030	DIST. EASTERN
SUBM'D. KSL	CHKD. KSL	DATE: 11/24/2016	SITE: 3-041
DRAWN: JM	CHKD. ESO	APPD. FJH	DWG. 2

MINISTRY OF TRANSPORTATION, ONTARIO

PLOT DATE: April 4, 2017
FILENAME: N:\Active\Spatial_IM\MTO\Hwy417RehabWidening\99_PROJ\1546542_MTO_Hwy417RehabWidening\40_PROD\Phase1030_Geotech\1546542-1030-BG-0001.dwg

APPENDIX A

Borehole and Drillhole Records, Current Investigation

Lists of Abbreviations and Symbols
Lithological and Geotechnical Rock Description Terminology
Records of Boreholes 16-301 to 16-306 and 16-310 to 16-312
Bedrock Core Photographs, Figures A1 to A6

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
FoS	factor of safety

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
$\sigma_1, \sigma_2, \sigma_3$	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

* 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

LIST OF ABBREVIATIONS

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

I. SAMPLE TYPE

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

II. PENETRATION RESISTANCE

Standard Penetration Resistance (SPT), N:

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

Dynamic Cone Penetration Resistance; N_d:

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

PH: Sampler advanced by hydraulic pressure
PM: Sampler advanced by manual pressure
WH: Sampler advanced by static weight of hammer
WR: Sampler advanced by weight of sampler and rod

Piezo-Cone Penetration Test (CPT)

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

III. SOIL DESCRIPTION

(a) Non-Cohesive (Cohesionless) Soils

Density Index **Relative Density**	**N** **Blows/300 mm or Blows/ft**
Very loose	0 to 4
Loose	4 to 10
Compact	10 to 30
Dense	30 to 50
Very dense	over 50

(b) Cohesive Soils
Consistency

	c_u, s_u **kPa**	c_u, s_u **psf**
Very soft	0 to 12	0 to 250
Soft	12 to 25	250 to 500
Firm	25 to 50	500 to 1,000
Stiff	50 to 100	1,000 to 2,000
Very stiff	100 to 200	2,000 to 4,000
Hard	over 200	over 4,000

IV. SOIL TESTS

w	water content
w_p	plastic limit
w_l	liquid limit
C	consolidation (oedometer) test
CHEM	chemical analysis (refer to text)
CID	consolidated isotropically drained triaxial test[1]
CIU	consolidated isotropically undrained triaxial test with porewater pressure measurement[1]
D_R	relative density (specific gravity, G_s)
DS	direct shear test
M	sieve analysis for particle size
MH	combined sieve and hydrometer (H) analysis
MPC	Modified Proctor compaction test
SPC	Standard Proctor compaction test
OC	organic content test
SO_4	concentration of water-soluble sulphates
UC	unconfined compression test
UU	unconsolidated undrained triaxial test
V	field vane (LV-laboratory vane test)
γ	unit weight

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

V. MINOR SOIL CONSTITUENTS

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

WEATHERINGS STATE

Fresh: no visible sign of weathering

Faintly weathered: weathering limited to the surface of major discontinuities.

Slightly weathered: penetrative weathering developed on open discontinuity surfaces but only slight weathering of rock material.

Moderately weathered: weathering extends throughout the rock mass but the rock material is not friable.

Highly weathered: weathering extends throughout rock mass and the rock material is partly friable.

Completely weathered: rock is wholly decomposed and in a friable condition but the rock and structure are preserved.

BEDDING THICKNESS

Description	Bedding Plane Spacing
Very thickly bedded	Greater than 2 m
Thickly bedded	0.6 m to 2 m
Medium bedded	0.2 m to 0.6 m
Thinly bedded	60 mm to 0.2 m
Very thinly bedded	20 mm to 60 mm
Laminated	6 mm to 20 mm
Thinly laminated	Less than 6 mm

JOINT OR FOLIATION SPACING

Description	Spacing
Very wide	Greater than 3 m
Wide	1 m to 3 m
Moderately close	0.3 m to 1 m
Close	50 mm to 300 mm
Very close	Less than 50 mm

GRAIN SIZE

Term	Size*
Very Coarse Grained	Greater than 60 mm
Coarse Grained	2 mm to 60 mm
Medium Grained	60 microns to 2 mm
Fine Grained	2 microns to 60 microns
Very Fine Grained	Less than 2 microns

Note: * Grains greater than 60 microns diameter are visible to the naked eye.

CORE CONDITION

Total Core Recovery (TCR)

The percentage of solid drill core recovered regardless of quality or length, measured relative to the length of the total core run.

Solid Core Recovery (SCR)

The percentage of solid drill core, regardless of length, recovered at full diameter, measured relative to the length of the total core run.

Rock Quality Designation (RQD)

The percentage of solid drill core, greater than 100 mm length, recovered at full diameter, measured relative to the length of the total core run. RQD varied from 0% for completely broken core to 100% for core in solid sticks.

DISCONTINUITY DATA

Fracture Index

A count of the number of discontinuities (physical separations) in the rock core, including both naturally occurring fractures and mechanically induced breaks caused by drilling.

Dip with Respect to Core Axis

The angle of the discontinuity relative to the axis (length) of the core. In a vertical borehole a discontinuity with a 90^{o} angle is horizontal.

Description and Notes

An abbreviation description of the discontinuities, whether naturally occurring separations such as fractures, bedding planes and foliation planes or mechanically induced features caused by drilling such as ground or shattered core and mechanically separated bedding or foliation surfaces. Additional information concerning the nature of fracture surfaces and infillings are also noted.

Abbreviations

JN	Joint	PL	Planar
FLT	Fault	CU	Curved
SH	Shear	UN	Undulating
VN	Vein	IR	Irregular
FR	Fracture	K	Slickensided
SY	Stylolite	PO	Polished
BD	Bedding	SM	Smooth
FO	Foliation	SR	Slightly Rough
CO	Contact	RO	Rough
AXJ	Axial Joint	VR	Very Rough
KV	Karstic Void		
MB	Mechanical Break		

Golder Associates

RECORD OF BOREHOLE No 16-301

SHEET 1 OF 2 **METRIC**

PROJECT 1546542-1030
W.P. 4015-E-0017
LOCATION N 5024851.3 ;E 362135.6
ORIGINATED BY DG
DIST Eastern HWY 417
BOREHOLE TYPE Power Auger 200 mm Diam. (Hollow Stem)/Rotary Drill, NQ Core
COMPILED BY ZS
DATUM Geodetic
DATE June 23, 2016
CHECKED BY KSL

ELEV DEPTH	SOIL PROFILE DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	WATER CONTENT (%)	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
75.9	GROUND SURFACE						
0.0	ASPHALTIC CONCRETE						
75.7 / 0.2	Gravelly sand (FILL) Very dense Grey Dry	1	SS	74			
75.3	Sandy gravel (FILL)				75		
75.0 / 0.9	Compact Grey Dry	2	SS	15		○	
	Silty sand, some clay, trace gravel (TILL) Compact to loose Grey brown Moist	3	SS	11	74		
		4	SS	9		○	8 44 34 14
					73		
		5	SS	9			
72.2 / 3.7	Limestone (BEDROCK) Bedrock cored from depths of 3.7 m to 7.3 m For bedrock coring details refer to Record of Drillhole 16-301	1	RC	REC 100%	72		RQD = 100%
		2	RC	REC 100%	71, 70		RQD = 100%
		3	RC	REC 100%	69		RQD = 100%
68.6 / 7.3	END OF BOREHOLE						

Column headings: SOIL PROFILE; STRAT PLOT; SAMPLES; GROUND WATER CONDITIONS; ELEVATION SCALE; DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100; SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × REMOULDED 20 40 60 80 100; PLASTIC LIMIT W_P, NATURAL MOISTURE CONTENT W, LIQUID LIMIT W_L; WATER CONTENT (%) 25 50 75; UNIT WEIGHT γ kN/m³; REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL

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

PROJECT: 1546542-1030

RECORD OF DRILLHOLE: 16-301

SHEET 2 OF 2

LOCATION: N 5024851.3 ;E 362135.6

DRILLING DATE: June 23, 2016

DATUM: Geodetic

INCLINATION: -90° AZIMUTH: ---

DRILL RIG: CME 750

DRILLING CONTRACTOR: CCC

NOTE: For abbreviations, symbols and descriptions refer to LITHOLOGICAL AND GEOTECHNICAL ROCK DESCRIPTION TERMINOLOGY

DEPTH SCALE METRES	DRILLING RECORD	DESCRIPTION	SYMBOLIC LOG	ELEV. / DEPTH (m)	RUN No.	FLUSH RETURN	RECOVERY TOTAL CORE % (80 60 40 20)	RECOVERY SOLID CORE % (80 60 40 20)	R.Q.D. % (80 60 40 20)	FRACT. INDEX PER (5 10 15 20)	DISCONTINUITY DATA DIP w.r.t. CORE AXIS (0 30 60 90)	DISCONTINUITY DATA TYPE AND SURFACE DESCRIPTION	Jr	Ja	HYDRAULIC CONDUCTIVITY K, cm/sec (10^{-6} 10^{-5} 10^{-4} 10^{-3})	WEATHERING INDEX (W1 W2 W3 W4 W5 W6)	FEATURES
		Continued from Record of Borehole 16-301															
4	Rotary Drill, NQ Core	Limestone (BEDROCK), with shale interbeds Fresh Medium bedded Grey Medium strong to strong		72.22 3.68	1	100											
5					2	100											
6, 7					3	100											
		END OF DRILLHOLE		68.58 7.32													
8, 9, 10, 11, 12, 13																	

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DEPTH SCALE

1 : 50

Golder Associates

LOGGED: DG

CHECKED: KSL

RECORD OF BOREHOLE No 16-302

SHEET 1 OF 3 **METRIC**

PROJECT 1546542-1030
W.P. 4015-E-0017
LOCATION N 5024821.6 ;E 362167.2
ORIGINATED BY DG
DIST Eastern HWY 417
BOREHOLE TYPE Power Auger 200 mm Diam. (Hollow Stem)/Rotary Drill, NQ Core
COMPILED BY ZS
DATUM Geodetic
DATE June 27, 2016
CHECKED BY KSL

ELEV DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	WATER CONTENT (%)	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
76.8	GROUND SURFACE					
0.0	Silty sand (TOPSOIL)					
0.1	Brown Dry Silty sand (FILL) Compact	1	SS	15		
76.2 / 0.6	Brown Moist SILTY CLAY (WEATHERED CRUST) Grey-brown Very stiff Moist	2	SS	26	○	
75.4 / 1.4	Silty SAND, some clay, trace gravel, with occasional silt layer (TILL) Loose Brown Moist to wet	3	SS	9	○	
		4	SS	9		
		5	SS	7	○	9 41 36 14
		6	SS	7		
72.4 / 4.4	SAND and GRAVEL Compact to dense Grey Wet	7	SS	>50	○	52 45 (3)
71.9 / 4.9	Limestone (BEDROCK)	1	RC	REC 84%		RQD = 26%
		2	RC	REC 82%		RQD = 43%
		3	RC	REC 67%		RQD = 17%
68.8 / 8.0	Shale (BEDROCK)					
68.5 / 8.3	Limestone (BEDROCK) Bedrock cored from depths of 4.9 m to 10.2 m For bedrock coring details refer to Record of Drillhole 16-302	4	RC	REC 100%		RQD = 81%
		5	RC	REC 95%		RQD = 85%

Elevation scale: 76, 75, 74, 73, 72, 71, 70, 69, 68, 67

DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100
SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × REMOULDED 20 40 60 80 100
PLASTIC LIMIT W_P NATURAL MOISTURE CONTENT W LIQUID LIMIT W_L WATER CONTENT (%) 25 50 75
UNIT WEIGHT γ kN/m³

Continued Next Page

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

Foundation Design

RECORD OF BOREHOLE No 16-302 SHEET 2 OF 3 **METRIC**

PROJECT 1546542-1030

W.P. 4015-E-0017 LOCATION N 5024821.6 ;E 362167.2 ORIGINATED BY DG

DIST Eastern HWY 417 BOREHOLE TYPE Power Auger 200 mm Diam. (Hollow Stem)/Rotary Drill, NQ Core COMPILED BY ZS

DATUM Geodetic DATE June 27, 2016 CHECKED BY KSL

SOIL PROFILE			SAMPLES			GROUND WATER CONDITIONS	ELEVATION SCALE	DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100; SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × REMOULDED 20 40 60 80 100	PLASTIC LIMIT W_P NATURAL MOISTURE CONTENT W LIQUID LIMIT W_L; WATER CONTENT (%) 25 50 75	UNIT WEIGHT γ kN/m³	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
ELEV DEPTH	DESCRIPTION	STRAT PLOT	NUMBER	TYPE	"N" VALUES						
	--- CONTINUED FROM PREVIOUS PAGE ---										
66.6			5	RC							
10.2	END OF BOREHOLE										

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

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PROJECT: 1546542-1030

RECORD OF DRILLHOLE: 16-302

LOCATION: N 5024821.6 ;E 362167.2

DRILLING DATE: June 27, 2016

DATUM: Geodetic

INCLINATION: -90° AZIMUTH: ---

DRILL RIG: CME 750

DRILLING CONTRACTOR: CCC

NOTE: For abbreviations, symbols and descriptions refer to **LITHOLOGICAL AND GEOTECHNICAL ROCK DESCRIPTION TERMINOLOGY**

DEPTH SCALE METRES	DRILLING RECORD	DESCRIPTION	ELEV. / DEPTH (m)	RUN No.	FLUSH RETURN
		Continued from Record of Borehole 16-302	71.87		
5	Rotary Drill, NQ Core	Limestone (BEDROCK) Slightly weathered to fresh Medium bedded Grey Medium strong	4.93	1	0
6–7				2	0
7–8			68.80	3	0
8		Shale (BEDROCK) Fresh Black Medium strong	8.00	4	0
		Limestone (BEDROCK) with shale interbeds Fresh Medium bedded Grey Medium strong	68.50 8.30		
9–10			66.59	5	0
		END OF DRILLHOLE	10.21		

NOTES:

1. Fractured rock for Run 1 and 3 may be a result of drilling techniques/equipment (i.e., mechanical breaks).

Column headers: RECOVERY (TOTAL CORE %, SOLID CORE %), R.Q.D. %, FRACT. INDEX PER, DISCONTINUITY DATA (DIP w.r.t. CORE AXIS, TYPE AND SURFACE DESCRIPTION, Jr, Ja), HYDRAULIC CONDUCTIVITY K, cm/sec (10^{-6}, 10^{-5}, 10^{-4}, 10^{-3}), WEATHERING INDEX (W1–W6), FEATURES

Depth scale: 5, 6, 7, 8, 9, 10, 11, 12, 13, 14

DEPTH SCALE
1 : 50

Golder Associates

LOGGED: DG
CHECKED: KSL

Golder Associates

Foundation Design

RECORD OF BOREHOLE No 16-303

SHEET 1 OF 2

METRIC

PROJECT 1546542-1030

W.P. 4015-E-0017

LOCATION N 5024888.8 ;E 362143.7

ORIGINATED BY DG

DIST Eastern HWY 417

BOREHOLE TYPE Power Auger 200 mm Diam. (Hollow Stem)/Rotary Drill, NQ Core

COMPILED BY ZS

DATUM Geodetic

DATE June 26, 2016

CHECKED BY KSL

ELEV DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
75.7	GROUND SURFACE						
0.0	Silty sand (TOPSOIL)						
0.1	Brown Dry	1	SS	18			
75.3 0.4	Silty sand (FILL) Compact Brown Dry					75	
	SILTY CLAY to CLAYEY SILT (WEATHERED CRUST) Very stiff to stiff Grey-brown Wet	2	SS	9			
		3	SS	2		74	1 24 42 33
73.6 2.1	SILTY CLAY to CLAYEY SILT Firm Grey Wet						
73.1 2.6	Probable TILL					73	
72.8 2.9	Limestone (BEDROCK) Bedrock cored from depths of 2.9 m to 6.4 m For bedrock coring details refer to Record of Drillhole 16-303	1	RC	REC 100%			RQD = 75%
		2	RC	REC 88%		72 71	RQD = 60%
		3	RC	REC 100%		70	RQD = 100%
69.3 6.4	END OF BOREHOLE						

DYNAMIC CONE PENETRATION RESISTANCE PLOT: 20 40 60 80 100

SHEAR STRENGTH kPa: ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × REMOULDED: 20 40 60 80 100

PLASTIC LIMIT W_P NATURAL MOISTURE CONTENT W LIQUID LIMIT W_L

WATER CONTENT (%): 25 50 75

UNIT WEIGHT γ kN/m³

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

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PROJECT: 1546542-1030

RECORD OF DRILLHOLE: 16-303

LOCATION: N 5024888.8 ;E 362143.7

DRILLING DATE: June 26, 2016

DATUM: Geodetic

DRILL RIG: CME 45

INCLINATION: -90° AZIMUTH: ---

DRILLING CONTRACTOR: CCC

NOTE:
For abbreviations, symbols and descriptions refer to
LITHOLOGICAL AND GEOTECHNICAL ROCK DESCRIPTION TERMINOLOGY

DEPTH SCALE METRES	DRILLING RECORD	DESCRIPTION	ELEV. DEPTH (m)	RUN No.	FLUSH RETURN
		Continued from Record of Borehole 16-303	72.83		
3	Rotary Drill NQ Core	Limestone (BEDROCK), with shale interbeds Fresh Medium bedded Grey Medium Strong	2.87	1	100
4				2	100
5–6			69.27	3	100
		END OF DRILLHOLE NOTES: 1. Fractured rock for Run 2 may be a result of drilling techniques/equipment (i.e., mechanical breaks).	6.43		

Other column headings: SYMBOLIC LOG; RECOVERY (TOTAL CORE %, SOLID CORE %); R.Q.D. %; FRACT. INDEX PER; DISCONTINUITY DATA (DIP w.r.t. CORE AXIS; TYPE AND SURFACE DESCRIPTION; Jr; Ja); HYDRAULIC CONDUCTIVITY K, cm/sec (10^{-6}, 10^{-5}, 10^{-4}, 10^{-3}); WEATHERING INDEX (W1–W6); FEATURES

Depth scale: 3, 4, 5, 6, 7, 8, 9, 10, 11, 12

DEPTH SCALE
1 : 50

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LOGGED: DG
CHECKED: KSL

RECORD OF BOREHOLE No 16-304

SHEET 1 OF 1

METRIC

PROJECT 1546542-1030
W.P. 4015-E-0017
LOCATION N 5024794.4 ;E 362148.3
ORIGINATED BY JD
DIST Eastern HWY 417
BOREHOLE TYPE Power Auger 200 mm Diam. (Hollow Stem)
COMPILED BY ZS
DATUM Geodetic
DATE July 28, 2016
CHECKED BY KSL

ELEV DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	WATER CONTENT / LIMITS	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
81.2	GROUND SURFACE					
0.0	ASPHALTIC CONCRETE					
0.2	Sandy gravel (FILL) Grey-brown Moist					
80.6 / 0.6	Sand, some silt, trace clay and gravel, contains silty clay pockets (FILL) Compact Brown Moist	1	SS	11		
		2	SS	29		
		3	SS	27	w plotted	8 56 29 7
		4	SS	17		
77.4 / 3.8	Silty clay, some sand, some gravel (FILL) Dark grey-brown Moist	5	SS	14		
		6	SS	9		
75.9 / 5.3	Sand and silt, some clay, trace gravel, contains rootlets (FILL) Compact Dark grey-brown Moist	7	SS	13		
75.1 / 6.1	SILTY CLAY to CLAY, some sand (WEATHERED CRUST) Very stiff Grey-brown Wet	8	SS	6	wP, w, wL plotted	1 14 37 48
74.5 / 6.7	Silty SAND, some clay and gravel (TILL) Very loose Grey-brown Wet	9	SS	3		
		10	SS	2		
73.0 / 8.2	END OF BOREHOLE					

Column headings: SOIL PROFILE; SAMPLES; GROUND WATER CONDITIONS; ELEVATION SCALE (81–73); DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100; SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × REMOULDED 20 40 60 80 100; PLASTIC LIMIT W_P, NATURAL MOISTURE CONTENT W, LIQUID LIMIT W_L; WATER CONTENT (%) 25 50 75; UNIT WEIGHT γ kN/m³; STRAT PLOT.

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

Golder Associates

RECORD OF BOREHOLE No 16-305

SHEET 1 OF 1

METRIC

PROJECT: 1546542-1030			
W.P.: 4015-E-0017	LOCATION: N 5024885.1 ;E 362113.0	ORIGINATED BY: JD	
DIST: Eastern	HWY: 417	BOREHOLE TYPE: Power Auger 200 mm Diam. (Hollow Stem)	COMPILED BY: ZS
DATUM: Geodetic	DATE: July 26, 2016	CHECKED BY: KSL	

ELEV / DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	WATER CONTENT (%)	GR	SA	SI	CL
81.3	GROUND SURFACE									
81.1 / 0.0	ASPHALTIC CONCRETE									
0.2	Sandy silt, some gravel and clay (FILL) Grey-brown Moist				81					
80.8 / 0.5	Sand, contains silty clay pockets (FILL) Loose to compact Brown Moist	1	SS	8	80					
		2	SS	20						
		3	SS	11	79					
78.2 / 3.1	Sand and silt, some clay, trace gravel, contains wood fragments (FILL) Compact Dark grey-brown Moist to wet	4	SS	16	78					
		5	SS	17	77	○	7	30	36	27
		6	SS	10	76					
		7	SS	12						
75.2 / 6.1	Silty CLAY, some sand (WEATHERED CRUST) Very stiff to stiff Grey-brown Wet	8	SS	10	75					
		9	SS	2	74					
73.7 / 7.6	Sandy SILT, some gravel and clay (TILL) Very loose Brown Wet	10	SS	3		○	15	23	38	24
73.1 / 8.2	END OF BOREHOLE									

Column headings: SOIL PROFILE; STRAT PLOT; SAMPLES; GROUND WATER CONDITIONS; ELEVATION SCALE; DYNAMIC CONE PENETRATION RESISTANCE PLOT (20 40 60 80 100); SHEAR STRENGTH kPa: ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × REMOULDED (20 40 60 80 100); PLASTIC LIMIT W_P, NATURAL MOISTURE CONTENT W, LIQUID LIMIT W_L; WATER CONTENT (%) 25 50 75; UNIT WEIGHT γ kN/m³; REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL

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

Golder Associates

RECORD OF BOREHOLE No 16-310

SHEET 1 OF 1 **METRIC**

PROJECT 1546542-1030
W.P. 4015-E-0017
LOCATION N 5024902.8 ;E 362037.9
ORIGINATED BY DG
DIST Eastern HWY 417
BOREHOLE TYPE Power Auger 200 mm Diam. (Hollow Stem)
COMPILED BY ZS
DATUM Geodetic
DATE June 15, 2016
CHECKED BY KSL

ELEV DEPTH (m)	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	ELEVATION SCALE	WATER CONTENT (%)	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
75.1	GROUND SURFACE				75		
74.9 / 0.0	Silty sand (TOPSOIL) Dark brown Moist						
74.7 / 0.4	Sand (FILL) Light brown Dry	1	SS	8			
	Silt, some sand and clay (FILL) Loose Grey-brown Moist	2	SS	5	74	~27	0 23 49 28
74.1 / 1.0	SILTY CLAY Firm Grey Moist to wet						
73.6 / 1.5	Silty SAND, some gravel, trace clay, with cobbles and boulders (TILL) Loose Grey Wet	3	SS	3	73		
		4	SS	8			
		5	SS	50/0.03	72		
71.9 / 3.3	END OF BOREHOLE AUGER REFUSAL						

NOTES:

1. Water level in well screen at a depth of 1.7 m below ground surface (Elev. 73.4 m), measured on September 30, 2016.

Chart headings: DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100; SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × REMOULDED 20 40 60 80 100; PLASTIC LIMIT W_P, NATURAL MOISTURE CONTENT W, LIQUID LIMIT W_L; WATER CONTENT (%) 25 50 75; UNIT WEIGHT γ kN/m³; STRAT PLOT; GROUND WATER CONDITIONS.

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

Foundation Design

Golder Associates

RECORD OF BOREHOLE No 16-311

SHEET 1 OF 1 **METRIC**

PROJECT 1546542-1030

W.P. 4015-E-0017 LOCATION N 5024866.7 ;E 362074.2 ORIGINATED BY DG

DIST Eastern HWY 417 BOREHOLE TYPE Power Auger 200 mm Diam. (Hollow Stem) COMPILED BY ZS

DATUM Geodetic DATE June 15, 2016 CHECKED BY KSL

ELEV / DEPTH	DESCRIPTION	NUMBER	TYPE	"N" VALUES	WATER CONTENT (%)	GR	SA	SI	CL
76.6	GROUND SURFACE								
76.4 / 0.0–0.2	Silty sand (TOPSOIL) Dark brown Moist								
76.0 / 0.6	Silty sand, some gravel (FILL) Compact Brown Moist	1	SS	10	○				
	Silty SAND, some gravel and clay (TILL) Loose to compact Grey-brown to grey Wet	2	SS	9	○				
		3	SS	14	○				
		4	SS	9	○	12	40	34	14
73.5 / 3.1	END OF BOREHOLE AUGER REFUSAL	5	SS	50/0.2	○				

Column headings: SOIL PROFILE (ELEV DEPTH, DESCRIPTION, STRAT PLOT); SAMPLES (NUMBER, TYPE, "N" VALUES); GROUND WATER CONDITIONS; ELEVATION SCALE (76, 75, 74); DYNAMIC CONE PENETRATION RESISTANCE PLOT 20 40 60 80 100; SHEAR STRENGTH kPa ○ UNCONFINED + FIELD VANE ● QUICK TRIAXIAL × REMOULDED 20 40 60 80 100; PLASTIC LIMIT W_P, NATURAL MOISTURE CONTENT W, LIQUID LIMIT W_L, WATER CONTENT (%) 25 50 75; UNIT WEIGHT γ kN/m³; REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL

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

GTA-MTO 001 N:\ACTIVE\SPATIAL_IM\MTO\HWY417REHAB&WIDENING\02_DATA\GINT\1546542.GPJ GAL-GTA.GDT 04/04/17 JM

Golder Associates

RECORD OF BOREHOLE No 16-312

SHEET 1 OF 1

METRIC

PROJECT 1546542-1030

W.P. 4015-E-0017

LOCATION N 5024850.9 ;E 362007.2

ORIGINATED BY DG

DIST Eastern HWY 417

BOREHOLE TYPE Power Auger 200 mm Diam. (Hollow Stem)

COMPILED BY ZS

DATUM Geodetic

DATE June 15, 2016

CHECKED BY KSL

ELEV DEPTH	DESCRIPTION	SAMPLE NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	WATER CONTENT (%)	UNIT WEIGHT γ kN/m³	GR	SA	SI	CL
75.3	GROUND SURFACE											
0.0	Silty sand (TOPSOIL) Dark brown Moist	1	SS	10		75						
0.1	Silty sand, some gravel (FILL) Compact Brown Moist											
74.5 0.8	CLAYEY SILT to Sandy SILT (TILL) Loose to compact Grey Moist	2	SS	8		74	~25		0	12	53	35
		3	SS	10								
73.2 2.1	END OF BOREHOLE AUGER REFUSAL											

Legend: DYNAMIC CONE PENETRATION RESISTANCE PLOT (20, 40, 60, 80, 100); SHEAR STRENGTH kPa (20, 40, 60, 80, 100): ○ UNCONFINED, + FIELD VANE, ● QUICK TRIAXIAL, × REMOULDED; PLASTIC LIMIT W_P, NATURAL MOISTURE CONTENT W, LIQUID LIMIT W_L; WATER CONTENT (%) 25, 50, 75; REMARKS & GRAIN SIZE DISTRIBUTION (%)

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

GTA-MTO 001 N:\ACTIVE\SPATIAL_IM\MTO\HWY417REHAB&WIDENING\02_DATA\GINT\1546542.GPJ GAL-GTA.GDT 04/04/17 JM

BH 16-301 (Dry)
Cored Length of 3.68 to 7.32 metres
Core Box 1 to 2 of 2

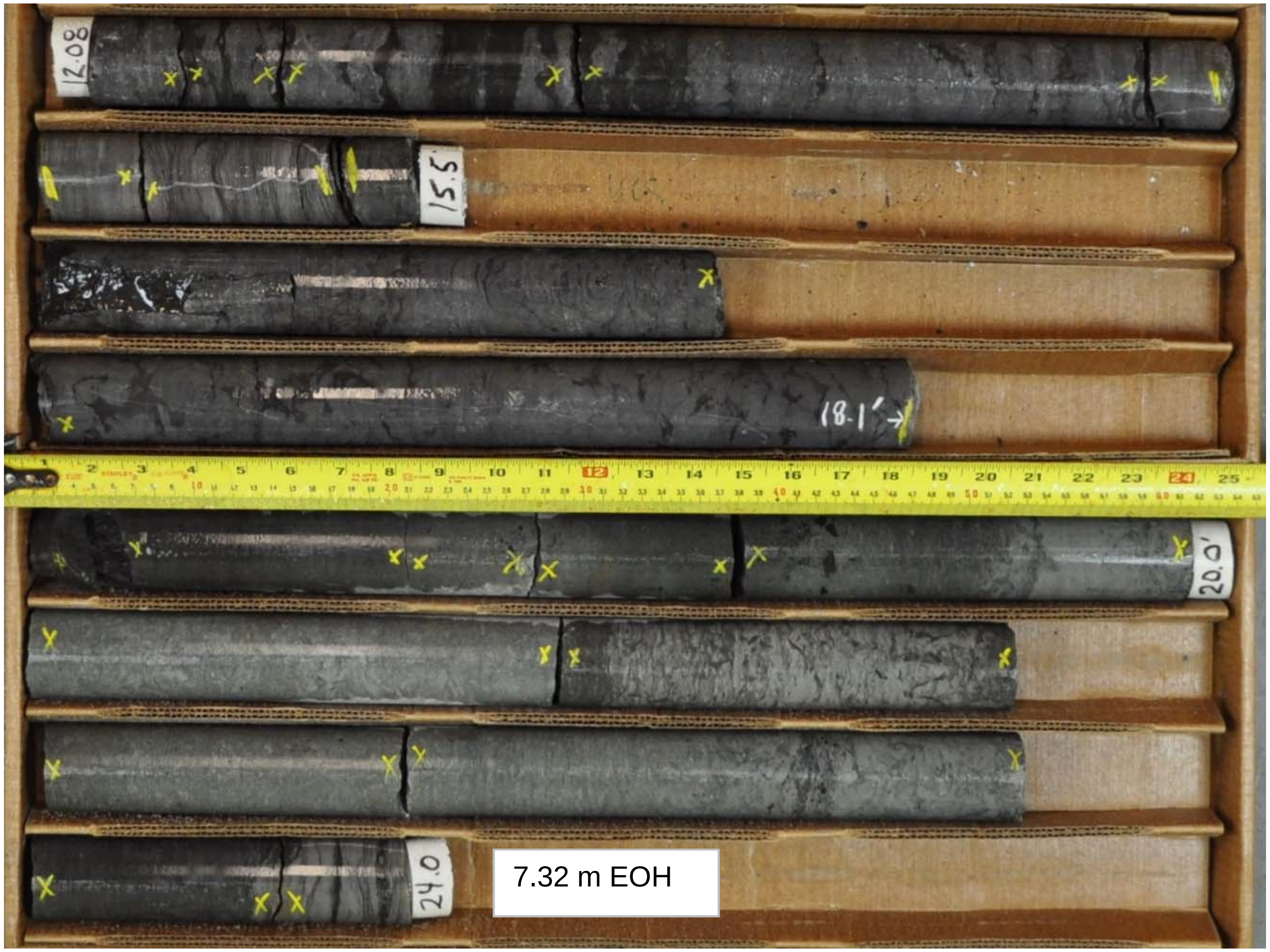
3.68 m Top of bedrock

CLIENT MMM Group Limited		PROJECT MMM/ MTO 4014-E-0017 HIGHWAY 417/ OTTAWA WOODROFFE UNDERPASS	
CONSULTANT Golder Associates	YYY/MM/DD: 2/23/2017 PREPARED: KM DESIGN: KM REVIEW: KSL APPROVED: ESO	TITLE **BOREHOLE 16-301 (DRY)** **CORE PHOTOGRAPHS**	
		PROJECT No. 1546542	PHASE 1030
		Rev. 0a	FIGURE A1

Path: N:\Active\2015\3 Proj\1546542 MMM MTO 4015-E-0017Ottawa\Foundations\6 - Reports\1030 - Woodroffe Avenue\Appendix A\16-301 Core Photo Plate.xlsx | File: 16-301 Core Photo Plate.xlsx

BH 16-301 (Wet)
Cored Length of 3.68 to 7.32 metres
Core Box 1 to 2 of 2

3.68 m Top of bedrock



7.32 m EOH

CLIENT		PROJECT
MMM Group Limited		MMM/ MTO 4014-E-0017 HIGHWAY 417/ OTTAWA WOODROFFE UNDERPASS

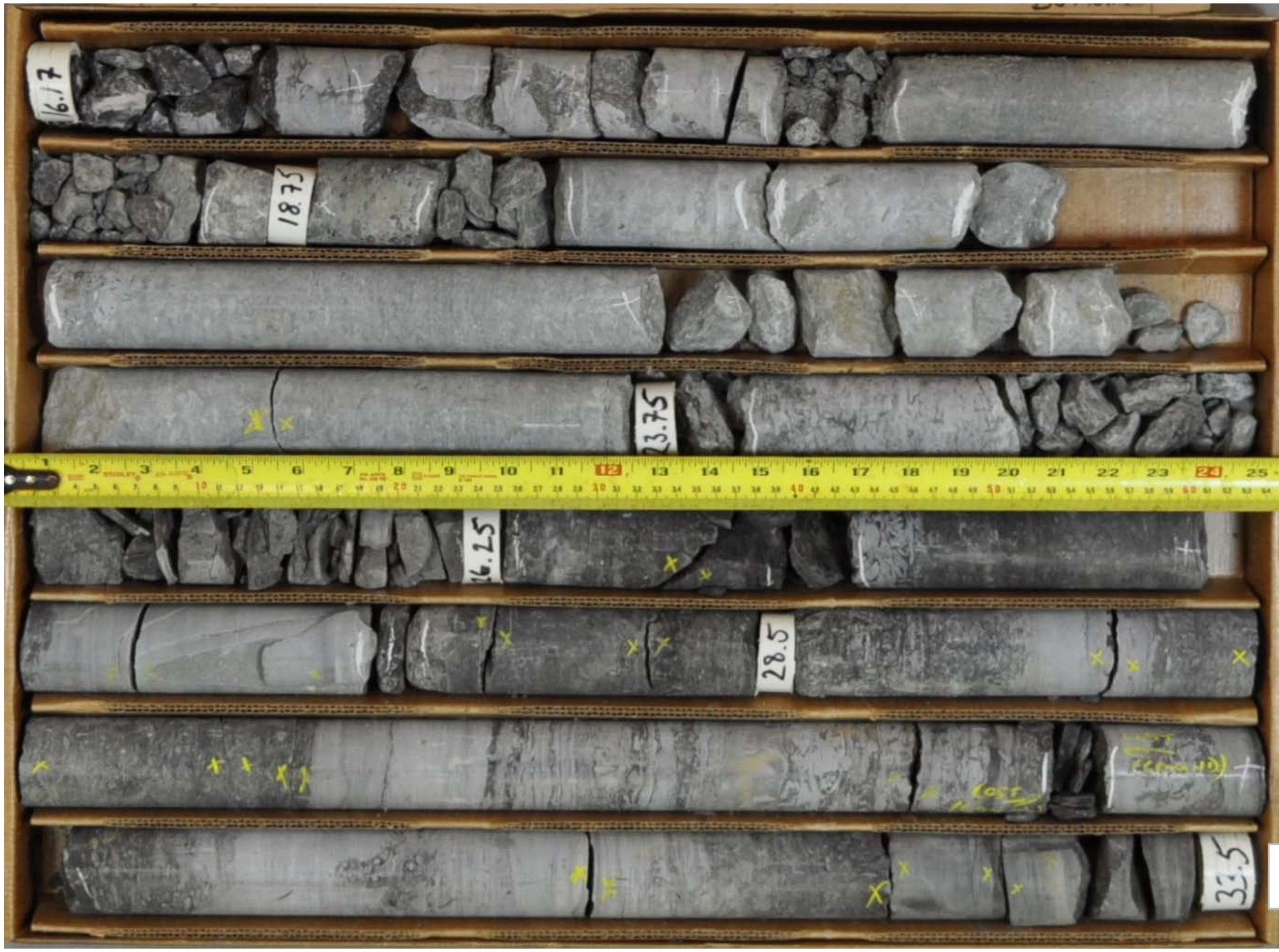
CONSULTANT			TITLE
Golder Associates	YYY/MM/DD	2/23/207	**BOREHOLE 16-301 (WET) CORE PHOTOGRAPHS**
	PREPARED	KM	
	DESIGN	KM	
	REVIEW	KSL	
	APPROVED	ESO	

PROJECT No.	PHASE	Rev.	FIGURE
1546542	1030	0a	A2

Path: N:\Active\2015\3 Proj\1546542 MMM MTO 4015-E-0017Ottawa\Foundations\6 - Reports\1030 - Woodroffe Avenue\Appendix A\16-302 Core Photo Plate.xlsx | File: 16-302 Core Photo Plate.xlsx

BH 16-302 (Dry)
Cored Length of 4.93 to 10.21 metres
Core Box 1 to 2 of 2

4.93 m Top of bedrock



10.21 m EOH

CLIENT	PROJECT
MMM Group Limited	MMM/ MTO 4014-E-0017 HIGHWAY 417/ OTTAWA WOODROFFE UNDERPASS

CONSULTANT			TITLE
Golder Associates	YYY/MM/DD	2/23/2017	**BOREHOLE 16-302 (DRY)** **CORE PHOTOGRAPHS**
	PREPARED	KM	
	DESIGN	KM	
	REVIEW	KSL	
	APPROVED	ESO	

PROJECT No.	PHASE	Rev.	FIGURE
1546542	1030	0a	A3

BH 16-302 (Wet)
Cored Length of 4.93 to 10.21 metres
Core Box 1 to 2 of 2

4.93 m Top of bedrock

10.21 m EOH

CLIENT	PROJECT
MMM Group Limited	MMM/ MTO 4014-E-0017 HIGHWAY 417/ OTTAWA WOODROFFE UNDERPASS

CONSULTANT
Golder Associates

YYY/MM/DD	2/23/2017
PREPARED	KM
DESIGN	KM
REVIEW	KSL
APPROVED	ESO

TITLE
BOREHOLE 16-302 (WET)
CORE PHOTOGRAPHS

PROJECT No.	PHASE	Rev.	FIGURE
1546542	1030	0a	A4

BH 16-303 (Dry)
Cored Length of 2.87 to 6.43 metres
Core Box 1 to 2 of 2

2.87 m Top of bedrock

6.43 m EOH

CLIENT	PROJECT
MMM Group Limited	MMM/ MTO 4014-E-0017 HIGHWAY 417/ OTTAWA WOODROFFE UNDERPASS

CONSULTANT		
Golder Associates	YYY/MM/DD	2/23/2017
	PREPARED	KM
	DESIGN	KM
	REVIEW	KSL
	APPROVED	ESO

TITLE
BOREHOLE 16-303 (DRY)
CORE PHOTOGRAPHS

PROJECT No.	PHASE	Rev.	FIGURE
1546542	1030	0a	A5

BH 16-303 (Wet)
Cored Length of 2.87 to 6.43 metres
Core Box 1 to 2 of 2

2.87 m Top of bedrock

6.43 m EOH

CLIENT		PROJECT
MMM Group Limited		MMM/ MTO 4014-E-0017 HIGHWAY 417/ OTTAWA WOODROFFE UNDERPASS

CONSULTANT			TITLE
Golder Associates	YYY/MM/DD	2/23/2017	**BOREHOLE 16-303 (WET)** **CORE PHOTOGRAPHS**
	PREPARED	KM	
	DESIGN	KM	
	REVIEW	KSL	
	APPROVED	ESO	

PROJECT No.	PHASE	Rev.	FIGURE
1546542	1030	0a	A6

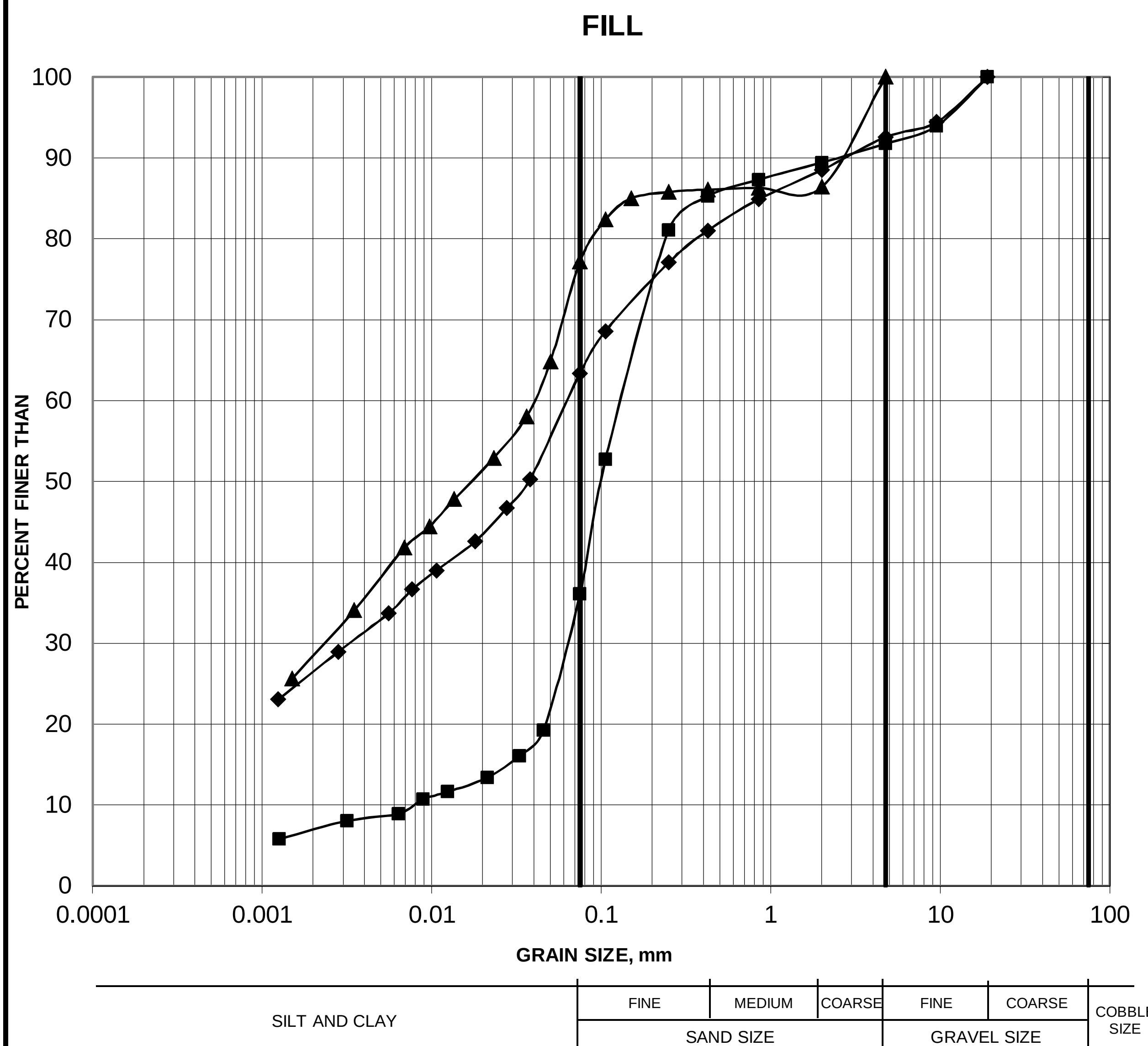
APPENDIX B

Laboratory Test Results, Current Investigation

Figure 1 - Grain Size Distribution Test Results –Sand and Silt (FILL)
Figure 2 - Plasticity Chart – Silty Clay to Clayey Silt (Weathered Crust)
Figure 3 - Grain Size Distribution Test Results – Silty Clay to Clayey Silt (Weathered Crust)
Figure 4 - Grain Size Distribution Test Results – Till
Figure 5 - Grain Size Distribution Test Results – Sand and Gravel
Figure 6 - UCS Test Result – Bedrock

GRAIN SIZE DISTRIBUTION

FIGURE 1

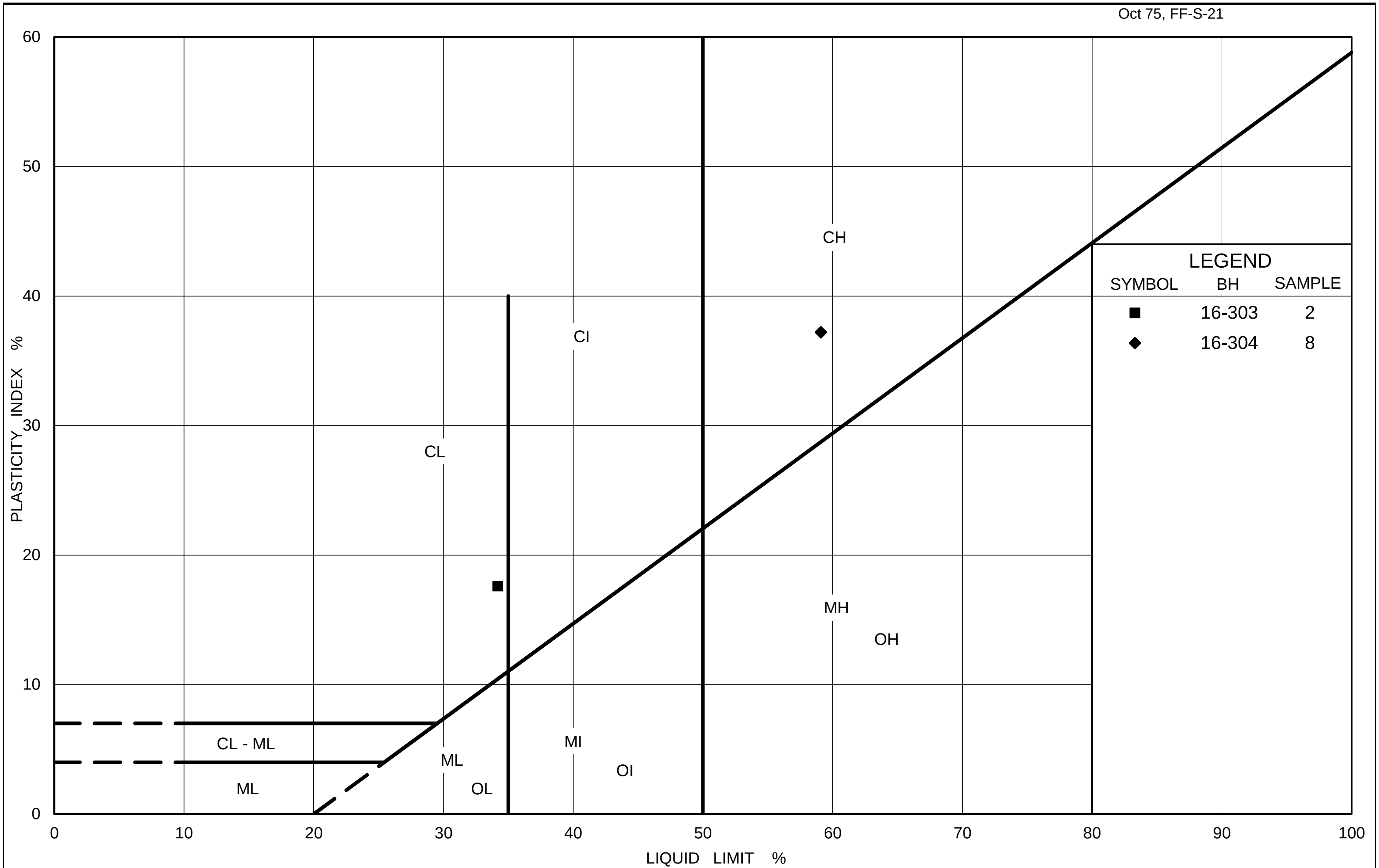


Borehole	Sample	Depth (m)
16-304	3	2.29-2.90
16-305	5	3.81-4.42
16-310	2A	0.76-1.04

Project: 1546542-1030

Golder Associates

Created by:	CW
Checked by:	CNM



Ministry of Transportation

Ontario

PLASTICITY CHART

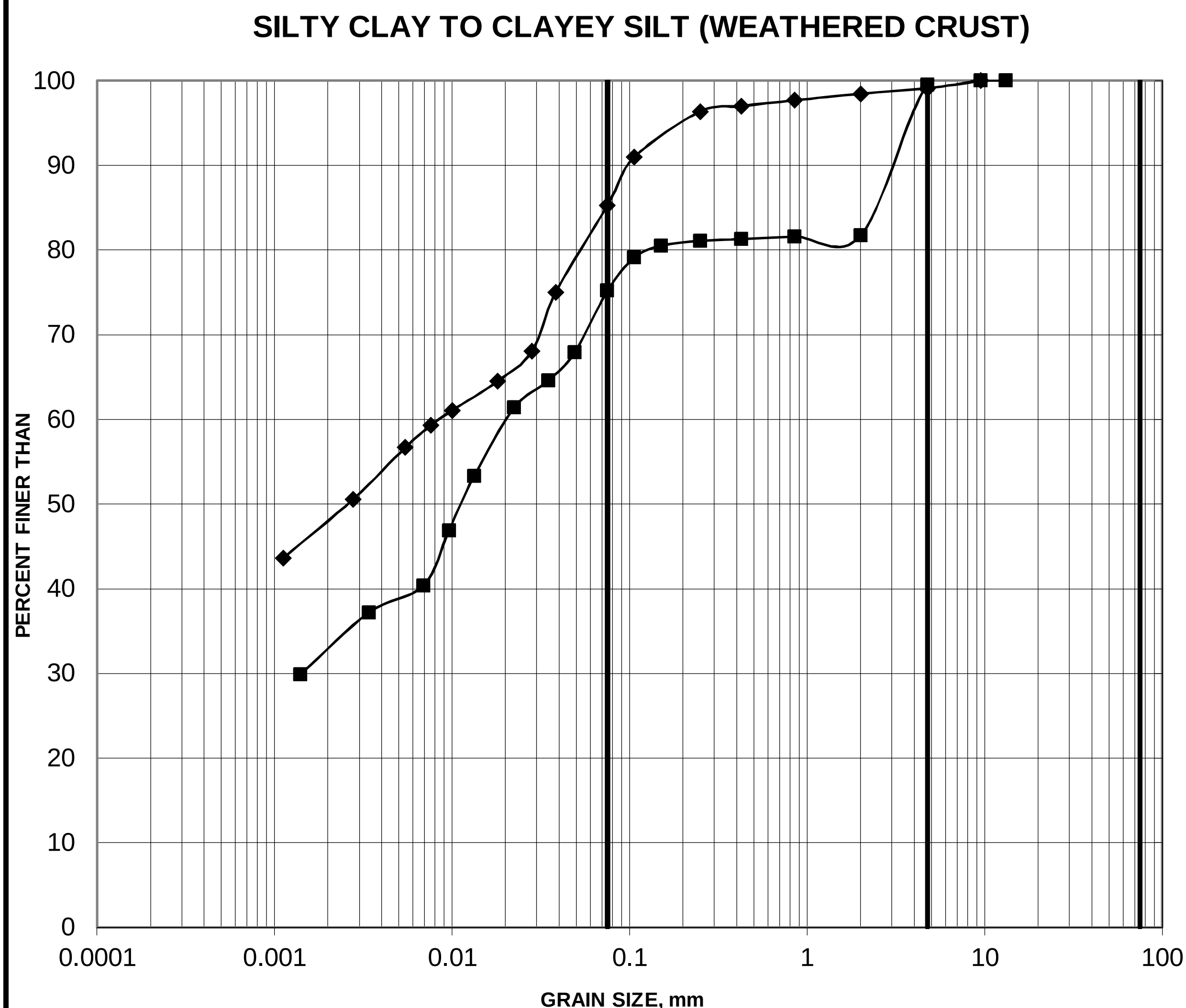
SILTY CLAY TO CLAYEY SILT (WEATHERED CRUST)

FIG No. 2

Project No. 1546542-1030

Compiled By : CW Checked By : CNM

GRAIN SIZE DISTRIBUTION	FIGURE 3



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

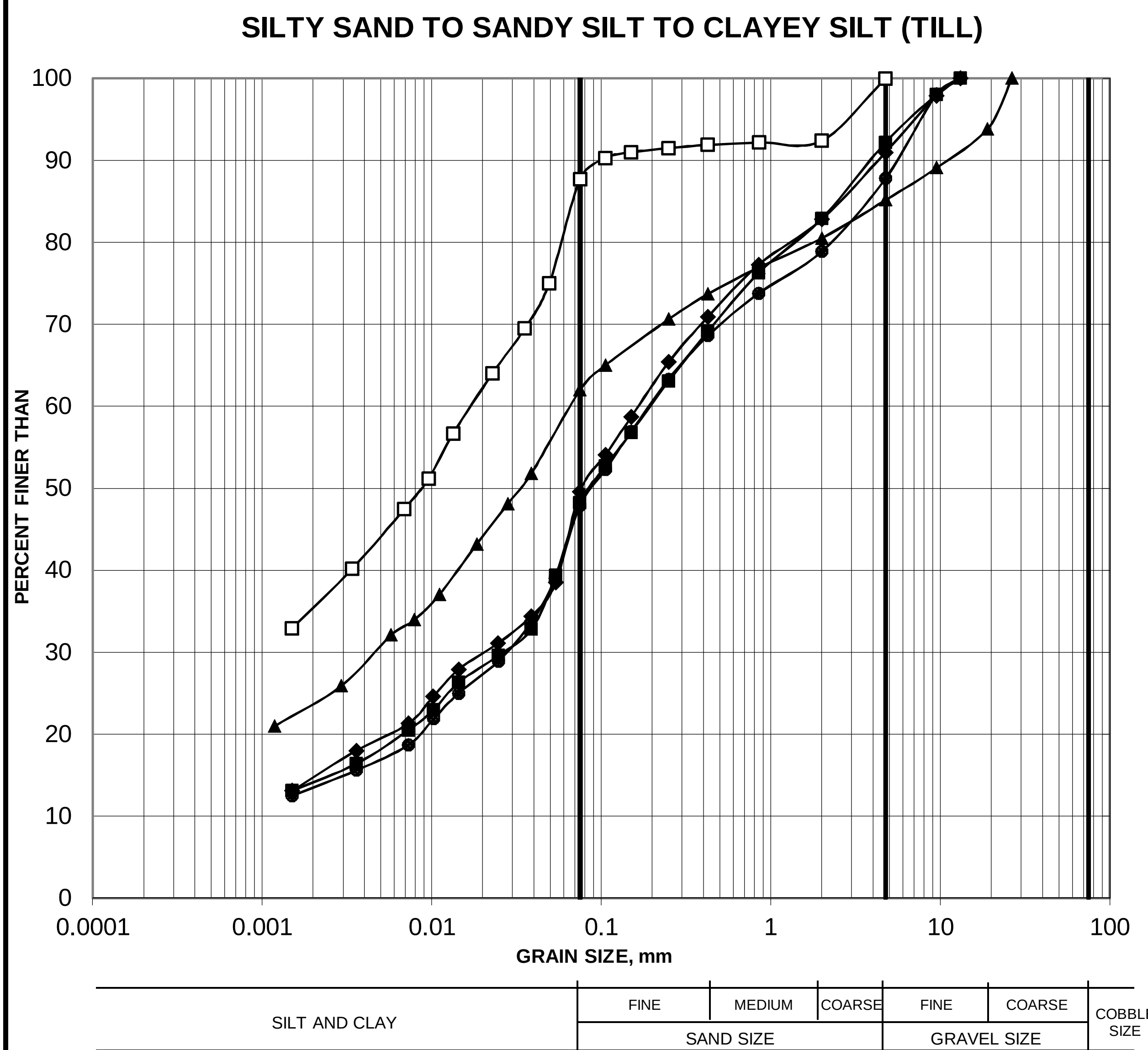
Borehole	Sample	Depth (m)
16-303	3	1.52-2.13
16-304	8	6.10-6.71

Project: 1546542-1030

Golder Associates

Created by: CW
Checked by: CNM

GRAIN SIZE DISTRIBUTION	FIGURE 4



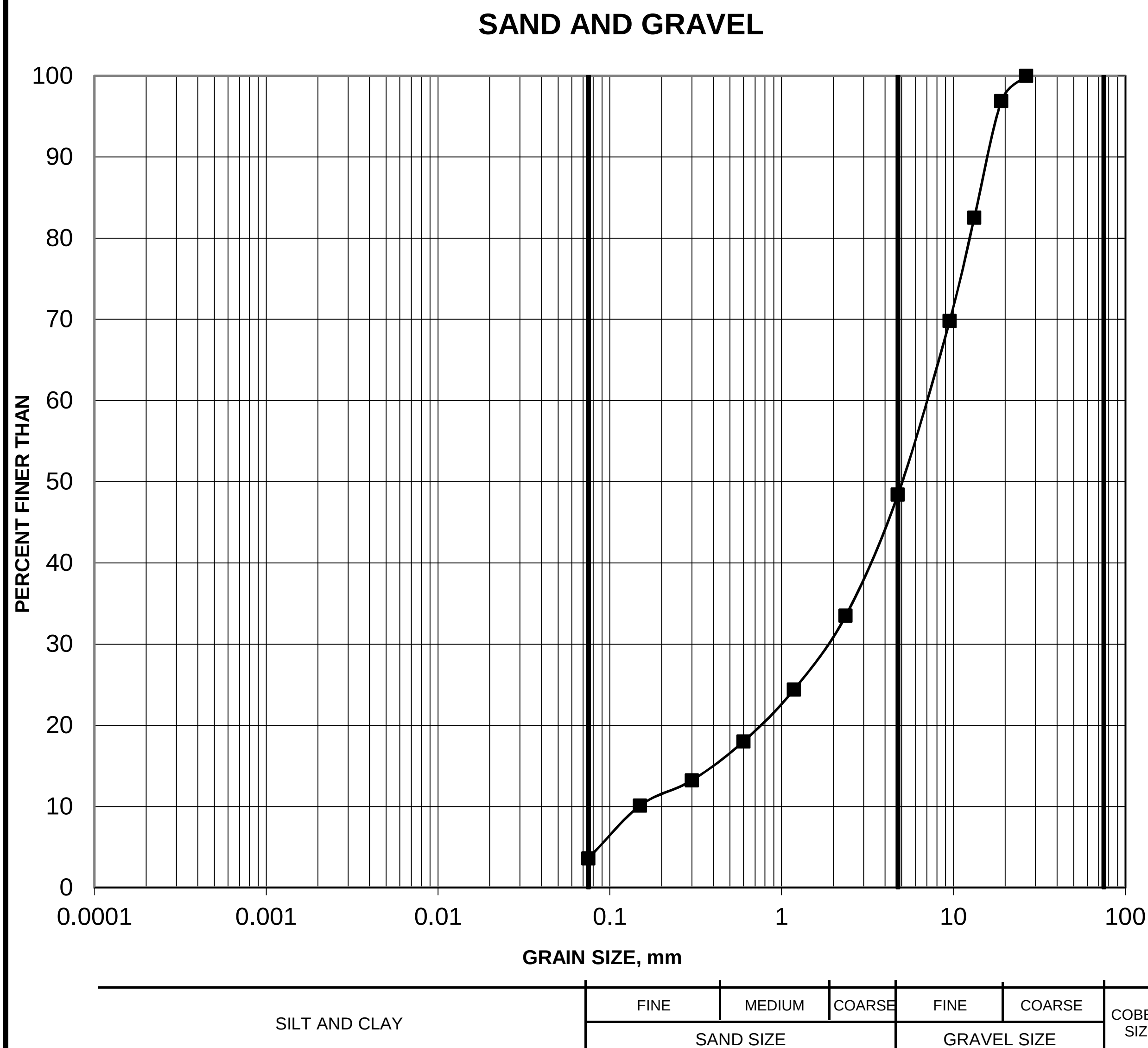
Borehole	Sample	Depth (m)
16-301	4	2.29-2.90
16-302	5	3.05-3.66
16-305	10	7.62-8.23
16-311	4	2.29-2.90
16-312	2	0.76-1.37

Project: 1546542-1030

Golder Associates

Created by: CW
Checked by: CNM

GRAIN SIZE DISTRIBUTION	FIGURE 5



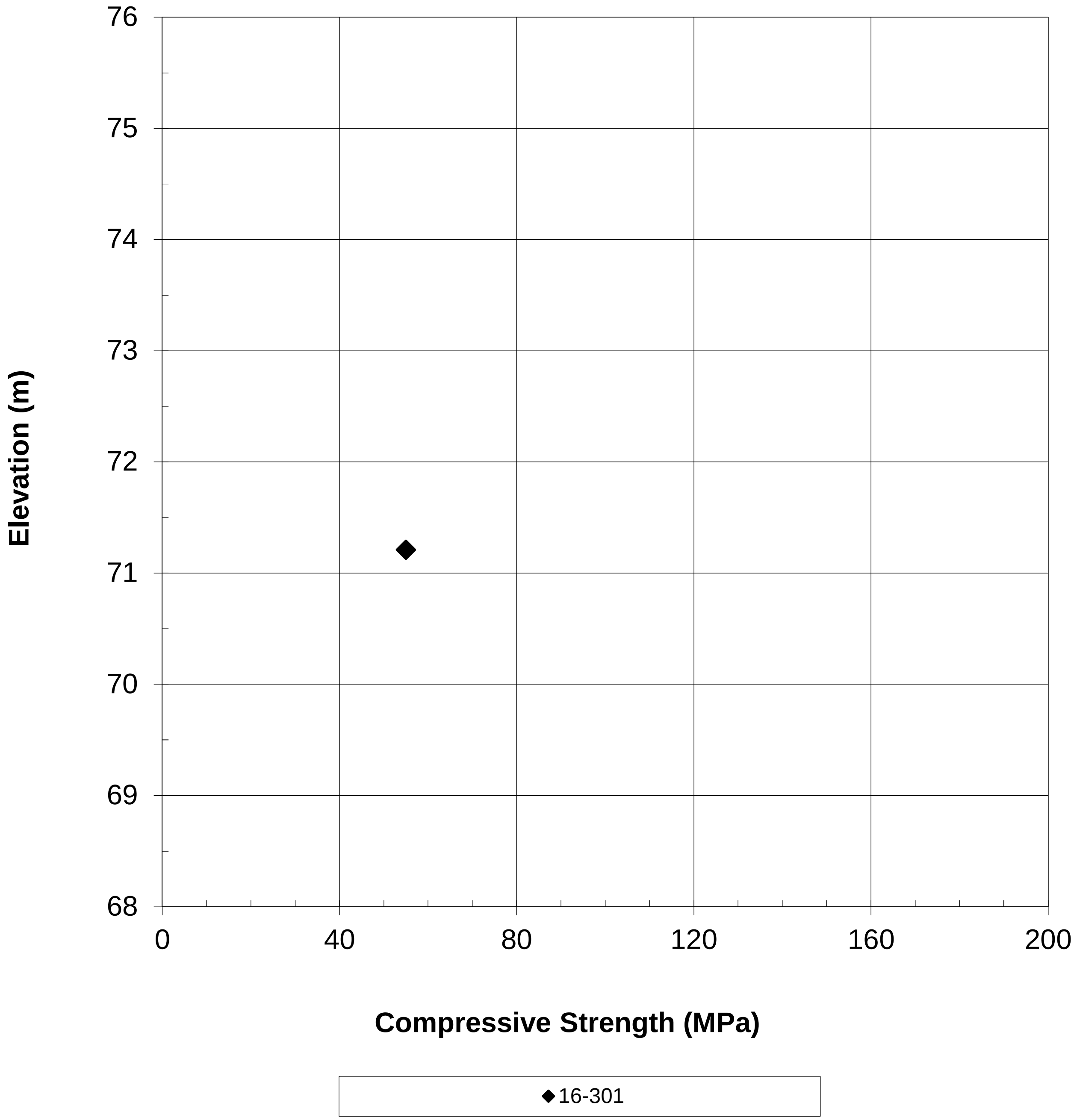
Borehole	Sample	Depth (m)
16-302	7	4.57-4.85

Project: 1546542-1030

Golder Associates

Created by: CW
Checked by: CNM

SUMMARY OF LABORATORY COMPRESSIVE STRENGTH UNCONFINED COMPRESSION TESTS	FIGURE 6



Project: 1546542-1030

Golder Associates

Created by: CNM
Checked by: CW

APPENDIX C

Records of Previous Boreholes 1 to 6 (Geocres No. 31G5-021)

FORM S-10-2

McROSTIE & ASSOCIATES
CONSULTING ENGINEERS
OTTAWA CANADA

SOIL PROFILE AND SUMMARY OF LABORATORY TESTS

QUEENSWAY AT WOODROFFE
BRIDGE No. 2

ELEVATION OF GROUND SURFACE (ZERO DEPTH) 245.7 GEODETIC

HOLE No. 1

REMARKS REF. BM No. 11-G El. 252.3

DATE MAY 16, 1958

UNCONFINED COMPRESSIVE STRENGTH Kips/Ft.²	SMALL SCALE PENETROMETER KIPS/FT.²	STANDARD PENETRATION BLOWS/FT.	SAMPLE NUMBER	DESCRIPTION OF SOIL (GROUND SURFACE)	DEPTH IN FEET	ELEVATION
					0	245.7
				TOP SOIL (1.0)		244.7
				CLAY (2.5)	2	243.2
			1-1	LOOSE TILL	4	
		8	1-2	(6.5)	6	239.2
		50	1-3	DENSE TILL (9.0)	8	236.7
				SHALY LIMESTONE (DRILLED) CORE RECOVERY 85% BEDDING THICKNESS 2" (14.0)	10, 12, 14	231.7
				(DRILLED) SHALY LIMESTONE CORE RECOVERY 70% (16.5)	16	229.2
				LIMESTONE (DRILLED) CORE RECOVERY 96% BEDDING THICKNESS 4" (19.0)	18	226.7
				BOTTOM OF HOLE	20	

PENETRATION TEST

.......LB. HAMMER ......INCH DROP — NO CASING ......INCH DIA. ROD — BLOWS PER FOOT

NO OVERNIGHT WATER

% WATER CONTENT

PLATE 2

McROSTIE & ASSOCIATES
CONSULTING ENGINEERS
OTTAWA CANADA

SOIL PROFILE AND SUMMARY OF LABORATORY TESTS

QUEENSWAY AT WOODROFFE
BRIDGE No. 2

ELEVATION OF GROUND SURFACE (ZERO DEPTH) 248.3 - GEODETIC

REMARKS SEE PLATE 2

DATE MAY 20' 1958

HOLE No. 2

UNCONFINED COMPRESSIVE STRENGTH KIPS/FT.²	SMALL SCALE PENETROMETER KIPS/FT.²	STANDARD PENETRATION BLOWS/FT.	SAMPLE NUMBER	DESCRIPTION OF SOIL	DEPTH IN FEET	ELEVATION
				GROUND SURFACE	0	248.3
				TOP SOIL 1.0		247.3
	9.0 9.0 9.0 9.0	7	2-1	HARD, FISSURED SILTY BROWNISH-GRAY CLAY 4.5	2, 4	243.8
		22	2-2	MEDIUM DENSE TILL	6	
		29	2-3	9.0	8	239.3
		89	2-4	DENSE TILL 12.0	10, 12	236.3
				SHALY LIMESTONE (DRILLED - CORE RECOVERY 100%) BEDDING THICKNESS 3" 17.3	14, 16	231.0
				LIMESTONE (DRILLED) CORE RECOVERY 97% BEDDING THICKNESS 3" 1/2" DROP & WATER LOST AT 17'-10" 22.4	18, 20, 22	225.9
				BOTTOM OF HOLE		

PENETRATION TEST
......LB. HAMMER ......INCH DROP
NO CASING ......INCH DIA. ROD
BLOWS PER FOOT

OVERNIGHT WATER LEVEL 11.7 FT.

% WATER CONTENT

PLATE 3

FORM S-10-2

McROSTIE & ASSOCIATES
CONSULTING ENGINEERS
OTTAWA CANADA

SOIL PROFILE AND SUMMARY OF LABORATORY TESTS

QUEENSWAY AT WOODROFFE
BRIDGE No. 2

ELEVATION OF GROUND SURFACE (ZERO DEPTH) 247.0 - GEODETIC

REMARKS SEE PLATE 2

DATE MAY 21 1958

HOLE No. 3

Unconfined Compressive Strength Kips/Ft.²	Small Scale Penetrometer Kips/Ft.²	Standard Penetration Blows/Ft.	Sample Number	Description of Soil	Depth in Feet	Elevation
				GROUND SURFACE		
				TOP SOIL (1.0)	0	247.0
						246.0
	6.0 5.3 4.6	5	3-1	VERY STIFF, FISSURED SILTY BROWNISH-GRAY CLAY	2, 4	
		1 for 6"	3-2A	(5.5)		241.5
		4	3-2B	LOOSE TILL	6	
		8 / 10 for 6"	3-3	(8.5)	8	238.5
				MEDIUM DENSE TILL (10.0)	10	237.0
		37 for 6" / 35 for 4"		DENSE TILL (10.8)		236.2
				SHALY LIMESTONE (DRILLED) CORE RECOVERY 86% BEDDING THICKNESS 2" (14.5)	12, 14	232.5
				SHALY LIMESTONE CORE RECOVERY 98% BEDDING THICKNESS 3" (19.7)	16, 18	227.3
				LIMESTONE (DRILLED) - CORE RECOVERY 100% - BEDDING 3" (21.1)	20	225.9
				BOTTOM OF HOLE	22	

PENETRATION TEST

........LB. HAMMER ....INCH DROP | NO CASING ....INCH DIA. ROD

BLOWS PER FOOT

OVERNIGHT WATER LEVEL 10.6 FT.

% WATER CONTENT

PLATE 4

FORM S-10-2

McROSTIE & ASSOCIATES
CONSULTING ENGINEERS
OTTAWA CANADA

SOIL PROFILE AND SUMMARY OF LABORATORY TESTS

QUEENSWAY AT WOODROFFE
BRIDGE No. 2

ELEVATION OF GROUND SURFACE (ZERO DEPTH) 247.9 - GEODETIC
REMARKS SEE PLATE 2

HOLE No. 4

DATE MAY 21-22, 1958

Unconfined Compressive Strength Kips/Ft.²	Small Scale Penetrometer Kips/Ft.²	Standard Penetration Blows/Ft.	Sample Number	Description of Soil	Depth in Feet	Elevation	Penetration Test
				GROUND SURFACE	0	247.9	
				TOP SOIL 1.0		246.9	
	6.0 5.3 4.8	5	4-1	VERY STIFF FISSURED SILTY BROWNISH-GRAY CLAY 4.0	2 4	243.9	
	2.4 2.2 2.0	3	4-2	STIFF, FISSURED, SILTY BROWNISH-GRAY CLAY 6.5	6	241.4	
		8	4-3	LOOSE TILL 10.0	8 10	237.9	
		19 20 for 6"	4-4	MEDIUM DENSE TILL 11.0			
		90	4-5	11.7 DENSE SANDY TILL 16.7	12 14 16	231.2	OVERNIGHT WATER LEVEL 11.8 FT.
				LIMESTONE (DRILLED) CORE RECOVERY 95% BEDDING THICKNESS 3" 21.8	18 20 22	226.1	
				SHALY LIMESTONE (DRILLED - CORE RECOVERY 68% PORTION OF CORE COULD NOT BE RETRIEVED) BEDDING THICKNESS 2" 27.0	24 26	220.9	
				BOTTOM OF HOLE	28		

PENETRATION TEST: ....LB. HAMMER ....INCH DROP; NO CASING ....INCH DIA. ROD; BLOWS PER FOOT

% WATER CONTENT

PLATE 5

L.-M. CO.—A26553

FORM S-10-2

McROSTIE & ASSOCIATES
CONSULTING ENGINEERS
OTTAWA CANADA

SOIL PROFILE AND SUMMARY OF LABORATORY TESTS

QEENSWAY AT WOODROFFE
BRIDGE No. 2

ELEVATION OF GROUND SURFACE (ZERO DEPTH) 247.8

REMARKS SEE PLATE 2

DATE MAY 22-25, 1958

HOLE No. 5

UNCONFINED COMPRESSIVE STRENGTH KIPS/FT.²	SMALL SCALE PENETROMETER KIPS/FT.²	STANDARD PENETRATION BLOWS/FT.	SAMPLE NUMBER	DESCRIPTION OF SOIL	DEPTH IN FEET	ELEVATION
				GROUND SURFACE	0	247.8
				TOP SOIL	1.0	246.8
	6.0 / 5.6 / 3.4	6	S-1	VERY STIFF, FISSURED SILTY BROWNISH-GRAY CLAY	2	
	4.8 / 4.4 / 4.2	4	S-2		4	
					6.5	241.3
		204	S-3	DENSE SANDY TILL	8	
		115			10.5	237.3
				SHALY LIMESTONE (DRILLED) CORE RECOVERY 93% BEDDING THICKNESS 2"	12, 14	
					15.8	232.0
				LIMESTONE (DRILLED) CORE RECOVERY 91% BEDDING THICKNESS 4"	16, 18, 20	
				BOTTOM OF HOLE	21.7	226.1

PENETRATION TEST

........LB. HAMMER ....INCH DROP

NO CASING ....INCH DIA. ROD

BLOWS PER FOOT

NO OVERNIGHT WATER

% WATER CONTENT

PLATE 6

FORM S-10-2

McROSTIE & ASSOCIATES
CONSULTING ENGINEERS
OTTAWA CANADA

SOIL PROFILE AND SUMMARY OF LABORATORY TESTS

QUEENSWAY AT WOODROFFE
BRIDGE No. 2

ELEVATION OF GROUND SURFACE (ZERO DEPTH): 247.7 - GEODETIC

REMARKS: SEE PLATE 2

HOLE No. 6

DATE MAY 20-21-1958

PENETRATION TEST: ....LB. HAMMER; ....INCH DROP; NO CASING; ....INCH DIA. ROD; BLOWS PER FOOT

UNCONFINED COMPRESSIVE STRENGTH Kips/Ft.²	SMALL SCALE PENETROMETER KIPS/FT.²	STANDARD PENETRATION BLOWS/FT.	SAMPLE NUMBER	DESCRIPTION OF SOIL	DEPTH IN FEET	ELEVATION
				GROUND SURFACE	0	247.7
				TOP SOIL 1.0		246.7
	6.4, 6.3, 6.0	6	6-1	VERY STIFF, FISSURED SILTY BROWNISH-GRAY CLAY 4.0	2, 4	243.7
		14	6-2	MEDIUM DENSE	6	
		13	6-3	TILL	8	
		15, 3 for 2"	6-4	11.2	10	236.5
				SHALY LIMESTONE (DRILLED) CORE RECOVERY 78% BEDDING THICKNESS 2" 15.3	12, 14	232.4
				SHALY LIMESTONE 1" drop - WATER LOST AT 16'-4" BEDDING THICKNESS 2" (DRILLED CORE RECOVERY 88%)	16, 18	
				LIMESTONE BEDDING THICKNESS 2" 20.8	20	226.9
				BOTTOM OF HOLE	22	

OVERNIGHT WATER LEVEL 11.2 FT. (at elevation 236.5)

% WATER CONTENT

PLATE 7

L.-M. CO.—A2655S

APPENDIX D

Results of MASW Testing

TECHNICAL MEMORANDUM

DATE February 15, 2017 **PROJECT No.** 1546542

TO Kim Lesage
Golder Associates Ltd.

CC

FROM Stephane Sol, Christopher Phillips **EMAIL** ssol@golder.com;cphillips@golder.com

NBCC SEISMIC SITE CLASS TESTING RESULTS - HWY417 WIDENING PROJECT
4 LOOP RAMP LOCATIONS ALONG HIGHWAY417, OTTAWA, ONTARIO

This technical memorandum presents the results of four Multichannel Analysis of Surface Waves (MASW) tests performed for the purpose of the 2010 National Building Code of Canada (NBCC2010) Seismic Site Classification for a Highway 417 widening project located along HWY417, Ottawa, Ontario. Site 1 is located within the HWY417 southwest loop ramp just west of Richmond Road (Richmond Site - Figure 1). Site 2 is located within the HWY417 southwest loop ramp just west of Pinecrest/ Greenbank Road (Pinecrest Site - Figure 2). Site 3 is located within the HWY417 northwest loop ramp just west of Woodroffe Avenue (Woodroffe Site - Figure 3). Site 4 is located within the HWY417 northwest loop ramp just west of Maitland Avenue (Maitland Site - Figure 4).

The geophysical testing was performed by Golder personnel on May 26 and 27, 2016.

Figure 1: MASW Location Site Map at the Richmond site (MASW Line 1 in red)

Figure 2: MASW Location Site Map at the Pinecrest site (MASW Line 2 in red)

Figure 3: MASW Location Site Map at the Woodroffe site (MASW Line 3 in red)

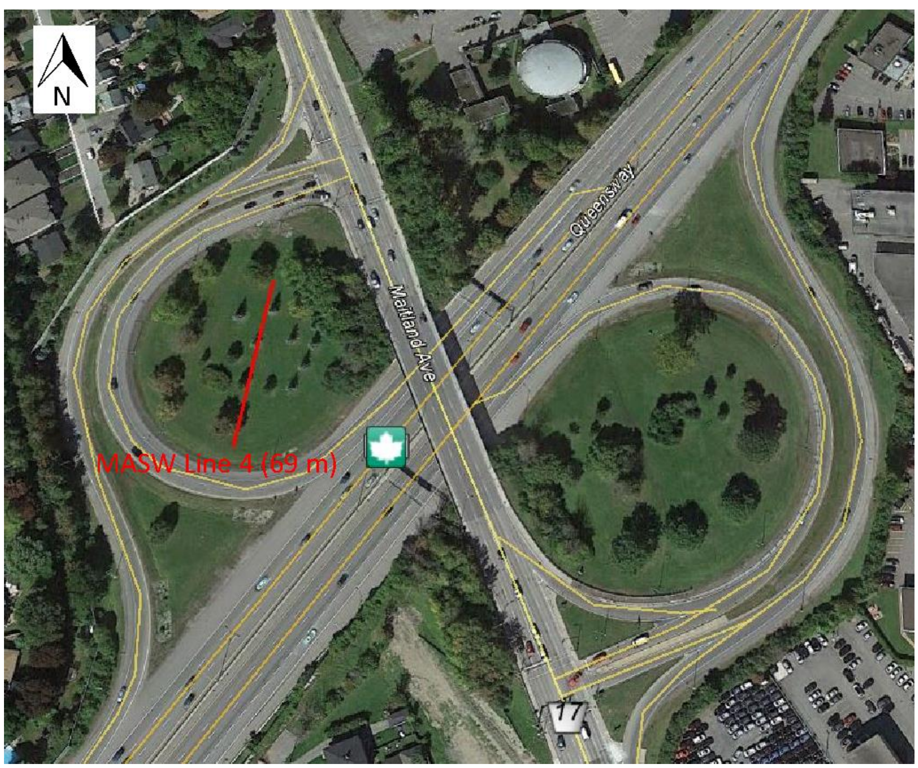


Figure 4: MASW Location Site Map at the Maitland site (MASW Line 4 in red)

Methodology

The MASW method measures variations in surface-wave velocity with increasing distance and wavelength and can be used to infer the rock/soil types, stratigraphy and soil conditions.

A typical MASW survey requires a seismic source, to generate surface waves, and a minimum of two geophone receivers, to measure the ground response at some distance from the source. Surface waves are a special type of seismic wave whose propagation is confined to the near surface medium.

The depth of penetration of a surface wave into a medium is directly proportional to its wavelength. In a non-homogeneous medium, surface waves are dispersive, i.e., each wavelength has a characteristic velocity owing to the subsurface heterogeneities within the depth interval that particular wavelength of surface wave propagates through. The relationship between surface-wave velocity and wavelength is used to obtain the shear-wave velocity and attenuation profile of the medium with increasing depth.

The seismic source used can be either active or passive, depending on the application and location of the survey. Examples of active sources include explosives, weight-drops, sledge hammer and vibrating pads. Examples of passive sources are road traffic, micro-tremors, and water-wave action (in near-shore environments).

The geophone receivers measure the wave-train associated with the surface wave travelling from a seismic source at different distances from the source.

The participation of surface waves with different wavelengths can be determined from the wave-train by transforming the wave-train results into the frequency domain. The surface-wave velocity profile with respect to wavelength (called the ‘dispersion curve’) is determined by the delay in wave propagation measured between the geophone receivers. The dispersion curve is then matched to a theoretical dispersion curve using an iterative forward-modelling procedure. The result is a shear-wave velocity profile of the tested medium with depth, which can be used to estimate the dynamic shear-modulus of the medium as a function of depth.

Field Work

The MASW field work was conducted on May 26 and 27 by personnel from the Golder Mississauga and Ottawa offices. One MASW line was collected at each of the four sites (Figures 1, 2, 3 and 4).

For each survey line a series of 24 low frequency (4.5 Hz) geophones were laid out at 3-metre intervals. Both active and passive readings were recorded along each MASW lines. For the active investigation, a seismic drop of 45 kg and a 9.9 kg sledge hammer were used as seismic sources. Active seismic records were collected with seismic sources located 5, 10, 15, and 20 metres from and collinear to the geophone array. An example of active seismic records collected for MASW Lines 1, 2 and 3 are shown in Figures 5, 6, 7 and 8, respectively below. MASW Line 4 located west of Maitland Avenue had a higher noise level due to large amount of road traffic.

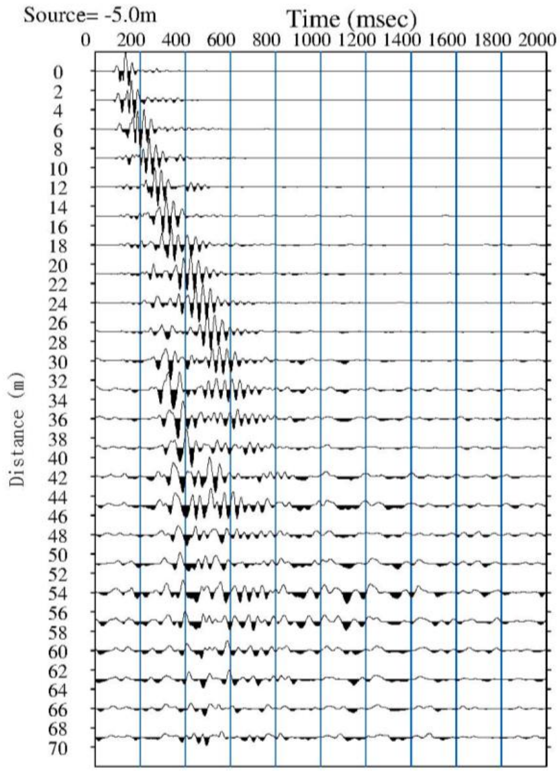


Figure 5: Typical seismic record collected along MASW Line 1

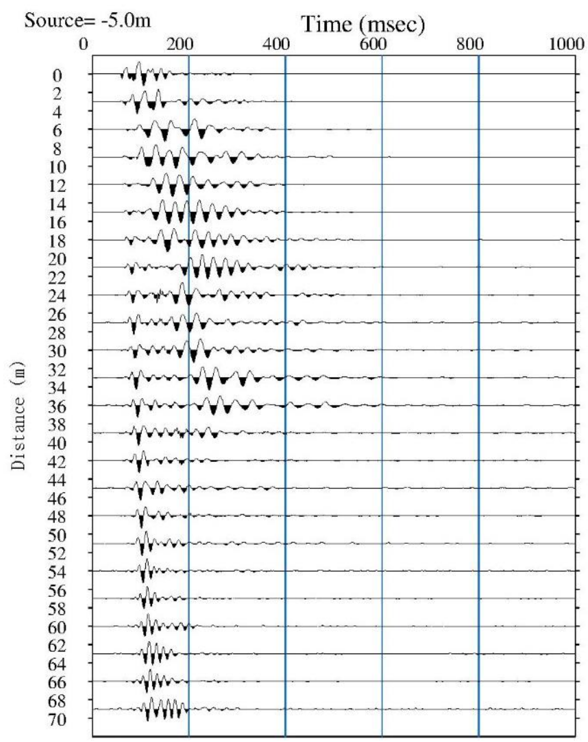


Figure 6: Typical seismic record collected along MASW Line 2

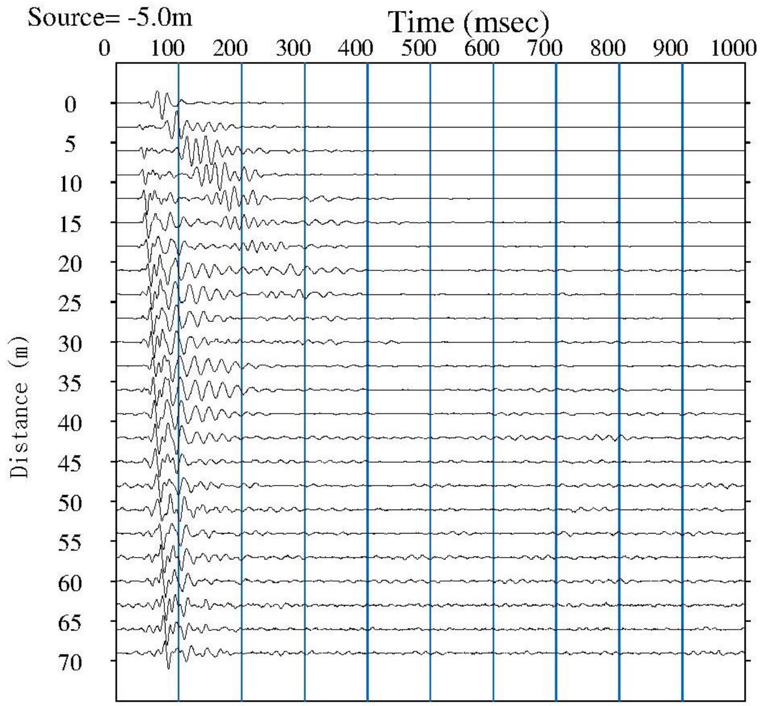


Figure 7: Typical seismic record collected along MASW Line 3

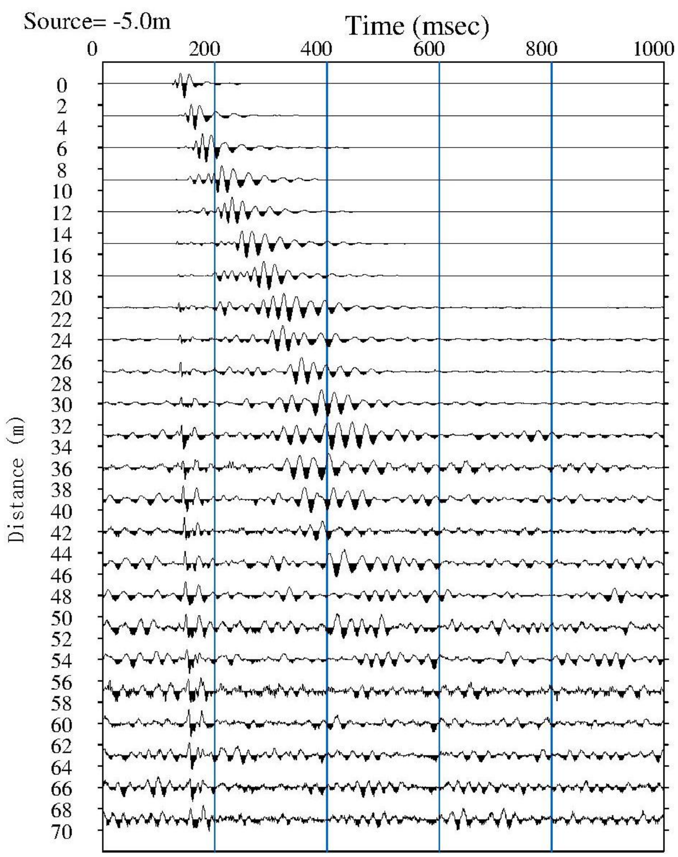


Figure 8: Typical seismic record collected along MASW Line 4

Data Processing

Processing of the MASW test results consisted of the following main steps:

1) Transformation of the time domain data into the frequency domain using a Fast-Fourier Transform (FFT) for each source location;
2) Calculation of the phase for each frequency component;
3) Linear regression to calculate phase velocity for each frequency component;
4) Filtering of the calculated phase velocities based on the Pearson correlation coefficient (r2) between the data and the linear regression best fit line used to calculate phase velocity;
5) Generation of the dispersion curve by combining calculated phase velocities for each shot location of a single MASW test; and,
6) Generation of the stiffness profile, through forward iterative modelling and matching of model data to the field collected dispersion curve.

Processing of the MASW data was completed using the SeisImager/SW software package (Geometrics Inc.). The calculated phase velocities for a seismic shot point were combined and the dispersion curve generated by choosing the minimum phase velocity calculated for each frequency component as shown on Figures 9, 10, 11 and 12. Shear-wave velocity profiles were generated through inverse modelling to best fit the calculated dispersion curves.

Along MASW Line 1, the active survey provided a dispersion curve with a suitable frequency range (5 to 27 Hz), providing information for both shallow and deeper depths. The minimum measured surface-wave frequency with sufficient signal-to-noise ratio to accurately measure phase velocity was approximately 5 Hz.

Along MASW Line 2, the active survey provided a dispersion curve with a suitable frequency range (30-150 Hz), providing information for both shallow and deeper depths. The minimum measured surface-wave frequency with sufficient signal-to-noise ratio to accurately measure phase velocity was approximately 30 Hz.

Along MASW Line 3, the active survey provided a dispersion curve with a suitable frequency range (35-135 Hz), providing information for both shallow and deeper depths. The minimum measured surface-wave frequency with sufficient signal-to-noise ratio to accurately measure phase velocity was approximately 35 Hz.

Along MASW Line 4, the active survey provided a dispersion curve with a suitable frequency range (17-58 Hz), providing information for both shallow and deeper depths. The minimum measured surface-wave frequency with sufficient signal-to-noise ratio to accurately measure phase velocity was approximately 17 Hz.

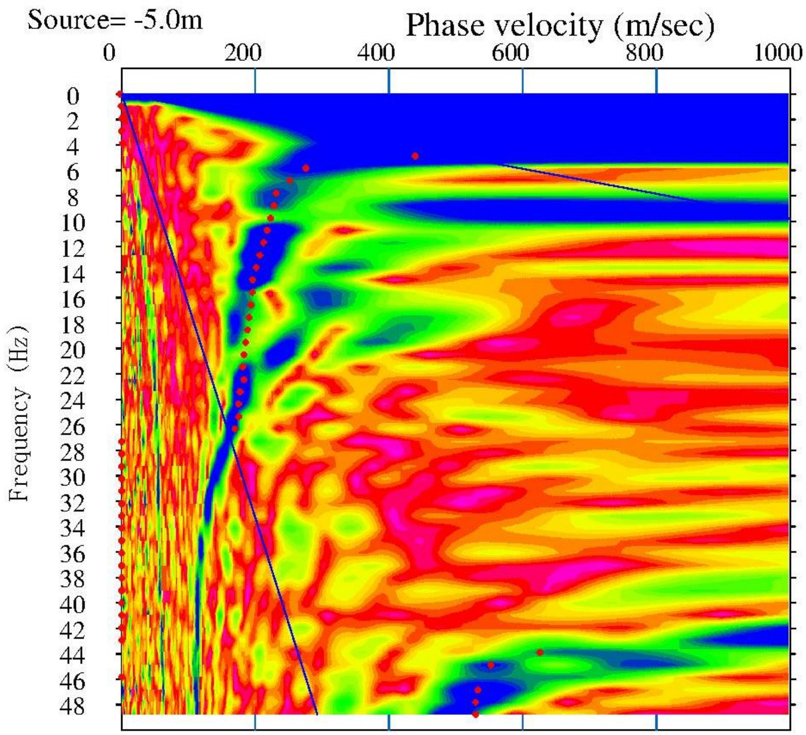


Figure 9: Active MASW Dispersion Curve Picks (red dots) along MASW Line 1 (Richmond)

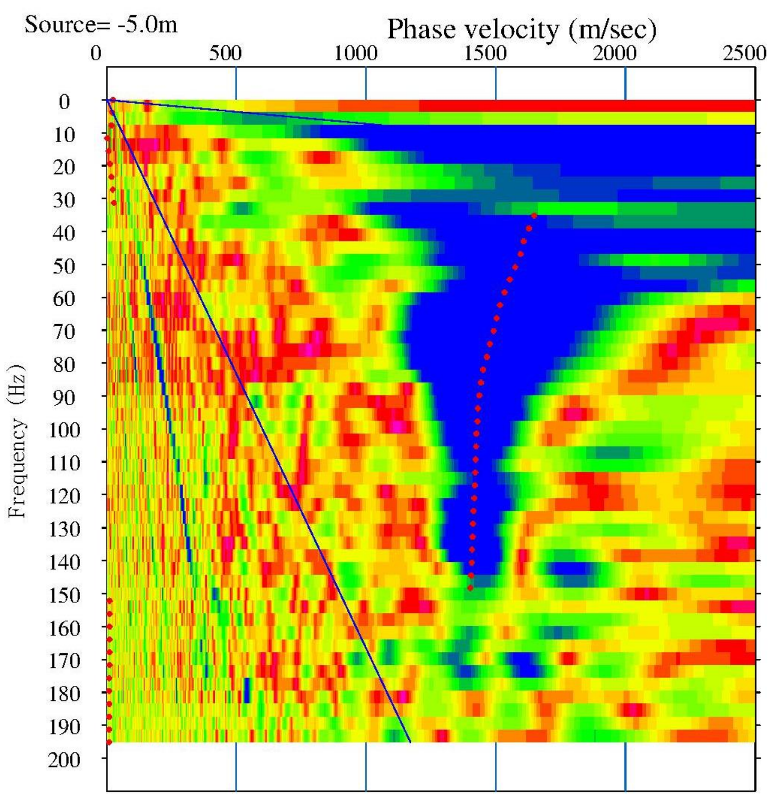


Figure 10: Active MASW Dispersion Curve Picks (red dots) along MASW Line 2 (Pinecrest).

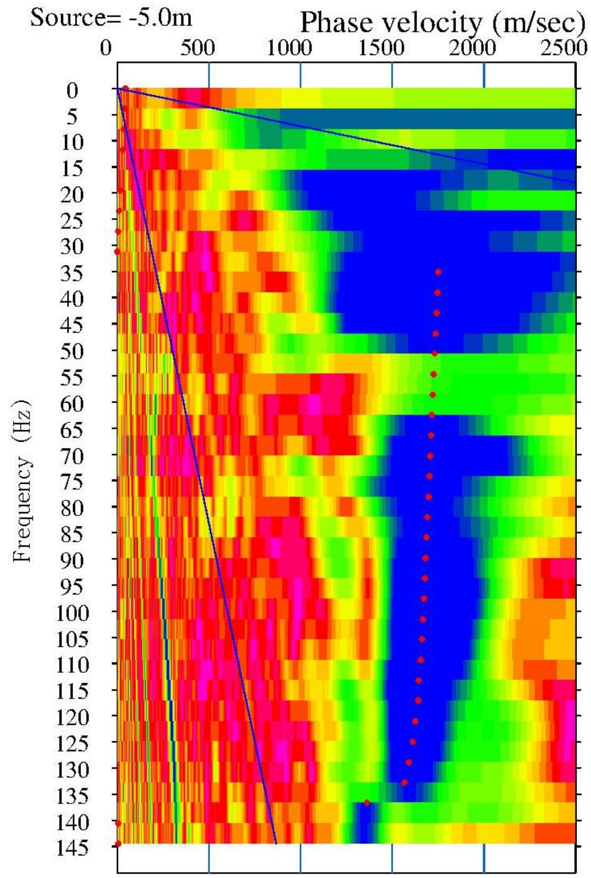


Figure 11: Active MASW Dispersion Curve Picks (red dots) along MASW Line 3 (Woodroffe).

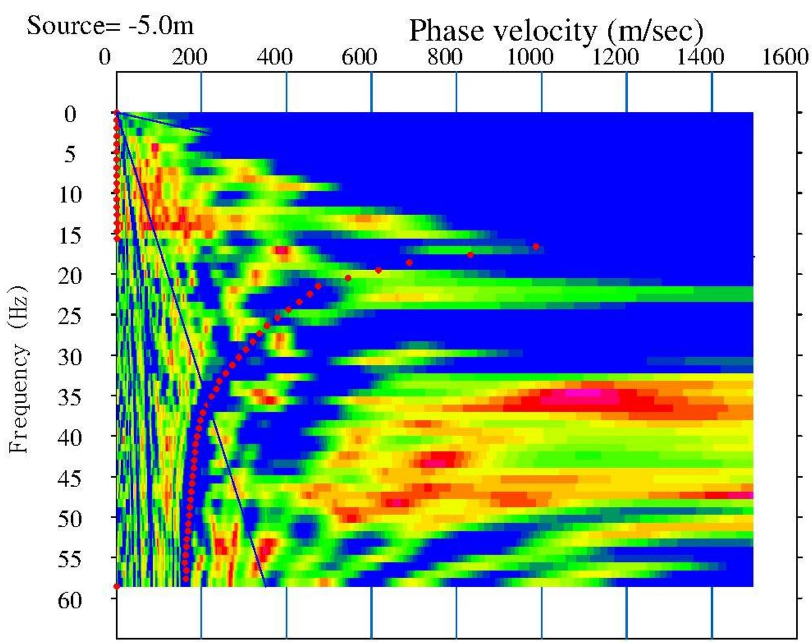


Figure 12: Active MASW Dispersion Curve Picks (red dots) along MASW Line 4 (Maitland).

Results

The MASW test results are presented in Figure 13 (MASW Line 1 - Richmond), Figure 14 (MASW Line 2 - Pinecrest), Figure 15 (MASW Line 3 - Woodroofe) and Figure 16 (MASW Line 4 - Maitland), which present the calculated shear wave velocity profile derived from the field testing. The results along MASW Lines 1, 2, and 3 have been calculated using weight-drop located at 5 metres from the last geophone, respectively. The field collected dispersion curves are compared with the model generated dispersion curves on Figures 17, 18, 19 and 20. There is a satisfactory correlation between the field collected and model calculated dispersion curves, with a root mean squared error of less than 4% along the three MASW lines.

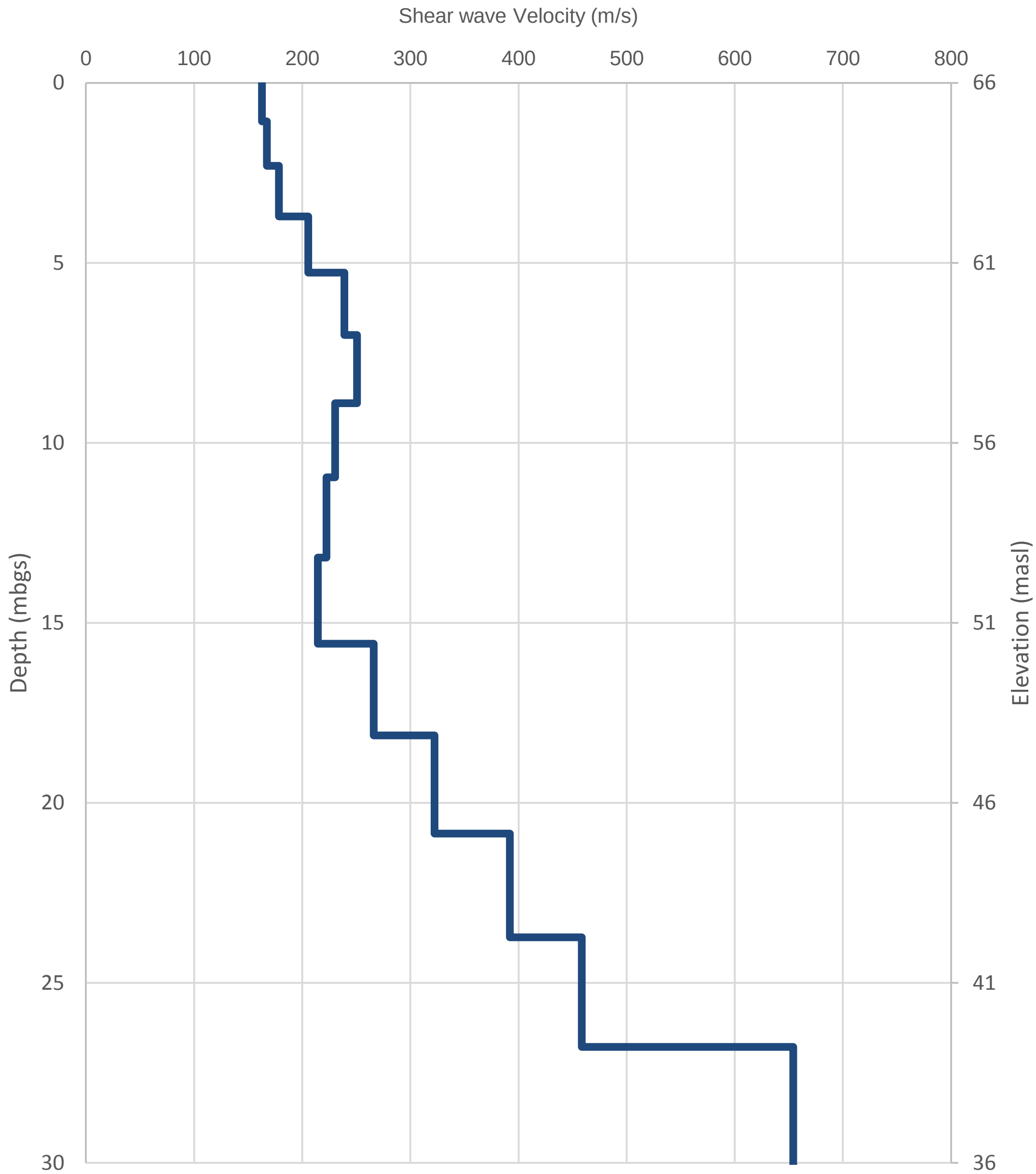


Figure 13: MASW Modelled Shear-Wave Velocity Depth profile along MASW Line 1

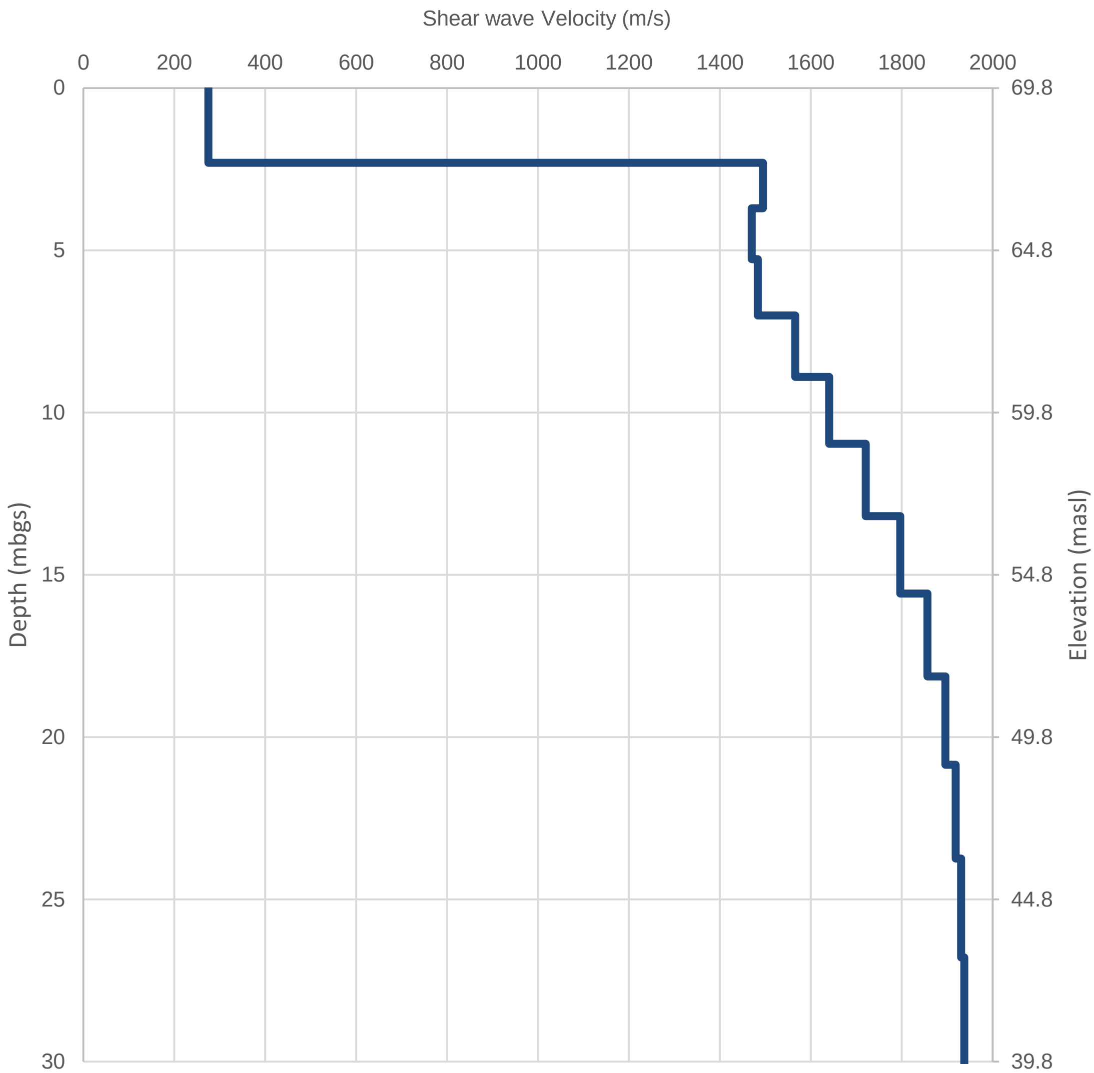


Figure 14: MASW Modelled Shear-Wave Velocity Depth profile along MASW Line 2

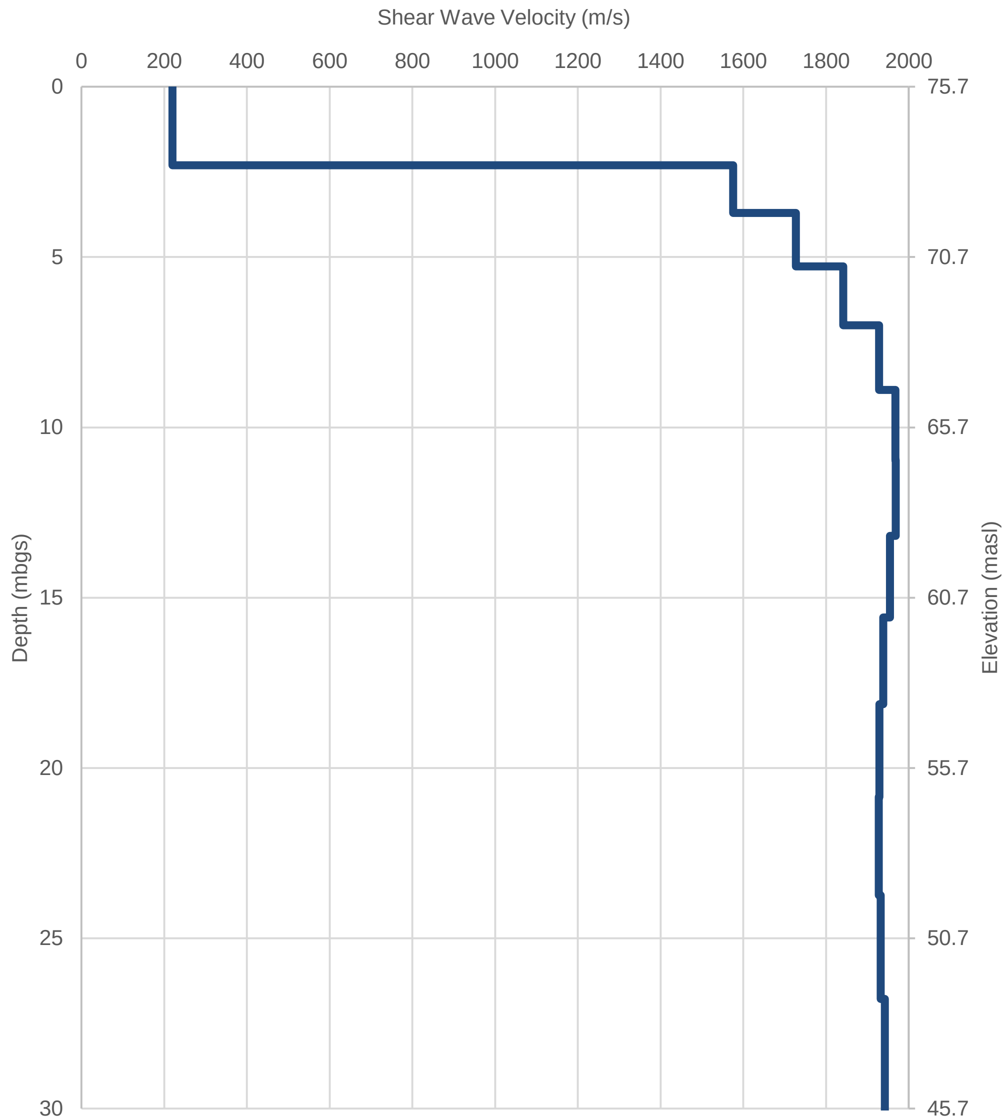


Figure 15: MASW Modelled Shear-Wave Velocity Depth profile along MASW Line 3

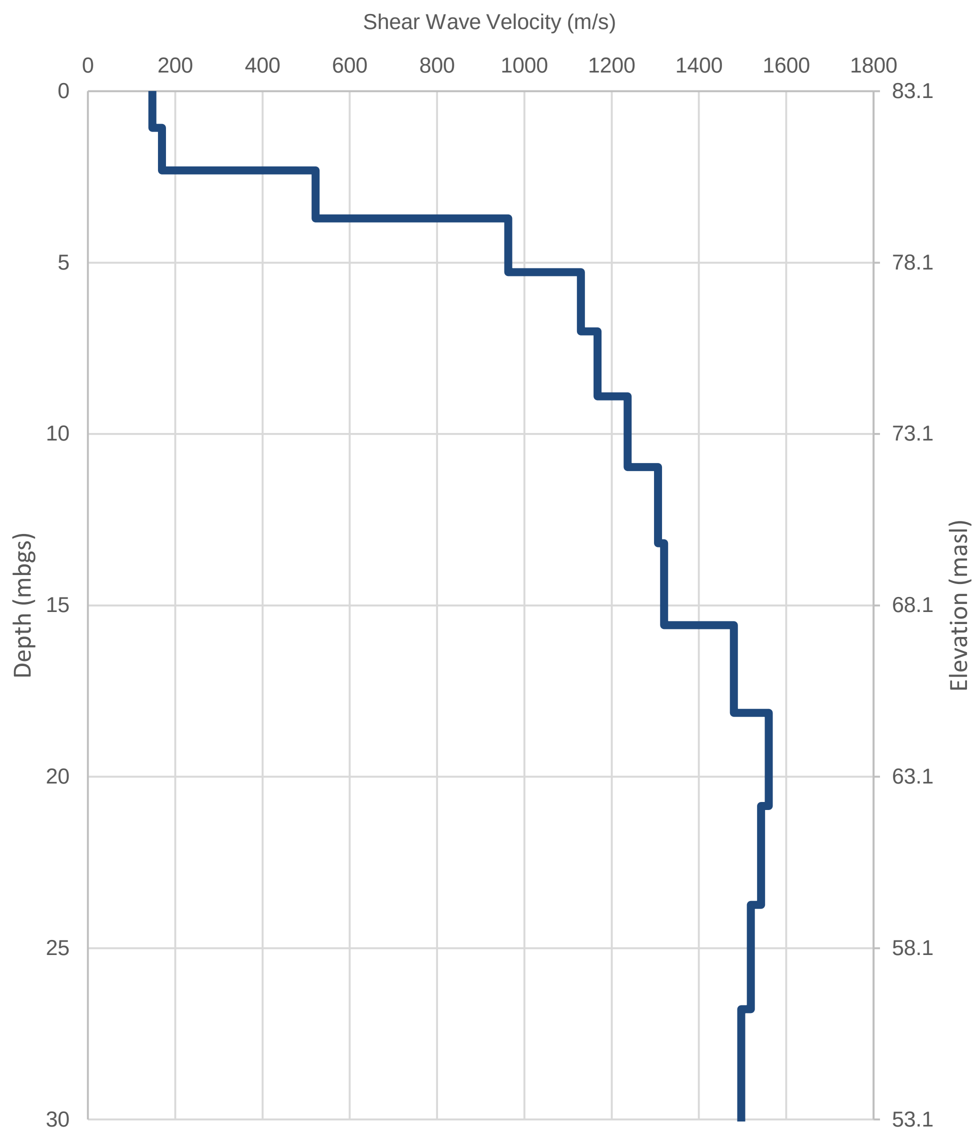


Figure 16: MASW Modelled Shear-Wave Velocity Depth profile along MASW Line 4

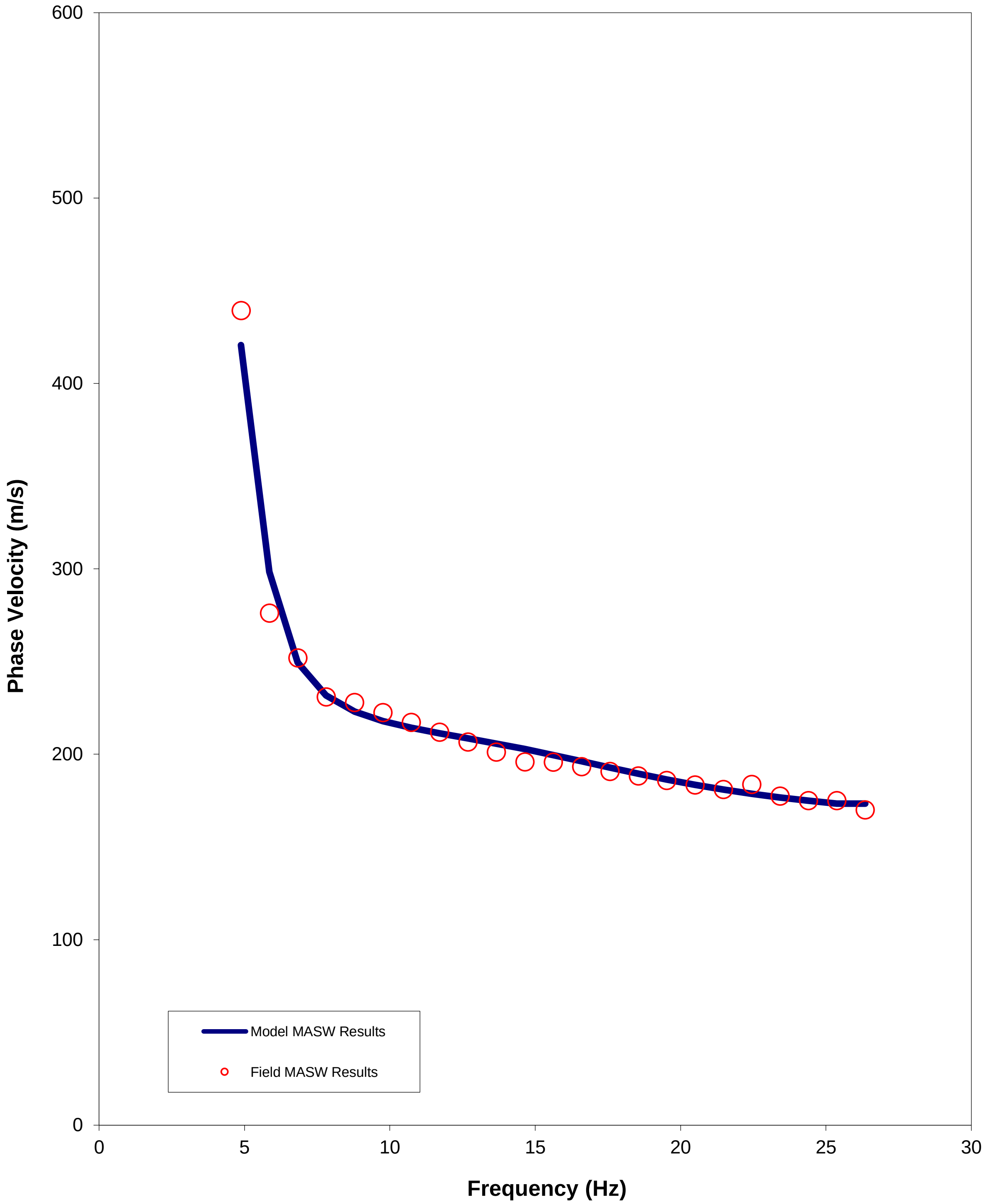


Figure 17: Comparison of Field (red dots) vs. Modelled Data (blue line) along MASW Line 1

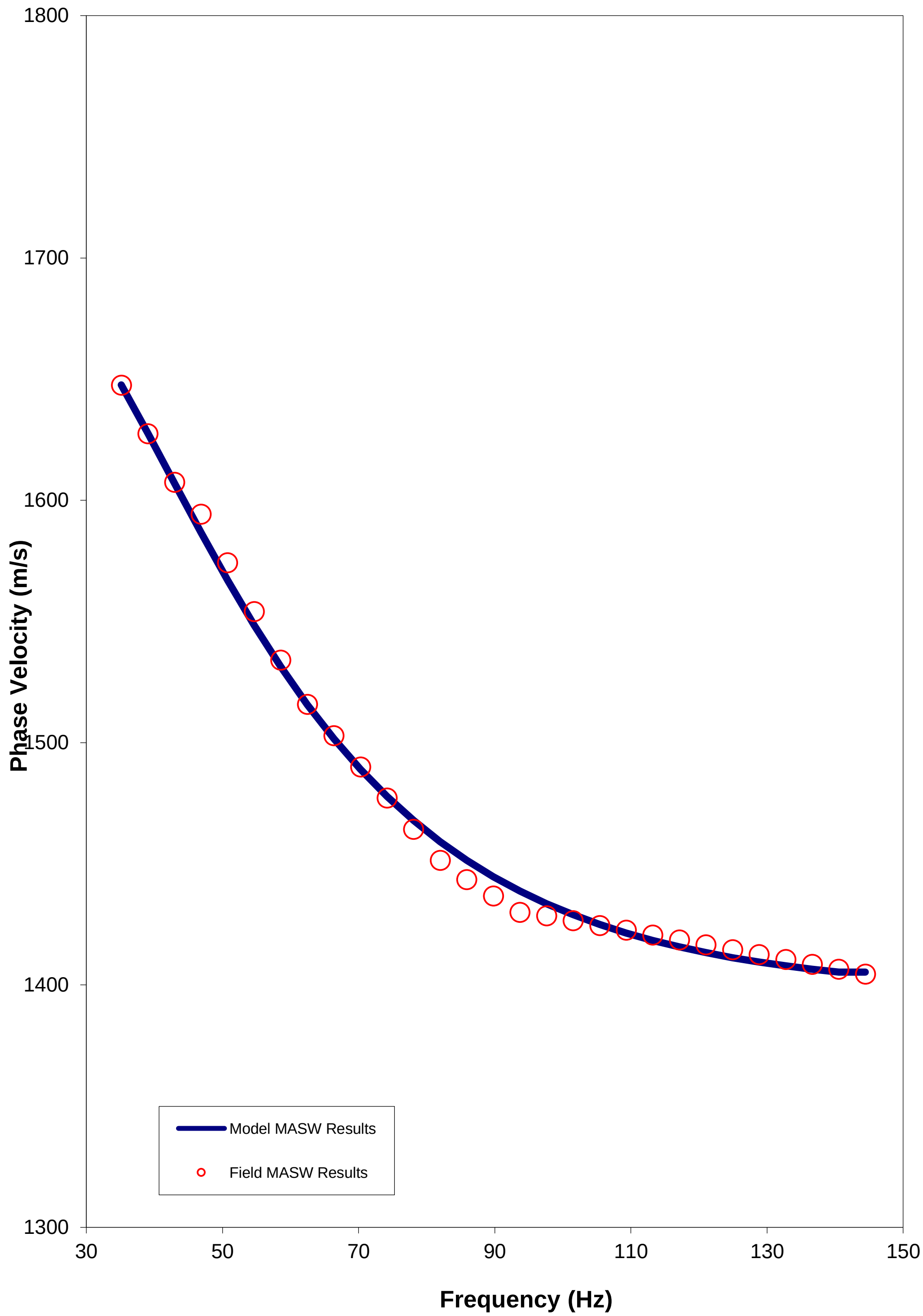


Figure 18: Comparison of Field (red dots) vs. Modelled Data (blue line) along MASW Line 2

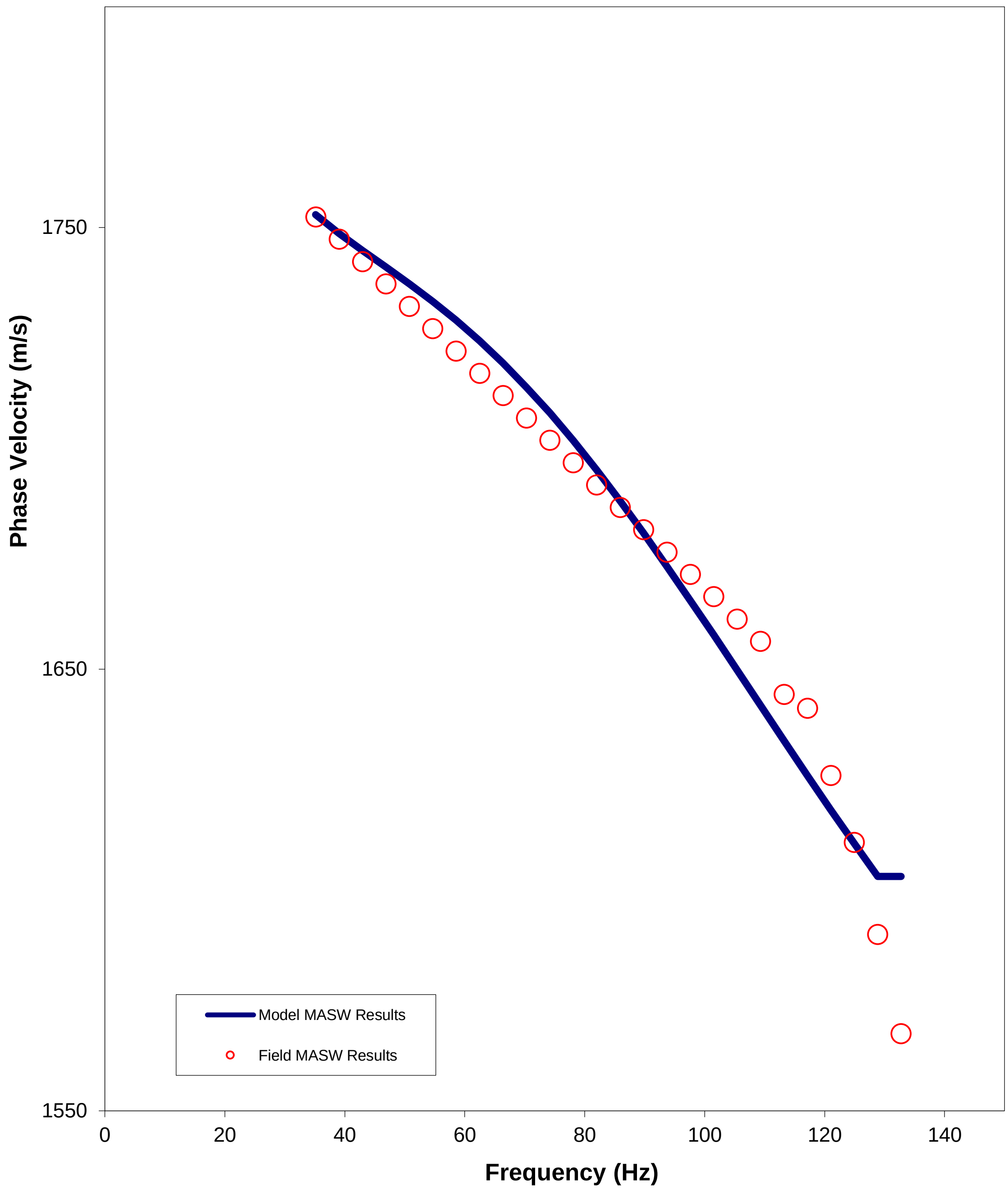


Figure 19: Comparison of Field (red dots) vs. Modelled Data (blue line) along MASW Line 3

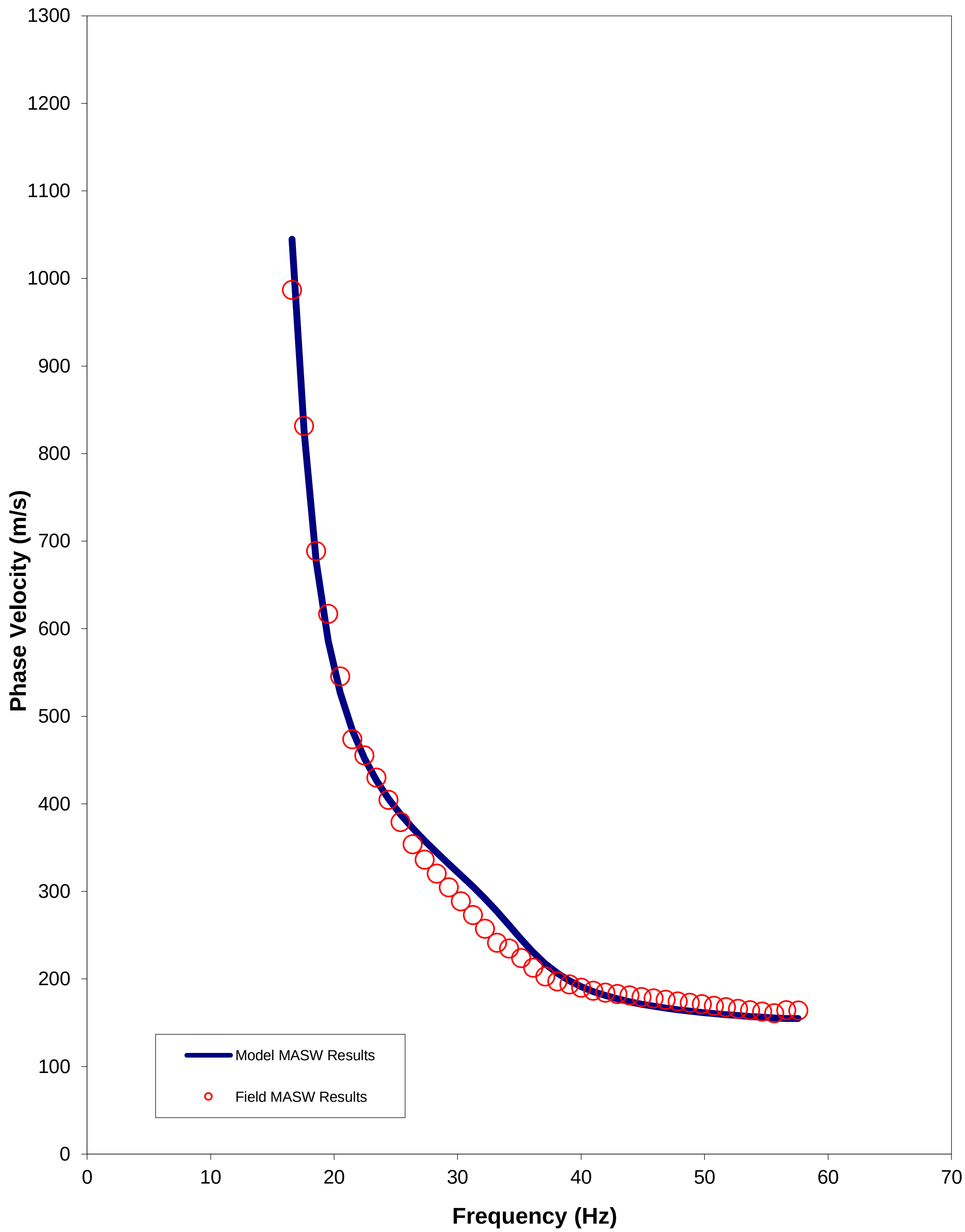


Figure 20: Comparison of Field (red dots) vs. Modelled Data (blue line) along MASW Line 3

To calculate the average shear-wave velocity as required by the NBCC2010, the results were modelled to 30 metres below ground surface. The average shear-wave velocity along MASW Line 1 (Richmond) was found to be 270 m/s (Table 1). The average shear-wave velocity along MASW Line 2 (Pinecrest) was found to be 1,239 m/s (Table 2). The average shear-wave velocity along MASW Line 3 (Woodroffe) was found to be 1,197 m/s (Table 3). The average shear-wave velocity along MASW Line 4 (Maitland) was found to be 818 m/s (Table 4).

The NBCC2010 requires special site specific evaluation if certain soil types are encountered on the site, so the site classification stated here should be reviewed, and modified if necessary, according to borehole stratigraphy, standard penetration resistance results, and undrained shear strength measurements, if available for this site.

Table 1: Shear-Wave Velocity Profile along MASW Line 1 (Richmond)

Model Layer Depth (mbgs)		Model Layer Elevation (masl)		Layer Thickness (m)	Shear Wave Velocity (m/s)	Shear Wave Travel Time Through Layer (s)
Top	**Bottom**	**Top**	**Bottom**			
0.00	1.07	66.00	64.93	1.07	163	0.006580
1.07	2.31	64.93	63.69	1.24	167	0.007384
2.31	3.71	63.69	62.29	1.40	178	0.007852
3.71	5.27	62.29	60.73	1.57	206	0.007613
5.27	7.01	60.73	58.99	1.73	239	0.007239
7.01	8.90	58.99	57.10	1.90	251	0.007562
8.90	10.96	57.10	55.04	2.06	230	0.008945
10.96	13.19	55.04	52.81	2.23	223	0.010001
13.19	15.58	52.81	50.42	2.39	214	0.011154
15.58	18.13	50.42	47.87	2.55	266	0.009603
18.13	20.85	47.87	45.15	2.72	322	0.008436
20.85	23.74	45.15	42.26	2.88	392	0.007361
23.74	26.79	42.26	39.21	3.05	458	0.006652
26.79	30.00	39.21	36.00	3.21	654	0.004914
					Vs Average to 30 mbgs (m/s)	**270**

Table 2: Shear-Wave Velocity Profile along MASW Line 2 (Pinecrest):

Model Layer Depth (mbgs)		Model Layer Elevation (masl)		Layer Thickness (m)	Shear Wave Velocity (m/s)	Shear Wave Travel Time Through Layer (s)
Top	Bottom	Top	Bottom			
0.00	1.07	69.80	68.73	1.07	275	0.003896
1.07	2.31	68.73	67.49	1.24	275	0.004496
2.31	3.71	67.49	66.09	1.40	1495	0.000937
3.71	5.27	66.09	64.53	1.57	1470	0.001065
5.27	7.01	64.53	62.79	1.73	1484	0.001167
7.01	8.90	62.79	60.90	1.90	1566	0.001211
8.90	10.96	60.90	58.84	2.06	1641	0.001256
10.96	13.19	58.84	56.61	2.23	1720	0.001293
13.19	15.58	56.61	54.22	2.39	1797	0.001330
15.58	18.13	54.22	51.67	2.55	1857	0.001376
18.13	20.85	51.67	48.95	2.72	1896	0.001434
20.85	23.74	48.95	46.06	2.88	1918	0.001504
23.74	26.79	46.06	43.01	3.05	1930	0.001580
26.79	30.00	43.01	39.80	3.21	1938	0.001659
					Vs Average to 30 mbgs (m/s)	**1239**

Table 3: Shear-Wave Velocity Profile along MASW Line 3 (Woodroffe)

Model Layer Depth (mbgs)		Model Layer Elevation (masl)		Layer Thickness (m)	Shear Wave Velocity (m/s)	Shear Wave Travel Time Through Layer (s)
Top	Bottom	Top	Bottom			
0.00	1.07	75.70	74.63	1.07	220	0.004870
1.07	2.31	74.63	73.39	1.24	220	0.005619
2.31	3.71	73.39	71.99	1.40	1575	0.000889
3.71	5.27	71.99	70.43	1.57	1727	0.000907
5.27	7.01	70.43	68.69	1.73	1841	0.000940
7.01	8.90	68.69	66.80	1.90	1929	0.000983
8.90	10.96	66.80	64.74	2.06	1968	0.001047
10.96	13.19	64.74	62.51	2.23	1969	0.001130
13.19	15.58	62.51	60.12	2.39	1955	0.001223
15.58	18.13	60.12	57.57	2.55	1939	0.001318
18.13	20.85	57.57	54.85	2.72	1929	0.001410
20.85	23.74	54.85	51.96	2.88	1928	0.001496

Model Layer Depth (mbgs)		Model Layer Elevation (masl)		Layer Thickness (m)	Shear Wave Velocity (m/s)	Shear Wave Travel Time Through Layer (s)
Top	Bottom	Top	Bottom			
23.74	26.79	51.96	48.91	3.05	1932	0.001578
26.79	30.00	48.91	45.70	3.21	1942	0.001655
					Vs Average to 30 mbgs (m/s)	**1197**

Table 4: Shear-Wave Velocity Profile along MASW Line 4 (Maitland)

Model Layer Depth (mbgs)		Model Layer Elevation (masl)		Layer Thickness (m)	Shear Wave Velocity (m/s)	Shear Wave Travel Time Through Layer (s)
Top	Bottom	Top	Bottom			
0.00	1.07	83.10	82.03	1.07	148	0.007243
1.07	2.31	82.03	80.79	1.24	169	0.007299
2.31	3.71	80.79	79.39	1.40	521	0.002687
3.71	5.27	79.39	77.83	1.57	963	0.001626
5.27	7.01	77.83	76.09	1.73	1129	0.001533
7.01	8.90	76.09	74.20	1.90	1167	0.001624
8.90	10.96	74.20	72.14	2.06	1236	0.001667
10.96	13.19	72.14	69.91	2.23	1307	0.001703
13.19	15.58	69.91	67.52	2.39	1320	0.001810
15.58	18.13	67.52	64.97	2.55	1480	0.001726
18.13	20.85	64.97	62.25	2.72	1560	0.001744
20.85	23.74	62.25	59.36	2.88	1542	0.001870
23.74	26.79	59.36	56.31	3.05	1519	0.002008
26.79	30.00	56.31	53.10	3.21	1497	0.002148
					Vs Average to 30 mbgs (m/s)	**818**

Limitations

This technical memorandum is based on data and information collected by Golder Associates Ltd. and is based solely on the conditions of the properties at the time of the work, supplemented by historical information and data obtained by Golder Associates Ltd. as described in this memo.

Golder Associates Ltd. has relied in good faith on all information provided and does not accept responsibility for any deficiency, misstatements, or inaccuracies contained in the reports as a result of omissions, misinterpretation, or fraudulent acts of the persons contacted or errors or omissions in the reviewed documentation.

The services performed, as described in this memo, were conducted in a manner consistent with that level of care and skill normally exercised by other members of the engineering and science professions currently practicing under similar conditions, subject to the time limits and financial and physical constraints applicable to the services.

Any use which a third party makes of this memo, or any reliance on, or decisions to be made based on it, are the responsibilities of such third parties. Golder Associates Ltd. accepts no responsibility for damages, if any, suffered by any third party as a result of decisions made or actions based on this memo.

The findings and conclusions of this memo are valid only as of the date of this memo. If new information is discovered in future work, including excavations, borings, or other studies, Golder Associates Ltd. should be requested to re-evaluate the conclusions of this memo, and to provide amendments as required.

Closure

We trust that this technical memorandum meets your needs at the present time. If you have any questions or require clarification, please contact the undersigned at your convenience.

GOLDER ASSOCIATES LTD.

Stephane Sol, Ph.D, P. Geo.
Senior Geophysicist

Christopher Phillips, M. Sc., P. Geo.
Senior Geophysicist, Principal

SS/CRP/jl

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At Golder Associates we strive to be the most respected global company providing consulting, design, and construction services in earth, environment, and related areas of energy. Employee owned since our formation in 1960, our focus, unique culture and operating environment offer opportunities and the freedom to excel, which attracts the leading specialists in our fields. Golder professionals take the time to build an understanding of client needs and of the specific environments in which they operate. We continue to expand our technical capabilities and have experienced steady growth with employees who operate from offices located throughout Africa, Asia, Australasia, Europe, North America, and South America.

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