REPORT

Foundation Investigation Proposed Culvert Rehabilitation

Unnamed Creek, Highway 417 - Site No. 3-763/C
Ottawa, Ontario

G.W.P. No. 4099-11-00
W.P. No. 4326-13-01

Submitted to:

WSP Canada Group Limited
300-2611 Queensview Drive
Ottawa, Ontario
K2B 8K2

Submitted by:

Golder Associates Ltd.
1931 Robertson Road,
Ottawa, Ontario, K2H 5B7, Canada
+1 613 592 9600

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Geocres No.: 31G5-311
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PART A

Foundation Investigation
Proposed Culvert Rehabilitation
Unnamed Creek, Highway 417 - Site No. 3-763/C
Ottawa, Ontario

G.W.P. No. 4099-11-00

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1.0 INTRODUCTION

Golder Associates Ltd. (Golder) has been retained by WSP Canada Group Limited (WSP) on behalf of the Ministry of Transportation, Ontario (MTO) to carry out foundation investigations associated with numerous bridge and structural culvert rehabilitations and/or replacements on Highway 417 between the Aviation Parkway and Ramsayville Road as well as the widening of Highway 417 from Ottawa Regional Road 174 (OR 174) to Hunt Club Road in Ottawa, Ontario (Assignment number 4016-E-0008, G.W.P. 4099-11-00 and W.P. 4326-13-01).

This report presents the results of the foundation investigation carried out to provide foundation design recommendations for the proposed rehabilitation and associated water diversion for the Unnamed Creek Culvert (Site No. 3-763/C) located beneath the westbound lane (WBL) of Highway 417 in Ottawa, Ontario.
The rehabilitation of the existing structure is to be carried out in accordance with the current version of the Canadian Highway Bridge Design Code (CHBDC, S6-14).

The terms of reference and scope of work for the foundation investigation are outlined in the MTO's Request for Proposal (RFP), dated May 2016, and subsequent addenda. Golder's scope of work for foundation engineering services associated with the Highway 417 Unnamed Creek Culvert is contained in Table 17.8.3 of WSP'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 March 13, 2017.

2.0 SITE DESCRIPTION AND GEOLOGY

2.1 General

The Unnamed Creek Culvert (Site No. 3-763/C) is located approximately 125 m north of Cyrville Road in Ottawa, Ontario. At this location, Highway 417 is a divided highway with two travel lanes in the east direction and three in the west direction, separated by a 40 m wide green area. A third lane extending over the existing culvert in the west direction is the continuation of the E-417W Innes Road on-ramp lane, with the westbound lanes as part of a rural cross section with paved shoulders, ditches, and a median grass area.

The existing Unnamed Creek Culvert was constructed in 1973 and consists of a cast-in-place rigid frame concrete box culvert, with a width of 3.7 m, height of 1.5 m and length of 57 m. The Unnamed Creek flows from northwest to southeast, with the culvert invert at approximately Elevation 63.15 m at the inlet and at approximately Elevation 63.10 m at the outlet based on a survey carried out by WSP. Based on the original contract drawings provided by WSP, the stream bed is about 0.3 m above the culvert invert. Based on the original RFP, there is approximately 1.5 m of fill cover on the existing culvert.

The existing embankments were observed during field work and were showing no signs of erosion or instability and are considered to be performing in good condition.

The existing culvert requires rehabilitation, including removal of sediment buildup within the culvert barrel; concrete repairs to inlet and outlet portals, soffit and interior wall; and application of waterproofing membrane and protection board. A temporary flow passage system and temporary protection systems will be required to support the rehabilitation works.

2.2 Regional Geology

As delineated in *The Physiography of Southern Ontario*[1], this section of Highway 417 lies on the boundary of the minor physiographic regions known as the Ottawa Valley Clay Plain and the Russell and Prescott Sand 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]. The Russell and Prescott Sand Plains are generally characterized by a sand mantle about 3 to 5 m thick overlying an extensive deposit of sensitive marine clay deposited within the Champlain Sea basin, underlain by glacial till and shale bedrock.

The Bedrock Geology mapping indicates that the bedrock consists of black shale of the Billings Formation of the Ordovician period. It should be noted that the Billings Formation shale is susceptible to swelling if allowed to weather in the presence of oxygen.

The site falls within the Western Québec (WQ) seismic zone according to the Geological Survey of Canada. The WQ zone constitutes a large area which encompasses the urban areas of Montreal, Ottawa-Hull and Cornwall. Within the WQ zone recent seismic activity has been concentrated in two subzones; one along the Ottawa River and another more active subzone along the Montreal-Maniwaki axis. The two major earthquakes in the WQ zone includes the 1935 Témiscaming event which had a magnitude (i.e., a measure of the intensity of the earthquake) of 6.2, and the 1944 Cornwall-Massena event which had a magnitude of 5.6.

3.0 INVESTIGATION PROCEDURES

The subsurface investigation for the culvert rehabilitation was carried out between July 25 and August 15, 2018. During that time, three boreholes (designated as Boreholes 18-3201 to 18-3203) were advanced along in close proximity to the existing culvert structure. Borehole 18-3202 was advanced through the Highway 417 WBL road grade, while Boreholes 18-3201 and 18-3203 were advanced in close proximity to the culvert outlet and inlet, respectively. The borehole locations are shown on Drawing 1.

Boreholes 18-3201 and 18-3203 were advanced using portable rotary drill equipment, supplied and operated by Ohlmann Geotechnical Services Inc (OGS). The boreholes were advanced to a depth of 4.0 m below ground surface, including coring of bedrock for core lengths of 2.8 m and 2.6 m in Boreholes 18-3201 and 18-3203, respectively. Bedrock core samples were obtained using an ‘NQ’ size rock core barrel.

Borehole 18-3202 was advanced using 108 mm inside diameter (200 mm outside diameter) continuous flight hollow stem augers on track mounted drill rigs, supplied and operated by George Downing Estate Drilling Ltd. The borehole was advanced to a depth of 5.1 m below ground surface, including coring of bedrock for a core length of 3.4 m. Bedrock core samples were obtained using an ‘NQ’ size rock core barrel.

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[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.

Soil samples were obtained at vertical intervals of about 0.6 m to 0.76 m, using a 50 mm outer diameter split-spoon sampler in accordance with Standard Penetration Test (SPT) procedures (ASTM D1586)[3]. A water truck was on site to supply the drill rigs with water for advancing the casing in the overburden (portable drill rig) and for coring of the bedrock. Traffic control required to allow the water truck and support vehicles to park adjacent to the site was supplied by Beacon Lite Ltd. of Ottawa, Ontario. Borehole 18-3202 was advanced in the left shoulder and required the closure of the left lane.

A monitoring well was installed in Borehole 18-3202 to monitor the groundwater level at the site. The monitoring wells consisted of 32 mm outside diameter PVC tubing with a 1.5 m long screen. The groundwater level was measured in the monitoring well on June 23, 3019. The monitoring well was subsequently decommissioned on January 8, 2020 by backfilling the monitoring well with bentonite, removing the top section of the monitoring well, and the asphalt patched upon completion, as per MOE Regulation 903.

The remainder of the boreholes were backfilled with bentonite mixed with soil cuttings in accordance with Ontario Regulation 903, Wells (as amended) and Borehole 18-3202 was sealed to the roadway surface with cold patch asphalt upon completion. 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 visual examination and to Golder’s laboratories in Ottawa and Mississauga for geotechnical laboratory testing on selected samples. Index and classification tests consisting of water content determinations and grain size distribution analyses were carried out on selected soil samples at the Golder Ottawa laboratory.
The laboratory tests were carried out to MTO and/or ASTM Standards, as appropriate.

Rock quality (i.e., Total Core Recovery (TCR), Solid Core Recovery (SCR), Rock Quality Designation (RQD), weathering and strength index), discontinuity characteristics and classification data were recorded in the field based on visual inspection of the recovered rock cores upon extraction from the core barrel. The bedrock was sequentially photographed, packed and transported to Golder’s Ottawa laboratory for further visual examination. An unconfined compressive strength test was carried out on one selected rock core sample in the Golder Mississauga laboratory. The remainder of the bedrock core samples were placed in wooden core boxes and kept in storage.

Classification of the rock mass quality of the bedrock with respect to the RQD is described based on Table 3.10 of the Canadian Foundation Engineering Manual (CFEM, 2006)[4] while the strength of the bedrock core samples is based on Table 3.5 of CFEM, (2006)[4]. The degree of weathering of the bedrock core samples and the strength classification of the intact rock mass based on field identification are described in accordance with Table B.3 and Table B.6, respectively of the International Society of Rock Mechanics (ISRM, 1985)[5] standard classification system.

One soil sample from Borehole 18-3203 was submitted to Eurofins Environment Testing (Eurofins) for chemical analysis related to potential corrosion of exposed buried steel and potential sulphate attack on buried concrete elements (corrosion and sulphate attack).

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[3] ASTM D1586 – Standard Test Method for Standard Penetration Tests and Split Barrel Sampling of Soils.

[4] Canadian Foundation Engineering Manual. 2006. Fourth Edition, Canadian Geotechnical Society: Richmond, British Columbia.

[5] International Society for Rock Mechanics Commission on test Methods. 1985. Int. J. Rock Mech. Min. Sci & Geomech. Abstr. Vol 22, No. 2, pp.51-60.

In addition to the borehole investigation, shear wave velocity profiling was completed at the Cyrville Road Overpass site, located about 130 m south of the Unnamed Creek Culvert, using the Multichannel Analysis of Surface Waves (MASW) technique. Two tests were conducted on June 26, 2018 by personnel from the Golder Associates' Mississauga office. 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, and 15 m off the end and collinear with the geophone array.

The as-drilled borehole locations and elevations were surveyed by Golder using a Trimble R8 GPS unit, to an accuracy of 2 cm in the horizontal and 3 cm in the vertical directions. The locations given in the Record of Borehole sheets and shown on Drawing 1 are positioned relative to MTM NAD83 (Zone 9) northing and easting coordinates and the ground surface elevations are referenced to geodetic datum (CGVD28). The borehole locations, the ground surface elevations and borehole drilled depths are summarized below.

Table 1: Summary of Borehole Locations

Borehole Number	Borehole Location	MTM NAD83 Zone 9 Northing (m)	MTM NAD83 Zone 9 Easting (m)	Ground Surface Elevation (m)	Borehole Depth (m)
18-3201	Near culvert outlet	5031459.7	374193.4	66.7	4.0
18-3202	Highway 417 left / west shoulder	5031468.0	374170.0	66.5	5.1
18-3203	Near culvert inlet	5031481.5	374150.6	65.8	4.0

4.0 DESCRIPTION OF SUBSURFACE CONDITIONS

4.1 General Site Stratigraphy

The subsurface soil, bedrock and groundwater conditions encountered in the boreholes and the results of in-situ and laboratory testing are given on the Record of Borehole sheets presented in Appendix A. Photographs of the bedrock core are provided on Figures A1 to A3 contained in Appendix A. The results of geotechnical laboratory testing are presented on Figures B1 to B3 and are contained in Appendix B. The results of the chemical testing performed on one soil sample are provided in Appendix C.

An interpreted stratigraphic profile projected along the Unnamed Creek culvert structure is shown on Drawing 1. The stratigraphic boundaries shown on the Record of Borehole sheets and on the interpreted stratigraphic profile are inferred from observations of drilling progress and noncontinuous- 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.

The MASW test results and technical memorandum are presented in Appendix D and include the calculated shear wave velocity profile measured from the field testing and a graphical representation of the shear wave velocity profile with depth.

Photographs of the site are shown in Appendix E (to be provided by WSP).

In general, the subsurface conditions at the borehole locations consist of topsoil and asphaltic concrete over embankment fill extending down to depths of about 1.2 m to 1.4 m (Elevations 64.6 m to 65.5 m).
The embankment fill is underlain by a discontinuous deposit of glacial till/weathered shale bedrock extending to

depths of about 1.4 m to 1.7 m (Elevations 64.4 m to 64.8 m) and the shale bedrock. Shale bedrock was indicated to be present at depths of about 1.2 to 1.7 m (Elevations 64.4 to 65.5 m). The groundwater level was encountered at a depth of about1.6 m (Elevation 64.9 m).

A detailed description of the subsurface conditions encountered in the boreholes is provided in the following sections.

4.2 Topsoil

A layer of topsoil was encountered at the ground surface in Boreholes 18-3201 and 18-3203 with a thickness of about 200 mm.

4.3 Pavement Structure and Embankment Fill

Borehole 18-3202 was advanced through the pavement structure of the Highway 417 WBL left shoulder. The pavement structure consists of 400 mm of asphaltic concrete over a 200 mm base layer consisting of gravel and sand fill.

The pavement structure and topsoil, where encountered, are underlain by a 0.8 m to 1.0 m thick layer of embankment fill consisting of sand and gravel to gravelly sand with varying amounts of silt, clay and shale fragments. The embankment fill generally extends to depths ranging between 1.2 m to 1.4 m below the existing ground surface, to about Elevations 65.5 m to 64.4 m.

The Standard Penetration Test (SPT) “N”-values measured in the embankment fill range from 8 to 94 blows per 0.3 m of penetration, indicating a very loose to very dense state of compactness. The higher SPT “N”-values likely reflect the presence of the bedrock surface, rather than the state of compactness of the soil matrix.

The results of grain size distribution testing carried out on three selected samples of the gravel and sand base material are shown on Figure B1 in Appendix B. The results of grain size distribution testing carried out on one selected sample of the embankment fill material are shown on Figure B2 in Appendix B. The measured natural water content of six samples of the fill range from about 2 to 6 per cent.

4.4 Till/Highly Weathered Shale

A deposit of till/highly weathered shale was encountered underlying the embankment fill in Boreholes 18-3202 and 18-3203. The surface of the till / highly weathered shale deposit was encountered at depths of 1.4 m and 1.2 m, corresponding to Elevations 65.2 m and 64.6 m in Boreholes 18-3202 and 18-3203, respectively. The transitional glacial till/highly weathered shale generally consists of silty sand, some gravel to gravelly, containing shale fragments. The till/highly weathered shale extends to depths of about 1.7 m and 1.4 m below the existing ground surface, with a thickness ranging from about 0.3 m and 0.2 m, in Boreholes 18-3202 and 18-3203, respectively.

The SPT “N”-values measured within the till / highly weathered shale deposit 50 blows per 0.15 m of penetration and 50 blows per 0.05 m of penetration, indicating a very dense state of compactness.

4.5 Bedrock

Bedrock was encountered underlying the embankment fill in Borehole 18-3201 and underlying the till / highly weathered shale deposit in Boreholes 18-3202 and 18-3203, at depths ranging from 1.2 m to 1.7 m below the existing ground surface (Elevations 65.5 m to 64.4 m). The upper 0.2 to 0.3 m of the bedrock encountered in Boreholes 18-3202 and 18-3203 was described as highly weathered (see Section 4.4 above) and was drilled and sampled using the augers and/or SPT sampler. The underlying sound bedrock was cored between about 2.6 m and 3.4 m depth using NQ sized coring equipment.

The following table summarizes the sound (i.e., required coring) bedrock surface depths and elevations as encountered at the borehole locations.

Table 2: Summary of Observed Bedrock Depth and Elevation

Borehole Number	Existing Ground Surface Elevation (m)	Depth to Bedrock Surface (m)	Bedrock Surface/ Refusal Elevation (m)
18-3201	66.7	1.2	65.5
18-3202	66.5	1.7	64.8
18-3203	65.8	1.4	64.4

The sound bedrock encountered below the transitional glacial till / highly weathered bedrock consist of fresh, thinly to medium bedded, black to dark grey, fine grained, porous shale. The Rock Quality Designation (RQD) values measured on recovered bedrock core samples ranged from about 74 to 100 percent, indicating a fair to excellent quality rock.

Photos of the bedrock core are shown on Figures A1 to A3 in Appendix A.

The result of the unconfined compressive strength test carried out on one bedrock core sample is presented on Figure B3. Based on the measured unconfined compressive strength of 60.5 MPa, the shale bedrock is classified as relatively strong.

4.6 Groundwater Conditions

A groundwater monitoring well was installed in Borehole 18-3102 to monitor the groundwater level at the site. The water levels were measured in the monitoring well on June 23, 2019 and are summarized in the table below.

Table 3: Summary of Observed Groundwater Conditions

Borehole	Ground Surface Elevation (m)	Screened Interval Material	Water Level Depth (m)	Water Level Elevation (m)	Date of Reading
18-3102	66.5	Bedrock	1.6	64.9	June 23, 2019

It is expected that these water levels will be subject to fluctuations both seasonally and as a result of precipitation events.

4.7 Corrosion and Sulphate Attack Potential

One soil sample from Borehole 18-3202 was submitted to Eurofins for chemical analysis related to potential corrosion of exposed buried steel and potential sulphate attack on buried concrete elements (corrosion and sulphate attack). The results of the testing are attached in Appendix C and are summarized in the table below.

Table 4: Results of Chemical Analysis

Borehole No.	Sample Depth (m)	Sample Type	Chloride Soil (%)	pH	Electrical Conductivity Soil (mS/cm)	Resistivity (ohm-cm)	Sulphate Soil (%)
18-3202	0.61 – 1.22	Soil	0.005	8.09	0.69	1450	0.05

5.0 CLOSURE

This report was prepared by Mr. Alex Meacoe, P.Eng. and Ms. Nikol Kochmanová, P.Eng., and reviewed by Mr. Michael Snow P.Eng., a senior geotechnical engineer and Principal with 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.

Kim MacDonalds, EIT.
Pavement/Geotechnical

Michael Snow, P.Eng.
Principal, Senior Geotechnical Engineer

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

LICENSED PROFESSIONAL ENGINEER
M.S. SNOW
Feb. 6, 2020
PROVINCE OF ONTARIO

REGISTERED PROFESSIONAL ENGINEER
F. J. HEFFERNAN
FEB 6, 2020
PROVINCE OF ONTARIO

WAM/NK/MSS/FJH/hdw
https://golderassociates.sharepoint.com/sites/11263g/shared documents/01_foundations/6 - reports/1320 unamed creek 417/final/1662565-1320-001-r-rev0-unnamed creek culvert-2706_19 fidr.docx

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Canadian Standards Association (CSA). 2014. *Canadian Highway Bridge Design Code and Commentary on CAN/CSA-S6-14*. CSA Special Publication.

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.

International Society for Rock Mechanics Commission on Test Methods, 1985. Int. J. Rock Mech.Min. Sci. & Geomech. Abstr. Vol 22, No. 2, pp. 51-60.

ASTM International Standards:

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

Ontario Provisional Standard Drawings:

OPSD 802.013	Flexible Pipe, Embedment and Backfill, Rock Excavation
OPSD 802.014	Flexible Pipe, Embedment in Embankment, Original Ground: Earth or Rock
OPSD 810.010	General Rip-Rap Layout for Sewer And Culvert Outlets
OPSD 3090.101	Foundation Frost Penetration Depths for Southern Ontario

Ontario Provincial Standard Specification:

OPSS.PROV 421	Construction Specification for Pipe Culvert Installation in Open Cut
OPSS.PROV 517	Construction Specification for Dewatering
OPSS.PROV 539	Construction Specification for Temporary Protection Systems
OPSS.PROV 1010	Material Specification for Aggregates – Base, Subbase, Select Subgrade and Backfill Material

Special Provision (SP)

SP105S19	Amendment to OPSS 539, November 2014
SP517F01	Temporary Flow Passage System - Amendment to OPSS 517, November 2016

Ontario Water Resources Act:

Ontario Regulation 903	Wells (as amended)

Ontario Occupational Health and Safety Act:

Ontario Regulation 213/91	Construction Projects (as amended)

MINISTRY OF TRANSPORTATION, ONTARIO

CONT No.
GWP No. 4099-11-00

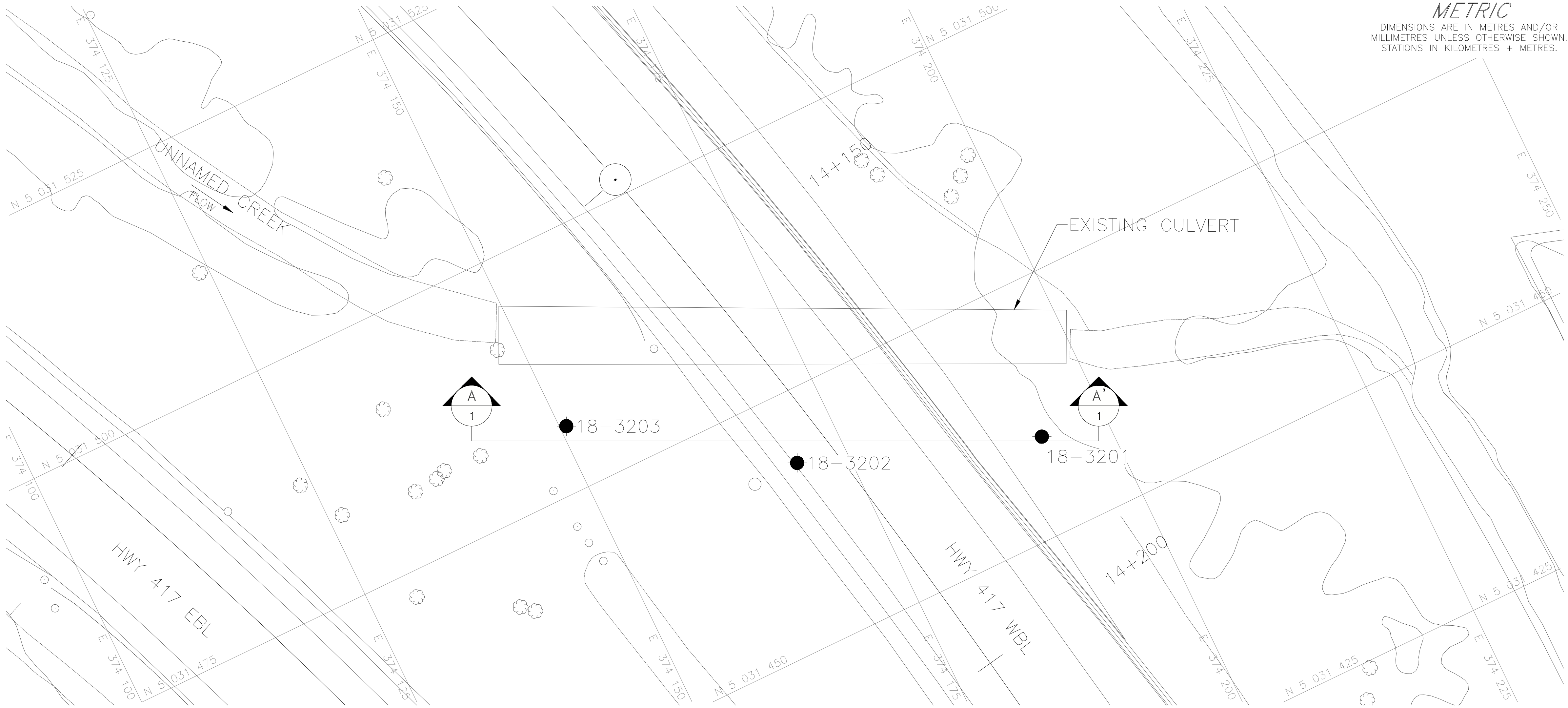
SHEET

UNNAMED CREEK CULVERT

HIGHWAY 417
BOREHOLE LOCATIONS AND SOIL STRATA
LAT. 45.419734 LONG. -75.613476

GOLDER

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



PLAN

SCALE
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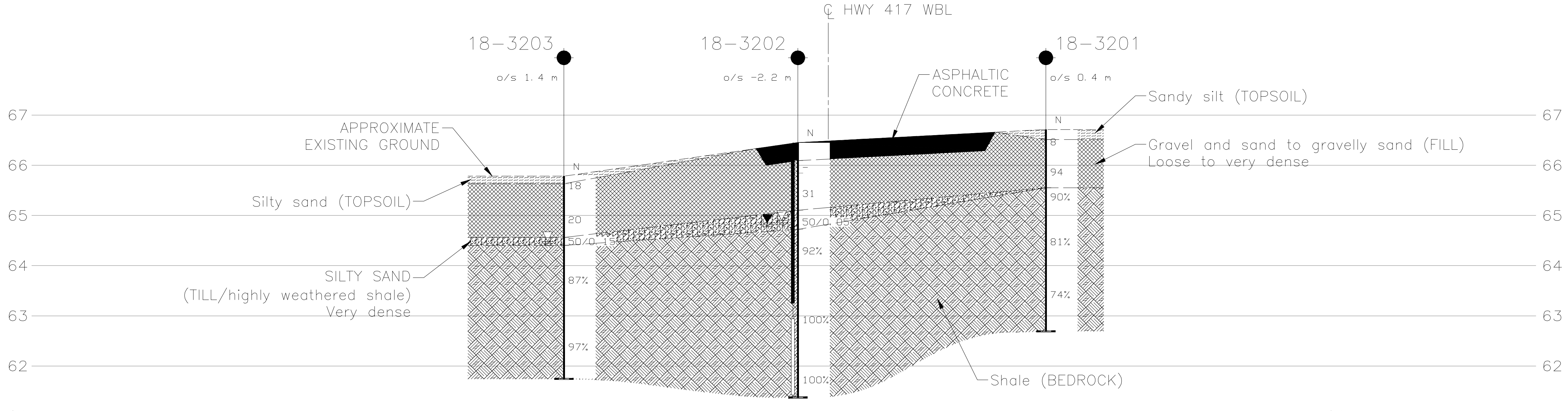

CROSS-SECTION A-A'

SCALE
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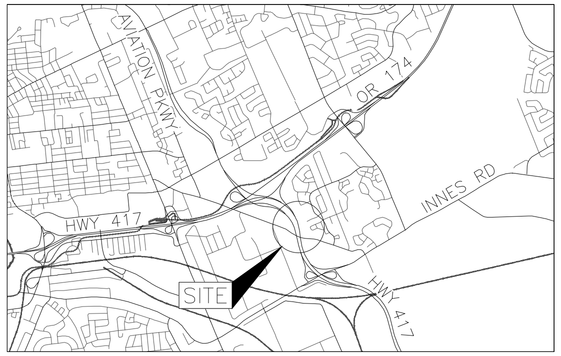
1 0 1 2



KEY PLAN

SCALE
1 0 1 2 km

LEGEND

●	Borehole – Current Investigation
▮	Seal
▯	Piezometer
N	Standard Penetration Test Value
16	Blows/0.3m unless otherwise stated (Std. Pen. Test, 475 j/blow)
100%	Rock Quality Designation (RQD)
▼	WL in piezometer, measured on JUNE 23, 2019
▽	WL upon completion of drilling

BOREHOLE CO-ORDINATES NAD 83 (CSRS)/MTM ZONE 9			
No.	ELEVATION	NORTHING	EASTING
18-3201	66.7	5031459.7	374193.4
18-3202	66.5	5031468.0	374170.0
18-3203	65.8	5031481.5	374150.6

NOTES

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

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

REFERENCE

Base plans provided in digital format by WSP, drawing file nos. XA1-NAD 83.dwg and XB1-NAD 83 (CSRS).dwg, received APR. 19, 2017.

M.S. SNOW
2/19/2020

F. J. HEFFERNAN
FEB 18, 2020

NO.	DATE	BY	REVISION

Geocres No. 31G5-311

HWY. 417		PROJECT NO. 1662565	DIST. EASTERN
SUBM'D. WAM	CHKD. WAM	DATE: 2/19/2020	SITE: 3-763/C
DRAWN: JM	CHKD. MSS	APPD. FJH	DWG. 1

PLOT DATE: February 19, 2020
FILENAME: N:\Active\Spatial_IM\MTO\Hwy417Rehab&Widening\99_PROJ\1662565_MTO_Hwy417Replacements\40_PROD\0018_UnnamedCreekCulvert_417\1662565-0018-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 18-3201 to 18-3203

Bedrock Core Photographs, Figures A1 to A3

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
	total stress
σ'	effective stress ($\sigma' = \sigma - u$)
σ'_{vo}	initial effective overburden stress
σ_1, σ_2, σ_3	principal stress (major, 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	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

Compactness Condition	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	kPa	psf
Very soft		
Soft	0 to 12	0 to 250
Firm	12 to 25	250 to 500
Stiff	25 to 50	500 to 1,000
Very stiff	100 to 200	1,000 to 2,000
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 10	Trace	Trace sand
10 to 20	Some	Some sand
20 to 35	(ey) or (y)	Sandy
over 35	And	Sand and Gravel

LITHOLOGICAL AND GEOTECHNICAL ROCK DESCRIPTION TERMINOLOGY

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, as measured along the centerline axis of the core, relative to the length of the total core run. RQD varies from 0% for completely broken core to 100% for core in solid segments.

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° 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		

RECORD OF BOREHOLE No 18-3201

SHEET 1 OF 2

METRIC

PROJECT 1662565-1320

G.W.P. 4099-11-00

LOCATION N 5031459.7; E 374193.4 NAD 83 MTM ZONE 9 (LAT. 45.419630; LONG. -75.613312)

ORIGINATED BY DJG

DIST Eastern HWY 417

BOREHOLE TYPE Portable Drill, DO Sampler/Rotary Drill, NQ Core

COMPILED BY ZS

DATUM Geodetic

DATE August 7, 2018

CHECKED BY WAM

SOIL PROFILE: ELEV DEPTH	SOIL PROFILE: DESCRIPTION	STRAT PLOT	SAMPLES: NUMBER	SAMPLES: TYPE	SAMPLES: "N" VALUES	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
66.7	GROUND SURFACE										
0.0	(ML) Sandy silt (TOPSOIL) Dark brown Moist										
66.5 0.2	(SW-SM) Sand and gravel, trace to some silt, trace clay (FILL) Loose to very dense Brown Dry		1	SS	8				○		
			2	SS	94		66		○		37 50 11 2
65.5 1.2	Shale (BEDROCK) Bedrock cored from depths 1.2 m to 4.0 m For bedrock coring details refer to Record of Drillhole 18-3201		1	RC	REC 100%		65				RQD = 90%
			2	RC	REC 100%		64				RQD = 81%
			3	RC	REC 100%		63				RQD = 74%
62.7 4.0	END OF BOREHOLE										

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

○$^{3\%}$ STRAIN AT FAILURE

PROJECT: 1662565-1320

RECORD OF DRILLHOLE: 18-3201

SHEET 2 OF 2

LOCATION: N 5031459.7 ;E 374193.4

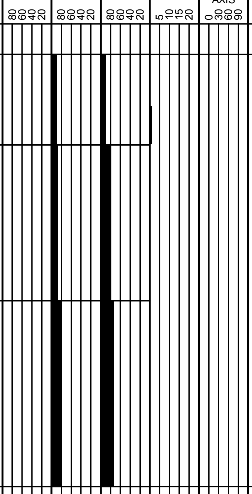
INCLINATION: -90° AZIMUTH: ---

DRILLING DATE: August 7, 2018
DRILL RIG: Portable Drill
DRILLING CONTRACTOR: OGS

DATUM: Geodetic

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 %	RECOVERY SOLID CORE %	R.Q.D. %	FRACT. INDEX PER	DISCONTINUITY DATA DIP w.r.t. CORE AXIS	DISCONTINUITY DATA TYPE AND SURFACE DESCRIPTION	Jr	Ja	HYDRAULIC CONDUCTIVITY K, cm/sec	WEATH-ERING INDEX	FEATURES
		BEDROCK SURFACE		65.55													
	Rotary Drill NQ Core	Shale (BEDROCK) Fresh Thinly laminated Black Fine grained Porous Strong		1.16	1	75											
2					2	75											
3					3	80											
4		END OF DRILLHOLE		62.69 4.02													
5																	
6																	
7																	
8																	
9																	
10																	
11																	



DEPTH SCALE
1 : 50

LOGGED: DJG
CHECKED: WAM

RECORD OF BOREHOLE No 18-3202

SHEET 1 OF 2

METRIC

PROJECT 1662565-1320
G.W.P. 4099-11-00
DIST Eastern HWY 417
DATUM Geodetic

LOCATION N 5031468.0; E 374170.0 NAD 83 MTM ZONE 9 (LAT. 45.419708; LONG. -75.613609)
BOREHOLE TYPE Power Auger, 200 mm Diam. (Hollow Stem)/Rotary Drill, NQ3 Core
DATE August 14-15, 2018

ORIGINATED BY KM
COMPILED BY ZS
CHECKED BY WAM

SOIL PROFILE: ELEV DEPTH	SOIL PROFILE: DESCRIPTION	STRAT PLOT	SAMPLES: NUMBER	SAMPLES: TYPE	SAMPLES: "N" VALUES	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
66.5	GROUND SURFACE													
0.0	ASPHALTIC CONCRETE													
66.1	(GP/GM) Gravel and sand, trace to some silt, trace clay (FILL) Brown Moist		1	GRAB	-		66				52	35	11	2
65.9 0.6	(SW-SM) Gravelly sand, trace to some silt, trace clay, contains shale fragments (FILL) Dense Brown Moist		2	SS	31						21	69	8	2
65.2 1.4	(SM) SILTY SAND, some gravel and clay, contains shale fragments (TILL/highly weathered shale) Very dense Dark brown to black Moist		3	SS	50/0.05		65							
64.8 1.7	Shale (BEDROCK) Bedrock cored from depths 1.7 m to 5.1 m For bedrock coring details refer to Record of Drillhole 18-3202		1	RC	REC 97%		64				RQD = 92%			
			2	RC	REC 100%		63				RQD = 100%			
			3	RC	REC 100%		62				RQD = 100%			
61.4 5.1	END OF BOREHOLE NOTES: 1. Water level measured upon completion of borehole drilling in open borehole at 1.6 m depth (Elev. 64.9 m) on August 15, 2018. 2. Water level measured in standpipe piezometer at a depth of 1.6 m below ground surface (Elev. 64.9 m) on June 23, 2019.													

GTA-MTO 001 N:\ACTIVE\SPATIAL_IM\MTO\HWY417REHAB&WIDENING\02_DATA\GINT\1662565.GPJ GAL-GTA.GDT 10/7/19 ZS

$+^{3}, \times^{3}$: Numbers refer to Sensitivity

$\circ^{3\%}$ STRAIN AT FAILURE

PROJECT: 1662565-1320

RECORD OF DRILLHOLE: 18-3202

SHEET 2 OF 2

LOCATION: N 5031468.0 ;E 374170.0

DRILLING DATE: August 14-15, 2018

DATUM: Geodetic

INCLINATION: -90° AZIMUTH: ---

DRILL RIG: CME 75

DRILLING CONTRACTOR: Downing Drilling

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})	WEATH-ERING INDEX (W1 W2 W3 W4 W5 W6)	FEATURES
		BEDROCK SURFACE		64.72													
2	Rotary Drill NQ3 Core	Shale (BEDROCK) Fresh Thinly bedded Dark grey Fine grained Porous Strong		1.73	1	10											
3					2	0											
4																	
5				61.37	3	0											
		END OF DRILLHOLE		5.08													
6																	
7																	
8																	
9																	
10																	
11																	

DEPTH SCALE
1 : 50

GOLDER

LOGGED: KM
CHECKED: WAM

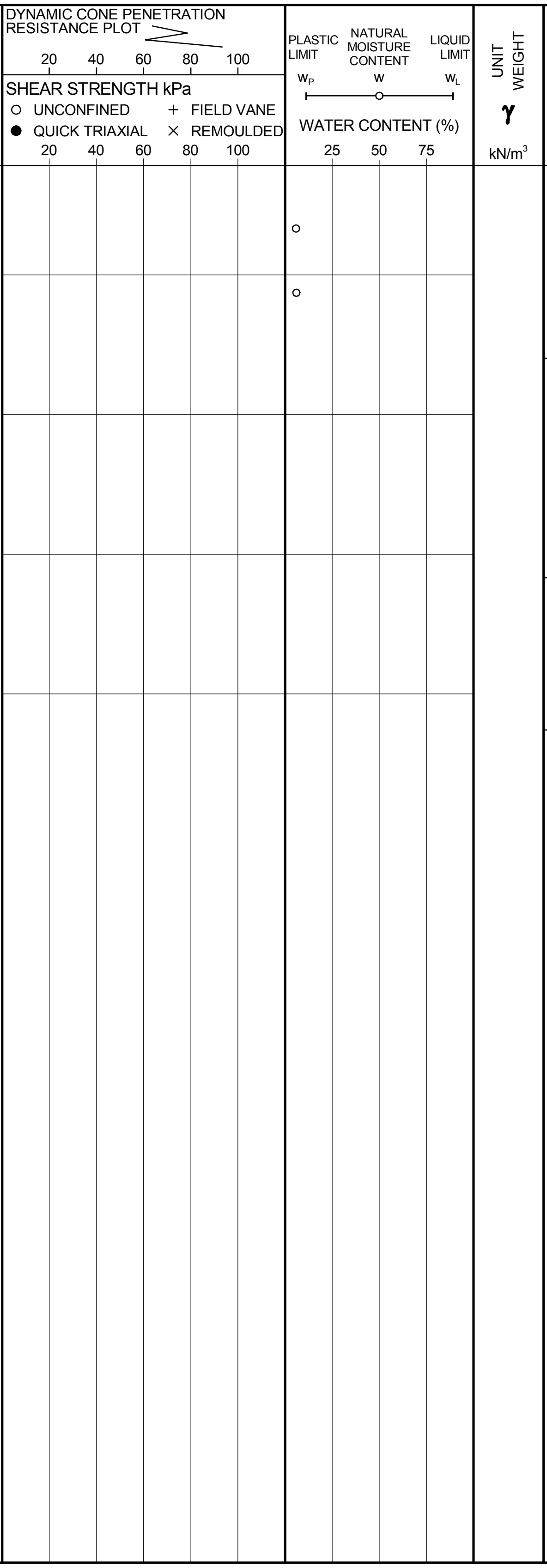
RECORD OF BOREHOLE No 18-3203

SHEET 1 OF 2

METRIC

PROJECT 1662565-1320
G.W.P. 4099-11-00
DIST Eastern HWY 417
DATUM Geodetic
LOCATION N 5031481.5; E 374150.6 NAD 83 MTM ZONE 9 (LAT. 45.419831; LONG. -75.613855)
BOREHOLE TYPE Portable Drill, DO Sampler/Rotary Drill, NQ Core
DATE July 25, 2018
ORIGINATED BY DJG
COMPILED BY ZS
CHECKED BY WAM

ELEV DEPTH	SOIL PROFILE – DESCRIPTION	SAMPLES – NUMBER	TYPE	"N" VALUES	GROUND WATER CONDITIONS	ELEVATION SCALE	REMARKS & GRAIN SIZE DISTRIBUTION (%) GR SA SI CL
65.8	GROUND SURFACE						
0.0	(SM) Silty sand (TOPSOIL) Brown						
0.2	(GW-GM) Gravel and sand, some silt, trace clay (FILL) Compact Dark brown Moist to wet	1	SS	18			53 32 10 5
		2	SS	20		65	
64.6 1.4	(SM) SILTY SAND, some gravel to gravelly, some clay, contains shale fragments(TILL/highly weathered shale) Very dense Black Moist	3	SS	50/0.15	∇		
	Shale (BEDROCK) Bedrock cored from depths 1.4 m to 4.0 m For bedrock coring details refer to Record of Drillhole 18-3203	1	RC	REC 100%		64 63	RQD = 87%
		2	RC	REC 100%		62	RQD = 97%
61.8 4.0	END OF BOREHOLE NOTES: 1. Water level in open borehole at 1.3 m depth (Elev. 64.6 m), measured during drilling.						



+³, ×³: Numbers refer to Sensitivity

○³% STRAIN AT FAILURE

PROJECT: 1662565-1320

RECORD OF DRILLHOLE: 18-3203

SHEET 2 OF 2

LOCATION: N 5031481.5 ;E 374150.6

DRILLING DATE: July 25, 2018

DATUM: Geodetic

INCLINATION: -90° AZIMUTH: ---

DRILL RIG: Portable Drill

DRILLING CONTRACTOR: OGS

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 %	RECOVERY SOLID CORE %	R.Q.D. %	FRACT. INDEX PER	DISCONTINUITY DATA DIP w.r.t. CORE AXIS	DISCONTINUITY DATA TYPE AND SURFACE DESCRIPTION	Jr	Ja	HYDRAULIC CONDUCTIVITY K, cm/sec	WEATH-ERING INDEX	FEATURES
		BEDROCK SURFACE		64.40													
2 3	Rotary Drill NQ Core	Shale (BEDROCK) Fresh Thinly to medium bedded Grey-black Fine grained Slightly porous Strong		1.38	1	90											
					2	90											
4				61.74													
		END OF DRILLHOLE		4.04													
5 6 7 8 9 10 11																	

DEPTH SCALE

1 : 50

GOLDER

LOGGED: DJG

CHECKED: WAM

BH 18-3201

Cored Length of 1.16 to 4.02 metres

Core Box 1 of 1

1.16 m Top of Core

4.02 m EOH

GOLDER

Foundation Investigation

Unnamed Creek North of Cyrville Road

Ottawa, Ontario

Project No.	1662565 / 1320
Drawn:	WAM
Date:	2019-03-19
Checked:	
Review:	

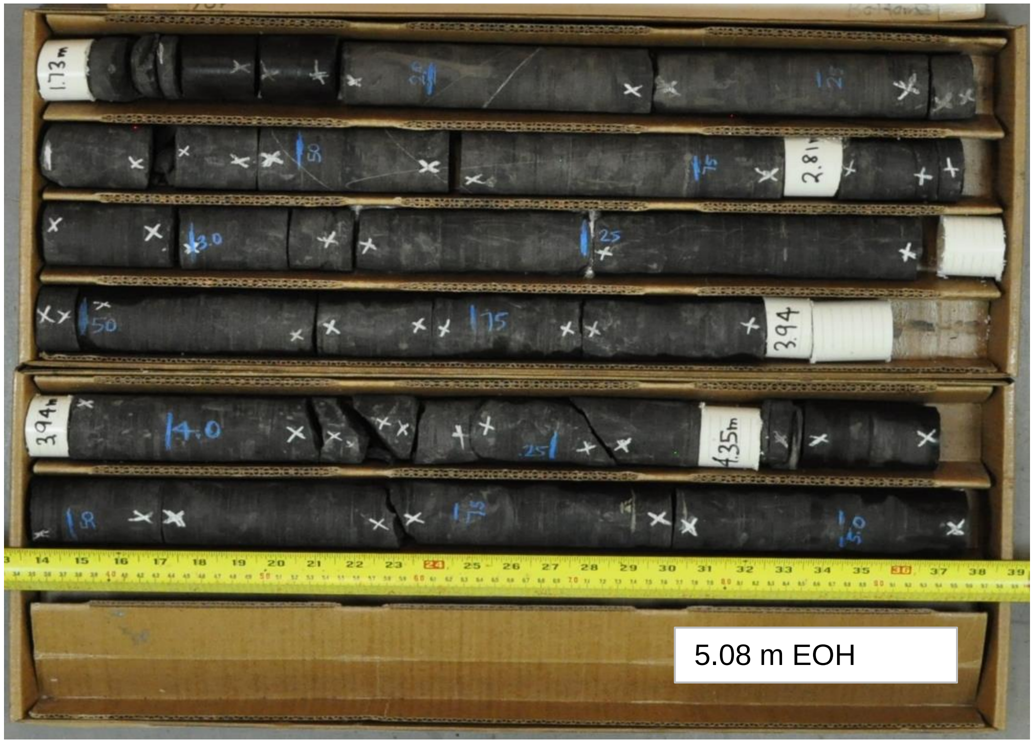
Figure A1

BH 18-3202

Cored Length of 1.73 to 5.08 metres

Core Box 1 and 2 of 2

1.73 m Top of Core



Foundation Investigation

Unnamed Creek North of Cyrville Road

Ottawa, Ontario

Project No.	1662565 / 1320
Drawn:	WAM
Date:	2019-03-19
Checked:	
Review:	

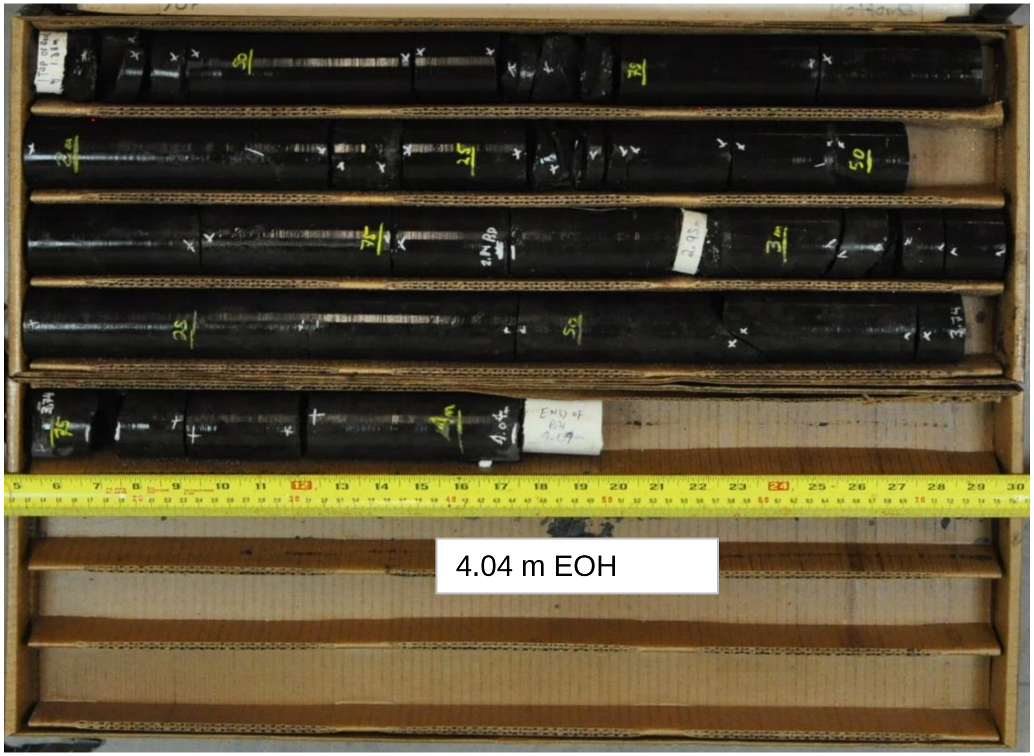
Figure A2

BH 18-3203

Cored Length of 1.38 to 4.04 metres

Core Box 1 and 2 of 2

1.38 m Top of Core



4.04 m EOH

GOLDER

Foundation Investigation

Unnamed Creek North of Cyrville Road

Ottawa, Ontario

Project No.	1662565 / 1320
Drawn:	WAM
Date:	2019-03-19
Checked:	
Review:	

Figure A3

APPENDIX B

Laboratory Test Results, Current Investigation

Figure B1 – Grain Size Distribution Test Results – Gravel and Sand (FILL)

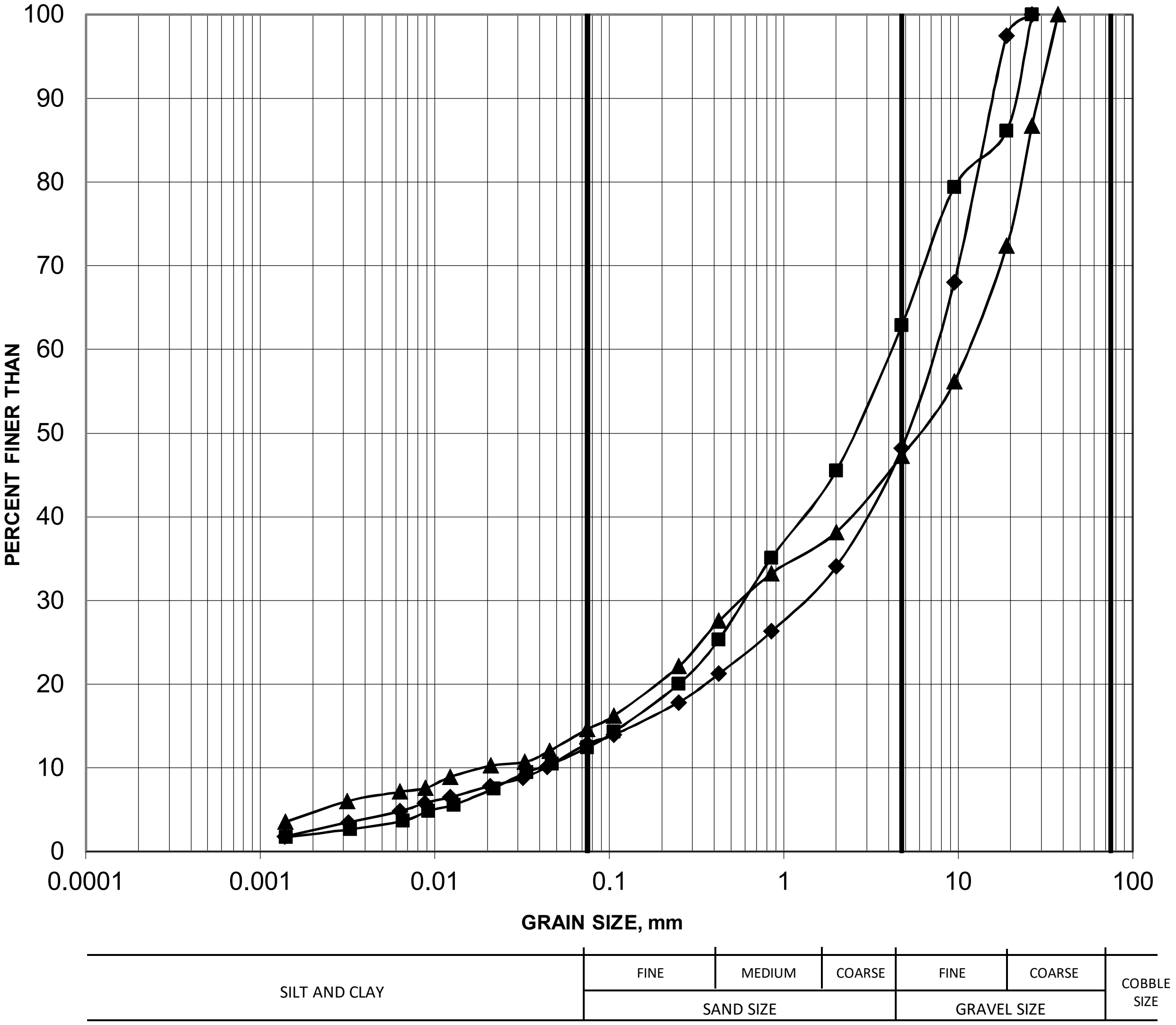
Figure B2 – Grain Size Distribution Test Results – Gravelly Sand (FILL)

Figure B3 – Summary of Laboratory Compressive Strength Testing – Unconfined Compression Test

GRAIN SIZE DISTRIBUTION

FIGURE B1

GRAVEL AND SAND (FILL)



Borehole	Sample	Depth (m)
■ 18-3201	2	0.61-1.07
◆ 18-3202	1	0.00-0.61
▲ 18-3203	2	0.61-1.22

Created by: CW
Checked by: MI

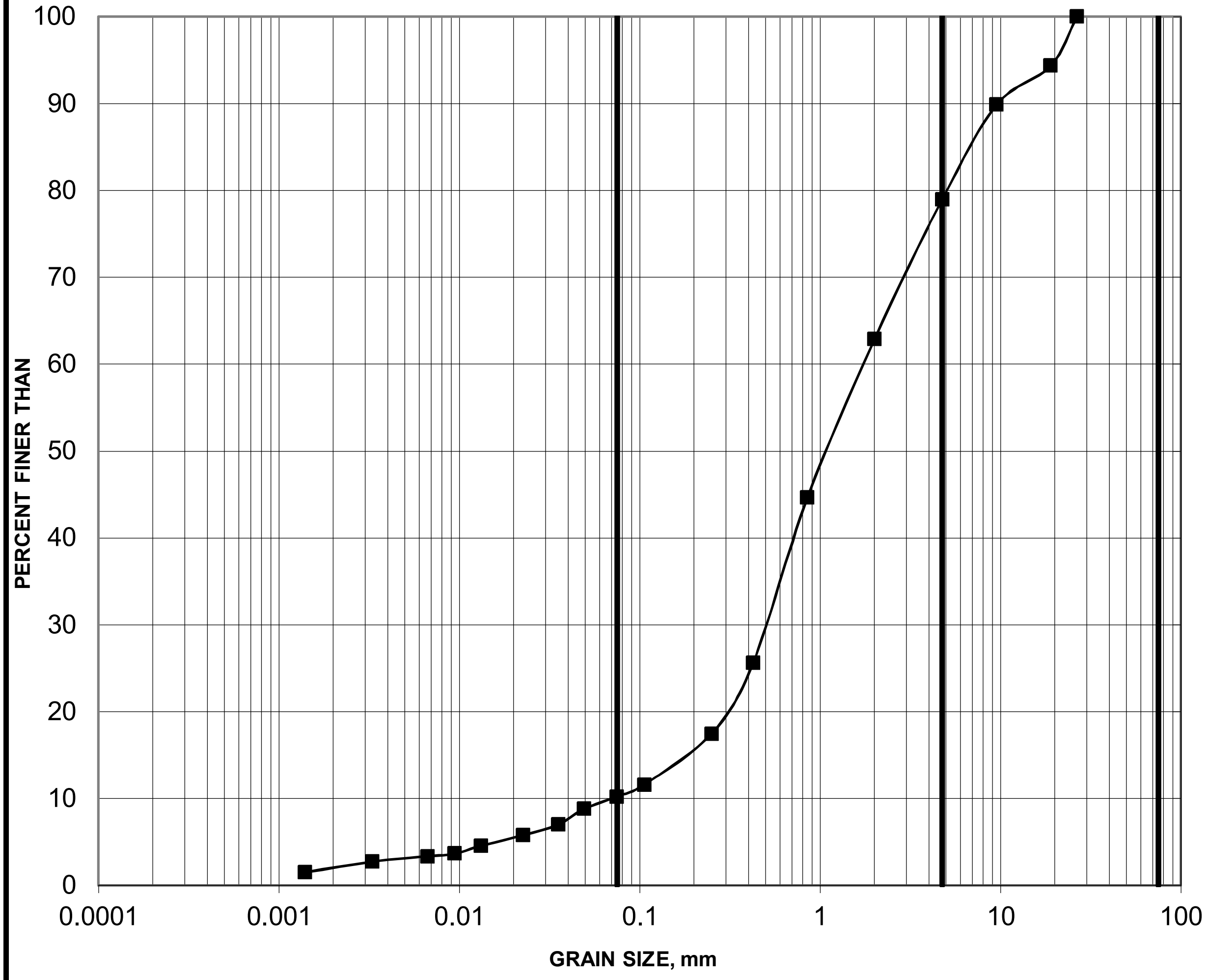
Project: 1662565/1320

Golder Associates

GRAIN SIZE DISTRIBUTION

FIGURE B2

GRAVELLY SAND (FILL)



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

	Borehole	Sample	Depth (m)
─■─	18-3202	2	0.76-1.37

Project: 1662565/1320

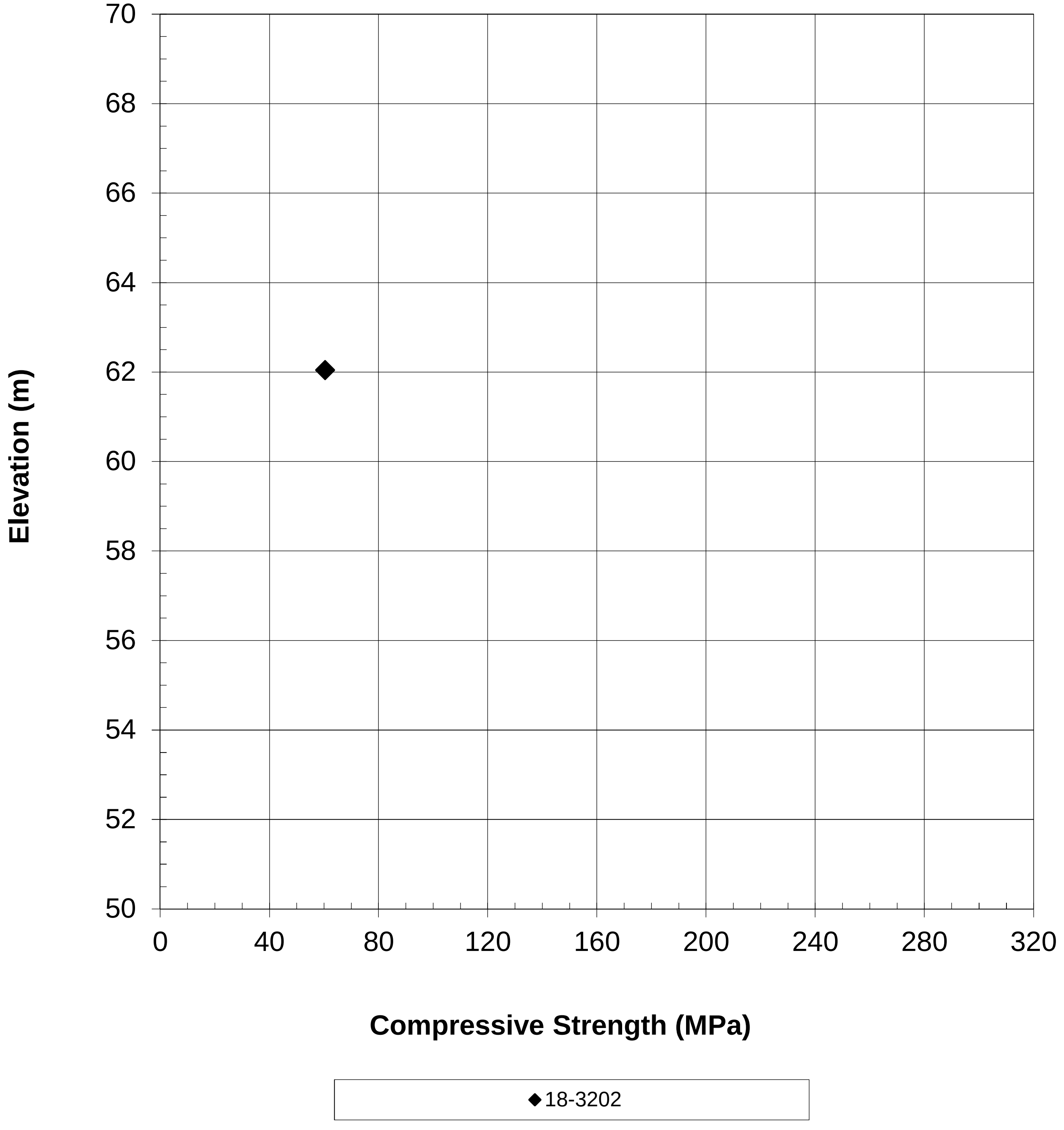
Golder Associates

Created by: CW

Checked by: MI

SUMMARY OF LABORATORY COMPRESSIVE STRENGTH UNCONFINED COMPRESSION TESTS

FIGURE B3



Project: 1662565 /1320

Created by: CW

Checked by: MI

APPENDIX C

Basic Chemical Analysis – Eurofins Report Number 1816328

eurofins Environment Testing

Certificate of Analysis

Client:	Golder Associates Ltd (Ottawa) 1931 Robertson Road, Ottawa, Ontario K2E 7Y1
Attention:	Ms. Gabrielle Marcotte
PO#:	
Invoice to:	Golder Associates Ltd

Report Number:	1816328
Date Submitted:	2018-09-10
Date Reported:	2018-09-13
Project:	1662565/1320
COC #:	835568

				Lab I.D.	1386360
				Sample Matrix	Soil
				Sample Type	
				Sampling Date	2018-07-25
				Sample I.D.	18-3203 SA2/2-4
Group	**Analyte**	**MRL**	**Units**	**Guideline**	
Anions	Cl	0.002	%		0.005
	SO4	0.01	%		0.05
General Chemistry	Electrical Conductivity	0.05	mS/cm		0.69
	pH	2.00			8.09
	Resistivity	1	ohm-cm		1450

Guideline = *** = Guideline Exceedence**

MRL = Method Reporting Limit, AO = Aesthetic Objective, OG = Operational Guideline, MAC = Maximum Acceptable Concentration, IMAC = Interim Maximum Acceptable Concentration, STD = Standard, PWQO = Provincial Water Quality Guideline, IPWQO = Interim Provincial Water Quality Objective, TDR = Typical Desired Range

Results relate only to the parameters tested on the samples submitted.
Methods references and/or additional QA/QC information available on request.

APPENDIX D

Results of MASW Testing

GOLDER

TECHNICAL MEMORANDUM

DATE July 16, 2018

Project No. 1662565/1240

TO Susan Trickey, Golder Associates Ltd.

FROM Stephane Sol, Christopher Phillips

EMAIL ssol@golder.com, cphillips@golder.com

CHBDC SEISMIC SITE CLASS TESTING RESULTS
CYRVILLE ROAD AND HIGHWAY 417, OTTAWA, ONTARIO

This technical memorandum presents the results of two Multichannel Analysis of Surface Waves (MASW) tests performed for the purpose of the Canadian Highway Bridge Design Code (CHBDC 2014) Seismic Site Classification (Figure 1). The tests are located on each side of the interchange between Cyrville Road and Highway 417 in Ottawa. The geophysical testing was performed by Golder Associates Ltd. (Golder) personnel on June 26, 2018.

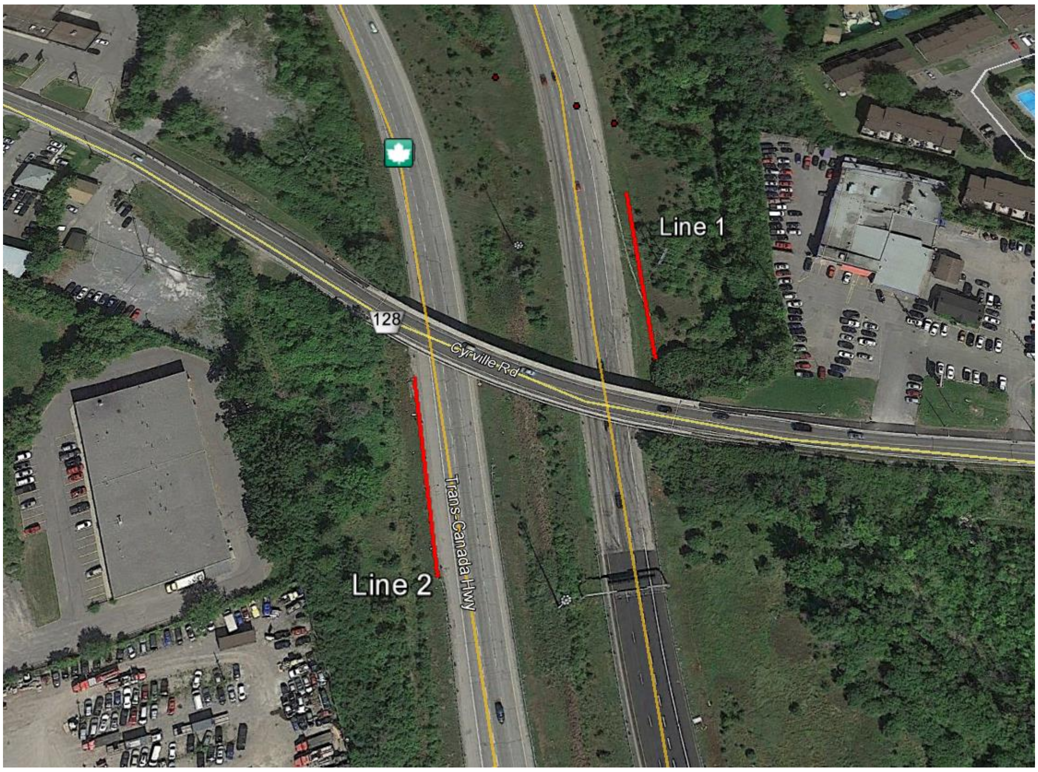


Figure 1: MASW Location Site Map. MASW Lines in red – Line 1 (Northbound) and Line 2 (Southbound).

Golder and the G logo are trademarks of Golder Associates Corporation

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 June 26, 2018, by personnel from the Golder Mississauga office. For each MASW line, a series of 24 low frequency (4.5 Hz) geophones were laid out at 3 m intervals. Both active and passive readings were recorded along the 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, and 15 m from and collinear to the geophone array. A seismic refraction survey was also conducted along both lines to be able to determine the depth to bedrock as well as to estimate the shear wave velocity of the overburden. An example of active seismic records collected at each line are shown in Figures 2 and 3, below.

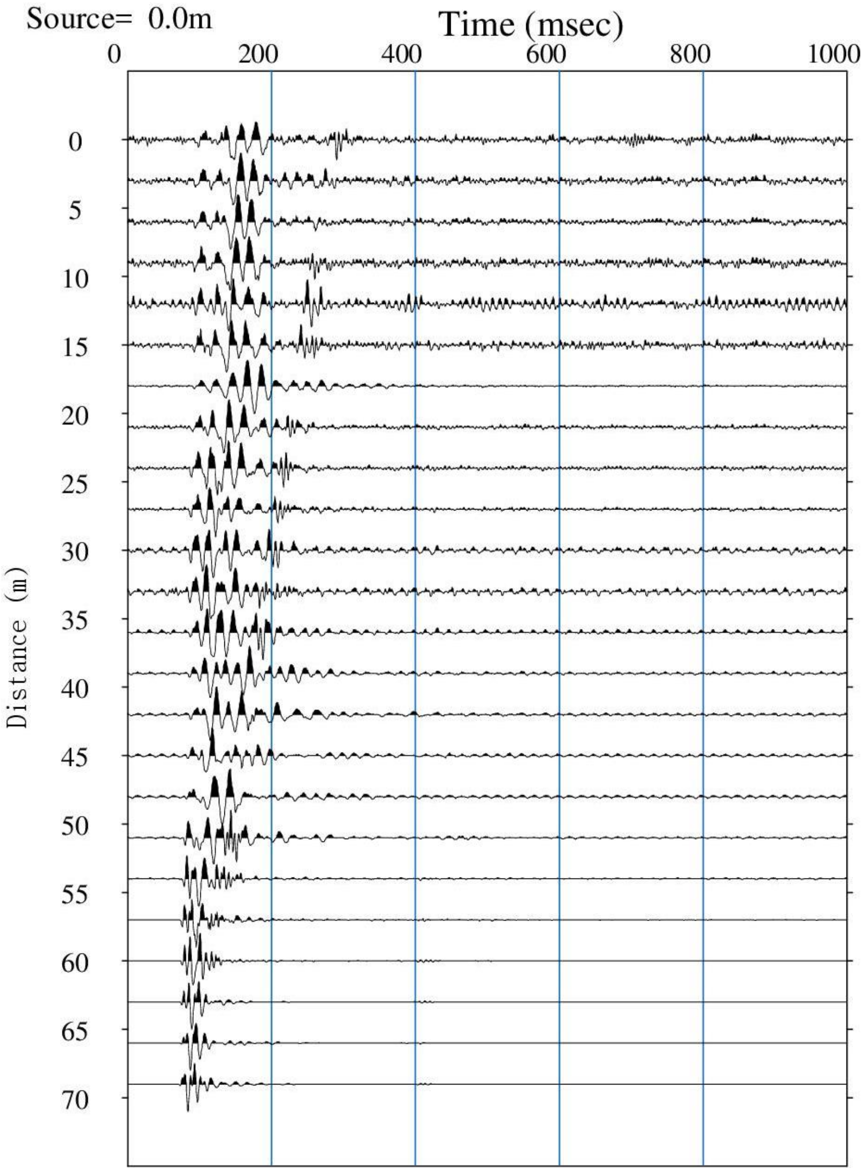


Figure 2: Typical seismic record collected at the site of MASW Line 1.

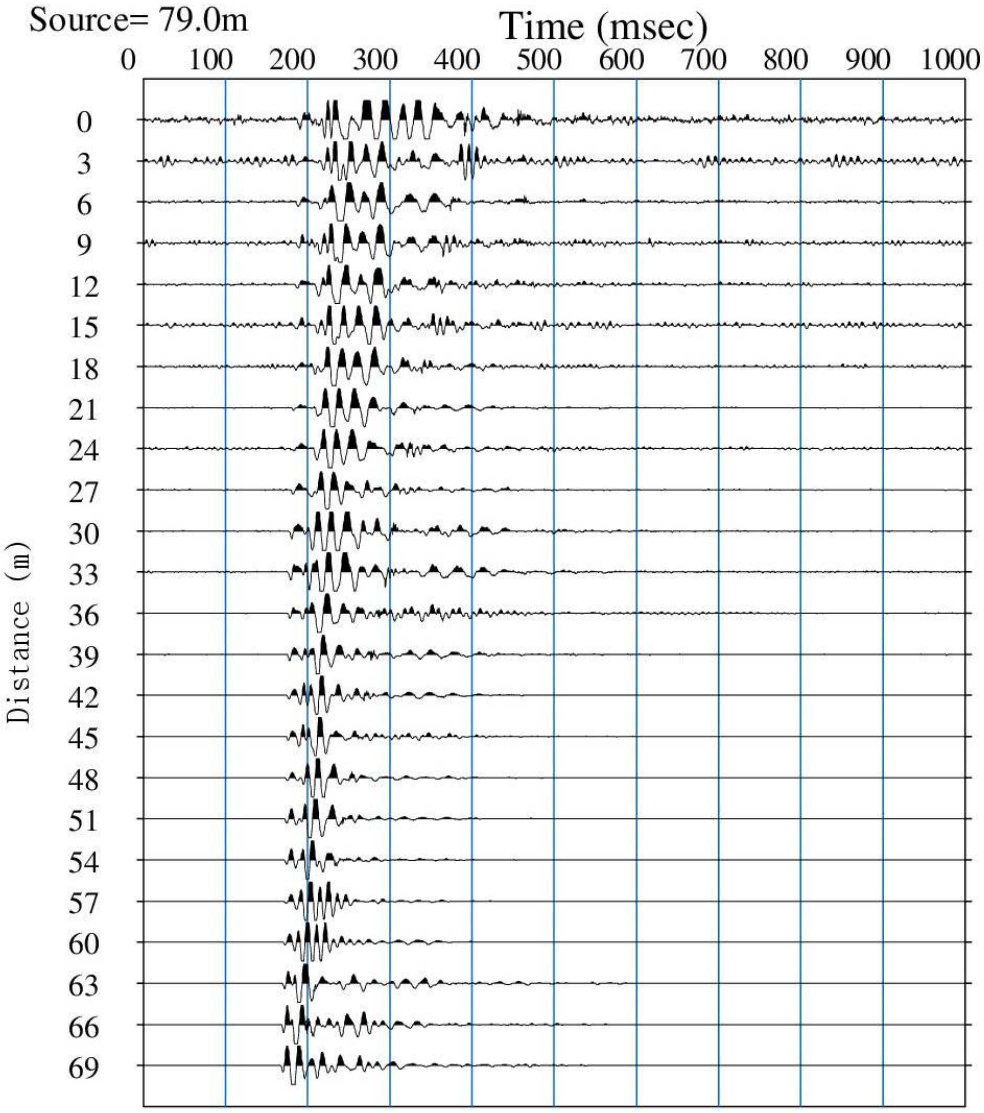


Figure 3: Typical seismic record collected at the site of MASW Line 2.

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 Figure 4 for Line 1 and Figure 5 for Line 2. Shear wave velocity profiles were generated through inverse modelling to best fit the calculated dispersion curves. The active survey of Line 1 provided a dispersion curve with a suitable frequency range (9-31 Hz). The active survey of Line 2 provided a dispersion curve with a suitable frequency range (9-81 Hz). The minimum measured surface wave frequency with sufficient signal-to-noise ratio to accurately measure phase velocity was approximately 9 Hz at Lines 1 and 2.

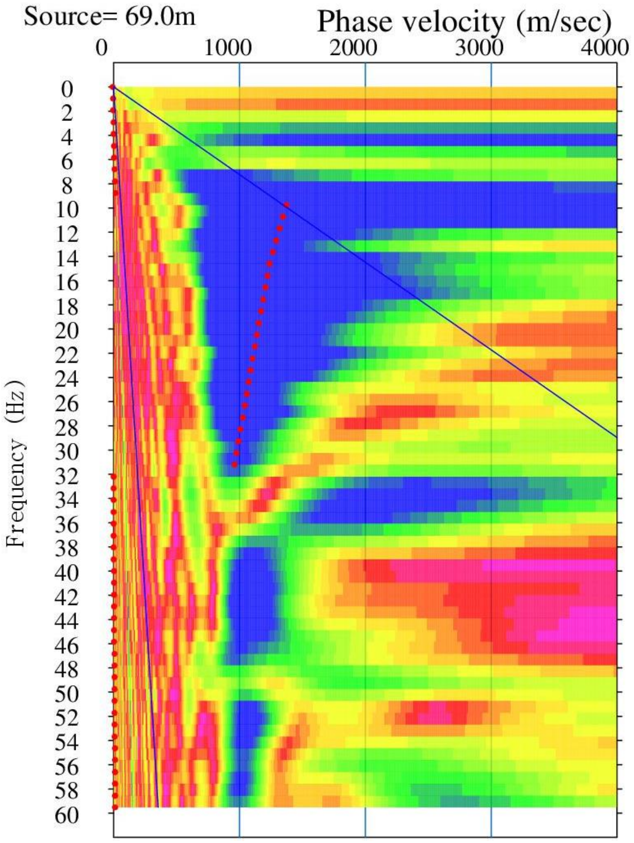


Figure 4: Active MASW Dispersion Curve Picks (red dots) along MASW Line 1

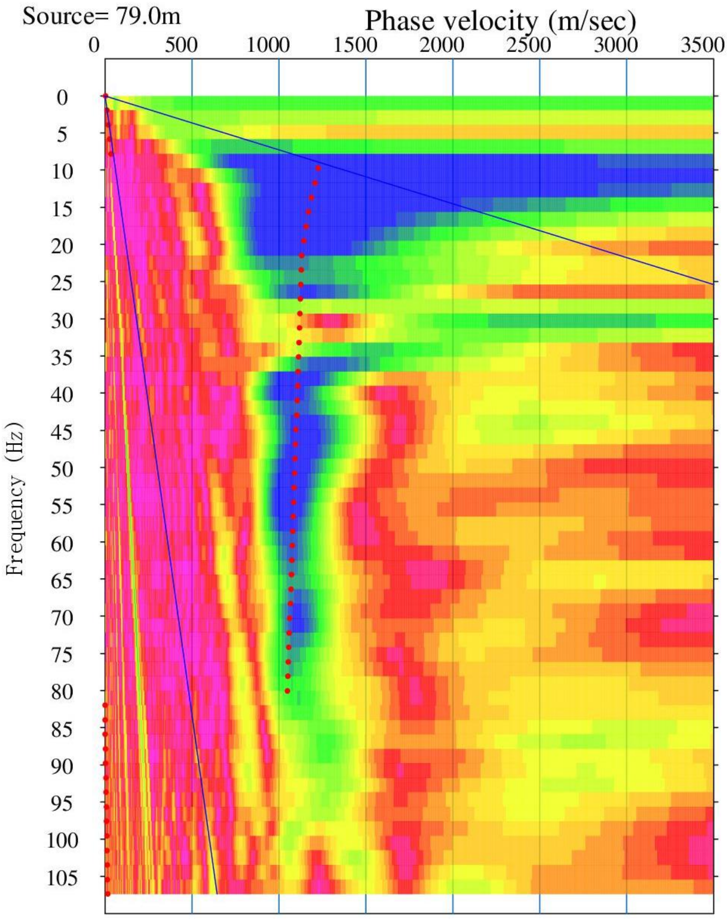


Figure 5: Active MASW Dispersion Curve Picks (red dots) along MASW Line 2

Results

The MASW test results are presented in Figures 6 and 7, which present the calculated shear wave velocity profile derived from the field testing along MASW Lines 1 and 2, respectively. The results along MASW Line 1 have been calculated using a weight-drop located 5 m from the last geophone. The results along MASW Line 2 have also been calculated using a weight-drop located 5 m from the last geophone. The field collected dispersion curves are compared with the model generated dispersion curves on Figures 8 and 9 for MASW Lines 1 and 2, respectively. There is a satisfactory correlation between the field collected and model calculated dispersion curves, with a root mean squared error of less than 1% along both lines.

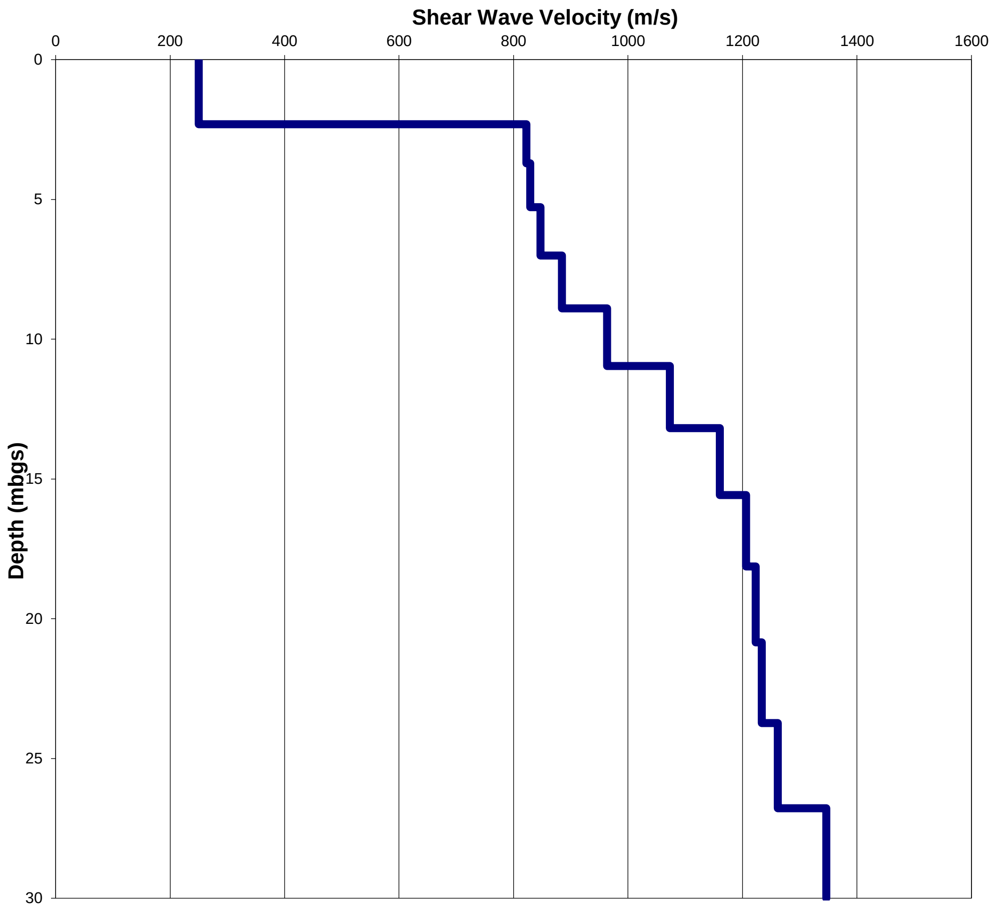


Figure 6: MASW Modelled Shear-Wave Velocity Depth profile along MASW Line 1

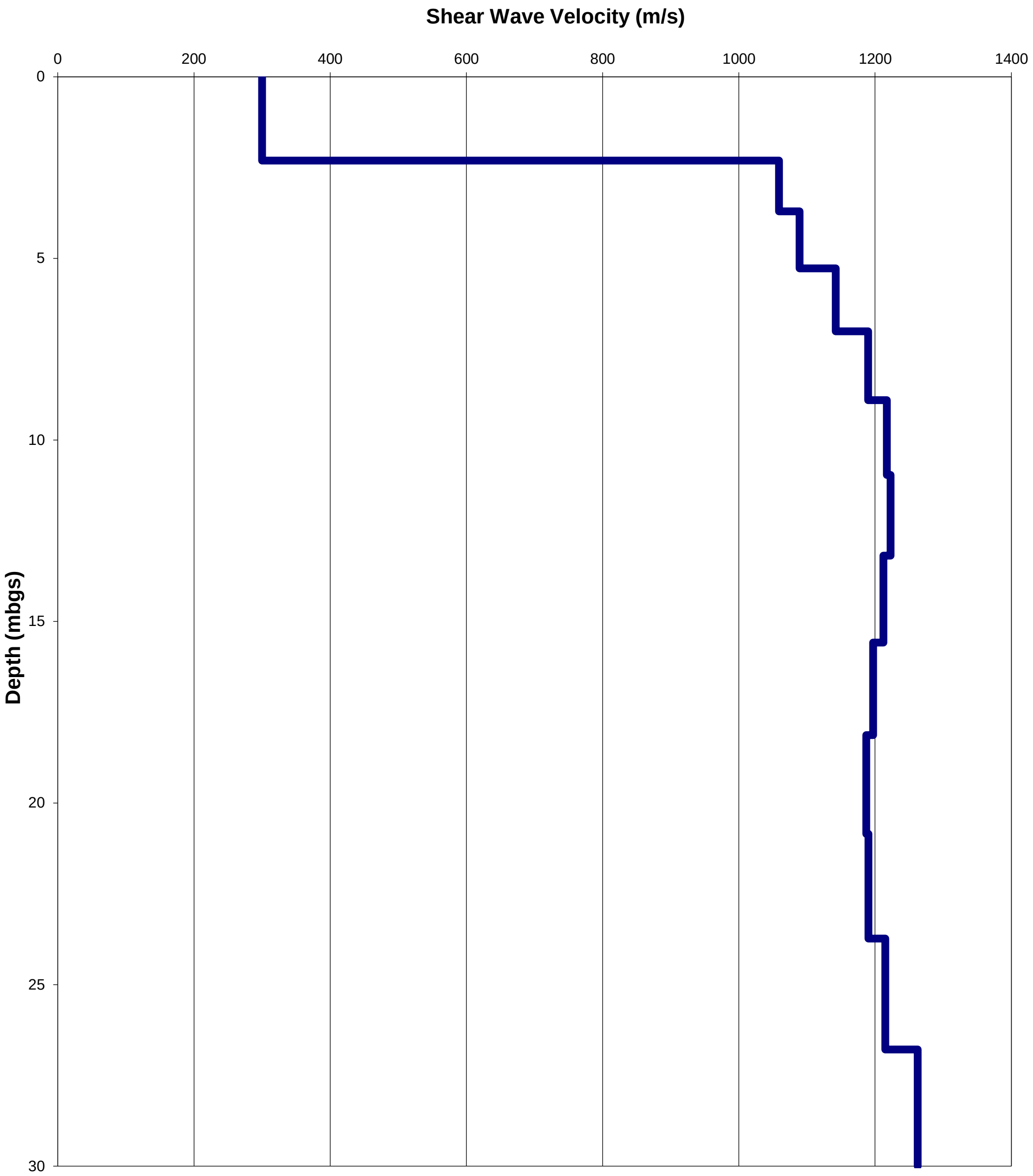


Figure 7: MASW Modelled Shear-Wave Velocity Depth profile along MASW Line 2

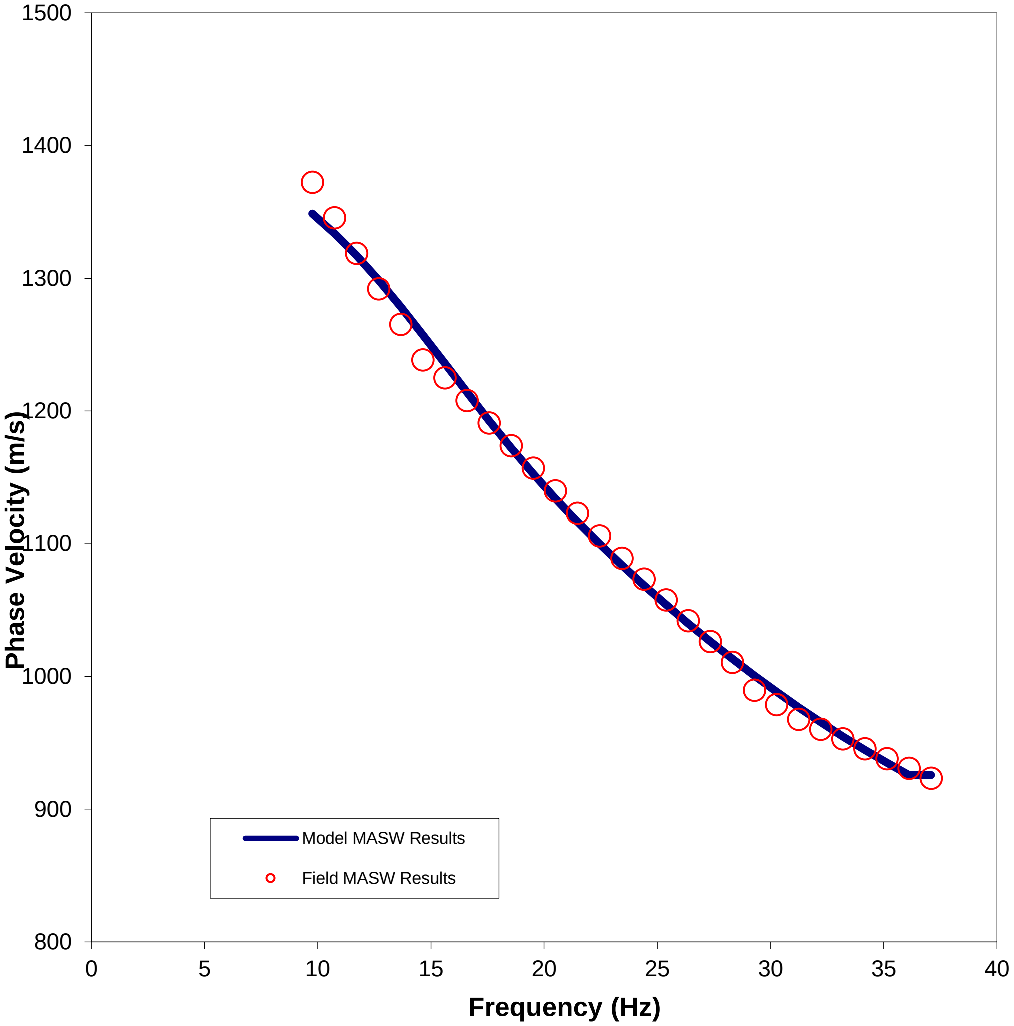


Figure 8: Comparison of Field (red dots) vs. Modelled Data (blue line) along MASW Line 1

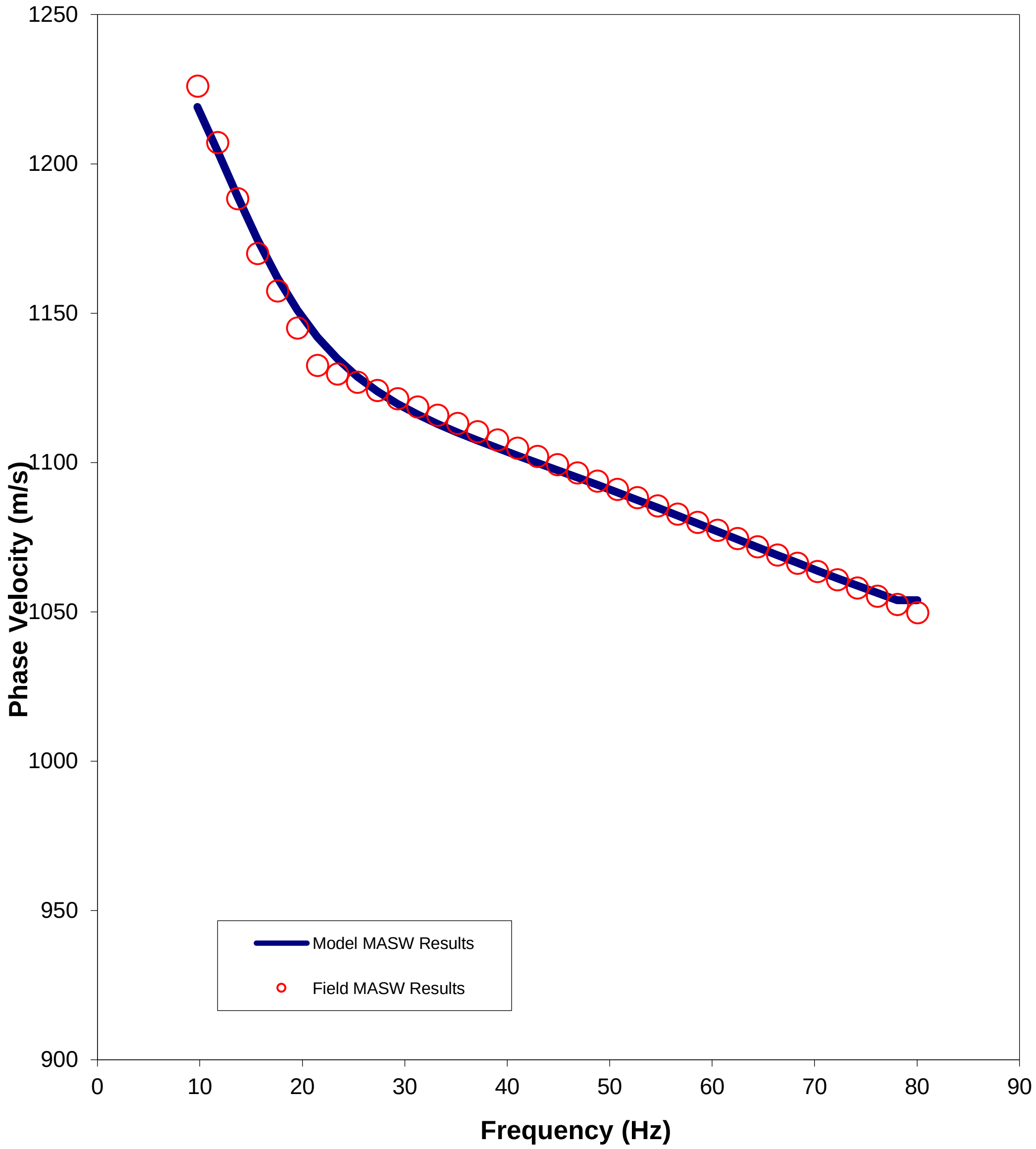


Figure 9: Comparison of Field (red dots) vs. Modelled Data (blue line) along MASW Line 2

To calculate the average shear-wave velocity as required by the CHBDC 2014, the results were modelled to 30 metres below ground surface. The average shear-wave velocity along MASW Line 1 in the north was found to be 863 m/s (Table 1). The average shear-wave velocity along MASW Line 2 in the south was found to be 969 m/s (Table 2).

Table 1: Shear-Wave Velocity Profile along MASW Line 1

Model Layer (mbgs)		Layer Thickness (m)	Shear Wave Velocity (m/s)	Shear Wave Travel Time Through Layer (s)
Top	Bottom			
0.00	1.07	1.07	250	0.004286
1.07	2.31	1.24	250	0.004945
2.31	3.71	1.40	823	0.001703
3.71	5.27	1.57	829	0.001889
5.27	7.01	1.73	847	0.002044
7.01	8.90	1.90	885	0.002143
8.90	10.96	2.06	964	0.002138
10.96	13.19	2.23	1073	0.002074
13.19	15.58	2.39	1160	0.002060
15.58	18.13	2.55	1206	0.002118
18.13	20.85	2.72	1223	0.002224
20.85	23.74	2.88	1234	0.002338
23.74	26.79	3.05	1261	0.002417
26.79	30.00	3.21	1346	0.002387
			Vs Average to 30 mbgs (m/s)	**863**

Table 2: Shear-Wave Velocity Profile along MASW Line 2

Model Layer (mbgs)		Layer Thickness (m)	Shear Wave Velocity (m/s)	Shear Wave Travel Time Through Layer (s)
Top	Bottom			
0.00	1.07	1.07	300	0.003571
1.07	2.31	1.24	300	0.004121
2.31	3.71	1.40	1059	0.001323
3.71	5.27	1.57	1089	0.001438
5.27	7.01	1.73	1142	0.001515
7.01	8.90	1.90	1190	0.001593
8.90	10.96	2.06	1217	0.001693
10.96	13.19	2.23	1223	0.001820
13.19	15.58	2.39	1212	0.001972
15.58	18.13	2.55	1197	0.002134
18.13	20.85	2.72	1187	0.002291
20.85	23.74	2.88	1190	0.002424
23.74	26.79	3.05	1215	0.002511
26.79	30.00	3.21	1262	0.002546
			Vs Average to 30 mbgs (m/s)	**969**

The CHBDC 2014 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.

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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APPENDIX E

Site Photographs

Photograph 1: Site No. 3-763C, East outlet (WBL), looking west (November 08, 2018).

Photograph 2: Site No. 3-763C, West inlet, looking east (September 20, 2019).

CLIENT
WSP CANADA GROUP LIMITED

PROJECT
UNNAMED CREEK CULVERT
SITE NO. 3-763C
HIGHWAY 417, OTTAWA, ONTARIO

CONSULTANT
GOLDER

YYYY-MM-DD	2019/12/13
PREPARED	KM
DESIGN	--
REVIEW	MSS
APPROVED	FJH

TITLE
SELECTED SITE PHOTOGRAPHS

PROJECT No.	Phase	Rev.	Figure
1662565	**1320**	**1**	**E1**

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